THE UNIVERSITY OF SYDNEY

Surgical reconstruction of the mandible and maxilla:

A health technology assessment in the Australian context

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A thesis submitted in fulfilment of the requirements of the degree of Doctor of Philosophy

CANDIDATE'S CERTIFICATE

I, George Andrew Petrides, hereby declare that the work contained within this thesis is my own and has not been submitted to any other university of institution for any higher degree. I, George Andrew Petrides, hereby declare that I was the principal researcher of all work contained in this thesis, including work published with multiple authors. I, George Andrew Petrides, understand that if I am awarded a higher degree for my thesis entitled *Surgical reconstruction of the mandible and maxilla: A health technology assessment in the Australian context* being submitted herewith for examination, the thesis will be lodged in the University of Sydney Library and will be available immediately for use. I agree that the University Librarian (or in the case of the department, the Head of Department) may supply a photocopy of microform of the thesis to an individual for research or study or to a library.

Dr George Andrew Petrides

31st December 2025

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This is to certify that the thesis entitled *Surgical reconstruction of the mandible and maxilla: A health technology assessment in the Australian context* submitted by George Andrew Petrides for the degree of Doctor of Philosophy is in a form ready for examination.

Professor Jonathan Clark

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31st December 2025

AUTHOR ATTRIBUTION STATEMENT

In accordance with the University of Sydney Higher Degree Research Policy, this thesis contains a combination of manuscripts submitted for publication, manuscripts under review, and standalone chapter. I, George Andrew Petrides, led each of the included studies and chapters, which were conducted under the supervision of Professor Jonathan Clark, Doctor Rebecca Venchiarutti, Associate Professor Michael Elliot, and in collaboration with other co-authors. The specific contributions of each author for each chapter are described below using the Contributor Roles Taxonomy (CRediT) shown in **Table 1**.

Table 1. Contributor Roles Taxonomy (CRediT) for collaborators of manuscripts.

Contributor Roles Taxonomy*	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
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Masako Dunn[1,2]				✓						✓		✓	✓	
Timothy G.H. Manzie[1,2]				✓						✓		✓	✓	
Rebecca L. Venchiarutti[1,2]	✓			✓						✓		✓	✓	
Jonathan R. Clark[1,2,7]	✓	✓		✓						✓		✓	✓	✓
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Masako Dunn[1,2]	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
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Timothy G.H. Manzie[1,2]		✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
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Michael Boyer[1,2]				✓			✓			✓	✓			
Rebecca L. Venchiarutti[1,2]	✓	✓		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Tsu-Hui (Hubert) Low[1,2]				✓			✓			✓				
David Leinkram[1,2]				✓			✓			✓				
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James Wykes[1,2]				✓			✓			✓				

Contributor Roles Taxonomy*	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
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Masako Dunn[1,2]	✓	✓		✓		✓	✓	✓	✓	✓	✓	✓	✓	✓
Catriona Froggatt[1,2]		✓		✓		✓	✓	✓	✓	✓	✓		✓	
Timothy G.H. Manzie[1,2]		✓		✓		✓	✓	✓	✓	✓	✓	✓	✓	
Rebecca L. Venchiarutti[1,2]	✓	✓		✓		✓	✓	✓	✓	✓	✓	✓	✓	
Tsu-Hui (Hubert) Low[1,2]				✓			✓			✓				
David Leinkram[1,2]				✓			✓			✓				
Sydney Ch'ng[1,2]				✓			✓			✓				
James Wykes[1,2]				✓			✓			✓				
Carsten Palme[1,2]				✓			✓			✓				
Hansoo Kim[6]		✓		✓	✓	✓		✓	✓	✓	✓	✓		
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Chapter 6: Mapping FACE-Q to EQ-5D in a cohort of mandibular and maxillary reconstruction patients to facilitate cost-utility analysis														
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Namal N. Balasooriya[6]		✓		✓	✓	✓	✓	✓		✓	✓	✓		
Masako Dunn[1,2]				✓		✓	✓			✓		✓	✓	
Catriona Froggatt[1,2]				✓		✓	✓			✓		✓		
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I attest that the above statements are correct.

Doctor George Andrew Petrides

31st December 2025

As the supervisor for the candidature upon which this thesis is based, I can confirm that the authorship attribution statements above are correct.

Professor Jonathan Clark

31st December 2025

* Contributor Roles Taxonomy definitions

No.	Term	Definition
1	Conceptualisation	Ideas; formulation or evolution of overarching research goals and aims
2	Methodology	Development or design of methodology; creation of models
3	Software	Programming, software development; designing computer programs; implementation of the computer code and supporting algorithms; testing of existing code components
4	Validation	Verification, whether as a part of the activity or separate, of the overall replication/reproducibility of results/experiments and other research outputs
5	Formal analysis	Application of statistical, mathematical, computational, or other formal techniques to analyse or synthesise study data
6	Investigation	Conducting a research and investigation process, specifically performing the experiments, or data/evidence collection
7	Resources	Provision of study materials, reagents, materials, patients, laboratory samples, animals, instrumentation, computing resources, or other analysis tools
8	Data Curation	Management activities to annotate (produce metadata), scrub data and maintain research data (including software code, where it is necessary for interpreting the data itself) for initial use and later reuse
9	Writing – Original Draft	Preparation, creation and/or presentation of the published work, specifically writing the initial draft (including substantive translation)
10	Writing – Review and Editing	Preparation, creation and/or presentation of the published work by those from the original research group, specifically critical review, commentary or revision – including pre-or post-publication stages
11	Visualisation	Preparation, creation and/or presentation of the published work, specifically, visualisation/ data presentation
12	Supervision	Oversight and leadership responsibility for the research activity planning and execution, including mentorship external to the core team
13	Project Administration	Management and coordination responsibility for the research activity planning and execution
14	Funding Acquisition	Acquisition of the financial support for the project leading to this publication

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ARTIFICIAL INTELLIGENCE

During the preparation of the thesis, the author used Claude for the purposes of minimal copyediting. The use of this generative AI tool included spelling corrections, minor sentence restructuring, and clarity enhancement. The author confirms that where the text was modified by generative AI, the content was reviewed for possible errors, inaccuracies, and bias. The author takes full responsibility for the submitted thesis, confirms the work is their own, and has used generative AI in accordance with the University of Sydney guidelines and policies.

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CONFLICTS OF INTEREST

There are no conflicts of interest to disclose. As part of the works comprising this thesis, several people with backgrounds in health economics were consulted. Despite holding private affiliations, their involvement was pro bono, and no conflicts of interest exists.

THESIS ABSTRACT

Surgical resection of the mandible and maxilla is a standard treatment modality in the management of pathology affecting the jaw, including tumours, trauma, infection, and osteonecrosis. However, jaw resection profoundly impacts the postoperative health-related quality of life (HRQoL) of patients through impairments in aesthetics, breathing, speech, swallowing and mastication. Therefore, whilst complete resection of the disease remains the primary objective, a larger emphasis has been placed on reconstructing the jaw to maximise postoperative appearance and function. Microvascular free flap reconstruction refers to the transfer of donor tissue from one anatomical site to the jaw to reconstruct complex resection defects and is currently the gold-standard for jaw reconstruction. In addition, surgical adjuncts, including virtual surgical planning (VSP) and immediate dental rehabilitation, have been increasingly utilised given their link to improved postoperative outcomes and HRQoL.

Jaw reconstruction is one of the most resource-intensive procedures in head and neck surgery, with considerable costs arising from extended operations, the need for multidisciplinary input, and complicated postoperative management. It is critical that the economic implications of jaw reconstruction are well understood so that informed decisions around resource allocation can be made by healthcare providers, administrators, and policymakers. However, there are considerable gaps and limitations in the existing literature, ultimately precluding evidence-based decisions from being made. The existing literature is limited by a lack of comprehensive synthesis of the economic literature, a predominance of partial economic evaluations, a deficiency of standardised and transparent reporting of cost measurement, an unknown adequacy of reimbursement compared to true costs, and an absence of validated tools to derive

health utilities for cost-utility analysis. This thesis aims to address these gaps through a series of interrelated studies examining the health economics of jaw reconstruction.

The first study aimed to systematically map the current knowledge around the economic implications of jaw reconstruction. A scoping review was performed using PRISMA-ScR guidelines, identifying 36 studies examining the economic aspects of mandibular and maxillary reconstruction. This study found that the costs of personnel represented the primary cost-contributor in jaw reconstruction admissions. However, only three studies (8%) conducted full economic evaluations, with the remainder limited to partial analyses that assessed costs in isolation. The predominance of partial economic evaluations, combined with inconsistent costing methodologies, severely constrains evidence-based decision-making for surgeons, administrators, and policymakers. The study highlighted an urgent need for full economic evaluations employing standardised micro-costing methodologies, validated outcome measures, and transparent reporting.

The second study aimed to establish the true financial costs and cost-drivers of jaw reconstruction. A retrospective micro-costing study of 100 patients was performed using an individualised and transparent bottom-up costing methodology. The mean direct admission cost was US$36,416 (A$54,988) with the largest cost contributors being ward staffing and disposable equipment (35.7%), prostheses including VSP (25.0%), and operating room staffing (21.0%). Early postoperative complications requiring return to the operating room added US$19,920 (A$30,079), while return to the intensive care unit (ICU) added US$25,316 (A$38,227) per admission. This study underscores the need to implement approaches to minimise the likelihood of these adverse outcomes, including thorough preoperative

assessment incorporating risk assessment tools, optimisation of comorbidities, and ensuring complex head and neck cancer surgeries are performed in high-volume centres.

The considerable expense of outsourcing VSP to commercial providers (C-VSP) has prompted many institutions to develop in-house capabilities using commercially available software and three-dimensional printers (POC-VSP. The third study aimed to compare the direct costs of C-VSP and VSP workflows. A cost-minimisation analysis between C-VSP and POC-VSP – based on pre-established clinical equivalence – was performed on 64 patients. VSP achieved an average cost reduction of A$9,835 per case compared to C-VSP following propensity score matching, with the VSP workflow itself being the primary driver of cost differences. The analysis also demonstrated that the economic value of POC-VSP is driven by economies of scale, with the crossover point at which POC-VSP becomes more economical than C-VSP at our institution being seven cases annually, increasing to 17 cases when Therapeutic Goods Administration (TGA) conformity assessment requirements are factored in.

The fourth study aimed to compare the micro-costed direct costs of jaw reconstruction patients with private health insurance (PHI) reimbursement and identify factors contributing to any observed discrepancies. A cost-reimbursement analysis was performed on 61 privately insured patients, finding that when overhead costs were modelled, 93-100% of cases became loss-making, with mean deficits ranging from A$26,066 to A$49,540. It was also found that the reimbursement model was independently associated with the funding gap, with fee-for-service patients demonstrating a deficit of A$10,825 larger on average than that of per-episode patients. Nevertheless, when overhead costs were included, both models failed to recover true costs, suggesting that current reimbursement, regardless of model, does not adequately capture the resource-intensive nature of jaw reconstruction.

The fifth study aimed to map the disease-specific FACE-Q Head and Neck Cancer (FACE-Q) to the generic preference-based EQ-5D-5L instrument. A mapping study on 181 patients was performed, evaluating multiple regression frameworks (OLS, Tobit, CLAD, and beta regression) using Australian preference weights. This analysis demonstrated that beta regression was the optimal mapping framework due to its ability to accommodate the bounded, right-skewed distribution of EQ-5D-5L data (RMSE = 0.131; MAE = 0.084). This study represents the first FACE-Q mapping study and provides a validated algorithm for deriving quality-adjusted life years (QALYs) from FACE-Q data in the absence of utility scores collected directly from patients, enabling future cost-utility analyses of jaw reconstruction interventions.

Collectively, this thesis establishes foundational economic evidence to inform clinical decision-making, institutional resource allocation, health policy, and future research. Future research must prioritise full economic evaluations, validate these findings across multiple centres, and adopt extended time horizons and societal perspectives to build upon this foundation and ensure that patients continue to have access to high-quality jaw reconstruction services.

DISSEMINATION OF RESEARCH

Parts of the work presented in this thesis have been under review/published and/or presented in the following journals and at the following conferences.

JOURNAL SUBMISSIONS (CURRENTLY UNDER REVIEW)

- **G.A. Petrides,** M. Dunn, A.R. Sharman, C. Froggat, T.G. Manzie, B. Agresta, D. Beard, H. Kim, M. Boyer, R.L. Venchiarutti, T.H. Low, D. Leinkram, S. Ch'ng, J. Wykes, C. Palme, and J.R. Clark. "Economic evaluation of microvascular reconstruction of the jaw: A micro-costing analysis and identification of key cost-drivers". *Oral Oncology*. Submitted 3rd August 2025.

CONFERENCE PRESENTATIONS

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POSTER PRESENTATIONS

- **G.A. Petrides,** M. Dunn, A.R. Sharman, C. Froggat, T.G. Manzie, B. Agresta, D. Beard, H. Kim, M. Boyer, R.L. Venchiarutti, T.H. Low, D. Leinkram, S. Ch'ng, J. Wykes, C. Palme, and J.R. Clark. "Surgical reconstruction of the mandible and maxilla: A micro-costing study in the Australian context", *Chris O'Brien Lifehouse Research Symposium,* Sydney, Australia. November, 2023.

AWARDS

- **G.A. Petrides.** Best Oral Presentation. *ANZHNCS Annual Scientific Meeting 2023.*

LIST OF ABBREVIATIONS

Abbreviation	Definition
ABF	Activity-based funding
AIC	Akaike information criterion
AR-DRG	Australian Refined Diagnosis Related Group
ASA	American Society of Anaesthesiologists
CBA	Cost-benefit analysis
CEA	Cost-effectiveness analysis
CHEERS	Consolidated Health Economic Evaluation Reporting Standards
CI	Confidence interval
CMA	Cost-minimisation analysis
COBL	Chris O'Brien Lifehouse Hospital
CT	Computed tomography
CUA	Cost-utility analysis
C-VSP	Commercial virtual surgical planning
EQ-5D-5L	EuroQol five-dimension five-level
FFF	Fibula free flap
HRQoL	Health-related quality of life
HT	Health technology assessment
ICU	Intensive care unit
MAE	Mean absolute error
MDHTAC	Medical Devices and Human Tissue Advisory Committee
NSW	New South Wales
OLS	Ordinary least squares
OR	Operating room
PHI	Private health insurance
POC-VSP	Point-of-care virtual surgical planning
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PRISMA-ScR	PRISMA extension for Scoping Reviews
QALY	Quality-adjusted life year
RFFF	Radial forearm free flap
RMSE	Root mean square error
SCC	Squamous cell carcinoma
SD	Standard deviation
SE	Standard error
TGA	Therapeutic Goods Administration
VSP	Virtual surgical planning

TABLE OF CONTENTS

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND TO THE THESIS

1.1.1 RESECTION AND RECONSTRUCTION OF THE MANDIBLE AND MAXILLA

Surgical resection of the mandible and maxilla – commonly termed mandibulectomy and maxillectomy – is a standard treatment modality in the management of pathology affecting the jaw (Argiris et al., 2008; Cognetti et al., 2008). Whilst resection may be utilised to treat traumatic defects, infection, and osteonecrosis, the predominant indication remains head and neck cancer. Head and neck cancer encompasses tumours arising from the oral cavity, salivary glands, pharynx, nasal cavity, paranasal sinuses, and larynx, and remains a substantial health problem in Australia (Australian Institute of Health & Welfare, 2014). In 2022, an estimated 5,189 new cases of head and neck cancer were diagnosed in Australia, comprising approximately 3.2% of all new cancer cases (Australian Institute of Health & Welfare, 2022). Surgical resection remains the primary treatment for many of these patients, and consequently, a substantial number of patients undergo mandibulectomy and maxillectomy in Australian hospitals each year (Cancer Council Victoria, 2021).

Surgical resection of the mandible or maxilla profoundly impacts health-related quality of life (HRQoL). Following their operation, jaw resection patients suffer from impairments in aesthetics, breathing, speech, swallowing, and mastication (Kumar et al., 2013; Rathod et al., 2015). Additionally, there patients are more likely to experience social stigma and adverse psychological outcomes (McGrouther, 1997). Therefore, whilst complete resection of the disease remains the primary objective, increasing emphasis has been placed on reconstructing the jaw to maximise postoperative appearance and function (Futran & Mendez, 2006). Historically, patients with maxillectomy defects were commonly rehabilitated using obturator prostheses, however, these were limited by poor denture retention, instability, and leakage

(Okay et al., 2001; Tang et al., 2008). Instead, microvascular free flap reconstruction is now considered the gold-standard for both maxillary and mandibular rehabilitation due to better postoperative outcomes (Brown et al., 2017; McCarthy & Cordeiro, 2010; Petrides et al., 2022).

Microvascular free flap reconstruction refers to the transfer of donor tissue from one anatomical site to another to reconstruct complex defects, such as those resulting from jaw resection (Spiegel & Polat, 2007). Following tumour ablation, the donor tissue is transplanted with its vascular pedicle intact and re-anastomosed to recipient vessels using microsurgery to re-establish perfusion (Macnamara et al., 1994). This is often accomplished using a two-team approach, with separate ablative and reconstructive surgical teams (Mark et al., 2022). Several donor sites have been described for jaw reconstruction, including fasciocutaneous flaps such as the anterolateral thigh (ALT) and radial forearm free flap (RFFF), as well as osseous flaps such as the fibula (**Figure 1**), scapula, and the deep circumflex iliac artery (DCIA) flap (Bak et al., 2010; Petrides et al., 2021). Each of these donor site options carries unique characteristics with the choice made for each patient based on the site and size of the ablation defect, length of the pedicle, and availability of donor tissue (Futran & Mendez, 2006).

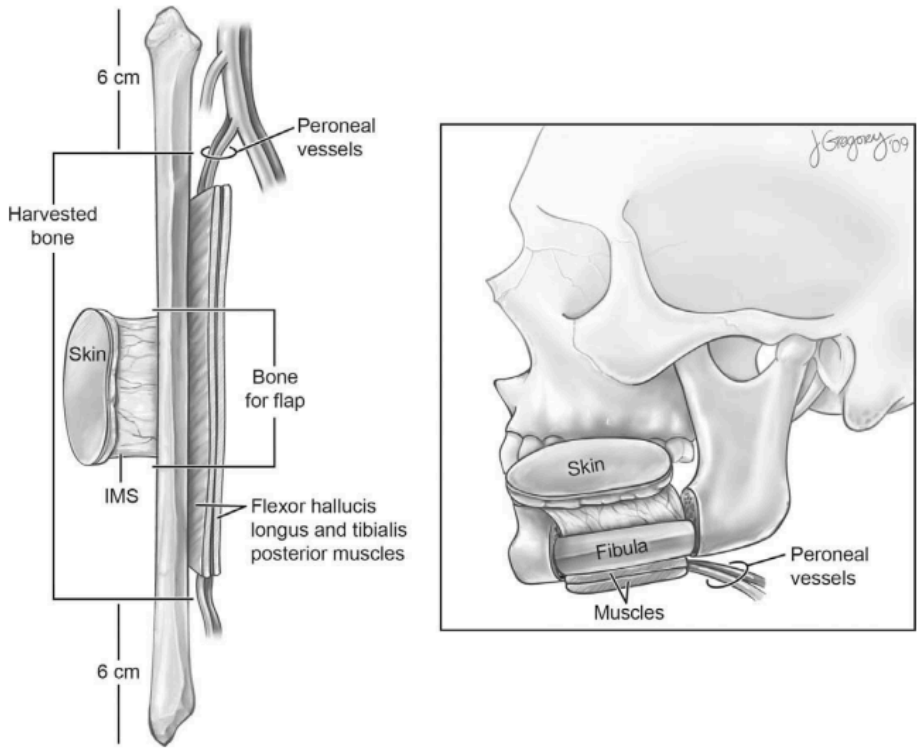

Figure 1. The anatomy of the osseous fibula free flap and an example of a segmental mandibular defect with the fibula graft inset (Bak et al., 2010).

1.1.2 VIRTUAL SURGICAL PLANNING

In jaw reconstruction where osseous free flap transfer and immediate dental rehabilitation takes place, postoperative outcomes are linked to the precision of bone modelling and implant placement due to influence on bony union, dental occlusion, and facial contour (van Gemert et al., 2012). Virtual surgical planning (VSP) assists in this process through the use of three-dimensional (3D) models of the affected jaw and donor-site. These are used to preoperatively plan the positioning of bony segments, osteotomies, and dental implants before being translated to the operative setting via patient-specific surgical guides, anatomical models, and custom reconstruction plates (**Figure 2**) (Ferreira et al., 2014; Jeong et al., 2025; McCarthy & Cordeiro, 2010; Okay et al., 2001; Tang et al., 2008; Tarsitano et al., 2015).

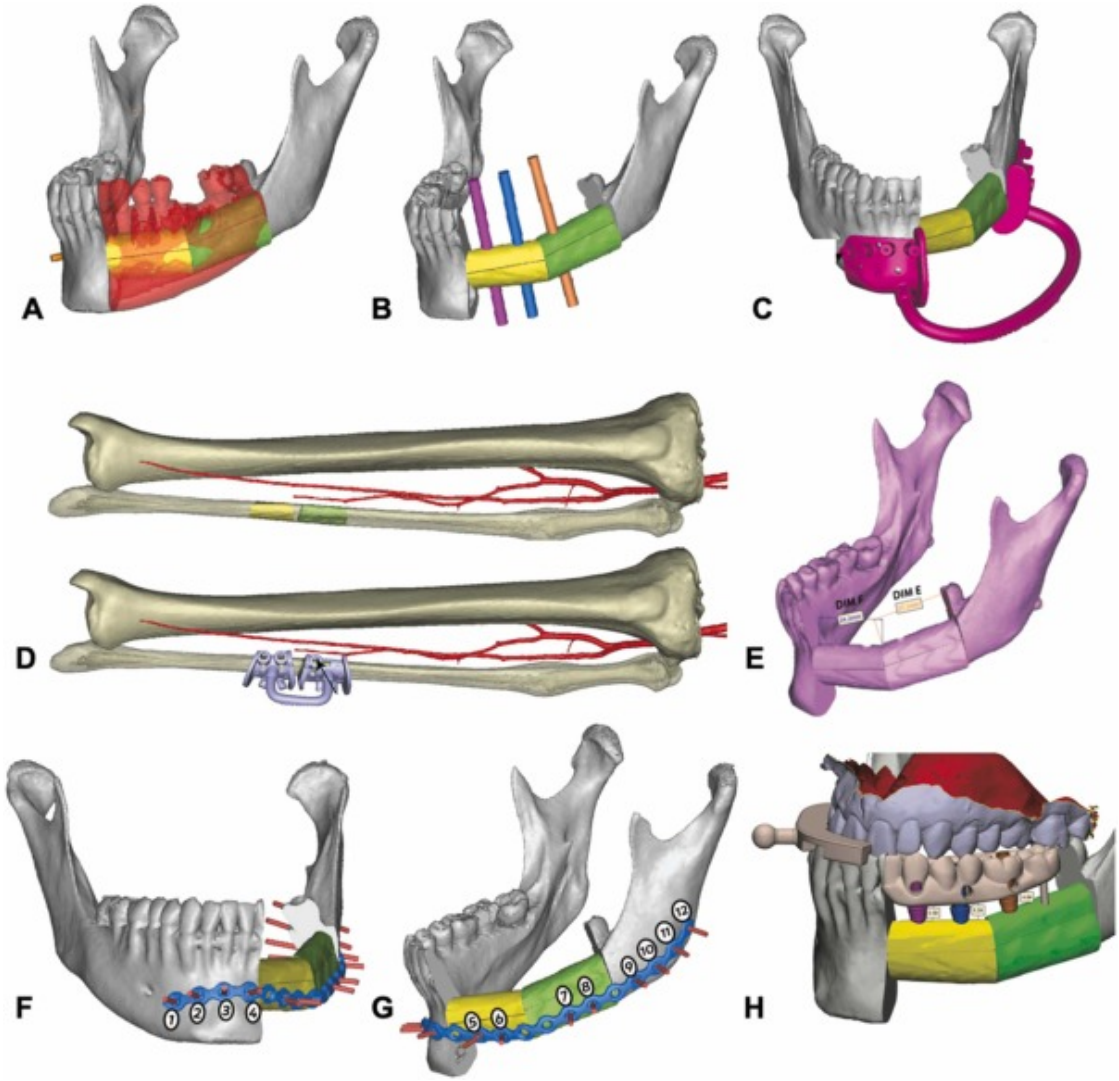

Figure 2. Virtual surgical planning (VSP) for jaw reconstruction. A. Native mandible with planned resection indicated in red. Fibula bone segments have been overlain in yellow and green. B. Planned position of dental implants (purple, blue, and orange). C. Mandible surgical guide (pink) with fibula bone segments (yellow and green). D. Planned fibula osteotomies (above) with fibula surgical guide (below). E. Anatomical model of planned mandibular reconstruction. F. and G. Pre-bent reconstruction plate (blue) optically scanned on the reconstruction model, with screws (numbered) virtually installed in screw holes. H. Provisional denture with occlusal guide (salmon) with superimposed intraoral scan of maxillary dentition (Jeong et al., 2025).

The benefits of VSP are well documented and include greater reconstruction accuracy, reduced ischaemic and operative time, shorter length of stay, fewer complications, and higher rates of successful dental rehabilitation (Foley et al., 2013; Li et al., 2018; Metzler et al., 2014; Petrides et al., 2021; Powcharoen et al., 2019; Roser et al., 2010; Salgueiro & Stevens, 2010). Traditionally, the VSP process has been outsourced to third-party commercial companies. However, this approach is limited by considerable financial costs and long lead times, with the latter being particularly disadvantageous for patients with malignant pathologies (Fatima et al., 2019; Smithers et al., 2018). To address these limitations, many institutions have instead developed in-house or point-of-care VSP (POC-VSP) workflows with commercially available software and 3D printers (Bosc et al., 2017; Luu et al., 2018; Mottini et al., 2016; Smithers et al., 2018).

1.1.3 DENTAL REHABILITATION

As part of jaw resection, the teeth and their underlying bony architecture are often removed, resulting in the loss of functional dentition (Ch'ng et al., 2016). Loss of functional dentition impacts mastication, aesthetics, and lower lip support in jaw reconstruction patients, resulting in poorer postoperative HRQoL. Consequently, there has been an increasing emphasis on incorporating dental rehabilitation to restore these critical functions. This may be achieved through conventional dentures or, more commonly, osseointegrated implants that provide superior support, retention, or stability for prostheses (Manzie et al., 2023; Petrides et al., 2021; Petrides et al., 2022; Shaw et al., 2005). Osseointegrated implant placement is a two-stage process. In the first stage, dental implants are inserted into native mandible, native maxilla, and/or vascularised bone flap, either at the time of ablative and reconstructive surgery or as a delayed procedure. Following a period of osseointegration – during which the implant fuses with the surrounding bone – the implants are exposed and tested for stability before abutments

are fitted to support the final prosthesis (Bak et al., 2010; Ch'ng et al., 2016). VSP is increasingly utilised in prosthodontic planning to optimise intraoperative implant positioning.

1.1.4 HEALTH ECONOMICS AND HEALTH TECHNOLOGY ASSESSMENT

The rapid expansion of research and development across all areas of medicine has placed increasing emphasis on understanding the economic implications of healthcare treatments and technologies. Health economics refers to the field concerned with how to best allocate scarce resources to optimise health outcomes across the population (Mushkin, 1958). The principle of scarcity is fundamental to this field, denoting how healthcare resources – such as hospital beds, operating room time, specialised equipment, and clinicians – are inherently limited, whilst the needs of patients are unlimited. Therefore, decision-making is necessary to allocate these finite resources in order to achieve the greatest possible health benefit (Drummond, 2015).

Health technology assessment (HTA) provides the evidence required for making these decisions. HTAs are multidisciplinary studies that examine the economic, clinical, organizational, and ethical costs and consequences of healthcare technologies (Centre for Epidemiology and Evidence, 2017; Reeves, 1999). In the context of surgery, HTAs provide healthcare providers, administrators, and policymakers with evidence to guide decisions on whether to adopt, modify, or reject specific procedures, devices, or treatment pathways (Banta, 2003; Centre for Health Economics Research and Evaluation, 2008).

Economic evaluation is a central component of HTA and comprises of several methodological approaches including partial or full economic evaluations. Partial economic evaluations examine costs or outcomes in isolation. These include cost descriptions or cost analyses that comparing the expense of alternative interventions without considering their relative

effectiveness (Drummond, 2015). While helpful for appreciating resource consumption, partial evaluations do not determine the value of an intervention and are less useful for decision-making. In contrast, full economic evaluations simultaneously compare both the costs and outcomes of alternative interventions, providing comprehensive evidence that informs resource allocation.

There are numerous forms of full economic evaluation. Cost-effectiveness analysis (CEA) compares the relative costs and health outcomes of alternative interventions. Cost-minimisation analysis (CMA) is used when interventions have been demonstrated to produce equivalent clinical outcomes (i.e. clinical equivalency), thus making cost the sole determinant of which intervention is the better choice. Cost-benefit analysis (CBA) expresses both costs and outcomes in monetary terms to enable direct comparison of economic value. Finally, cost-utility analysis (CUA) measures health outcomes in terms of quality-adjusted life years (QALYs), incorporating both the quantity and quality of life gained from an intervention (Fayanju et al., 2021).

In all scenarios, it is critical that the true costs of the intervention being evaluated are determined. The most precise way of measuring costs remains micro-costing, where each resource consumed during a patient's treatment is directly identified, quantified, and valued (Centre for Health Economics Research and Evaluation, 2008; Frick, 2009; Shepard, 1999). Micro-costing allows the resources consumed during specific activities that comprise an intervention to be measured, facilitating the identification of specific cost-drivers and meaningful comparison between interventions. This approach is also valuable when evaluating new or complex interventions where standardised cost estimates do not exist or where substantial variability in resource use is expected (Frick, 2009). Jaw reconstruction is a perfect

example of a complex intervention given the substantial heterogeneity between patients, pathologies, and surgical approaches as well as the increasing use of technologies such as VSP and immediate dental rehabilitation.

1.1.5 HEALTH ECONOMICS OF MAXILLARY AND MANDIBULAR RECONSTRUCTION

The resource-intensive and costly nature of jaw reconstruction is obvious. Operations are lengthy, particularly when both ablation and primary reconstruction are performed, frequently extending beyond normal theatre hours (Petrides et al., 2021; Riaz & Warraich, 2010). The operative team is large, typically comprising separate ablative and reconstructive surgical teams, an experienced anaesthetist, and scrub, scout, and anaesthetic nursing staff (Baujat et al., 2011; Haddock et al., 2010; Jones et al., 2007). Postoperative hospitalisation costs are similarly substantial. Patients are commonly admitted to the intensive care unit (ICU) immediately following surgery for airway management, free flap monitoring, and observation for potential complications (Haddock et al., 2010; Panwar et al., 2016). ICU admission is a major contributor to overall cost, as ICU beds cost several times that of general ward beds due to one-to-one nursing ratios and the use of specialised interventions including continuous cardiac monitoring and mechanical ventilation (Karabatsou et al., 2016; Rechner & Lipman, 2005).

Early postoperative complications in jaw reconstruction patients further contribute to admission costs, both through their high incidence and potential severity (Tan et al., 2010). In two case series of 85 maxillary reconstructions and 25 mandibular reconstructions with fibula free flaps, postoperative complication rates were 33% and 56%, respectively (Chaine et al., 2009; Petrides et al., 2021). Complications range from minor – including medical complications, donor or recipient site wound dehiscence, wound infection, and haematoma –

to major, such as free flap failure from arterial or venous thrombosis requiring return to the operating room for revision or flap replacement. Regardless of severity, complications meaningfully increase total resource costs through extended hospital length of stay, additional operating room time, and increased consumable use (Gourin et al., 2011; Jones et al., 2007; Miller et al., 1991).

Existing micro-costing studies provide estimates on the direct costs of microvascular head and neck reconstruction. Jones et al. (2007) reported a total hospitalisation cost of US$35,099, with the cost of the hospital representing the largest cost contribution (36.4%). Setälä et al. (2009) found the average cost of microsurgical reconstruction in head and neck cancer to be €20,000, with primary free flap failure nearly doubling total expenses. However, despite the clinical importance of jaw reconstruction, comprehensive economic evaluations on these specific procedures remain scarce. The existing literature is constrained by a predominance of partial economic evaluations, inconsistent costing methodologies, and variable reporting standards – limiting meaningful comparison and evidence synthesis. The current state of the economic literature on jaw reconstruction is systematically examined in **Chapter 2**.

1.1.6 HEALTH ECONOMICS OF VSP

Despite the established clinical benefits of VSP for jaw reconstruction, its considerable upfront cost dissuades many surgeons and patients from incorporating this technology into their treatment (Chen et al., 2021; Fatima et al., 2019; Zweifel et al., 2015). The studies focusing only on the costs of VSP do not account for potential downstream savings associated with reduced operative time, shorter hospital length of stay, and fewer complications (Foley et al., 2013; Li et al., 2018; Petrides et al., 2021; Powcharoen et al., 2019). Furthermore, in much of the literature, VSP was outsourced to third-party commercial providers (C-VSP), which charge

substantial fees and, being located off-site, impose extensive lead times that may be problematic for patients with malignancies requiring timely surgical intervention. Faced with these costs and logistical constraints, some institutions have instead focused on improving the efficiency and accuracy of conventional non-VSP approaches (Rommel et al., 2017).

To circumvent the expense of outsourcing to commercial providers, many institutions have developed POC-VSP workflows using commercially available software and available 3D printers (Dupret-Bories et al., 2018; McAllister et al., 2018; Mottini et al., 2016; Smithers et al., 2018). While several economic comparisons between POC-VSP and C-VSP exist, these are limited by incomplete costing methodologies and, critically, a lack of regulatory approval and pre-established clinical equivalency – a pre-requisite for valid CMA. The economic evidence for VSP in jaw reconstruction is examined in detail in **Chapter 2.**

1.2 RATIONALE FOR THE THESIS

Surgical reconstruction of the mandible and maxilla is clearly a resource-intensive intervention, with considerable costs arising from extended operations, the need for multidisciplinary input, and complicated postoperative management. It is critical that the economic implications of jaw reconstruction are well understood so that informed decisions around resource allocation can be made by healthcare providers, administrators, and policymakers. However, there are considerable gaps and limitations in the existing literature, ultimately precluding evidence-based decisions from being made.

Firstly, no comprehensive synthesis of the economic literature on jaw reconstruction currently exists. As a result, it is not possible to appreciate the current evidence base, highlight consistent findings, or identify methodological limitations. This limits the ability to draw meaningful conclusions and to identify focus areas for future research.

Second, existing economic evaluations have significant methodological issues. The methods used to measure costs are inconsistent. These range from micro-costing to gross-costing, to not being described at all. Key components in jaw reconstruction admissions are often either assumed or completely ignored from the total cost. Costing methodologies are rarely presented with sufficient transparency, preventing replication at other institutions, applications for other interventions, and comparison across studies. Furthermore, while existing economic frameworks are broadly applicable across therapeutic areas, the evaluation of medical devices presents unique considerations not encountered in pharmaceutical evaluations including manufacturing costs and regulatory conformity assessment requirements. These limitations affect the validity of known cost estimates.

Third, there is a predominance of partial economic evaluations that examine costs in isolation without comparing both the costs and outcomes of alternative interventions. Partial evaluations provide limited guidance for decision-making as they cannot establish cost-effectiveness or inform choices between treatment alternatives. Full economic evaluation – particularly CUA – requires preference-based health utility values, yet generic preference-based instruments are rarely collected in jaw reconstruction cohorts. While disease-specific instruments such as the European Organization for Research and Treatment of Cancer Questionnaire Head and Neck Module (QLQ-H&N35), the University of Washington Quality of Life Questionnaire (UWQOL), and the FACE-Q Head and Neck Cancer (FACE-Q) capture clinically relevant

outcomes, they cannot be used directly in CUA. The absence of validated tools to derive health utilities from existing data, therefore, represents a critical barrier to comprehensive economic evaluation.

Fourth, whilst the clinical benefits of VSP are well-established and its use in jaw reconstruction is increasing, the detailed economic implications of POC-VSP as an alternative to commercial outsourcing remain unclear. Existing comparisons between POC-VSP and C-VSP are limited by incomplete costing methodologies that often exclude labour, start-up costs, and regulatory compliance considerations. Most critically, these studies lack pre-established clinical equivalency between the approaches being compared – a prerequisite for valid CMA.

Fifth, despite the substantial costs incurred to healthcare institutions that provide jaw reconstruction treatment, little is known about the effectiveness of hospital reimbursement in this population. To the best of our knowledge, no Australian or international study has compared insurance reimbursement to accurate direct costs. If under-recovery of these costs exists, healthcare institutions may be disincentivised from providing jaw reconstruction services, ultimately limiting patient access to these essential procedures.

Finally, nearly all existing economic evaluations originate from settings outside of Australia, predominantly the United States and Europe. Healthcare structures, population groups, and funding models are considerably different in these locations and limits the generalisability of existing findings to the Australian context, ultimately constraining evidence-based decision-making for Australian clinicians, institutions, and policymakers.

In summary, the economic considerations of jaw reconstruction remain poorly understood due to the absence of comprehensive evidence synthesis, methodological limitations in existing cost studies, incomplete understanding of cost-drivers, lack of rigorous comparison between VSP approaches, unknown adequacy of reimbursement, absence of tools to enable CUA, and limited Australian-specific evidence. This thesis aims to address these gaps through a series of interrelated studies examining the health economics of jaw reconstruction.

1.3 AIMS AND STRUCTURE OF THE THESIS

This thesis aims to provide a comprehensive analysis of the health economics of jaw reconstruction to inform clinical practice, institutional and government decision-making, and future research. To address the gaps identified in the existing literature, this thesis comprises five interrelated studies with the following specific aims:

- Aim 1: To map the current knowledge around the economic considerations of jaw reconstruction.
- Aim 2: To estimate the direct financial costs and cost drivers associated with jaw reconstruction from the perspective of the healthcare provider.
- Aim 3: To compare the direct costs of C-VSP and POC-VSP for patients undergoing jaw reconstruction, providing evidence to inform institutional decision-making regarding investment in similar services.
- Aim 4: To compare the true costs of jaw reconstruction (based on a micro-costing methodology) with private health insurance reimbursement and to identify the factors contributing to any unwarranted variation.
- Aim 5: To map FACE-Q to the EQ-5D-5L in a cohort of jaw reconstruction patients to facilitate future cost-utility analysis.

These aims are addressed across five manuscript chapters. The structure of the thesis is as follows:

- **Chapter 2** addresses Aim 1 (to map the current knowledge around the economic considerations of jaw reconstruction) through a scoping review conducted in accordance with PRISMA-ScR guidelines. This chapter systematically maps the existing economic literature on mandibular and maxillary reconstruction, identifies methodological trends, and highlights gaps that informed the design of subsequent studies in this thesis.
- **Chapter 3** addresses Aim 2 (to estimate the direct financial costs and cost drivers associated with jaw reconstruction from the perspective of the healthcare provider) through a retrospective micro-costing study of 100 patients who underwent jaw reconstruction at Chris O'Brien Lifehouse Hospital (COBL). Using an individualised bottom-up costing methodology, this chapter establishes the true direct costs of jaw reconstruction and identifies patient, operative, and postoperative factors independently associated with increased cost. The transparent methodology presented in this chapter serves as the foundation for economic evaluations in **Chapters 4 and 5**.
- **Chapter 4** addresses Aim 3 (to compare the direct costs of C-VSP and POC-VSP for patients undergoing jaw reconstruction, providing evidence to inform institutional decision-making regarding investment in similar services) through a cost-minimisation analysis comparing POC-VSP and C-VSP. Building on pre-established clinical equivalency between these approaches at COBL, this chapter quantifies the cost differences between VSP workflows and determines the annual caseload thresholds at which POC-VSP becomes economically favourable.

- **Chapter 5** addresses Aim 4 (to compare the true costs of jaw reconstruction with private health insurance reimbursement and to identify the factors contributing to any unwarranted variation) through a cost-reimbursement analysis comparing micro-costed direct costs with private health insurance reimbursement for 61 patients. This chapter evaluates the adequacy of current funding models and identifies patient and clinical factors independently associated with unwarranted variation.
- **Chapter 6** addresses Aim 5 (to map FACE-Q to the EQ-5D-5L on a cohort of jaw reconstruction patients to facilitate future cost-utility analysis) through a mapping study deriving EQ-5D-5L health utility values from FACE-Q responses. Using data from 181 patients, this chapter develops and validates a mapping algorithm that enables quality-adjusted life year calculation from existing FACE-Q datasets, facilitating future cost-utility analyses of jaw reconstruction interventions.
- **Chapter 7** synthesises the findings from **Chapters 2-6**, discussing their clinical and research implications, acknowledging the limitations of this body of work, placing the findings within the context of the broader literature, and identifying priorities for future research.

Figure 3 outlines the framework of this thesis including the relationships between chapters and the publication status of included studies.

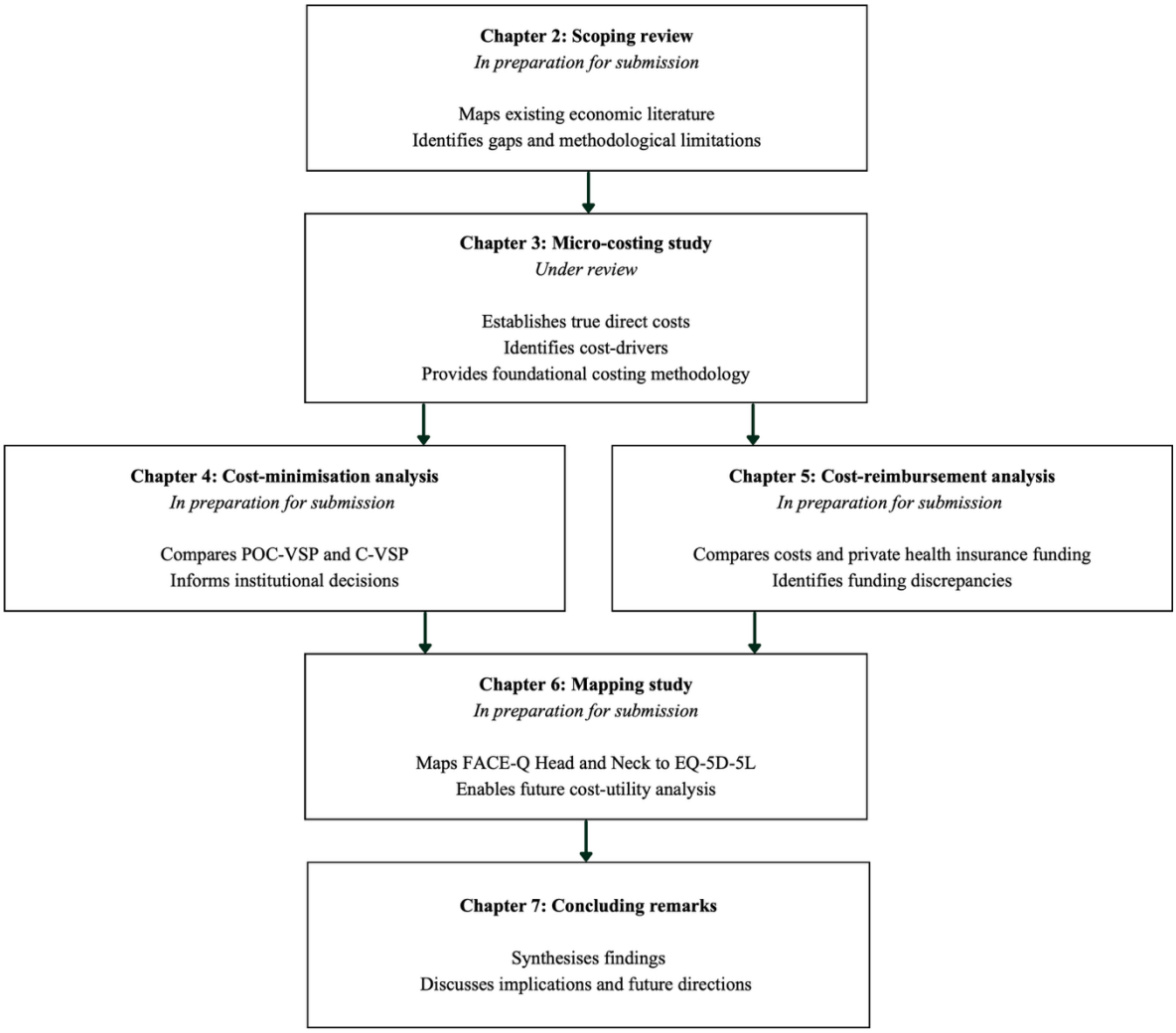

Figure 3. Conceptual framework of the thesis including the relationships between chapters and publication status of included studies.

1.4 REFERENCES

Argiris, A., Karamouzis, M. V., Raben, D., & Ferris, R. L. (2008). Head and neck cancer. *The Lancet*, 371(9625), 1695–1709. https://doi.org/10.1016/S0140-6736(08)60728-X

Australian Institute of Health and Welfare. (2014). Head and neck cancers in Australia. https://www.aihw.gov.au/reports/cancer/head-neck-cancers-australia

Australian Institute of Health and Welfare. (2022). Cancer data in Australia. https://www.aihw.gov.au/reports/cancer/cancer-data-in-australia

Bak, M., Jacobson, A. S., Buchbinder, D., & Urken, M. L. (2010). Contemporary reconstruction of the mandible. *Oral Oncology*, 46(2), 71–76. https://doi.org/10.1016/j.oraloncology.2009.11.006

Banta, D. (2003). The development of health technology assessment. *Health Policy*, 63(2), 121–132. https://doi.org/10.1016/S0168-8510(02)00059-3

Baujat, B., Altabaa, K., Meyers, M., Wagner, I., Leclerc, C., & Chabolle, F. (2011). Medicoeconomic study of microsurgical head and neck reconstructions. *European Annals of Otorhinolaryngology, Head and Neck Diseases*, 128(3), 121–126. https://doi.org/10.1016/j.anorl.2011.01.002

Bosc, R., Hersant, B., Carloni, R., Niddam, J., Bouhassira, J., De Kermadec, H., Bequignon, E., Wojcik, T., Julieron, M., & Meningaud, J. P. (2017). Mandibular reconstruction after cancer: An in-house approach to manufacturing cutting guides. *International Journal of Oral and Maxillofacial Surgery*, 46(1), 24–31. https://doi.org/10.1016/j.ijom.2016.10.004

Brown, J., Lowe, D., Kanatas, A., & Schache, A. (2017). Mandibular reconstruction with vascularised bone flaps: A systematic review over 25 years. *British Journal of Oral and Maxillofacial Surgery*, 55(2), 113–126. http://doi.org/10.1016/j.bjoms.2016.12.010

Cancer Council Victoria (2021). Optimal care pathway for people with head and neck cancer. https://www.cancer.org.au/health-professionals/optimal-cancer-care-pathways

Centre for Epidemiology and Evidence. (2017). Commissioning economic evaluations: A guide. https://preventioncentre.org.au/resources/commissioning-economic-evaluations

Centre for Health Economics Research and Evaluation. (2008). Issues in the costing of large projects in health and healthcare. https://www.health.nsw.gov.au/research/Pages/costing-large-health-projects.aspx

Chaine, A., Pitak-Arnnop, P., Hivelin, M., Dhanuthai, K., Bertrand, J.-C., & Bertolus, C. (2009). Postoperative complications of fibular free flaps in mandibular reconstruction: An analysis of 25 consecutive cases. *Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology*, 108(4), 488–495. http://doi.org/10.1016/j.tripleo.2009.05.043

Chen, Z., Mo, S., Fan, X., You, Y., Ye, G., & Zhou, N. (2021). A meta-analysis and systematic review comparing the effectiveness of traditional and virtual surgical planning for orthognathic surgery: Based on randomized clinical trials. *Journal of Oral and Maxillofacial Surgery,* 79(2), 471.e1–471.e19. https://doi.org/10.1016/j.joms.2020.09.005

Ch'ng, S., Skoracki, R. J., Selber, J. C., Yu, P., Martin, J. W., Hofstede, T. M., Chambers, M. S., Liu, J., & Hanasono, M. M. (2016). Osseointegrated implant-based dental rehabilitation in head and neck reconstruction patients. *Head & Neck*, 38(Suppl. 1), E321–E327. https://doi.org/10.1002/hed.23993

Cognetti, D. M., Weber, R. S., & Lai, S. Y. (2008). Head and neck cancer: An evolving treatment paradigm. *Cancer*, 113(Suppl. 7), 1911–1932. https://doi.org/10.1002/cncr.23654

Drummond, M. (2015). Methods for the economic evaluation of health care programmes (4th ed.). Oxford University Press.

Dupret-Bories, A., Vergez, S., Meresse, T., Brouillet, F., & Bertrand, G. (2018). Contribution of 3D printing to mandibular reconstruction after cancer. *European Annals of*

Otorhinolaryngology, Head and Neck Diseases, 135(2), 133–136. https://doi.org/10.1016/j.anorl.2017.09.007

Fatima, A., Hackman, T. G., & Wood, J. S. (2019). Cost-effectiveness analysis of virtual surgical planning in mandibular reconstruction. *Plastic and Reconstructive Surgery*, 143(4), 1185–1194. https://doi.org/10.1097/prs.0000000000005418

Fayanju, O. M., Haukoos, J. S., & Tseng, J. F. (2021). CHEERS reporting guidelines for economic evaluations. *JAMA Surgery*, 156(7), 677–678. https://doi.org/10.1001/jamasurg.2021.0540

Ferreira, J. J., Zagalo, C. M., Oliveira, M. L., Correia, A. M., & Reis, A. R. (2014). Mandible reconstruction: History, state of the art and persistent problems. *Prosthetics and Orthotics International*, 39(3), 182–189. https://doi.org/10.1177/0309364613520032

Foley, B. D., Thayer, W. P., Honeybrook, A., McKenna, S., & Press, S. (2013). Mandibular reconstruction using computer-aided design and computer-aided manufacturing: An analysis of surgical results. *Journal of Oral and Maxillofacial Surgery*, 71(2), e111–e119. https://doi.org/10.1016/j.joms.2012.08.022

Frick, K. D. (2009). Microcosting quantity data collection methods. *Medical Care*, 47(Suppl. 1), S76–S81. https://doi.org/10.1097/MLR.0b013e31819bc064

Futran, N. D., & Mendez, E. (2006). Developments in reconstruction of midface and maxilla. *The Lancet Oncology*, 7(3), 249–258. https://doi.org/10.1016/S1470-2045(06)70616-7

Gold, M. R., Siegel, J. E., Russell, L. B., & Weinstein, M. C. (1999). Cost-effectiveness in health and medicine. Oxford University Press.

Gourin, C. G., Forastiere, A. A., Sanguineti, G., Marur, S., Koch, W. M., & Bristow, R. E. (2011). Impact of surgeon and hospital volume on short-term outcomes and cost of

oropharyngeal cancer surgical care. *The Laryngoscope*, 121(4), 746–752. https://doi.org/10.1002/lary.21456

Haddock, N. T., Gobble, R. M., & Levine, J. P. (2010). More consistent postoperative care and monitoring can reduce costs following microvascular free flap reconstruction. *Journal of Reconstructive Microsurgery*, 26(7), 435–439. https://doi.org/10.1055/s-0030-1254232

Jeong, Y. J., Dunn, M., Manzie, T., Aung, Y. M., Cheng, K., Froggatt, C., Wykes, J., Leinkram, D., Low, T.-H., Ch'ng, S., & Clark, J. (2025). Point-of-care virtual surgical planning for jaw reconstruction: An update on the experience with 50 patients at a tertiary referral center. *Journal of Plastic, Reconstructive & Aesthetic Surgery*, 111, 182–188. https://doi.org/10.1016/j.bjps.2025.09.027

Jones, N. F., Jarrahy, R., Song, J. I., Kaufman, M. R., & Markowitz, B. (2007). Postoperative medical complications—not microsurgical complications—negatively influence the morbidity, mortality, and true costs after microsurgical reconstruction for head and neck cancer. *Plastic and Reconstructive Surgery*, 119(7), 2053–2060. https://doi.org/10.1097/01.prs.0000260591.82762.b5

Karabatsou, D., Tsironi, M., Tsigou, E., Boutzouka, E., Katsoulas, T., & Baltopoulos, G. (2016). Variable cost of ICU care, a micro-costing analysis. *Intensive and Critical Care Nursing*, 35, 66–73. https://doi.org/10.1016/j.iccn.2016.01.001

Kumar, P., Alvi, H. A., Rao, J., Singh, B. P., Jurel, S. K., Kumar, L., & Aggarwal, H. (2013). Assessment of the quality of life in maxillectomy patients: A longitudinal study. *The Journal of Advanced Prosthodontics*, 5(1), 29–35. https://doi.org/10.4047/jap.2013.5.1.29

Li, S. S., Copeland-Halperin, L. R., Kaminsky, A. J., Li, J., Lodhi, F. K., & Miraliakbari, R. (2018). Computer-aided surgical simulation in head and neck reconstruction: A cost

comparison among traditional, in-house, and commercial options. *Journal of Reconstructive Microsurgery,* 34(5), 341–347. https://doi.org/10.1055/s-0037-1621735

Luu, K., Pakdel, A., Wang, E., & Prisman, E. (2018). In house virtual surgery and 3D complex head and neck reconstruction. *Journal of Otolaryngology – Head & Neck Surgery*, 47(1), Article 75. https://doi.org/10.1186/s40463-018-0320-9

Macnamara, M., Pope, S., Sadler, A., Grant, H., & Brough, M. (1994). Microvascular free flaps in head and neck surgery. *The Journal of Laryngology & Otology*, 108(11), 962–968. https://doi.org/10.1017/s0022215100128634

Manzie, T., MacDougall, H., Cheng, K., Venchiarutti, R., Fox, R., Sharman, A., Charters, E., Seyfi, D., Dunn, M., & Mukherjee, P. (2023). Virtual reality digital surgical planning for jaw reconstruction: A usability study. *ANZ Journal of Surgery*, 93(5), 1341–1347. https://doi.org/10.1111/ans.18307

Mark, M., Eggerstedt, M., Urban, M. J., Al-Khudari, S., Smith, R., & Revenaugh, P. (2022). Designing an evidence-based free-flap pathway in head and neck reconstruction. *World Journal of Otorhinolaryngology – Head and Neck Surgery*, 8(2), 126–132. https://doi.org/10.1002/wjo2.22

McAllister, P., Watson, M., & Burke, E. (2018). A cost-effective, in-house, positioning and cutting guide system for orthognathic surgery. *Journal of Maxillofacial and Oral Surgery,* 17(1), 112–114. https://doi.org/10.1007/s12663-017-1067-y

McCarthy, C. M., & Cordeiro, P. G. (2010). Microvascular reconstruction of oncologic defects of the midface. *Plastic and Reconstructive Surgery*, 126(6), 1947–1959. https://doi.org/10.1097/PRS.0b013e3181f446f1

McGrouther, D. A. (1997). Facial disfigurement. *BMJ*, 314(7086), 991. https://doi.org/10.1136/bmj.314.7086.991

Metzler, P., Geiger, E. J., Alcon, A., Ma, X., & Steinbacher, D. M. (2014). Three-dimensional virtual surgery accuracy for free fibula mandibular reconstruction: Planned versus actual results. *Journal of Oral and Maxillofacial Surgery*, 72(12), 2601–2612. https://doi.org/10.1016/j.joms.2014.07.024

Miller, M. J., Swartz, W. M., Miller, R. H., & Harvey, J. M. (1991). Cost analysis of microsurgical reconstruction in the head and neck. *Journal of Surgical Oncology*, 46(4), 230–234. https://doi.org/10.1002/jso.2930460405

Mottini, M., Seyed Jafari, S. M., Shafighi, M., & Schaller, B. (2016). New approach for virtual surgical planning and mandibular reconstruction using a fibula free flap. *Oral Oncology*, 59, e6–e9. https://doi.org/10.1016/j.oraloncology.2016.06.001

Mushkin, S. J. (1958). Toward a definition of health economics. *Public Health Reports*, 73(9), 785. https://doi.org/10.2307/4590242

Okay, D. J., Genden, E., Buchbinder, D., & Urken, M. (2001). Prosthodontic guidelines for surgical reconstruction of the maxilla: A classification system of defects. *The Journal of Prosthetic Dentistry,* 86(4), 352–363. https://doi.org/10.1067/mpr.2001.119524

Panwar, A., Smith, R., Lydiatt, D., Lindau, R., Wieland, A., Richards, A., Shostrom, V., Militsakh, O., & Lydiatt, W. (2016). Vascularized tissue transfer in head and neck surgery: Is intensive care unit–based management necessary? *The Laryngoscope*, 126(1), 73–79. https://doi.org/10.1002/lary.25608

Petrides, G. A., Dunn, M., Charters, E., Venchiarutti, R., Cheng, K., Froggatt, C., Mukherjee, P., Wallace, C., Howes, D., & Leinkram, D. (2022). Health-related quality of life in maxillectomy patients undergoing dentoalveolar rehabilitation. *Oral Oncology*, 126, Article 105757. https://doi.org/10.1016/j.oraloncology.2022.105757

Petrides, G. A., Hicks, G., Dunn, M., Froggatt, C., Wallace, C., Howes, D., Leinkram, D., Low, T.-H., Ch'ng, S., Wykes, J., Palme, C. E., & Clark, J. R. (2021). Dentoalveolar

outcomes in maxillary reconstruction: A retrospective review of 85 maxillectomy reconstructions. *ANZ Journal of Surgery*, 91(7–8), 1472–1479. https://doi.org/10.1111/ans.17001

Powcharoen, W., Yang, W. F., Yan Li, K., Zhu, W., & Su, Y. X. (2019). Computer-assisted versus conventional freehand mandibular reconstruction with fibula free flap: A systematic review and meta-analysis. *Plastic and Reconstructive Surgery,* 144(6), 1417–1428. https://doi.org/10.1097/prs.0000000000006261

Rathod, S., Livergant, J., Klein, J., Witterick, I., & Ringash, J. (2015). A systematic review of quality of life in head and neck cancer treated with surgery with or without adjuvant treatment. *Oral Oncology*, 51(10), 888–900. https://doi.org/10.1016/j.oraloncology.2015.07.002

Rechner, I., & Lipman, J. (2005). The costs of caring for patients in a tertiary referral Australian intensive care unit. *Anaesthesia and Intensive Care*, 33(4), 477–482. https://doi.org/10.1177/0310057X0503300409

Reeves, B. (1999). Health-technology assessment in surgery. *The Lancet*, 353, S3–S5. https://doi.org/10.1016/S0140-6736(99)90413-0

Riaz, N., & Warraich, R. (2010). Reconstruction of mandible by free fibular flap. *Journal of the College of Physicians and Surgeons Pakistan*, 20(11), 723–727.

Rommel, N., Kesting, M. R., Rohleder, N. H., Bauer, F. M. J., Wolff, K. D., & Weitz, J. (2017). Mandible reconstruction with free fibula flaps: Outcome of a cost-effective individual planning concept compared with virtual surgical planning. *Journal of Cranio-Maxillofacial Surgery,* 45(8), 1246–1250. https://doi.org/10.1016/j.jcms.2017.04.010

Roser, S. M., Ramachandra, S., Blair, H., Grist, W., Carlson, G. W., Christensen, A. M., Weimer, K. A., & Steed, M. B. (2010). The accuracy of virtual surgical planning in

free fibula mandibular reconstruction: Comparison of planned and final results. *Journal of Oral and Maxillofacial Surgery*, 68(11), 2824–2832. https://doi.org/10.1016/j.joms.2010.06.177

Salgueiro, M. I., & Stevens, M. R. (2010). Experience with the use of prebent plates for the reconstruction of mandibular defects. *Craniomaxillofacial Trauma & Reconstruction*, 3(4), 201–208. http://doi.org/10.1055/s-0030-1268520

Setälä, L., Koskenvuori, H., Gudaviciene, D., Berg, L., & Mustonen, P. (2009). Cost analysis of 109 microsurgical reconstructions and flap monitoring with microdialysis. *Journal of Reconstructive Microsurgery,* 25(9), 521–526. https://doi.org/10.1055/s-0029-1238218

Shaw, R. J., Sutton, A. F., Cawood, J. I., Howell, R. A., Lowe, D., Brown, J. S., Rogers, S. N., & Vaughan, E. D. (2005). Oral rehabilitation after treatment for head and neck malignancy. *Head & Neck*, 27(6), 459–470. https://doi.org/10.1002/hed.20176

Smithers, F. A. E., Cheng, K., Jayaram, R., Mukherjee, P., & Clark, J. R. (2018). Maxillofacial reconstruction using in-house virtual surgical planning. *ANZ Journal of Surgery*, 88(9), 907–912. https://doi.org/10.1111/ans.14353

Spiegel, J. H., & Polat, J. K. (2007). Microvascular flap reconstruction by otolaryngologists: Prevalence, postoperative care, and monitoring techniques. *The Laryngoscope*, 117(3), 485–490. https://doi.org/10.1097/MLG.0b013e31802d6e66

Tan, B.-K., Por, Y.-C., & Chen, H.-C. (2010). Complications of head and neck reconstruction and their treatment. *Seminars in Plastic Surgery*, 24(3), 288–298. https://doi.org/10.1055/s-0030-1263070

Tang, J. A., Rieger, J. M., & Wolfaardt, J. F. (2008). A review of functional outcomes related to prosthetic treatment after maxillary and mandibular reconstruction in patients with head and neck cancer. *The International Journal of Prosthodontics*, 21(4), 337–354.

Tarsitano, A., Del Corso, G., Ciocca, L., Scotti, R., & Marchetti, C. (2015). Mandibular reconstructions using computer-aided design/computer-aided manufacturing: A systematic review of a defect-based reconstructive algorithm. *Journal of Cranio-Maxillofacial Surgery,* 43(9), 1785–1791. https://doi.org/10.1016/j.jcms.2015.08.006

van Gemert, J. T., van Es, R. J., Rosenberg, A. J., van der Bilt, A., Koole, R., & Van Cann, E. M. (2012). Free vascularized flaps for reconstruction of the mandible: Complications, success, and dental rehabilitation. *Journal of Oral and Maxillofacial Surgery*, 70(7), 1692–1698. https://doi.org/10.1016/j.joms.2011.08.024

Zweifel, D. F., Simon, C., Hoarau, R., Pasche, P., & Broome, M. (2015). Are virtual planning and guided surgery for head and neck reconstruction economically viable? *Journal of Oral and Maxillofacial Surgery,* 73(1), 170–175. https://doi.org/10.1016/j.joms.2014.07.038

CHAPTER 2: HEALTH ECONOMICS OF MANDIBULAR AND MAXILLARY RECONSTRUCTION: A SCOPING REVIEW

2.1 PREFACE

This chapter addresses Aim 1 of the thesis by mapping the current knowledge around the economic implications of jaw reconstruction. The specific objectives were to: (1) identify and characterise all published economic analyses; (2) examine the types of economic evaluations performed; (3) synthesise costs, resource utilisation, and key cost-drivers; and (4) highlight methodological gaps to guide future economic research. To the best of the author's knowledge, a review of the economic implications of jaw reconstruction has not been conducted.

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- Petrides, G. A., Lee, L., Dunn, M., Manzie, T. G., Venchiarutti, R. L., & Clark, J. R. Health economics of mandibular and maxillary reconstruction: A scoping review. *In preparation.*

2.2 AUTHORSHIP STATEMENT

The co-authors of the paper *"Health economics of mandibular and maxillary reconstruction: A scoping review"* confirm that George Andrew Petrides has made the following contributions:

- Conceptualisation and design of methodology.
- Collection and extraction of data.
- Analysis and interpretation of findings.
- Drafting and revising of the manuscript and critical appraisal of content.

As the primary supervisor for the candidature upon which this thesis is based, I can confirm that the above authorship attribution statement is correct.

Professor Jonathan Clark

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31st December 2025

2.3 ABSTRACT

INTRODUCTION

Jaw reconstruction is one of the most resource-intensive interventions within head and neck surgery. However, its health economic components have been rarely explored. The aim of this scoping review was to synthesise the existing literature on the economics of jaw reconstruction.

METHODOLOGY

A scoping review was performed following PRISMA-ScR guidelines. PubMed, EMBASE, and Cochrane databases were searched for studies evaluating the economics of jaw reconstruction. Articles were screened independently by two authors. Data was extracted from included articles on the number of participating centres, sample size, study design, type of economic evaluation, and outcomes.

RESULTS

Thirty-six studies on the economics of jaw reconstruction were included. The majority of studies were partial economic evaluations (92%), which assessed costs in isolation. The most common cost-driver for jaw reconstruction admissions was personnel costs. Studies commonly evaluated the economic implications of virtual surgical planning (VSP), commonly finding that the upfront costs are largely offset by downstream benefits of the technology, including reduced operative duration and length of admission. Point-of-care VSP workflows were consistently less expensive than the traditional approach of outsourcing to commercial companies. The validity of findings in most studies was undermined by methodological issues, including single-centre retrospective designs, imprecise and non-transparent cost measurement methodologies, and a lack of quality-of-life outcomes.

CONCLUSION

The findings from this review emphasise that existing studies evaluating the economic implications of jaw reconstruction are inadequate to effectively inform decisions around the allocation of resources. There are few full economic evaluations, and other studies are inconsistent in their methodology, ultimately preventing meaningful comparisons across studies and interventions. Hence, future studies should be designed with transparent and standardised methodologies with the incorporation of both the costs and outcomes of jaw reconstruction treatments.

2.4 INTRODUCTION

Surgical resection is a primary treatment modality for pathology affecting the jaw, including tumours, trauma, infection, and osteonecrosis (Argiris et al., 2008; Cognetti et al., 2008). Mandibular and maxillary reconstruction – referred to here as jaw reconstruction – using microvascular free tissue transfer is now the gold-standard to restore function and aesthetics following resection (Abo Sharkh & Makhoul, 2020; Petrides et al., 2021; Petrides et al., 2022; Shaw et al., 2005). To improve surgical accuracy and operative efficiency, virtual surgical planning (VSP) is increasingly as an adjunct in jaw reconstruction. VSP involves the use of virtual three-dimensional (3D) models of the jaw and free flap bony donor-site to plan bone placement, osteotomies, and dental implant sites. These plans are then translated into the operative setting via patient-specific surgical guides, anatomical models, and reconstruction plates (Ferreira et al., 2014; Leinkram et al., 2021; McCarthy & Cordeiro, 2010; Okay et al., 2001; Tang et al., 2008; Tarsitano et al., 2015).

Jaw reconstruction is undeniably resource-intensive. These patients undergo long operations, require multidisciplinary input, are often admitted to the intensive care unit postoperatively, and experience high rates of early postoperative complications (Dassonville et al., 2017). The associated costs are compounded by the use of surgical adjuncts such as VSP and immediate dental rehabilitation, which, whilst having been shown to improve health-related quality of life (HRQoL), demand considerable initial investment and currently lack proven cost-effectiveness (Petrides et al., 2022). Therefore, health economic evaluations of jaw reconstruction are urgently needed to inform decisions around resource-allocation and improve patient access to beneficial treatments.

Economic evaluation is a central component of Health Technology Assessments (HTAs) and comprises of several methodological approaches including partial or full economic evaluations. Partial economic evaluations examine costs or outcomes in isolation (Drummond, 2015). While helpful for appreciating resource consumption, partial evaluations do not determine the value of an intervention and are less useful for decision-making. In contrast, full economic evaluations simultaneously compare both the costs and outcomes of alternative interventions, providing comprehensive evidence that informs resource allocation. There are numerous forms of full economic evaluation including cost-effectiveness analysis (CEA), cost-minimisation analysis (CMA), cost-benefit analysis (CBA), cost-utility analysis (CUA).

The aim of this study was to map the current state of economic evidence for mandibular and maxillary reconstruction and identify the methodological limitations that should inform future research design. Specifically, the objectives were to: (1) identify and characterise all published economic analyses; (2) examine the types of economic evaluations performed; (3) synthesise costs and key cost-drivers; and (4) highlight methodological gaps to guide future economic research. We hypothesised that existing economic evaluations of jaw reconstructions would be dominated by partial economic evaluations with inconsistent costing methodologies, and that VSP-specific analysis would be limited by incomplete comparisons.

2.5 METHODOLOGY

2.5.1 STUDY DESIGN

A scoping review of the literature was performed to map the current knowledge around the economic implications of reconstruction of the mandible and maxilla. A scoping review design

was selected rather than a systematic review or meta-analysis because the existing literature is characterised by substantial methodological heterogeneity in costing approaches, variable reporting standards, and predominance of single-institution case series. This precludes meaningful pooling of cost estimates and instead requires a broad mapping of the evidence landscape to identify methodological patterns and gaps. Guidelines for conducting a scoping review were followed and the manuscript was prepared according to the Prepared Reporting Items for Systematic Reviews and Meta-analyses extension for Scoping Reviews (PRISMA-ScR) (**Appendix A1**) (Tricco et al., 2018). The study protocol was registered prospectively on the Open Science Framework (OSF) (DOI: 10.17605/OSF.IO/5GZNM; https://doi.org/10.17605/OSF.IO/5GZNM) (**Appendix A2)**.

2.5.2 SEARCH STRATEGY AND STUDY SELECTION

The final literature searches were conducted on October 29, 2025 via PubMed, EMBASE, and Cochrane Library. The complete search strategies are detailed in **Appendix A3**. In summary, the search terms related to “mandible” or “maxilla” or “jaw” and “reconstruction” and “economics” or “cost”. All studies resulting from the search were uploaded to the Rayyan software, a web-based application for conducting systematic reviews (Ouzzani et al., 2016). Potential duplicates were detected and excluded if appropriate based on manual review by the lead author (G.A.P.). The remaining studies were then screened (title and abstract) by two members of the research team (G.A.P. and L.L.) using the inclusion and exclusion criteria outlined in **Table 1**. Each screener was blinded to the decision of the others and discrepancies were discussed until a consensus was reached for each study. The full texts of the remaining studies were then reviewed by the same two members of the research team and studies were excluded using the same criteria as screening. The final list of studies underwent data extraction and analysis.

Table 1. Inclusion and exclusion criteria.

	Inclusion criteria	**Exclusion criteria**
Study population	Patients undergoing maxillary and/or mandibular reconstruction.	Non-human studies, not involving maxillary and/or mandibular reconstruction (e.g. orthognathic surgery only, dental implants without reconstruction, temporomandibular joint surgery without reconstruction).
Setting	All healthcare settings. All countries.	N/A
Outcome measures	Costs, cost-benefit, cost-utility, and cost-effectiveness.	No economic component.
Study design	Original research.	Non-original research including systematic reviews, book chapters, or expert opinion. Case reports or series' with less than five patients were also excluded.
Date	Any publication date.	N/A
Language	Studies available in English	Any study without an English language version available.

2.5.3 DATA EXTRACTION AND ANALYSIS

The metadata of studies including publication year, country, currency, design, sample size, number of participating centres, and patient population were recorded. Methodology details including the study design, type of economic evaluation (e.g. partial or full), costing methodology, and the costing perspective chosen were recorded. As a scoping review, a critical appraisal of study quality was not indicated. Data was stored on Rayyan software and

exported to Microsoft Excel. Descriptive statistics were used to summarise study characteristics.

2.6 RESULTS

2.6.1 STUDY IDENTIFICATION AND CHARACTERISTICS

The search returned 3,484 articles and 2,688 articles after removing duplicates. After screening by title and abstract, the full texts of 69 articles were reviewed. Ultimately, 36 articles were included in the study (**Figure 1).** The publication year ranged from 1992 to 2025 (**Table 2**). Studies were conducted in 12 countries, with the most frequent being United States (n = 17, 47%). The sample sizes ranged from five to 18,942 participants. Most studies were conducted at a single centre (n = 31, 86%). The study populations were most commonly mandibular reconstruction (n = 20, 56%) only or both mandibular and maxillary reconstruction (n = 7, 19%). The most common study design were observational comparative studies (n = 21, 58%), and case series (n = 9, 25%).

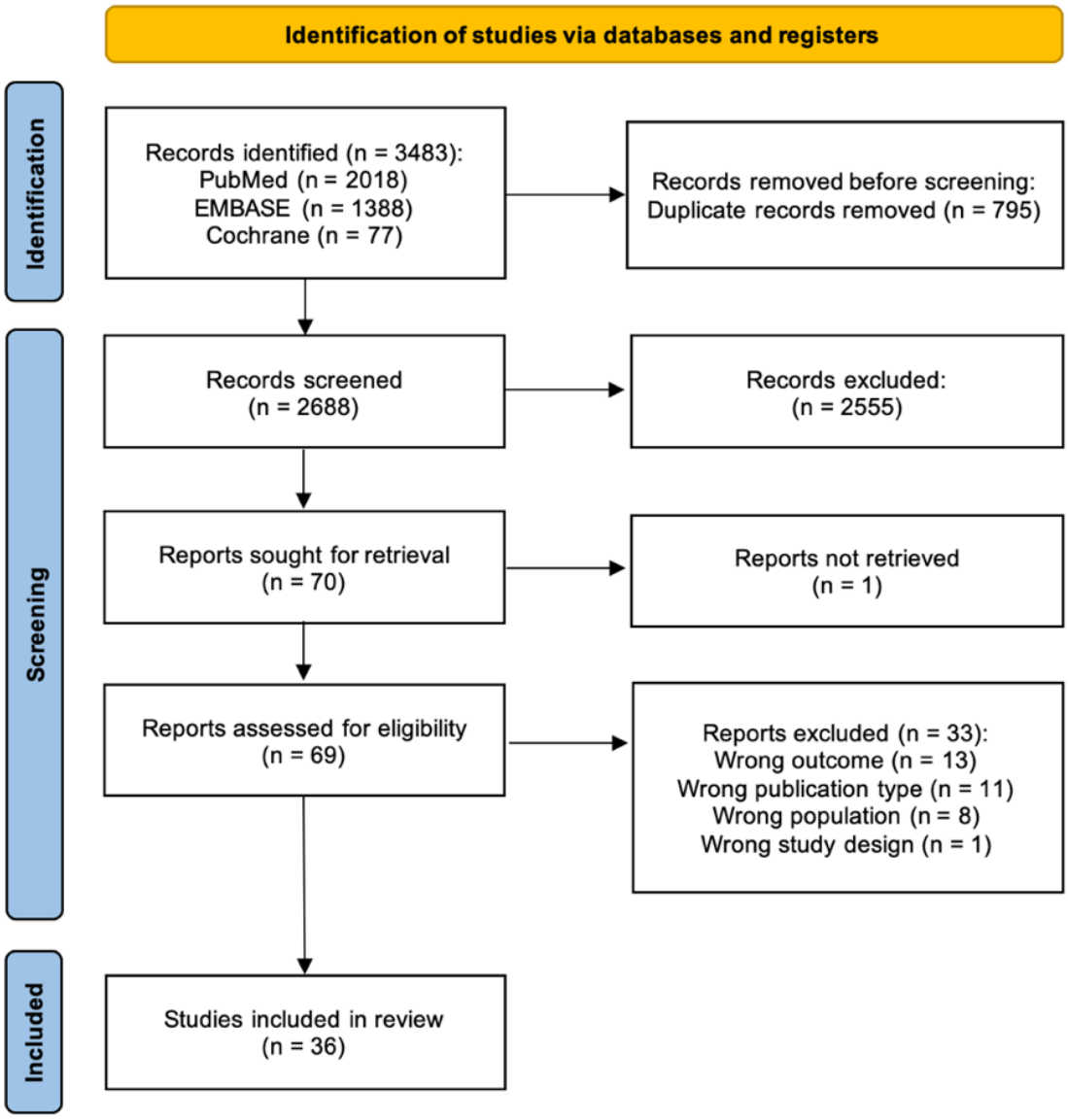

Figure 1. PRISMA 2020 flow diagram for new systematic reviews which included searches of databases and registers only.

Table 2. Characteristics of included studies.

Study characteristic (N = 36)	**n (%)**
Year of publication	
Before 2000	2 (6)
2000 – 2004	1 (3)
2005 – 2009	0 (0)
2010 – 2014	4 (11)
2015 - 2019	14 (39)
2020 – 2024	12 (33)
2025	3 (8)
Country of origin	
United States	17 (47)
France	3 (8)
China	3 (8)
Germany	3 (8)
Canada	2 (6)
Italy	2 (6)
Spain	1 (3)
Mexico	1 (3)
New Zealand	1 (3)
Belgium	1 (3)
Switzerland	1 (3)
Australia	1 (3)
Number of participating centres	
Single centre	31 (86)
Multiple centres	5 (14)
Study population	
Mandibular reconstruction	20 (56)
Mandibular and maxillary reconstruction	7 (19)
Head and neck cancer†	5 (14)
Oropharyngeal cancer†	2 (6)
Virtual surgical planning†	1 (3)
Just maxillary reconstruction	0 (0)
Study design	
Observational comparative study	21 (58)
Case series	9 (25)
Cross-sectional study	4 (11)
Modelling study	2 (6)

† Includes patients undergoing jaw reconstruction.

2.6.2 OUTCOMES AND ECONOMIC ANALYSIS METHODS

The studies comprised of 33 partial economic evaluations (92%) (i.e. assessed or compared costs only) and three full economic evaluations (8%) (i.e. compared both costs and outcomes) (**Table 3)**. Partial economic evaluations included comparative cost analyses (n = 20) and cost-description studies (n = 13), whereas full economic evaluations included cost-utility analyses (n = 2) and a cost-effectiveness analysis (n = 1). The majority of studies were retrospective in nature (n = 32, 89%). The costing methodologies comprised micro-costing (i.e. bottom-up or activity-based costing) in 16 studies (44%), gross costing (i.e. top-down) in 13 studies (36%), survey-based in one study (3%), and was not described in six studies (17%). The costing perspective was clearly stated in four studies (11%) and included the healthcare provider in three studies and the patient in one study. In the full economic evaluations, the outcomes evaluated were health utility scores based on quality of life (n = 1), health utility scores based on postoperative complications (n = 1), and costs of postoperative complications (n = 1).

Table 3. Economic analysis methods of included studies.

Study economic analysis method (N = 36)	n (%)
Type of economic evaluation	
Partial economic evaluation	33 (92)
Cost analysis	20 (57)
Cost-description study	13 (36)
Full economic evaluation	3 (8)
Cost-utility analysis	2 (6)
Cost-effectiveness analysis	1 (3)
Retrospective or prospective	
Retrospective	32 (89)
Prospective	4 (11)
Costing methodology	
Micro-costing	16 (44)
Gross-costing	13 (36)
Survey-based	1 (3)
Not described	6 (17)
Cost perspective	
Healthcare provider	3 (8)
Patient	1 (3)
Not clearly stated	32 (89)

2.6.3 COST COMPONENTS

All studies assessed only direct medical costs (100%). The time horizons for costing ranged from only the virtual surgical planning (VSP) process (n = 14, 39%), only the operative period (n = 4, 11%), the operative period and any postoperative complications (n = 1, 3%), the entire hospital admission (n = 15, 42%), the entire hospital admission, and any postoperative Emergency Department visits (n = 1, 3%), and the entire hospital admission and all activities up until 35 years postoperatively (including long-term complications and disease recurrence) (n = 1, 3%). In the studies with micro-costing methodologies, the direct medical costs reported varied considerably with only two of 16 studies (13%) including the costs of operating theatre time and staff, materials and disposables, the ICU and ward bed, and relevant investigations.

2.6.4 COSTS OF MANDIBULAR AND MAXILLARY RECONSTRUCTION

Thirteen studies reported total admission costs of jaw reconstruction procedures (Anton et al., 2025; Baujat et al., 2011; Chang et al., 2017; Dassonville et al., 2017; Gourin et al., 2011; Gourin & Frick, 2012; Jayakar et al., 2017; Kroll et al., 1992; Lydiatt et al., 2000; Madrigal et al., 2022; Talesnik et al., 1996; Yang et al., 2019; Zhao et al., 2025). Among head and neck cancer sites, Jayakar et al. (2017) demonstrated that oral cavity cancers requiring reconstruction incurred the highest admission costs (NZ$22,695 per patient). For mandibular reconstruction specifically, Dassonville et al. (2017) reported mean costs of €34,009 (median €27,452), with surgical and nursing staff representing the largest cost component. Similarly, Yang et al. (2019) identified three primary cost categories in maxillofacial free flap reconstruction: personnel (surgical and anaesthetic staff), materials, and medications.

Two studies demonstrated that institutional factors significantly influenced reconstruction costs (Lydiatt et al., 2000; Madrigal et al., 2022). Lydiatt et al. (2000) found that costs decreased over time as surgical teams gained experience, with reductions in operative time, length of stay, and intraoperative resource utilisation in a group of patients who were treated more recently. Madrigal et al. (2022) quantified this volume-outcome relationship, showing hospitalisation costs decreased by 10% from US$57,100 per patient at low-volume centres (<21 cases/year) to US$51,200 per patient at high-volume centres (>52 cases/year).

Four studies directly compared costs between reconstruction techniques (Anton et al., 2025; Kroll et al., 1992; Talesnik et al., 1996; Zhao et al., 2025). Microvascular free flaps were consistently more expensive than pedicled flaps, though costs varied by donor site. Talesnik et al. (1996) found microvascular reconstruction significantly costlier than pectoralis major flaps, except for radial forearm flaps which showed comparable costs. Among free flap options, soft-

tissue flaps averaged US$36,137 versus US$49,285 for composite mandibular reconstructions (Kroll et al., 1992). When considering only bony free flap options, another study illustrated that the cost of fibula flaps (US$14,295) exceeded iliac crest flaps (US$11,993) due to longer operative times and higher resource utilisation (Zhao et al., 2025). One study found that immediate tissue-engineered bone grafts were associated a lower cost per successful reconstruction (US$261,712) than fibula free flaps (US$549,910) (Anton et al., 2025).

Four studies identified other factors that significantly increased total costs (Chang et al., 2017; Gourin et al., 2011; Gourin & Frick, 2012; Yang et al., 2019). Patient complexity emerged as a major driver, with advanced comorbidities, neck dissection, and mandibulectomy independently predicting higher costs in two studies on oropharyngeal cancer (Gourin et al., 2011; Gourin & Frick, 2012). Surgical complications dramatically impacted economics, with atrial complications (i.e. thromboses or need for anastomotic revision) nearly doubling the overall cost of head and neck free flap reconstruction (Chang et al., 2017). Multivariate analysis by Yang et al. (2019) confirmed that flap type, tracheostomy, postoperative complications, and extended length of stay were the strongest predictors of increased hospitalisation costs.

2.6.5 COSTS OF VSP

Twenty-three studies (64%) examined VSP costs (Abo Sharkh & Makhoul, 2020; Block et al., 2024; Bolzoni et al., 2020; DeBusk et al., 2025; Dupret-Bories et al., 2018; Fatima et al., 2019; Gardiner et al., 2024; Garza-Cisneros et al., 2024; Guest et al., 2019; Kurlander et al., 2023; Lai et al., 2022; Li et al., 2018; Mazzola et al., 2020; Miles et al., 2022; Moe et al., 2021; Rodríguez-Arias et al., 2022; Rommel et al., 2017; Rustemeyer et al., 2014; Spaas & Lenssen, 2019; Tarsitano et al., 2016; Toto et al., 2015; Williams et al., 2020; Zweifel et al., 2015). Six partial economic evaluations compared VSP to conventional free-hand reconstruction, finding

that the upfront costs of VSP were largely offset by cost savings from its downstream benefits (Bolzoni et al., 2020; Mazzola et al., 2020; Rodríguez-Arias et al., 2022; Tarsitano et al., 2016; Toto et al., 2015; Zweifel et al., 2015). VSP was commonly associated with lower operative durations across included studies. For instance, Mazzola et al. (2020) reported 497 vs. 555 minutes, while Toto et al. (2015) found 534 vs. 707 minutes, translating to lower operative costs (US$20,950 vs. US$24,533). Bolzoni et al. (2020) found no significant differences in total costs (VSP €22,503 vs. conventional €22,433), with the higher upfront costs of VSP offset by shorter hospital stays (12.3 vs. 16.6 days).

Three studies conducted full economic evaluations using decision-analytic modelling (Fatima et al., 2019; Gardiner et al., 2024; Kurlander et al., 2023). Gardiner et al. (2024) calculated an incremental cost-effectiveness ratio (ICER) of US$68,382/QALY for VSP, below their US$100,000 willingness-to-pay (WTP) threshold. However, VSP become unfavourable for patients older than 75.5 years or when institutional costs exceeded US$10,745. Kurlander et al. (2023) reported a more favourable ICER of US$32,503/QALY (WTP threshold US$50,000), remaining cost-effective when VSP costs less than US$42,903 or flap failure rates are less than 4.5%. Conversely, Fatima et al. (2019) found VSP increased costs without reducing complications, though they evaluated only complication rates rather than QALYs.

Two studies analysed how specific VSP features influenced total costs (DeBusk et al., 2025; Rustemeyer et al., 2014). Rustemeyer et al. (2014) demonstrated positive correlation between total costs and number of CAD/CAM devices used (i.e. cutting guides, mandibular and maxillary models, and pre-bent reconstruction plates), reflecting case complexity. DeBusk et al. (2025) quantified the premium for industry-milled custom plates versus surgeon-bent plates to be an additional US$6,256.

Eight studies described institutional or point-of-care (POC-VSP) workflows designed to reduce commercial outsourcing costs (Abo Sharkh & Makhoul, 2020; Block et al., 2024; Dupret-Bories et al., 2018; Lai et al., 2022; Li et al., 2018; Moe et al., 2021; Rommel et al., 2017; Spaas & Lenssen, 2019; Williams et al., 2020). Two studies outlined the cost of their techniques without any comparative analysis finding costs per case of US$4 (Moe et al., 2021) and C$18 (Abo Sharkh & Makhoul, 2020), respectively Five comparative studies all demonstrated substantial cost savings versus commercial VSP (Block et al., 2024; Dupret-Bories et al., 2018; Li et al., 2018; Spaas & Lenssen, 2019; Williams et al., 2020). Spaas and Lenssen (2019) reported €1,026 for POC-VSP per case versus €3,500 for commercial VSP (a 71% reduction). Williams et al. (2020) achieved savings for dental prosthesis: US$8 in resin (POC-VSP) vs. US$617 (outsourced), with faster turnaround time (24 hours vs. 2 weeks). Li et al. (2018) found that POC-VSP (US$38,212) was cheaper than both commercial VSP (US$40,951) and conventional surgery (US$46,140). Interestingly, they showed that more than 27 cases were required annually to offset in-house the POC-VSP-associated costs such as infrastructure and maintenance.

2.7 DISCUSSION

Jaw reconstruction is one of the most resource-intensive interventions within head and neck surgery, yet its health economic implications have rarely been explored. This study synthesised the current literature on the economic aspects of jaw reconstruction. The 36 included studies commonly found the primary cost-component in jaw reconstruction admissions to be personnel costs and illustrated that VSP, particularly point-of-care workflows, may actually be cost-effective despite initial upfront costs. However, the validity of findings in most studies was

undermined by methodological issues, highlighting the urgent need for future research to comprise full economic evaluations with consistent costing methodologies to inform decisions around resource allocation.

The currently available research studies consistently underscore the resource-intensive nature of jaw reconstruction, with personnel costs – particularly operative and ward staffing – representing the primary cost component in the hospital admission. This is unsurprising given jaw reconstruction procedures necessitate extended operative times that frequently extend outside normal hours and require large, highly-skilled teams often comprising separate ablative and reconstructive surgeons, anaesthetists, and nursing staff (Baujat et al., 2011; Haddock et al., 2010; Jones et al., 2007; Petrides et al., 2021; Riaz & Warraich, 2010). Another consistent finding was that indicators of higher complexity, including tracheostomy and neck dissection, were associated with considerably higher cost (Anton et al., 2025; Kroll et al., 1992; Talesnik et al., 1996; Zhao et al., 2025). This cost-complexity relationship similarly applied to free flap donor site section, where osseous free flaps, such as the fibula flap, incurred higher costs than soft-tissue donor site options due to increased operative complexity, extended operative duration, and higher perioperative resource requirements.

The postoperative admission was also associated with substantial costs. Most jaw reconstruction patients require immediate postoperative admission to the intensive care unit (ICU) for airway management, free flap observations, and monitoring for potential complications (Haddock et al., 2010; Panwar et al., 2016). ICU care costs several times more than general ward care due to one-to-one nursing staff and the occasional use of specialised interventions such as continuous cardiac monitoring and mechanical ventilation (Karabatsou et al., 2016; Rechner & Lipman, 2005). Numerous studies identified postoperative

complications as a key cost-driver, with free flap failure in particular compounding costs due to the need for free flap revision, adding operative time and extending admission duration. (Chang et al., 2017; Kroll et al., 1992; Yang et al., 2019). This association between postoperative complication and costs underpins the influence of institutional experience on the economics of jaw reconstruction, with high-volume institutions and more experienced surgeons generating lower costs likely due to reduced operative durations and fewer complications (Lydiatt et al., 2000; Madrigal et al., 2022).

Despite documented clinical benefits, the upfront costs of VSP in jaw reconstruction often discourage surgeons and patients from its utilisation (Chen et al., 2021). As a result, numerous studies have focused on the economic implications of VSP. Partial economic evaluations included indicate the downstream benefits of VSP – primarily reduced operative time and hospital stays – may largely or completely offset the initial financial investment (Bolzoni et al., 2020; Mazzola et al., 2020; Rodríguez-Arias et al., 2022; Tarsitano et al., 2016; Toto et al., 2015; Zweifel et al., 2015). However, more useful evidence can be drawn from the full economic evaluations available. Two of three studies illustrated the cost-effectiveness of VSP across most patient populations, excluding elderly patients or institutions with high rates of postoperative complications (Fatima et al., 2019; Gardiner et al., 2024; Kurlander et al., 2023). The third study found no economic benefit. However, this analysis did not evaluate QALYs and assumed higher rates of infection and flap failure with VSP, a finding not supported in the literature (Powcharoen et al., 2019).

Many institutions have developed POC-VSP workflows to avoid commercial costs, utilising open-source software and commercially-available 3D printers to eliminate vendor fees and minimise lead times (Dupret-Bories et al., 2018; McAllister et al., 2018; Mottini et al., 2016;

Smithers et al., 2018). While studies uniformly reported substantial cost savings with POC-VSP, significant limitations remain unaddressed (Block et al., 2024; Dupret-Bories et al., 2018; Li et al., 2018; Spaas & Lenssen, 2019; Williams et al., 2020). First, the quality of POC-VSP compared to the commercial standard inherently varies considerably between institutions due to differences in regulatory requirements and clinical-equivalence remained largely unvalidated. Second, most analyses excluded startup, regulatory, and maintenance costs, likely to be the largest expense components. The single study that comprehensively assessed these components revealed that POC-VSP viability depends entirely on case volume, identifying 27 annual cases as the break-even threshold below which commercial VSP remains more economical (Li et al., 2018).

This scoping review exemplifies the methodological limitations of existing literature as hypothesised. The majority of studies utilised costing data that was retrospectively collected from patients treated at a single institution, diminishing accuracy and external validity (Potter et al., 2020). Moreover, as most studies were from the United States and Europe, applicability to Australian healthcare structures is limited. The foundation of any economic analysis is an appreciation for true costs (Ridyard & Hughes, 2010). Across included studies, the costs of jaw reconstruction were measured very inconsistently. The costing methodology was heterogenous, ranging from micro-costing to gross-costing, with many studies not describing their measurement approach at all. Despite micro-costing being the most precise method, many studies instead utilised gross-costing methods such as healthcare resource groups or insurance payments. Gross-costing is limited by a lack of granularity, meaning specific cost-drivers cannot be identified and costs cannot be differentiated between interventions in the same healthcare resource groups (Polsky & Glick, 2009). The included micro-costing studies were still limited by short time horizons, the exclusion or assumption of relevant cost components,

and poor transparency in their cost measurement approach. These methodological inconsistencies prevent meaningful comparison between studies and limit evidence synthesis. Future economic evaluations must prioritise standardised micro-costing approaches with transparent reporting to enable valid intervention comparisons (Potter et al., 2020).

Included studies were predominantly partial economic evaluations that assessed only costs without outcomes. Partial economic evaluations cannot establish cost-effectiveness or guide choices between treatment alternatives (Drummond, 2015). Instead, full economic evaluations offer much greater utility by simultaneously compare costs and outcomes across interventions (Fayanju et al., 2021). Only three identified studies were full economic evaluations and all focused on the comparison between VSP and conventional free-hand reconstruction. Moreover, the outcome measures in these evaluations were limited; either focusing on only postoperative complications or basic assessments of quality of life. No studies incorporated disease-specific patient-reported outcome measures (PROMs). This represents a critical gap, as outcomes specific to jaw reconstruction — including oral competence, speech, and psychosocial wellbeing — are inadequately captured by generic measures and may differ significantly between VSP and non-VSP groups. This lack of comprehensive economic evidence limits evidence-based decision making around resource allocation in jaw reconstruction, highlighting an urgent need for rigorous and high-quality economic evaluation in this field.

This review had numerous methodological limitations. A formal quality assessment or risk of bias evaluation was not performed as per scoping review guidelines given the heterogeneity of included studies. However, this prevented a detailed critical appraisal of these studies. As with any review and in spite of a comprehensive search in multiple databases, the search strategy

may have missed relevant studies. For example, we did not capture grey literature and publications not available in English.

2.8 CONCLUSION

Given its resource-intensive nature, appreciating the economic implications of the jaw reconstruction is essential to guide decisions around resource allocation. This scoping review illustrated that the primary cost-driver for jaw reconstruction are personnel costs and that VSP, particularly point-of-care workflows, may result in favourable cost-effectiveness through downstream benefits. Nevertheless, these findings support the hypothesis that current literature suffers from methodological limitations, highlighting the need for full economic evaluations with consistent costing methodologies to guide evidence-based decision-making.

2.9 REFERENCES

Abo Sharkh, H., & Makhoul, N. (2020). In-house surgeon-led virtual surgical planning for maxillofacial reconstruction. *Journal of Oral and Maxillofacial Surgery*, 78(4), 651–660. https://doi.org/10.1016/j.joms.2019.11.013

Anton, S. M., Gayed, A., Chadwick, J. W., Addamo, P., Holland, J. N., Wong, M. E., Benavidez, R., & Melville, J. C. (2025). Cost-effectiveness analysis of immediate tissue engineering bone graft versus fibula-free flap reconstruction for mandibular continuity defects secondary to benign pathology. *Journal of Oral and Maxillofacial Surgery*, 83(8), 1024–1031. https://doi.org/10.1016/j.joms.2025.05.002

Argiris, A., Karamouzis, M. V., Raben, D., & Ferris, R. L. (2008). Head and neck cancer. *The Lancet,* 371(9625), 1695–1709. https://doi.org/10.1016/S0140-6736(08)60728-X

Baujat, B., Altabaa, K., Meyers, M., Wagner, I., Leclerc, C., & Chabolle, F. (2011). Medicoeconomic study of microsurgical head and neck reconstructions. *European Annals of Otorhinolaryngology, Head and Neck Diseases*, 128(3), 121–126. https://doi.org/10.1016/j.anorl.2011.01.002

Block, O. M., Khromov, T., Hoene, G., Schliephake, H., & Brockmeyer, P. (2024). In-house virtual surgical planning and guided mandibular reconstruction is less precise, but more economical and time-efficient than commercial procedures. *Head & Neck,* 46(4), 871–883. https://doi.org/10.1002/hed.27642

Bolzoni, A. R., Segna, E., Beltramini, G. A., Sweed, A. H., Giannì, A. B., & Baj, A. (2020). Computer-aided design and computer-aided manufacturing versus conventional free fibula flap reconstruction in benign mandibular lesions: An Italian cost analysis. *Journal of Oral and Maxillofacial Surgery,* 78(6), 1035.e1–1035.e6. https://doi.org/10.1016/j.joms.2019.03.003

Chang, C. S., Chu, M. W., Nelson, J. A., Basta, M., Gerety, P., Kanchwala, S. K., & Wu, L. C. (2017). Complications and cost analysis of intraoperative arterial complications in head and neck free flap reconstruction. *Journal of Reconstructive Microsurgery*, 33(5), 318–327. https://doi.org/10.1055/s-0037-1598618

Chen, Z., Mo, S., Fan, X., You, Y., Ye, G., & Zhou, N. (2021). A meta-analysis and systematic review comparing the effectiveness of traditional and virtual surgical planning for orthognathic surgery: Based on randomized clinical trials. Journal of *Oral and Maxillofacial Surgery*, 79(2), 471.e1–471.e19. https://doi.org/10.1016/j.joms.2020.09.005

Cognetti, D. M., Weber, R. S., & Lai, S. Y. (2008). Head and neck cancer: An evolving treatment paradigm. *Cancer,* 113(Suppl. 7), 1911–1932. https://doi.org/10.1002/cncr.23654

Dassonville, O., Bozec, A., Château, Y., Reyt, E., Devauchelle, B., Louis, M. Y., Breton, P., Julieron, M., Yachouh, J., Mallet, Y., Sarini, J., Dolivet, G., Schiappa, R., Gal, J., Orlanducci, M. H., Poissonnet, G., & Chamorey, E. (2017). Multicenter prospective micro-costing study evaluating mandibular free-flap reconstruction. *European Archives of Oto-Rhino-Laryngology,* 274(2), 1103–1111. https://doi.org/10.1007/s00405-016-4360-3

DeBusk, W. T., Bhethanabotla, R. M., David, A. P., Heaton, C. M., Park, A. M., Seth, R., & Knott, P. D. (2025). Cost comparison of industry versus in-house three-dimensional printed models for microvascular mandible reconstruction. *Facial Plastic Surgery & Aesthetic Medicine*, 27(2), 157–162. https://doi.org/10.1089/fpsam.2024.0172

Drummond, M. (2015). Methods for the economic evaluation of health care programmes (4th ed.). Oxford University Press.

Dupret-Bories, A., Vergez, S., Meresse, T., Brouillet, F., & Bertrand, G. (2018). Contribution of 3D printing to mandibular reconstruction after cancer. *European Annals of Otorhinolaryngology, Head and Neck Diseases,* 135(2), 133–136. https://doi.org/10.1016/j.anorl.2017.09.007

Fatima, A., Hackman, T. G., & Wood, J. S. (2019). Cost-effectiveness analysis of virtual surgical planning in mandibular reconstruction. *Plastic and Reconstructive Surgery,* 143(4), 1185–1194. https://doi.org/10.1097/prs.0000000000005418

Fayanju, O. M., Haukoos, J. S., & Tseng, J. F. (2021). CHEERS reporting guidelines for economic evaluations. *JAMA Surgery,* 156(7), 677–678. https://doi.org/10.1001/jamasurg.2021.0540

Ferreira, J. J., Zagalo, C. M., Oliveira, M. L., Correia, A. M., & Reis, A. R. (2014). Mandible reconstruction: History, state of the art and persistent problems. *Prosthetics and Orthotics International*, 39(3), 182–189. https://doi.org/10.1177/0309364613520032

Gardiner, L., Smith, B., Kubik, M., Solari, M., Smith, K., de Almeida, J. R., & Sridharan, S. (2024). Long-term outcomes in virtual surgical planning for mandibular reconstruction: A cost-effectiveness analysis. *Microsurgery*, 44(5), Article e31206. https://doi.org/10.1002/micr.31206

Garza-Cisneros, A. N., García-Pérez, M. M., Rodriguez-Guajardo, W. J., Elizondo-Riojas, G., & Negreros-Osuna, A. A. (2024). Cost-effective solution for maxillofacial reconstruction surgery with virtual surgical planning and 3D printed cutting guides reduces operative time. *Plastic Surgery*, 32(1), 70–77. https://doi.org/10.1177/22925503221078692

Gourin, C. G., Forastiere, A. A., Sanguineti, G., Marur, S., Koch, W. M., & Bristow, R. E. (2011). Impact of surgeon and hospital volume on short-term outcomes and cost of

oropharyngeal cancer surgical care. *The Laryngoscope*, 121(4), 746–752. https://doi.org/10.1002/lary.21456

Gourin, C. G., & Frick, K. D. (2012). National trends in oropharyngeal cancer surgery and the effect of surgeon and hospital volume on short-term outcomes and cost of care. *The Laryngoscope,* 122(3), 543–551. https://doi.org/10.1002/lary.22447

Guest, W., Forbes, D., Schlosser, C., Yip, S., Coope, R., & Chew, J. (2019). Imaging-based 3-dimensional printing for improved maxillofacial presurgical planning: A single center case series. *Canadian Association of Radiologists Journal*, 70(1), 74–82. https://doi.org/10.1016/j.carj.2018.10.002

Haddock, N. T., Gobble, R. M., & Levine, J. P. (2010). More consistent postoperative care and monitoring can reduce costs following microvascular free flap reconstruction. *Journal of Reconstructive Microsurgery*, 26(7), 435–439. https://doi.org/10.1055/s-0030-1254232

Jayakar, R., Choi, J., MacKinnon, C., & Tan, S. (2017). The cost of major head and neck cancer surgery. *New Zealand Medical Journal,* 130(1455), 111–119.

Jones, N. F., Jarrahy, R., Song, J. I., Kaufman, M. R., & Markowitz, B. (2007). Postoperative medical complications—not microsurgical complications—negatively influence the morbidity, mortality, and true costs after microsurgical reconstruction for head and neck cancer. *Plastic and Reconstructive Surgery*, 119(7), 2053–2060. https://doi.org/10.1097/01.prs.0000260591.82762.b5

Karabatsou, D., Tsironi, M., Tsigou, E., Boutzouka, E., Katsoulas, T., & Baltopoulos, G. (2016). Variable cost of ICU care, a micro-costing analysis. *Intensive and Critical Care Nursing*, 35, 66–73. https://doi.org/10.1016/j.iccn.2016.01.001

Kroll, S. S., Schusterman, M. A., & Reece, G. P. (1992). Costs and complications in mandibular reconstruction. *Annals of Plastic Surgery*, 29(4), 341–347. https://doi.org/10.1097/00000637-199210000-00011

Kurlander, D. E., Garvey, P. B., Largo, R. D., Yu, P., Chang, E. I., Hanasono, M. M., & Mericli, A. F. (2023). The cost utility of virtual surgical planning and computer-assisted design/computer-assisted manufacturing in mandible reconstruction using the free fibula osteocutaneous flap. *Journal of Reconstructive Microsurgery*, 39(3), 221–230. https://doi.org/10.1055/s-0042-1755260

Lai, Y., Wang, C., Mao, C., Lu, M., Ouyang, Q., Fang, Y., Cai, Z., & Chen, W. (2022). Mandible reconstruction with free fibula flaps: Accuracy of a cost-effective modified semicomputer-assisted surgery compared with computer-assisted surgery—A retrospective study. *Journal of Cranio-Maxillofacial Surgery*, 50(3), 274–280. https://doi.org/10.1016/j.jcms.2021.12.004

Leinkram, D., Wykes, J., Palme, C., Deshpande, S., McLaughlin, M., Garg, P., Wallace, C., Howes, D., & Clark, J. R. (2021). Occlusal-based planning for dental rehabilitation following segmental resection of the mandible and maxilla. *ANZ Journal of Surgery*, 91(3), 451–452. https://doi.org/10.1111/ans.16441

Li, S. S., Copeland-Halperin, L. R., Kaminsky, A. J., Li, J., Lodhi, F. K., & Miraliakbari, R. (2018). Computer-aided surgical simulation in head and neck reconstruction: A cost comparison among traditional, in-house, and commercial options. *Journal of Reconstructive Microsurgery*, 34(5), 341–347. https://doi.org/10.1055/s-0037-1621735

Lydiatt, D. D., Hollins, R. R., Friedman, A., & Lydiatt, C. A. (2000). The team concept in mandibular reconstruction after ablative oncologic surgery. *Journal of Oral and*

Maxillofacial Surgery, 58(6), 607–610. https://doi.org/10.1016/s0278-2391(00)90150-2

Madrigal, J., Mukdad, L., Han, A. Y., Tran, Z., Benharash, P., St John, M. A., & Blackwell, K. E. (2022). Impact of hospital volume on outcomes following head and neck cancer surgery and flap reconstruction. *The Laryngoscope,* 132(7), 1381–1387. https://doi.org/10.1002/lary.29903

Mazzola, F., Smithers, F., Cheng, K., Mukherjee, P., Hubert Low, T. H., Ch'ng, S., Palme, C. E., & Clark, J. R. (2020). Time and cost-analysis of virtual surgical planning for head and neck reconstruction: A matched pair analysis. *Oral Oncology,* 100, Article 104491. https://doi.org/10.1016/j.oraloncology.2019.104491

McAllister, P., Watson, M., & Burke, E. (2018). A cost-effective, in-house, positioning and cutting guide system for orthognathic surgery. *Journal of Maxillofacial and Oral Surgery,* 17(1), 112–114. https://doi.org/10.1007/s12663-017-1067-y

McCarthy, C. M., & Cordeiro, P. G. (2010). Microvascular reconstruction of oncologic defects of the midface. *Plastic and Reconstructive Surgery*, 126(6), 1947–1959. https://doi.org/10.1097/PRS.0b013e3181f446f1

Miles, B. A., McMullen, C. P., Sweeny, L., Zenga, J., Li, R., Divi, V., Jackson, R., Patel, U. A., & Richmon, J. D. (2022). Practice patterns of virtual surgical planning: Survey of the reconstructive section of the American Head and Neck Society. *American Journal of Otolaryngology*, 43(1), Article 103225. https://doi.org/10.1016/j.amjoto.2021.103225

Moe, J., Foss, J., Herster, R., Powell, C., Helman, J., Ward, B. B., & VanKoevering, K. (2021). An in-house computer-aided design and computer-aided manufacturing workflow for maxillofacial free flap reconstruction is associated with a low cost and

high accuracy. *Journal of Oral and Maxillofacial Surgery*, 79(1), 227–236. https://doi.org/10.1016/j.joms.2020.07.216

Mottini, M., Seyed Jafari, S. M., Shafighi, M., & Schaller, B. (2016). New approach for virtual surgical planning and mandibular reconstruction using a fibula free flap. *Oral Oncology,* 59, e6–e9. https://doi.org/10.1016/j.oraloncology.2016.06.001

Okay, D. J., Genden, E., Buchbinder, D., & Urken, M. (2001). Prosthodontic guidelines for surgical reconstruction of the maxilla: A classification system of defects. *The Journal of Prosthetic Dentistry*, 86(4), 352–363. https://doi.org/10.1067/mpr.2001.119524

Ouzzani, M., Hammady, H., Fedorowicz, Z., & Elmagarmid, A. (2016). Rayyan—A web and mobile app for systematic reviews. *Systematic Reviews,* 5(1), Article 210. https://doi.org/10.1186/s13643-016-0384-4

Panwar, A., Smith, R., Lydiatt, D., Lindau, R., Wieland, A., Richards, A., Shostrom, V., Militsakh, O., & Lydiatt, W. (2016). Vascularized tissue transfer in head and neck surgery: Is intensive care unit–based management necessary? *The Laryngoscope*, 126(1), 73–79. https://doi.org/10.1002/lary.25608

Petrides, G. A., Dunn, M., Charters, E., Venchiarutti, R., Cheng, K., Froggatt, C., Mukherjee, P., Wallace, C., Howes, D., Leinkram, D., Singh, J., Nguyen, K., Hubert Low, T. H., Ch'ng, S., Wykes, J., & Clark, J. R. (2022). Health-related quality of life in maxillectomy patients undergoing dentoalveolar rehabilitation. *Oral Oncology*, 126, Article 105757. https://doi.org/10.1016/j.oraloncology.2022.105757

Petrides, G. A., Hicks, G., Dunn, M., Froggatt, C., Wallace, C., Howes, D., Leinkram, D., Low, T.-H., Ch'ng, S., Wykes, J., Palme, C. E., & Clark, J. R. (2021). Dentoalveolar outcomes in maxillary reconstruction: A retrospective review of 85 maxillectomy reconstructions. *ANZ Journal of Surgery*, 91(7–8), 1472–1479. https://doi.org/10.1111/ans.17001

Polsky, D., & Glick, H. (2009). Costing and cost analysis in randomized controlled trials: Caveat emptor. *PharmacoEconomics,* 27(3), 179–188. https://doi.org/10.2165/00019053-200927030-00001

Potter, S., Davies, C., Davies, G., Rice, C., & Hollingworth, W. (2020). The use of micro-costing in economic analyses of surgical interventions: A systematic review. *Health Economics Review,* 10(1), Article 3. https://doi.org/10.1186/s13561-020-0260-8

Powcharoen, W., Yang, W. F., Yan Li, K., Zhu, W., & Su, Y. X. (2019). Computer-assisted versus conventional freehand mandibular reconstruction with fibula free flap: A systematic review and meta-analysis. *Plastic and Reconstructive Surgery,* 144(6), 1417–1428. https://doi.org/10.1097/prs.0000000000006261

Rechner, I., & Lipman, J. (2005). The costs of caring for patients in a tertiary referral Australian intensive care unit. *Anaesthesia and Intensive Care*, 33(4), 477–482. https://doi.org/10.1177/0310057X0503300409

Riaz, N., & Warraich, R. (2010). Reconstruction of mandible by free fibular flap. *Journal of the College of Physicians and Surgeons Pakistan*, 20(11), 723–727.

Ridyard, C. H., & Hughes, D. A. (2010). Methods for the collection of resource use data within clinical trials: A systematic review of studies funded by the UK Health Technology Assessment program. *Value in Health*, 13(8), 867–872. https://doi.org/10.1111/j.1524-4733.2010.00788.x

Rodríguez-Arias, J. P., Tapia, B., Pampín, M. M., Morán, M. J., Gonzalez, J., Barajas, M., Del Castillo, J. L., Navarro Cuéllar, C., & Cebrian, J. L. (2022). Clinical outcomes and cost analysis of fibula free flaps: A retrospective comparison of CAD/CAM versus conventional technique. *Journal of Personalized Medicine,* 12(6), Article 930. https://doi.org/10.3390/jpm12060930

Rommel, N., Kesting, M. R., Rohleder, N. H., Bauer, F. M. J., Wolff, K. D., & Weitz, J. (2017). Mandible reconstruction with free fibula flaps: Outcome of a cost-effective individual planning concept compared with virtual surgical planning. *Journal of Cranio-Maxillofacial Surgery*, 45(8), 1246–1250. https://doi.org/10.1016/j.jcms.2017.04.010

Rustemeyer, J., Melenberg, A., & Sari-Rieger, A. (2014). Costs incurred by applying computer-aided design/computer-aided manufacturing techniques for the reconstruction of maxillofacial defects. *Journal of Cranio-Maxillofacial Surgery*, 42(8), 2049–2055. https://doi.org/10.1016/j.jcms.2014.09.014

Shaw, R. J., Sutton, A. F., Cawood, J. I., Howell, R. A., Lowe, D., Brown, J. S., Rogers, S. N., & Vaughan, E. D. (2005). Oral rehabilitation after treatment for head and neck malignancy. *Head & Neck*, 27(6), 459–470. https://doi.org/10.1002/hed.20176

Smithers, F. A. E., Cheng, K., Jayaram, R., Mukherjee, P., & Clark, J. R. (2018). Maxillofacial reconstruction using in-house virtual surgical planning. *ANZ Journal of Surgery*, 88(9), 907–912. https://doi.org/10.1111/ans.14353

Spaas, C., & Lenssen, O. (2019). Economic analysis of a low-cost virtual surgical planning protocol for mandibular reconstruction: A case series. *British Journal of Oral and Maxillofacial Surgery*, 57(8), 743–748. https://doi.org/10.1016/j.bjoms.2019.06.017

Talesnik, A., Markowitz, B., Calcaterra, T., Ahn, C., & Shaw, W. (1996). Cost and outcome of osteocutaneous free-tissue transfer versus pedicled soft-tissue reconstruction for composite mandibular defects. *Plastic and Reconstructive Surgery*, 97(6), 1167–1178. https://doi.org/10.1097/00006534-199605000-00011

Tang, J. A., Rieger, J. M., & Wolfaardt, J. F. (2008). A review of functional outcomes related to prosthetic treatment after maxillary and mandibular reconstruction in patients with head and neck cancer. *The International Journal of Prosthodontics*, 21(4), 337–354.

Tarsitano, A., Battaglia, S., Crimi, S., Ciocca, L., Scotti, R., & Marchetti, C. (2016). Is a computer-assisted design and computer-assisted manufacturing method for mandibular reconstruction economically viable? *Journal of Cranio-Maxillofacial Surgery*, 44(7), 795–799. https://doi.org/10.1016/j.jcms.2016.04.003

Tarsitano, A., Del Corso, G., Ciocca, L., Scotti, R., & Marchetti, C. (2015). Mandibular reconstructions using computer-aided design/computer-aided manufacturing: A systematic review of a defect-based reconstructive algorithm. *Journal of Cranio-Maxillofacial Surgery*, 43(9), 1785–1791. https://doi.org/10.1016/j.jcms.2015.08.006

Toto, J. M., Chang, E. I., Agag, R., Devarajan, K., Patel, S. A., & Topham, N. S. (2015). Improved operative efficiency of free fibula flap mandible reconstruction with patient-specific, computer-guided preoperative planning. *Head & Neck*, 37(11), 1660–1664. https://doi.org/10.1002/hed.23815

Tricco, A. C., Lillie, E., Zarin, W., O'Brien, K. K., Colquhoun, H., Levac, D., Moher, D., Peters, M. D. J., Horsley, T., Weeks, L., Hempel, S., Akl, E. A., Chang, C., McGowan, J., Stewart, L., Hartling, L., Aldcroft, A., Wilson, M. G., Garritty, C., . . . Straus, S. E. (2018). PRISMA extension for scoping reviews (PRISMA-ScR): Checklist and explanation. *Annals of Internal Medicine*, 169(7), 467–473. https://doi.org/10.7326/M18-0850

Williams, F. C., Hammer, D. A., Wentland, T. R., & Kim, R. Y. (2020). Immediate teeth in fibulas: Planning and digital workflow with point-of-care 3D printing. *Journal of Oral and Maxillofacial Surgery*, 78(8), 1320–1327. https://doi.org/10.1016/j.joms.2020.04.006

Yang, Y., Li, P. J., Shuai, T., Wang, Y., Mao, C., Yu, G. Y., Guo, C. B., & Peng, X. (2019). Cost analysis of oral and maxillofacial free flap reconstruction for patients at an

institution in China. *International Journal of Oral and Maxillofacial Surgery*, 48(5), 590–596. https://doi.org/10.1016/j.ijom.2018.10.020

Zhao, X., Ding, M., Diarra, D., Ouyang, S., Lin, H., Zhou, R., Zeng, B., Ma, L., Liu, B., & Wu, T. (2025). Iliac crest free flap versus fibula free flap for mandibular reconstruction: Cost-effectiveness analysis in a Chinese population. *Journal of Cranio-Maxillofacial Surgery,* 53(9), 1399–1406. https://doi.org/10.1016/j.jcms.2025.05.007

Zweifel, D. F., Simon, C., Hoarau, R., Pasche, P., & Broome, M. (2015). Are virtual planning and guided surgery for head and neck reconstruction economically viable? *Journal of Oral and Maxillofacial Surgery*, 73(1), 170–175. https://doi.org/10.1016/j.joms.2014.07.038

CHAPTER 3: ECONOMIC EVALUATION OF MICROVASCULAR RECONSTRUCTION OF THE JAW: A MICRO-COSTING ANALYSIS AND IDENTIFICATION OF KEY COST-DRIVERS

3.1 PREFACE

This chapter addresses Aim 2 of the thesis through a retrospective micro-costing study of 100 patients who underwent jaw reconstruction at Chris O'Brien Lifehouse. Using an individualised bottom-up costing methodology, this chapter establishes the true direct costs of jaw reconstruction and identifies patient, operative, and postoperative factors independently associated with increased cost.

This chapter is under review in Oral Oncology:

- Petrides, G. A., Dunn, M., Sharman, A. R., Froggatt, C., Manzie, T. G., Agresta, B., Beard, D., Kim, H., Boyer, M., Venchiarutti, R. L., Low, T. H., Leinkram, D., Ch'ng, S., Wykes, J., Palme, C., & Clark, J. R. Economic evaluation of microvascular reconstruction of the jaw: A micro-costing analysis and identification of key cost-drivers**.** *Under review.*

3.2 AUTHORSHIP STATEMENT

The co-authors of the paper "Economic evaluation of microvascular reconstruction of the jaw: A micro-costing analysis and identification of key cost-drivers" confirm that George Andrew Petrides has made the following contributions:

- Conceptualisation and design of methodology.
- Collection and extraction of data.
- Analysis and interpretation of findings.
- Drafting and revising of the manuscript and critical appraisal of content.

As the primary supervisor for the candidature upon which this thesis is based, I can confirm that the above authorship attribution statement is correct.

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31st December 2025

3.3 ABSTRACT

INTRODUCTION

Efficient resource allocation in surgery requires thorough economic evaluation that reflects the true costs of a procedure, with micro-costing being a primary method. Existing economic studies on microvascular jaw reconstruction of the jaw often exclude or estimate key cost-drivers. The aim of this study was to estimate the direct financial costs and cost-drivers associated with surgical reconstruction of the jaw from the perspective of the healthcare provider.

METHODOLOGY

A retrospective micro-costing study from the perspective of the healthcare provider was performed on 100 patients who underwent mandibular or maxillary free flap reconstruction. Direct financial costs of activities (in US$) from admission to discharge were examined, and classified into operative and perioperative admission periods.

RESULTS

The mean cost for the entire admission was $36,416 ± 14,247 comprising 57.7% from the operative period and 42.3% from the perioperative admission period. Ward staffing and consumables (35.7%), prostheses (25.0%), and operating room staffing (21.0%) were the largest cost contributors. In adjusted analyses, higher costs were associated with vasculopathy (+$9,142, $p = 0.044$), ASA IV (+$19,496, $p = 0.023$), tracheostomy (+$10,446, $p = 0.012$), return to the operating room (+$19,920, $p = 0.005$), and return to the intensive care unit (+$25,316, $p = 0.014$).

CONCLUSION

Jaw reconstruction is associated with considerable direct financial costs to the healthcare provider with complications requiring return to the operating room and/or return to the intensive care unit the critical key cost-drivers. These insights will support future health technology assessments focused on jaw reconstruction to assist decision-makers in implementing or reimbursing these procedures.

3.4 INTRODUCTION

Health technology assessments (HTAs) are multidisciplinary studies that examine the economic, clinical, organisational, and ethical costs and consequences of healthcare technologies (Centre for Epidemiology and Evidence, 2017; Reeves, 1999). In the context of surgery, HTAs provide healthcare providers and payers with evidence to guide decisions on whether to adopt, modify, or reject a specific procedure or tool (Banta, 2003; Centre for Health Economics Research and Evaluation, 2008). Economic evaluations as components of HTAs may include cost-effectiveness, cost-utility, and cost-benefit analyses depending on the outcome measure and overall goal. In all cases, it is crucial to accurately assess and incorporate the inputs or costs of the technology to better inform decision-making around allocation of resources and reduce uncertainty (Drummond, 2015). One main method for estimating cost is micro-costing, where each health resource used in a patient's treatment is directly identified and priced (Centre for Health Economics Research and Evaluation, 2008; Frick, 2009; Shepard, 1999; Xu et al., 2021). In addition to forming the basis of economic evaluation, micro-costing analyses are valuable where an intervention is new or there has not yet been an opportunity to establish its cost (Frick, 2009). Despite its utility, micro-costing is rarely conducted for complex surgical procedures. When they are performed, estimations or assumptions are often used for the labour-intensive and time-consuming elements of data collection. However, the more complex the procedure is, the greater the risk that estimates may inappropriately guide decisions around resource allocation.

Mandibular and maxillary reconstruction – referred to here as jaw reconstruction – using microvascular free tissue transfer aims to restore orofacial anatomy, helping patients return as closely as possible to their pre-morbid aesthetics and function (Abo Sharkh & Makhoul, 2020;

Petrides et al., 2021; Petrides et al., 2022; Shaw et al., 2005). Despite substantial evidence illustrating the benefits of microvascular jaw reconstruction, detailed studies evaluating the economic implications of these complex surgeries remain scarce. The few studies that have been published are limited by the exclusion or estimation of meaningful cost-drivers in their costing methodology (Dassonville et al., 2017; Gao et al., 2017; Ismail et al., 2015; Jones et al., 2007; Setälä et al., 2009). To guide decisions regarding effective resource allocation effectively, there is an unmet need for a comprehensive HTA that addresses these gaps (Markiewicz & Bell, 2011). The aim of this study is to estimate the direct financial costs and cost-drivers associated with surgical reconstruction of the jaw from the perspective of the healthcare provider. We hypothesised that jaw reconstruction admissions would be associated with substantial direct financial costs, with bony reconstruction associated with higher operative period costs and postoperative complications representing the primary independent modifiable cost-drivers.

3.5 METHODOLOGY

3.5.1. STUDY DESIGN AND POPULATION

A retrospective micro-costing analysis from the perspective of the healthcare provider was performed on 100 mandibular and maxillary free flap reconstruction procedures taking place at Chris O'Brien Lifehouse Hospital (COBL) – a public-private not-for-profit hospital in Sydney, Australia – between September 2019 and June 2023 (Ethics Protocol No 2020/ETH02415). A target of 100 cases was selected to ensure adequate representation of the demographic, pathological, and procedural heterogeneity of jaw reconstruction at this institution. Participants were purposefully selected to ensure appropriate representation of patient demographics, pathology, defect extent, and procedures. Information on patient

demographics, comorbidities including American Society of Anaesthesiologists (ASA) physical status classification score, pathological features, surgical management, length of stay, postoperative complications, and return to the intensive care unit (ICU) and operating room (OR) was collected from clinical notes and the COBL Integrated Prosthetics & Reconstruction Maxillofacial Database.

Postoperative complications were classified using the Clavien-Dindo grading system (Dindo et. al, 2004), a validated and widely used instrument for grading surgical complications by severity. Classification was applied retrospectively at the point of data extraction from clinical records by the lead author, based on the documented clinical course and interventions required. Cases were excluded if they involved only a marginal mandibulectomy or did not receive microvascular free flap reconstruction. Cases were stratified by reconstruction type (soft tissue vs. bony) because bony reconstructions incorporate additional cost components not present in soft tissue cases, including VSP, osteotomy guides, reconstruction plates, and dental implants. A health economic analysis plan was not developed for this study, reflecting its descriptive nature as a micro-costing exercise rather than a comparative economic evaluation. Instead, the analytical framework was guided by previous publications (Centre for Health Economics Research and Evaluation, 2008; Frick, 2009; Ismail et al., 2015; Potter et al., 2020).

The typical pathway for a patient undergoing jaw reconstruction is detailed in **Appendix B1.** This study examined activities and associated costs from admission to discharge, dividing them into operative and perioperative periods, further subclassified into staffing and equipment costs **(Appendix B2**) (Agency for Clinical Innovation, 2015). Only direct costs were included; overhead costs, onboard costs, and societal costs (such as time off work and travel costs) as well as health outcomes were not measured. Costs were initially calculated in Australian dollars

(A$) before being converted and reported in United States dollars (US$) (as per the World Bank Group Official Exchange Rate for 2023 of 1.51) to facilitate direct comparison with the international literature, the majority of which reports economic outcomes in US$. Costs were not adjusted for inflation due to the risk of overestimating the cost data. Discounting was not applied due to the short time horizon.

3.5.2. Operative Period Costs

Operative period staffing costs were calculated based on the standard salary of each type and grade of staff present during a typical jaw reconstruction at COBL. For example, a two-team approach typically included two surgical consultants, one postgraduate surgical fellow, one surgical registrar, two scrub nurses, one scout nurse, one anaesthetic consultant, and one anaesthetic nurse. The annual full-time salary for each team member was divided by the average number of minutes in a typical working year (n = 118,967.40) to determine the salary per minute (**Appendix B3**). The salaries were summed and adjusted to calculate the total cost per operative minute for a one-team and two-team approach and multiplied by the length of anaesthesia for each case.

Operative period equipment costs included standard OR environment equipment, disposable equipment, non-disposable equipment, and intraoperative medications. The purchase costs for all equipment in the standard OR environment were amortised over 10 years (based on an approximate average lifespan) (**Appendix B4**) and divided by the number of active minutes in the head and neck OR per year (n = 131,280) to determine the cost per minute. The cost of sterilising non-disposable equipment was sourced from the instrument trays and equipment labels on each patient's Reusable Medical Device Traceability Form. A list of disposable equipment used was sourced from the senior author's preference card and cross-referenced

with the surgical count sheet (**Appendix B5**). The prostheses used were sourced from the patient's file. Equipment costs were sourced from the COBL finance department database and third-party invoices. The route, dose, and quantity of intraoperative medications were collected from the anaesthesia chart, with costs based on the most recent purchase prices.

3.5.3. PERIOPERATIVE ADMISSION PERIOD COSTS

The ICU and ward nursing staffing costs were sourced from the COBL Financial Statement 2021-2022. This incorporated the cost of food and disposable equipment. The cost of medical staff was calculated by dividing the average daily salary of the surgical team by the average number of active inpatients (n = 20). Based on this, the estimated cost per bed day equated to $1,749.76 in the ICU and $483.79 on the ward (**Appendix B6**). The cost of consulting teams was determined using annual full-time salaries, proportioned by the average duration of initial and subsequent consultations (**Appendix B7**). The costs of investigations were estimated by multiplying the number and type of investigations performed for each patient by the current Australian Medicare Benefits Schedule (MBS) fee. The route, dose, and quantity of medications were collected from the medication chart, with costs based on the most recent purchase prices.

3.5.4. STATISTICAL ANALYSIS

Total costs were calculated by summing the cost of each activity comprising the operative and perioperative admission periods. The raw costs for each activity were presented as means with standard deviations. Adjusted cost estimates were calculated using multivariable linear regression analyses to identify patient-level, operative, and postoperative factors independently associated with total admission cost, after controlling for confounders. This incorporated robust standard errors in three domains: comorbidities, operative procedures, and postoperative

events. Unadjusted (raw) cost comparisons are susceptible to confounding because patient complexity, comorbidities, and surgical approach are interrelated; adjustment ensures that the contribution of each factor to total cost is estimated independently. In each domain, clinically relevant and statistically significant covariates on unadjusted analyses were included in the multivariable model and a backwards stepwise elimination method was employed to achieve the most parsimonious model whilst still retaining clinically relevant covariates, regardless of their statistical significance. Relevant interactions were explored and significant variables in the final multivariable models were used to identify potential cost-drivers which are presented as marginal estimates at the mean of other covariates within the model. Statistical analyses were performed by the senior author (J.R.C.) using Stata version 12.0 SE (Stata Corporation, College Station, Texas).

3.6 RESULTS

3.6.1. CLINICOPATHOLOGICAL CHARACTERISTICS

The cohort comprised 52 males and 48 females, with a mean age at surgery of 62.37 ± 16.25 years (**Table 1**). The majority were classified as ASA III (n = 62). The most common indication for surgery was oral cavity squamous cell carcinoma (SCC) (n = 52).

3.6.2. OPERATIVE CHARACTERISTICS

All but two cases (98%) involved both ablation and reconstruction at the time of surgery and 19 patients had undergone preoperative radiotherapy and/or chemotherapy (**Table 2**). The reconstruction site was the mandible in 68 cases, the maxilla in 30 cases, and both in two cases. The microvascular free flap was soft-tissue in 29 cases and bony in 71 cases. The fibula was the most common donor site (n = 50). The team approach was one-team in 20 cases and two-

team in 80 cases. Virtual surgical planning (VSP) was used in 66 cases, tracheostomy in 62 cases, neck dissection in 83 cases, and endosseous dental implants were placed in 55 cases. The mean operative duration was 526 ± 122 minutes (range: 264–1008) and the mean anaesthetic duration was 609 ± 127 minutes (range: 307–1135).

Table 1. Clinicopathological characteristics of cases included in the study.

Clinicopathological characteristics	n (%)
Sex	
Male	52 (52)
Female	48 (48)
Age at time of surgery (years) (mean ± SD)	62.37 ± 16.25
American Society of Anaesthesiologists (ASA) Score	
I	18 (18)
II	18 (18)
III	62 (62)
IV	2 (2)
Comorbidities	
Diabetes mellitus	14 (14)
Current smoker	31 (31)
Vasculopathy	14 (14)
Hypertension	36 (36)
Pathology	
Oral squamous cell carcinoma (SCC)	52 (52)
Osteoradionecrosis	13 (13)
Defect following previous surgery	8 (8)
Ameloblastoma	7 (7)
Adenoid cystic carcinoma	4 (4)
Osteosarcoma	4 (4)
Mucosal melanoma	2 (2)
Other†	10 (10)
Tumour (T) category	
1	5 (5)
2	10 (10)
3	4 (4)
4	55 (55)
NA	26 (26)

† Other pathology (basal cell carcinoma = 1, mucomycosis of the palate = 1, mucoepidermoid carcinoma = 1, oral pemphigoid = 1, polymorphous low-grade carcinoma = 1, rhabdomyosarcoma =1, spindle cell rhabdomyosarcoma = 1, salivary duct carcinoma = 1, sarcomatoid carcinoma = 1, verrucous carcinoma = 1).

3.6.3. PERIOPERATIVE CHARACTERISTICS

The mean length of admission was 19 ± 13 days (range: 7–96). This comprised, on average, 4 ± 4 days in the ICU (range: 2–38) and 15 ± 13 days in the general ward (range: 1–94). There were 50 patients who experienced at least one postoperative complication with most being Clavien-Dindo IIIb (n = 19). There were 23 patients who returned to the OR at least once, with four patients returning twice and one patient returning four times. The most common indication was wound debridement (n = 7). There were four cases of free flap ischemia, of which two cases were successfully salvaged. There were 10 patients readmitted to the ICU, mostly following free flap compromise (n = 3) and/or for respiratory support (n = 3).

Table 2. Surgical and hospital admission characteristics for the total cohort, those receiving a soft tissue flap, and those receiving a bony flap.

Surgical reconstruction characteristics	Total cohort (N = 100)		Soft tissue flap (n = 29)		Bony flap (n = 71)	
	N (%)	Range	N (%)	Range	N (%)	Range
Surgery type						
Ablation and reconstruction	98 (98)		29 (100)		70 (97)	
Reconstruction	2 (2)		0 (0)		1 (3)	
Previous radiotherapy and/or chemotherapy	19 (19)		5 (17)		14 (20)	
Reconstruction site						
Mandible	68 (68)		4 (14)		64 (89)	
Maxilla	30 (30)		24 (83)		6 (8)	
Mandible and maxilla	2 (2)		1 (4)		1 (1)	
Reconstruction type						
Fibula free flap	50 (50)		–		50 (70)	
Anterolateral thigh (ALT) flap	19 (19)		19 (66)		–	
Scapula free flap	14 (14)		–		14 (20)	
Radial forearm free flap	9 (9)		9 (31)		–	
Radius (bone) flap	3 (3)		–		3 (4)	
Deep circumflex iliac artery (DCIA) flap	3 (3)		–		3 (4)	
Ulna flap	2 (2)		2 (7)		0 (0)	
Team approach						
One team	20 (20)		2 (7)		18 (25)	
Two team	80 (80)		27 (93)		53 (75)	
Operative adjuncts						
Tracheostomy	62 (62)		10 (34)		52 (73)	

Surgical reconstruction characteristics	Total cohort (N = 100)		Soft tissue flap (n = 29)		Bony flap (n = 71)	
	N (%)	Range	N (%)	Range	N (%)	Range
Neck dissection	83 (83)		23 (79)		60 (85)	
Virtual surgical planning (VSP)	66 (66)		2 (7)		64 (90)	
Endosseous dental implants	55 (55)		11 (38)		45 (63)	
Mean duration (minutes)						
Operative duration (mean ± SD)	526 ± 122	264 – 1008	471 ± 110	264 – 822	548 ± 121	348 – 1008
Anaesthetic duration (mean ± SD)	609 ± 127	307 – 1135	556 ± 117	307 – 872	631 ± 125	399 – 1135
Mean length of admission (days)	19 ± 13	7 – 96	16 ± 16	8 – 96	19 ± 11	7 – 70
Intensive care unit (ICU) (mean ± SD)	4 ± 4	2 – 38	3 ± 1	2 – 6	4 ± 5	2 – 38
General ward (mean ± SD)	15 ± 13	1 – 94	14 ± 16	6 – 94	15 ± 11	1 – 62
Complication during hospital admission (Clavien-Dindo)	50 (50)		10 (34)		40 (56)	
I	4 (4)		2 (7)		2 (3)	
II	19 (19)		4 (14)		15 (21)	
IIIa	2 (2)		0 (0)		2 (3)	
IIIb	19 (19)		4 (14)		15 (21)	
IVa	4 (4)		0 (0)		4 (6)	
IVb	0 (0)		0 (0)		0 (0)	
V	2 (2)		0 (0)		2 (3)	
Return to the operating room (OR) (at least one)	23 (23)		4 (14)		19 (27)	
Wound debridement	7 (30)		0 (0)		7 (10)	
Postoperative bleeding/hematoma	4 (17)		1 (4)		3 (4)	
Free flap ischemia	4 (17)		0 (0)		4 (6)	
Free flap salvaged	2 (2)		0 (0)		2 (3)	
Free flap replaced	2 (2)		0 (0)		2 (3)	

Surgical reconstruction characteristics	Total cohort (N = 100)		Soft tissue flap (n = 29)		Bony flap (n = 71)	
	N (%)	Range	N (%)	Range	N (%)	Range
Removal of zygomatic implant	1 (4)		0 (0)		1 (1)	
Elective indication	7 (30)		3 (10)		4 (6)	
Return to the Intensive Care Unit (ICU)	10 (10)		1 (4)		9 (13)	
Free flap ischemia	3 (3)		0 (0)		3 (4)	
Respiratory support	3 (3)		0 (0)		3 (4)	
Hypocalcaemia	1 (1)		0 (0)		1 (1)	
Neck hematoma/swelling	1 (1)		0 (0)		1 (1)	
Monitoring whilst on furosemide infusion	1 (1)		0 (0)		1 (1)	
Vasopressor requirement	1 (1)		1 (4)		0 (0)	

3.6.4 COSTS OF JAW RECONSTRUCTION

The mean cost for the entire admission was $36,416 ± 14,247 (range $16,882 – $98,283). This comprised $21,019 ± 7,779 (57.7%) from the operative period and $15,397 ± 10,133 (42.3%) from the perioperative admission period (**Table 3**). The main costs in the operative period were prostheses at $9,092 ± 6,299 comprising 25.0% of the overall cost, followed by OR staffing at $7,654 ± 2,945 (21.0%), disposable equipment at $2,343 ± 703 (6.4%), non-disposable equipment at $1,610 ± 430 (4.4%), intraoperative medications at $164 ± 178 (0.5%), and OR equipment at $157 ± 55 (0.4%). The cost of prostheses included VSP at $5,229 ± 4,689 (14.4%), screws and plates at $1,888 ± 1,814 (5.2%), dental implants at $1,015 ± 1,089 (2.8%), venous couplers at $605 ± 247 (1.7%), ligating clips at $246 ± 343 (0.7%), haemostatic agents at $89 ± 178 (0.2%), and other at $19 ± 90 (<0.1%). During the perioperative admission period, the main costs were ward staff and consumables at $13,013 ± 8,594 comprising 35.7% of the overall cost, followed by investigations at $1,200 ± 970 (3.3%), consultations at $819 ± 517 (2.2%), and medications at $365 ± 448 (1.0%).

Table 3. Mean cost and proportion of total costs for all activities during the hospital admission.

Activity	Mean cost (US$)	Range (US$)	SD	95% CI	Proportion of total cost (%)
Operative period	21,019	7,531 – 43,495	7,779	19,476 – 22,563	57.7
Prostheses	9,092	511 – 26,256	6,299	7,842 – 10,342	25.0
Virtual surgical planning (VSP)	5,229	0 – 16,868	4,689	4,299 – 6,160	14.4
Dental implants	1,015	0 – 3,672	1,089	799 – 1,231	2.8
Screws and plates	1,888	0 – 9,999	1,814	1,528 – 2,248	5.2
Ligating clips	246	25 – 2,124	343	178 – 314	0.7
Venous couplers	605	0 – 1,210	247	556 – 654	1.7
Haemostatic agents	89	0 – 881	178	54 – 124	0.2
Other†	19	0 – 553	90	1 – 37	0.1
Staffing	7,654	3,430 – 26,826	2,945	7,070 – 8,239	21.0
Disposable equipment	2,343	1,719 – 5,865	703	2,203 – 2,482	6.4
Non-disposable equipment	1,610	906 – 3,167	430	1,525 – 1,695	4.4
Intraoperative medications	164	29 – 1,049	178	129 – 199	0.5
Operating room equipment	157	73 – 515	55	146 – 168	0.4
Perioperative period	15,397	7,135 – 77,251	10,133	13,387 – 17,407	42.3
Staffing and disposable equipment	13,013	5,742 – 63,624	8,594	11,308 – 14,718	35.7
Investigations	1,200	344 – 8,418	970	1,007 – 1,392	3.3
Consultations	819	306 – 3,308	517	716 – 921	2.2
Medications	365	43 – 3,759	448	276 – 454	1.0
Total admission	36,416	16,882 – 98,283	14,247	33,589 – 39,243	100.0

†Includes eyelid weights, meshes, and bone cement.

3.6.5 VARIABLES ASSOCIATED WITH TOTAL COSTS ON ADJUSTED ANALYSES

The results of the multivariable regression analyses are summarised in **Table 4** and presented in detail in **Appendix B8**. Comorbidities associated with the total cost were the presence of vasculopathy ($p = 0.044$) and ASA Class IV ($p = 0.023$) and lower costs were observed for patients with hypertension ($p = 0.027$) after adjusting for the effect of age, diabetes mellitus, and smoking status. The increased cost associated with vasculopathy ($10,893) and ASA status ($19,496) was in part due to the increased length of stay of 7.8 days ($p = 0.033$) and 46.9 days ($p < 0.001$), respectively. The only operative procedures associated with total cost were tracheostomy ($p = 0.012$) after adjusting for the number of dental implants, recipient site, the use of VSP, type of free flap and two-way interactions between site, VSP, and type of flap. However, there was a significant interaction between the use of VSP and the type of free flap ($p = 0.038$) favouring a reduction in total cost for the use of VSP in bony free flaps compared to soft tissue flaps (note, VSP was used in soft tissue flaps for dental implant planning).

Postoperative complications were associated with an increased cost of $14,716 per admission on unadjusted analysis ($p < 0.001$). Postoperative complications were significantly more common in patients with vasculopathy ($p = 0.021$) and those undergoing tracheostomy ($p = 0.039$), whilst there was a weak association with bony free flap reconstruction ($p = 0.075$). Postoperative complications were strongly associated with return to the OR in 44% ($p < 0.001$), readmission to ICU in 20% ($p = 0.001$), increased ICU length of stay of 2.0 days ($p = 0.009$), and longer ward length of stay of 10.1 days ($p < 0.001$). However, postoperative complications were not significantly associated with total cost on multivariable analysis, where the significant cost-drivers were the number of days in hospital ($504 per day, $p < 0.001$) and whether return to the OR ($8,025, $p = 0.005$) and/or ICU ($12,425, $p = 0.014$) was required.

Table 4. Marginal total cost estimates for significant preoperative, operative, and postoperative variables on multivariable regression analyses.

Variable	Total cost (US$)	SE	95% CI	*p*-value
Comorbidities and Preoperative Variables				
Vasculopathy				
Yes	44,278	4,798	34,874 – 53,682	**0.044**
No	35,136	1,350	32,490 – 37,782	
Hypertension				
Yes	34,567	1,947	30,751 – 38,382	**0.027**
No	37,456	1,787	33,953 – 40,959	
ASA Score				
I	30,749	2,858	25,147 – 36,351	
II	39,181	2,736	33,819 – 44,543	
III	36,745	1,821	33,176 – 40,313	
IV	52,342	6,697	39,216 – 65,467	**0.023**
Operative Variables				
Tracheostomy				
Yes	40,385	1,757	36,941 – 43,829	**0.012**
No	29,940	1,629	26,747 – 33,132	
Postoperative Variables				
Return to OR				
Yes	51,755	2,602	46,655 – 56,854	**0.005**
No	31,834	798	30,270 – 33,399	
Return to ICU				
Yes	59,201	4,946	49,506 – 68,895	**0.014**
No	33,884	779	32,358 – 35,410	

SE: standard error. CI: confidence interval. ASA: American Society of Anaesthesiologists. OR: operating room. ICU: intensive care unit.

3.7 DISCUSSION

Understanding the true financial cost of surgical procedures is crucial for economic evaluation, procedure optimisation, and informed decision-making around resource allocation. This study is the first to establish the direct financial cost of jaw reconstruction using a micro-costing methodology with an individualised bottom-up approach. Our findings support our hypothesis, highlighting that jaw reconstruction is resource-intensive, translating to considerable direct financial costs to the healthcare provider. While the majority of costs were derived from the operative period, the key cost drivers were postoperative events that resulted in prolonged length of stay, return to the OR and/or the ICU. This was more likely to occur in patients with serious comorbidity, vasculopathy, and/or those requiring tracheostomy – a common procedure in free flap reconstruction of the jaw.

The average cost of the total hospital admission was comparable to previous micro-costing studies at $35,416 (Jones et al., 2007; Setälä et al., 2009; Tewfik et al., 2021). In 2016, Dassonville et al. (2017) found that the mean cost per case for 108 free flap mandibular reconstructions across 11 French centres was €34,009 (US$37,662). However, it must be noted that this study also included pre-admission activities (e.g. physician consultations) in the costing methodology. In a Californian study of 100 patients undergoing head and neck microsurgical reconstruction, the estimated cost was US$35,099 in 2007, or approximately US$54,136 in 2025 after adjusting for inflation (Jones et al., 2007). The reason for this discrepancy is unclear because specific cost components were not disclosed in their methodology, underscoring the limitations of the existing literature.

The total cost was significantly higher in patients with serious comorbidity (ASA Class IV, i.e. a patient with severe systemic disease that is a constant threat to life such as recent myocardial infarction, cerebrovascular events, severe heart failure, and end-stage renal disease). A small proportion of this cost stems from increased medication use, investigations, and consultations with specialty teams, but the primary cost-driver was increased length of hospital stay which was likely a consequence of postoperative complications. Admissions are often extended to optimise patients' comorbidities before discharge, as with chronic organ failure. Mehra et al. (2021) also found that the ASA score was significantly associated with an increased length of stay (ASA IV = 36.5 days vs. ASA I = 11 days), complication rate (ASA IV = 5.5% vs. ASA I = 3%), and total costs (ASA IV = CHF146,505 vs. ASA I = CHF41,812). Although these variables are uncommon (14% for vasculopathy and 2% for ASA Class IV in our cohort), thorough preoperative assessment incorporating risk assessment tools (e.g. the Revised Cardiac Risk Index) and optimization of comorbidities is likely to reduce the need for costly interventions, complications, and length of stay (Datema et al., 2010; Ghazali et al., 2017; Rosado et al., 2015). However, there is currently little data to support this in the context of jaw reconstruction.

Postoperative complications occurred in half of the cohort, increasing the total admission cost by 50.6%. Other literature highlights postoperative complications as a significant cost-driver in patients undergoing head and neck reconstruction (Gourin et al., 2011; Miller et al., 1991). In their study of 100 patients undergoing head and neck microvascular reconstruction, Jones et al. (2007) found that the presence of a postoperative complication nearly doubled the average hospital stay (13.5 to 24 days) and more than quadrupled the average ICU stay (2.3 to 11.4 days), resulting in a 70.7% increase in total cost. Our study provides a more detailed understanding of how complications impact costs; while patients with complications consume

greater resources (including medications, consumables, and consultations), the critical cost-drivers were return to the OR, return to ICU, and prolonged LOS. For instance, a complication that resulted in the return to the OR and ICU – as commonly occurs with free flap failure – more than doubled the usual cost of jaw reconstruction. This is considerable given a return to the OR occurred in 23% of cases in our cohort, higher than rates reported in comparable literature (Jones et al., 2007).

This study's findings illuminate several modifiable interventions and jaw reconstruction paradigms that could be challenged to minimise cost. Selected potentially modifiable activities are listed in **Table 5** with their raw and adjusted costs. Notably, the most substantial cost-saving measure is to reduce the rate of postoperative complications. Although high rates of postoperative complications following complex surgery are expected in populations where cigarette smoking, excess alcohol intake, cachexia, and prior radiotherapy are prevalent, it remains an important modifiable cost-driver (Jones et al., 2007; Lindell et al., 2021). These findings suggest that strategies to reduce postoperative complications may yield cost savings such as ensuring that cases with high predicted complexity are managed in centres with established expertise (Dautremont et al., 2013; Madrigal et al., 2022). However, a detailed analysis of the volume-outcome relationship and formal definition of case complexity thresholds is beyond the scope of this thesis and represents an important area for future research.

Table 5. The raw cost (US$) and adjusted cost (%) of potentially modifiable interventions for microvascular jaw reconstruction.

Intervention	Raw cost		Adjusted cost†	
	US$	%	US$	%
Tracheostomy placement	431*	1.1	10,446	34.9
ICU postoperative care	3,323¶	9.1	Unknown	–
Virtual surgical planning	5,229	14.4	–152	–0.4
Postoperative complication	Unknown	–	14,716	50.6

†Adjusted for covariates in multiple regression analysis. *Calculated as 30 minutes of operating time and one tracheostomy tube. ¶Calculated as two additional days in ICU and two fewer days on the ward.

All institutions need to critically evaluate their own practices to ensure that patient care is efficiently optimised. A prime example in our institution is tracheostomy placement, performed in 62% of participants to secure the airway in the early postoperative period. In our cohort, this potentially life-saving activity was associated with a 34.9% increase in the total admission cost. Tracheostomy necessitates additional resources, including consumables and staff for placement, monitoring, maintenance, and patient education (Madgar et al., 2022; Rubin et al., 2020). More importantly, we found that these patients were at an increased risk for postoperative complications, which may include wound and respiratory infections, bleeding, and accidental decannulation that can lead to airway obstruction and death (Alijanpour, 2018; Halfpenny & McGurk, 2000; McDevitt et al., 2016). The increased costs associated with tracheostomy should not be interpreted as a direct argument against the procedure. However, it is therefore critical that the need for tracheostomy be carefully assessed in each patient, with strong consideration for alternatives such as close observation and overnight intubation where appropriate (Cameron et al., 2009; Madgar et al., 2022).

Another protocol-driven, high-cost activity in our institution is postoperative ICU care for two days for airway management, free flap observation, and monitoring for immediate complications (Haddock et al., 2010; Panwar et al., 2016). ICU beds are substantially more expensive than general ward beds due to the need for high nurse-to-patient ratios and specialised interventions such as continuous cardiac monitoring and mechanical ventilation (Karabatsou et al., 2016; Rechner & Lipman, 2005). Some have underlined the cost-effectiveness of improved nursing training and postoperative protocols that allow immediate postoperative care outside the ICU (Dautremont et al., 2013; Haddock et al., 2010; Lindell et al., 2021). Panwar et al. (2016) estimated a 15.2% reduction in total hospital costs when head and neck reconstruction patients were managed in non-ICU settings. Despite a theoretical raw cost reduction of 9.1%, the reimbursement peculiarities of the Australian healthcare system complicate this decision by incentivising ICU utilisation. Unfortunately, all patients in this cohort were admitted to the ICU following free tissue transfer, precluding any adjusted analyses. Nevertheless, immediate non-ICU postoperative care should be considered by all high-volume centres, given the potential cost-benefit.

It is important to consider both the raw cost of an activity and the potential cost implications of performing or omitting it. This is particularly true for VSP, which comprised 14.4% of the total admission cost, representing a substantial initial financial burden (Chen et al., 2021; Fatima et al., 2019; Petrides et al., 2021). However, the literature suggests potential downstream savings of using VSP by reducing operative time, shortening hospital stays, and decreasing complications (Foley et al., 2013; Li et al., 2018; Petrides et al., 2021; Powcharoen et al., 2019). We found that the use of VSP did not increase the total cost of admission, particularly in bony free flap cases. We plan to explore this further in a detailed HTA of VSP.

Future economic evaluations of jaw reconstruction should incorporate prospective collection of complication data and include return to OR and return to ICU as mandatory cost-driver variables. The micro-costing framework presented here, including the specific cost components and multivariable regression approach, provides a replicable template for future studies. Further, future studies should additionally collect long-term data on readmissions, revision surgery, and patient-reported outcomes to capture additional cost-drivers and enable cost-utility analyses over extended time horizons. Given that the primary cost-drivers are postoperative complications rather than VSP technology costs, the focus of innovation should be on complication prevention strategies, optimised patient selection, and care pathway improvements rather than purely on reducing technology acquisition costs.

There are several limitations to this study. Data was collected from a single Australian centre, which limits the external validity of the results. As with all economic evaluations, the exact costs will intrinsically vary by location and over time. Nevertheless, the drivers identified in this study are likely similar in other centres as supported by existing literature. The collection of micro-costing data is inherently dependent on the accuracy and accessibility of resource documentation and in cases of missing data may result in a slight underestimation of costs. For example, penalty rates were not adjusted for, salaries of additional hospital staff were not included, and perioperative staffing and disposable costs were unable to be accurately separated, impacting our findings. Finally, only the direct financial costs associated with hospital admission were evaluated, while the costs of follow-up appointments, additional procedures, long-term complications, and overheads were excluded.

3.8 CONCLUSION

Appropriate resource allocation in surgery requires thorough economic evaluation that accurately reflects the true costs of an activity, with micro-costing remaining a primary method. This study is the first to establish the true direct financial cost of jaw reconstruction using a thorough micro-costing methodology. By employing this approach, we identified that the key cost-drivers were adverse events in the postoperative period such as complications requiring return to the operating room and/or return to the intensive care unit. These insights will support future HTAs focused on jaw reconstruction to assist decision-makers in implementing or reimbursing these procedures.

3.9 REFERENCES

Abo Sharkh, H., & Makhoul, N. (2020). In-house surgeon-led virtual surgical planning for maxillofacial reconstruction. *Journal of Oral and Maxillofacial Surgery,* 78(4), 651–660. https://doi.org/10.1016/j.joms.2019.11.013

Agency for Clinical Innovation. (2015). Operating theatre efficiency guidelines: A guide to the efficient management of operating theatres in New South Wales hospitals. https://aci.health.nsw.gov.au/__data/assets/pdf_file/0004/252436/ACI-Operating-theatre-efficiency-clinical-practice-guide.pdf

Alijanpour, E. (2018). Tracheostomy: Complications and causes of complications. *Asian Journal of Pharmaceutics*, 12(2). https://doi.org/10.22377/ajp.v12i02.2410

Banta, D. (2003). The development of health technology assessment. *Health Policy*, 63(2), 121–132. https://doi.org/10.1016/S0168-8510(02)00059-3

Cameron, M., Corner, A., Diba, A., & Hankins, M. (2009). Development of a tracheostomy scoring system to guide airway management after major head and neck surgery. *International Journal of Oral and Maxillofacial Surgery*, 38(8), 846–849. https://doi.org/10.1016/j.ijom.2009.03.713

Centre for Epidemiology and Evidence. (2017). Commissioning economic evaluations: A guide. NSW Ministry of Health. https://www.health.nsw.gov.au/research/Publications/commissioning-economic-evaluations.pdf

Centre for Health Economics Research and Evaluation. (2008). Issues in the costing of large projects in health and healthcare. https://www.health.nsw.gov.au/research/Publications/costing-large-projects.pdf

Chen, Z., Mo, S., Fan, X., You, Y., Ye, G., & Zhou, N. (2021). A meta-analysis and systematic review comparing the effectiveness of traditional and virtual surgical planning for orthognathic surgery: Based on randomized clinical trials. *Journal of Oral and Maxillofacial Surgery*, 79(2), 471.e1–471.e19. https://doi.org/10.1016/j.joms.2020.09.005

Dassonville, O., Bozec, A., Château, Y., Reyt, E., Devauchelle, B., Louis, M. Y., Breton, P., Julieron, M., Yachouh, J., Mallet, Y., Sarini, J., Dolivet, G., Schiappa, R., Gal, J., Orlanducci, M. H., Poissonnet, G., & Chamorey, E. (2017). Multicenter prospective micro-costing study evaluating mandibular free-flap reconstruction. *European Archives of Oto-Rhino-Laryngology,* 274(2), 1103–1111. https://doi.org/10.1007/s00405-016-4360-3

Datema, F. R., Poldermans, D., & Baatenburg de Jong, R. J. (2010). Incidence and prediction of major cardiovascular complications in head and neck surgery. *Head & Neck*, 32(11), 1485–1493. https://doi.org/10.1002/hed.21351

Dautremont, J. F., Rudmik, L. R., Yeung, J., Asante, T., Nakoneshny, S. C., Hoy, M., Lui, A., Chandarana, S. P., Matthews, T. W., Schrag, C., & Dort, J. C. (2013). Cost-effectiveness analysis of a postoperative clinical care pathway in head and neck surgery with microvascular reconstruction. *Journal of Otolaryngology – Head & Neck Surgery*, 42(1), 59. https://doi.org/10.1186/1916-0216-42-59

Dindo, D., Demartines, N., & Clavien, P.A. (2004). Classification of surgical complications: a new proposal with evaluation in a cohort of 6336 patients and results of a survey. *Annals of Surgery,* 240(2):205-13. doi: 10.1097/01.sla.0000133083.54934.ae

Drummond, M. (2015). Methods for the economic evaluation of health care programmes (4th ed.). Oxford University Press.

Fatima, A., Hackman, T. G., & Wood, J. S. (2019). Cost-effectiveness analysis of virtual surgical planning in mandibular reconstruction. *Plastic and Reconstructive Surgery*, 143(4), 1185–1194. https://doi.org/10.1097/prs.0000000000005418

Foley, B. D., Thayer, W. P., Honeybrook, A., McKenna, S., & Press, S. (2013). Mandibular reconstruction using computer-aided design and computer-aided manufacturing: An analysis of surgical results. *Journal of Oral and Maxillofacial Surgery*, 71(2), e111–e119. https://doi.org/10.1016/j.joms.2012.08.022

Frick, K. D. (2009). Microcosting quantity data collection methods. *Medical Care*, 47(Suppl. 1), S76–S81. https://doi.org/10.1097/MLR.0b013e31819bc064

Gao, L. L., Basta, M., Kanchwala, S. K., Serletti, J. M., Low, D. W., & Wu, L. C. (2017). Cost-effectiveness of microsurgical reconstruction for head and neck defects after oncologic resection. *Head & Neck*, 39(3), 541–547. https://doi.org/10.1002/hed.24644

Ghazali, N., Caldroney, S., Dyalram, D., & Lubek, J. E. (2017). Cardiovascular complications in head & neck microvascular flap reconstruction: A retrospective risk

stratification and outcomes assessment. *Journal of Cranio-Maxillofacial Surgery*, 45(12), 2120–2127. https://doi.org/10.1016/j.jcms.2017.10.002

Gold, M. R., Siegel, J. E., Russell, L. B., & Weinstein, M. C. (1999). Cost-effectiveness in health and medicine. Oxford University Press.

Gourin, C. G., Forastiere, A. A., Sanguineti, G., Marur, S., Koch, W. M., & Bristow, R. E. (2011). Impact of surgeon and hospital volume on short-term outcomes and cost of oropharyngeal cancer surgical care. *The Laryngoscope,* 121(4), 746–752. https://doi.org/10.1002/lary.21456

Haddock, N. T., Gobble, R. M., & Levine, J. P. (2010). More consistent postoperative care and monitoring can reduce costs following microvascular free flap reconstruction. *Journal of Reconstructive Microsurgery,* 26(7), 435–439. https://doi.org/10.1055/s-0030-1254232

Halfpenny, W., & McGurk, M. (2000). Analysis of tracheostomy-associated morbidity after operations for head and neck cancer. *British Journal of Oral and Maxillofacial Surgery*, 38(5), 509–512. https://doi.org/10.1054/bjom.2000.0310

Hurwitz, E. E., Simon, M., Vinta, S. R., Zehm, C. F., Shabot, S. M., Minhajuddin, A., & Abouleish, A. E. (2017). Adding examples to the ASA-Physical Status classification improves correct assignment to patients. *Anesthesiology,* 126(4), 614–622. https://doi.org/10.1097/ALN.0000000000001541

Ismail, I., Wolff, S., Gronfier, A., Mutter, D., & Swanström, L. L. (2015). A cost evaluation methodology for surgical technologies. *Surgical Endoscopy,* 29(8), 2423–2432. https://doi.org/10.1007/s00464-014-3929-4

Jones, N. F., Jarrahy, R., Song, J. I., Kaufman, M. R., & Markowitz, B. (2007). Postoperative medical complications—not microsurgical complications—negatively influence the morbidity, mortality, and true costs after microsurgical reconstruction for head and

neck cancer. *Plastic and Reconstructive Surgery,* 119(7), 2053–2060. https://doi.org/10.1097/01.prs.0000260591.82762.b5

Karabatsou, D., Tsironi, M., Tsigou, E., Boutzouka, E., Katsoulas, T., & Baltopoulos, G. (2016). Variable cost of ICU care, a micro-costing analysis. *Intensive and Critical Care Nursing,* 35, 66–73. https://doi.org/10.1016/j.iccn.2016.01.001

Li, S. S., Copeland-Halperin, L. R., Kaminsky, A. J., Li, J., Lodhi, F. K., & Miraliakbari, R. (2018). Computer-aided surgical simulation in head and neck reconstruction: A cost comparison among traditional, in-house, and commercial options. *Journal of Reconstructive Microsurgery*, 34(5), 341–347. https://doi.org/10.1055/s-0037-1621735

Lindell, J.S., Blaschke, B.L., Only, A.J., Parikh, H.R., Gorman, T., Vang, S., Mahajan, A.Y., & Cunningham, B.P. (2021). The cost of care associated with microvascular free tissue transfer by anatomical region: A time-driven activity-based model. *Journal of Reconstructive Microsurgery Open*, 6, e28–e34. https://doi.org/10.1055/s-0041-1729639

Madgar, O., Livneh, N., Dobriyan, A., Dagan, E., & Alon, E. E. (2022). Airway management following head and neck microvascular reconstruction: Is tracheostomy mandatory? *Brazilian Journal of Otorhinolaryngology,* 88(Suppl. 4), S44–S49. https://doi.org/10.1016/j.bjorl.2021.07.007

Madrigal, J., Mukdad, L., Han, A. Y., Tran, Z., Benharash, P., St John, M. A., & Blackwell, K. E. (2022). Impact of hospital volume on outcomes following head and neck cancer surgery and flap reconstruction. *The Laryngoscope*, 132(7), 1381–1387. https://doi.org/10.1002/lary.29903

Markiewicz, M. R., & Bell, R. B. (2011). Modern concepts in computer-assisted craniomaxillofacial reconstruction. *Current Opinion in Otolaryngology & Head and Neck Surgery*, 19(4), 295–301. https://doi.org/10.1097/MOO.0b013e328348a924

McDevitt, J., de Camargo Cancela, M., Kelly, M., Comber, H., & Sharp, L. (2016). Tracheostomy and infection prolong length of stay in hospital after surgery for head and neck cancer: A population based study. *Oral Surgery, Oral Medicine, Oral Pathology and Oral Radiology*, 121(1), 22–28.e1. https://doi.org/10.1016/j.oooo.2015.08.004

Mehra, T., Schönegg, D., Ebner, J., Moos, R. M., Schumann, P., Gander, T., Essig, H., & Lanzer, M. (2021). ASA score and procedure type predict complications and costs in maxillofacial reconstructive surgery: A retrospective study using a hospital administrative database. *Swiss Medical Weekly,* 151, Article w20497. https://doi.org/10.4414/smw.2021.20497

Miller, M. J., Swartz, W. M., Miller, R. H., & Harvey, J. M. (1991). Cost analysis of microsurgical reconstruction in the head and neck. *Journal of Surgical Oncology*, 46(4), 230–234. https://doi.org/10.1002/jso.2930460405

Panwar, A., Smith, R., Lydiatt, D., Lindau, R., Wieland, A., Richards, A., Shostrom, V., Militsakh, O., & Lydiatt, W. (2016). Vascularized tissue transfer in head and neck surgery: Is intensive care unit–based management necessary? *The Laryngoscope*, 126(1), 73–79. https://doi.org/10.1002/lary.25608

Petrides, G. A., Dunn, M., Charters, E., Venchiarutti, R., Cheng, K., Froggatt, C., Mukherjee, P., Wallace, C., Howes, D., & Leinkram, D. (2022). Health-related quality of life in maxillectomy patients undergoing dentoalveolar rehabilitation. *Oral Oncology*, 126, Article 105757. https://doi.org/10.1016/j.oraloncology.2022.105757

Petrides, G. A., Hicks, G., Dunn, M., Froggatt, C., Wallace, C., Howes, D., Leinkram, D., Low, T.-H., Ch'ng, S., Wykes, J., Palme, C. E., & Clark, J. R. (2021). Dentoalveolar outcomes in maxillary reconstruction: A retrospective review of 85 maxillectomy reconstructions. *ANZ Journal of Surgery,* 91(7–8), 1472–1479. https://doi.org/10.1111/ans.17001

Potter, S., Davies, C., Davies, G., Rice, C., & Hollingworth, W. (2020). The use of micro-costing in economic analyses of surgical interventions: A systematic review. *Health Economics Review*, 10(1), Article 3. https://doi.org/10.1186/s13561-020-0260-8

Powcharoen, W., Yang, W. F., Yan Li, K., Zhu, W., & Su, Y. X. (2019). Computer-assisted versus conventional freehand mandibular reconstruction with fibula free flap: A systematic review and meta-analysis. *Plastic and Reconstructive Surgery,* 144(6), 1417–1428. https://doi.org/10.1097/prs.0000000000006261

Rechner, I., & Lipman, J. (2005). The costs of caring for patients in a tertiary referral Australian intensive care unit. *Anaesthesia and Intensive Care*, 33(4), 477–482. https://doi.org/10.1177/0310057X0503300409

Reeves, B. (1999). Health-technology assessment in surgery. *The Lancet,* 353, S3–S5. https://doi.org/10.1016/S0140-6736(99)90413-0

Rosado, P., Cheng, H.-T., Wu, C.-M., & Wei, F.-C. (2015). Influence of diabetes mellitus on postoperative complications and failure in head and neck free flap reconstruction: A systematic review and meta-analysis. *Head & Neck,* 37(4), 615–618. https://doi.org/10.1002/hed.23624

Rubin, S. J., Saunders, S. S., Kuperstock, J., Gadaleta, D., Burke, P. A., Grillone, G., Moses, J. M., Murphy, J. P., Rodriguez, G., Salama, A., & Platt, M. P. (2020). Quality improvement in tracheostomy care: A multidisciplinary approach to standardizing

tracheostomy care to reduce complications. *American Journal of Otolaryngology,* 41(2), Article 102376. https://doi.org/10.1016/j.amjoto.2019.102376

Setälä, L., Koskenvuori, H., Gudaviciene, D., Berg, L., & Mustonen, P. (2009). Cost analysis of 109 microsurgical reconstructions and flap monitoring with microdialysis. *Journal of Reconstructive Microsurgery,* 25(9), 521–526. https://doi.org/10.1055/s-0029-1238218

Shaw, R. J., Sutton, A. F., Cawood, J. I., Howell, R. A., Lowe, D., Brown, J. S., Rogers, S. N., & Vaughan, E. D. (2005). Oral rehabilitation after treatment for head and neck malignancy. *Head & Neck,* 27(6), 459–470. https://doi.org/10.1002/hed.20176

Tewfik, K., Chiarelli, P., Copelli, C., Pederneschi, N., Cassano, L., Manfuso, A., Covelli, C., & Longo, F. (2021). Italian cost analysis of free flap surgery in head and neck reconstruction using the activity-based costing (ABC). *Journal of Plastic, Reconstructive & Aesthetic Surgery*, 74(6), 1279–1285. https://doi.org/10.1016/j.bjps.2020.10.096

Xu, X., Lazar, C. M., & Ruger, J. P. (2021). Micro-costing in health and medicine: A critical appraisal. *Health Economics Review*, 11(1), Article 1. https://doi.org/10.1186/s13561-020-00298-5

CHAPTER 4: POINT-OF-CARE COMPARED TO COMMERCIAL VIRTUAL SURGICAL PLANNING FOR MANDIBULAR AND MAXILLARY RECONSTRUCTION: A COST-MINIMISATION ANALYSIS

4.1 PREFACE

This chapter addresses Aim 3 of the thesis through a cost-minimisation analysis comparing point-of-care virtual surgical planning (POC-VSP) and commercial virtual surgical planning (C-VSP). Building on pre-established clinical equivalency between these approaches, this chapter quantifies the cost differences between virtual surgical planning (VSP) workflows and determines the annual caseload thresholds at which POC-VSP becomes economically favourable.

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4.2 AUTHORSHIP STATEMENT

The co-authors of the paper "Point-of-care compared to commercial virtual surgical planning for mandibular and maxillary reconstruction: A cost-minimisation analysis." confirm that George Andrew Petrides has made the following contributions:

- Conceptualisation and design of methodology.
- Collection and extraction of data.
- Drafting and revising of the manuscript and critical appraisal of content.

As the primary supervisor for the candidature upon which this thesis is based, I can confirm that the above authorship attribution statement is correct.

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31st December 2025

4.3 ABSTRACT

INTRODUCTION

Virtual surgical planning (VSP) improves outcomes in jaw reconstruction, but it is typically outsourced to commercial providers (C-VSP), incurring substantial costs. Many institutions have developed point-of-care VSP (POC-VSP) to reduce expenses, though few economic evaluations have been conducted on the basis of pre-established clinical equivalence. The aim of this study was to compare the direct costs of POC-VSP and C-VSP for patients undergoing jaw reconstruction.

METHODOLOGY

A cost-minimisation analysis from the perspective of the healthcare provider was performed comparing POC-VSP and C-VSP in 64 patients undergoing bony jaw reconstruction at a single institution between December 2020 and June 2023. Financial costs were calculated using micro-costing methodology. Propensity score matching controlled for baseline differences. An economies-of-scale model examined the cost-volume relationship between approaches.

RESULTS

Following propensity score matching (n = 36), POC-VSP was associated with significantly lower total operative period costs (A$30,490 vs. $39,522; $p < 0.001$) and costs (A$8,925 vs. $18,760; $p < 0.001$) compared to C-VSP. Operative time was significantly longer for POC-VSP (582 vs. 506 minutes; $p = 0.010$), though this did not significantly affect staffing costs. Results remained consistent on regression adjustment and genetic matching. The crossover point at which POC-VSP becomes less costly than C-VSP was seven cases annually, increasing to 17 cases when regulatory conformity assessment costs were included.

CONCLUSION

POC-VSP offers substantial cost savings compared to C-VSP for jaw reconstruction, though initial investment means C-VSP remains less costly at lower case volumes. Institutions performing seven or more cases annually may benefit from establishing POC-VSP capabilities.

4.4 INTRODUCTION

Mandibulectomy and maxillectomy are standard surgical treatments for pathology affecting the jaw (Argiris et al., 2008; Cognetti et al., 2008). Following ablation, microvascular free flap reconstruction is typically performed to minimise postoperative impairment in aesthetics, breathing, speech, swallowing, and mastication (Kumar et al., 2013; Rathod et al., 2015). These procedures require careful surgical planning and a thorough understanding of the complex anatomy of the head and neck (Probst et al., 2023). In osseous reconstructions where dental rehabilitation is planned, the accuracy of bone positioning and implant placement directly influences key outcomes such as bony union, dental occlusion, and facial contour (van Gemert et al., 2012).

Virtual surgical planning (VSP) uses three-dimensional (3D) digital models of the facial skeleton and free flap donor site to virtually plan osteotomy sites and where fixation plates and dental implants will be positioned to achieve the desired reconstructive outcomes. These plans are then translated into the operative setting via patient-matched devices such as surgical guides, anatomical models, and titanium reconstruction plates (Ferreira et al., 2014; McCarthy & Cordeiro, 2010; Okay et al., 2001; Tang et al., 2008; Tarsitano et al., 2015). VSP has been shown to improve reconstruction accuracy, reduce ischemia and operative time, shorten hospital length of admission, lower complication rates, and increase rates of successful dental rehabilitation, resulting in greater quality of life (Foley et al., 2013; Li et al., 2018; Metzler et al., 2014; Petrides et al., 2021; Powcharoen et al., 2019; Roser et al., 2010; Salgueiro & Stevens, 2010).

The VSP workflow has traditionally been outsourced to commercial providers (C-VSP). However, this approach is associated with considerable costs for healthcare funds or patients, resulting in many forgoing VSP despite its proven benefits (Chen et al., 2021; Fatima et al., 2019; Smithers et al., 2018). In response, numerous institutions have developed point-of-care (in-house) VSP workflows (POC-VSP) using commercially available software and 3D printers (Dupret-Bories et al., 2018; McAllister et al., 2018; Mottini et al., 2016; Smithers et al., 2018). Additional potential benefits of POC-VSP include shorter lead times to product release and more adaptive and flexible workflows that facilitate innovation.

While previous studies have compared the costs of C-VSP and POC-VSP, few have been conducted based on pre-established clinical equivalence. Moreover, costing methodologies in these studies frequently exclude or make assumptions about significant cost drivers, introducing potential bias (Abo Sharkh & Makhoul, 2020; Li et al., 2018; Moe et al., 2021). We recently demonstrated that the POC-VSP workflow at Chris O'Brien Lifehouse Hospital (COBL) is clinically equivalent to C-VSP with respect to postoperative intercondylar and intergonial distance, segment length, and angles between segments, providing a robust foundation for cost-minimisation analysis (CMA) (Johal et al., 2022). CMA is appropriate when interventions produce equivalent clinical outcomes, making cost the primary determinant of choice between them (Drummond, 2015). The aim of this study is to compare the direct costs of C-VSP and POC-VSP for patients undergoing jaw reconstruction, providing evidence to inform institutional decision-making regarding investment in similar services.

4.5 METHODOLOGY

A CMA from the perspective of the healthcare provider was performed comparing C-VSP and POC-VSP in patients undergoing bony mandibular and/or maxillary reconstruction at COBL between December 2020 and June 2023 using the Consolidated Health Economic Evaluation Reporting Standards 2022 (CHEERS 2022) Statement (**Appendix C1**). Ethics approval was obtained from St Vincent's Hospital Human Ethics Review Committee (2020/ETH02415). The health economic analysis plan was developed and registered on the Open Science Framework (OSF) (DOI: 10.17605/OSF.IO/89NPQ; https://doi.org/10.17605/OSF.IO/89NPQ) (**Appendix C2)**.

Patients who underwent marginal mandibulectomy or soft-tissue-only microvascular reconstruction were excluded. Data on patient demographics, pathology, surgical management, VSP type, length of stay, postoperative complications, and returns to the intensive care unit (ICU) or operating room (OR) were extracted from clinical notes and the COBL Maxillofacial Database. Health outcomes (including postoperative function, bone segment alignment, and implant success) were assumed equivalent between groups based on prior evidence, and no additional outcome measures were collected (Johal et al., 2022).

4.5.1 VSP

All participants underwent VSP as part of their reconstruction. Patients received either C-VSP or POC-VSP; POC-VSP was used for patients without private insurance or where a short lead time to surgery precluded commercial planning. The typical pathway for each approach is presented in **Figure 1.** In both workflows, high-resolution (<1.0mm) computed tomography (CT) scans of the craniofacial skeleton, donor site, and vasculature were acquired

preoperatively and converted to Digital Imaging and Communications in Medicine (DICOM) format. Where dental rehabilitation was planned, intraoral scans of the dentition were obtained and converted to STL files.

For C-VSP, DICOM images were provided to the commercial company, where a design engineer segmented regions of interest to generate 3D models (digital twin) of the craniofacial skeleton, teeth, donor site bone, and vessels. A planning meeting of approximately 60 minutes was then held, attended by the design engineer, ablative surgeon, reconstructive surgeon, and prosthodontist. During this meeting, resection, reconstruction, and dental rehabilitation were planned using the 3D models, with consideration of tumour margins, dental occlusion, and aesthetic contour. The biomedical engineers subsequently designed the surgical guides, anatomical models, and patient-specific plates offline. STL files of the donor models, cutting guides, and fixation guide were compiled in a VSP report for surgical team review and amendment as required. Final devices were manufactured, shipped to COBL, and sterilised prior to the procedure (Mazzola et al., 2020).

The POC-VSP protocol at COBL, modified since Smithers et al. (2018) to comply with ISO13485:2016 regulations, has been described in detail by Jeong et al. (2025). The acquisition and planning phases were similar to C-VSP, applying an occlusal-based planning protocol using Materialise Mimics™ and ProPlan CMF™ (Materialise, Leuven, Belgium). However, during the design phase, the reconstructed anatomical model was 3D printed in polylactic acid (PLA) using a Raise3D Pro2 printer (Raise3D, California, USA) and a commercial titanium reconstruction plate was then contoured and fixated to the anatomical model. This was then optically scanned before the plate was removed, cleaned, packaged, and sterilised. The STL file generated from the optical scan was overlaid on the virtual plan to register the location of

the screw holes. This allowed the surgical guides to include accurate screw hole locations and the anatomical modules to include the reconstruction plate. Finally, during the manufacturing phase, the surgical guides and anatomical models were 3D printed using a FORMIGA P110 Velocis printer (EOS, Krailing, Germany), verified as part of the quality control process, cleaned, packaged, labelled, and sterilised prior to use.

4.5.2 COSTING METHODOLOGY

Financial costs for activities from planning to discharge were calculated using an individualised micro-costing approach. Activities were classified as either staffing or equipment costs. Only direct costs were included; overhead, onboarding, and societal costs (such as time off work and travel costs) were excluded. The detailed micro-costing methodology is described in **Chapter 3**. Costs were calculated in Australian dollars (A$) and were not adjusted for inflation to avoid overestimating historical costs. Given the short time horizon (perioperative period only), no discounting was applied.

Preoperative CT costs were excluded as these were routine for all patients and did not differ between groups. For C-VSP, staffing costs comprised the reconstructive surgeon, ablative surgeon, and prosthodontists' time investment in the VSP planning meeting using the average annual salary from the COBL Enterprise Agreement 2022. Equipment costs included the custom-milled plate, model, and guide, obtained directly from vendor invoices.

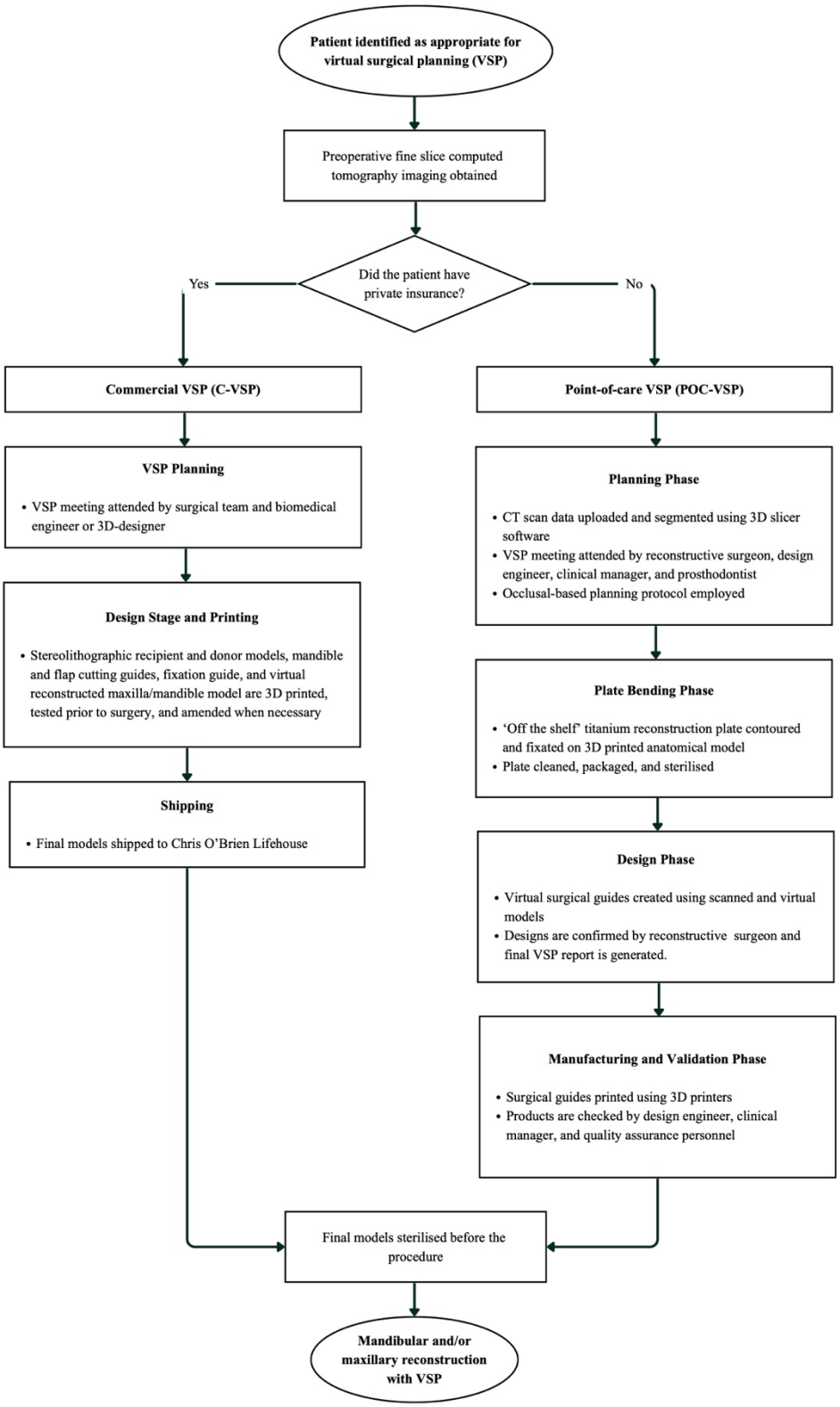

Figure 1. The pathway and activities involved in virtual surgical planning (VSP) for jaw reconstruction at Chris O'Brien Lifehouse Hospital. Patients received either commercial VSP (C-VSP) or point-of-care VSP (POC-VSP) primarily based on private insurance status.

For POC-VSP, staffing costs were calculated by multiplying each staff member's per-minute salary by their estimated time investment in each phase of the workflow (**Table 1**). For the planning phase, staff included the ablative surgeon, reconstructive surgeon, and design engineer. For the design and manufacturing phase, staff included the design engineer, 3D printing technician, program manager, quality assurance and regulatory personnel. Equipment costs included 3D printing materials, calculated based on average volume and unit price. Start-up costs were calculated using the purchase price of the 3D scanner (Trios), 3D printers (Raise 3D Pro 2, Form 3 Formlab with Cure/Wash, EOS P110, Asiga Pro 4k), software (Materialise MIMICS Suite, Materialise Magics), and prosthodontic equipment. Annual costs were based on subscription fees or estimated depreciation period, then divided by the number of cases utilising each item in 2023 (16 VSP cases and 40 dental prosthesis cases) to derive a per-case cost.

Table 1. Calculation of direct financial costs per case for point-of-care virtual surgical planning.

Activity	Cost ($A)
Staffing	
Planning Phase	863.25
Plate Bending Phase	695.70
Design Phase	801.75
Manufacturing and Validation Phase	981.53
Equipment	
FDM Raise 3D Pro 2 Printer	65.79
Form 3 Formlab Printer	80.72
EOS P110 Printer	1,443.75
Asiga Pro 4K Printer	170.60
Materialise MIMICS Suite Software	3,366.98
Materialise Magics Software	535.33
Reconstruction plate	As per invoice
Screws	As per invoice

4.5.3 STATISTICAL ANALYSIS

Total costs were calculated by summing all operative and perioperative activities. Costs were presented as means with standard deviations. Initial between-group comparisons were performed using t-tests.

To control for baseline differences, propensity score matching (PSM) was used to compare patients receiving POC-VSP versus C-VSP. Propensity scores were estimated using logistic regression with covariates as identified in the study presented in **Chapter 3.** The American Society of Anaesthesiologists (ASA) IV status, vasculopathy, surgical site, neck dissection, and tracheostomy. One-to-one nearest-neighbour matching was performed using a calliper width of 0.2 standard deviations of the logit of the propensity score (Austin, 2011). Balance was assessed using standardised mean differences and visual diagnostics. Sensitivity analysis repeated t-test comparisons in the matched cohort (Austin, 2009). Regression adjustment was performed to control for characteristics not included in PSM (age at surgery, sex, pathology type, comorbidities, and treatment history). Genetic matching with a 0.2 calliper was performed as a robustness check to assess the sensitivity of results to the matching algorithm. This approach optimises covariate balance directly than relying solely on propensity score distance.

4.5.4 ECONOMY-OF-SCALE MODEL

The cost-volume relationship between C-VSP and POC-VSP was examined using an economy-of-scale model. Total costs were modelled as a function of annual case volume using a linear cost equation comprising fixed and variable components. For C-VSP, costs were modelled linearly, reflecting the average per-case commercial service fee. For POC-VSP, costs included the fixed start-up costs distributed across annual case volume, plus variable per-case staffing and equipment costs. An additional scenario modelled POC-VSP with conformity assessment

requirements, incorporating higher initial fixed costs of $150,000 and the ongoing annual Australian Register of Therapeutic Goods (ARTG) listing fee of $2,374 to account for regulatory compliance while maintaining the same variable per-case cost. Break-even analysis was performed to identify the annual case volume at which POC-VSP becomes cost-equivalent to C-VSP.

4.6 RESULTS

4.6.1 BASELINE CHARACTERISTICS

In total, 64 patients underwent VSP as part of their mandibular and/or maxillary bony reconstruction. This comprised 43 patients in the C-VSP group and 21 patients in the POC-VSP group with a mean age at the time of surgery of 64.36 ± 16.96 and 61.81 ± 11.32 years, respectively (**Table 2**). The proportion of male patients was 51% in the C-VSP and 48% in the POC-VSP group. In both groups, the majority of patients were ASA Class III (63% for C-VSP and 57% for POC-VSP). Vasculopathy was present preoperatively in 12% of C-VSP and 10% of POC-VSP patients. The pathology was malignant for 63% of C-VSP and 52% of POC-VSP patients. Across all unmatched comorbidity covariates (i.e. ASA Class and presence of vasculopathy), there were no statistically significant differences between C-VSP and POC-VSP groups.

Table 2. Baseline clinicopathological characteristics of the cohort.

Characteristics	All VSP (N = 64)		C-VSP (n = 43)		POC-VSP (n = 21)		*p*-value
	% (n)	Range	% (n)	Range	% (n)	Range	
Sex							
Male	50 (32)		51 (22)		48 (10)		–
Female	50 (32)		49 (21)		52 (11)		–
Age at time of surgery (years) (mean ± SD)	62.78 ± 15.36	15 – 94	64.36 ± 16.96	15 – 94	61.81 ± 11.32	29 – 76	–
ASA Score							
I	17 (11)		16 (7)		19 (4)		0.787
II	22 (14)		21 (9)		24 (5)		0.798
III	61 (39)		63 (27)		57 (12)		0.670
IV	0 (0)		0 (0)		0 (0)		N/A
Comorbidities							
Diabetes mellitus	11 (7)		9 (4)		14 (3)		–
Current smoker	34 (22)		30 (13)		43 (9)		–
Vasculopathy	11 (7)		12 (5)		10 (2)		0.804
Hypertension	28 (18)		30 (13)		24 (5)		–
Pathology							
Malignant	59 (38)		63 (27)		52 (11)		–
Non-malignant	41 (26)		37 (16)		48 (10)		–
Previous chemotherapy and/or radiotherapy							
Yes	16 (10)		14 (6)		19 (4)		–
No	84 (54)		86 (37)		81 (17)		–

Note: This table presents the comparison between patients who received C-VSP versus POC-VSP, using unmatched data. Values are shown as mean (standard deviation). P-values are based on two-sample t-tests for continuous variables and proportion comparisons for binary variables. For binary variables (e.g., gender, smoker), the standard deviation is based on the variability of proportions within each group (i.e. $\sqrt{p(1-p)}$. ASA: American Society of Anaesthesiologists Physical Status Classification.

The reconstruction site was predominantly mandibular in both groups (93% for C-VSP and 90% for POC-VSP), with the most common donor site being the fibula (74% for C-VSP and 57% for POC-VSP) (**Table 3).** Tracheostomy, neck dissection, and endosseous dental implants were performed in 72%, 88%, and 74% of C-VSP patients and 86%, 81%, and 48% of POC-VSP patients, respectively. Across all unmatched treatment covariates (i.e. site of reconstruction, tracheostomy, and neck dissection), there were no statistically significant differences between C-VSP and POC-VSP groups.

4.6.2 COMPARISONS BEFORE MATCHING

Before matching, substantial differences were noted in some outcomes that may increase resource utilisation with the C-VSP group having a significantly higher number of complications during the hospital admission (65% vs. 33%; $p = 0.016$) and more likely to return to the OR (33% vs 10%; $p = 0.047$) (**Table 4**). Regarding the overall cost outcomes, C-VSP patients incurred significantly higher mean OR total costs ($39,845 vs. $30,411; $p < 0.001$) with higher VSP costs ($18,453 vs. $8,925; $p < 0.001$), endosseous dental implants costs ($1,794 vs. $1,088; $p < 0.05$), and OR non-disposable equipment costs ($2,711 vs. $2,297; $p < 0.05$).

Table 3. Operative characteristics of patients included in the study.

Characteristics	**All VSP % (n) (N = 64)**	**C-VSP % (n) (n = 43)**	**POC-VSP % (n) (n = 21)**
Surgery type			
Ablation and reconstruction	98 (63)	98 (42)	100 (21)
Reconstruction	2 (1)	2 (1)	0 (0)
Reconstruction site			
Mandible	92 (59)	93 (40)	90 (19)
Maxilla	8 (5)	7 (3)	10 (2)
Mandible and maxilla	0 (0)	0 (0)	0 (0)
Reconstruction type			
Fibula free flap	69 (44)	74 (32)	57 (12)
Scapula free flap	22 (14)	21 (9)	24 (5)
Radius (bone) flap	5 (3)	2 (1)	10 (2)
Deep circumflex iliac artery (DCIA)	5 (3)	2 (1)	10 (2)
Team approach			
One team	28 (18)	21 (9)	43 (9)
Two team	72 (46)	79 (34)	57 (12)
Operative adjuncts			
Tracheostomy	77 (49)	72 (31)	86 (18)
Neck dissection	86 (55)	88 (38)	81 (17)
Endosseous dental implants	66 (42)	74 (32)	48 (10)

Note: This table presents the comparison between patients who received C-VSP versus POC-VSP, using unmatched data. Cost outcomes are reported in Australian dollars (AUD). Values are shown as mean (standard deviation). P-values are based on two-sample t-tests for continuous variables and proportion comparisons for binary variables. For binary variables (e.g., gender, smoker), the standard deviation is based on the variability of proportions within each group (i.e. $\sqrt{p(1-p)}$.)

Table 4. Resource utilisation and cost outcomes by VSP type before matching.

Characteristics	All VSP (N = 64)		C-VSP (n = 43)		POC-VSP (n = 21)		*p*-value
	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	
Resource use outcomes							
Mean duration (minutes)							
Operative duration (minutes)	538.97 ± 102.15	348 – 846	521.44 ± 108.65	399 – 897	574.86 ± 81.18	462 – 750	0.051
Anaesthetic duration (minutes)	616.86 ± 104.45	399 – 897	600.44 ± 109.65	348 – 846	650.48 ± 89.04	522 – 847	0.074
Mean length of admission (days)	18 ± 10	7 – 48	19 ± 10	7 – 48	16 ± 8	8 – 39	0.311
Intensive care unit (ICU) (days)	4 ± 5	2 – 38	4 ± 2	2 – 10	5 ± 8	2 – 38	0.433
General ward (days)	14 ± 9	1 – 46	15 ± 10	1 – 46	12 ± 6	1 – 29	
Complication during admission (% (N))	35 (55)		65 (28)		7 (33)		**0.016**
Return to OR (at least one) (% (N))	25 (16)		33 (14)		10 (2)		**0.047**
Return to ICU (% (N))	11 (7)		14 (6)		5 (1)		0.276
Cost outcomes ($A)							
Operative period	34,122 ± 8,602	19,528 – 57,584	39,845 ± 9,684	19,528 – 57,584	30,411 ± 2,443	24,605 – 31,757	**<0.001**
Prostheses							
VSP	15,326 ± 7,402	3,547 – 36,162	18,453 ± 7,190	3,547 – 36,162	8,925 ± 0	8,925 – 8.925	**<0.001**
Dental implants	1,562 ± 1,354	0 – 4,865	1,794 ± 1.348	0 – 4,865	1,088 ± 1,267	0 – 3,508	**0.049**
Screws and plates	789 ± 1,371	0 – 7,186	0 ± 0	0 – 0	2,405 ± 1,357	334 – 7,186	**<0.001**
Ligating clips	259 ± 357	38 – 2,025	309 ± 420	38 – 2,025	157 ± 118	44 – 585	0.109
Venous couplers	942 ± 359	0 – 1,827	949 ± 383	0 – 1,827	928 ± 312	0 – 1,218	0.829

Characteristics	All VSP (N = 64)		C-VSP (n = 43)		POC-VSP (n = 21)		*p*-value
	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	
Haemostatic agents	52 ± 115	0 – 574	45 ± 96	0 – 527	67 ± 148	0 – 574	0.471
Other†	45 ± 168	0 – 835	31 ± 147	0 – 835	74 ± 206	0 – 835	0.339
Staffing	8,501 ± 1,833	5,179 – 13,447	10,668 ± 2,238	5,179 – 13,447	11,353 ± 3,036	6,776 – 11,254	0.362
Disposable equipment	3,594 ± 1,014	2,596 – 8,856	3,391 ± 573	2,596 – 8,856	3,693 ± 1,164	2,984 – 5,624	0.266
Non-disposable equipment	2,575 ± 569	1,625 – 3,939	2,297 ± 445	1,800 – 3939	2,711 ± 578	1,625 – 2,870	**0.005**
Operating room equipment	235 ± 51	143 – 371	237 ± 36	143 – 371	234 ± 57	187 – 311	0.812
Perioperative period	24,288 ± 15,357	10,570 – 116,649	24,329 ± 11,029	10,773 – 54,201	24,205 ± 22,077	11,327 – 116,649	0.976
Staffing and disposable equipment	20,358 ± 12,576	8,671 – 96,072	20,246 ± 18,120	8,671 – 43,449	20,413 ± 8,994	9,401 – 96,072	0.961
Investigations	2,009 ± 1,698	519 – 12,711	2,041 ± 2,518	519 – 5,995	1,994 ± 1,144	739 – 12,711	0.917
Consultations	1,298 ± 804	580 – 4,995	1,153 ± 510	580 – 4,995	1,368 ± 911	600 – 2,356	0.320
Medications	623 ± 771	116 – 5,676	764 ± 1,197	116 – 1,866	554 ± 441	149 – 5,676	0.311
Total admission	58,410 ± 18,182	36,697 – 148,407	64,174 ± 15,417	36,697 – 92,537	54,616 ± 22,570	40,594 – 148,407	0.051

Note: This table presents the comparison between patients who received C-VSP versus POC-VSP, using unmatched data. Cost outcomes are reported in Australian dollars (AUD). Values are shown as mean (standard deviation). P-values are based on two-sample t-tests for continuous variables and proportion comparisons for binary variables. For binary variables (e.g., gender, current smoker), the standard deviation is based on the variability of proportions within each group (i.e. $\sqrt{p(1-p)}$.) †Includes eyelid weights, meshes, and bone cement.

4.6.3 BALANCE ASSESSMENT

The matching procedure resulted in a reasonably robust matched sample suitable for causal comparison between the C-VSP and POC-VSP groups. The matching confounders revealed no statistically significant differences between groups after matching (**Table 5**). The covariate balance plot shows standardised mean differences (SMDs) for each covariate before and after matching (**Figure 2**). After matching, nearly all covariates fell within the acceptable range (SMD < 0.1). The propensity score distributions (**Figure 3)** show that the overlap between treated and control groups improves notably post-matching, reflecting successful pairing of similar individuals on the basis of their propensity scores.

Table 5. Comparison of baseline covariates between POC-VSP and C-VSP groups before and after matching

Variable	Unmatched (mean)			Matched (mean)		
	C-VSP (n = 21)	POC-VSP (n = 43)	*p*-value	C-VSP (n = 18)	POC-VSP (n = 18)	*p*-value
ASA Score						
I	0.163	0.190	0.793	0.222	0.167	0.684
II	0.209	0.238	0.802	0.167	0.222	0.684
III	0.628	0.571	0.674	0.611	0.611	1.000
Vasculopathy (yes)	0.116	0.095	0.799	0.111	0.111	1.000
Reconstruction site						
Mandible	0.930	0.905	0.741	1	1	1
Maxilla	0.070	0.095	0.741	–	–	–
Neck dissection (yes)	0.884	0.810	0.467	0.889	0.944	0.560
Tracheostomy (yes)	0.721	0.857	0.198	0.833	0.889	0.642

Note: This table presents the mean values of baseline covariates for patients receiving C-VSP versus POC-VSP, before and after propensity score matching. Values are reported as proportions for binary variables and means for continuous variables. P-values are based on two-sample t-tests. ASA: American Society of Anaesthesiologists Classification.

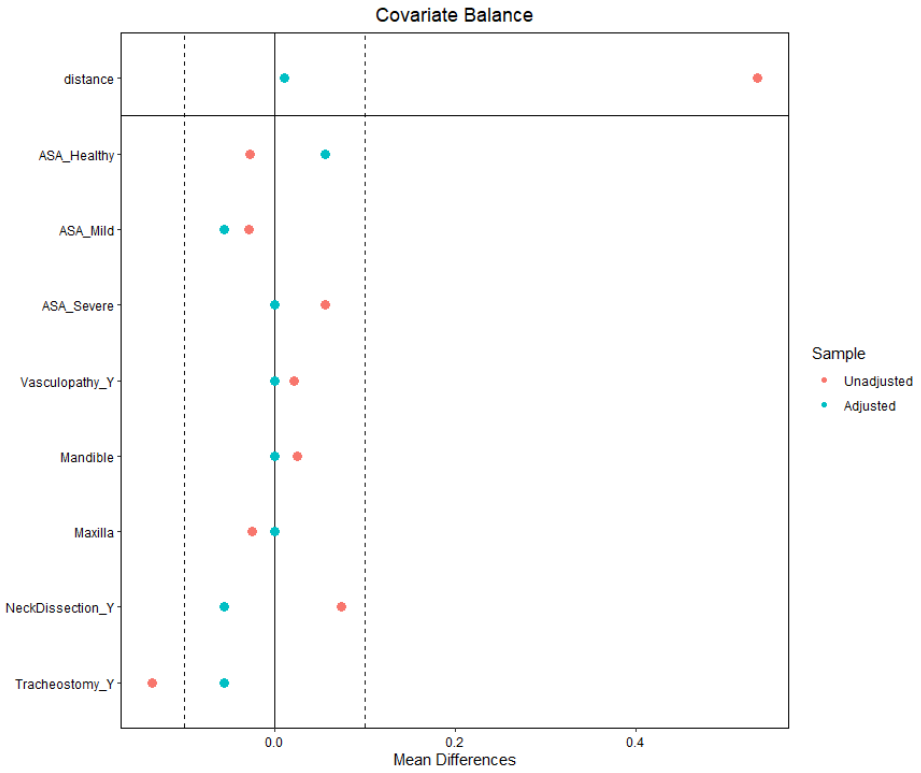

Figure 2. Standardised mean differences (SMDs) of covariates before and after propensity score matching between C-VSP and POC-VSP for each baseline covariate before (red) and after (blue) 1:1 nearest-neighbour matching. The vertical dashed lines represent the threshold of ± 0.1.

4.6.4 Comparisons After Matching

Following matching (n = 36), there were no statistically significant differences in mean length of admission (including ICU and general ward), return to ICU, or return to the OR between C-VSP and POC-VSP groups (**Table 6**). There was a significantly longer operative and anaesthetic duration in the POC-VSP group compared to the C-VSP group (582 vs. 506 minutes, p = 0.010; and 653 vs. 589 minutes, p = 0.030, respectively). These differences remained significant after adjusting for background characteristics (i.e. age, sex, malignancy, diabetes, smoking, hypertension, and prior radiotherapy/surgery) (**Table 7**). POC-VSP was associated with a significantly lower total operative period cost ($30,490 vs. $39,522; p <

0.001), lower VSP cost ($8,924 vs. $18,760; $p < 0.001$), and lower non-disposable equipment cost ($2,305 vs. $2,705; $p = 0.011$). These differences remained significant on regression analysis. Genetic matching produced results consistent with those obtained with propensity score matching (**Table 8**).

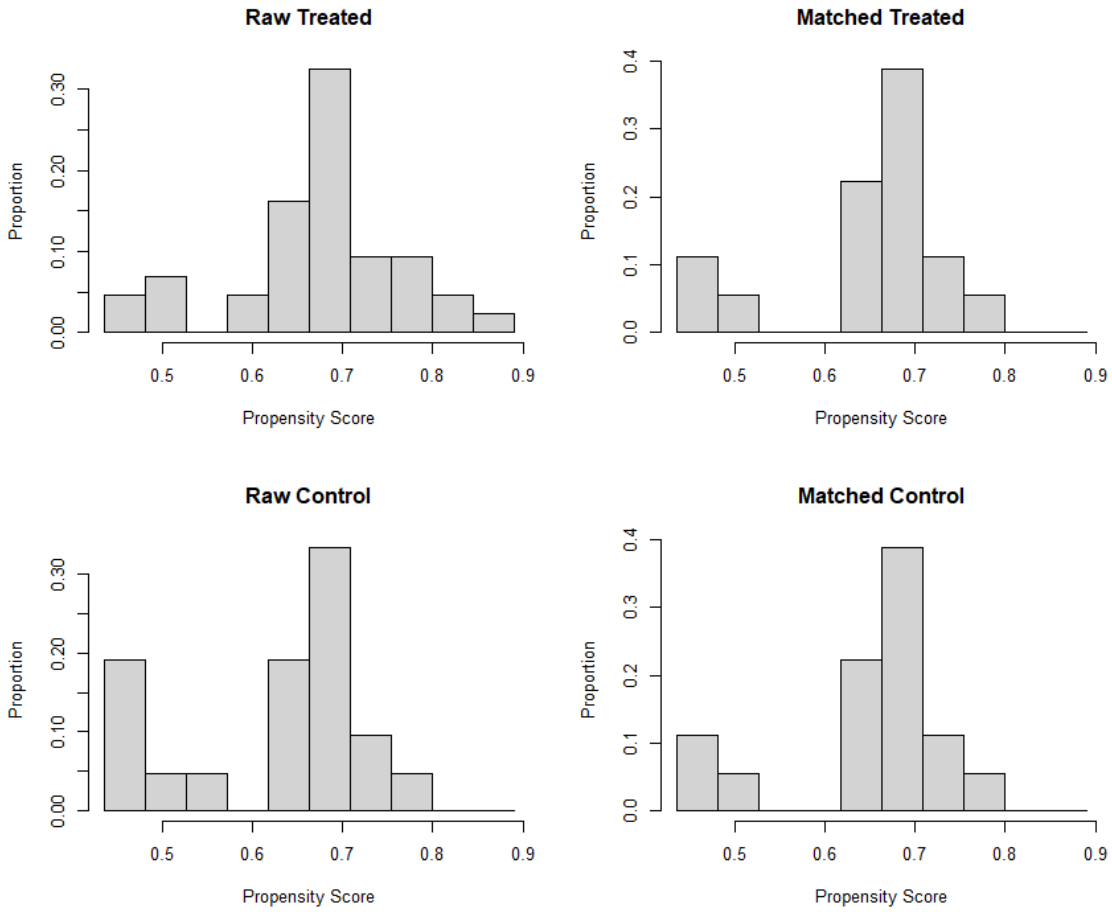

Figure 3. Distribution of propensity scores before and after matching. Histograms display the distribution of estimated propensity scores for POC-VSP (treated) and C-VSP (control), before (left) and after (right) matching. The overlap between treated and control groups improves notably post-matching, reflecting the successful pairing of similar individuals on the basis of their propensity scores.

Table 6. Resource utilisation and cost outcomes by VSP type after matching.

Characteristics	C-VSP (n = 18)	POC-VSP (n = 18)	*p-value*
	Mean ± SD	Mean ± SD	
Resource use outcomes			
Mean duration (minutes)			
Operative duration (minutes)	505.67 ± 85.32	581.67 ± 82.90	**0.010**
Anaesthetic duration (minutes)	588.78 ± 79.83	653.50 ± 91.46	**0.030**
Mean length of admission (days)	19.67 ± 11.38	16.78 ± 8.43	0.393
Intensive care unit (ICU) (days)	3.33 ± 2.22	5.00 ± 8.29	0.416
General ward (days)	16.33 ± 11.49	11.78 ± 6.73	0.156
Complication during hospital admission (%)	61 ± 50	33 ± 49	0.100
Return to OR (at least one) (%)	22 ± 43	11 ± 32	0.386
Return to ICU (%)	6 ± 24	6 ± 24	1.000
Cost outcomes ($A)			
Operative period	39,522 ± 7,220	30,490 ± 2,578	**<0.001**
Prostheses			
Virtual surgical planning (VSP)	18,760 ± 6,139	8,925 ± 0	**0.001**
Dental implants	1,641 ± 1,299	1,123 ± 1,268	0.234
Screws and plates	–	2,553 ± 1,364	–
Ligating clips	315 ± 442	169 ± 123	0.187
Venous couplers	981 ± 425	880 ± 312	0.419
Haemostatic agents	26 ± 40	46 ± 133	0.552
Other†	28 ± 118	63 ± 205	0.531
Staffing	10,931 ± 2,528	10,660 ± 2,175	0.733
Disposable equipment	3,578 ± 859	3,357 ± 575	0.370
Non-disposable equipment	2,705 ± 454	2,305 ± 440	**0.011**
Operating room equipment	227 ± 523	239 ± 37	0.463
Perioperative period	24,179 ± 10,988	25,342 ± 23,697	0.851
Staffing and disposable equipment	20,295 ± 9.359	21,149 ± 19,441	0.868
Investigations	1,911 ± 877	2,189 ± 2,699	0.680
Consultations	1,422 ± 794	1,153 ± 542	0.244
Medications	551 ± 427	851 ± 1,277	0.352
Total admission	63,701 ± 14,385	55,833 ± 23,174	0.244

Note: This table presents the mean values and standard deviations of healthcare resource use for C-VSP and POC-VSP after 1:1 propensity score matching. ICU: intensive care unit, OR: operating room.

Table 7. Results from least squares regression models estimating the effect of VSP type on cost and resource use outcomes.

Outcome	Coef. for C-VSP	SE	CI lower	CI upper	*p*-value
Costs (A$)					
Operative period	8,930	1,984	4,859	13,002	**<0.01**
VSP	10,307	1,612	7,000	13,614	**<0.01**
Non-disposable equipment	415	174	59	771	**<0.05**
Resource used (minutes)					
Anaesthetic duration	–77.17	27.16	–132.9	–21.44	**<0.05**
Operation duration	–85.23	28.11	–142.9	–27.56	**<0.05**

Note: This table summarises the estimated effects of receiving C-VSP (vs. POC-VSP) on various cost and resource outcomes using least squares regression models, adjusted for some background characteristics (i.e., age at surgery, female, malignant pathology, diabetes mellitus, current smoker, hypertension and previous chemotherapy and/or radiotherapy). Controlling for the background characteristics in regression after matching strengthens the estimates by reducing remaining bias and increasing precision. VSP: virtual surgical planning; OR: operating room; Coef.: coefficient; SE: standard error; CI: confidence interval.

Table 8. Comparison of mean outcomes between C-VSP and POC-VSP using genetic matching.

Outcome	Mean		ATT	CI lower	CI upper	*p*-value
	C-VSP (n = 18)	POC-VSP (n = 18)				
Operative period (A$)	39,522	30,490	9,032	–12,787	–5,277	**<0.01**
VSP (A$)	18,760	8,925	9,835	–12,888	–6,782	**<0.01**
Non-disposable equipment (A$)	2,705	2,305	401	–704	–98	**<0.05**
Anaesthetic duration (minutes)	588.78	653.50	-64.72	6.53	122.91	**<0.05**
Operative duration (minutes)	505.67	581.65	-76	19.02	132.98	**<0.05**

Note: calliper = 0.2. Results are presented as mean values, average treatment effect on the treated (ATT), *p*-values, and 95% confidence intervals.

4.6.5 Economy-of-Scale Model

The cost-volume relationship between POC-VSP and C-VSP is presented in **Figure 4.** Due to the initial investment costs associated with POC-VSP, C-VSP is less costly at lower case volumes. The crossover point at which POC-VSP becomes the more economical option occurs at seven cases per year. When the additional investment required to meet Therapeutic Goods Administration (TGA) conformity assessment requirements is included, this crossover point increases to 17 cases per year.

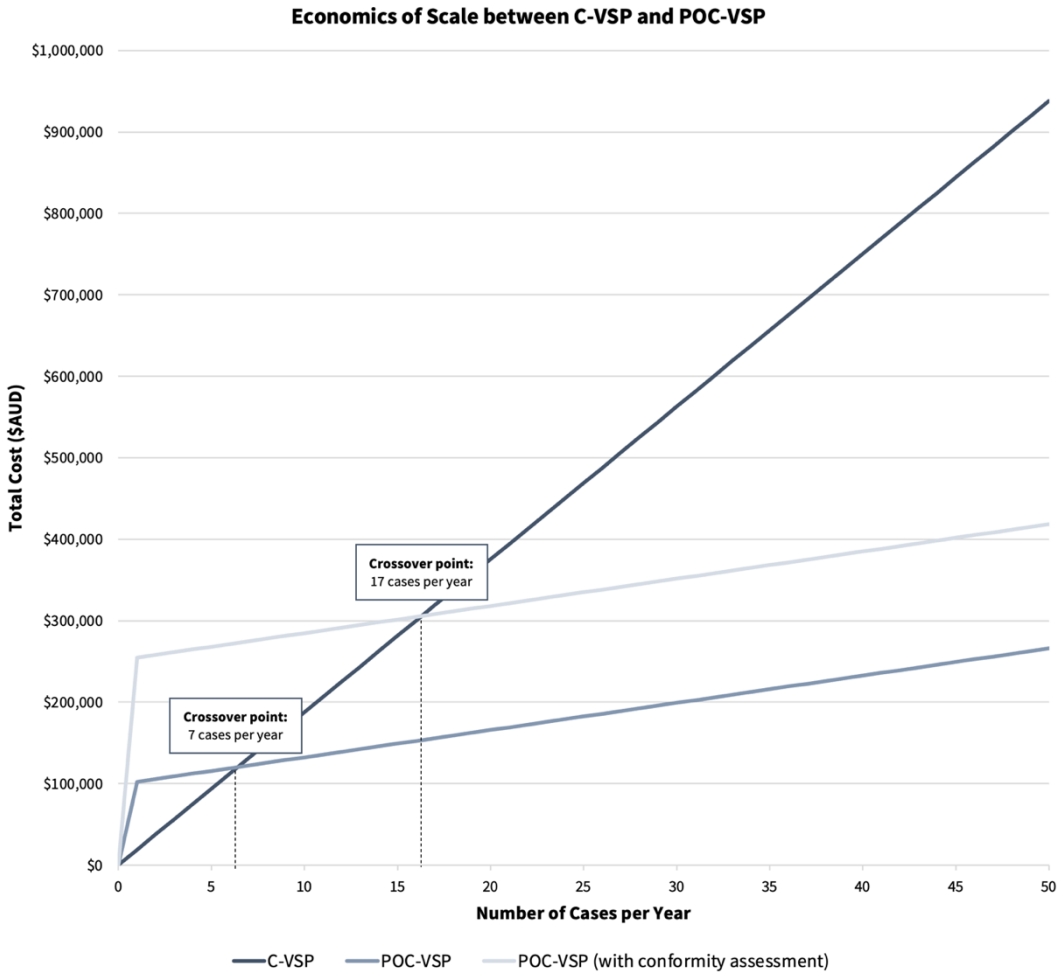

Figure 4. Chart modelling the number of cases needed to break even when comparing C-VSP, POC-VSP, and POC-VSP that meet conformity assessment requirements at Chris O'Brien Lifehouse (COBL).

4.7 DISCUSSION

VSP is increasingly employed in jaw reconstruction due to its established benefits, including greater reconstruction accuracy, reduced ischemia and operative time, shorter length of stay, lower complication rates, and higher rates of successful dental rehabilitation (Foley et al., 2013; Li et al., 2018; Metzler et al., 2014; Petrides et al., 2021; Powcharoen et al., 2019; Roser et al., 2010; Salgueiro & Stevens, 2010). Multiple studies have demonstrated that the cost savings stemming from these benefits offset the additional upfront cost of VSP (Bolzoni et al., 2020; Mazzola et al., 2020; Rodríguez-Arias et al., 2022; Zweifel et al., 2015). However, the considerable expense of outsourcing VSP to commercial providers has prompted many institutions to develop in-house or point-of-care capabilities using commercially available software and three-dimensional printers (Dupret-Bories et al., 2018; McAllister et al., 2018; Mottini et al., 2016; Smithers et al., 2018). To our knowledge, this is the first CMA comparing POC-VSP and C-VSP conducted based on clear pre-established clinical equivalency (Johal et al., 2022). Our analysis demonstrated that the POC-VSP workflow at COBL achieved an average cost reduction of $9,032 per case for the total operative period and $9,836 for VSP compared to C-VSP in a matched cohort of jaw reconstruction patients. These cost savings have meaningful implications for institutional resource allocation and, potentially, for improving patient access to VSP as a component of routine care.

The VSP workflow itself was the primary driver of cost differences between groups. Commercial providers do not disclose their pricing structure, precluding direct comparison of individual cost components. For POC-VSP, the major expenditure relates to upfront investment in software and hardware, consistent with previous reports (Abo Sharkh & Makhoul, 2020). Although our equipment is industry-grade, it is smaller in scale and considerably less expensive

than that used by commercial companies. Furthermore, eliminating vendor fees and markup contributes substantially to the cost differential. Another notable cost differential related to the fixation devices used in C-VSP and POC-VSP workflows, where C-VSP cases utilised custom-milled titanium plates and POC-VSP used pre-bent stock plates, which are substantially less expensive.

The financial benefits of POC-VSP against C-VSP have been consistently noted (Block et al., 2024; Dupret-Bories et al., 2018; Li et al., 2018; Spaas & Lenssen, 2019; Williams et al., 2020; Xiao et al., 2025). A systematic review of VSP in craniomaxillofacial surgery performed by Heron et al. (2023) showed that POC-VSP was significantly less expensive than VSP acquired from commercial companies (US$252 vs. US$2,736, $p < 0.01$). Moe et al. (2021) reported that after an initial start-up cost of less than US$500, per case POC-VSP costs were only US$4 compared to US$5,275 for outsourced planning. However, their analysis excluded labour costs and pre-bent reconstruction plates. Similarly, Abo Sharkh and Makhoul (2020) reduced the cost of VSP for maxillofacial reconstruction in their cohort from CAD$2,625 to CAD$18 per case using a surgeon-led POC-VSP.

The POC-VSP costs in this study were notably higher than those reported elsewhere, at approximately AUD$10,000 per case (Abo Sharkh & Makhoul, 2020; Heron et al., 2023; Moe et al., 2021). However, this difference should be interpreted carefully. Although existing studies consistently illustrate the financial benefits of POC-VSP, the majority lack pre-established clinical equivalency and employ insufficient cost measurements – shortcomings addressed in this study. The increased cost of the workflow in this study likely reflects higher quality and more rigorous regulatory standards. For instance, the POC-VSP workflow at COBL has evolved to meet local regulatory requirements, including Therapeutic Goods

Administration (TGA)-approved design software and manufacturing hardware, and an ISO13485:2016-compliant quality management system (Jeong et al., 2025). This regulatory compliance generates additional costs through more expensive equipment and increased staffing for documentation, verification, and quality assurance. We consider these costs necessary to ensure the safety and quality of in-house products, and they more accurately reflect the true investment required for a sustainable, clinically robust POC-VSP program.

This study again demonstrates the clinical equivalency between our POC-VSP workflow and VSP in regards to short-term postoperative outcomes, with no significant differences in complication rates, unplanned returns to the OR or ICU, or length of admission. As a result, there were no significant differences in the costs of the perioperative hospital admission period (Mazzola et al., 2020). Prior to matching, the C-VSP cohort interestingly had higher rates of early postoperative complications and returns to the OR. The reason for this is not clear but may reflect underlying selection bias. Nevertheless, these differences were no longer significant after propensity score matching.

The operative duration was longer in POC-VSP cases by 85 minutes on average. This is consistent with the findings from Heron et al. (2023) who reported longer intraoperative VSP times for POC-VSP compared to C-VSP (123.4 vs. 102.9 minutes), although this difference did not reach statistical significance. The longer operative duration in our study may reflect a learning curve effect or the higher proportion of cases performed by registrars or fellows, as all POC-VSP patients were publicly insured. Despite this additional time, there was no significant impact on total operative staffing or operating theatre equipment costs. This challenges the widely cited assumption in the VSP health economics literature that operative time savings alone translate directly into proportionate cost savings. It also demonstrates the

importance of micro-costing economic analyses over simplified time-based cost estimates and should be considered when interpreting VSP economic evaluations in the existing literature.

The economic value of POC-VSP is directly driven by an economy-of-scale effect. We found that the initial investment and setup costs of POC-VSP may make C-VSP more viable for institutions performing fewer jaw reconstruction cases. However, as annual caseload increases, initial investments into hardware and software are distributed across more cases, reducing the cost per case until a crossover point is reached (Ismail et al., 2015). In our analysis, this point occurred at seven cases annually but increased to 17 cases annually when the additional costs required for TGA conformity assessment were included. A similar analysis was performed by Li et al. (2018), finding that the maintenance costs of their program were only offset when 27 or more cases were performed per year. These thresholds highlight the importance of leveraging POC-VSP infrastructure beyond mandibular and maxillary reconstructions for purposes such as dental rehabilitation, orthopaedics, neurosurgery, and academic research. High-volume institutions may also benefit from improved staff efficiency, workflow optimisation, and better equipment utilisation.

Despite the demonstrated cost savings, the challenges and upfront investment required to establish POC-VSP infrastructure should not be underestimated (Li et al., 2018). The facility at COBL was developed over several years and required software licensing, hardware acquisition, staff recruitment and training, dedicated space, and workflow integration – indirect costs not captured in this analysis. The advantages of C-VSP must also be acknowledged, many of which are difficult to quantify: the availability of patient-specific custom reconstruction plates, reduced burden on institutional resources, and greater research and development investment enabling more rapid innovation (Block et al., 2024).

This study has several limitations. While clinical equivalency was demonstrated for short-term reconstruction accuracy measures and postoperative outcomes, long-term outcomes, particularly relating to patient-reported outcomes for oral function, aesthetics, and quality of life, has not been formally established. Future cost-effectiveness analyses comparing C-VSP and POC-VSP should incorporate PROM data to truly establish clinical equivalency. The analysis did not capture hidden or indirect POC-VSP costs, including information technology support, software updates, future equipment upgrades, or system downtime. Group allocation was determined by insurance status rather than randomisation or clinical criteria which introduces potential selection bias as privately insured patients may systematically differ from uninsured patients in terms of socioeconomic status, health literacy, comorbidity burden, and access to pre-operative optimisation. Additionally, data on equity-relevant variables such as patient income, geographic location, ethnicity, or education level were not collected, precluding assessment of whether the financial implications of POC-VSP versus C-VSP differ across population subgroups. This is a notable limitation given the potential for differential access to surgical technologies in resource-constrained settings.

4.8 CONCLUSION

This study demonstrates that POC-VSP is substantially less expensive than C-VSP for jaw reconstruction. However, POC-VSP is characterised by an economy of scale effect with in-house setups only financially advantageous in institutions performing seven or more cases annually or 17 cases when regulatory conformity assessment costs are included. These findings support institutional investment in POC-VSP infrastructure; however, decision-makers must weigh upfront costs, regulatory requirements, and case volumes when determining feasibility.

4.9 REFERENCES

Abo Sharkh, H., & Makhoul, N. (2020). In-house surgeon-led virtual surgical planning for maxillofacial reconstruction. *Journal of Oral and Maxillofacial Surgery*, 78(4), 651–660. https://doi.org/10.1016/j.joms.2019.11.013

Argiris, A., Karamouzis, M. V., Raben, D., & Ferris, R. L. (2008). Head and neck cancer. *The Lancet,* 371(9625), 1695–1709. https://doi.org/10.1016/S0140-6736(08)60728-X

Austin, P. C. (2009). Balance diagnostics for comparing the distribution of baseline covariates between treatment groups in propensity-score matched samples. *Statistics in Medicine*, 28(25), 3083–3107. https://doi.org/10.1002/sim.3697

Austin, P. C. (2011). Optimal caliper widths for propensity-score matching when estimating differences in means and differences in proportions in observational studies. *Pharmaceutical Statistics*, 10(2), 150–161. https://doi.org/10.1002/pst.433

Block, O. M., Khromov, T., Hoene, G., Schliephake, H., & Brockmeyer, P. (2024). In-house virtual surgical planning and guided mandibular reconstruction is less precise, but more economical and time-efficient than commercial procedures. *Head & Neck*, 46(4), 871–883. https://doi.org/10.1002/hed.27642

Bolzoni, A. R., Segna, E., Beltramini, G. A., Sweed, A. H., Giannì, A. B., & Baj, A. (2020). Computer-aided design and computer-aided manufacturing versus conventional free fibula flap reconstruction in benign mandibular lesions: An Italian cost analysis. *Journal of Oral and Maxillofacial Surgery,* 78(6), 1035.e1–1035.e6. https://doi.org/10.1016/j.joms.2019.03.003

Chen, Z., Mo, S., Fan, X., You, Y., Ye, G., & Zhou, N. (2021). A meta-analysis and systematic review comparing the effectiveness of traditional and virtual surgical

planning for orthognathic surgery: Based on randomized clinical trials. *Journal of Oral and Maxillofacial Surgery*, 79(2), 471.e1–471.e19. https://doi.org/10.1016/j.joms.2020.09.005

Cognetti, D. M., Weber, R. S., & Lai, S. Y. (2008). Head and neck cancer: An evolving treatment paradigm. *Cancer,* 113(Suppl. 7), 1911–1932. https://doi.org/10.1002/cncr.23654

Drummond, M. (2015). Methods for the economic evaluation of health care programmes (4th ed.). Oxford University Press.

Dupret-Bories, A., Vergez, S., Meresse, T., Brouillet, F., & Bertrand, G. (2018). Contribution of 3D printing to mandibular reconstruction after cancer. *European Annals of Otorhinolaryngology, Head and Neck Diseases,* 135(2), 133–136. https://doi.org/10.1016/j.anorl.2017.09.007

Fatima, A., Hackman, T. G., & Wood, J. S. (2019). Cost-effectiveness analysis of virtual surgical planning in mandibular reconstruction. *Plastic and Reconstructive Surgery*, 143(4), 1185–1194. https://doi.org/10.1097/prs.0000000000005418

Ferreira, J. J., Zagalo, C. M., Oliveira, M. L., Correia, A. M., & Reis, A. R. (2014). Mandible reconstruction: History, state of the art and persistent problems. *Prosthetics and Orthotics International,* 39(3), 182–189. https://doi.org/10.1177/0309364613520032

Foley, B. D., Thayer, W. P., Honeybrook, A., McKenna, S., & Press, S. (2013). Mandibular reconstruction using computer-aided design and computer-aided manufacturing: An analysis of surgical results. *Journal of Oral and Maxillofacial Surgery,* 71(2), e111–e119. https://doi.org/10.1016/j.joms.2012.08.022

Heron, M. J., Zhu, K. J., Yusuf, C. T., Njoroge, M. W., Bhagwat, A. M., Galaria, A. I., Lopez, C. D., & Yang, R. (2023). Three-dimensional printing for craniomaxillofacial

surgery: A systematic review and meta-analysis of applications and logistical outcomes. *FACE,* 4(2), 160–170. https://doi.org/10.1177/27325016231156385

Ismail, I., Wolff, S., Gronfier, A., Mutter, D., & Swanström, L. L. (2015). A cost evaluation methodology for surgical technologies. *Surgical Endoscopy*, 29(8), 2423–2432. https://doi.org/10.1007/s00464-014-3929-4

Jeong, Y. J., Dunn, M., Manzie, T., Aung, Y. M., Cheng, K., Froggatt, C., Wykes, J., Leinkram, D., Low, T.-H., Ch'ng, S., & Clark, J. (2025). Point-of-care virtual surgical planning for jaw reconstruction: An update on the experience with 50 patients at a tertiary referral center. *Journal of Plastic, Reconstructive & Aesthetic Surgery,* 111, 182–188. https://doi.org/10.1016/j.bjps.2025.09.027

Johal, M., Ma, J. N. B., Parthasarathi, K., Dunn, M., Howes, D., Wallace, C., Palme, C. E., Leinkram, D., Cheng, K., & Clark, J. R. (2022). Institutional-based and commercial virtual surgical planning in maxillomandibular reconstruction—Comparing the digital plan and postoperative scan. *Journal of Plastic, Reconstructive & Aesthetic Surgery,* 75(4), 1399–1407. https://doi.org/10.1016/j.bjps.2021.11.075

Kumar, P., Alvi, H. A., Rao, J., Singh, B. P., Jurel, S. K., Kumar, L., & Aggarwal, H. (2013). Assessment of the quality of life in maxillectomy patients: A longitudinal study. *The Journal of Advanced Prosthodontics,* 5(1), 29–35. https://doi.org/10.4047/jap.2013.5.1.29

Li, S. S., Copeland-Halperin, L. R., Kaminsky, A. J., Li, J., Lodhi, F. K., & Miraliakbari, R. (2018). Computer-aided surgical simulation in head and neck reconstruction: A cost comparison among traditional, in-house, and commercial options. *Journal of Reconstructive Microsurgery*, 34(5), 341–347. https://doi.org/10.1055/s-0037-1621735

Mazzola, F., Smithers, F., Cheng, K., Mukherjee, P., Hubert Low, T. H., Ch'ng, S., Palme, C. E., & Clark, J. R. (2020). Time and cost-analysis of virtual surgical planning for head and neck reconstruction: A matched pair analysis. *Oral Oncology,* 100, Article 104491. https://doi.org/10.1016/j.oraloncology.2019.104491

McAllister, P., Watson, M., & Burke, E. (2018). A cost-effective, in-house, positioning and cutting guide system for orthognathic surgery. *Journal of Maxillofacial and Oral Surgery,* 17(1), 112–114. https://doi.org/10.1007/s12663-017-1067-y

McCarthy, C. M., & Cordeiro, P. G. (2010). Microvascular reconstruction of oncologic defects of the midface. *Plastic and Reconstructive Surgery,* 126(6), 1947–1959. https://doi.org/10.1097/PRS.0b013e3181f446f1

Metzler, P., Geiger, E. J., Alcon, A., Ma, X., & Steinbacher, D. M. (2014). Three-dimensional virtual surgery accuracy for free fibula mandibular reconstruction: Planned versus actual results. *Journal of Oral and Maxillofacial Surgery*, 72(12), 2601–2612. https://doi.org/10.1016/j.joms.2014.07.024

Moe, J., Foss, J., Herster, R., Powell, C., Helman, J., Ward, B. B., & VanKoevering, K. (2021). An in-house computer-aided design and computer-aided manufacturing workflow for maxillofacial free flap reconstruction is associated with a low cost and high accuracy. *Journal of Oral and Maxillofacial Surgery*, 79(1), 227–236. https://doi.org/10.1016/j.joms.2020.07.216

Mottini, M., Seyed Jafari, S. M., Shafighi, M., & Schaller, B. (2016). New approach for virtual surgical planning and mandibular reconstruction using a fibula free flap. *Oral Oncology*, 59, e6–e9. https://doi.org/10.1016/j.oraloncology.2016.06.001

Okay, D. J., Genden, E., Buchbinder, D., & Urken, M. (2001). Prosthodontic guidelines for surgical reconstruction of the maxilla: A classification system of defects. *The Journal of Prosthetic Dentistry,* 86(4), 352–363. https://doi.org/10.1067/mpr.2001.119524

Petrides, G. A., Hicks, G., Dunn, M., Froggatt, C., Wallace, C., Howes, D., Leinkram, D., Low, T.-H., Ch'ng, S., Wykes, J., Palme, C. E., & Clark, J. R. (2021). Dentoalveolar outcomes in maxillary reconstruction: A retrospective review of 85 maxillectomy reconstructions. *ANZ Journal of Surgery,* 91(7–8), 1472–1479. https://doi.org/10.1111/ans.17001

Powcharoen, W., Yang, W. F., Yan Li, K., Zhu, W., & Su, Y. X. (2019). Computer-assisted versus conventional freehand mandibular reconstruction with fibula free flap: A systematic review and meta-analysis. *Plastic and Reconstructive Surgery,* 144(6), 1417–1428. https://doi.org/10.1097/prs.0000000000006261

Probst, F. A., Liokatis, P., Mast, G., & Ehrenfeld, M. (2023). Virtual planning for mandible resection and reconstruction. *Innovative Surgical Sciences,* 8(3), 137–148. https://doi.org/10.1515/iss-2021-0045

Rathod, S., Livergant, J., Klein, J., Witterick, I., & Ringash, J. (2015). A systematic review of quality of life in head and neck cancer treated with surgery with or without adjuvant treatment. *Oral Oncology,* 51(10), 888–900. https://doi.org/10.1016/j.oraloncology.2015.07.002

Rodríguez-Arias, J. P., Tapia, B., Pampín, M. M., Morán, M. J., Gonzalez, J., Barajas, M., Del Castillo, J. L., Navarro Cuéllar, C., & Cebrian, J. L. (2022). Clinical outcomes and cost analysis of fibula free flaps: A retrospective comparison of CAD/CAM versus conventional technique. *Journal of Personalized Medicine,* 12(6), Article 930. https://doi.org/10.3390/jpm12060930

Roser, S. M., Ramachandra, S., Blair, H., Grist, W., Carlson, G. W., Christensen, A. M., Weimer, K. A., & Steed, M. B. (2010). The accuracy of virtual surgical planning in free fibula mandibular reconstruction: Comparison of planned and final results.

Journal of Oral and Maxillofacial Surgery, 68(11), 2824–2832. https://doi.org/10.1016/j.joms.2010.06.177

Salgueiro, M. I., & Stevens, M. R. (2010). Experience with the use of prebent plates for the reconstruction of mandibular defects. *Craniomaxillofacial Trauma & Reconstruction*, 3(4), 201–208. https://doi.org/10.1055/s-0030-1268520

Smithers, F. A. E., Cheng, K., Jayaram, R., Mukherjee, P., & Clark, J. R. (2018). Maxillofacial reconstruction using in-house virtual surgical planning. *ANZ Journal of Surgery*, 88(9), 907–912. https://doi.org/10.1111/ans.14353

Spaas, C., & Lenssen, O. (2019). Economic analysis of a low-cost virtual surgical planning protocol for mandibular reconstruction: A case series. *British Journal of Oral and Maxillofacial Surgery*, 57(8), 743–748. https://doi.org/10.1016/j.bjoms.2019.06.017

Tang, J. A., Rieger, J. M., & Wolfaardt, J. F. (2008). A review of functional outcomes related to prosthetic treatment after maxillary and mandibular reconstruction in patients with head and neck cancer. *The International Journal of Prosthodontics,* 21(4), 337–354.

Tarsitano, A., Del Corso, G., Ciocca, L., Scotti, R., & Marchetti, C. (2015). Mandibular reconstructions using computer-aided design/computer-aided manufacturing: A systematic review of a defect-based reconstructive algorithm. *Journal of Cranio-Maxillofacial Surgery,* 43(9), 1785–1791. https://doi.org/10.1016/j.jcms.2015.08.006

van Gemert, J. T., van Es, R. J., Rosenberg, A. J., van der Bilt, A., Koole, R., & Van Cann, E. M. (2012). Free vascularized flaps for reconstruction of the mandible: Complications, success, and dental rehabilitation. *Journal of Oral and Maxillofacial Surgery*, 70(7), 1692–1698. https://doi.org/10.1016/j.joms.2011.08.024

Williams, F. C., Hammer, D. A., Wentland, T. R., & Kim, R. Y. (2020). Immediate teeth in fibulas: Planning and digital workflow with point-of-care 3D printing. *Journal of*

Oral and Maxillofacial Surgery, 78(8), 1320–1327. https://doi.org/10.1016/j.joms.2020.04.006

Xiao, J. B., Banyi, N., Tran, K. L., & Prisman, E. (2025). Cost outcomes of virtual surgical planning in head and neck reconstruction: A systematic review. *Head & Neck,* 47(3), 1037–1057. https://doi.org/10.1002/hed.28035

Zweifel, D. F., Simon, C., Hoarau, R., Pasche, P., & Broome, M. (2015). Are virtual planning and guided surgery for head and neck reconstruction economically viable? *Journal of Oral and Maxillofacial Surgery*, 73(1), 170–175. https://doi.org/10.1016/j.joms.2014.07.038

CHAPTER 5: PRIVATE HEALTH INSURANCE REIMBURSEMENT IN COMPARISON TO THE TRUE COST OF MANDIBULAR AND MAXILLARY RECONSTRUCTION IN AN AUSTRALIAN HOSPITAL

5.1 PREFACE

This chapter addresses Aim 4 of the thesis through a cost-reimbursement analysis comparing micro-costed direct costs with private health insurance reimbursement for 61 patients. This chapter evaluates the adequacy of current funding models and identifies patient and clinical factors independently associated with unwarranted variation.

This chapter is in preparation for submission to the Medical Journal of Australia:

- Petrides, G. A., Dunn, M., Manzie, T. G., Venchiarutti, R. L., & Clark, J. R. Private health insurance reimbursement in comparison to the true cost of mandibular and maxillary reconstruction in an Australian hospital. *In preparation.*

5.2 AUTHORSHIP STATEMENT

The co-authors of the paper "Private health insurance reimbursement in comparison to the true cost of mandibular and maxillary reconstruction in an Australian hospital" confirm that George Andrew Petrides has made the following contributions:

- Conceptualisation and design of methodology.
- Collection and extraction of data.
- Analysis and interpretation of findings.
- Drafting and revising of the manuscript and critical appraisal of content.

As the primary supervisor for the candidature upon which this thesis is based, I can confirm that the above authorship attribution statement is correct.

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31st December 2025

5.3 ABSTRACT

INTRODUCTION

Jaw reconstruction is among the most resource-intensive surgical procedures, yet no Australian study has compared micro-costed direct results with private health insurance (PHI) reimbursement. This study aimed to quantify the funding gap between true costs and PHI reimbursement and identify factors contributing to any discrepancy.

METHODOLOGY

A retrospective cost-reimbursement analysis was performed for 61 patients undergoing mandibular and/or maxillary reconstruction with microvascular free tissue transfer at a tertiary referral hospital between December 2020 and June 2023. Direct costs were estimated using micro-costing methodology, with overhead costs modelled at 20-40% of total costs. Reimbursement data were obtained from hospital invoices. Univariate and multivariable regression analyses identified factors associated with reimbursement amount and funding gap.

RESULTS

The mean direct cost for the total admission (excluding overheads) was A$43,066 ± 15,772, with virtual surgical planning representing the largest component (29.2%). Mean PHI reimbursement was A$45,505 ± 18,421. Excluding overheads, 64% of cases were profitable (mean surplus +A$2,439). When overheads were included at 20–40%, 92–100% of cases became loss-making, with mean deficits ranging from A$26,066 to A$49,540. On multivariable analysis, fee-for-service reimbursement was associated with a A$10,825 larger deficit compared to per-episode models ($p = 0.003$).

CONCLUSION

This study indicates that current PHI reimbursement is inadequate for jaw reconstruction patients. If this reflects a systemic issue, hospitals providing complex reconstructive surgery may face under-recovery of costs, potentially impacting patient access to treatment. Further research across multiple institutions and funding contexts is needed to evaluate whether these findings are generalisable.

5.4 INTRODUCTION

The aim of health economic evaluations is to inform decisions around the allocation of healthcare resources to maximise efficiency and value (Mushkin, 1958). Hospital payment mechanisms may represent a critical area where substantial efficiency gains can be achieved (World Health Organisation, 2010). In Australia, private hospitals are primarily funded through private health insurance (PHI) and patient co-payments, with reimbursement intended to cover the complete cost of a patient's hospital stay (Grant & Parry, 2016). Reimbursement is typically calculated based on the Diagnosis-Related Group (DRG) assigned to the admission or linked to pre-negotiated rates for specific activities such as accommodation, operating theatre, prostheses, and consumables (Australian Government, 2025). These methods assume relatively predictable resource consumption within diagnostic and procedure categories. However, for highly complex surgical procedures with substantial variability between patients in operative approaches and the postoperative course, standard reimbursement mechanisms may inadequately capture true costs.

Mandibular and maxillary reconstruction – referred to here as jaw reconstruction – is one example of a highly complex surgical procedure. These procedures are among the most resource-intensive in surgery, demanding extended operative times, large multidisciplinary teams, postoperative intensive care admission, prolonged hospital stays, and management of high complication rates (Dassonville et al., 2017). The heterogeneity of pathology, reconstructive techniques, and patient factors results in wide cost variability that may not be adequately reflected in standardised reimbursement models (Vaikuntam et al., 2020). If reimbursement systematically under-recovers true costs, institutions providing these services face financial disincentives that may compromise service provision and, ultimately, patient

access to necessary treatment. No Australian study has directly compared the true cost of jaw reconstruction with private insurance reimbursement. The aim of this study was to compare the true costs of jaw reconstruction (based on a micro-costing methodology) with private insurance reimbursement and identify any factors contributing to unwarranted variation. It was hypothesised that PHI reimbursement for jaw reconstruction would not adequately recover the true direct costs borne by the healthcare provider, resulting in a systematic funding deficit, and that higher direct costs (driven by case complexity and complications) would be associated with a larger funding deficit.

5.5 METHODOLOGY

A retrospective cost-reimbursement analysis from the perspective of the healthcare provider was performed to compare micro-costed direct treatment costs with private insurance reimbursement for 61 patients undergoing jaw reconstruction at the Chris O'Brien Lifehouse Hospital (COBL) between December 2020 and June 2023. COBL is a not-for-profit private hospital in Sydney, Australia that serves as a referral centre for public and private patients with head and neck cancer from across New South Wales (NSW). The hospital performs the highest caseload of complex head and neck cancer surgery in NSW, and is a quaternary referral centre for jaw reconstruction. Ethics approval was obtained from St Vincent's Hospital Human Ethics Review Committee (2020/ETH02415). To our knowledge, no published study has applied a micro-costing methodology to compare true direct costs with insurance reimbursement in jaw reconstruction; the approach is presented transparently to allow replication and extension.

Patients were identified from the COBL Maxillofacial Database. Inclusion criteria were adult patients (≥18 years) who underwent mandibular and/or maxillary reconstruction with

microvascular free tissue transfer. Patients were excluded if they underwent a marginal mandibulectomy or did not undergo a microvascular free flap. Information on patient demographics, pathological features, surgical management, length of stay, postoperative complications, and return to the intensive care unit (ICU) and operating room (OR) was extracted from clinical records.

5.5.1 DETERMINATION OF COSTS

Direct costs were estimated using a retrospective micro-costing approach, capturing all resource use between admission and discharge. Costs were classified into: staffing, equipment, and overhead. Other indirect costs including productivity losses and travel costs were not examined. The micro-costing methodology is described in detail in **Chapter 3.** Briefly, individualised costing was performed for all activities during the operative and perioperative period, as outlined in **Table 1**. To ensure comparability with private insurance reimbursement, the activities included in total costs were adjusted to reflect only those components covered by the hospital invoices to insurers. For example, pathology and imaging investigations are billed separately at COBLH and were therefore excluded from this analysis.

Costs were sourced from hospital administrative databases, supplier invoices, and consultation with relevant hospital departments. As institutional overhead costs were not available at the patient level and not addressed through micro-costing, overhead rates were modelled at 20%, 30%, and 40% of total direct costs based on published estimates (Christou et al., 2022). The range reflects the substantial variability in overhead allocation across insitutitons. All costs were expressed in Australian dollars (A$). Costs were not adjusted for inflation, as both expenditure and reimbursement occurred within the same time period, minimising the risk of temporal price variation affecting the cost-reimbursement comparison.

Table 1. The activity inputs and associated costs constituting the operative and perioperative periods were subclassified into staffing costs and equipment costs.

Activity input	Operative period	Perioperative period
Staffing	Medical officers:* • Surgical consultants • Surgical fellows • Surgical registrars • Anaesthetic consultants Nursing staff: • Scrub nurses • Scout nurses • Anaesthetic nurses	Medical officers:* • Head and neck surgical team • Intensive care medical team Nursing staff: • Intensive care nurses • General ward nurses Consultations: • Allied health • Medical and surgical * Other staffing: • Food preparation • Sanitation • Porters
Equipment	Operating theatre equipment Non-disposable equipment Disposable equipment Intraoperative medications Prostheses: • Virtual surgical planning (VSP) • Dental implants • Screws and plates • Ligating clips • Venous couplers • Haemostatic agents • Other†	Investigations:* • Laboratory studies • Diagnostic imaging • Anatomical pathology Disposable equipment Medications Meals

*Not incorporated into private health insurance invoices and the total cost calculations.

†Includes eyelid weights, meshes, and bone cement.

5.5.2 PRIVATE INSURANCE REIMBURSEMENT

In Australia, PHI reimbursement remains complex with considerable variability between institutions and insurance funds. Private hospitals receive revenue primarily through PHI reimbursement and patient co-payments (Bloom, 2002). For insured patients, the hospital submits an invoice to the health fund following treatment, with the reimbursement amount determined by the contractual arrangement between the hospital and insurer.

Two principal reimbursement models exist and are used at COBL. Under a *fee-for-service* (or per-diem) model, reimbursement is based on pre-negotiated rates for discrete service components, including operating theatre time, bed-days, and prostheses. Alternatively, under a *per-episode* (or case mix-based) model, reimbursement is linked to the Australian Refined Diagnosis-Related Group (AR-DRG) assigned to the admission, with a fixed payment covering all services provided during the episode – analogous to the activity-based funding model used in Australian public hospitals. For each patient in the cohort, total reimbursement and the applicable reimbursement model were obtained from invoices issued by COBL to the relevant health funds, sourced through the hospital finance department. Reimbursement included all payments received for hospital services; Medicare Benefits Schedule (MBS) rebates for medical practitioner fees were excluded, as these are paid directly to clinicians rather than the hospital.

5.5.3 Statistical Analysis

Summary statistics were calculated for the total direct costs, PHI reimbursement amounts, and funding gap. The funding gap was calculated as PHI reimbursement amount minus total direct costs, with positive values indicating surplus and negative indicated deficit. Cases were categorised as profitable (surplus) or loss-making (deficit). The reimbursement-cost ratio was calculated as reimbursement divided by total cost. Univariate associations between key clinical, operative, and admission factors and outcomes (reimbursement amount and funding gap) were assessed using independent samples t-tests for categorical variables and Pearson correlation coefficients for continuous variables. Variables with $p < 0.05$ on univariate analysis or deemed clinically relevant were entered into multivariable linear regression models for each outcome. All analyses were performed using SPSS version 31.0 (IBM Corp, Armonk, NY).

5.6 RESULTS

5.6.1 CLINICOPATHOLOGICAL CHARACTERISTICS

In total, 61 patients with PHI underwent mandibular and/or maxillary reconstruction with a mean age at the time of surgery of 63.54 ± 16.67 years (**Table 2**). This comprised 32 males (52%) and 29 females (48%). The majority of patients were classified as American Society of Anaesthesiologists (ASA) Physical Status Classification II (n = 38). The most common indication for surgery was oral cavity squamous cell carcinoma (SCC) (n = 31).

Table 2. Clinicopathological characteristics of the cohort.

Clinicopathological characteristic	**n (%)**
Sex	
Male	32 (52)
Female	29 (48)
Age at time of surgery (years) (mean ± SD)	63.54 ± 16.67
American Society of Anaesthesiologists (ASA) Score	
I	10 (16)
II	12 (20)
III	38 (62)
IV	1 (2)
Pathology	
Oral squamous cell carcinoma (SCC)	31 (51)
Osteoradionecrosis	9 (15)
Defect following previous surgery	5 (8)
Ameloblastoma	3 (5)
Adenoid cystic carcinoma	3 (5)
Osteosarcoma	3 (5)
Other†	7 (11)
Tumour (T) category	
1	3 (5)
2	2 (3)
3	0 (0)
4	38 (62)
NA	18 (30)

† Other pathology (basal cell carcinoma = 1, mucoepidermoid carcinoma = 1, oral pemphigoid = 1, salivary duct carcinoma = 1, sarcomatoid carcinoma = 1, spindle cell rhabdomyosarcoma = 1, verrucous carcinoma = 1).

5.6.2 OPERATIVE CHARACTERISTICS

All but two cases (97%) involved both ablation and reconstruction at the time of surgery, with 13 patients (21%) having undergone radiotherapy and/or chemotherapy at some point prior to the surgery (**Table 3**). The reconstruction site was the mandible in 42 cases, the maxilla in 17 cases, and both in two cases with the majority being bony microvascular free flaps (n = 44). The fibula was the most common donor site used in 32 cases. The team approach was one-team in nine cases and two-team in 52 cases. As part of their procedure, 35 patients underwent tracheostomy, 51 patients underwent neck dissection, and 34 patients received endosseous dental implants. Virtual surgical planning (VSP) was used in 42 cases (69%), with 40 of these being outsourced to commercial providers (C-VSP) and two being performed in-house or at point-of-care (POC-VSP). The mean operative duration was 505 ± 126 minutes (range: 264–1008) and the mean anaesthetic duration was 593 ± 134 minutes (range: 307–1135).

Table 3. Surgical and perioperative characteristics of the cohort.

Surgical and hospital characteristic	n (%)	Range
Surgery type		
Ablation and reconstruction	59 (97)	
Reconstruction	2 (3)	
Previous radiotherapy and/or chemotherapy	13 (21)	
Reconstruction site		
Mandible	42 (69)	
Maxilla	17 (28)	
Mandible and maxilla	2 (3)	
Reconstruction type		
Fibula free flap	32 (52)	
Scapula free flap	9 (15)	
Anterolateral thigh (ALT) flap	8 (13)	
Radial forearm free flap	8 (13)	
Ulna flap	2 (3)	
Radius (bone) flap	1 (2)	
Deep circumflex iliac artery (DCIA) flap	1 (2)	
Team approach		
One team	9 (15)	
Two team	52 (85)	
Operative adjuncts		
Tracheostomy	35 (41)	
Neck dissection	51 (84)	
Virtual surgical planning (VSP)	42 (69)	
Endosseous dental implants	34 (56)	
Mean duration (minutes)		
Operative duration (mean ± SD)	505 ± 126	264 – 1008
Anaesthetic duration (mean ± SD)	593 ± 134	307 – 1135
Mean length of admission (days)	19 ± 14	7 – 96
Intensive care unit (ICU) (mean ± SD)	3 ± 2	2 – 10
General ward (mean ± SD)	16 ± 14	1 – 94
Complication during hospital admission (Clavien-Dindo)	35 (57)	
I	2 (3)	
II	12 (20)	
IIIa	2 (3)	
IIIb	14 (23)	
IVa	4 (7)	
IVb	0 (0)	
V	1 (2)	
Return to OR (at least one)	17 (28)	
Return to ICU	8 (13)	

OR: operating room. ICU: intensive care unit.

5.6.3 PERIOPERATIVE CHARACTERISTICS

The mean length of hospital admission was 19 ± 14 days (range 7 – 96), comprising 3 ± 2 days in the intensive care unit (ICU) (range 2 – 10) and 16 ± 14 days (range 1 – 94) on the general ward. During their hospital stay, 35 patients (57%) experienced at least one postoperative complication, with most being Clavien-Dindo IIIb (n = 14). There were 17 patients (28%) who returned to the OR at least once, with the most common reason being wound debridement (n = 7). Eight patients (13%) were readmitted to the ICU, with the most common indication being free flap compromise (n = 2).

5.6.4 COSTS OF JAW RECONSTRUCTION COMPARED TO PRIVATE HEALTH

The mean true cost for the activities covered by PHI reimbursement (excluding overheads) was $43,066 ± 15,772 (range $18,039 – $74,278). This comprised $24,035 ± 11,405 (55.8%) from the operative period and $19,031 ± 9,753 (44.2%) from the perioperative admission period (**Table 4**). The main costs in the operative period were VSP at $12,586 ± 10,411 (52.4%), disposable equipment at $3,515 ± 1,088 (14.6%), prostheses at $3,258 ± 1,903 (13.6%), and non-disposable equipment at $2,486 ± 659 (10.3%). For the perioperative admission period, the primary cost was hospital staffing and disposable equipment at $17,656 ± 9,116 (92.8%).

All patients were privately insured, with the reimbursement model being fee-for-service in 35 cases (57%) and per-episode in 26 cases (43%). The mean reimbursement amount was $45,5045 ± 18,421 (range $14,918 – $93,514). Excluding overheads, this reimbursement amount led to a mean funding surplus of +$2,439 ± 15,607 (range –$45,874 – +$42,253), a mean reimbursement-cost ratio of 1.10 ± 0.34 (range 0.32 – 2.01), and 39 encounters (64%) being classified as profitable (**Table 5**). A range of values (20%, 30%, and 40% of the total cost) for overhead costs was then modelled. The mean funding deficit progressed from –

$26,066 ± 20,322 at 20%, to –$36,292 ± 22,726 at 30%, and to –$49,540 ± 26,174 at 40% of total costs being overheads. When overheads comprised 40% of total cost, 100% of encounters were classified as loss-making.

On univariate analysis, several factors were significantly associated with reimbursement amount **(Table 6).** These included patients who underwent bony free flaps (+$21,645, $p < 0.001$), had a tracheostomy (+$15,297, $p = 0.001$), received VSP (+$18,399, $p < 0.001$), experienced a postoperative complication (+$14,521, $p = 0.002$), returned to the OR (+$11,507, $p = 0.029$), and returned to the ICU (+$26,749, $p < 0.001$). Reimbursement amount was also positively correlated with operative duration ($r = 0.331$, $p = 0.009$).

Fewer variables were significantly associated with the funding gap. The only significant categorical variables were the ASA classification (ASA I = $4,925 surplus vs. ASA IV = $45,874 deficit, $p = 0.004$) and reimbursement model (fee-for-service = $1,179 deficit vs. per-episode = $7,308 surplus, $p = 0.036$). Length of admission was negatively correlated with funding gap ($r = –0.321$, $p = 0.012$).

Table 4. Mean cost and proportion of total costs for all activities during the hospital admission

Activity	Mean cost (A$)	Range (A$)	SD	95% CI	Proportion of total cost (%)
Operative period	24,035	6,961 – 49,374	11,405	21,114 – 26,956	55.8
Virtual surgical planning (VSP)	12,586	0 – 36,162	10,411	9,920 – 15,253	29.2
Disposable equipment	3,515	2,596 – 8,856	1,088	3,236 – 3,793	8.2
Prostheses	3,258	742 – 7,399	1,903	2,771 – 3,745	7.6
Dental implants	1,604	0 – 5,545	1,629	1,186 – 2,021	3.7
Screws and plates	210	0 – 1,375	685	35 – 386	0.5
Ligating clips	384	38 – 2,025	481	260 – 507	0.9
Venous couplers	909	0 – 1,827	345	820 – 997	2.1
Haemostatic agents	130	0 – 1,205	248	67 – 194	0.3
Other†	22	0 – 835	32	–10 – 54	0.1
Non-disposable equipment	2,486	1,368 – 4,394	659	2,318 – 2,655	5.8
Staffing	1,707	826 – 3,963	551	1,566 – 1,849	4.0
Intraoperative medications	252	48 – 870	235	191 – 312	0.6
Operating room equipment	231	110 – 514	72	212 – 249	0.5
Perioperative period	19,031	8,767 – 59,981	9,753	16,533 – 21,529	44.2
Staffing and disposable equipment	17,656	8,098 – 58,183	9,116	15,321 – 19,990	41.0
Consultations	860	249 – 2,086	487	735 – 984	2.0
Medications	516	64 – 2,068	459	398 – 634	1.2
Total admission	43,066	18,039 – 74,278	15,772	39,027 – 47,106	100.0

†Includes eyelid weights, meshes, and bone cement. Note: VSP planning and surgical guide fabrication are pre-operative activities; they are grouped with operative prosthesis costs for consistency with the micro-costing methodology in Chapter 3, but future studies will consider a pre-operative cost category to better reflect the care pathway.

Table 5. The mean total cost, funding gap, reimbursement-cost ratio, and classification of the cohort based on varying levels of overhead cost modelling. The percentages represent the proportion of overheads contributed to the total cost.

Overheads (% of total cost)	**0%**	**20%**	**30%**	**40%**
Total cost ($A)				
Mean (SD)	43,066 ± 15,643	71,571 ± 23,858	81,797 ± 27,267	95,046 ± 31,684
Range	18,039 – 74,278	31,866 – 118,526	36,418 – 135,461	42,317 – 157,403
Funding gap ($A)				
Mean (SD)	+2,439 ± 15,607	–26,066 ± 20,322	–36,292 ± 22,726	–49,540 ± 26,174
Range	–45,874 – +42,253	–97,030 – 15,082	–113,965 – +3,876	–135,907 – –9,494
Reimbursement-cost ratio				
Mean (SD)	1.10 ± 0.34	0.65 ± 0.20	0.57 ± 0.18	0.49 ± 0.15
Range	0.32 – 2.01	0.18 – 1.19	0.16 – 1.04	0.14 – 0.90
Classification (n (%))				
Profitable	39 (64)	5 (8)	1 (2)	0 (0)
Loss-making	22 (36)	56 (92)	60 (98)	61 (100)

Table 6. Univariate associations between clinical and operative variables and private health insurance reimbursement amount and funding gap (surplus/deficit).

Variable	N	Reimbursement (A$)	*p*-value	Funding gap (surplus/deficit) (A$)	*p*-value
Categorical variables		**Mean ± SD**		**Mean ± SD**	
Hypertension					
Yes	20	46,669 ± 22,096	0.736	4,995 ± 18,367	0.380
No	41	44,937 ± 16,870		1,191 ± 14,365	
Vasculopathy					
Yes	9	47,346 ± 25,420	0.812	–311 ± 22,666	0.575
No	52	45,186 ± 17,431		2,914 ± 14,463	
Current smoker					
Yes	18	47,606 ± 23,795	0.631	1,050 ± 18,311	0.659
No	43	44,626 ± 16,155		3,020 ± 14,726	
Diabetes mellitus					
Yes	5	48,232 ± 11,277	0.735	–5,135 ± 10,822	0.265
No	56	45,261 ± 19,141		3,115 ± 15,998	
ASA Classification					
I	10	40,232 ± 19,350	0.429	4,925 ± 13,492	**0.004**
II	12	47,123 ± 17,260		–3,469 ± 17,888	
III	38	47,014 ± 18,803		4,921 ± 13,407	
IV	1	21,496 ± 0		–45,874 ± 0	
Bony free flap					
Yes	44	51,535 ± 17,936	**<0.001**	2,796 ± 16,454	0.778
No	17	29,890 ± 8,8395		1,514 ± 14,133	
Tracheostomy					
Yes	35	52,025 ± 19,324	**0.001**	3,426 ± 17,938	0.553
No	26	36,728 ± 14,436		1,109 ± 12,390	

Variable	N	Reimbursement (A$)	*p*-value	Funding gap (surplus/deficit) (A$)	*p*-value
Neck dissection					
Yes	51	46,848 ± 18,282	0.205	2,281 ± 14,707	0.862
No	10	38,654 ± 19,513		3,242 ± 21,173	
VSP					
Yes	42	51,236 ± 17,275	**<0.001**	1,843 ± 16,476	0.664
No	19	32,837 ± 14,975		3,755 ± 14,299	
Endosseous dental implants					
Yes	34	48,810 ± 15,839	0.120	1,831 ± 15,285	0.738
No	27	41,344 ± 21,106		3,204 ± 16,548	
Postoperative complication					
Yes	35	51,694 ± 18,489	**0.002**	1,601 ± 17.881	0.634
No	26	37,173 ± 15,405		3,566 ± 12,536	
Return to the OR					
Yes	17	53,805 ± 15,079	**0.029**	–1,320 ± 18,283	0.250
No	44	42,298 ± 18,948		3,891 ± 14,608	
Return to ICU					
Yes	8	68,746 ± 16,421	**<0.001**	11,050 ± 16,247	0.097
No	53	41,997 ± 16,314		1,139 ± 15,397	
Reimbursement model					
Fee-for-service	35	43,140 ± 17,315	0.252	–1,179 ± 12,772	**0.036**
Per-episode	26	48,689 ± 20,047		7,308 ± 18,152	
Continuous variables		**r**		**r**	
Age at time of surgery (years)	61	0.073	0.574	–0.061	0.639
Operative duration (minutes)	61	0.331	**0.009**	–0.052	0.693
Length of admission	61	0.162	0.212	–0.321	**0.012**

Values are mean ± SD for categorical variables and Pearson correlation coefficient (r) for continuous variables. P-values derived from independent samples t-test (categorical variables) and Pearson correlation (continuous variables). Bold indicates statistical significance ($p < 0.05$). Funding gap calculated as reimbursement minus total direct costs; positive values indicate surplus, negative values indicate deficit. ICU: intensive care unit; OR: operating room; VSP: virtual surgical planning.

On multivariable regression, the model with reimbursement as the dependant variable explained 46% of variance (adjusted $R^2 = 0.464$, $F(7,53) = 8.41$, $p < 0.001$) (**Table 7**). Return to ICU was the only independent predictor, associated with an increase of $20,253.14 (95% CI: 9,023.80 – 31,482.47, $p < 0.001$). Bony free flap, tracheostomy, VSP, postoperative complications, return to the OR, and operative duration were not independently associated with reimbursement amount following adjustment. The model with funding gap model as the dependent variable explained 31% of variance (adjusted $R^2 = 0.307$, $F(7,53) = 4.80$, $p < 0.001$). An ASA Classification IV ($51,526.38 deficit, 95% CI: –94,623.53 – –8,429.22, $p = 0.020$), return to ICU ($10,723.45 surplus, 95% CI: 201.27 – 21,245.63, $p = 0.046$), and fee-for-service reimbursement model ($10,825.03 deficit, 95% CI: –17,787.51 – –3,862.57, $p = 0.003$) were statistically significant. Length of admission and VSP were not independently associated with the funding gap after adjustment.

Table 7. Multivariable linear regression analysis of factors associated with private health insurance reimbursement amount and funding gap.

Variable	B	95% CI	*p*-value
Model 1: Reimbursement amount as the dependent variable			
Bony free flap (yes vs. no)	8,104	–5,203 – 21,411	0.227
Tracheostomy (yes vs. no)	3,520	–4,637 – 11,678	0.391
VSP (yes vs. no)	9,631	–2,828 – 22,090	0.127
Operative duration (per minute)	18	–14 – 50	0.270
Return to the OR (yes vs. no)	–2,324	–11,919 – 7,272	0.629
Return to ICU (yes vs. no)	20,253	9,024 – 31,482	**<0.001**
Postoperative complication	6,190	–2,732 – 15,112	0.170
Model 2: Funding gap as the dependant variable			
ASA Classification (reference: ASA I)			
ASA II	–8.170	–20,322 – 3,982	0.183
ASA III	2,475	–7,279 – 12,230	0.613
ASA IV	–51,526	–94,624 – –8,429	**0.020**
VSP (yes vs. no)	–3,419	–11,037 – 4,198	0.372
Return to ICU (yes vs. no)	10,723	201 – 21,246	**0.046**
Length of admission (days)	–63	–442 – 316	0.740
Reimbursement model (fee-for-service vs. per-episode)	–10,825	–17,788 – –3,863	**0.003**

B = unstandardised regression coefficient representing change in outcome (AUD$) per unit change in predictor. 95% CI = 95% confidence interval. Funding gap calculated as reimbursement minus total direct costs; positive values indicate surplus, negative values indicate deficit. ASA: American Society of Anaesthesiologists; ICU: intensive care unit; OR: operating room; VSP: virtual surgical planning.

5.7 DISCUSSION

This is the first Australian study to compare micro-costed direct costs of jaw reconstruction with PHI reimbursement. When considering direct costs alone, PHI reimbursement appeared adequate, with a mean funding surplus of $2,439 and 64% of cases classified as profitable. However, this apparent profitability is contingent on excluding institutional overheads. Once overheads were modelled at 20% to 40% of total costs, the funding position reversed substantially: 92% to 100% of cases became loss-making with mean deficits ranging from $26,066 to $49,540. If systematic cost under-recovery exists, institutions providing these services may face financial disincentives that could ultimately compromise patient access to necessary treatment.

Overhead costs represent a substantial component of total admission costs and include utilities, laundry, and wages for non-clinical personnel such as administrative, security, and cleaning staff (Childers & Maggard-Gibbons, 2018; Raft et al., 2015). Despite this, overheads are historically poorly characterised in surgical costing studies, likely because of methodological challenges and because they are often assumed not to differ substantially between patients or procedures (Christou et al., 2022; Drummond, 2015; Potter et al., 2020). In the present study, institutional overhead rates were not available at the patient level, so we modelled overheads using percentages reported in the literature (20-40% of total costs) (Christou et al., 2022; Oostenbrink et al., 2002; St-Hilaire & Crépeau, 2000). Even at the lower end of these estimates, PHI reimbursement was insufficient to cover the full cost of admission for the majority of jaw reconstruction patients. Whilst hospital overhead costs should be recoverable through reimbursement, the difficulty in accurately apportioning these costs to individual patients may explain why they remain inadequately captured in current funding models.

For reimbursement to be adequate, funding models must appropriately adjust for the cost-drivers encountered during jaw reconstruction admissions. Excluding overhead costs, our findings suggest that current PHI reimbursement generally accounts for most complexity indicators shown to increase costs – including bony free flap reconstruction, tracheostomy, operative duration, postoperative complications, and return to the OR – with higher absolute reimbursement amounts but no significant difference in funding gap (Chang et al., 2017; Gourin et al., 2011; Gourin & Frick, 2012; Yang et al., 2019). This is expected given fee-for-service models directly reimburse for cost-drivers like additional bed days and theatre time, while per-episode models typically use AR-DRG classification, which adjusts for clinical complexity based on resource use (Authority, 2025; Bloom, 2002). It is important to note that a high proportion of patients in our cohort experienced a return to the OR compared to the previous literature, which may represent the complexity of cases performed at COBL (Jones et al, 2007). However, return to ICU was the only variable independently associated with reimbursement after multivariable adjustment, suggesting it may serve as a composite marker of case complexity, capturing the effects of these other variables.

In this cohort, VSP represented the largest single cost component at 29.2% of total direct admission costs. Although recent studies demonstrate that the downstream efficiencies of VSP – including reduced operative time and length of stay – largely offset the initial investment, the substantial upfront costs remain a potential barrier for private institutions (Bolzoni et al., 2020; Chen et al., 2021; Mazzola et al., 2020; Rodríguez-Arias et al., 2022; Tarsitano et al., 2016; Toto et al., 2015; Zweifel et al., 2015). Our findings indicate that current PHI models adequately reimburse for VSP, with no significant association with funding gap on either univariate or multivariable analysis. However, the future of VSP funding is uncertain.

The Medical Devices and Human Tissue Advisory Committee (MDHTAC) is currently conducting a post-listing review with preliminary findings proposing delisting biomodels and surgical guides from the Prescribed List, citing insufficient economic evidence (Australian Government, 2023). If VSP items are delisted, the cost structure for privately insured jaw reconstruction patients would change significantly, with this cost shifting from a listed prosthesis expense to an out-of-pocket or institutional cost. It is critical that such decisions be informed by comprehensive economic evaluations to avoid inappropriate restrictions on access to VSP for jaw reconstruction patients.

The reimbursement model was independently associated with the funding gap, with fee-for-service patients demonstrating a deficit $10,825 larger on average than per-episode patients. This may reflect limitations in fee-for-service models: itemised rates may be negotiated below true cost, certain activities may not be captured as billable items, and payments do not adjust for case complexity Hanning, 2005). PHI funds have increasingly transitioned to per-episode or DRG models (Bloom, 2002). Per-episode models address some of these limitations by providing a bundled payment adjusted for clinical complexity, with reversion to fee-for-service beyond a maximum length of stay trim point – particularly relevant for jaw reconstruction patients, where admissions reached 96 days in our cohort (Rankin, 2018). Nevertheless, when overhead costs were included, both models failed to recover true costs, suggesting that current reimbursement – regardless of model – does not adequately capture the resource-intensive nature of jaw reconstruction in private institutions.

This study has several limitations. As a single-centre study at a tertiary referral hospital, findings may not be generalisable to lower-volume centres. Reimbursement arrangements at other private providers may differ significantly. The funding model for private healthcare in

Australia is complex, with other sources of reimbursement including government subsidisation not captured in this study. Micro-costing accuracy is dependent on the quality of resource documentation in clinical and administrative records. Institutional overhead rates were not available at the patient level and were therefore modelled using published estimates, introducing uncertainty. Pathology and imaging costs were excluded to ensure comparability with PHI invoice components these are billed separately at our institutions.

5.8 CONCLUSION

These findings suggest that current PHI reimbursement inadequately covers the true cost of jaw reconstruction, particularly once institutional overheads are considered. Fee-for-service reimbursement was associated with larger funding deficits than per-episode models. These findings have implications for hospitals providing complex reconstructive surgery and warrant further investigation across multiple institutions.

5.9 REFERENCES

Australian Government. (2023). Review of surgical guides and biomodels currently listed on the Prostheses List. Australian Government Department of Health and Aged Care. https://www.health.gov.au/resources/publications/prostheses-list-post-listing-review-consultants-report

Australian Government. (2025). Out of pocket costs. Private Health Insurance Ombudsman. https://www.privatehealth.gov.au/health_insurance/howitworks/out_of_pocket.htm

Bloom, A. L. (2002). The funding of private hospitals in Australia. *Australian Health Review*, 25(1), 19–39. https://doi.org/10.1071/AH020019

Bolzoni, A. R., Segna, E., Beltramini, G. A., Sweed, A. H., Giannì, A. B., & Baj, A. (2020). Computer-aided design and computer-aided manufacturing versus conventional free fibula flap reconstruction in benign mandibular lesions: An Italian cost analysis. *Journal of Oral and Maxillofacial Surgery,* 78(6), 1035.e1–1035.e6. https://doi.org/10.1016/j.joms.2019.03.003

Chang, C. S., Chu, M. W., Nelson, J. A., Basta, M., Gerety, P., Kanchwala, S. K., & Wu, L. C. (2017). Complications and cost analysis of intraoperative arterial complications in head and neck free flap reconstruction. *Journal of Reconstructive Microsurgery*, 33(5), 318–327. https://doi.org/10.1055/s-0037-1598618

Chen, Z., Mo, S., Fan, X., You, Y., Ye, G., & Zhou, N. (2021). A meta-analysis and systematic review comparing the effectiveness of traditional and virtual surgical planning for orthognathic surgery: Based on randomized clinical trials. Journal of *Oral and Maxillofacial Surgery,* 79(2), 471.e1–471.e19. https://doi.org/10.1016/j.joms.2020.09.005

Childers, C. P., & Maggard-Gibbons, M. (2018). Understanding costs of care in the operating room. *JAMA Surgery*, 153(4), Article e176233. https://doi.org/10.1001/jamasurg.2017.6233

Christou, C. D., Athanasiadou, E. C., Tooulias, A. I., Tzamalis, A., & Tsoulfas, G. (2022). The process of estimating the cost of surgery: Providing a practical framework for surgeons. *The International Journal of Health Planning and Management,* 37(4), 1926–1940. https://doi.org/10.1002/hpm.3431

Dassonville, O., Bozec, A., Château, Y., Reyt, E., Devauchelle, B., Louis, M. Y., Breton, P., Julieron, M., Yachouh, J., Mallet, Y., Sarini, J., Dolivet, G., Schiappa, R., Gal, J.,

Orlanducci, M. H., Poissonnet, G., & Chamorey, E. (2017). Multicenter prospective micro-costing study evaluating mandibular free-flap reconstruction. European *Archives of Oto-Rhino-Laryngology,* 274(2), 1103–1111. https://doi.org/10.1007/s00405-016-4360-3

Drummond, M. (2015). Methods for the economic evaluation of health care programmes (4th ed.). Oxford University Press.

Gourin, C. G., & Frick, K. D. (2012). National trends in oropharyngeal cancer surgery and the effect of surgeon and hospital volume on short-term outcomes and cost of care. *The Laryngoscope*, 122(3), 543–551. https://doi.org/10.1002/lary.22447

Gourin, C. G., Forastiere, A. A., Sanguineti, G., Marur, S., Koch, W. M., & Bristow, R. E. (2011). Impact of surgeon and hospital volume on short-term outcomes and cost of oropharyngeal cancer surgical care. *The Laryngoscope*, 121(4), 746–752. https://doi.org/10.1002/lary.21456

Grant, J., & Parry, Y. (2016). Understanding the Australian health care system. In E. Willis, L. Reynolds, & H. Keleher (Eds.), Understanding the Australian health care system (3rd ed.). Elsevier.

Hanning, B. W. T. (2005). Combining DRGs and per diem payments in the private sector: The Equitable Payment Model. *Australian Health Review,* 29(1), 80–86. https://doi.org/10.1071/ah050080

Independent Health and Aged Care Pricing Authority. (2025). Australian Refined Diagnosis Related Groups Version 12.0. https://www.ihacpa.gov.au/sites/default/files/2025-07/ar-drg_v12.0_final_report.pdf

Jones, N. F., Jarrahy, R., Song, J. I., Kaufman, M. R., & Markowitz, B. (2007). Postoperative medical complications—not microsurgical complications—negatively influence the morbidity, mortality, and true costs after microsurgical reconstruction for head and

neck cancer. *Plastic and Reconstructive Surgery,* 119(7), 2053–2060. https://doi.org/10.1097/01.prs.0000260591.82762.b5

Mazzola, F., Smithers, F., Cheng, K., Mukherjee, P., Hubert Low, T. H., Ch'ng, S., Palme, C. E., & Clark, J. R. (2020). Time and cost-analysis of virtual surgical planning for head and neck reconstruction: A matched pair analysis. *Oral Oncology,* 100, Article 104491. https://doi.org/10.1016/j.oraloncology.2019.104491

Mushkin, S. J. (1958). Toward a definition of health economics. Public Health Reports, 73(9), 785. https://doi.org/10.2307/4590242

Oostenbrink, J. B., Koopmanschap, M. A., & Rutten, F. F. (2002). Standardisation of costs: The Dutch Manual for Costing in economic evaluations. *PharmacoEconomics,* 20(7), 443–454. https://doi.org/10.2165/00019053-200220070-00002

Potter, S., Davies, C., Davies, G., Rice, C., & Hollingworth, W. (2020). The use of micro-costing in economic analyses of surgical interventions: A systematic review. *Health Economics Review,* 10(1), Article 3. https://doi.org/10.1186/s13561-020-0260-8

Raft, J., Millet, F., & Meistelman, C. (2015). Example of cost calculations for an operating room and a post-anaesthesia care unit. *Anaesthesia Critical Care & Pain Medicine,* 34(4), 211–215. https://doi.org/10.1016/j.accpm.2014.11.002

Rankin, D. (2018). Private health and insurance. M. Kron & A. Mackay (Eds.), Textbook of medical administration and leadership (pp. 127–152). Springer.

Rodríguez-Arias, J. P., Tapia, B., Pampín, M. M., Morán, M. J., Gonzalez, J., Barajas, M., Del Castillo, J. L., Navarro Cuéllar, C., & Cebrian, J. L. (2022). Clinical outcomes and cost analysis of fibula free flaps: A retrospective comparison of CAD/CAM versus conventional technique. *Journal of Personalized Medicine,* 12(6), Article 930. https://doi.org/10.3390/jpm12060930

St-Hilaire, C., & Crépeau, P. K. (2000). Hospital and unit cost allocation methods. *Healthcare Management Forum*, 13(2), 12–32. https://doi.org/10.1016/s0840-4704(10)60742-9

Tarsitano, A., Battaglia, S., Crimi, S., Ciocca, L., Scotti, R., & Marchetti, C. (2016). Is a computer-assisted design and computer-assisted manufacturing method for mandibular reconstruction economically viable? *Journal of Cranio-Maxillofacial Surgery,* 44(7), 795–799. https://doi.org/10.1016/j.jcms.2016.04.003

Toto, J. M., Chang, E. I., Agag, R., Devarajan, K., Patel, S. A., & Topham, N. S. (2015). Improved operative efficiency of free fibula flap mandible reconstruction with patient-specific, computer-guided preoperative planning. *Head & Neck*, 37(11), 1660–1664. https://doi.org/10.1002/hed.23815

Vaikuntam, B. P., Middleton, J. W., McElduff, P., Walsh, J., Pearse, J., Connelly, L., & Sharwood, L. N. (2020). Gap in funding for specialist hospitals treating patients with traumatic spinal cord injury under an activity-based funding model in New South Wales, Australia. *Australian Health Review*, 44(3), 365–376. https://doi.org/10.1071/ah19083

World Health Organization. (2010). The world health report: Health systems financing: The path to universal coverage. https://www.who.int/publications/i/item/9789241564021

Yang, Y., Li, P. J., Shuai, T., Wang, Y., Mao, C., Yu, G. Y., Guo, C. B., & Peng, X. (2019). Cost analysis of oral and maxillofacial free flap reconstruction for patients at an institution in China. *International Journal of Oral and Maxillofacial Surgery,* 48(5), 590–596. https://doi.org/10.1016/j.ijom.2018.10.020

Zweifel, D. F., Simon, C., Hoarau, R., Pasche, P., & Broome, M. (2015). Are virtual planning and guided surgery for head and neck reconstruction economically viable? *Journal of*

Oral and Maxillofacial Surgery, 73(1), 170–175.

https://doi.org/10.1016/j.joms.2014.07.038

CHAPTER 6: MAPPING FACE-Q TO EQ-5D-5L IN A COHORT OF MANDIBULAR AND MAXILLARY RECONSTRUCTION PATIENTS TO FACILITATE COST-UTILITY ANALYSIS

6.1 PREFACE

This chapter addresses Aim 5 of the thesis through a mapping study deriving EQ-5D-5L health utility values from FACE-Q Head and Neck Cancer (FACE-Q) responses. Using data from 181 patients, this chapter develops and validates a mapping algorithm that enables quality-adjusted life year calculation from existing FACE-Q datasets, facilitating future cost-utility analyses of jaw reconstruction interventions.

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6.2 AUTHORSHIP STATEMENT

The co-authors of the paper "Mapping FACE-Q to EQ-5D in a cohort of mandibular and maxillary reconstruction patients to facilitate cost-utility analysis" confirm that George Andrew Petrides has made the following contributions:

- Conceptualisation and design of methodology.
- Interpretation of findings.
- Drafting and revising of the manuscript and critical appraisal of content.

As the primary supervisor for the candidature upon which this thesis is based, I can confirm that the above authorship attribution statement is correct.

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31st December 2025

6.3 ABSTRACT

INTRODUCTION

Jaw reconstruction using micro-vascular free tissue transfer is resource-intensive, yet economic evaluations remain limited. The FACE-Q Head and Neck Cancer (FACE-Q) effectively captures disease-specific outcomes but cannot be used directly in cost-utility analyses. Mapping to generic preference-based instruments enables health utility derivation from existing datasets. The aim of this study was to map FACE-Q to the EQ-5D-5L in a cohort of jaw reconstruction patients to facilitate future economic evaluations.

METHODOLOGY

Patients undergoing jaw reconstruction at a single institution completed FACE-Q and EQ-5D-5L questionnaires at baseline and postoperatively. EQ-5D-5L utilities were derived using Australian preference weights. Four regression frameworks were evaluated: ordinary least squares (OLS), Tobit, censored least absolute deviations (CLAD), and beta regression. Model performance was assessed using root mean square error (RMSE), mean absolute error (MAE), and information criteria.

RESULTS

The analysis included 181 patients (mean age 62.6 years) with 270 paired observations. Mean EQ-5D-5L utility was 0.868. Beta regression demonstrated superior predictive performance (RMSE = 0.131; MAE = 0.084; AIC = −647.3) and respected the bounded distribution of utility data. Significant predictors included oral competence, speaking, smiling, salivation, and worry. Meaningful interactions were identified between functional and psychosocial domains, indicating these do not operate independently in determining health utility.

CONCLUSION

This is the first study to map FACE-Q to EQ-5D-5L. Beta regression was the optimal framework due to its ability to accommodate the bounded, right-skewed distribution of health utility data. This mapping algorithm enables quality-adjusted life year calculation and cost-utility analyses from existing FACE-Q datasets.

6.4 INTRODUCTION

Surgical resection is the primary treatment for many pathologies affecting the mandible and maxilla. Removing a segment of the jaw inevitably results in impairments in appearance, speech, swallowing, and mastication (Rathod et al., 2015; Umino et al., 1998). Clinicians are, therefore, focused on maximising patients' postoperative aesthetics, function, and health-related quality of life (HRQoL). Mandibular and maxillary reconstruction using microvascular free tissue transfer – referred to here as jaw reconstruction – aims to restore patients as closely as possible to their pre-morbid status, thereby improving HRQoL (Abo Sharkh & Makhoul, 2020; Petrides et al., 2021; Petrides et al., 2022; Shaw et al., 2005). While the literature demonstrates significant HRQoL benefits from these procedures, their economic implications remain poorly understood (Petrides et al., 2022). Jaw reconstruction is inherently costly, particularly when incorporating newer treatment modalities such as virtual surgical planning (VSP) and immediate dental rehabilitation (Dassonville et al., 2017; Gao et al., 2017; Ismail et al., 2015; Jones et al., 2007; Setälä et al., 2009). Thus, some institutions still advocate for conventional free-hand (non-VSP) free-flap reconstruction, particularly in resource-constrained settings (Chen et al., 2021; Trivedi et al., 2013).

Given the profound impact of head and neck cancer on all domains of HRQoL, numerous disease-specific HRQoL measures have been developed and validated. The most commonly reported measures in the literature have been the European Organization for Research and Treatment of Cancer Questionnaire Head and Neck Module (QLQ-H&N35) (Bjordal et al., 1999) and the University of Washington Quality of Life Questionnaire (Weymuller Jr et al., 2001) (UWQOL). However, these measures are limited by their lack of emphasis on functional domains relevant to patients undergoing jaw reconstruction (Cracchiolo et al., 2019; Ojo et al.,

2012). The recently validated FACE-Q Head and Neck Cancer Module (FACE-Q) was specifically developed to address these specific functional limitations (Tonsbeek et al., 2024; Venchiarutti et al., 2023).

While FACE-Q and other disease-specific measures effectively assess psychosocial and functional outcomes, they cannot be utilised in economic evaluations comparing different programs or treatment strategies for differing pathologies (Drummond, 2015; McTaggart-Cowan et al., 2013). Economic evaluation requires generic preference-based instruments that assess broad dimensions potentially affected by any disease, including physical function, mental well-being, social function, and pain. The EQ-5D-5L is one of the most widely recognised generic preference-based instruments (Brauer et al., 2006). These measures enable standardised calculation of cost per quality-adjusted life year (QALY), forming the foundation for cost-utility analyses. Mapping methodology allows health state preference values to be predicted when preference-based measures were not included in clinical studies, thereby enabling disease-specific instruments to contribute to economic evaluations. Although mapping has been performed for numerous disease-specific measures, no such analysis exists for FACE-Q (McTaggart-Cowan et al., 2013; Rowen et al., 2009). Therefore, this study aims to map FACE-Q to the EQ-5D-5L on a cohort of jaw reconstruction patients.

6.5 METHODOLOGY

6.5.1 PATIENT POPULATION AND SETTING

Data was collected from the Chris O'Brien Lifehouse Hospital (COBL) Integrated Prosthetics & Reconstruction Maxillofacial Database. This study was conducted under the same ethics approval as the micro-costing analysis (Protocol No. 2020/ETH02415), which covered the

collection and analysis of patient-reported outcome data in jaw reconstruction patients. COBL is a not-for-profit private hospital in Sydney, Australia that serves as a referral centre for public and private patients with head and neck cancer from across New South Wales (NSW). The hospital performs the highest caseload of complex head and neck cancer surgery in NSW, and is a quaternary referral centre for jaw reconstruction. This database comprises all patients undergoing jaw reconstruction at COBL and includes details on patient demographics, clinicopathological characteristics, and treatment modalities. For this study, patients included those undergoing operations between July 2024 and June 2025.

6.5.2 INSTRUMENTS

The FACE-Q module consists of 14 independently functioning scales measuring healthcare experience and treatment outcomes following head and neck cancer procedures (Cracchiolo et al., 2019). All 14 scales were used in this study: the facial appearance scale included face overall; facial function scales included eating and drinking, oral competence, salivation, smiling, speaking, swallowing; quality of life scales included appearance distress, cancer worry, drooling distress, eating distress, smiling distress, and speaking distress; and the experience of care scale included satisfaction with information. The raw scores for items that make up each scale are added to provide a total score and converted to 0 to 100 with higher scores for all scales but one (cancer worry) reflecting a better outcome.

The EQ-5D-5L is a generic preference-based instrument that defines health in terms of five dimensions: mobility, self-care, usual activities, pain/discomfort, and anxiety/depression (Brooks, 1996). It is a modification to the original EQ-5D, changing three to five levels of severity in each of the existing five EQ-5D dimensions (Herdman et al., 2011). Participants are

asked to select one of the five levels for each dimension which results in 3,125 possible unique health states.

Eligible patients were invited and provided with HRQOL information at their preoperative appointment or sent an invitation letter with a copy of the FACE-Q and EQ-5D-5L questionnaires electronically or via mail. Patients who did not respond within four weeks of initial contact were followed up by phone. FACE-Q and EQ-5D-5L data were collected at baseline preoperatively and postoperatively at 3, 6, 12, 24, 36, 48, 60, 72, 84, and 96 months after surgery.

6.5.3 VARIABLES

Weighted EQ-5D-5L utilities were derived by applying the Australian preference weights reported by Norman et al. (2023). Each observed EQ-5D-5L health state was decomposed into its five dimensions (mobility, self-care, usual activities, pain/discomfort, anxiety/depression), and the corresponding decrements were weighted using the Australian value set coefficients. For individual *i*, the utility score was calculated as:

$$U_i = 1 - \sum_{j=1}^{5} w_i \, d_{ij},$$

where d_{ij} is a value of a dimension *j* of individual *i*, and w_i is the preference weight that level derived from Norman et al. (2023).

6.5.4 MODEL SPECIFICATION

The correlation structure among FACE-Q predictors was first examined to identify potential multicollinearity and clinically meaningful associations **(Appendix D1).** Guided by both the correlation values and theoretical considerations, interaction terms were introduced stepwise,

beginning with a parsimonious set of clinically interpretable pairs. To further capture the functional form of the relationship between FACE-Q domains and EQ-5D-5L, non-linearities were assessed using generalised additive models (GAM) (**Appendix D2**). Where evidence of curvature was observed, we extended the models with corresponding non-linear terms (squared or cubic terms).

A series of stepwise ordinary least squares (OLS) regressions was then estimated, beginning with models including only the original FACE-Q domains, followed by sequential addition of interaction terms, and finally inclusion of selected non-linear terms. Five candidate models (A to E) were tested (**Appendix D3**). Model fit was compared using R-squared, root mean squared error (RMSE), mean absolute error (MAE), Akaike information criterion (AIC), and Bayesian information criterion (BIC). Based on these criteria, model B which included the FACE-Q domains and the initial set of theoretically justified interactions was selected as the preferred specification. Let Y_i denote the EQ-5D-5L utility score for participant i. The model includes the full set of 14 FACE-Q domain scores X_{ij} $(j=1, \ldots, 14)$ as main effects, plus a set of K theory-driven interaction terms Z_{ik} (appearance × smile, oral competence × speech, swallowing × saliva, worry × appearance, worry × oral competence, information × eating/drinking, information × oral competence, information × worry, and information × smile). Then, the model is defined as:

$$Y_i = \beta_0 + \sum_{j=1}^{14} \beta_j X_{ij} + \sum_{k=1}^{K} \gamma_k Z_{ik} + \varepsilon_i,$$

where β_0, β_j and γ_k represent constant, regression coefficients of face q items and coefficients of selected interaction terms, respectively. ε_i is the error term.

After identifying Model B as the preferred specification, four different regression frameworks commonly used in mapping studies were applied to further evaluate predictive performance: (i) OLS regression (Model B specification), (ii) a Tobit regression censoring at the upper bound of 1 to account for the ceiling effect of EQ-5D-5L **(Appendix D4),** (iii) censored least absolute deviations (CLAD) regression to provide a more robust median-based estimator under heteroskedasticity, and (iv) Beta regression on rescaled EQ-5D-5L values to exploit the bounded and skewed distribution of the outcome.

6.5.5 SENSITIVITY ANALYSIS

The robustness of the mapping results was assessed by comparing four regression models: OLS, Tobit (right-censored at 1), CLAD, and beta regression, estimated with and without an intercept on the original sample. Model selection was based primarily on RMSE/MAE and information criteria, because R^2 for no-intercept fits is uncentered and not comparable with intercept models. Across models, models with an intercept consistently performed slightly better than their no-intercept counterparts (e.g., beta RMSE 0.131 vs 0.133; MAE 0.084 vs 0.085; AIC −647.3 vs −642.8). The beta regression with intercept provided the best overall fit (RMSE = 0.131; MAE =0.084; AIC = −647.3; BIC = −559.5), aligning with the bounded nature of EQ-5D-5L utilities.

6.6 RESULTS

6.6.1 PATIENT DEMOGRAPHICS

The analysis included 181 patients with a mean age at surgery of 62.6 ± 14.4 years (**Table 1**). The most common indication for surgery was oral cavity squamous cell carcinoma (SCC) (n = 93). The reconstruction site was the mandible in 111 cases, the maxilla in 61 cases, and both

in five cases. Microvascular free flap reconstruction was performed in 179 patients, with this being soft tissue in 68 and bony in 111 cases. Virtual surgical planning (VSP) was used in 112 cases, tracheostomy in 97 cases, and neck dissection in 133 cases. A total of 270 FACE-Q and EQ-5D-5L paired observations were completed with 22 being preoperatively at baseline whilst 63 observations were completed at three months, 58 at six months, 53 at 12 months, and 27 at 24 months, 17 at 36 months, and 13 at 48 months, seven at 60 months, seven at 72 months, two at 84 months, and one at 96 months postoperatively.

Table 1. Patient demographics of the sample.

Clinicopathological characteristics	**n (%)**
Sex	
Male	98 (54)
Female	83 (46)
Age at time of surgery (years) (mean ± SD)	62.6 ± 14.4
Pathology	
Oral squamous cell carcinoma (SCC)	93 (51)
Osteoradionecrosis	33 (18)
Adenoid cystic carcinoma	12 (7)
Ameloblastoma	8 (4)
Mucosal melanoma	8 (4)
Defect following previous surgery	7 (4)
Osteosarcoma	5 (3)
Verrucous carcinoma	3 (2)
Other	15 (8)
Surgery type	
Ablation and reconstruction	177 (98)
Reconstruction	4 (2)
Reconstruction site	
Mandible	111 (63)
Maxilla	61 (34)
Mandible and maxilla	5 (3)
Reconstruction type	
Bony microvascular reconstruction	111 (61)
Soft-tissue microvascular reconstruction	68 (38)

Obturator	2 (1)
Operative adjuncts	
Tracheostomy	97 (54)
Neck dissection	133 (73)
Virtual surgical planning (VSP)	112 (62)

6.6.2 SUMMARY STATISTICS

Table 2 shows that weighted EQ-5D-5L averaged 0.868 (SD 0.173) with a right-skew distribution **(Appendix D5**). EQ-5D-5L dimensions indicated relatively mild problems overall: self-care had the lowest mean level (1.15), followed by mobility (1.52) and usual activities (1.61), whereas pain/discomfort was highest (2.01) and anxiety/depression moderate (1.78). FACE-Q scales showed heterogeneity across domains (**Appendix D6).**

Table 2. Summary statistics of EQ-5D-5L and FACE-Q items.

Variable	Mean	SD	Min	P25	Median	P75	Max
Weighted EQ-5D-5L	0.868	0.173	0.093	0.853	0.924	0.9645	1
Mobility	1.515	0.822	1	1	1	2	5
Self-care	1.154	0.527	1	1	1	1	5
Usual activities	1.612	0.946	1	1	1	2	5
Pain/discomfort	2.008	0.932	1	1	2	3	5
Anxiety/depression	1.781	0.952	1	1	2	2	5
Appearance	0.631	0.279	0	0.485	0.59	0.89	1
Appearance distress	0.599	0.323	0	0.41	0.585	1	1
Drooling distress	0.724	0.338	0	0.48	0.9	1	1
Eating and drinking	0.561	0.239	0	0.42	0.57	0.72	1
Eating distress	0.600	0.340	0	0.32	0.62	0.9175	1
Information	0.767	0.227	0	0.6	0.81	1	1
Oral competence	0.621	0.268	0	0.41	0.66	0.87	1
Salivation	0.695	0.271	0	0.53	0.72	1	1
Smiling	0.650	0.282	0	0.48	0.64	0.88	1
Smiling distress	0.745	0.293	0	0.48	0.88	1	1

Speaking	0.639	0.308	0	0.5	0.63	1	1
Speaking distress	0.717	0.259	0	0.49	0.72	1	1
Swallowing	0.762	0.244	0	0.58	0.8	1	1
Cancer worry	0.313	0.246	0	0.135	0.29	0.45	1

SD: standard deviation.

6.6.3 RELATIONSHIP BETWEEN FACE-Q AND EQ-5D-5L

Figure 1 shows correlations between all FACE-Q scales and EQ-5D-5L domains. The strongest associations were observed for the EQ-5D-5L anxiety/depression dimension when compared with all FACE-Q scales. Worry was positively correlated with anxiety/depression (r = 0.41). All functional FACE-Q scales, including eating, speaking, swallowing, and drooling, were negatively correlated with anxiety/depression (r = –0.37 – –0.51) and pain/discomfort (r = –0.29 – –0.36). In comparison, correlations with self-care and mobility were consistently weak (r ≤ –0.25). The information scale from FACE-Q was weakly correlated with EQ-5D-5L domains, including anxiety/depression, where coefficients did not exceed –0.26.

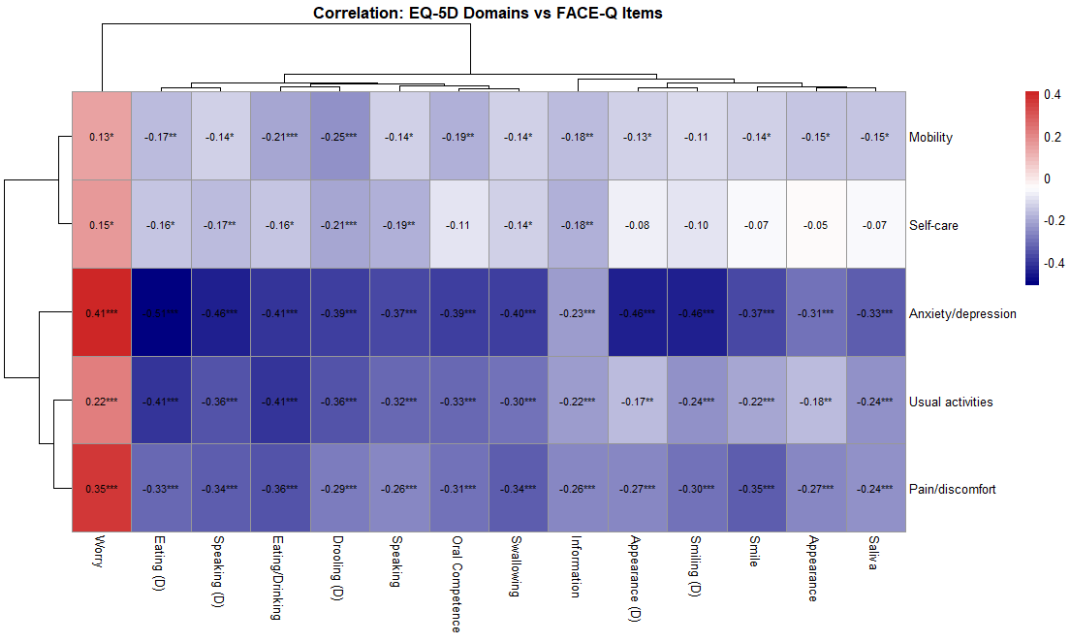

Figure 1. Association patterns between FACE-Q scales and EQ-5D-5L functional domains. This presents a heatmap of the correlation matrix between the five EQ-5D-5L domains and

the 14 FACE-Q scales, with hierarchical clustering dendrograms. The colour intensity represents the strength and direction of the Pearson correlation coefficients. The clustering of rows and columns reflects patterns of similarity in the relationships among EQ-5D-5L and FACE-Q scales.

Table 3 summarises the regression coefficients predicting EQ-5D-5L utilities from FACE-Q scales. In the final model (Beta), several FACE-Q scales remained significant predictors. Oral competence (b = –6.38, $p < 0.001$) and salivation (b = –1.44, $p = 0.02$) were strongly negatively associated with EQ-5D-5L, indicating that impaired oral competence directly reduces health utility. Speaking (b = –1.58, $p = 0.004$) and worry (b = –2.20, $p = 0.02$) were also significant negative predictors, reflecting the impact of communication limitations and psychosocial distress. In contrast, smile (b = 2.57, $p = 0.006$) was a positive predictor, suggesting that the ability to smile contributes meaningfully to perceived health.

On assessment for interactions, the combination of oral competence and speaking (b = 2.42, $p = 0.006$) and salivation and swallowing (b = 2.18, $p = 0.03$) were significant positive predictors, indicating that when both oral competence and swallowing function are preserved, the benefit to utility is amplified. Conversely, interactions between worry and information (b = –2.38, $p = 0.04$) and smile and information (b = –2.71, $p = 0.02$) were negatively associated with EQ-5D-5L, suggesting that when distress or dissatisfaction with information is present, even improvements in functional or aesthetic domains do not translate into equivalent utility gains. The strong positive interaction between oral competence and worry (b = 5.69, $p < 0.001$) further highlights that psychosocial and functional domains do not operate independently but instead modify each other's effect on utility.

Clinically, these findings demonstrate that both core facial functions (oral competence, salivation, speaking, swallowing) and psychosocial outcomes (smile, worry, information) contribute to health utility, often in combination. This supports the idea that FACE-Q captures dimensions of recovery that influence generic HRQoL through both direct effects and interactions.

Table 3. Coefficients of regression estimates for predicting EQ-5D-5L using the original sample.

Predictor	OLS	Tobit	CLAD	Beta	
	b(se)	b(se)	b(se)	b(se)	Marginal effect
(Intercept)	0.79 (0.161)***	0.907 (0.184)***	0.844 (0.093)***	2.527 (0.988)*	0.3067
Appearance	0.025 (0.115)	0.036 (0.131)	–0.058 (0.066)	0.355 (0.722)	0.043
Eating and drinking	0.262 (0.278)	0.262 (0.315)	0.153 (0.175)	0.469 (1.734)	0.057
Oral competence	–0.97 (0.255)***	–1.207 (0.29)***	–0.339 (0.157)*	–6.383 (1.586)***	–0.7746
Salivation	–0.128 (0.118)	–0.195 (0.132)	–0.015 (0.071)	–1.444 (0.702)*	–0.1753
Smiling	0.505 (0.158)**	0.513 (0.175)**	0.204 (0.142)	2.568 (0.941)**	0.3117
Speaking	–0.155 (0.092)	–0.221 (0.104)*	–0.085 (0.059)	–1.575 (0.566)**	–0.1912
Swallowing	–0.033 (0.116)	–0.094 (0.129)	-0.01 (0.07)	–0.903 (0.701)	–0.1095
Appearance distress	0.011 (0.042)	0.011 (0.047)	0.029 (0.023)	0.034 (0.264)	0.0041
Drooling distress	0.064 (0.047)	0.079 (0.052)	0.066 (0.032)*	0.462 (0.284)	0.0561
Eating distress	0.069 (0.059)	0.071 (0.065)	0.019 (0.035)	0.338 (0.362)	0.041
Smiling distress	–0.031 (0.054)	–0.011 (0.06)	–0.002 (0.034)	-0.124 (0.336)	–0.0151
Speaking distress	0.041 (0.086)	0.033 (0.097)	–0.013 (0.053)	0.568 (0.538)	0.069
Cancer worry	–0.26 (0.169)	–0.334 (0.191)	–0.426 (0.116)***	–2.204 (1.021)*	–0.2675
Information	0.367 (0.171)*	0.335 (0.194)	0.198 (0.106)	1.38 (1.074)	0.1675
Appearance:Smiling	–0.134 (0.13)	–0.09 (0.147)	0.065 (0.08)	–0.29 (0.811)	–0.0351
Oral competence:Speaking	0.226 (0.137)	0.381 (0.156)*	0.105 (0.08)	2.418 (0.875)**	0.2934
Slivation:Swallowing	0.173 (0.157)	0.277 (0.176)	0.033 (0.094)	2.175 (0.956)*	0.264
Appearance:Cancer worry	0.097 (0.148)	0.074 (0.167)	0.009 (0.107)	0.125 (0.895)	0.0152
Oral competence:Cancer worry	0.836 (0.189)***	1.014 (0.217)***	0.544 (0.16)***	5.688 (1.179)***	0.6903
Eating and drinking:Information	–0.246 (0.332)	–0.232 (0.376)	–0.102 (0.211)	0.175 (2.093)	0.0212
Oral competence:Information	0.6 (0.297)*	0.678 (0.331)*	0.119 (0.224)	2.92 (1.821)	0.3543

Predictor	OLS	Tobit	CLAD	Beta	
	b(se)	b(se)	b(se)	b(se)	Marginal effect
Cancer worry:Information	–0.541 (0.198)**	–0.554 (0.222)*	0.019 (0.164)	–2.384 (1.225).	–0.2893
Smiling:Information	–0.506 (0.196)*	–0.528 (0.218)*	–0.257 (0.181)	–2.708 (1.188)*	–0.3286
Log(scale)		–1.879 (0.051)***			
R Squared	0.406				
RMSE	0.133	0.138	0.145	0.131	
MAE	0.089	0.092	0.076	0.084	
AIC	–244.656	–68.924	–388.364	–647.3	
BIC	–156.921	18.811		–559.5	

Note: *$p < .05$, ** $p < .01$, *** $p < .001$ This table presents the estimated coefficients of four regression models mapping FACE-Q scales onto EQ-5D-5L utility scores: OLS estimates (Model 2), a Tobit model with censoring at 1 (Model 2), a CLAD model (Model 3), and Beta regression models (Model 4) Performance metrics (R^2, RMSE, MAE, AIC, BIC) are also reported for model comparison.

6.6.4 MAPPING MODELS

The baseline OLS regression model explained a moderate proportion of the variance in EQ-5D-5L scores ($R^2 = 0.406$). **Table 3** shows that the Beta regression achieved the lowest RMSE (0.131) with competitive MAE (0.084) and the most favourable information criteria (AIC −647; BIC −560), aligning with the bounded, right-skewed utility distribution. CLAD delivered the lowest MAE (0.076), useful for median prediction and robustness, but RMSE is higher (0.145). Tobit, while appropriate for ceiling at 1, did not improve accuracy (RMSE 0.138; MAE 0.092). Also, the Q–Q plots show beta regression residuals align most closely with normality (**Appendix D4**).

The scatterplots (**Figure 2**) show that the correlation between observed and predicted EQ-5D-5L from the Beta model is relatively higher (r = 0.653; cf. OLS = 0.638, Tobit = 0.629, CLAD = 0.574; all $p < 0.001$). Calibration plots show that the Beta regression tracks the observed series across the full range with the least systematic bias while OLS and Tobit overshoot in the upper tail (**Figure 3**). **Table 4** further confirmed that distributionally, beta prediction respects the 0–1 bounds (min = 0.286, max = 0.974) and delivers a mean close to observed (0.859 vs 0.868) with reasonable percentiles (e.g., p25 = 0.817 vs 0.853; p75 = 0.933 vs 0.965). By contrast, OLS and Tobit yield illegal values (>1; OLS max = 1.067; Tobit max = 1.160) and CLAD markedly under-disperses (SD = 0.088 (predicted) vs 0.173 (observed)). Post-hoc "LE" rescaling improves marginal moments but can generate values outside (Abo Sharkh & Makhoul, 2020) (e.g., Beta-LE min < 0), so we do not prefer it. An example of the application of the final mapping function using a hypothetical patient is presented in **Appendix D7.**

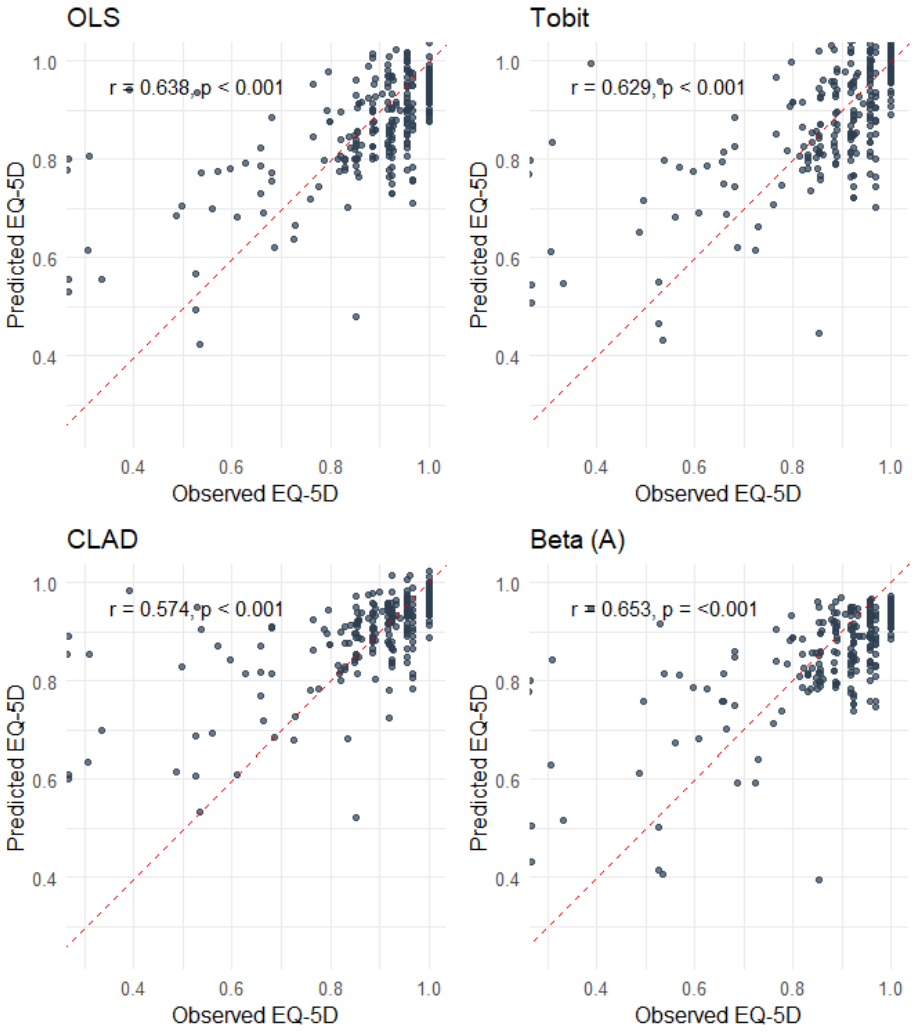

Figure 2. Scatter plots comparing observed and predicted EQ-5D-5L utility scores. Each plot includes a reference line (dashed red) representing perfect prediction. Pearson correlation coefficients (r) and associated *p*-values are displayed for each model.

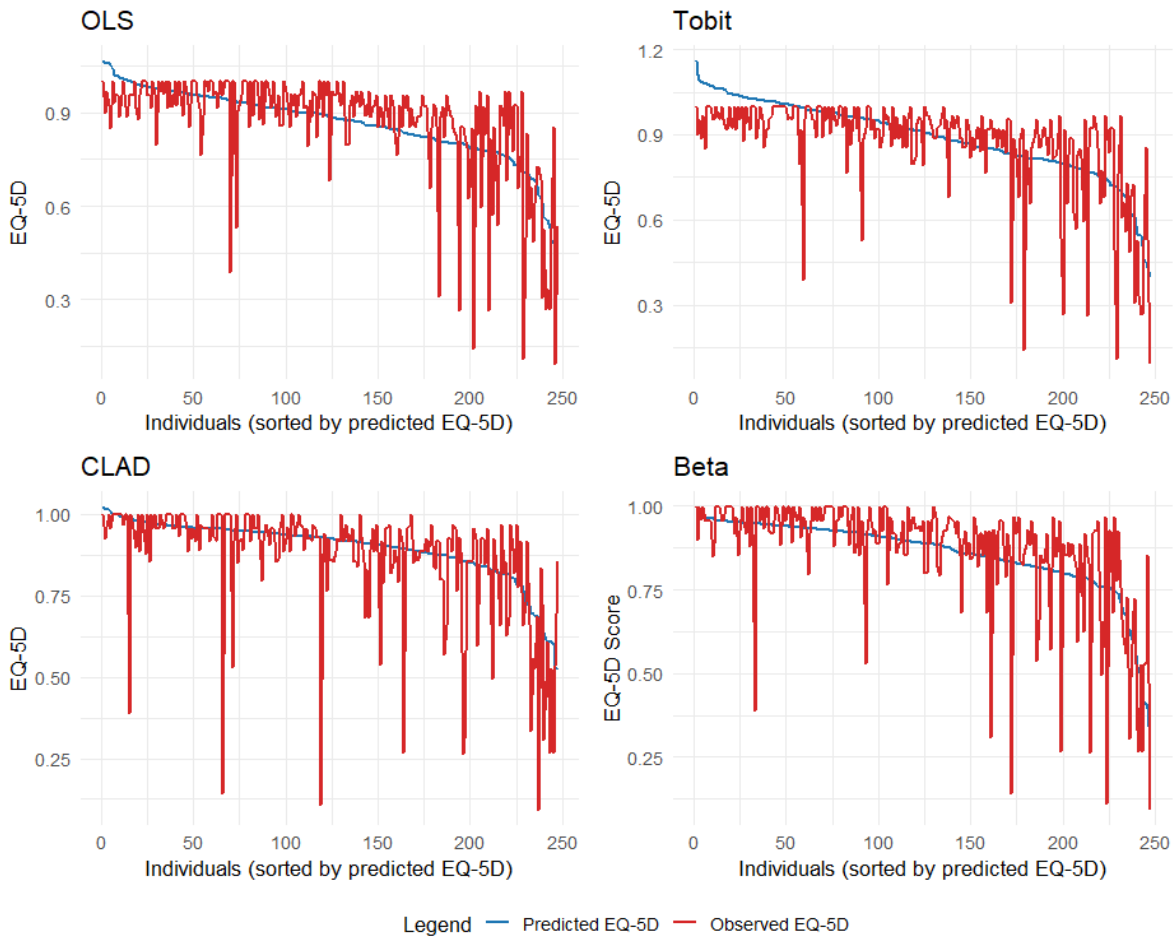

Figure 3. Observed vs predicted EQ-5D-5L utility scores for OLS, Tobit, CLAD, and beta models. Individuals were sorted by predicted EQ-5D-5L values.

Table 4. Distribution of observed and predicted EQ-5D-5L utility score for different scenarios.

Model	Mean	SD	p1	p5	p10	p25	p50	p75	p90	p95	p99	IQR	Min	Max
Observed vs Predicted values (Original Data Set)														
Observed EQ5D	0.868	0.173	0.197	0.505	0.658	0.853	0.924	0.965	1.000	1.000	1.000	0.112	0.093	1.000
OLS	0.868	0.111	0.486	0.683	0.748	0.805	0.885	0.948	0.980	1.007	1.058	0.143	0.425	1.067
OLS_LE	0.868	0.173	0.270	0.577	0.680	0.770	0.894	0.994	1.044	1.086	1.166	0.224	0.173	1.180
Tobit	0.891	0.130	0.455	0.668	0.745	0.813	0.907	0.987	1.034	1.062	1.087	0.173	0.397	1.160
Tobit LE	0.868	0.173	0.287	0.571	0.673	0.764	0.889	0.995	1.058	1.095	1.128	0.231	0.210	1.226
CLAD	0.899	0.088	0.604	0.689	0.805	0.874	0.924	0.955	0.974	0.985	1.014	0.081	0.521	1.024
CLAD LE	0.868	0.173	0.285	0.453	0.683	0.818	0.918	0.979	1.016	1.039	1.096	0.161	0.121	1.115
Beta	0.859	0.109	0.410	0.651	0.758	0.817	0.889	0.933	0.950	0.958	0.966	0.116	0.286	0.974
Beta LE	0.868	0.173	0.154	0.537	0.708	0.801	0.916	0.986	1.014	1.025	1.039	0.185	-0.044	1.051

Note: Table 3 presents descriptive statistics for the observed EQ-5D-5L scores and the predicted values from four models (OLS, Tobit, CLAD, and Beta regression.

6.7 DISCUSSION

This study is the first to report mapping functions from the FACE-Q Head and Neck Cancer Module to the EQ-5D-5L. FACE-Q is a valuable disease-specific patient-reported outcome measure that addresses multiple HRQoL domains and overcomes limitations of existing tools for head and neck cancer patients (Cracchiolo et al., 2019). However, its disease specificity precludes its use in economic evaluations comparing different treatments or conditions (Drummond, 2015; McTaggart-Cowan et al., 2013). Given the substantial morbidity associated with jaw reconstruction, the priority of maximising postoperative HRQoL, and the resource-intensive nature of these treatments, there is a clear need to understand the overall health state utility of these patients. While this can be achieved using generic preference-based instruments like the EQ-5D-5L, these are uncommonly collected as part of routine HRQoL measurement in many centres due to response burden. In the absence of this data, mapping from disease-specific instruments provides a valuable alternative (Meregaglia & Cairns, 2017). This study presents an effective mapping function to the EQ-5D-5L, a widely recognised generic preference-based instrument, enabling future QALY calculation and cost-utility analyses (Brauer et al., 2006).

This study evaluated a range of regression models to determine which would most accurately predict EQ-5D-5L scores from FACE-Q data. We found beta regression to be the optimal framework, outperforming OLS, Tobit, and CLAD approaches (RMSE = 0.131; MAE = 0.084; AIC = –647.3; BIC = –559.5). This finding aligns with recent literature emphasising beta regression as the most effective model for predicting EQ-5D utilities, though it contrasts with historical practice (Khan & Morris, 2014; Khan et al., 2016; Lamu & Olsen, 2018; Wailoo et al., 2017). Traditionally, OLS regression has been the most commonly reported method for

health state utility mapping, used in over 75% of all studies in a recent systematic review (Mukuria et al., 2019). However, OLS is not necessarily optimal due to systematic patterns of over-prediction at the lower end and under-prediction at the upper end of health-state utility values (Brazier et al., 2010). Moreover, OLS regression relies on the assumption of normally distributed residuals and may predict values outside the feasible 0-1 range for EQ-5D-5L as observed in this study where OLS produced a maximum predicted value of 1.067. These limitations underscore the importance of estimating mapping functions using multiple regression methods (Mukuria et al., 2019).

The superior performance of beta regression is secondary to its ability to accommodate the unique distributional characteristics of EQ-5D-5L data. Health utility data are naturally bounded between 0 and 1 and typically exhibit right-skewness with clustering at higher utility values (Wailoo et al., 2017). This pattern was evident in our cohort, where EQ-5D-5L scores averaged 0.868 with a right-skewed distribution. Beta regression explicitly models this bounded and skewed distribution through a flexible link function, accounting for heteroskedasticity while ensuring all predicted utilities remain within the valid range (Lamu & Olsen, 2018). This improvement in prediction accuracy has important implications for economic evaluations, where even small improvements in utility estimates can meaningfully impact incremental cost-effectiveness ratios and influence resource allocation decisions.

Several existing studies have mapped patient-reported outcomes to preference-based utilities in head and neck cancer patients, though with varying methodological approaches and results. Thankappan et al. (2022) mapped the Head and Neck Patient Concerns Inventory (PCI) to the EQ-5D-5L, finding that a reduced OLS model (excluding social care and social wellbeing scores) provided the most accurate predictions with an MAE of 0.1099 and an RMSE of

0.1408. Noel et al. (2020) developed mapping algorithms for both the Health Utilities Index-Mark 3 (HUI-3) and EQ-5D-5L from the European Organisation for Research and Treatment of Cancer Quality of Life Questionnaire-Core 30 and QLQ-H&N35, using OLS techniques and achieving high accuracy with MAEs of 0.05 and 0.08 and an RMSEs of 0.067 and 0.168 for EQ-5D-5L and HUI-3, respectively. Beck et al. (2019) mapped the EORTC QLQ-30 to the EQ-5D-3L, similarly finding beta regression to be most robust with an MAE of 0.0949 and RMSE of 0.1209.

Our results are comparable to those of these studies in regard to prediction accuracy, with an MAE of 0.084. However, several factors may explain the variation in performance across studies. The choice of source instrument greatly differed across studies. For instance, EORTC QLQ-C30 is a generic cancer questionnaire with broad applicability, whereas FACE-Q contains highly disease-specific domains tailored to concerns unique to patients with head and neck cancer (Tonsbeek et al., 2024). Our finding that outcomes specific to head and neck cancer assessed by FACE-Q – including oral competence, speaking, and smiling – were strongly associated with EQ-5D-5L contrasts with Beck et al.'s (2019) observation that adding head and neck cancer-specific scales from QLQ-H&N35 did not result in considerable model improvements. This divergence likely reflects differences in how disease-specific content is captured and structured between instruments. FACE-Q domains may more directly capture functional limitations (eating, speaking, social interaction) that map onto EQ-5D dimensions like usual activities and anxiety/depression, whereas QLQ-H&N35 symptom scales (pain, swallowing problems, dry mouth) may overlap less directly with EQ-5D's conceptual framework

The need for mapping from disease-specific instruments like FACE-Q to generic preference-based measures raises broader questions about measurement approaches in health economic evaluation. A proposed limitation of generic preference-based measures is their lack of sensitivity to certain disease-specific improvements (Versteegh et al., 2012). This is supported by some studies demonstrating poor correlation between head and neck cancer-specific domains and generic preference-based measures (Beck et al., 2019; Rogers et al., 2006). In response, condition-specific preference-based measures (CS-PBMs) have been developed across various pathologies to address these perceived sensitivity gaps (Krahn et al., 2007; Solans et al., 2008; Wasserman et al., 2005). To the best of our knowledge, only one CS-PBM for head and neck cancer currently exists. de Almeida et al. (2025) developed a head and neck cancer-specific utility instrument through a two-phase process in which an expert panel first selected disease-specific quality of life domains, which were then validated with members of the general public. The final instrument comprised eight items with three response levels, generating 6,561 possible health states.

Despite theoretical improvements in sensitivity, CS-PBMs have notable drawbacks: focusing effects may cause downward bias by exaggerating health problems, while their narrower scope can produce upward bias in utility estimates (Versteegh et al., 2012). Most critically, CS-PBMs forgo comparability of utility values across conditions, limiting their utility for healthcare decision-makers who must allocate resources across diverse patient populations and interventions. Generic preference-based measures like EQ-5D-5L, despite potential limitations in capturing disease-specific nuances, retain an essential role in health economic evaluation by enabling consistent cross-condition comparisons (Drummond, 2015; McTaggart-Cowan et al., 2013). Our mapping function provides a practical solution by allowing researchers to derive EQ-5D-5L utilities from existing FACE-Q data, thereby facilitating economic evaluations

while preserving the rich disease-specific information captured by FACE-Q for clinical interpretation.

This study has several limitations. This algorithm was developed using only data from patients undergoing jaw reconstruction, and its performance in the general head and neck cancer population is unknown. External validation in broader and independent samples is required to assess generalisability. Australian preference weights were used to derive EQ-5D-5L utilities. Those considering the application of the algorithm in different regions should carefully consider using appropriate value sets for their context, as the algorithm presented in this study may yield different results. This study relied on cross-sectional data, and the algorithm's performance in detecting changes over time has not been evaluated, which may be particularly relevant for longitudinal cost-effectiveness analyses where utility changes are the primary outcome. Finally, a limitation of all mapping functions is the introduction of prediction error, and it must be considered that the estimated utilities represent approximations rather than directly measured preferences (Beck et al., 2019). Whenever feasible, researchers should collect EQ-5D-5L directly; this mapping algorithm is intended for situations where EQ-5D-5L was not originally collected or for retrospective analyses where mapped utilities provide acceptable approximations.

6.8 CONCLUSION

This is the first study to report a mapping function from FACE-Q to the EQ-5D-5L using an Australian data set of jaw reconstruction patients. We found beta regression to be the optimal mapping framework due to its ability to accommodate the unique distributional characteristics of EQ-5D-5L data. In the absence of utility scores collected directly from patients, mapping

from FACE-Q provides a valuable alternative, enabling future economic evaluations including QALY calculation and cost-utility analyses.

6.9 REFERENCES

Abo Sharkh, H., & Makhoul, N. (2020). In-house surgeon-led virtual surgical planning for maxillofacial reconstruction. *Journal of Oral and Maxillofacial Surgery*, 78(4), 651–660. https://doi.org/10.1016/j.joms.2019.11.013

Beck, A.-J. C. C., Kieffer, J. M., Retèl, V. P., van Overveld, L. F. J., Takes, R. P., van den Brekel, M. W. M., van Harten, W. H., & Stuiver, M. M. (2019). Mapping the EORTC QLQ-C30 and QLQ-H&N35 to the EQ-5D for head and neck cancer: Can disease-specific utilities be obtained? *PLOS ONE,* 14(12), Article e0226077. https://doi.org/10.1371/journal.pone.0226077

Bjordal, K., Hammerlid, E., Ahlner-Elmqvist, M., De Graeff, A., Boysen, M., Evensen, J. F., Biorklund, A., De Leeuw, J. R. J., Fayers, P. M., & Jannert, M. (1999). Quality of life in head and neck cancer patients: Validation of the European Organization for Research and Treatment of Cancer Quality of Life Questionnaire-H&N35. *Journal of Clinical Oncology,* 17(3), 1008–1019. https://doi.org/10.1200/JCO.1999.17.3.1008

Brauer, C. A., Rosen, A. B., Greenberg, D., & Neumann, P. J. (2006). Trends in the measurement of health utilities in published cost-utility analyses. *Value in Health,* 9(4), 213–218. https://doi.org/10.1111/j.1524-4733.2006.00116.x

Brazier, J. E., Yang, Y., Tsuchiya, A., & Rowen, D. L. (2010). A review of studies mapping (or cross walking) non-preference based measures of health to generic preference-based measures. *The European Journal of Health Economics,* 11(2), 215–225. https://doi.org/10.1007/s10198-009-0168-z

Brooks, R. (1996). EuroQol: The current state of play. *Health Policy*, 37(1), 53–72. https://doi.org/10.1016/0168-8510(96)00822-6

Chen, Z., Mo, S., Fan, X., You, Y., Ye, G., & Zhou, N. (2021). A meta-analysis and systematic review comparing the effectiveness of traditional and virtual surgical planning for orthognathic surgery: Based on randomized clinical trials. *Journal of Oral and Maxillofacial Surgery,* 79(2), 471.e1–471.e19. https://doi.org/10.1016/j.joms.2020.09.005

Cracchiolo, J. R., Klassen, A. F., Young-Afat, D. A., Albornoz, C. R., Cano, S. J., Patel, S. G., Pusic, A. L., & Matros, E. (2019). Leveraging patient-reported outcomes data to inform oncology clinical decision making: Introducing the FACE-Q head and neck cancer module. *Cancer,* 125(6), 863–872. https://doi.org/10.1002/cncr.31900

Dassonville, O., Bozec, A., Château, Y., Reyt, E., Devauchelle, B., Louis, M. Y., Breton, P., Julieron, M., Yachouh, J., Mallet, Y., Sarini, J., Dolivet, G., Schiappa, R., Gal, J., Orlanducci, M. H., Poissonnet, G., & Chamorey, E. (2017). Multicenter prospective micro-costing study evaluating mandibular free-flap reconstruction. *European Archives of Oto-Rhino-Laryngology*, 274(2), 1103–1111. https://doi.org/10.1007/s00405-016-4360-3

de Almeida, J. R., Su, J., AlShenaiber, A., Noroozi, H., Buttner, M., Goldstein, D. P., Hansen, A., Kowalski, L. P., Licitra, L., Mehanna, H., Noel, C. W., Parmar, A., Porceddu, S., Ringash, J., Rogers, S., Dos Santos, M. A., Simon, C., Truong, M.-T., & Xu, W. (2025). Development, validation, and valuation of a head and neck cancer-specific health utility instrument (HNC-8D): A Head and Neck Cancer International Group collaborative study. *JAMA Otolaryngology–Head & Neck Surgery,* 151(6), 549–557. https://doi.org/10.1001/jamaoto.2025.0160

Drummond, M. (2015). Methods for the economic evaluation of health care programmes (4th ed.). Oxford University Press.

Gao, L. L., Basta, M., Kanchwala, S. K., Serletti, J. M., Low, D. W., & Wu, L. C. (2017). Cost-effectiveness of microsurgical reconstruction for head and neck defects after oncologic resection. *Head & Neck*, 39(3), 541–547. https://doi.org/10.1002/hed.24644

Herdman, M., Gudex, C., Lloyd, A., Janssen, M., Kind, P., Parkin, D., Bonsel, G., & Badia, X. (2011). Development and preliminary testing of the new five-level version of EQ-5D (EQ-5D-5L). *Quality of Life Research,* 20(10), 1727–1736. https://doi.org/10.1007/s11136-011-9903-x

Ismail, I., Wolff, S., Gronfier, A., Mutter, D., & Swanström, L. L. (2015). A cost evaluation methodology for surgical technologies. *Surgical Endoscopy,* 29(8), 2423–2432. https://doi.org/10.1007/s00464-014-3929-4

Jones, N. F., Jarrahy, R., Song, J. I., Kaufman, M. R., & Markowitz, B. (2007). Postoperative medical complications—not microsurgical complications—negatively influence the morbidity, mortality, and true costs after microsurgical reconstruction for head and neck cancer. *Plastic and Reconstructive Surgery*, 119(7), 2053–2060. https://doi.org/10.1097/01.prs.0000260591.82762.b5

Khan, I., & Morris, S. (2014). A non-linear beta-binomial regression model for mapping EORTC QLQ-C30 to the EQ-5D-3L in lung cancer patients: A comparison with existing approaches. Health and Quality of Life Outcomes, 12(1), Article 163. https://doi.org/10.1186/s12955-014-0163-7

Khan, I., Morris, S., Pashayan, N., Matata, B., Bashir, Z., & Maguire, J. (2016). Comparing the mapping between EQ-5D-5L, EQ-5D-3L and the EORTC-QLQ-C30 in non-small cell lung cancer patients. *Health and Quality of Life Outcomes,* 14(1), Article 60. https://doi.org/10.1186/s12955-016-0455-1

Krahn, M., Bremner, K. E., Tomlinson, G., Ritvo, P., Irvine, J., & Naglie, G. (2007). Responsiveness of disease-specific and generic utility instruments in prostate cancer patients. *Quality of Life Research*, 16(3), 509–522. https://doi.org/10.1007/s11136-006-9132-x

Lamu, A. N., & Olsen, J. A. (2018). Testing alternative regression models to predict utilities: Mapping the QLQ-C30 onto the EQ-5D-5L and the SF-6D. *Quality of Life Research,* 27(11), 2823–2839. https://doi.org/10.1007/s11136-018-1981-6

McTaggart-Cowan, H., Teckle, P., & Peacock, S. (2013). Mapping utilities from cancer-specific health-related quality of life instruments: A review of the literature. *Expert Review of Pharmacoeconomics & Outcomes Research*, 13(6), 753–765. https://doi.org/10.1586/14737167.2013.850420

Meregaglia, M., & Cairns, J. (2017). A systematic literature review of health state utility values in head and neck cancer. *Health and Quality of Life Outcomes,* 15(1), Article 174. https://doi.org/10.1186/s12955-017-0748-z

Mukuria, C., Rowen, D., Harnan, S., Rawdin, A., Wong, R., Ara, R., & Brazier, J. (2019). An updated systematic review of studies mapping (or cross-walking) measures of health-related quality of life to generic preference-based measures to generate utility values. *Applied Health Economics and Health Policy,* 17(3), 295–313. https://doi.org/10.1007/s40258-019-00467-6

Noel, C. W., Stephens, R. F., Su, J. S., Xu, W., Krahn, M., Monteiro, E., Goldstein, D. P., Giuliani, M., Hansen, A. R., & de Almeida, J. R. (2020). Mapping the EORTC QLQ-C30 and QLQ-H&N35 onto EQ-5D-5L and HUI-3 indices in patients with head and neck cancer. *Head & Neck,* 42(9), 2277–2286. https://doi.org/10.1002/hed.26181

Norman, R., Mulhern, B., Lancsar, E., Lorgelly, P., Ratcliffe, J., Street, D., & Viney, R. (2023). The use of a discrete choice experiment including both duration and dead for

the development of an EQ-5D-5L value set for Australia. *PharmacoEconomics,* 41(4), 427–438. https://doi.org/10.1007/s40273-023-01243-0

Ojo, B., Genden, E. M., Teng, M. S., Milbury, K., Misiukiewicz, K. J., & Badr, H. (2012). A systematic review of head and neck cancer quality of life assessment instruments. *Oral Oncology,* 48(10), 923–937. https://doi.org/10.1016/j.oraloncology.2012.03.025

Petrides, G. A., Dunn, M., Charters, E., Venchiarutti, R., Cheng, K., Froggatt, C., Mukherjee, P., Wallace, C., Howes, D., Leinkram, D., Singh, J., Nguyen, K., Hubert Low, T. H., Ch'ng, S., Wykes, J., & Clark, J. R. (2022). Health-related quality of life in maxillectomy patients undergoing dentoalveolar rehabilitation. *Oral Oncology,* 126, Article 105757. https://doi.org/10.1016/j.oraloncology.2022.105757

Petrides, G. A., Hicks, G., Dunn, M., Froggatt, C., Wallace, C., Howes, D., Leinkram, D., Low, T.-H., Ch'ng, S., Wykes, J., Palme, C. E., & Clark, J. R. (2021). Dentoalveolar outcomes in maxillary reconstruction: A retrospective review of 85 maxillectomy reconstructions. *ANZ Journal of Surgery,* 91(7–8), 1472–1479. https://doi.org/10.1111/ans.17001

Rathod, S., Livergant, J., Klein, J., Witterick, I., & Ringash, J. (2015). A systematic review of quality of life in head and neck cancer treated with surgery with or without adjuvant treatment. *Oral Oncology,* 51(10), 888–900. https://doi.org/10.1016/j.oraloncology.2015.07.002

Rogers, S. N., Miller, R. D., Ali, K., Minhas, A. B., Williams, H. F., & Lowe, D. (2006). Patients' perceived health status following primary surgery for oral and oropharyngeal cancer. *International Journal of Oral and Maxillofacial Surgery*, 35(10), 913–919. https://doi.org/10.1016/j.ijom.2006.07.017

Rowen, D., Brazier, J., & Roberts, J. (2009). Mapping SF-36 onto the EQ-5D index: How reliable is the relationship? *Health and Quality of Life Outcomes,* 7(1), Article 27. https://doi.org/10.1186/1477-7525-7-27

Setälä, L., Koskenvuori, H., Gudaviciene, D., Berg, L., & Mustonen, P. (2009). Cost analysis of 109 microsurgical reconstructions and flap monitoring with microdialysis. *Journal of Reconstructive Microsurgery,* 25(9), 521–526. https://doi.org/10.1055/s-0029-1238218

Shaw, R. J., Sutton, A. F., Cawood, J. I., Howell, R. A., Lowe, D., Brown, J. S., Rogers, S. N., & Vaughan, E. D. (2005). Oral rehabilitation after treatment for head and neck malignancy. *Head & Neck*, 27(6), 459–470. https://doi.org/10.1002/hed.20176

Solans, M., Pane, S., Estrada, M. D., Serra-Sutton, V., Berra, S., Herdman, M., Alonso, J., & Rajmil, L. (2008). Health-related quality of life measurement in children and adolescents: A systematic review of generic and disease-specific instruments. *Value in Health,* 11(4), 742–764. https://doi.org/10.1111/j.1524-4733.2007.00293.x

Thankappan, K., Patel, T., Ajithkumar, K. K., Balasubramanian, D., Raj, M., Subramanian, S., & Iyer, S. (2022). Mapping of head and neck cancer patient concerns inventory scores on to Euroqol-Five Dimensions-Five Levels (EQ-5D-5L) health utility scores. *The European Journal of Health Economics,* 23(2), 225–235. https://doi.org/10.1007/s10198-021-01369-y

Tonsbeek, A. M., Hundepool, C. A., Roubos, J., Rijken, B., Sewnaik, A., Verduijn, G. M., Jonker, B. P., Corten, E. M., & Mureau, M. A. (2024). Quality of life in 583 head and neck cancer survivors assessed with the FACE-Q head and neck cancer module. *Oral Oncology,* 153, Article 106813. https://doi.org/10.1016/j.oraloncology.2024.106813

Trivedi, N. P., Trivedi, P., Trivedi, H., Trivedi, S., & Trivedi, N. (2013). Microvascular free flap reconstruction for head and neck cancer in a resource-constrained environment in

rural India. *Indian Journal of Plastic Surgery*, 46(1), 82–86. https://doi.org/10.4103/0970-0358.113715

Umino, S., Masuda, G., Ono, S., & Fujita, K. (1998). Speech intelligibility following maxillectomy with and without a prosthesis: An analysis of 54 cases. *Journal of Oral Rehabilitation,* 25(2), 153–158. https://doi.org/10.1046/j.1365-2842.1998.00238.x

Venchiarutti, R. L., Charters, E. K., Dunn, M., & Clark, J. R. (2023). Construct and discriminant validity testing of the FACE-Q Head and Neck Cancer Module for assessing speech and swallowing outcomes for patients undergoing maxillectomy or mandibulectomy. *Head & Neck*, 45(6), 1519–1529. https://doi.org/10.1002/hed.27366

Versteegh, M. M., Leunis, A., Uyl-de Groot, C. A., & Stolk, E. A. (2012). Condition-specific preference-based measures: Benefit or burden? *Value in Health,* 15(3), 504–513. https://doi.org/10.1016/j.jval.2011.12.003

Wailoo, A. J., Hernandez-Alava, M., Manca, A., Mejia, A., Ray, J., Crawford, B., Botteman, M., & Busschbach, J. (2017). Mapping to estimate health-state utility from non-preference-based outcome measures: An ISPOR Good Practices for Outcomes Research Task Force report. *Value in Health*, 20(1), 18–27. https://doi.org/10.1016/j.jval.2016.11.006

Wasserman, J., Aday, L., Begley, C., Ahn, C., & Lairson, D. (2005). Measuring health state preferences for hemophilia: Development of a disease-specific utility instrument. *Haemophilia,* 11(1), 49–57. https://doi.org/10.1111/j.1365-2516.2005.01054.x

Weymuller, E. A., Jr., Alsarraf, R., Yueh, B., Deleyiannis, F. W.-B., & Coltrera, M. D. (2001). Analysis of the performance characteristics of the University of Washington Quality of Life instrument and its modification (UW-QOL-R). *Archives of Otolaryngology–Head & Neck Surgery,* 127(5), 489–493. https://doi.org/10.1001/archotol.127.5.489

CHAPTER 7: CONCLUDING REMARKS

7.1 OVERVIEW OF MAIN FINDINGS AND CONTRIBUTIONS

Mandibular and maxillary reconstruction – referred to here as jaw reconstruction – using microvascular free tissue transfer is the gold-standard for restoring aesthetics and function following the resection of pathology affecting the jaw (Abo Sharkh & Makhoul, 2020; Shaw et al., 2005). Despite the established quality-of-life benefits associated with microvascular reconstruction and surgical adjuncts including virtual surgical planning (VSP), the true economic implications remain unclear. Jaw reconstruction is among the most resource-intensive procedures in head and neck surgery, with substantial costs arising from extended operative time, multidisciplinary team involvement, and prolonged postoperative care (Petrides et al., 2021; Riaz & Warraich, 2010). Understanding the economic implications of these procedures is therefore essential to assist healthcare providers, administrators, and policymakers in decisions around resource allocation.

This thesis provides a comprehensive analysis of the health economics of jaw reconstruction, establishing foundational evidence to inform clinical practice, institutional decision-making, and future research. Across five interrelated studies, this work mapped the existing economic literature, established the true direct costs and key-cost drivers, evaluated strategies for cost-minimisation, examined the adequacy of private health insurance reimbursement, and developed a validated mapping algorithm to facilitate future cost-utility analysis.

7.1.1 MAPPING THE CURRENT KNOWLEDGE

Chapter 2 addressed the first aim of this thesis by systematically mapping the current knowledge around the economic implications of jaw reconstruction. Health economic studies on jaw reconstruction are essential to make evidence-based decisions around resource

allocation that ultimately impact patient access to health technologies and treatments. This scoping review identified 36 studies examining economic aspects of mandibular and maxillary reconstruction, revealing a rapidly growing but methodologically constrained field.

The findings suggest that personnel costs represent the primary cost-contributor and that VSP, particularly point-of-care workflows (POC-VSP), may offer favourable cost-effectiveness through reduced operative time and improved outcomes. However, only three studies (8%) conducted full economic evaluations, with the remainder limited to partial analyses that assessed costs in isolation. The predominance of partial economic evaluations, combined with inconsistent costing methodologies – ranging from micro-costing to gross-costing, with many failing to describe the approach entirely – severely constrains evidence-based decision-making for surgeons, administrators, and policymakers (Drummond, 2015; Potter et al., 2020; Ridyard & Hughes, 2010). The review highlighted an urgent need for full economic evaluations employing standardised micro-costing methodologies, validated outcome measures, and transparent reporting. This chapter represents the first scoping review to comprehensively synthesise the economic literature on jaw reconstruction and directly informed the methodological approach of subsequent studies in this thesis.

7.1.2 ESTABLISHING THE TRUE COST AND COST-DRIVERS

The methodological gaps identified in **Chapter 2** directly informed the approach taken in **Chapter 3,** which addressed the second aim of establishing the true direct financial costs and cost-drivers of jaw reconstruction. This retrospective micro-costing study of 100 patients employed an individualised bottom-up costing methodology, developed using existing literature and presented transparently to allow replication at other institutions. The mean direct admission cost was US$36,416 (A$54,988), comparable to previous micro-costing studies

despite substantial heterogeneity in existing estimates (Jones et al., 2007; Setälä et al., 2009; Tewfik et al., 2021). The largest cost contributors were ward staffing and disposable equipment (35.7%), prostheses including VSP (25.0%), and operating room staffing (21.0%).

Consistent with existing literature, adjusted analyses illustrated that factors related to surgical complexity and postoperative complications significantly increased costs (Gourin et al., 2011; Miller et al., 1991). Early postoperative complications requiring return to the operating room added US$19,920 (A$30,079), while return to the intensive care unit (ICU) added US$25,316 (A$38,227) per admission. Preoperative factors including vasculopathy (+US$9,142 (+A$13,804)) and ASA IV status (+US$19,496 (A$29,439)), in addition to tracheostomy (+US$10,446 (A$15,773)), were also independently associated with higher costs. These findings underscore the need to implement approaches to minimise the likelihood of these adverse outcomes, including thorough preoperative assessment incorporating risk assessment tools, optimisation of comorbidities, and ensuring complex head and neck cancer surgeries are performed in high-volume centres (Datema et al., 2010; Dautremont et al., 2013; Ghazali et al., 2017; Madrigal et al., 2022; Rosado et al., 2015). This chapter represents one of the first comprehensive micro-costing studies of jaw reconstruction using an individualised bottom-up approach and establishes a robust cost foundation for subsequent economic evaluations in this thesis.

7.1.3 COMPARING THE COSTS OF COMMERCIAL AND POINT-OF-CARE VSP

Given the substantial costs identified in **Chapter 3,** strategies to minimise expenditure without compromising clinical outcomes warrant investigation. VSP is increasingly employed in jaw reconstruction due to its established benefits, including greater reconstruction accuracy, reduced ischemia and operative time, shorter length of stay, lower complication rates, and

higher rates of successful dental rehabilitation (Foley et al., 2013; Li et al., 2018; Metzler et al., 2014; Petrides et al., 2021; Powcharoen et al., 2019; Roser et al., 2010; Salgueiro & Stevens, 2010). However, the considerable expense of outsourcing VSP to commercial providers has prompted many institutions to develop in-house capabilities using commercially available software and three-dimensional printers (Dupret-Bories et al., 2018; McAllister et al., 2018; Mottini et al., 2016; Smithers et al., 2018). **Chapter 4** addressed the third aim by comparing the direct costs of commercial VSP (C-VSP) and POC-VSP.

This cost-minimisation analysis demonstrated that POC-VSP achieves an average cost reduction of A$9,835 per case compared to C-VSP following propensity score matching, with the VSP workflow itself being the primary driver of cost differences. While the financial advantages of POC-VSP over C-VSP have been consistently reported, most existing studies lack pre-established clinical equivalency and employ limited costing methodologies – shortcomings that this study specifically addresses (Block et al., 2024; Dupret-Bories et al., 2018; Li et al., 2018; Spaas & Lenssen, 2019; Williams et al., 2020; Xiao et al., 2025). These savings have meaningful implications for institutional budgets and may improve patient access to VSP as a component of routine care.

However, the analysis also demonstrated that the economic value of POC-VSP is driven by economies of scale (Li et al., 2018). At our institution, the crossover point at which POC-VSP becomes more economical than C-VSP was seven cases annually, increasing to 17 cases when Therapeutic Goods Administration (TGA) conformity assessment requirements are factored in. This exemplifies the importance of utilising POC-VSP infrastructure to applications other than jaw reconstruction such as dental rehabilitation, orthopaedic surgery, neurosurgery, and academic research. Moreover, the POC-VSP workflow examined in this study was made more

expensive by ensuring it meets local regulatory requirements. However, we feel these costs are necessary to ensure the safety and quality of in-house products and more accurately reflect the true investment required for a sustainable and clinically robust POC-VSP program (Jeong et al., 2025). This chapter represents one of the first cost-minimisation analyses of VSP approaches conducted on the basis of pre-established clinical equivalency and provides institutions with guidance around whether POC-VSP is economically viable for their population.

7.1.4 Evaluating Private Health Insurance Reimbursement

Beyond institutional cost minimisation, the sustainability of jaw reconstruction services depends on adequate reimbursement to recover true costs. **Chapter 5** addressed the fourth aim by comparing the micro-costed direct costs established in **Chapter 3** with private health insurance (PHI) reimbursement and identifying factors contributing to any observed discrepancies. When considering direct costs alone, PHI reimbursement appeared adequate with 64% of cases classified as profitable and a mean surplus of A$2,439. However, when overhead costs were modelled at 20% to 40% of total costs, the funding position reversed substantially: 92% to 100% of cases became loss-making, with mean deficits ranging from A$26,066 to A$49,540 (Christou et al., 2022; Oostenbrink et al., 2002; St-Hilaire & Crépeau, 2000). Even at the lower end of these estimates, PHI reimbursement was insufficient to cover the full cost of admission for the majority of jaw reconstruction patients.

Current PHI reimbursement generally accounts for complexity indicators shown to increase costs – including bony free flap reconstruction, tracheostomy, operative duration, postoperative complications, and return to the operating room – with higher absolute reimbursement amounts but no significant difference in funding gap (Chang et al., 2017; Gourin et al., 2011; Gourin &

Frick, 2012; Yang et al., 2019). However, the reimbursement model was independently associated with the funding gap, with fee-for-service patients demonstrating a deficit of A$10,825 larger on average than that of per-episode patients. This may reflect limitations in fee-for-service models: itemised rates may be negotiated below true cost, certain activities may not be captured as billable items, and payments do not adjust for case complexity (Hanning, 2005). Nevertheless, when overhead costs were included, both models failed to recover true costs, suggesting that current reimbursement – regardless of model – does not adequately capture the resource-intense nature of jaw reconstruction. This chapter represents the first Australian study, and to our knowledge the first internationally, to compare micro-costed direct costs with insurance reimbursement for jaw reconstruction, providing critical evidence regarding the financial sustainability of these essential services.

7.1.5 MAPPING FACE-Q TO EQ-5D-5L TO FACILITATE COST-UTILITY ANALYSIS

While **Chapters 3-5** focused on the cost side of economic evaluation, understanding the health effects and quality of life gains from jaw reconstruction is also essential for comprehensive economic analysis. **Chapter 6** addressed the fifth aim by mapping the disease-specific FACE-Q Head and Neck Cancer (FACE-Q) to the generic preference-based EQ-5D-5L instrument. FACE-Q is a valuable disease-specific patient-reported outcome measure that addresses multiple health-related quality-of-life domains and overcomes limitations of existing tools for head and neck cancer patients (Cracchiolo et al., 2019). However, its disease specificity precludes its use in economic evaluations comparing different treatments or conditions (Drummond, 2015; McTaggart-Cowan et al., 2013).

The analysis of 270 paired observations from 181 patients demonstrated that beta regression was the optimal mapping framework due to its ability to accommodate the bounded, right-

skewed distribution of EQ-5D-5L data (RMSE = 0.131; MAE = 0.084). This finding aligns with recent literature emphasising beta regression as the most effective model for predicting EQ-5D utilities, though it contrasts with historical practice (Khan & Morris, 2014; Khan et al., 2016; Lamu & Olsen, 2018; Wailoo et al., 2017). Several FACE-Q domains were significant predictors of health utility, including oral competence, speaking, smiling, and worry, with notable interactions between functional and psychosocial domains. This chapter represents the first FACE-Q mapping study and provides a validated algorithm for deriving quality-adjusted life years (QALYs) from FACE-Q data in the absence of utility scores collected directly from patients, enabling future cost-utility analyses of jaw reconstruction interventions.

7.2 CLINICAL AND RESEARCH IMPLICATIONS

The findings from this thesis have implications for clinicians, researchers, healthcare institutions, policymakers and funders working in jaw reconstruction and health economics.

7.2.1 IMPLICATIONS FOR CLINICIANS

The findings from this thesis have several implications for clinical decision-making and patient care. **Chapter 3** highlighted that jaw reconstruction is inherently expensive; however, the findings also demonstrated that certain modifiable factors drive total cost. Most notably, early postoperative complications necessitating return to the OR and ICU were the strongest independent cost-drivers. While a proportion of this additional cost stems from increased medication use, investigations, and consultations with speciality teams, the primary driver was increased length of hospital admission as a consequence of these complications. Many postoperative complications are unavoidable; however, strategies aimed at reducing preventable complications – including meticulous surgical technique, vigilant postoperative monitoring, early involvement of consulting teams, and advocacy for complex head and neck

cancer surgeries to be performed in high-volume centres – may yield substantial cost savings in addition to improving patient outcomes.

These considerations extend to the preoperative stage of jaw reconstruction, including patient selection and optimisation of comorbidities. Total cost was significantly higher in patients with serious comorbidities such as American Society of Anaesthesiologists (ASA) Class and vasculopathy. Therefore, appropriate patient selection and preoperative optimisation of modifiable comorbidities through multidisciplinary assessment – including involvement of anaesthetics and relevant medical specialities – and incorporation of validated risk assessment tools such as the Revised Cardiac Risk Index may reduce the risk of costly postoperative complications and prolonged admission. **Chapter 3** also identified several modifiable clinical factors that may be targeted to minimise cost. Tracheostomy was independently associated with a 35% increase in admission costs. However, this association should be interpreted with caution as tracheostomy is clinically indicated in many patients' undergoing jaw reconstruction, with avoidance introducing potential risks. The most clinically appropriate approach to cost reduction is through strategies that simultaneously improve patient outcomes including complication prevention and patient optimisation.

Routine ICU admission is common following jaw reconstruction, yet ICU beds are substantially more expensive than general ward beds due to high nurse-to-patient ratios and specialised interventions including continuous cardiac monitoring and mechanical ventilation. **Chapter 3** demonstrated a theoretical cost reduction of 9.1% with the avoidance of ICU admission. These findings suggest that protocols for postoperative care – including criteria for ICU admission, step-down pathways, and immediate non-ICU postoperative care approaches – warrant ongoing evaluation. High-volume centres should consider whether routine ICU

admission remains appropriate for all patients or whether selected low-risk patients may be safely managed in alternative settings.

7.2.2 IMPLICATIONS FOR RESEARCHERS

The studies comprising this thesis hold implications for researchers in the field of jaw reconstruction health economics by providing insight into future research methodologies and priorities. It is clear from the scoping review in **Chapter 2** that current economic literature is limited by considerable issues in methodology. For instance, the validity of many studies' findings is undermined by inadequate and unclear methods of measuring costs. The micro-costing analysis presented in **Chapter 3** directly addresses this gap by presenting a detailed and transparent methodology that can be replicated by researchers at other institutions and adapted to other complex surgical interventions. Future economic evaluations of jaw reconstruction should consider adopting similar micro-costing approaches to improve accuracy and meaningful comparison across studies.

Further, the scoping review in **Chapter 2** highlighted a current deficiency in high-quality full economic evaluations on jaw reconstruction, comprising only 8% of included studies. The overwhelming proportion of existing studies were instead partial economic evaluations, which assess costs in isolation and provide limited evidence for decisions around resource allocation. Researchers interested in the economics of jaw reconstruction must focus on conducting full economic evaluations, which assess both costs and outcomes, to determine the true value of treatment options. This thesis provides a foundation for said analyses, with the micro-costing data in **Chapter 3** and the mapping algorithm in **Chapter 6** planned to be used together to perform future cost-utility analyses.

The mapping algorithm presented in **Chapter 6** also carries implications for researchers outside of COBL. The preferred mapping model is presented transparently and allows researchers with existing FACE-Q datasets to retrospectively extract EQ-5D-5L health-utility values where these have not been previously collected. These health-utility values can then be applied for use in cost-utility analyses of various interventions in their own jaw reconstruction cohorts. Moreover, given the utility of health-preference data for economic evaluation in general, researchers should incorporate general preference-based measures such as EQ-5D-5L into their routine prospective HRQoL outcome collection.

7.2.3 IMPLICATIONS FOR HEALTHCARE INSTITUTIONS

The findings from this thesis carry meaningful implications for healthcare institutions that currently provide jaw reconstruction services. The micro-costing methodology in **Chapter 3** is presented transparently and in detail, facilitating its application at other centres. Through an appreciation of the true total costs, major cost-contributors, and specific cost-drivers associated with jaw reconstruction in their cohorts, micro-costing analyses can help institutions to identify potential areas of improved efficiency, compare economic findings to other institutions, and inform discussions with funding bodies. Further, this methodology is equally relevant and can be modified for use in other complex surgical interventions to enable similar insights to be recognised across other specialties.

The findings from the cost-minimisation analysis in **Chapter 4** are valuable to healthcare institutions currently performing jaw reconstruction using VSP. The results quantified the considerable cost savings associated with POC-VSP workflows compared to traditional commercial outsourcing. However, this study also emphasised the considerable initial investment and setup costs required with POC-VSP resulting in an economy of scale effect,

whereby C-VSP may be more economical for institutions with lower case volumes. At our institution, the annual case volume at which POC-VSP becomes more cost-effective (i.e. the crossover point) was seven cases, increasing to 17 cases when TGA conformity assessment costs were included. Despite the additional costs, we consider the costs associated with adherence to more rigorous quality and regulatory standards necessary to ensure the safety and quality of in-house products. This crossover point can also be decreased by applying POC-VSP infrastructure to applications other than jaw reconstruction such as dental rehabilitation, neurosurgery, orthopaedic surgery, and academic research. Nevertheless, institutions considering setting up POC-VSP workflows must assess their own expected case volumes to determine economic viability.

The cost-reimbursement study in **Chapter 5** suggested that PHI reimbursement for jaw reconstruction patients may be inadequate. If this finding is consistent across other institutions, the provision of and patient access to jaw reconstruction services may be compromised. Other institutions must perform similar evaluations in their own populations to identify potential reimbursement gaps. If consistent and meaningful gaps are found, findings can be used to inform discussions with PHI funds around the need to reevaluate funding models or renegotiate pre-established rates or jaw reconstruction patients.

7.2.4 IMPLICATIONS FOR POLICYMAKERS AND FUNDERS

The findings from this thesis have direct relevance for health policy and funding decisions affecting jaw reconstruction services. As previously mentioned, the scoping review in **Chapter 2** highlighted a lack of full economic evaluations on jaw reconstruction. Consequently, there is currently limited evidence available to inform decisions around resource allocation in this population.

For example, the Medical Devices and Human Tissue Advisory Committee (MDHTAC) recently published a post-listing review on biomodels and surgical guides used in VSP, proposing that these be delisted from the Prescribed List given insufficient economic evidence (Australian Government, 2023). It is critical that the findings from comprehensive economic evaluations be used to guide decisions regarding the listing or delisting of VSP-related items, particularly as much of the literature supports potential downstream economic benefits of VSP including reduced operative time, shorter length of admission, and improved clinical outcomes. Moreover, the MDHTAC review does not address the economic benefit of POC-VSP workflows which, at our institution, have been shown to achieve equivalent short-term clinical outcomes at lower costs than outsourcing to commercial companies (**Chapter 4**). To ensure the most evidence-based and economical decisions are made, policymakers must support researchers in conducting and incorporating findings from full economic evaluations of potential interventions.

Chapter 5 suggests that current PHI reimbursement inadequately recovers the true costs of jaw reconstruction. Consequently, institutions offering jaw reconstruction services may face financial disincentives that could compromise service provision and patient access. We identified several factors that may contribute to this funding inadequacy: reimbursement models may not adequately capture overhead costs; current funding models may insufficiently adjust for the complexity and heterogeneity of jaw reconstruction admissions; and fee-for-service reimbursement models may induce larger funding deficits secondary to incomplete capture and billing of all activities and pre-negotiated rates being below true cost. Further research to confirm the generalisability of our findings is needed; however, it may be that funds

should consider transitioning to an activity-based or per-episode funding model – which better reflects case complexity – to improve the appropriateness of reimbursement.

7.3 STRENGTHS OF THE THESIS

This thesis has several methodological and conceptual strengths that enhance the validity and contribution of its findings.

7.3.1 TRANSPARENT AND REPLICABLE MICRO-COSTING METHODOLOGY

To the best of our knowledge, the micro-costing analysis in **Chapter 3** is the most detailed and transparent micro-costing study on jaw reconstruction to date. The individualised and bottom-up costing approach ensured that resource consumption was estimated at the patient level, allowing specific cost-drivers to be identified and analysed. This costing study provides a strong foundation for the economic evaluations presented in **Chapters 4 and 5,** ensuring internal consistency across the thesis. Most importantly, the detailed and transparent presentation of our micro-costing methodology facilitates replication at other institutions and for other surgical interventions. Each activity, source of costing data, and approach to measuring resources is described comprehensively. This directly addresses a key limitation identified in the scoping review presented in **Chapter 2,** where numerous studies did not describe their costing methodology transparently or failed to include this at all.

7.3.2 RIGOROUS METHODOLOGICAL APPROACHES

The studies comprising this thesis were conducted in accordance with existing literature, protocols, and established guidelines. The scoping review presented in **Chapter 2** was reported in accordance with the PRISMA extension for scoping reviews (PRISMA-ScR) to ensure

comprehensive identification of relevant literature and reproducibility (Tricco et al., 2018). The micro-costing analysis presented in **Chapter 3** was designed using previous systematic reviews and methodological publications on micro-costing (Centre for Health Economics Research and Evaluation, 2008; Frick, 2009; Ismail et al., 2015; Potter et al., 2020). This ensured that the approach to measuring costs was valid and addressed the methodological limitations of existing literature.

Under the guidance of a specialist in health economic statistical analysis (H.K.), **Chapters 4 and 6** comprised rigorous statistical approaches to minimise bias in the results. For example, the CMA presented in **Chapter 4** included propensity score matching to minimise selection bias from the non-randomised nature of treatment allocation when comparing POC-VSP to C-VSP. This analysis was also conducted based on pre-established clinical equivalency between interventions, a prerequisite for CMA that is often absent from existing comparative studies. The mapping study presented in **Chapter 6** utilised multiple regression frameworks with model selection based on established statistical criteria. Hence, the chosen approach effectively accommodated the distributional characteristics of EQ-5D-5L data, improving the accuracy of our prediction model.

7.3.3 HIGH-VOLUME TERTIARY REFERRAL CENTRE SETTING

All empirical studies in this thesis utilised data from patients undergoing jaw reconstruction at COBL. COBL is a not-for-profit private hospital that serves as a referral centre for public and private patients with head and neck cancer from across New South Wales (NSW). The hospital performs the highest caseload of complex head and neck cancer surgery in NSW, and is a quaternary referral centre for jaw reconstruction. There are methodological advantages to this research setting. Given the high caseload, research was conducted using a large and

heterogeneous jaw reconstruction cohort, allowing for meaningful conclusions to be drawn from statistical analyses across all studies. Moreover, clinical care pathways for jaw reconstruction have been established and optimised at COBL to ensure that documentation and resource capture were comprehensive and differences in care between patients were minimal.

7.4 LIMITATIONS OF THE THESIS

There are numerous limitations of this thesis that must be addressed. The primary limitations of the overall thesis are discussed here with the limitations of the studies presented in **Chapters 2-6** presented in detail in their respective chapters.

7.4.1 DATA COLLECTION

The micro-costing data collected in **Chapter 3** served as the foundation for economic evaluations in **Chapters 4 and 5.** Despite the granularity of data collection being a strength of this thesis, several limitations must be noted. Data was collected retrospectively through extraction from medical records, administrative databases, and consultation with hospital departments. Consequently, the accuracy of cost estimates is dependent on the quality and completeness of resource documentation. In a small number of instances, information was unavailable and required modelling or estimation. For example, perioperative staffing and disposable costs could not be accurately separated in **Chapter 3**, and overhead costs in **Chapter 5** were modelled using published estimates (20-40% of direct costs) rather than institution-specific data. Prospective data collection would enable more precise capture of resource consumption, particularly for items not routinely documented. However, prospective collection was not feasible for this thesis as it would have considerably limited the size of the cohort evaluated.

7.4.2 GENERALISABILITY

The empirical studies in this thesis were conducted using data from patients treated at a single Australian institution, Chris O'Brien Lifehouse Hospital (COBL), limiting external validity. Collecting data from a single centre was necessary from a feasibility perspective and facilitated methodological consistency across individual patients and studies. However, COBL is a unique institution: it is a not-for-profit private hospital treating both public and private patients, serves as a quaternary referral centre for jaw reconstruction, and performs the highest caseload of complex head and neck cancer surgery in New South Wales. The findings may not generalise to lower-volume centres, hospitals operating in different healthcare systems – including those in other Australian states or countries – or institutions with alternative clinical pathways. This high-volume tertiary referral setting may result in cost structures, complication rates, and patient complexity that differ from smaller or non-specialist centres.

Similarly, the cost-minimisation analysis in **Chapter 4** reflects the specific POC-VSP workflow and infrastructure at COBL. Institutions with different equipment, software, staffing models, or regulatory requirements may experience different cost structures. The break-even thresholds identified may therefore not directly transfer to other settings, although the analytical framework and relative cost relationships still apply.

The FACE-Q Head and Neck to EQ-5D-5L mapping algorithm developed in **Chapter 6** employed Australian preference weights for the EQ-5D-5L value set. Health state preferences vary between populations, and the algorithm may require recalibration for application in other jurisdictions where different value sets are used.

Despite these limitations, the relative cost-drivers and proportional relationships identified in this thesis are likely to apply in other settings, as supported by similar findings in the existing international literature.

7.4.3 Focus on Specific Costs

Whilst this thesis conducted a variety of economic evaluations, the analyses focused on specific cost categories and time horizons. Only direct financial costs associated with the index hospital admission were evaluated. Long-term costs – including follow-up appointments, readmissions, additional procedures, management of long-term complications, disease recurrence, dental rehabilitation, and ongoing surveillance – were not captured. A lifetime horizon would provide a more complete understanding of the total economic burden of jaw reconstruction.

Furthermore, this thesis adopted a healthcare provider perspective throughout, excluding broader patient and societal costs. These costs are particularly relevant in the jaw reconstruction population, where patients frequently experience extended recovery periods, and include productivity losses, caregiver burden, travel expenses, and out-of-pocket costs.

7.5 Future Directions

The findings from this thesis provide a foundation for future research in the health economics of jaw reconstruction. Several priorities have emerged from both the contributions and limitations of this work. The empirical economic studies in this thesis were conducted at a single quaternary referral centre with high case volumes and established clinical pathways. Future research should replicate the micro-costing methodology at other institutions – including lower-volume centres and those operating in different healthcare systems – to

evaluate the generalisability of cost estimates and cost-driver associations presented here. Multi-centre replication would also facilitate analysis of institutional factors influencing cost, including case volume, staffing models, and postoperative care protocols. The development of collaborative networks incorporating standardised data collection and multi-institutional databases would further strengthen the evidence base and facilitate future high-quality economic evaluations of jaw reconstruction.

As outlined in the limitations section, this thesis focused on the direct financial costs associated with the index hospital admission and excluded costs from the perspective of the patient and society. The resource-intensive nature of jaw reconstruction undeniably extends beyond this time horizon, with substantial costs resulting from ongoing follow-up appointments, surveillance imaging, readmissions, revision surgery, management of long-term complications, and treatment of disease recurrence. Moreover, jaw reconstruction patients frequently experience prolonged recovery periods with a significant impact on employment, productivity, and caregiver burden. Future research should address these gaps by adopting a societal perspective and an extended time horizon to provide a more comprehensive assessment of economic burden and to inform resource allocation decisions beyond the acute hospital setting.

There is a clear need for full economic evaluations of jaw reconstruction, particularly focusing on VSP, where the economic benefit remains controversial. This thesis provides the direct foundation for a cost-utility analysis comparing VSP approaches to conventional non-VSP techniques, using the micro-costing data established in **Chapter 3** and the validated FACE-Q mapping algorithm developed in **Chapter 6**. This would enable health utility values to be derived from FACE-Q data already collected for these patients, establishing the cost per quality-adjusted life year of each approach in an Australian context. Full economic evaluations

of VSP are particularly urgent given the recent MDHTAC post-listing review of biomodels and surgical guides, where delisting from the Prescribed List was proposed, citing insufficient economic evidence. Comprehensive cost-utility data would provide the evidence base necessary to inform these policy decisions and ensure continued patient access to beneficial technology.

Dental rehabilitation as a component of jaw reconstruction is increasingly recognised as critical for restoring masticatory function and health-related quality of life. However, like VSP, dental rehabilitation is associated with high upfront costs and the economic implications of different strategies – including implant-supported prostheses, conventional dentures, obturator prosthesis, or no rehabilitation – remain poorly understood. Additionally, there are ongoing concerns around both public and private reimbursement for dental rehabilitation in jaw reconstruction patients. A substantial proportion of the jaw reconstruction population at COBL receive endosseous dental implants (55% in the micro-costing cohort in **Chapter 3**), providing an opportunity for future research comparing the costs, outcomes, and cost-effectiveness of alternative dental rehabilitation pathways. Such research would inform clinical decision-making regarding the timing and extent of rehabilitation and support advocacy for adequate funding of these services.

The cost-reimbursement analysis presented in **Chapter 5** examined PHI reimbursement only. A priority for future research is the evaluation of reimbursement adequacy for patients managed in the public sector. Future studies should compare micro-costed direct costs with activity-based funding under Australian Refined Diagnosis-Related Groups (AR-DRGs) in public hospitals. Given that COBL treats both public and private patients, and a meaningful proportion of patients in this thesis were not privately insured, this evaluation is feasible and is

currently planned. Such research would determine whether the funding inadequacy identified in **Chapter 5** also applies to the public sector and would identify patient and clinical factors associated with funding discrepancies. Ultimately, this would inform discussions with state health departments regarding the adequacy of AR-DRG weights for the complex and heterogeneous cohort of jaw reconstruction patients.

7.6 CONCLUDING STATEMENT

Jaw reconstruction is one of the most resource-intensive procedures in head and neck surgery, yet the economic implications have remained poorly understood. This thesis addressed this knowledge gap by presenting five interrelated studies examining the health economics of jaw reconstruction.

The scoping review highlighted that the current literature base was methodologically flawed and dominated by partial economic evaluations. The micro-costing analysis determined the true costs of jaw reconstruction admissions, finding the strongest independent cost-drivers to be early postoperative complications requiring return to the operating room and intensive care unit. The cost-minimisation analysis demonstrated that POC-VSP is considerably less expensive than outsourcing to commercial companies; however, break-even thresholds are dependent on annual caseloads and regulatory requirements. The cost-reimbursement analysis revealed that current reimbursement for private patients may not completely recover true costs, highlighting potential systemic issues around the financial sustainability of jaw reconstruction services. The FACE-Q to EQ-5D-5L mapping study provides a validated algorithm to derive health utilities from existing datasets, enabling future cost-utility analysis.

Collectively, this thesis establishes foundational economic evidence to inform clinical decision-making, institutional resource allocation, health policy, and future research. Future research must prioritise full economic evaluations, validate these findings across multiple centres, and adopt extended time horizons and societal perspectives to build upon this foundation and ensure that patients continue to have access to high-quality jaw reconstruction services.

7.7 REFERENCES

Abo Sharkh, H., & Makhoul, N. (2020). In-house surgeon-led virtual surgical planning for maxillofacial reconstruction. *Journal of Oral and Maxillofacial Surgery,* 78(4), 651–660. https://doi.org/10.1016/j.joms.2019.11.013

Australian Government. (2023). Review of surgical guides and biomodels currently listed on the Prostheses List. Australian Government Department of Health and Aged Care. https://www.health.gov.au/resources/publications/prostheses-list-post-listing-review-consultants-report

Block, O. M., Khromov, T., Hoene, G., Schliephake, H., & Brockmeyer, P. (2024). In-house virtual surgical planning and guided mandibular reconstruction is less precise, but more economical and time-efficient than commercial procedures. *Head & Neck*, 46(4), 871–883. https://doi.org/10.1002/hed.27642

Centre for Health Economics Research and Evaluation. (2008). Issues in the costing of large projects in health and healthcare. https://www.health.nsw.gov.au/research/Pages/costing-large-health-projects.aspx

Chang, C. S., Chu, M. W., Nelson, J. A., Basta, M., Gerety, P., Kanchwala, S. K., & Wu, L. C. (2017). Complications and cost analysis of intraoperative arterial complications in

head and neck free flap reconstruction. *Journal of Reconstructive Microsurgery*, 33(5), 318–327. https://doi.org/10.1055/s-0037-1598618

Christou, C. D., Athanasiadou, E. C., Tooulias, A. I., Tzamalis, A., & Tsoulfas, G. (2022). The process of estimating the cost of surgery: Providing a practical framework for surgeons. *The International Journal of Health Planning and Management*, 37(4), 1926–1940. https://doi.org/10.1002/hpm.3431

Cracchiolo, J. R., Klassen, A. F., Young-Afat, D. A., Albornoz, C. R., Cano, S. J., Patel, S. G., Pusic, A. L., & Matros, E. (2019). Leveraging patient-reported outcomes data to inform oncology clinical decision making: Introducing the FACE-Q head and neck cancer module. Cancer, 125(6), 863–872. https://doi.org/10.1002/cncr.31900

Datema, F. R., Poldermans, D., & Baatenburg de Jong, R. J. (2010). Incidence and prediction of major cardiovascular complications in head and neck surgery. *Head & Neck,* 32(11), 1485–1493. https://doi.org/10.1002/hed.21351

Dautremont, J. F., Rudmik, L. R., Yeung, J., Asante, T., Nakoneshny, S. C., Hoy, M., Lui, A., Chandarana, S. P., Matthews, T. W., & Schrag, C. (2013). Cost-effectiveness analysis of a postoperative clinical care pathway in head and neck surgery with microvascular reconstruction. *Journal of Otolaryngology – Head & Neck Surgery,* 42(1), Article 59. https://doi.org/10.1186/1916-0216-42-59

Drummond, M. (2015). Methods for the economic evaluation of health care programmes (4th ed.). Oxford University Press.

Dupret-Bories, A., Vergez, S., Meresse, T., Brouillet, F., & Bertrand, G. (2018). Contribution of 3D printing to mandibular reconstruction after cancer. European Annals of Otorhinolaryngology, *Head and Neck Diseases*, 135(2), 133–136. https://doi.org/10.1016/j.anorl.2017.09.007

Foley, B. D., Thayer, W. P., Honeybrook, A., McKenna, S., & Press, S. (2013). Mandibular reconstruction using computer-aided design and computer-aided manufacturing: An analysis of surgical results. *Journal of Oral and Maxillofacial Surgery*, 71(2), e111–e119. https://doi.org/10.1016/j.joms.2012.08.022

Frick, K. D. (2009). Microcosting quantity data collection methods. *Medical Care,* 47(Suppl. 1), S76–S81. https://doi.org/10.1097/MLR.0b013e31819bc064

Ghazali, N., Caldroney, S., Dyalram, D., & Lubek, J. E. (2017). Cardiovascular complications in head & neck microvascular flap reconstruction: A retrospective risk stratification and outcomes assessment. *Journal of Cranio-Maxillofacial Surgery,* 45(12), 2120–2127. https://doi.org/10.1016/j.jcms.2017.10.002

Gourin, C. G., & Frick, K. D. (2012). National trends in oropharyngeal cancer surgery and the effect of surgeon and hospital volume on short-term outcomes and cost of care. *The Laryngoscope,* 122(3), 543–551. https://doi.org/10.1002/lary.22447

Gourin, C. G., Forastiere, A. A., Sanguineti, G., Marur, S., Koch, W. M., & Bristow, R. E. (2011). Impact of surgeon and hospital volume on short-term outcomes and cost of oropharyngeal cancer surgical care. *The Laryngoscope,* 121(4), 746–752. https://doi.org/10.1002/lary.21456

Hanning, B. W. T. (2005). Combining DRGs and per diem payments in the private sector: The Equitable Payment Model. *Australian Health Review,* 29(1), 80–86. https://doi.org/10.1071/ah050080

Ismail, I., Wolff, S., Gronfier, A., Mutter, D., & Swanström, L. L. (2015). A cost evaluation methodology for surgical technologies. *Surgical Endoscopy,* 29(8), 2423–2432. https://doi.org/10.1007/s00464-014-3929-4

Jeong, Y. J., Dunn, M., Manzie, T., Aung, Y. M., Cheng, K., Froggatt, C., Wykes, J., Leinkram, D., Low, T.-H., Ch'ng, S., & Clark, J. (2025). Point-of-care virtual surgical

planning for jaw reconstruction: An update on the experience with 50 patients at a tertiary referral center. *Journal of Plastic, Reconstructive & Aesthetic Surgery*, 111, 182–188. https://doi.org/10.1016/j.bjps.2025.09.027

Jones, N. F., Jarrahy, R., Song, J. I., Kaufman, M. R., & Markowitz, B. (2007). Postoperative medical complications—not microsurgical complications—negatively influence the morbidity, mortality, and true costs after microsurgical reconstruction for head and neck cancer. *Plastic and Reconstructive Surgery*, 119(7), 2053–2060. https://doi.org/10.1097/01.prs.0000260591.82762.b5

Khan, I., & Morris, S. (2014). A non-linear beta-binomial regression model for mapping EORTC QLQ-C30 to the EQ-5D-3L in lung cancer patients: A comparison with existing approaches. *Health and Quality of Life Outcomes,* 12(1), Article 163. https://doi.org/10.1186/s12955-014-0163-7

Khan, I., Morris, S., Pashayan, N., Matata, B., Bashir, Z., & Maguire, J. (2016). Comparing the mapping between EQ-5D-5L, EQ-5D-3L and the EORTC-QLQ-C30 in non-small cell lung cancer patients. *Health and Quality of Life Outcomes,* 14(1), Article 60. https://doi.org/10.1186/s12955-016-0455-1

Lamu, A. N., & Olsen, J. A. (2018). Testing alternative regression models to predict utilities: Mapping the QLQ-C30 onto the EQ-5D-5L and the SF-6D. *Quality of Life Research,* 27(11), 2823–2839. https://doi.org/10.1007/s11136-018-1981-6

Li, S. S., Copeland-Halperin, L. R., Kaminsky, A. J., Li, J., Lodhi, F. K., & Miraliakbari, R. (2018). Computer-aided surgical simulation in head and neck reconstruction: A cost comparison among traditional, in-house, and commercial options. *Journal of Reconstructive Microsurgery,* 34(5), 341–347. https://doi.org/10.1055/s-0037-1621735

Madrigal, J., Mukdad, L., Han, A. Y., Tran, Z., Benharash, P., St John, M. A., & Blackwell, K. E. (2022). Impact of hospital volume on outcomes following head and neck cancer surgery and flap reconstruction. *The Laryngoscope,* 132(7), 1381–1387. https://doi.org/10.1002/lary.29903

McAllister, P., Watson, M., & Burke, E. (2018). A cost-effective, in-house, positioning and cutting guide system for orthognathic surgery. *Journal of Maxillofacial and Oral Surgery,* 17(1), 112–114. https://doi.org/10.1007/s12663-017-1067-y

McTaggart-Cowan, H., Teckle, P., & Peacock, S. (2013). Mapping utilities from cancer-specific health-related quality of life instruments: A review of the literature. *Expert Review of Pharmacoeconomics & Outcomes Research*, 13(6), 753–765. https://doi.org/10.1586/14737167.2013.850420

Metzler, P., Geiger, E. J., Alcon, A., Ma, X., & Steinbacher, D. M. (2014). Three-dimensional virtual surgery accuracy for free fibula mandibular reconstruction: Planned versus actual results. *Journal of Oral and Maxillofacial Surgery*, 72(12), 2601–2612. https://doi.org/10.1016/j.joms.2014.07.024

Miller, M. J., Swartz, W. M., Miller, R. H., & Harvey, J. M. (1991). Cost analysis of microsurgical reconstruction in the head and neck. *Journal of Surgical Oncology,* 46(4), 230–234. https://doi.org/10.1002/jso.2930460405

Mottini, M., Seyed Jafari, S. M., Shafighi, M., & Schaller, B. (2016). New approach for virtual surgical planning and mandibular reconstruction using a fibula free flap. *Oral Oncology,* 59, e6–e9. https://doi.org/10.1016/j.oraloncology.2016.06.001

Oostenbrink, J. B., Koopmanschap, M. A., & Rutten, F. F. (2002). Standardisation of costs: The Dutch Manual for Costing in economic evaluations. *PharmacoEconomics,* 20(7), 443–454. https://doi.org/10.2165/00019053-200220070-00002

Petrides, G. A., Hicks, G., Dunn, M., Froggatt, C., Wallace, C., Howes, D., Leinkram, D., Low, T.-H., Ch'ng, S., Wykes, J., Palme, C. E., & Clark, J. R. (2021). Dentoalveolar outcomes in maxillary reconstruction: A retrospective review of 85 maxillectomy reconstructions. *ANZ Journal of Surgery,* 91(7–8), 1472–1479. https://doi.org/10.1111/ans.17001

Potter, S., Davies, C., Davies, G., Rice, C., & Hollingworth, W. (2020). The use of micro-costing in economic analyses of surgical interventions: A systematic review. *Health Economics Review,* 10(1), Article 3. https://doi.org/10.1186/s13561-020-0260-8

Powcharoen, W., Yang, W. F., Yan Li, K., Zhu, W., & Su, Y. X. (2019). Computer-assisted versus conventional freehand mandibular reconstruction with fibula free flap: A systematic review and meta-analysis. *Plastic and Reconstructive Surgery*, 144(6), 1417–1428. https://doi.org/10.1097/prs.0000000000006261

Riaz, N., & Warraich, R. (2010). Reconstruction of mandible by free fibular flap. *Journal of the College of Physicians and Surgeons Pakistan*, 20(11), 723–727.

Ridyard, C. H., & Hughes, D. A. (2010). Methods for the collection of resource use data within clinical trials: A systematic review of studies funded by the UK Health Technology Assessment program. *Value in Health*, 13(8), 867–872. https://doi.org/10.1111/j.1524-4733.2010.00788.x

Rosado, P., Cheng, H.-T., Wu, C.-M., & Wei, F.-C. (2015). Influence of diabetes mellitus on postoperative complications and failure in head and neck free flap reconstruction: A systematic review and meta-analysis. *Head & Neck,* 37(4), 615–618. https://doi.org/10.1002/hed.23624

Roser, S. M., Ramachandra, S., Blair, H., Grist, W., Carlson, G. W., Christensen, A. M., Weimer, K. A., & Steed, M. B. (2010). The accuracy of virtual surgical planning in free fibula mandibular reconstruction: Comparison of planned and final results.

Journal of Oral and Maxillofacial Surgery, 68(11), 2824–2832. https://doi.org/10.1016/j.joms.2010.06.177

Salgueiro, M. I., & Stevens, M. R. (2010). Experience with the use of prebent plates for the reconstruction of mandibular defects. *Craniomaxillofacial Trauma & Reconstruction*, 3(4), 201–208. http://doi.org/10.1055/s-0030-1268520

Setälä, L., Koskenvuori, H., Gudaviciene, D., Berg, L., & Mustonen, P. (2009). Cost analysis of 109 microsurgical reconstructions and flap monitoring with microdialysis. *Journal of Reconstructive Microsurgery,* 25(9), 521–526. https://doi.org/10.1055/s-0029-1238218

Shaw, R. J., Sutton, A. F., Cawood, J. I., Howell, R. A., Lowe, D., Brown, J. S., Rogers, S. N., & Vaughan, E. D. (2005). Oral rehabilitation after treatment for head and neck malignancy. *Head & Neck,* 27(6), 459–470. https://doi.org/10.1002/hed.20176

Smithers, F. A. E., Cheng, K., Jayaram, R., Mukherjee, P., & Clark, J. R. (2018). Maxillofacial reconstruction using in-house virtual surgical planning. *ANZ Journal of Surgery*, 88(9), 907–912. https://doi.org/10.1111/ans.14353

Spaas, C., & Lenssen, O. (2019). Economic analysis of a low-cost virtual surgical planning protocol for mandibular reconstruction: A case series. *British Journal of Oral and Maxillofacial Surgery*, 57(8), 743–748. https://doi.org/10.1016/j.bjoms.2019.06.017

St-Hilaire, C., & Crépeau, P. K. (2000). Hospital and unit cost allocation methods. *Healthcare Management Forum,* 13(2), 12–32. https://doi.org/10.1016/s0840-4704(10)60742-9

Tewfik, K., Chiarelli, P., Copelli, C., Pederneschi, N., Cassano, L., Manfuso, A., Covelli, C., & Longo, F. (2021). Italian cost analysis of free flap surgery in head and neck reconstruction using the activity-based costing (ABC). *Journal of Plastic,*

Reconstructive & Aesthetic Surgery, 74(6), 1279–1285. https://doi.org/10.1016/j.bjps.2020.10.096

Tricco, A. C., Lillie, E., Zarin, W., O'Brien, K. K., Colquhoun, H., Levac, D., Moher, D., Peters, M. D. J., Horsley, T., Weeks, L., Hempel, S., Akl, E. A., Chang, C., McGowan, J., Stewart, L., Hartling, L., Aldcroft, A., Wilson, M. G., Garritty, C., . . . Straus, S. E. (2018). PRISMA extension for scoping reviews (PRISMA-ScR): Checklist and explanation. *Annals of Internal Medicine*, 169(7), 467–473. https://doi.org/10.7326/M18-0850

Wailoo, A. J., Hernandez-Alava, M., Manca, A., Mejia, A., Ray, J., Crawford, B., Botteman, M., & Busschbach, J. (2017). Mapping to estimate health-state utility from non-preference-based outcome measures: An ISPOR Good Practices for Outcomes Research Task Force report. *Value in Health*, 20(1), 18–27. https://doi.org/10.1016/j.jval.2016.11.006

Williams, F. C., Hammer, D. A., Wentland, T. R., & Kim, R. Y. (2020). Immediate teeth in fibulas: Planning and digital workflow with point-of-care 3D printing. *Journal of Oral and Maxillofacial Surgery*, 78(8), 1320–1327. https://doi.org/10.1016/j.joms.2020.04.006

Xiao, J. B., Banyi, N., Tran, K. L., & Prisman, E. (2025). Cost outcomes of virtual surgical planning in head and neck reconstruction: A systematic review. *Head & Neck,* 47(3), 1037–1057. https://doi.org/10.1002/hed.28035

Yang, Y., Li, P. J., Shuai, T., Wang, Y., Mao, C., Yu, G. Y., Guo, C. B., & Peng, X. (2019). Cost analysis of oral and maxillofacial free flap reconstruction for patients at an institution in China. *International Journal of Oral and Maxillofacial Surgery,* 48(5), 590–596. https://doi.org/10.1016/j.ijom.2018.10.020

APPENDICES

APPENDIX A: SUPPLEMENTARY MATERIAL FOR CHAPTER 2

APPENDIX A1: PRISMA-SCR CHECKLIST

Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) Checklist

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
TITLE			
Title	1	Identify the report as a scoping review.	Chapter Title
ABSTRACT			
Structured summary	2	Provide a structured summary that includes (as applicable): background, objectives, eligibility criteria, sources of evidence, charting methods, results, and conclusions that relate to the review questions and objectives.	Abstract
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known. Explain why the review questions/objectives lend themselves to a scoping review approach.	Introduction Paragraph 1 and 2
Objectives	4	Provide an explicit statement of the questions and objectives being addressed with reference to their key elements (e.g., population or participants, concepts, and context) or other relevant key elements used to conceptualize the review questions and/or objectives.	Introduction Paragraph 3
METHODS			
Protocol and registration	5	Indicate whether a review protocol exists; state if and where it can be accessed (e.g., a Web address); and if available, provide registration information, including the registration number.	Methods Paragraph 1
Eligibility criteria	6	Specify characteristics of the sources of evidence used as eligibility criteria (e.g., years considered, language, and publication status), and provide a rationale.	Methods Paragraph 2
Information sources*	7	Describe all information sources in the search (e.g., databases with dates of coverage and contact with authors to identify additional sources), as well as the date the most recent search was executed.	Methods Paragraph 2
Search	8	Present the full electronic search strategy for at least 1 database, including any limits used, such that it could be repeated.	Appendix A3
Selection of sources of evidence†	9	State the process for selecting sources of evidence (i.e., screening and eligibility) included in the scoping review.	Methods Paragraph 2
Data charting process‡	10	Describe the methods of charting data from the included sources of evidence (e.g., calibrated forms or forms that have been tested by the team before their use, and whether data charting was done independently or in duplicate) and any processes for obtaining and confirming data from investigators.	Methods Paragraph 3
Data items	11	List and define all variables for which data were sought and any assumptions and simplifications made.	Methods Paragraph 3
Critical appraisal of individual sources of evidence§	12	If done, provide a rationale for conducting a critical appraisal of included sources of evidence; describe the methods used and how this information was used in any data synthesis (if appropriate).	N/A
Synthesis of results	13	Describe the methods of handling and summarizing the data that were charted.	Methods Paragraph 3

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SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
RESULTS			
Selection of sources of evidence	14	Give numbers of sources of evidence screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally using a flow diagram.	Results Paragraph 1
Characteristics of sources of evidence	15	For each source of evidence, present characteristics for which data were charted and provide the citations.	Results Paragraph 1 and 2
Critical appraisal within sources of evidence	16	If done, present data on critical appraisal of included sources of evidence (see item 12).	N/A
Results of individual sources of evidence	17	For each included source of evidence, present the relevant data that were charted that relate to the review questions and objectives.	Results Paragraph 3-12
Synthesis of results	18	Summarize and/or present the charting results as they relate to the review questions and objectives.	Results Paragraph 3-12
DISCUSSION			
Summary of evidence	19	Summarize the main results (including an overview of concepts, themes, and types of evidence available), link to the review questions and objectives, and consider the relevance to key groups.	Discussion
Limitations	20	Discuss the limitations of the scoping review process.	Discussion Paragraph 8
Conclusions	21	Provide a general interpretation of the results with respect to the review questions and objectives, as well as potential implications and/or next steps.	Discussion
FUNDING			
Funding	22	Describe sources of funding for the included sources of evidence, as well as sources of funding for the scoping review. Describe the role of the funders of the scoping review.	N/A

JBI = Joanna Briggs Institute; PRISMA-ScR = Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews.
* Where *sources of evidence* (see second footnote) are compiled from, such as bibliographic databases, social media platforms, and Web sites.
† A more inclusive/heterogeneous term used to account for the different types of evidence or data sources (e.g., quantitative and/or qualitative research, expert opinion, and policy documents) that may be eligible in a scoping review as opposed to only studies. This is not to be confused with *information sources* (see first footnote).
‡ The frameworks by Arksey and O'Malley (6) and Levac and colleagues (7) and the JBI guidance (4, 5) refer to the process of data extraction in a scoping review as data charting.
§ The process of systematically examining research evidence to assess its validity, results, and relevance before using it to inform a decision. This term is used for items 12 and 19 instead of "risk of bias" (which is more applicable to systematic reviews of interventions) to include and acknowledge the various sources of evidence that may be used in a scoping review (e.g., quantitative and/or qualitative research, expert opinion, and policy document).

From: Tricco AC, Lillie E, Zarin W, O'Brien KK, Colquhoun H, Levac D, et al. PRISMA Extension for Scoping Reviews (PRISMAScR): Checklist and Explanation. Ann Intern Med. 2018;169:467–473. doi: 10.7326/M18-0850.

APPENDIX A2: SCOPING REVIEW PROTOCOL

Health economics of maxillary and mandibular reconstruction

A scoping review protocol

Prepared for Registration to Open Science Framework

Submitted 27/10/2025

Department of Head and Neck Surgery

Chris O'Brien Lifehouse Sydney

Contact:

Dr George A. Petrides

E: georgeapetrides@gmail.com

Review title and timescale

1. Review title:

Health economics of maxillary and mandibular reconstruction: A scoping review

2. Anticipated or actual start date:

15/10/2025

3. Anticipated completion date:

15/11/2025

4. Stage of review at time of this submission

The review has not yet started	☐	
Review stage *(Please check all that apply)*	**Started**	**Completed**
Preliminary searches	☐	✓
Piloting of the study selection process	☐	✓
Formal screening of search results against eligibility criteria	☐	☐
Data extraction	☐	☐
Risk of bias (quality assessment)	☐	N/A
Data analysis	☐	☐
Provide any other relevant information about the stage of the review here:	Not applicable	

Review team details

5. Named contact

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119-143 Missenden Rd, Camperdown NSW 2050.

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9. Organisational affiliation of the review

Department of Head and Neck Surgery, Chris O'Brien Lifehouse

10. Review team members and give their organisational affiliations

Give the title, first name and last name of all members of the team working directly on the review.
Give the organisational affiliations of each member of the review team

Title	First name	Last name	Affiliation
Dr	George	Petrides	Department of Head and Neck Surgery, Chris O'Brien Lifehouse, Sydney, Australia
Dr	Leonard	Lee	Department of Head and Neck Surgery, Chris O'Brien Lifehouse, Sydney, Australia
Dr	Masako	Dunn	Department of Head and Neck Surgery, Chris O'Brien Lifehouse, Sydney, Australia
Dr	Rebecca	Venchiarutti	Department of Head and Neck Surgery, Chris O'Brien Lifehouse, Sydney, Australia
Prof	Jonathan	Clark	Department of Head and Neck Surgery, Chris O'Brien Lifehouse, Sydney, Australia

11. Funding sources/sponsors

No funding sources or sponsors.

12. Conflicts of interest

Authors have no conflicts of interest to declare.

Review methods

13. Review questions:

This scoping review aims to assess the current knowledge base on the health economics of maxillary and mandibular reconstruction. The specific research questions are:

- What are the direct and indirect costs associated with maxillary and mandibular reconstruction?

- Which economic evaluation methods have been used (cost-effectiveness, cost-utility, cost-benefit)?

14. Literature search:

Comprehensive literature searches of electronic bibliographic databases were conducted by in MEDLINE, EMBASE, and the Cochrane Library. A grey literature search for unpublished and difficult to locate studies will be performed the reference list of all relevant reviews will be scanned.

15. URL to search strategy

Not applicable.

16. Condition or domain being studied

Health economics of jaw reconstruction.

17. Participants/population

Patients undergoing maxillary and/or mandibular reconstruction. The indication for resection and reconstruction includes malignant and non-malignant pathology. Examples of reconstruction include the use of obturator prosthesis or microvascular free flap reconstruction using options such as fibula, anterolateral thigh, scapula, and radial forearm donor sites.

18. Concept

Any economic analysis (costs, cost-effectiveness, resource utilisation, economic burden).

19. Context

All healthcare settings, all countries.

20. Types of studies to be included initially:

All types of publications including published articles, articles in conference proceedings, editorials, websites, and chapters in textbooks are relevant.

21. Primary outcome(s):

1. Identification of cost drivers and economic outcomes reported
2. Examine methodological approaches to economic evaluation
3. Identify gaps in the economic evidence base

22. Secondary outcome(s):

Not applicable

23. Data extraction (selection and coding):

1. Export all results to reference management software (e.g., EndNote, Mendeley)
2. Remove duplicates
3. Two reviewers independently screen titles/abstracts
4. Two reviewers independently screen full texts
5. Resolve disagreements through discussion or third reviewer
6. Document reasons for exclusion

Create a standardized extraction form including:

Study Characteristics:
- Author, year, country
- Study design
- Sample size
- Follow-up period

Clinical Data:
- Indication for reconstruction (cancer, trauma, etc.)
- Defect classification (Brown, Cordeiro, etc.)
- Reconstruction type
- Complications

Economic Data:
- Type of economic analysis
- Perspective (healthcare system, societal, patient)
- Time horizon
- Currency and year
- Direct costs (surgical, hospital, follow-up)
- Indirect costs (productivity loss, caregiver)
- Outcome measures (QALYs, cost per successful reconstruction)
- Sensitivity analyses performed

24. Risk of bias (quality assessment):

Since this is a scoping review, we will not conduct quality appraisal, which is consistent with the framework proposed by Arksey and O'Malley, as well as the Joanna Briggs Institute methodological guidance for Scoping Reviews.

25. Strategy for data synthesis

The synthesis will focus on providing: 1) a description on the current understanding of health economics of jaw reconstruction and 2) the validity of these results. This will be achieved by summarising the literature according to the types of participants, interventions, methodologies, and outcomes identified. Quantitative analysis will be conducted using descriptive methods (i.e., frequencies, summary statistics). As well, we will consider qualitative analysis (e.g., content analysis) for open-text data, as necessary, which will be conducted by two reviewers independently.

26. Analysis of subgroups or subsets

Not applicable.

Review general information

27. Type of review

Scoping review.

28. Language

English

29. Country

Australia

30. Other registration details

Not applicable

31. Reference and/or URL for published protocol

Awaiting upload to open sciences framework

32. Dissemination plans:

The summary of results will be formatted as a manuscript and submitted for consideration of publication in a relevant surgical journal.

Do you intend to publish the review on completion?
Yes ✓
No ☐

33. Keywords

Mandibular reconstruction; Maxillary reconstruction; Microvascular reconstruction; Free tissue flaps, Economics; Health care costs.

34. Details of any existing review of the same topic by the same authors

Not applicable

35. Current review status

Ongoing

36. Any additional information:

Not applicable

37. Details of final report/publication(s)

Not applicable (review still in progress)

APPENDIX A3: SEARCH STRATEGY FOR SCOPING REVIEW

Table 1. PubMed search strategy.

Line	Search Terms
1	maxilla [MeSH Terms]
2	mandible [MeSH Terms]
3	maxill*
4	mandibul*
5	jaw [MeSH Terms]
6	1 or 2 or 3 or 4 or 5
7	reconstructive surgical procedures [MeSH Terms]
8	free tissue flaps [MeSH Terms]
9	surgical flaps [MeSH Terms]
10	reconstruct*
11	7 or 8 or 9 or 10
12	economics [MeSH Terms]
13	costs and cost analysis [MeSH Terms]
14	quality-adjusted life years [MeSH Terms]
15	economic*
16	cost*
17	QALY
18	resource utilization
19	12 or 13 or 14 or 15 or 16 or 17 or 18
20	6 and 11 and 19

Table 2. EMBASE search strategy.

Line	Search Terms
1	(maxill*)mp.
2	(mandibul*)mp.
3	(jaw)mp.
4	1 or 2 or 3
5	(reconstructive surgical procedures)mp.
6	(free tissue flaps)mp.
7	(surgical flaps)mp.
8	(reconstruct*)mp.
9	5 or 6 or 7 or 8
10	(economics)mp.
11	(costs and cost analysis)mp.
12	(cost-benefit analysis)mp.

13	(quality-adjusted live years)mp.
14	(economic*)mp.
15	(cost*)mp.
16	(QALY)mp.
17	(resource utilization)mp.
18	10 or 11 or 12 or 13 or 14 or 15 or 16 or 17
19	4 and 9 and 18

Table 3. Cochrane search strategy.

Line	Search Terms
1	MeSH descriptor: [Maxilla] explode all trees
2	MeSH descriptor: [Mandible] explode all trees
3	MeSH descriptor: [Jaw] explode all trees
4	(1 or 2 or 3)ti,ab,kw
5	1 or 2 or 3 or 4
6	MeSH descriptor: [Mandibular Reconstruction] explode all trees
7	MeSH descriptor: [Free Tissue Flaps] explode all trees
8	MeSH descriptor: [Surgical Flaps] explode all trees
9	(reconstruct* or free flap* or tissue flap* or surgical flap*)ti,ab,kw
10	6 or 7 or 8 or 9
11	MeSH descriptor: (Evaluation) explode all trees
12	MeSH descriptor: [Costs and Cost Analysis] explode all trees
13	MeSH descriptor: [Cost-Benefit Analysis] explode all trees
14	MeSH descriptor: [Quality-Adjusted Life Years] explode all trees
15	MeSH descriptor: [Health Resources] explode all trees
16	MeSH descriptor: [Health Care Costs] explode all trees
17	(economic* or cost* price* or pricing or finance* or expenditure* or budget*)ti,ab,kw
18	(QALY or quality adjusted life year* or quality-adjusted life year*)ti,ab,kw
19	(cost effective* or cost-effective* or cost utility or cost-utility)ti,ab,kw
20	(resource utili* or healthcare utili*)ti,ab,kw
21	11 or 12 or 13 or 14 or 15 or 16 or 17 or 18 or 19 or 20
22	5 and 10 and 21

APPENDIX B: SUPPLEMENTAL MATERIAL FOR CHAPTER 3

APPENDIX B1: PATHWAY OF JAW RECONSTRUCTION PATIENTS

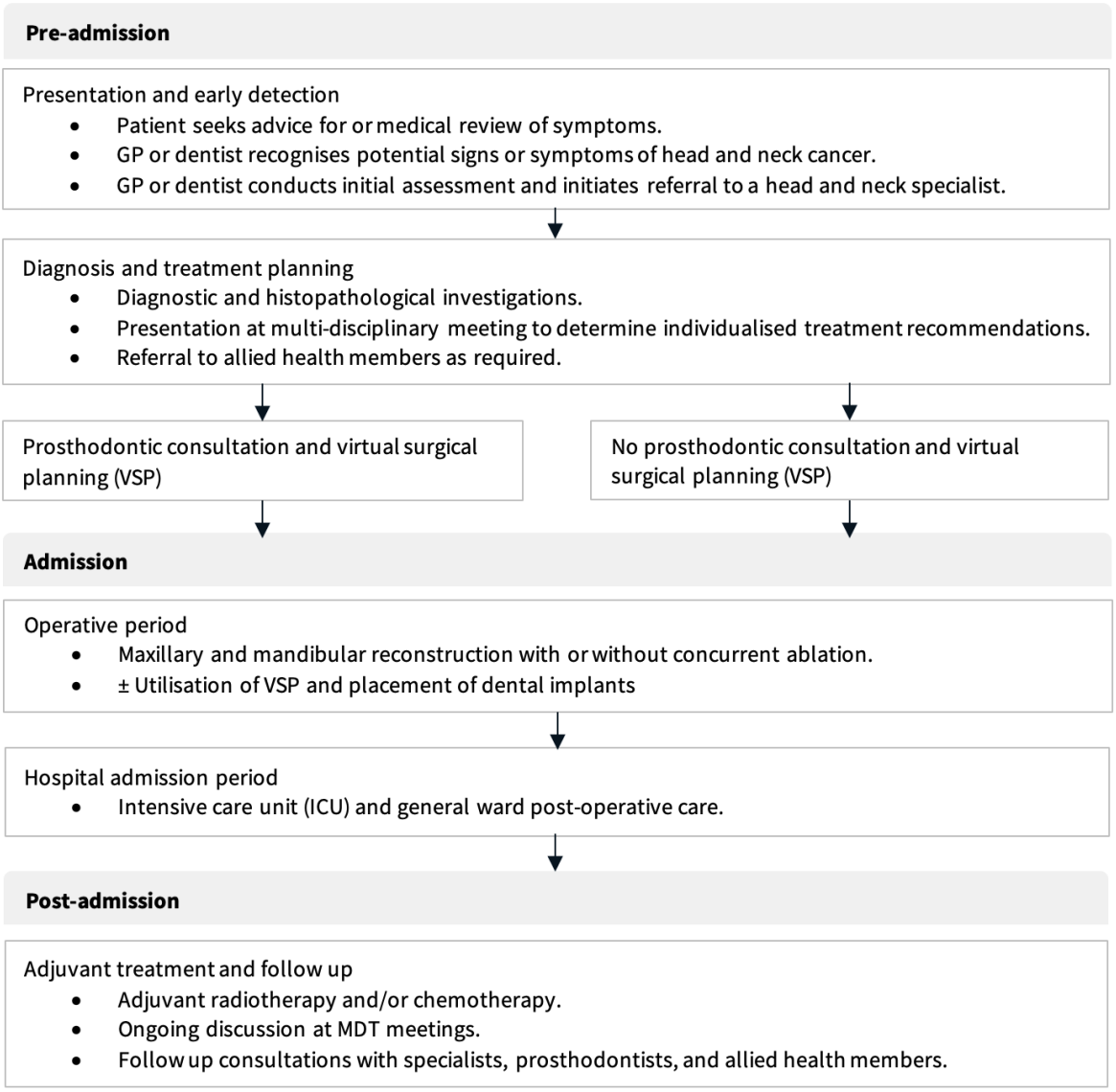

Figure 1. Pre-admission, admission, and post-admission activities involved in the reconstruction of the maxilla and mandible at Chris O'Brien Lifehouse Hospital (COBL). Only the activities constituting the admission period – consisting of the operative period and hospital admission period – were evaluated in this study.

APPENDIX B2: ACTIVITY INPUTS FOR JAW RECONSTRUCTION PATIENTS

Table 1. The activity inputs and associated costs constituting the operative and perioperative periods were subclassified into staffing costs and equipment costs.

Activity input	Operative period	Perioperative period
Staffing	Medical officers: • Surgical consultants • Surgical fellows • Surgical registrars • Anesthetic consultants Nursing staff: • Scrub nurses • Scout nurses • Anesthetic nurses	Medical officers: • Head and neck surgical team • Intensive care medical team Nursing staff: • Intensive care nurses • General ward nurses Consultations: • Allied health • Medical and surgical Other staffing: • Food preparation • Sanitation • Porters
Equipment	Operating theatre equipment Non-disposable equipment Disposable equipment Intraoperative medications Prostheses • Virtual surgical planning (VSP) • Dental implants • Screws and plates • Ligating clips • Venous couplers • Hemostatic agents • Other†	Investigations • Laboratory studies • Diagnostic imaging • Anatomical pathology Disposable equipment Medications Meals

†Includes eyelid weights, meshes, and bone cement.

APPENDIX B3: SALARY PER MINUTE OF STAFF MEMBERS

Table 2. Salary per minute from different staff members at Chris O'Brien Lifehouse Hospital (COBL) based on the Enterprise Agreements 2022 and NSW Health Award 2021.

Personnel	Annual salary (A$)	Annual salary (US$)	Salary per week (US$)	Salary per hour (US$)	Salary per minute (US$)
Specialist	428,097	283,508	–	143	2.38
Postgraduate fellow	209,389	138,668	–	70	1.17
Registrar	123,263	81,631	–	41	0.69
Registered Nurse	–		1,046	26	0.44

APPENDIX B4: COST OF OPERATING THEATRE EQUIPMENT

Table 3. The yearly cost for operating theatre equipment used in a typical maxillary or mandibular reconstruction case.

Item	Cost (A$)	Quantity	Total cost ($A)	Yearly cost ($A)	Yearly cost ($US)
Computers and Technology					
Keyboard	39.95	2	79.00	7.90	5.23
Mouse	19.95	2	39.90	3.99	2.64
Keyboard and Mouse	200.00	1	200.00	20.00	13.25
Keyboard	50.00	1	50.00	5.00	3.31
Printer 1	419.00	1	419.00	41.90	27.75
Printer 2	99.00	1	99.00	9.90	6.56
Phone	45.00	1	45.00	4.50	2.98
Display monitor	200.00	1	200.00	20.00	13.25
Computer	500.00	2	1,000.00	100.00	66.23
Computer monitor	300.00	2	600.00	60.00	39.74
Ethernet Extender	2157.38	1	2,157.38	215.74	142.87
Touch grade medical monitor	6,138.78	1	6.138.78	613.88	406.54
Surgical monitor	3,300.00	2	6,600.00	660.00	437.09
Wall monitor 1	5,000.00	1	5,000.00	500.00	331.13
Wall monitor 2	7,501.00	1	7,501.00	750.10	496.75

Item	Cost (A$)	Quantity	Total cost ($A)	Yearly cost ($A)	Yearly cost ($US)
Furniture					
Trolleys	520.00	5	2,600	260.00	172.19
Stryker chair	4,313.29	1	4,313.29	431.33	285.65
Surgical bowl stands	300.00	2	600.00	60.00	39.74
Doppler machine and handpiece	800.00	1	800.00	80.00	52.98
Surgical stool	275.00	4	1,100.00	110.00	72.85
Head ring	150.00	1	150.00	15.00	9.93
Jelly heel pad	150.00	2	300.00	30.00	19.87
Head and neck trolley	2,790.00	1	2,790.00	279.00	184.77
Mayo table	395.00	1	395.00	39.50	26.16
Bin	519.54	3	1,558.62	155.86	103.22
Linen skip	519.54	1	519.54	51.95	34.40
X-ray viewer	560.00	1	560.00	56.00	37.09
Anaesthetic trolley	2,350.00	1	2,350.00	235.00	155.63
Operating theatre table	40,000.00	1	40,000.00	4,000.00	2,649.01
White board	502.00	1	502.00	50.20	33.25
Table	300.00	1	300.00	30.00	19.87
Surgical equipment					
Surgical lights	10,000.00	2	20,000.00	2,000.00	1324.50
Anaesthesia workstation	38,273.13	1	38,273.13	3,827.31	2534.64
Anaesthetic monitor	5,800.00	2	11,600.00	1,160.00	768.21
Power and gas arm	10,000.00	2	20,000.00	2,000.00	1,324.50
Implant drill	9,090.91	1	9,090.91	909.09	602.05
Torniquet system	4,275.00	1	4,275.00	427.50	283.11
Diathermy machine	8,046.50	1	8,046.50	804.65	532.88
Diathermy machine	7,315.00	1	7,315.00	731.50	484.44
Convective warming system	1,050.00	1	1,050.00	105.00	69.54
Smoke evacuator	2,117.50	2	4,235.00	423.50	280.46
Camera system	25,000.00	1	25,000.00	2,500.00	1,655.63
Infusion pump	1,600.00	3	4,800.00	480.00	317.88
Microscope	220,000.00	1	220,000.00	22,000.00	14,569.54

APPENDIX B5: DISPOSABLE EQUIPMENT COSTS

Table 4. The costs of disposable equipment during a typical bony or soft tissue free flap based on senior author's preference card and typical items on count sheet.

Disposable item	Cost ($A)	Cost ($US)
Bony flap		
Major head and neck pack	76.72	50.81
Minor head and neck pack	44.89	29.73
Drape tape	0.96	0.64
Catheter pack	6.17	4.09
Back table cover	0.85	0.56
Kidney dish prep set	3.62	2.40
Lower extremity drape (if fibula free flap)	13	8.61
Bipolar forcep	48	31.79
Light handles	22.02	14.58
Needlemat	2.9	1.92
Alexis wound retractor	80	52.98
Instrument wipe	3.85	2.55
Spongostan	12.5	8.28
Microscope drape (shower cap)	30.05	19.90
Hourly urine bag	13.67	9.05
Statlock	5.6	3.71
10ml sterile water	0.16	0.11
Betadine	3.56	2.36
Chlorhexidine & centrimide for catheter	1.51	1.00
Sodium chloride 0.9% bottle	1.15	0.76
Sodium chloride 0.9% 500ml bag (for micro)	1.15	0.76
Warm water for wash (if neck dissection)	1.53	1.01
1/2" steristrips	0.54	0.36
Tegaderm 15 x 20cm x 3 (for drains)	1.32	0.87
Comfeel long	3.23	2.14
Diathermy pencil	0	0.00
Diathermy pad	4.6	3.05
Single bowl	6.98	4.62
Single jugs	7.38	4.89
2/0 silk	16.42	10.87
3/0 vicryl	30.32	20.08
3/0 monocryl	7.72	5.11
4/0 monocryl	8.78	5.81
4/0 nylon	4	2.65
2/0 vicryl undyed cutting	19.19	12.71
8/0 nylon		
Soft tissue flap		
Major head and neck pack	76.72	50.81

Disposable item	Cost ($A)	Cost ($US)
Minor head and neck pack	44.89	29.73
Drape tape	0.96	0.64
Catheter pack	6.17	4.09
Back table cover	0.85	0.56
Bipolar forcep	24.00	15.89
Light handles	7.34	4.86
Needlemat	1.45	0.96
Instrument wipe	3.85	2.55
Spongostan	12.50	8.28
Microscope drape (shower cap)	30.05	19.90
Hourly urine bag	13.67	9.05
Statlock	5.60	3.71
10ml sterile water	0.16	0.11
Betadine	3.56	2.36
Chlorhexidine & centrimide for catheter	1.51	1.00
Sodium chloride 0.9% bottle	1.15	0.76
Sodium chloride 0.9% 500ml bag (for micro)	1.15	0.76
Warm water for wash (if neck dissection)	1.53	1.01
1/2" steristrips	0.54	0.36
Tegaderm 15 x 20cm x 3 (for drains)	0.44	0.29
Comfeel long	3.23	2.14
Diathermy pad	4.60	3.05
2/0 silk	2.74	1.81
3/0 vicryl	3.79	2.51
3/0 monocryl	7.72	5.11
4/0 monocryl	8.78	5.81
4/0 vicryl rapide	8.33	5.52
8/0 nylon		
Count sheet		
Raytec swabs	0.00	0.00
Sponges	0.43	0.28
Atraumatic needles	3.79	2.51
Blades	1.48	0.98
Diathermy tip	4.30	2.85
Peanuts	1.06	0.70
Cartidges / ligaclips	0.00	0.00
Lonestars	22.20	14.70
Spears	2.22	1.47
Corneal shields	23.56	15.60
12Fr nasogastric tube	17.50	11.59
14Fr indwelling catheter	8.20	5.43
15Fr Blake drain	188.00	124.50
7Fr Jackson-Pratt drain	48.50	32.12
Neuropatties	1.00	0.66
Vessel loops	4.00	2.65

APPENDIX B6: WARD STAFFING COSTS

Table 5. Calculation of the cost per day for the intensive care unit (ICU) and general ward.

Parameter	ICU		Ward	
	A$	US$	A$	US$
Labour cost per bed day	2,435.00	1,612.58	630.77	417.73
Medical officers	-	-	167.77	111.11
Other staff	-	-	463.00	306.62
Medical consumables cost per bed day	144.57	95.74	37.46	24.81
Inpatient food cost per bed day	62.57	41.44	62.29	41.25
Total cost per bed day	2,642.14	1,749.76	730.52	483.79

APPENDIX B7: CONSULTATION COSTS

Table 6. Total cost of average consultations of allied health members in postoperative visits to microvascular head and neck consultations. Annual salaries taken from the Chris O'Brien Lifehouse Enterprise Agreement 2021 and average length of consultations determined through discussions with members from each discipline.

Discipline	Annual salary (A$)	Annual salary (US$)	Salary per minute (US$)	Length of initial consult (min)	Cost of initial consult (US$)	Length of subsequent consults (min)	Cost of subsequent consults (US$)
Dietitian	93,881.33	62,173.07	0.52	60	31.39	50	26.16
Speech pathology	93,881.33	62,173.07	0.52	45	23.54	25	13.08
Music therapist	93,881.33	62,173.07	0.52	35	18.31	35	18.31
Spiritual care	93,881.33	62,173.07	0.52	45	23.54	45	23.54
Occupational therapist	93,881.33	62,173.07	0.52	45	23.54	30	15.70
Physiotherapist	93,881.33	62,173.07	0.52	45	23.54	30	15.70
Social worker	93,881.33	62,173.07	0.52	60	31.39	30	15.70
Psychologist	93,881.33	62,173.07	0.52	60	31.39	30	15.70
Acute pain service	–	–	2.99	20	59.87	20	59.87
Consultant	428,097.00	283,507.95	2.38	–	–	–	–
Pain nurse	–	–	0.61	–	–	–	–
Medical consult	428,097.00	283,507.95	2.38	20	47.68	20	47.68

APPENDIX B8: MULTIVARIABLE REGRESSION RESULTS

Table 9. Multivariable regression model of total admission cost according to postoperative events.

Variable	Coefficient (US$)	SE	95% CI	*p*-value
Constant	22,814	1,543	19,751 – 25,877	-
Postoperative complication	2,756	1,842	–900 – 6,412	0.138
Hospital length of stay (per day)	504	103	301 – 708	**<0.001**
Return to OR	8,025	2,763	2,540 – 13,510	**0.005**
Return to ICU	12,425	4,984	2,530 – 22,320	**0.014**

SE: standard error. CI: confidence interval.

APPENDIX C: SUPPLEMENTARY MATERIALS FOR CHAPTER 4

APPENDIX C1: CHEERS 2022 CHECKLIST

CHEERS 2022 Checklist

Title			
Title	1	Identify the study as an economic evaluation and specify the interventions being compared.	Title
Abstract			
Abstract	2	Provide a structured summary that highlights context, key methods, results, and alternative analyses.	4.3 Abstract
Introduction			
Background and objectives	3	Give the context for the study, the study question, and its practical relevance for decision making in policy or practice.	4.4 Introduction: Paragraphs 1-4
Methods			
Health economic analysis plan	**4**	**Indicate whether a health economic analysis plan was developed and where available.**	**4.5 Methodology: Paragraph 1**
Study population	5	Describe characteristics of the study population (such as age range, demographics, socioeconomic, or clinical characteristics).	4.5 Methodology: Paragraph 2
Setting and location	6	Provide relevant contextual information that may influence findings.	4.5 Methodology: Paragraph 2
Comparators	7	Describe the interventions or strategies being compared and why chosen.	4.5.1 VSP
Perspective	8	State the perspective(s) adopted by the study and why chosen.	4.5 Methodology: Paragraph 1
Time horizon	9	State the time horizon for the study and why appropriate.	4.5 Methodology: Paragraph 1

(continued)

Discount rate	10	Report the discount rate(s) and reason chosen.	4.5 Methodology: Paragraph 1
Selection of outcomes	11	Describe what outcomes were used as the measure(s) of benefit(s) and harm(s).	4.5.2 Costing Methodology
Measurement of outcomes	12	Describe how outcomes used to capture benefit(s) and harm(s) were measured.	4.5 Methodology: Paragraph 2
Valuation of outcomes	13	Describe the population and methods used to measure and value outcomes.	4.5.2 Costing Methodology
Measurement and valuation of resources and costs	14	Describe how costs were valued.	4.5.2 Costing Methodology
Currency, price date, and conversion	15	Report the dates of the estimated resource quantities and unit costs, plus the currency and year of conversion.	4.5.2 Costing Methodology
Rationale and description of model	16	If modelling is used, describe in detail and why used. Report if the model is publicly available and where it can be accessed.	N/A
Analytics and assumptions	17	Describe any methods for analysing or statistically transforming data, any extrapolation methods, and approaches for validating any model used.	4.5.3 Statistical Analysis
Characterising heterogeneity	18	Describe any methods used for estimating how the results of the study vary for subgroups.	4.5.3 Statistical Analysis
Characterising distributional effects	19	Describe how impacts are distributed across different individuals or adjustments made to reflect priority populations.	4.5.3 Statistical Analysis

2

(continued)

Characterising uncertainty	20	Describe methods to characterise any sources of uncertainty in the analysis.	4.5.3 Statistical Analysis
Approach to engagement with patients and others affected by the study	21	Describe any approaches to engage patients or service recipients, the general public, communities, or stakeholders (such as clinicians or payers) in the design of the study.	N/A
Results			
Study parameters	22	Report all analytic inputs (such as values, ranges, references) including uncertainty or distributional assumptions.	4.6 Results
Summary of main results	23	Report the mean values for the main categories of costs and outcomes of interest and summarise them in the most appropriate overall measure.	4.6.2 Comparisons before matching
Effect of uncertainty	24	Describe how uncertainty about analytic judgments, inputs, or projections affect findings. Report the effect of choice of discount rate and time horizon, if applicable.	4.6.4 Comparisons after matching
Effect of engagement with patients and others affected by the study	25	Report on any difference patient/service recipient, general public, community, or stakeholder involvement made to the approach or findings of the study	N/A
Discussion			

(continued)

Study findings, limitations, generalisability, and current knowledge	26	Report key findings, limitations, ethical or equity considerations not captured, and how these could affect patients, policy, or practice.	4.7 Discussion
Other relevant information			
Source of funding	27	Describe how the study was funded and any role of the funder in the identification, design, conduct, and reporting of the analysis	N/A
Conflicts of interest	28	Report authors conflicts of interest according to journal or International Committee of Medical Journal Editors requirements.	N/A

From: Husereau D, Drummond M, Augustovski F, et al. Consolidated Health Economic Evaluation Reporting Standards 2022 (CHEERS 2022) Explanation and Elaboration: A Report of the ISPOR CHEERS II Good Practices Task Force. Value Health 2022;25. doi:10.1016/j.jval.2021.10.008

APPENDIX C2: HEALTH ECONOMICS ANALYSIS PLAN

Health Economic Analysis Plan (HEAP)

A cost-minimisation analysis between in-house and commercial virtual surgical planning for maxillary and mandibular reconstruction

Version 1.0

Date: May 11, 2025

1. BACKGROUND AND RATIONALE

1.1 Clinical Background

Surgical resection of the maxilla and mandible (maxillectomy and mandibulectomy) is a standard treatment for managing pathologies affecting the jaw. Microvascular free flap reconstructions are performed to repair the resultant midface defects to minimize postoperative impairments in aesthetics, breathing, speech, swallowing, and mastication. These procedures require precise surgical planning and understanding of complex head and neck anatomy.

In maxillary and mandibular reconstructions involving osseous free flap transfer and dental rehabilitation, precision in bone modelling and implant placement directly influences:

- Success of bony union
- Dental occlusion
- Facial contour

Virtual surgical planning (VSP) uses three-dimensional virtual models of the affected jaw and donor-site skeleton to plan osteotomy and dental implant sites. These plans are translated into the intraoperative setting via patient-specific surgical guides, anatomical models, and plates.

1.2 Justification for Economic Evaluation

Evidence shows VSP yields numerous benefits:

- Improved reconstruction accuracy
- Reduced ischemia and operative time
- Shorter hospital stays
- Lower complication rates

- Higher rates of successful dental rehabilitation

The VSP workflow has traditionally been outsourced to commercial companies (C-VSP), incurring significant financial costs for healthcare providers or patients. In response, many institutions have developed in-house VSP workflows (I-VSP) using commercially available software and 3D printers to mitigate these costs.

While existing studies have compared costs between I-VSP and C-VSP, none have been based on pre-established clinical equivalence between the two approaches. Recent evidence from Chris O'Brien Lifehouse Hospital (COBLH) demonstrated that their I-VSP workflow was clinically equivalent to C-VSP in terms of postoperative parameters (intercondylar and intergonial distance, segment length, and angles between segments), providing a strong basis for a cost-minimisation analysis.

1.3 Research Question

What is the difference in direct financial costs between in-house virtual surgical planning (I-VSP) and commercial virtual surgical planning (C-VSP) for patients undergoing maxillary or mandibular reconstruction at COBLH?

2. METHODS

2.1 Study Design

A cost-minimisation analysis (CMA) from the healthcare provider perspective, comparing I-VSP and C-VSP for maxillary or mandibular reconstruction.

2.2 Study Population

Target Population: Patients undergoing bony maxillary or mandibular reconstruction at COBLH.

Inclusion Criteria:

- Patients undergoing bony maxillary or mandibular reconstruction at COBLH between December 2020 and June 2023
- Patients who received either I-VSP or C-VSP as part of their surgical planning

Exclusion Criteria:

- Patients who underwent a marginal mandibulectomy or soft tissue flaps.

2.3 Time Horizon

The time horizon for this analysis is the perioperative period, from admission to discharge. This short-term horizon is appropriate for a CMA where clinical outcomes are assumed equivalent.

2.4 Comparators

1. **Commercial Virtual Surgical Planning (C-VSP)**:
    - Traditional outsourced approach using third-party commercial companies
    - Used for patients with private insurance coverage and adequate lead time to surgery
2. **In-House Virtual Surgical Planning (I-VSP)**:
    - COBLH's institutional approach using commercially available software and 3D printers
    - Used for patients without private insurance cover or where short lead time precluded C-VSP

2.5 Clinical Equivalence Assumption

Clinical equivalence between C-VSP and I-VSP has been established in previous research at COBLH, which demonstrated no significant differences in:

- Postoperative intercondylar distance
- Intergonial distance
- Segment length
- Angles between segments

Based on this established clinical equivalence, a cost-minimisation analysis is the appropriate method for economic evaluation.

2.6 Perspective

The analysis will be conducted from the perspective of the healthcare provider (COBLH).

3. DATA SOURCES AND COLLECTION

3.1 Patient Data Sources

Data for each patient will be sourced from:

- Clinical notes
- COBLH Maxillofacial Database

3.2 Data Elements

The following data elements will be collected:

- Patient demographics
- Pathological features
- Surgical management details
- Type of VSP used (C-VSP or I-VSP)
- Length of hospital stay
- Postoperative complications
- Return to Intensive Care Unit (ICU)
- Return to operating room (OR)

3.3 VSP Workflows

3.3.1 Common Elements for Both Approaches

- Fine slice (<1.0mm thickness) CT scans of craniofacial skeleton and donor site/vessels
- Conversion of CT scans to DICOM format
- Intraoral scans of dentitions (for dental rehabilitation cases)

3.3.2 C-VSP Workflow

- DICOM scans provided to commercial company
- Segmentation by biomedical engineers to create 3D models
- 60-minute VSP meeting (ablative surgeon, reconstructive surgeon, prosthodontist)
- Planning of resection, reconstruction, and dental rehabilitation
- Design of surgical guides and titanium fixation plate by biomedical engineers
- Review of STL files and VSP report by surgical team
- Printing, shipping, and sterilization of models before procedure

3.3.3 I-VSP Workflow

- Upload and segmentation of DICOM data using Materialise Prolan
- 60-minute planning meeting (reconstructive surgeon, design engineer, clinical manager, prosthodontist)
- Creation of cutting guides, drilling guides, and models using Materialise MIMICS
- In-house 3D printing of confirmed models

4. COST ANALYSIS METHODS

4.1 Costing Approach

An individualized micro-costing approach will be used to calculate financial costs for all activities from admission to discharge, including VSP.

4.2 Cost Categories

Costs will be subclassified into:

1. **Staffing costs**: Personnel time and expertise
2. **Equipment costs**: Hardware, software, disposables, and consumables

4.3 Cost Inclusions and Exclusions

Inclusions:

- Direct costs associated with VSP and hospital admission

Exclusions:

- Preoperative CT scan costs (routine for all patients)
- Overhead costs
- Onboard costs
- Societal costs (time off work, travel costs)

4.4 Cost Calculations for C-VSP

4.4.1 Staffing Costs

- VSP meeting (~60 minutes) for the reconstructive surgeon, based on COBLH Enterprise Agreement 2022

4.4.2 Equipment Costs

- 3D custom-made plate (as per invoice)
- Reconstructive 3D model (as per invoice)
- Cutting guides for donor and ablative site (as per invoice)
- Cost of screws (as per invoice)

4.5 Cost Calculations for I-VSP

4.5.1 Staffing Costs

Staff time investment for each stage:

- VSP planning
- Preparation of data
- VSP planning session
- Reconstruction plate bending

- Design stage
- Printing

Staff members include:

- Medical and dental officers (reconstructive surgeon, surgical fellow, prosthodontist)
- Engineers (design engineer, 3D printing engineer, additive design engineer)
- Clinical manager
- Quality assurance personnel

4.5.2 Equipment Costs

- 3D printing materials (calculated based on average volume and price per unit)
- Start-up costs for in-house workflow:
    - 3D scanner (Trios)
    - 3D printers (Raise 3D Pro 2, Form 3 Formlab+Cure/Wash, EOS P110, Asiga Pro 4k)
    - Software (Materialise MIMICS Suite, Materialise Magics, PDC+Shinning 3D Dental Scanner)
    - Prosthodontic equipment

Start-up costs will be annualized based on:

- Subscription fees
- Estimated equipment depreciation period
- Number of cases per year

4.6 Currency and Time Adjustments

- Costs will be calculated in Australian dollars (AUD)
- No inflation adjustment will be applied
- No discounting will be applied due to the short time horizon

5. STATISTICAL ANALYSIS PLAN

5.1 Primary Analysis

- Total costs will be calculated by summing the cost of each activity comprising the operative and perioperative admission periods
- Raw costs in each group for each activity will be presented as means with standard deviations
- Difference in total costs between I-VSP and C-VSP will be calculated

5.2 Sensitivity Analysis

A one-way sensitivity analysis will be conducted to test the robustness of the results by varying:

- Staff salaries (±20%)
- Equipment costs (±20%)
- Number of annual cases (±30%)
- Equipment depreciation periods (±2 years)

5.3 Subgroup Analyses

Given the assumption of clinical equivalence, no formal subgroup analyses are planned.

5.4 Statistical Software

Statistical analyses will be performed using Stata version 12.0 SE (Stata Corporation, College Station, Texas).

6. ETHICAL CONSIDERATIONS

Ethics approval has been obtained from St Vincent's Hospital Human Ethics Review Committee (2020/ETH02415).

7. LIMITATIONS

Potential limitations of this economic evaluation include:

- Non-randomized allocation of patients to I-VSP or C-VSP groups
- Single-center study, limiting generalizability
- Focus only on direct costs, excluding societal perspective
- Short time horizon that does not capture long-term outcomes

8. DISSEMINATION PLAN

Results of this cost-minimisation analysis will be:

- Published in peer-reviewed journals
- Presented at relevant medical and health economics conferences
- Shared with health service decision-makers to inform resource allocation

APPENDIX D: SUPPLEMENTAL MATERIALS FOR CHAPTER 6

APPENDIX D1: CORRELATION BETWEEN FACE-Q SCALES

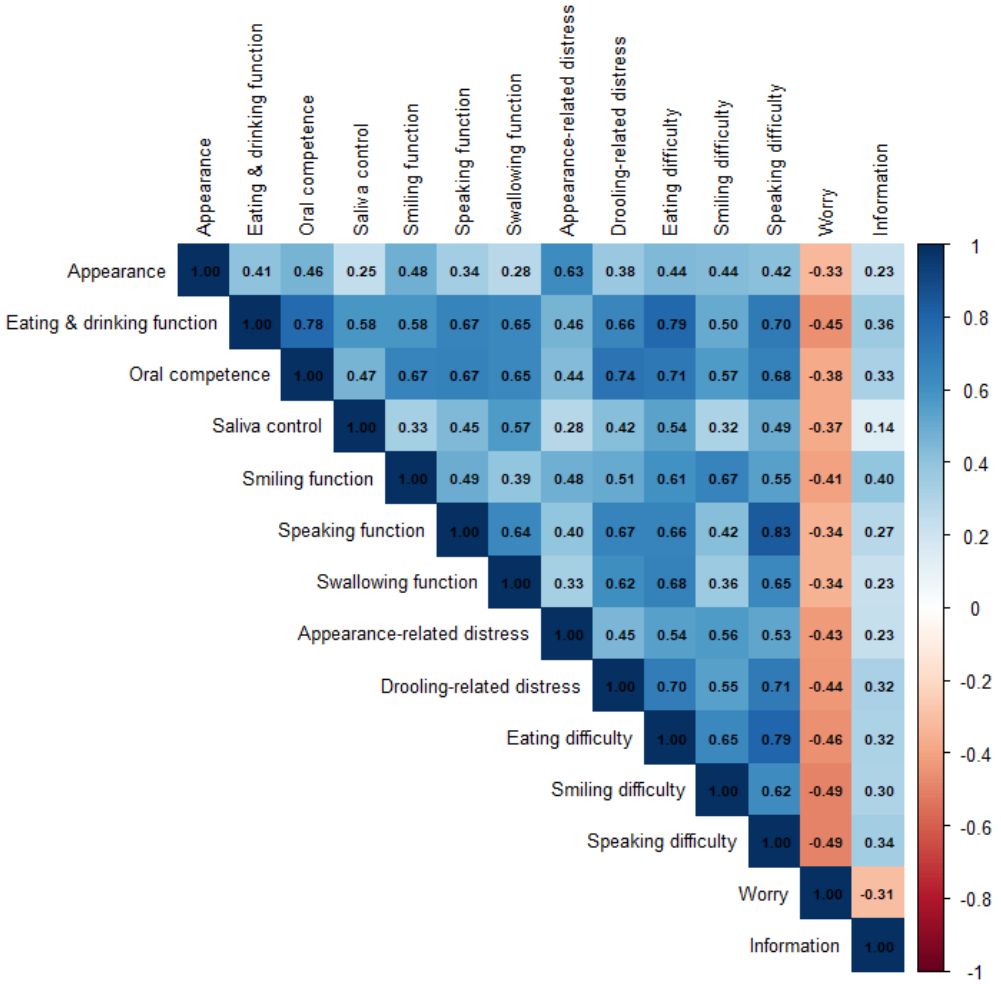

Figure 1. Correlation between independently functioning FACE-Q scales. This heatmap presents the Pearson correlation coefficients.

APPENDIX D2: PARTIAL EFFECT PLOTS FROM GAM MODELS

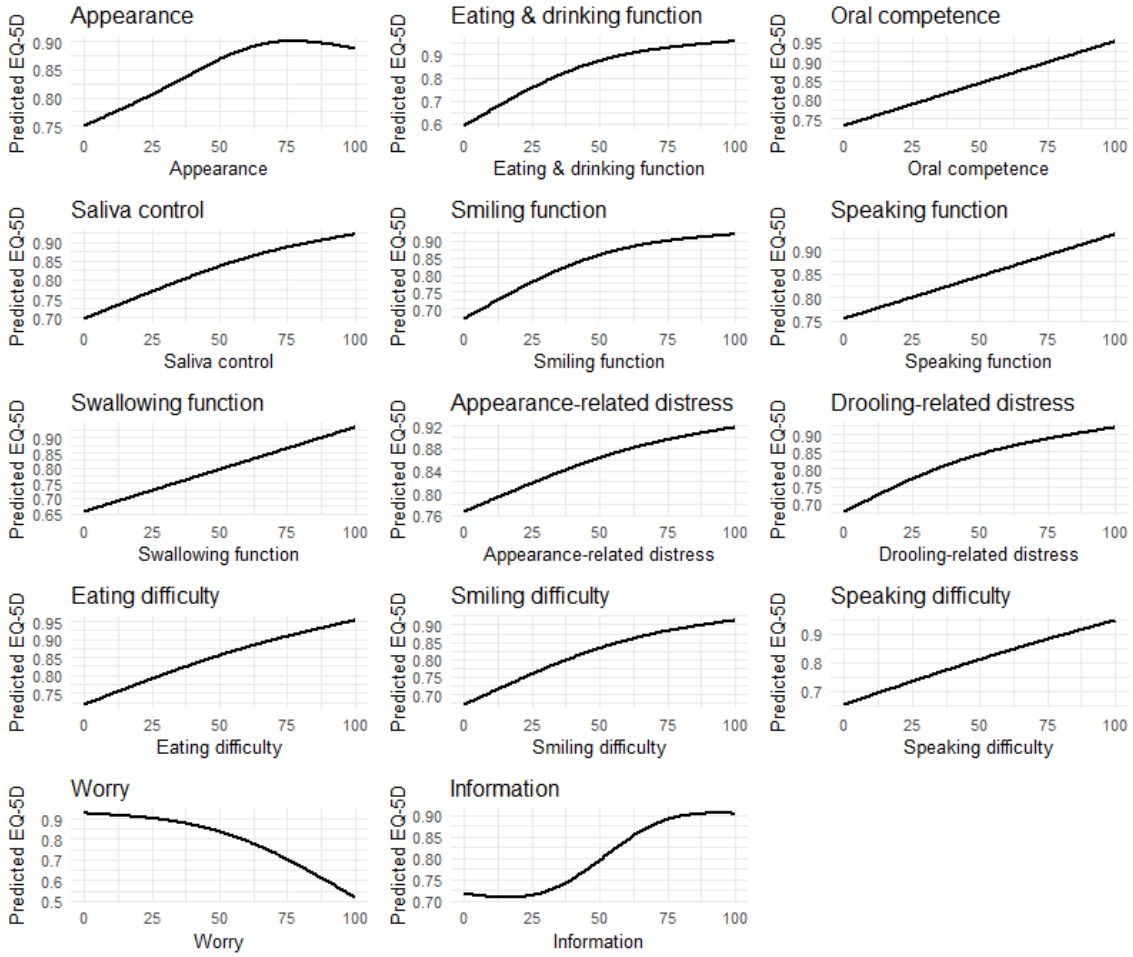

Figure 2. Partial effect plots from GAM models examining non-linear relationships between FACE-Q scales and EQ-5D-5L. Each panel displays the predicted EQ-5D-5L utility score based on a single FACE-Q scale using a smoothing spline (k = 3) in a Generalized Additive Model (GAM). The x-axis represents the value of the FACE-Q scale, and the y-axis shows the corresponding predicted EQ-5D-5L score.

APPENDIX D3: BASELINE OLS REGRESSION ESTIMATES

Table 1: Baseline regression estimates derived from OLS method.

Predictor	Model A	Model B	Model C	Model D	Model E
(Intercept)	0.696 (0.065)***	0.79 (0.161)***	0.727 (0.166)***	0.853 (0.213)***	0.928 (0.22)***
Appearance	-0.03 (0.046)	0.025 (0.115)	-0.044 (0.122)	-0.05 (0.133)	-0.034 (0.133)
Eating and drinking	0.127 (0.081)	0.262 (0.278)	0.323 (0.303)	0.251 (0.317)	0.178 (0.317)
Oral competence	-0.146 (0.073)*	-0.97 (0.255)***	-0.871 (0.286)**	-0.792 (0.304)**	-0.854 (0.305)**
Salivation	0.011 (0.046)	-0.128 (0.118)	-0.217 (0.129).	-0.234 (0.131).	-0.245 (0.131).
Smiling	0.061 (0.055)	0.505 (0.158)**	0.557 (0.163)***	0.405 (0.23).	0.359 (0.23)
Speaking	-0.083 (0.063)	-0.155 (0.092).	-0.278 (0.164).	-0.253 (0.166)	-0.239 (0.167)
Swallowing	0.099 (0.063)	-0.033 (0.116)	-0.056 (0.137)	-0.049 (0.14)	-0.057 (0.14)
Appearance distress	-0.019 (0.043)	0.011 (0.042)	0.022 (0.043)	0.007 (0.044)	0.005 (0.044)
Drooling distress	0.106 (0.048)*	0.064 (0.047)	0.19 (0.123)	0.142 (0.158)	0.139 (0.159)
Eating distress	0.055 (0.06)	0.069 (0.059)	0.161 (0.138)	0.073 (0.151)	0.069 (0.153)
Smiling distress	0.003 (0.054)	-0.031 (0.054)	0.103 (0.101)	0.087 (0.151)	0.062 (0.153)
Speaking distress	0.064 (0.089)	0.041 (0.086)	0.082 (0.124)	0.039 (0.127)	0.049 (0.128)
Cancer worry	-0.151 (0.049)**	-0.26 (0.169)	-0.135 (0.182)	-0.021 (0.195)	-0.041 (0.194)
Information	0.051 (0.047)	0.367 (0.171)*	0.27 (0.177)	0.238 (0.179)	0.225 (0.187)
Appearance:Smiling		-0.134 (0.13)	-0.035 (0.142)	0.007 (0.156)	-0.018 (0.156)
Oral competence:Speaking		0.226 (0.137)	0.612 (0.233)**	0.598 (0.234)*	0.56 (0.243)*
Salivation:Swallowing		0.173 (0.157)	0.306 (0.175).	0.335 (0.178).	0.352 (0.177)*
Appearance:Cancer worry		0.097 (0.148)	0.116 (0.15)	0.019 (0.158)	0.023 (0.157)
Oral competence:Cancer worry		0.836 (0.189)***	0.663 (0.207)**	0.618 (0.217)**	0.641 (0.221)**
Eating and drinking:Information		-0.246 (0.332)	-0.209 (0.339)	-0.145 (0.351)	-0.11 (0.35)
Oral competence:Information		0.6 (0.297)*	0.592 (0.298)*	0.49 (0.314)	0.537 (0.314).
Cancer worry:Information		-0.541 (0.198)**	-0.551 (0.199)**	-0.575 (0.2)**	-0.581 (0.207)**
Smiling:Information		-0.506 (0.196)*	-0.368 (0.207).	-0.264 (0.218)	-0.225 (0.224)
Eating and drinking:Oral competence			-0.191 (0.235)	-0.178 (0.241)	-0.109 (0.242)
Speaking:Swallowing			-0.12 (0.198)	-0.146 (0.201)	-0.161 (0.202)
Smiling:Smiling distress			-0.271 (0.159).	-0.221 (0.22)	-0.172 (0.222)
Oral competence:Drooling distress			-0.216 (0.218)	-0.17 (0.245)	-0.158 (0.246)
Eating distress:Speaking distress			-0.125 (0.18)	-0.025 (0.19)	-0.028 (0.191)
Appearance_rasch_c_sq				-0.14 (0.129)	-0.114 (0.129)
Smiling_rasch_c_sq				-0.099 (0.167)	-0.149 (0.168)
Drooling distress_rasch_c_sq				-0.071 (0.151)	-0.101 (0.151)
Smiling distress_rasch_c_sq				0.036 (0.159)	0.056 (0.159)
Cancer worry_rasch_c_sq				-0.232 (0.152)	-0.196 (0.152)

Predictor	Model A	Model B	Model C	Model D	Model E
Information_rasch_c_sq					-0.821 (0.376)*
Information_rasch_c_cu					-1.145 (0.568)*
R^2	0.312	0.407	0.422	0.436	0.448
RMSE	0.144	0.133	0.132	0.130	0.129
MAE	0.090	0.089	0.089	0.087	0.085
AIC	-226.092	-244.656	-241.200	-236.930	-238.469
BIC	-169.942	-156.921	-135.918	-114.102	-108.621

APPENDIX D4: QQ PLOTS

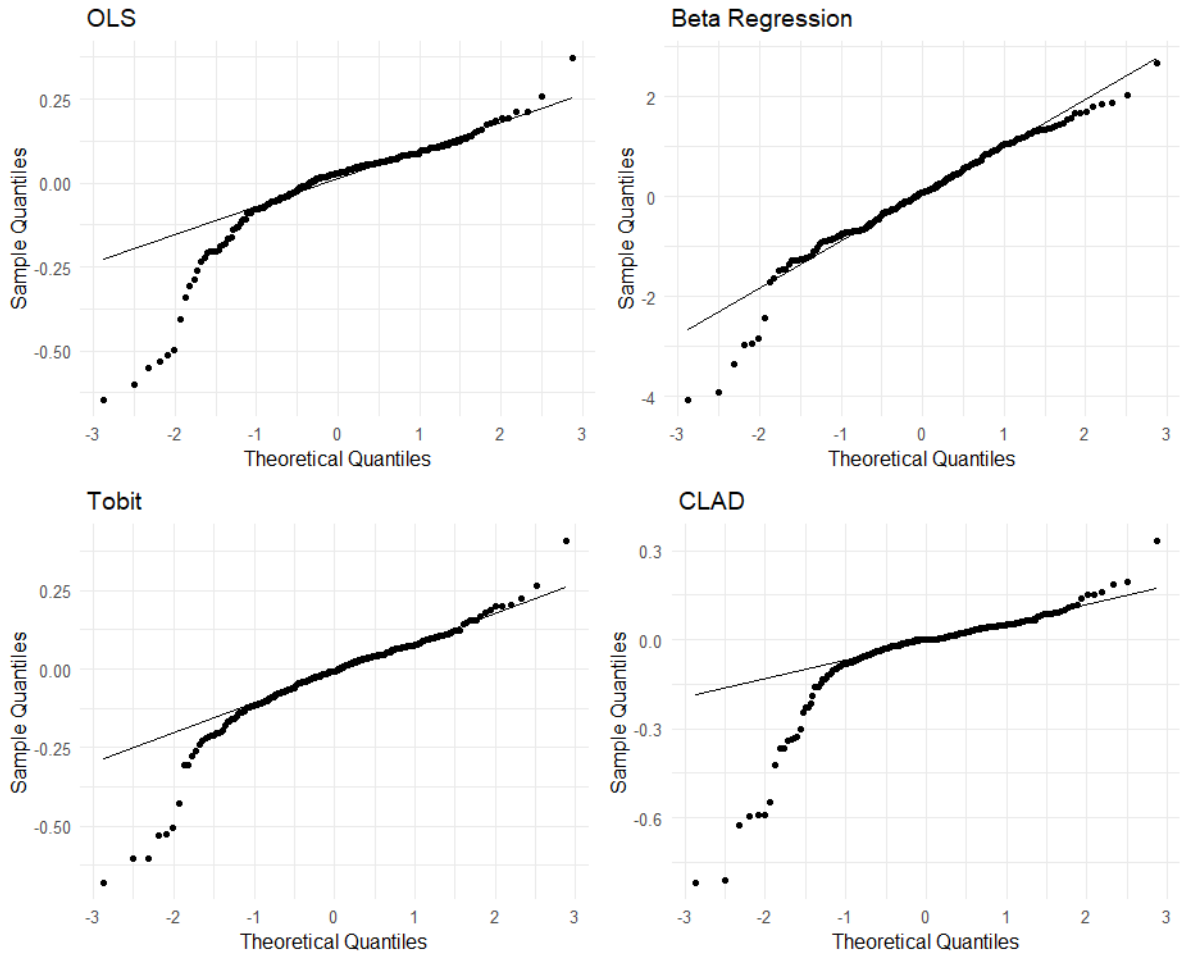

Figure 3. QQ plots.

APPENDIX D5: DISTRIBUTION OF EQ-5D-5L RESPONSES

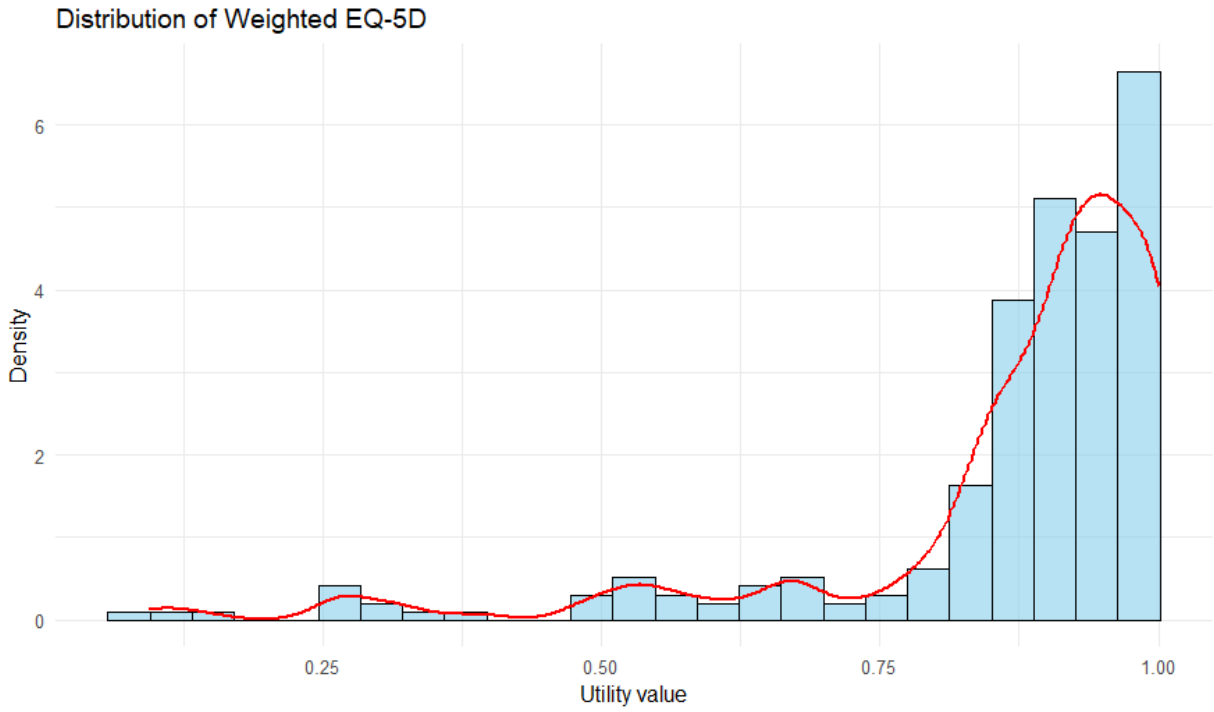

Figure 4. Distribution of EQ-5D-5L responses in the sample.

APPENDIX D6: DISTRIBUTION OF OBSERVED FACE-Q RESPONSES

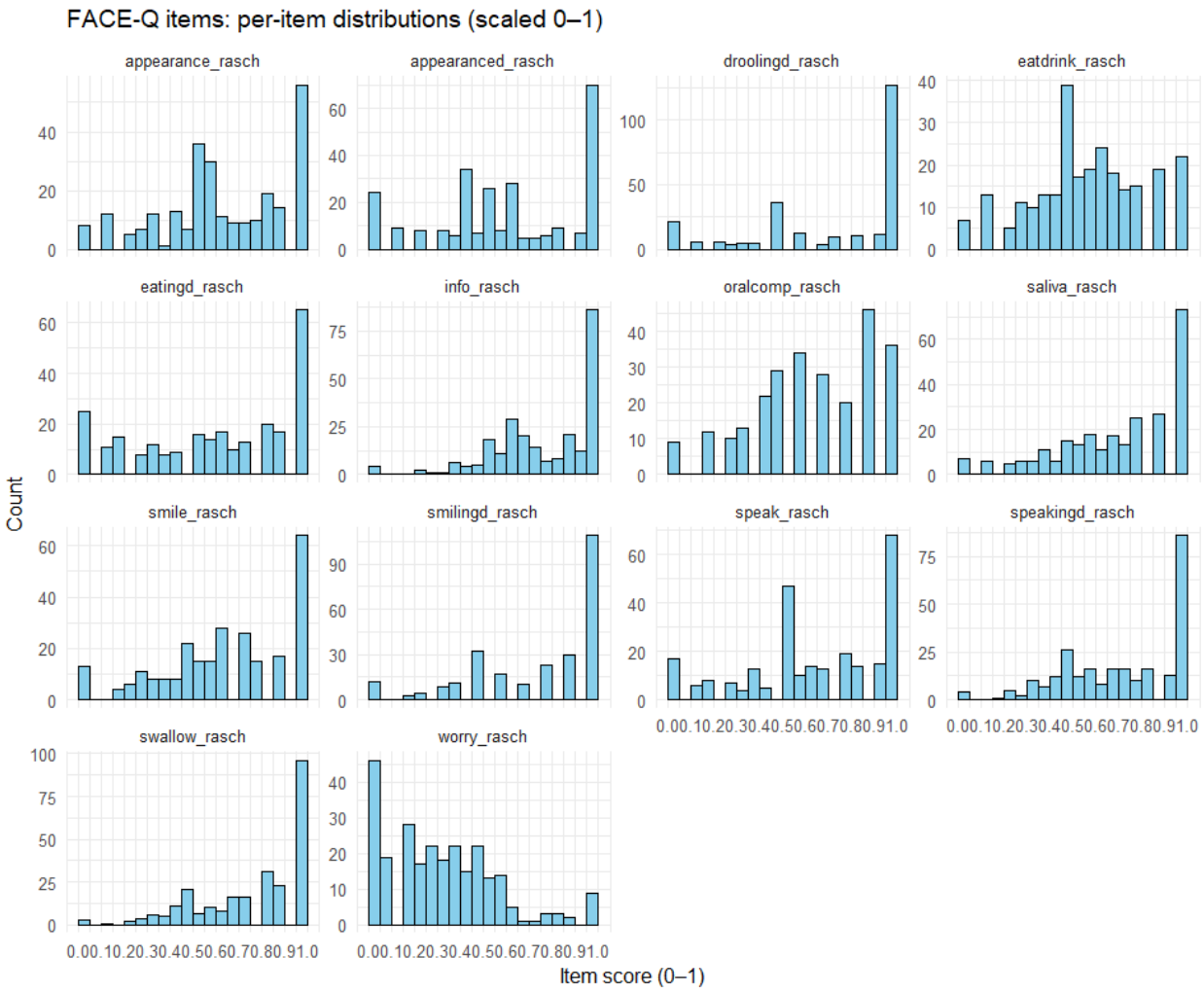

Figure 5. Distribution of observed FACE-Q scale responses in the sample.

APPENDIX D7: EXAMPLE APPLICATION OF MAPPING FUNCTION

Results 1: Example application of the mapping function using the results from the TOBIT regression.

To illustrate application of the final mapping function, we constructed a hypothetical patient profile with FACE-Q scores spanning 14 domains and their pre-specified interaction terms (**Table 2).** These values were entered into the beta regression equation, incorporating both main effects and significant interaction terms (**Table 3**). The summed main effects contributed –1.92, while interactions contributed +2.29, yielding a linear predictor of 0.37. Applying the beta regression link function resulted in a predicted EQ-5D-5L utility of 0.59 for this patient.

Table 2. Hypothetical patient profile with FACE-Q scores using the mapping model.

FACE-Q Domain	Patient Response	Rasch Score (0-1)	Model Coefficient	Contribution (Score × Coefficient)
Appearance	Agree	0.75	0.533	**+0.39975**
Eating and Drinking	A little bothered	0.75	1.864	**+1.39800**
Oral Competence	A little bothered	0.75	–5.754	**–4.31550**
Salivation	Not at all	1.00	–0.583	**–0.58300**
Smiling	A lot bothered	0.25	3.436	**+0.85900**
Speaking	A lot bothered	0.25	–1.410	**–0.35250**
Swallowing	A little bothered	0.75	–0.156	**–0.11700**
Appearance Distress	Somewhat disagree	0.25	0.089	**+0.02225**
Drooling Distress	All of the time	0.00	0.522	**+0.00000**
Eating Distress	Some of the time	0.50	0.187	**+0.09350**
Smiling Distress	Some of the time	0.50	0.010	**+0.00500**
Speaking Distress	all of the time	0.00	0.522	**+0.00000**

Cancer Worry	Some of the time	0.50	–0.218	**–0.10900**
Satisfaction with Information	Somewhat dissatisfied	0.25	3.111	**+0.77775**
Subtotal (main effects) = –1.922				

Table 3. Hypothetical patient values entered into beta regression model.

Interaction	**Value ($x_i \times x_j$)**	**Coefficient**	**Contribution**
Appearance × Smiling	0.75×0.25 = 0.1875	–0.564	**–0.10575**
Oral Competence × Speaking	0.75×0.25 = 0.1875	2.126	**+0.398625**
Salivation × Swallowing	1.00×0.75 = 0.75	1.140	**+0.855000**
Appearance × Cancer Worry	0.75×0.50 = 0.375	0.007	**+0.002625**
Oral Competence × Cancer Worry	0.75×0.50 = 0.375	4.163	**+1.561125**
Eating × Information	0.75×0.25 = 0.1875	–1.525	**–0.2859375**
Oral Competence × Information	0.75×0.25 = 0.1875	2.893	**+0.5424375**
Cancer Worry × Information	0.50×0.25 = 0.125	–3.624	**–0.453000**
Smiling × Information	0.25×0.25 = 0.0625	–3.541	**–0.2213125**
Subtotal (interactions) = +2.294			

Linear predictor (η) = (main effects) + (interactions) = –1.92175 +2.29381 = 0.37206

For Beta regression with logit link, the predicted mean is;

$$\hat{\mu} = logit^{-1}(\eta) \approx \frac{1}{1 - e^{-\eta}} = \frac{1}{1 - e^{-37206}} = 0.592$$

∴ Predicted EQ-5D-5L utility for this patient = 0.59

Evaluation, C. f. H. E. R. a. (2008). *Issues in the Costing of Large Projects in Health and Healthcare*.