THE UNIVERSITY OF SYDNEY

COPYRIGHT AND USE OF THIS THESIS

This thesis must be used in accordance with the provisions of the Copyright Act 1968.

Reproduction of material protected by copyright may be an infringement of copyright and copyright owners may be entitled to take legal action against persons who infringe their copyright.

Section 51 (2) of the Copyright Act permits an authorized officer of a university library or archives to provide a copy (by communication or otherwise) of an unpublished thesis kept in the library or archives, to a person who satisfies the authorized officer that he or she requires the reproduction for the purposes of research or study.

The Copyright Act grants the creator of a work a number of moral rights, specifically the right of attribution, the right against false attribution and the right of integrity.

You may infringe the author's moral rights if you:

- fail to acknowledge the author of this thesis if you quote sections from the work
- attribute this thesis to another author
- subject this thesis to derogatory treatment which may prejudice the author's reputation

For further information contact the University's Copyright Service.

sydney.edu.au/copyright

COMPARISON OF NEW AND 3-MONTH-OLD BRUSH HEADS IN THE REMOVAL OF PLAQUE USING A POWERED TOOTHBRUSH.

by

Dr Louise Hogan BDS (Syd), FRACDS

A treatise submitted in partial fulfilment of the requirements for the degree of

Master of Dental Science

Discipline of Periodontics

Faculty of Dentistry

University of Sydney

2006

© copyright Louise Hogan 2006

CANDIDATE'S CERTIFICATE

This is to certify that the work presented in this thesis was carried out by the candidate in the Faculty of Dentistry, University of Sydney, Westmead Centre for Oral Health and the Sydney Dental Hospital. Any contribution made to the research by others with whom I have worked is explicitly acknowledged in the treatise.

The work presented in this treatise has been submitted only to the University of Sydney for a higher degree.

Louise Hogan

ACKNOWLEDGEMENTS

I would like to extend my gratitude to the Dental Board of New South Wales for their generous financial support that made this clinical research possible. I am indebted to my research supervisor and mentor Associate Professor Chris Daly whose enthusiasm and advice has been endless and a source of continual inspiration. A special thank you goes to Dr Brad Curtis who provided the statistical support. There are many staff members of the Westmead Centre for Oral Health and The Sydney Dental Hospital who willingly gave their time in the collation of the clinical data and to whom I am very grateful. In particular, Torren Carter and Elham Shafi-Beigli deserve a special mention for their invaluable assistance. I would also like to thank Peter Murphy for the construction of the customized jig which played a pivotal role in the research protocol. This document is the result of the combined dedication and efforts of many people and could not have been completed without them all.

TABLE OF CONTENTS

	Page
Title Page	i
Certification	ii
Acknowledgements	iii
Table of Contents	iv
List of Tables	vii
Lists of Figures	viii
PART A: REVIEW OF THE LITERATURE	1
ABSTRACT	2
1. INTRODUCTION	3
2. Toothbrush Design	4
i) Manual Toothbrush	4
ii) Powered Toothbrush	4
3. Plaque Removal by Toothbrushes	6
3.1 Plaque Development	6
3.2 Frequency of Tooth Brushing and Plaque Removal	7
3.3 Toothbrushing Force and Plaque Removal	8
3.4 Toothbrushing Duration and Plaque Removal	9
3.5 Filament Design	10
i) Adverse Effects	11
ii) Bristle End-rounding	12
4. Comparison of Powered and Manual Toothbrushes	12
4.1 Introduction	12
4.2 Plaque Removal	13
4.3 Gingival Bleeding and Inflammation	15
4.4 Interdental Cleaning	15
4.5 Children	17
4.6 Orthodontic Patients	18
4.7 Periodontal Maintenance Patients	18
4.8 Patients with Dental Implants	19
4.9 Anti-Microbial Effects	20
4.10 Trauma to Hard and Soft Tissues	21
4.11 Toothbrush Instruction	22

4.12 Conclusion 23

5. Toothbrush Renewal 24
5.1 Introduction 24
5.2 Professional Recommendations 24
5.3 The General Population 26
5.4 Recommendations of Toothbrush Manufacturers 29
5.5 Microbial Contamination 29
5.6 Conclusions 30

6. Research Methodology Considerations 31
6.1 Reproducibility Testing 31
6.2 Sample Size 32
6.3 Plaque Indices 32
(i) The Oral Debris Index (Greene & Vermillion 1960) 35
(ii) The Plaque Index (Silness & Loe 1964) 38
(iii) Patient Hygiene Performance Index (Podshadley & Haley) 40
(iv) The Rustogi Modified Navy Plaque Index (Rustogi et al. 1992) 40
(v) The Turesky Modification (Turesky et al. 1970) of the Quigley & Hein Plaque Index (Quigley & Hein 1962) 41

7. Studies Evaluating the Effects of Toothbrush Bristle Wear and Time in Use on Plaque Removal Efficacy 44
7.1 Introduction 44
7.2 Pugh (1978) 45
7.3 Kreifelt et al. (1980) 46
7.4 Glaze & Wade (1986) 48
7.5 Daly et al. (1996) 49
7.6 Tan & Daly (2002) 51
7.7 Galgut (2001) 54
7.8 Sforza et al. (2000) 56
7.9 Warren et al. (2002) 57
7.10 Conforti et al. (2003) 60
7.11 Discussion 65

8. CONCLUSION 70

9. REFERENCES 72

PART B: SCIENTIFIC PAPER 93

TITLE PAGE 94

ABSTRACT 95

CLINICAL RELEVANCE 96

1. INTRODUCTION 97

2. MATERIALS AND METHODS 99
2.1 Experimental Design 99
2.2 Population Screening 99
2.3 Toothbrush 100
2.4 Experimental Steps 100
2.5 Plaque Scoring 101
2.6 Brush Head Wear 102
2.7 Statistical Analysis 103

3. RESULTS 105
3.1 Subjects 105
3.2 Measurement Reproducibility 105
3.3 Plaque Scores 105
3.4 Brush head Wear 106

4. DISCUSSION 113

5. REFERENCES 118

6. ACKNOWLEDGEMENTS 123

LIST OF TABLES

PART A: REVIEW OF THE LITERATURE		Page
Table 1	Plaque Indices Used in Toothbrush Wear Studies	34
Table 2	The Oral Debris Index (Greene & Vermillion 1960)	36
Table 3	The Plaque Index (Silness & Loe 1964)	39
Table 4	Plaque Index (Quigley & Hein 1962)	41
Table 5	The Turesky et al. (1970) Modification of the Quigley & Hein Plaque Index (1962)	43
Table 6	Summary of the Results of the Toothbrush Wear Studies	68

PART B: SCIENTIFIC PAPER		Page
Table 1	Comparison of the percentage plaque score reductions for the new and the 3-month-old brush heads	108
Table 2	Total plaque score reductions expressed as a percentage (mean ± SD) are shown for 3-month-old (worn) brush heads and new brush heads in the same subjects	109
Table 3	Approximal plaque score reductions expressed as a percentage (mean ± SD) are shown for 3-month-old brush heads as compared with new brush heads in the same subjects (*n*=34)	110

LIST OF FIGURES

PART A: REVIEW OF THE LITERATURE — Page

Figure 1	The Oral Debris Index (Greene & Vermillion 1960) Segments (World Health Organization Oral Health Country/Area Profile Programme)	36
Figure 2	The Oral Debris Index (Greene & Vermillion 1960) (World Health Organization Oral Health Country/Area Profile Programme)	37
Figure 3	Oral Hygiene Index- Simplified (Greene & Vermillion 1964) (World Health Organization Oral Health Country/Area Profile Programme)	38
Figure 4	Turesky et al. (1970) Modification of the Quigley & Hein (1962) Index (World Health Organization Oral Health Country/Area Profile Programme)	44

PART B: SCIENTIFIC PAPER — Page

Figure 1	Three month-old brush heads exhibiting variations in bristle wear. The percentage increase in brushing surface area for the illustrated brush heads was (from left to right) 0%, 16%, 46%, 72% and 94%.	111
Figure 2	The percentage plaque score reductions for total surfaces achieved with each of the 3-month-old brush heads are shown in relation to the increase in the brushing surface area (BSA) of each brush head (n=34).	111

Figure 3	The percentage plaque score reductions for approximal surfaces achieved with each of the 3-month-old brush heads are shown in relation to the increase in the brushing surface area (BSA) of each brush head (n=34).	111
Figure 4	Customized jig for taking standardized digital photographs of the brush heads.	111

PART A:

REVIEW OF THE LITERATURE

COMPARISON OF NEW AND 3-MONTH-OLD BRUSH HEADS IN THE REMOVAL OF PLAQUE USING A POWERED TOOTHBRUSH.

ABSTRACT

Aim: To review plaque removal with toothbrushes and to critically review the literature regarding the effects of toothbrush bristle wear on plaque removal efficacy with particular reference to rotation oscillation powered toothbrushes.

Method: The Cochrane Central Register of Controlled Trials, MEDLINE and EMBASE databases were searched up to January 2006 to identify appropriate studies. Selected journals and reference lists from relevant articles were hand searched up to May 2006.

Key words: toothbrush, powered, wear, renewal, replacement.

Results: Screening identified ten clinical trials studying the relationship between toothbrush bristle wear and plaque removal efficacy. Eight studies examined bristle wear on manual toothbrushes exclusively and a single study reported results from two independent clinical trials, one testing a manual toothbrush and the other a rotation oscillation powered toothbrush. The evidence indicates that manual toothbrush bristle wear generated from a 3-month period of routine home use does not impede the effectiveness of plaque removal. This result was also found for a rotation oscillation powered toothbrush although the authors reported that "extreme wear" diminished plaque removal efficiency.

Conclusions: There is insufficient data available to make definitive conclusions regarding the effects of bristle wear on a rotation oscillation powered toothbrush and plaque removal efficacy at three months.

1. INTRODUCTION

Tooth brushing with a dentifrice is the principal method of supra-gingival plaque removal in the western world. It is known that toothbrush bristles will become distorted and splayed with use (McKendrick et al. 1971, Bergstrom 1973, Kriefeldt et al. 1980, Glaze & Wade 1986, Rawls et al. 1989) and that the pattern and rate of bristle wear is highly individual and dependent upon multiple factors such as the brushing force and frequency, variations in technique and the presence of destructive toothbrush habits (Dean et al. 1992). Bristle splaying and wear has been identified as a primary indicator for manual toothbrush replacement (Daly & Marshall 1996, Abraham et al. 1990, Leichter & Pack 1999).When judging the effectiveness of a toothbrush, plaque removal is the logical benchmark and ideally toothbrush replacement should be linked to a reduction in performance. The relationship between toothbrush wear and plaque removal efficacy has importance for determining appropriate toothbrush renewal periods.

There have been a number of published studies that examine the effects of manual toothbrush wear on plaque removal (McKendrick et al. 1971, Kreifeldt et al. 1980, Glaze & Wade 1986, Daly et al. 1996, Sforza et al. 2000, Galgut 2001, Tan & Daly 2002, Warren et al. 2002, Conforti et al. 2003). A systematic review comparing manual and powered toothbrushes with respect to plaque removal and gingival health, found evidence to support greater plaque removal and reduction of gingivitis for powered toothbrushes with a rotation oscillation action (Robinson at al. 2005). There is limited scientific data available examining the effects of bristle wear on powered toothbrush heads. Studies based on manual toothbrushes may not be directly applicable to a powered toothbrush as

the automatic motion of the brush head, the differing number and arrangement of the bristles and a reduction in the force applied to the teeth during use (Van der Weijden et al. 1996) may result in a different pattern and rate of bristle wear. Currently only a single published study has examined toothbrush wear on a modern powered toothbrush (Conforti et al. 2003).

It is the aim of this literature review to analyze the current scientific evidence on the relationship of toothbrush bristle wear to plaque removal efficacy with particular reference to powered toothbrushes.

2. Toothbrush Design

i) Manual Toothbrush

There are numerous manual toothbrush designs available. Claims of superiority are often made based on the demonstration of improved short term plaque removal of statistical significance but questionable benefit on gingival health. There is little scientific evidence of the effectiveness of manual toothbrush design on long term plaque and gingivitis reduction (Jepson 1998). As a consequence there is no conclusive evidence to validate that any one style of manual toothbrush is clinically superior to another (Frandsen 1986).

ii) Powered Toothbrush

The aim of a powered toothbrush is to automatically reproduce the cleaning stroke of a manual brush with the anticipation that the automated mechanical action would

compensate for an inadequate brushing technique. Reportedly, the first electrically powered toothbrush was introduced in 1939 but the mass production of powered toothbrushes was not seen until the 1960's (Renton-Harper et al. 2001). The design and mechanical action of powered toothbrushes has evolved rapidly and powered toothbrushes with a variety of head and filament actions are currently available (Fischman 1997). Powered toothbrushes have been classified into seven categories according to their mode of action (Robinson et al. 2005).

1. Side to side, being a powered brush whose head moves from side to side laterally.
2. Counter oscillation, indicating a brush in which adjacent tufts of bristles are rotating in opposite directions.
3. Rotation oscillation, where the head as a whole rotates in alternating directions.
4. Circular, in which the brush head rotates in a single direction.
5. Ultrasonic, where the bristles vibrate at ultra-sonic frequencies.
6. Unknown.

In a Cochrane systematic review Robinson et al. (2005) found evidence to support a modest advantage in terms of greater plaque removal and reduction of gingivitis for powered toothbrushes with a rotation oscillation action in comparison to manual toothbrushes. The authors suggest that powered toothbrushing is at least as effective as manual brushing and that there is no evidence that it will cause any more injuries to the gums than manual brushing.

3. Plaque Removal by Toothbrushes

3.1 Plaque Development

Dental plaque represents a biofilm that forms on non-shedding surfaces in the fluid environment of the oral cavity. It has been defined as "the non-mineralized microbial accumulation that adheres tenaciously to tooth surfaces, restorations and prosthetic appliances, showing structural organization with a predominance of filamentous forms. It is composed of an organic matrix derived from salivary glycoproteins and extracellular microbial products and cannot be removed by rinsing or water spray" (Nolte 1982). The precipitation of salivary glycoproteins onto the tooth surface leads to the formation of a conditioning film called the acquired pellicle. Pellicle formation is the initiating step in biofilm development as it alters the free energy and charge of the tooth surface which increases the efficiency of bacterial adhesion. Bacterial adhesion to the pellicle occurs within minutes (Van Houte et al. 1970). The biofilm increases in size and complexity over time by both multiplication and microbial succession (Kolenbrander 2000).

Several studies have examined the pattern of plaque development following the cessation of oral hygiene measures. It has been shown that supragingival plaque accumulation begins initially at the approximal aspects of the molar and premolar teeth and subsequently develops on the approximal surfaces of the anterior teeth and the facial surfaces of the posterior teeth (Lang et al. 1973, Furuichi et al. 1992).

Loe et al. (1965) demonstrated the relationship between plaque accumulation and the development of gingivitis in humans. It was shown that following the cessation of oral hygiene bacterial plaque accumulation induced gingival inflammation and bleeding in all

subjects within seven to 21 days. The initiation of daily plaque removal led to resolution of the gingival inflammation in just a few days. This illustrated that plaque control is an effective way of treating and preventing gingivitis and thus forms a critical part of all procedures involved in the treatment and prevention of periodontal diseases.

3.2 Frequency of Tooth Brushing and Plaque Removal

Plaque forms continuously on tooth surfaces; therefore, the objective of plaque control is the periodic removal of accumulated plaque at intervals which are sufficient to prevent any clinical signs of inflammation. In a study on the rate and pattern of plaque development Lang et al. (1973) compared the plaque accumulation and Gingival Index (Loe & Silness 1963) of subjects performing plaque removal at the various intervals of 12, 48, 72 or 96 hours. Clinical signs of gingivitis only developed after periods of plaque accumulation in excess of 48 hrs. This study demonstrated that meticulous plaque removal at intervals of up to 48 hrs was compatible with gingiva that was clinically free from inflammation.

In the presence of clinical gingival inflammation the bacterial colonization of the cleaned tooth surface occurs more rapidly (Saxton 1973) and the rate of plaque development is increased (Ramberg et al. 1994). This would indicate that in the treatment of gingivitis more frequent and efficient toothbrushing may be necessary. Twice daily oral hygiene measures have been shown to facilitate the resolution of gingivitis within a few days (Loe et al. 1965), however, gingivitis will persist if plaque removal is only performed every third or fifth day (Bosman & Powell 1977).

When the effects of oral hygiene practices in a group of subjects was evaluated over 26 years it was found that subjects who reportedly brushed at least twice daily had a 49% reduction in the risk of tooth loss than subjects who brushed inconsistently (Kressin et al. 2003). It has been shown that meticulous removal of supragingival plaque has beneficial affects on both the clinical parameters of periodontal disease and on the nature of the microbiota both supra- and sub-gingivally (Smulow et al. 1983, Hellstrom et al. 1996, Ximenez-Fyvie et al. 2000). Axelsson et al. (2004) reported that individuals who consistently achieved more than 80% of plaque free tooth surfaces during 30 years of supportive periodontal therapy maintained periodontal stability and had minimal caries activity. It has been shown that the approximal surfaces and the lingual aspect of mandibular teeth consistently harbor plaque after brushing with a manual toothbrush (Cumming & Loe 1973, Lang et al. 1977, Rugg-Gunn et al. 1979). For this reason it is generally recommended that tooth cleaning be performed up to twice a day to maximize the amount of plaque removed in each 24 hr period (Van der Weijden & Hioe 2005).

3.3 Toothbrushing Force and Plaque Removal

The forces transmitted to the teeth during toothbrushing procedures vary widely between individuals regardless of the type of brush used (Fraleigh et al. 1967). A comparison on the brushing force of three powered toothbrushes (the Rotadent ®, the Interplak ® and the Braun D7 ®) and a manual toothbrush was made in a study by Van der Weijden et al. (1996). It was established that greater force was applied to the teeth during unsupervised manual toothbrushing (mean 267g) than with any of the three powered toothbrushes

(mean range of 96g to 146g). The force transferred to the tooth surface during toothbushing procedures had been shown to influence plaque removal (McCraken et al. 2003). Data from a study comparing the interaction of brushing force and brushing times with plaque removal using a Sensiflex 2000 powered toothbrush found that both increased force and increased time of brushing improved plaque removal, however, at 120 seconds there was no additional benefit for brushing forces above 150g (McCraken et al. 2003). Van der Weijden et al. (1998b) established that there is a linear relationship between increased force and plaque removal only for supervised toothbrushing. In a 'user model' of non-supervised brushing the relationship is non-linear, suggesting that brushing force is not the only factor influencing plaque removal.

3.4 Toothbrushing Duration and Plaque Removal

Two studies have focused specifically on the relationship between tooth brushing duration and plaque removal efficiency (Van der Weijden et al. 1993, Van der Weijden et al. 1996). In order to test the effects of time alone without the confounding factor of operator variation the toothbrushing in these studies was done professionally. They established that plaque removal efficiency increases with time for both manual and powered toothbrushes, the maximum effect being reached at intervals of 30 seconds per quadrant. It was found that after a two minute brushing interval the manual toothbrush on average had lower percentage plaque reduction scores (67%) than the three powered toothbrushes (73-85%) tested. The major area of superiority for the powered toothbrushes over the manual toothbrush was plaque removal from the approximal surfaces of the teeth.

Hansen and Gjermo (1971) evaluated the efficiency of supervised manual toothbrushing by a dental hygienist and found that between 2.75 to 4.25 minutes were required to remove the maximum amount of plaque, dependant upon the brushing technique used. Hawkins et al. (1986) found an almost linear relationship between the duration of manual toothbrushing and plaque removal in a group of 82 dental students when they were examined at timed intervals of 30, 90, or 150 seconds. The students were also asked to brush for their personal "ideal" interval. This period ranged from 3.25 minutes to 8.5 minutes (mean 5.1 minutes). The results demonstrated that only the "ideal" intervals consistently reduced plaque to levels that were statistically significant. The interval of toothbrushing performed by this group of dentally aware students is likely to be greater than the routine time spent toothbrushing by the average person. MacGregor (1984) found that the average time spent brushing with a manual toothbrush was 60.2 seconds in a sample of 128 dental patients. This finding supports that of Robinson (1946) who found that the average toothbrushing interval was 67 seconds in a group of 405 subjects. It would appear from the evidence that the time spent on toothbrushing by the average person is shorter than the time interval necessary to maximally reduce plaque levels.

3.5 Filament Design

There is conflicting evidence on whether the structure and the morphology of the toothbrush filaments on manual toothbrushes will influence plaque removal. Bergenholz et al. (1969) compared four manual toothbrushes with varying bristle stiffness and density (hard, soft, multi-tufted and space-tufted) and found no significant difference

between the brushes with respect to plaque removal. In contrast, it was concluded by Pretara-Spanedda et al. (1989) that manual brushes of a higher density were more efficient at plaque removal during a single use trial. Vowles & Wade (1977) observed that manual brushes with finer filaments removed less plaque than those with broader filaments. No clear recommendation on the ideal filament stiffness and density with respect to plaque removal can be made based on the current evidence.

i) Adverse Effects

Filament stiffness has been considered a factor contributing to cervical tooth abrasion; however, evidence on the relationship of filament stiffness and abrasion is inconclusive and the etiology is likely to be multi factorial (Litonjua et al. 2005). In an epidemiological study on dental abrasion Bergstrom & Lavstedt (1979) found that toothbrushing frequency and technique had a greater association with abrasion than toothbrush bristle stiffness. It has been suggested that the quality of end-rounding of toothbrush bristles may induce gingival trauma from toothbrushing (Breitenmoser et al. 1979). Animal studies have demonstrated that soft tissue abrasion lesions were caused by the use of toothbrushes with sharp edged bristle tips and poor end rounding quality (Alexander et al. 1977). In a manual toothbrushing study of 30 young adults it was shown that a 30 second brushing interval with the use of cut toothbrush bristles resulted in 30% more gingival abrasion lesions than when rounded toothbrush bristles were used (Breitenmoser et al. 1979).

ii) Bristle End-rounding

Studies evaluating the end-rounding of manual and powered toothbrush bristles have revealed considerable variation amongst brands and products (Checci et al. 2001, Checci et al. 2004, Jung et al. 2003, Jung et al. 2005). Jung et al. (2005) used a scanning electron microscope (SEM) to evaluate the geometry and quality of bristle tip-rounding on 14 commercially available brush heads for powered toothbrushes. They found that the percentage of bristles with acceptable end rounding according to the criteria of the Silverstone & Featherstone classification (1988) varied from 18.9 to 94.3%. They concluded that powered toothbrush heads had only a moderate quality standard. The Oral-B ® Flexi-soft brush-head was found to have between 70-80 % of bristles with acceptable end rounding. Checci et al. (2004) found that only four of the 14 powered toothbrushes studied under SEM had more than 50% of the bristles with acceptable end-rounding according to Silverstone & Featherstone (1988). It has been shown that the bristle tip morphology will change with toothbrush use (Massassati & Frank 1982). Massassati & Frank (1982) found that following a period of 3-months twice daily use, manual nylon toothbrush bristles underwent thinning, bending and irregular wear.

4. Comparison of Powered and Manual Toothbrushes

4.1 Introduction

Whilst manual toothbrushes are currently the most widely used type of toothbrush the popularity of powered toothbrushes is steadily increasing in western countries (Backdash 1995). This is demonstrated by powered toothbrush sales in the United Kingdom, where in the year 2000 they comprised a 5% market share of all toothbrush sales, with this

figure rising to 19% in 2004 (Davies 2006). Powered toothbrushes are purchased by the general public in response to advertising or personal and professional recommendation. Approximately 50% of Braun Oral B powered toothbrush sales in the United States are the result of advice from a dental professional (Warren et al. 1998). In a survey of German dentists it was found that 61% of respondents recommended the use of a powered toothbrush to their patients (Warren et al. 1998). It has been shown in a Swedish population that once purchased, the continued use of powered toothbrushes is high (Stalneke 1995). In a large scale study 600 American patients recruited from general dental practices were issued with a powered toothbrush and instructions for its correct use. In a follow-up phone survey 95% of subjects stated that they were using their powered toothbrush on a daily basis after a period of 4 weeks, and at 10 months 89% reported continued compliance with the powered toothbrush (Warren et al. 2000). With the continuing trend towards powered toothbrush use it is important to compare and contrast powered and manual toothbrushes with respect to their plaque removal efficiency, effects on gingival health and microbial parameters.

4.2 Plaque Removal

Recently published literature has supported superior plaque removal by powered toothbrushes when compared to manual brushes. A systematic review by the Cochrane Oral Health Group (Robinson et al. 2005) was designed to compare manual and powered toothbrushes in relation to the removal of plaque, the health of the gingiva, staining and calculus, dependability, adverse effects and cost. The aim of this review was to compare manual and powered toothbrushes under conditions that closely reflected normal routine

use. Evidence from randomized controlled trials that examined unsupervised manual and powered brushing by study populations of any age that were representative of the general population were examined specifically. Only trials with a duration of four weeks or longer were included. Cross-over trials and split mouth trials were excluded as it was felt that they did not represent typical "everyday" toothbrush use. Trials with combined oral hygiene interventions (for example, mouth rinses or irrigation) were also excluded to avoid any confounding factors. Some of the 42 included trials had children in the study sample (Clerehugh et al. 1998, Ho & Niederman 1997, McAllan et al. 1976) but the majority examined adult populations. When looking at the study variable of plaque removal alone it was found that only powered toothbrushes with a rotation oscillation action removed more plaque than manual toothbrushes in both the short (between 28 days and 3-months) and the longer term (over 3-months). This corresponded to a reduction in mean plaque scores (Turesky 1970) of 11% over a manual brush. Whilst this is statistically significant it is uncertain whether this relates to a clinically important improvement in oral health. There is no evidence that brushes with a circular action or sonic powered toothbrushes remove plaque more effectively than manual brushes in either the short or long term. There were significant methodological concerns for many of the included trials. The generation of the randomization sequence was inadequate for 15 and unclear for 25 trials and the concealment of allocation was unclear for 24 and inadequate for 16 trials. Manufacturer sponsorship was stated in 24 of the trials and was unclear in 14 trials which could potentially introduce bias.

4.3 Gingival Bleeding and Inflammation

Sicilia et al. (2002) completed a systematic review of the literature designed to compare the effectiveness of powered and manual toothbrushes with respect to gingival bleeding or inflammation resolution in the treatment of gingivitis and chronic periodontitis in adult populations. From the 21 studies reviewed it was concluded that "limited evidence exists of the higher efficacy of electric toothbrushes compared with manual ones to reduce gingival bleeding or inflammation." This was most evident in counter-rotational and rotation oscillation brushes. No evidence was found to support a higher efficacy of sonic brushes. The researchers expressed concern at the heterogeneity of indices used to measure plaque and gingival inflammation and the fact that many of the included studies did not clearly define the periodontal status of the study populations at baseline.

In the Robinson et al. (2005) review it was reported that there is a decrease in gingivitis equivalent to a 17% reduction on the Ainamo Bay Bleeding on Probing Gingival Index (Ainamo & Bay 1975) with use of a rotation oscillation powered toothbrush when compared to manual toothbrushing over periods greater than 3-months.

4.4 Interdental Cleaning

Microbial deposits which remain on the approximal surfaces after brushing will speed the recolonization of clean tooth sites (De La Rosa et al. 1979). Approximal sites most frequently harbor residual plaque deposits after (manual) toothbrushing (Hugoson & Koch 1979, Lang et al. 1977). Toothbrushing alone cannot effectively eliminate interdental plaque. It has been demonstrated that toothbrushing in combination with

flossing is more effective at plaque removal than toothbrushing alone (Reitman et al. 1980, Kinnane et al. 1992). Brushing with a manual toothbrush combined with flossing removes more plaque approximally than brushing alone with either a manual toothbrush or a powered toothbrush with a rotation oscillation action (Sjogren et al. 2004). It has been shown that regular interdental cleaning is not a widespread practice (Frandsen 1985, Johnson & McInnes 1994). It has been estimated that "in industrialized countries 15-20% of the population at most performs interdental oral hygiene on a regular basis" (Van der Weijden et al. 1998a).

The access of toothbrush bristles is restricted to the "approximal" areas defined as 'the visible spaces between the teeth that are not directly under the contact point' (Egelberg & Claffey 1998) as it is impossible to reach the true "interproximal" region which refers to 'the sites directly under the contact point of adjacent teeth' (Egelberg & Claffey 1998).

It has been suggested that the superiority of powered toothbrushes over manual brushes is related to more efficient plaque removal in approximal areas (Egelberg & Claffey 1998, Rapley & Killoy 1994). Approximal cleaning by both manual and powered toothbrushes has been directly compared. In a professional brushing study Rapley & Killoy (1994) found that a manual toothbrush achieved 30.57% of plaque free approximal surfaces compared to a rotation oscillation powered toothbrush which achieved 53.23% of plaque free approximal surfaces.

4.5 Children

Young individuals are thought to have reduced motor skills and generally poor brushing technique and it has been proposed that children may benefit from the use of a powered toothbrush (Brothwell et al. 1998). The published evidence, however, is conflicting. Jongenelis & Wiedemann (1997) showed that a powered toothbrush can achieve greater plaque removal than a manual toothbrush in children aged between five and ten years. The difference was most marked for the lingual surfaces. In a cross-over, single blind clinical trial on 73 children aged between four and six years a powered toothbrush removed significantly more plaque than a manual toothbrush with the exception of the approximal surfaces where the brushes were equal (Borutta 1997). Grossman & Proskin (1997) showed that a powered toothbrush had superior plaque removal in children aged between eight and 12 years in comparison to a manual toothbrush.

In contrast, Silverman et al. (2004) compared a Braun Oral B ® powered toothbrush and a manual toothbrush in a sample of children and found no difference in plaque removal by the two brushes after a single episode of toothbrushing. A similar result was found by Da Costa et al. (2001) in a group of 29 school children. No significant difference in plaque removal was found between manual and powered toothbrushes with the exception of the lingual aspect of the mandibular teeth where the powered toothbrush was superior. Overall, there is no clear consensus as to the additional benefits, if any, of a powered toothbrush above that of a manual toothbrush for children.

4.6 Orthodontic Patients

There have been several studies examining the comparative effectiveness of manual and powered toothbrushes in patients undergoing fixed orthodontic therapy. There is no decisive evidence for the superiority of either style of toothbrush. Clerehugh et al. (1998) found that orthodontic patients using a powered toothbrush had lower plaque and approximal bleeding scores than those using a manual toothbrush over an eight week study period. However, in a four week cross-over trial, Heasman et al. (1998) demonstrated no difference in plaque and gingival bleeding scores between a powered and a manual toothbrush in 60 orthodontic patients (aged 10-16 years). Thienpont et al. (2001) also found manual and powered toothbrushes to be equally effective in a single use cross-over trial on 33 children undergoing fixed orthodontic therapy. In contrast, a manual toothbrush was found to be to be more effective than a powered brush with respect to plaque and gingival scores over a two month study period in adolescent orthodontic patients (Trimeneers et al. 1997). From the evidence it is difficult to make specific recommendations on the most favorable type of toothbrush for patients undergoing fixed orthodontic therapy.

4.7 Periodontal Maintenance Patients

Plaque control is of the utmost importance for periodontally susceptible patients and it has been proposed that the use of a powered toothbrush may be advantageous for patients undergoing periodontal maintenance (Haffajee et al. 2001a, Quirynen et al. 1994). Haffajee et al. (2001a) compared the effects of powered and manual toothbrushing on clinical parameters in a group of 48 periodontal maintenance patients. Only the powered

toothbrush group showed significant reductions in mean gingival index and probing attachment levels over a six month period. The powered toothbrush group had superior reductions in Plaque Index (Turesky et al. 1970), greater reductions in the percentage of sites exhibiting bleeding on probing and reduction in probing pocket depths. The benefit of the powered brush was most evident at mandibular and lingual surfaces. Quirynen et al. (1994) compared powered with manual toothbrushing in a split mouth experiment on six patients with moderate periodontitis and six dental students. At all intervals up to week 34, manual brushing resulted in significantly less pocket depth reduction and plaque removal, particularly at approximal sites. However; the results of this study must be interpreted with caution due to the small sample size.

These findings were contradicted in a two week cross-over trial of toothbrushing in 28 periodontal maintenance patients which found no difference in plaque removal between a powered (Interplak®) and a manual toothbrush (Butler 311®) (Howorko et al. 1993). It can be concluded that for patients on periodontal maintenance, a powered toothbrush has been found to be equal to a manual toothbrush (Howorko et al. 1993) and in some patient groups' superior (Haffajee et al. 2001, Quirynen et al. 1994).

4.8 Patients with Dental Implants

The safety and efficacy of a rotation oscillation powered toothbrush has been assessed in patients rehabilitated with implant supported fixed prostheses (Vandekerckhove et al. 2002). The patients included in the trial had only ever used a manual toothbrush. They were asked to use a powered toothbrush exclusively for a 12 month study period. At

three, six and 12 months the clinical parameters of bleeding index; probing pocket depth (PPD) and gingival recession were recorded and then compared to baseline. It was found that PPD decreased from a mean of 3.3mm to 3.0mm and there was a mean decrease in recession of 0.1mm at the 12 month assessment. These minor differences in clinical parameters are of doubtful clinical importance.

In a Cochrane systematic review on the maintenance and re-establishment of healthy tissues around dental implants (Espositio 2003), only two clinical trials that compared manual, powered and sonic toothbrushing were accepted for inclusion (Tawse-Smith 2002, Wolff 1998) according to the Cochrane Oral Health Groups Guidelines. No statistically significant difference was found among toothbrush types in the included trials. It was concluded that there was no evidence that the use of powered or sonic toothbrushes is superior to manual toothbrushing for patients with dental implants (Espositio 2003).

4.9 Anti-Microbial Effects

When comparing the effects of manual and powered toothbrushes on subgingival plaque composition it has been shown that microbial counts and taxa are markedly reduced by both manual and powered toothbrushing (Murray et al. 1989). In both toothbrushing groups a statistically significant decrease was found in the levels of obligate anaerobes, Fusobacteria, Actinomyces, Spirochaetes and motile rods, while the levels of Streptococcus species increased. Haffajee et al. (2001b) similarly found reductions in total mean counts and prevalence of *Actinobacillus naeslundii* and *Actinobacillus israelii*

in supra and subgingival plaque samples over six months in patients using either a manual or a powered toothbrush. The greatest decrease was found in the subgingival plaque samples. Other species which were reduced significantly included members of the genus Streptococcus, *Porphyromonas gingivalis, Campylobacter rectus, Treponema denticola* and *Bacteroides forsythus*. These reductions were similar in both the powered and manual toothbrushing groups. It can be concluded that both manual and powered toothbrushes equally decrease the prevalence of periodontal pathogens in supragingival and subgingival plaque thereby lowering the potential reservoirs of these species.

4.10 Trauma to Hard and Soft Tissues

There is no evidence to suggest that powered and manual brushes differ in their effects on soft and hard tissues in the long term (Robinson et al. 2005). Schemehorn & Zwart (1996) demonstrated that a powered toothbrush had a lower mean relative dentine abrasion than a manual toothbrush as measured by a radiotracer technique using a V8 cross brushing machine for eight and a half minutes. A powered brush delivers more strokes per unit of time; however, the force transferred to the teeth is significantly less than with a manual brush (Van der Weijden et al. 1996). There is approximately 1.0 N less force generated with a powered toothbrush than with a manual toothbrush (Van der Weijden et al. 1996). The use of high force (3.5 N) is less effective in plaque reduction than low force (1.5 N) when using a rotation oscillation power toothbrush (Van der Weijden et al. 2004). In a group of Swiss dental students no difference in the incidence of gingival abrasion was found when a powered toothbrush was compared to a manual toothbrush (Mantokoudis et al. 2001). Other studies comparing powered and manual

toothbrushes have reported no significant difference in the incidence of gingival recession and dentinal abrasion lesions (Baab & Johnson 1989, Walsh et al. 1989, Van der Weijden et al. 1994, Heasman et al. 1999).

4.11 Toothbrush Instruction

Lazarescu et al. (2003) designed a study to test the effects of repeated oral hygiene instruction over an 18 week period on both manual and powered toothbrush users. Continued improvement in plaque removal was shown for the manual brush users for up to three weeks and for up to 12 weeks for subjects using a powered toothbrush. This would suggest that there is a learning curve with a powered toothbrush. Renton-Harper et al. (2001) compared plaque removal with a manual toothbrush and two different powered toothbrushes issued without instructions for use. There was no significant difference in plaque removal between the three toothbrush regimes suggesting that in the absence of oral hygiene instruction there is no advantage for either a powered or a manual toothbrush.

It has been shown that in the hands of a dental professional using an optimal brushing technique for two minutes; a rotation oscillation powered toothbrush was as effective at plaque removal as ten minutes of professional polishing with a rubber cup (Van der Weijden et al. 2004a). The brushing technique used was directed as much as possible towards the approximal surfaces. This study has shown that in the hands of a dental hygienist who has been specifically trained in the use of an optimal brushing technique, a 95% reduction in plaque scores can be achieved with a rotation oscillation toothbrush

when used on a patient. Similarly, when manual toothbrushes are used it has been found that professional plaque removal is more effective than unsupervised toothbrushing regardless of the type of toothbrush used or the brushing technique (Bergenholtz et al.1984). This highlights the importance of improving the skills of the user of the toothbrush by careful instruction and motivation.

4.12 Conclusion

Plaque removal depends not only on the type of brush or on the method of brushing, but on the individual having an effective technique. It is possible to achieve a reduction in supragingival plaque, and maintain gingival health with both a manual and a powered toothbrush (Haffajee et al. 2001a). Manual and powered toothbrushes appear to be equal in the incidence of gingival recession and abrasion lesions (Baab & Johnson 1989, Walsh et al. 1989, Van der Weijden et al. 1994, Heasman et al. 1999). Whilst some studies have found powered toothbrushes to have superior plaque control compared to manual toothbrushes in children (Jongenelis & Wiedemann 1997, Borutta 1997, Grossman & Proskin 1997) other studies have found no difference (Silverman et al. 2004, Willershausen & Watermann 2001, da Costa et al. 2001). In patients undergoing orthodontic treatment with fixed appliances some evidence favors a powered toothbrush (Clerehugh et al. 1998) while other studies found manual and powered toothbrushes to have equal plaque removal (Heasman et al. 1998). There may be some benefit for periodontal maintenance patients using a powered toothbrush with respect to improved oral hygiene and clinical indices (Hellstadius et al. 1993, Haffajee et al. 2001a, Quirynen et al. 1994) but not all studies have supported this finding (Howorko et al. 1993). The

improved plaque control and reduction in gingival indices of rotation oscillation powered brushes over manual brushes (Robinson et al. 2005, Sicilia et al. 2002) is statistically significant but may not have long term clinical significance. It can be concluded that a powered toothbrush is at least equal to a manual toothbrush with respect to plaque removal and may be superior in some subjects (Robinson et al. 2005).

5. Toothbrush Renewal

5.1 Introduction

Little literature exists on the subject of toothbrush replacement. The primary sources of toothbrush replacement recommendations made to the public are dental associations, toothbrush manufacturers and dental professionals.

5.2 Professional Recommendations

The American Dental Association's public website states that: "a toothbrush should be replaced every three to four months or sooner if the bristles become frayed" and that "a worn toothbrush will not do a good job of cleaning teeth." (American Dental Association website 2006). It is not stated whether this relates to manual or powered toothbrushes specifically.

The Australian Dental Association (ADA) does not provide published recommendations on toothbrush renewal. A survey of Australian general dental practitioner members of the ADA by Daly et al. (2000) may provide some insight into the views of Australian dentists on manual toothbrush wear, toothbrush renewal periods and their recommendations to

patients. It was found that 81.5% of respondents recommended the same renewal intervals to patients as they used for their own brushes. These intervals varied from less than one month to more than six months. The majority of respondents (56.6%) selected a renewal period of two or three months. Many respondents (54.7%) did not make any recommendations on toothbrush renewal to their patients.

A similar survey of Australian periodontists and dental hygienists (Daly & Marshall 1996) found that 73% of periodontists and 86.4% of hygienists reported giving manual toothbrush renewal recommendations to their patients. Bent or splaying bristles were specified as the indicators for toothbrush replacement by 81.2% of periodontists and 70.4% of hygienists. An interval of two months was given most frequently as the ideal replacement period, with intervals ranging from less then 1 month to more than 6 months. Abraham et al. (1990) surveyed American dentists and dental hygienists and found that 95% claimed to give their patients recommendations on manual toothbrush replacement, however; the dental hygienist typically served as the patient educator. A three month replacement schedule was recommended by the majority (51.8%) while 13.1% advised monthly renewal and 16.2% did not suggest a specific time interval at all. There was a similarity between interval recommendations for patients and the respondent's own renewal habits. The majority of respondents believed that splayed or bent toothbrush bristles were the first and most obvious indicators warranting replacement.

In a study designed to complement the Australian and American studies (Abraham et al. 1990, Daly & Marshall 1996), Leichter & Pack (1999) examined the attitudes of 467

New Zealand dentists and 49 dental hygienists towards manual toothbrushes and toothbrushing. Only 49.5% of responding dentists gave their patients' recommendations on toothbrush renewal and their renewal interval ranged from one month to more than six months. The majority (76.6%) said that the ideal replacement time was two to three months. Nearly all the hygienists surveyed (91.7%) told their patients' when to renew their brushes and all recommended intervals of three months or less. The most important indicators of the need for brush replacement by both dentists and hygienists were that a brush was "no longer removing plaque", that a brush had "bent or splayed bristles" or that a brush was "causing trauma to the gingiva". The recommended replacement intervals had a high correlation to their own personal practice, closely following the results of the other studies.

It would seem that amongst dental professionals in America, Australia and New Zealand a manual toothbrush replacement interval of two to three months has found widespread acceptance. It is also apparent that this is reflected in their personal toothbrush habits. There is no literature on toothbrush renewal intervals specific to powered toothbrush heads.

5.3 The General Population

An extensive study of the Swedish population by Bergstrom (1973) found that on average manual toothbrushes were replaced every four and a half months although subjects interviewed considered that toothbrushes should be replaced after 3.3 months on average. Toothbrush wear correlated with the length of time in use. The social factors affecting the

degree of wear of the brush were, firstly, the financial situation of the household and secondly, whether they were from rural or city communities. It was suggested that toothbrush replacement is affected by economic considerations and accessibility.

In a study on toothbrush usage patterns and factors in manual toothbrush wear of staff working at a British dental hospital (Grundy & Wetherill 1979), it was found that the age of toothbrushes being used ranged from one month to five years. The average age of the toothbrushes was three and a half months. There was considerable variation in toothbrush wear between individuals. The degree of wear did not correlate to the reported number of times of daily use, the temperature of the water used or the toothbrushing method. In this study no examination of the plaque levels of individuals was made, so no conclusions can be drawn on the effects of wear on the plaque removing efficiency of the brushes. This study did not question the study subjects on the factors influencing their toothbrush replacement pattern.

Dean et al. (1992) attempted to show a relationship between manual toothbrush wear and the subjects' tooth brushing behavior and socioeconomic status in an American population. They did a quantative analysis of the wear on used toothbrushes combined with a questionnaire of the toothbrush users. The majority of respondents (73%) stated that they used their brushes for three months or longer and that they discarded their brushes when they "looked worn out" relating to bristle splay and debris at the base. Their findings suggest that the length of time a brush remains in use is highly variable among individuals and that there is no linear correlation between time in use and the

degree of toothbrush wear. For the majority of survey participants toothbrush wear was determined by visual signs of bristle distortion. The perception of toothbrush wear by the user will have a significant influence on when they decide to renew their toothbrush.

In a study designed to examine the correlation between visual estimation of manual toothbrush usefulness and the ability of the same brush to remove artificial plaque from laboratory models, Dean (1991) found that manual toothbrushes thought to be worn out by 89% of 268 people surveyed demonstrated the same plaque removal efficiency as a new brush. It can be concluded that there is a lack of correlation between visual estimation of manual toothbrush usefulness by the general public and the cleansing ability of the toothbrush.

As reported by Bakdash (1995), a national telephone survey of 1256 adult Americans conducted by Louis Harris and Associates in 1991, found that 40% of respondents claimed to replace their toothbrush at least three times a year, 33% twice a year, and 27% once a year or less. This translates to a toothbrush renewal period of six months or longer for 60% of people surveyed.

These studies indicate that in most cases people will use a manual toothbrush for three months or longer before replacing it and that the stimulus for renewal is splaying of the bristles or debris accumulation at the base of the bristles.

5.4 Recommendations of Toothbrush Manufacturers

In an attempt to promote frequent toothbrush replacement some manufacturers have incorporated visual cues for toothbrush renewal into their products. Braun Oral B ® utilizes INDICATOR ® bristles on their powered toothbrush heads and Oral B ® manual toothbrushes. This is a design in which some of the bristles are colored blue. The color fades with use and acts as a prompt for brush replacement. It has reportedly been designed so that approximately 30-50% of the color is lost from the tip down the length of the indicator bristles after 3 months of use (Warren et al. 2002). Oral B ® powered toothbrushes also carry the statement in their instruction brochure: "Dentists recommend that you replace any toothbrush every three months. Therefore; the brush-head is provided with INDICATOR ® bristles. With proper brushing twice a day for two minutes, the colour will disappear half-way down the bristles in a three month period, provided you use toothpaste." It has not been demonstrated in published studies how this loss of color from the bristles affects the plaque removal efficiency of the brush. Thus, the clinical relevance of the INDICATOR ® bristles is yet to be established.

5.5 Microbial Contamination

Factors other than loss of efficacy may influence the ideal toothbrush replacement protocol. It has been shown that toothbrushes quickly become contaminated with micro-organisms through routine use (Glass & Martin Lare 1986, Nelson et al. 2000, Taji & Rogers 1998, Verran & Leahy-Gilmartin 1996). *Streptococcus mutans* in the order of 21 to 120 colony forming units (CFU) have been cultured from manual toothbrushes after only five days of use in a group of children (Nelson Filho et al. 2000). A total microbial

load of 10^4 to 10^5 CFU's were cultured from manual toothbrushes after a three week period of use by ten adults (Taji & Rogers 1998). The predominant species found were Staphylococci and Streptococci; however, *Candida*, Cornynebacteria, Pseudomonads and Coliforms were also identified. These results are consistent with the findings of Verran & Leahy-Gilmartin (1996), and Glass & Martin-Lare (1986). The immersion of toothbrushes in either 0.12% chlorhexidine gluconate or 1% sodium hypochlorite solution for 20 hours has been shown to effectively eliminate all micro-organisms from used toothbrushes (Nelson Filho et al. 2000). However, the presence of micro-organisms on toothbrushes does not correlate with clinical evidence of disease (Glass & Martin-Lare 1986). There is no clear evidence whether toothbrush disinfection is of clinical benefit or whether the presence of micro-organisms per se is a consideration for more frequent toothbrush replacement.

5.6 Conclusions

There is no data on the appropriate replacement interval for powered toothbrush heads. A time period of two to three months for manual toothbrush renewal has been advocated by toothbrush manufacturers, dental associations and dental professionals, but the basis for this specified time period is not clearly defined. It is important that the dental community make appropriate recommendations that are evidence based. It is known that during extended use, bristles become thin near their tips and take on a bent, matted appearance (Rawls et al. 1989). This is the result of the abrasive reduction in the diameter of the bristles, fatigue and the gradual accumulation of permanent strain. The splaying of bristles increases with increased use and different individuals will produce markedly

different patterns of toothbrush wear (Rawls et al. 1989). Studies examining the relationship between toothbrush bristle wear and plaque removal efficiency have widespread clinical relevance in providing a scientific basis for toothbrush replacement recommendations.

6. Research Methodology Considerations

6.1 Reproducibility Testing

Clinical trials are generally based on the measurement of a clinical parameter(s) that has been chosen as the outcome variable to measure the result of an intervention or study factor. The repeatability for measurement recording is a crucial factor in the level of reliability of the data collected and any conclusions that are drawn from this data. It is essential that evaluators be thoroughly trained and calibrated both prior to the commencement of the study and periodically throughout the study (Boardman 2002). Polson (1997) recommends that measurement reproducibility testing be done routinely on several different participants so that the reproducibility results are relevant within and between subjects. A decision is then made as to the adequacy of this variability according to the definitions of the trial and the standards for clinical trials in the literature. A kappa score can be used as a measure of agreement between multiple scores and is adjusted for the amount of agreement which would be expected to occur by chance alone. A value of one implies perfect agreement. It has been suggested that a kappa (K) score of 0.87 is considered substantial (Thompson & Walter 1988).

6.2 Sample Size

A symposium on powered toothbrushes held at the 2000 International Association of Dental Research general session discussed the elements of ideal statistical practice in the planning, execution and analysis of clinical trials assessing powered toothbrushes (Boardman 2002). It was suggested that the power (the ability to detect a difference if there is a difference) should be set at 0.80 or higher for calculations of sample size and that at least 35 subjects be included in each arm of the study to allow for possible subject losses.

6.3 Plaque Indices

Clinical trials designed to examine the efficacy of toothbrushes must by nature have a method of measuring outcome variables for assessment and comparison. This is achieved by the use of an index system. An index is a numerical value describing the relative status of a study population on a graduated scale with a definitive upper and lower limit designed to facilitate comparison with other populations classified by the same criteria and methods (Mandel 1974). An adequate index should be both reliable and valid in addition to being clinically meaningful (Polson 1997). The outcomes most frequently measured are plaque removal and gingival inflammation. Unfortunately, these variables are not easily quantifiable by objective means. Even the most clearly defined index system is subject to examiner variations such as training and clinical experience. This is further complicated when multiple examiners are utilized. This underlies the importance of calibration and reproducibility testing of examiners to avoid the introduction of measurement error. Index systems follow an ordinal scale and are non-parametric in

nature which will complicate data analysis. The choice of an index system to be used in a clinical trial is made in terms of the objectives of the trial, the period of the study, and the type and extent of the change anticipated. The number and age of patients to be examined, frequency of examination and the examination conditions will also dictate the most suitable index.

Indices for measuring plaque on the teeth are generally quantitative in terms of tooth area covered or the thickness of the material in the area measured. Because plaque is colourless, it is often visualized by a staining medium prior to scoring, a process called "disclosing". Common disclosing solutions have been described by Mandel (1974):

1. Bismark brown solution (3g in 10ml alcohol, 120ml glycerin and a drop of anise).
2. Flavored basic Fuchsin (Beta Rose).
3. Erythrosine (F.D.C. Red # 3) used as a chewable tablet or as a solution (generally 4-5 % in alcohol).
4. A combination of F.D.C. Red # 3 and F.D.C. Green # 3 to give a two-tone dye test for plaque where thick plaque appears blue and thinner plaque red.
5. Fluorescein sodium (FDC Yellow # 8) solution that only becomes visible with exposure to a specific light source utilizing a dichroic filter.

Plaque is then defined in an operational sense as "stainable material" because it will include pellicle as well as bacterial deposits. In studies assessing the effects of toothbrush wear there is a measurement of plaque made before and after toothbrushing so that a calculation of plaque removal can be made. The plaque scores for individual sites and

teeth are often combined and averaged to give a single mean mouth score that is assumed to be characteristic for each subject.

Table 1: Plaque Indices Used in Toothbrush Wear Studies

Plaque Index	**Study**
Oral Debris Index (Greene & Vermillion 1960).	○ McKendrick et al. (1971).
Plaque Index (Silness & Loe 1964).	○ Sforza et al. (2000).
Patient Hygiene Performance Index (Podshadley & Haley 1968).	○ Glaze & Wade (1986).
Rustogi Modified Navy Plaque Index (Rustogi et al. 1992).	○ Warren et al. (2002).
Proximal Marginal Plaque Index (Benson et al. 1993).	○ Conforti et al. (2003): Manual toothbrush Study.
Turesky et al. (1970) modification of the Quigley & Hein (1962) plaque index.	○ Daly et al. (1996). ○ Tan & Daly (2002). ○ Conforti et al. (2003): Powered toothbrush Study.

(i) The Oral Debris Index (Greene & Vermillion 1960)

This index was used by McKendrick et al. (1971) and scores "debris", of which plaque is one component. Debris is defined as the "soft foreign matter loosely attached to the teeth" which may include food debris and material alba. The Oral Hygiene Index (Greene & Vermillion 1960) is composed of the Debris Index combined with the Calculus Index. The original Oral Hygiene Index included a measurement of the buccal and lingual aspects of six segments of the mouth (Figure 1). For each segment the tooth with the greatest area of debris is used for calculating the index. The surface area covered by debris is estimated by running a number 23 explorer probe along the tooth surface being examined (Table 2). The scores are then totaled and divided by the number of segments scored to calculate the Debris Index. The Calculus Index is determined in a similar manner. The indices are combined and divided by two to calculate the Oral Hygiene Index (Greene & Vermillion 1960). This index is suitable for field studies where it may be inconvenient to disclose and rinse before evaluation of debris but is not a true measure of plaque. As such it has a limited application in clinical trials evaluating plaque removal procedures.

Figure 1: The Oral Debris Index (Greene & Vermillion 1960) segments (World Health Organization Country/Area Profile Programme).

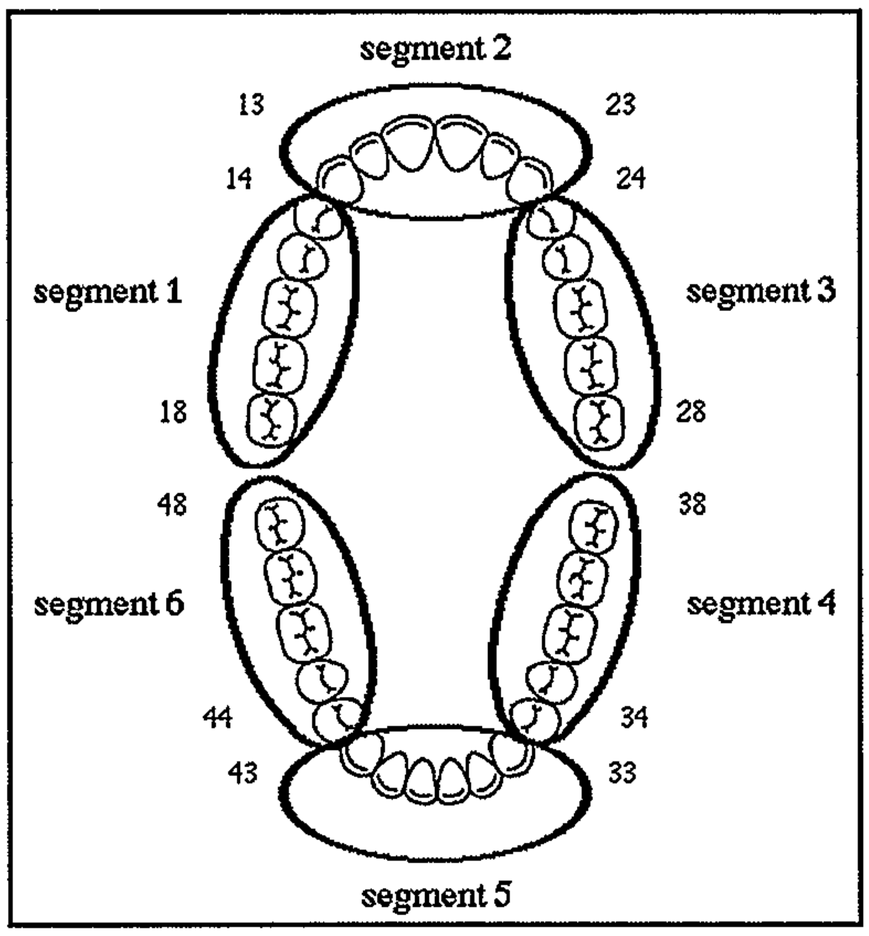
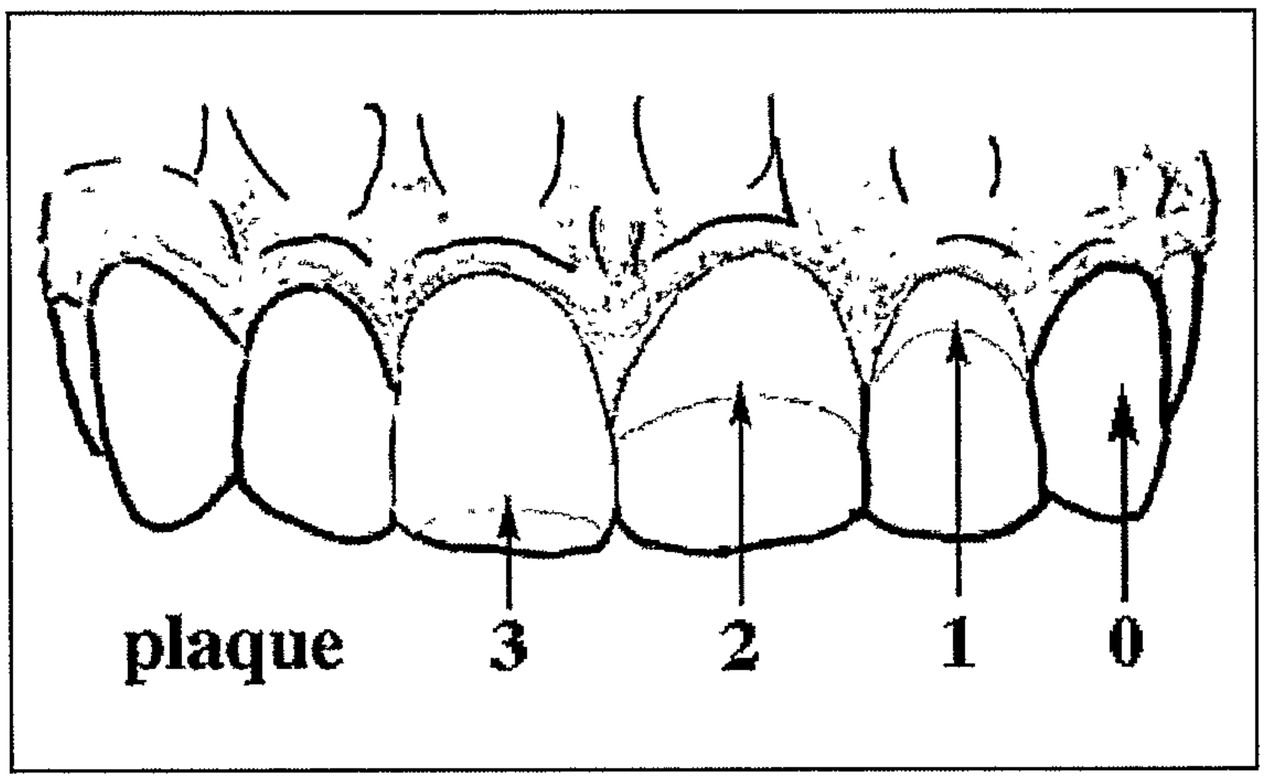


Table 2: The Oral Debris Index (Greene & Vermillion 1960).

Scores	Criteria
0	No debris or stain present
1	Soft debris covering not more than one third of the tooth surface, or presence of extrinsic stains without other debris regardless of surface area covered
2	Soft debris covering more then one third, but not more than two thirds, of the exposed tooth surface.
3	Soft debris covering more than two thirds of the exposed tooth surface.

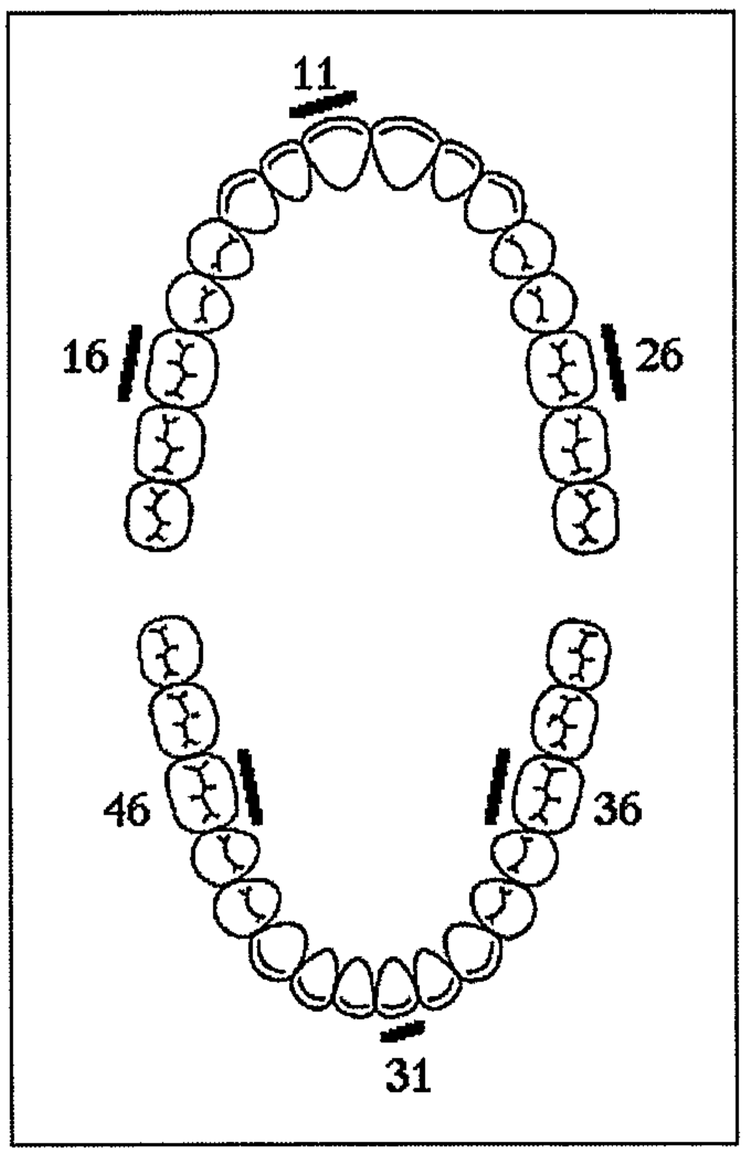
Figure 2: The Oral Debris Index (Greene & Vermillion 1960) (World Health Organization Oral Health Country/Area Profile Programme).



The original Oral Hygiene Index was later simplified (Greene & Vermillion 1964) so that only six tooth surfaces are scored (Figure 3). It is measured on the labial surfaces of the teeth 11, 16, 26, 31 and the lingual surfaces of 36 and 46. Adjacent teeth can be substituted for the study teeth if they are absent. Oral cleanliness is also considered and is assessed as being "good" if the debris index is between 0.3 and 0.6, "fair" if between 0.7 and 1.8 and "poor when scoring reaches between 1.9 and 3.0.

A shortcoming of this index is that it does not differentiate between extrinsic stains and debris, and has a low sensitivity when measuring small amounts of plaque in the gingival third of the crown. The index therefore, offers poor discrimination of the gingival plaque area scores and is unsuitable for evaluating mechanical anti-plaque procedures such as toothbrushing.

Figure 3: Oral Hygiene Index- Simplified (Greene & Vermillion 1964) (World Health Organization Oral Health Country/Area Profile Programme).



(ii) The Plaque Index (Silness & Loe 1964)

The Plaque Index was utilized in the Sforza et al. (2000) study for plaque scoring at four sites being the distofacial, facial, mesiofacial and lingual surfaces per study tooth. Compressed air is used to dry the tooth surfaces prior to the evaluation of the plaque deposits. A score is given based on the tooth surface area at the gingival margin covered by plaque (Table 3). This index may be used on a whole mouth or selected mouth basis. A limitation of this index is that only the mid lingual aspect and not the proximal lingual surfaces are scored. This may lead to an under-estimation of plaque as it has been shown that toothbrushing is least effective at the lingual and approximal aspects of the teeth (Lang et al. 1973, Cumming & Loe 1973). The plaque index only considers the variations

in plaque thickness in the gingival area rather than the coronal extension and surface area of the plaque. In the original index plaque is scored undisclosed, however, disclosing solution was utilized by Sforza et al. (2000). The Plaque Index is a descriptive rather than a quantitative measurement of plaque accumulation.

Table 3: The Plaque Index (Silness & Loe 1964)

0	The gingival area of the tooth surface is literally free of plaque. The surface is tested by running a pointed probe across the tooth surface at the entrance of the gingival crevice after the tooth has been properly dried. If no soft matter adheres to the point of the probe, the area is considered clean.
1	No plaque can be observed in situ by the unaided eye, but the plaque is made visual on the point of the probe after it has been moved across the tooth surface at the entrance to the gingival crevice.
2	The gingival area is covered with a thin to moderately thick layer of plaque. The deposit is visible to the naked eye.
3	Heavy accumulations of soft matter, the thickness of which fills out the niche produced by the gingival margin and the tooth surface. The interdental area is stuffed with soft debris.

(iii) Patient Hygiene Performance Index (Podshadley & Haley 1968)

This index which is an adaptation of the Oral Debris Index (Greene & Vermillion 1960) was developed to evaluate patient's hygiene performance and their ability to follow toothbrush instructions. Subjects are disclosed with erythrosine without rinsing and the six Ramfjord teeth: 16, 21, 24, 36, 41 and 44 are scored. Each respective surface is divided mentally into five sections, each of which is assessed for stained debris and totaled for the surface score and then a mean surface score for the mouth is calculated. Each section is given a dichotomous score of one or zero depicting the presence or absence of plaque. It has been questioned whether the scoring of these six select surfaces is truly representative of the full mouth plaque accumulation particularly when missing teeth necessitate substitution (Mandel 1974).

(iv) The Rustogi Modified Navy Plaque Index (RMNPI) (Rustogi et al. 1992)

The RMNPI uses a dichotomous score of zero if plaque is absent and one if plaque is present. A score is made for both the facial and lingual surfaces of all gradable teeth and a mean plaque index score for each subject is then calculated. The facial and lingual surfaces of each tooth are divided into nine regions (A- I) and a score is given for each region. Scores can be calculated for the whole mouth (regions A-I), approximal surfaces (D & F) or the gingival margin (A, B & C). The benefit of this index is its comprehensive nature and the flexibility to analyze the different anatomical areas individually. By the same token this also increases the complexity of the index and enhances the need for

calibration by an examiner prior to plaque scoring. This index is purely a measure of the surface area of plaque and does not quantify plaque mass.

(v) The Turesky Modification (Turesky et al. 1970) of the Quigley & Hein Plaque Index (Quigley & Hein 1962)

The original index by Quigley & Hein (1962) (Table 4), was designed for a partial mouth score confined to the labial surfaces of the anterior teeth that was calculated as an average score per tooth surface per person. Subjects rinsed with 20ml of a 0.075 % basic fuchsin mouthwash.

Table 4: Plaque Index (Quigley & Hein 1962)

0	No plaque.
1	Flecks of stain at the gingival margin.
2	Definite line of plaque at gingival margin.
3	Gingival third of surface
4	Two thirds of surface
5	Greater than two-thirds of surface.

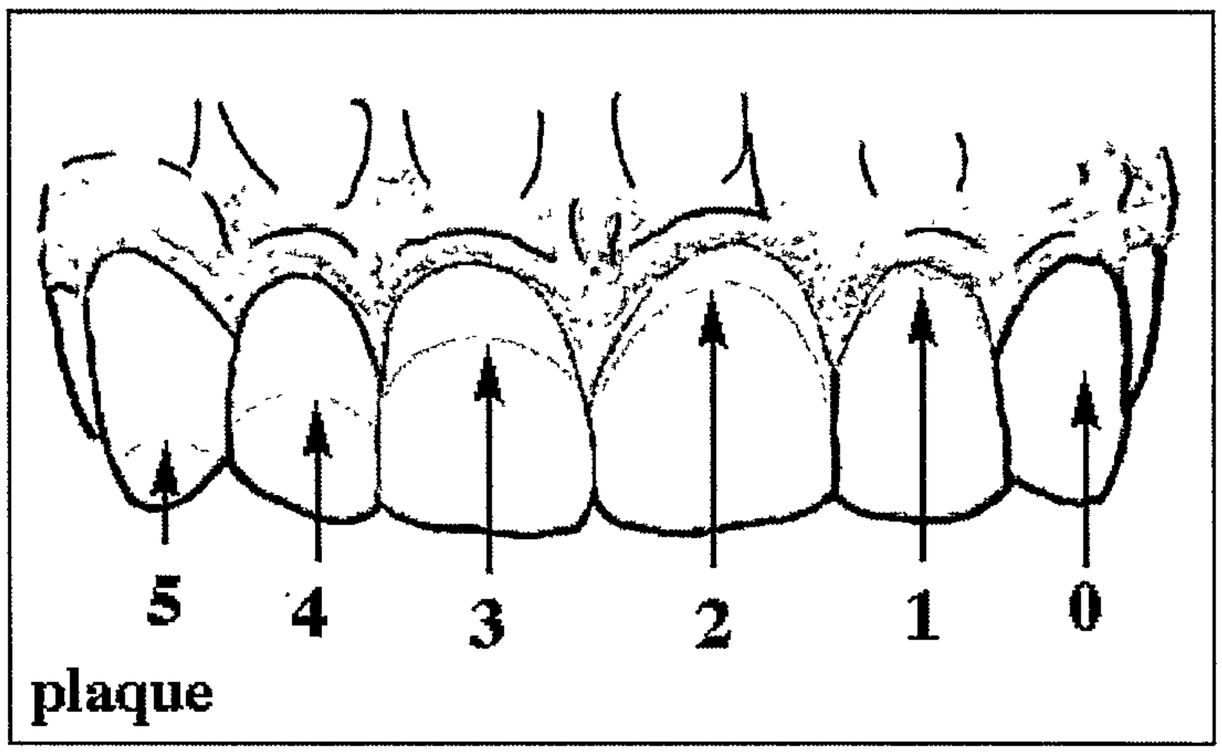
The modification by Turesky et al. (1970) more clearly defines the difference between scores 1, 2, and 3. This index is determined after disclosing with erythrosine solution. The area of the crown covered with plaque is scored on the mid facial and lingual surfaces of all teeth (Table 5, Figure 4), providing a comprehensive method of plaque evaluation. The score per person is derived by a sum of the plaque scores divided by the number of surfaces examined. This index emphasizes the difference in plaque accumulation in the gingival third of the tooth. Indices that give the highest scoring weight to plaque accumulation at the gingival margin are the most clinically relevant to gingival health as it is crevicular plaque that is directly responsible for gingival inflammation. The Turesky et al. (1970) index incorporates six categories and is sensitive enough to reflect small quantities of plaque accretion, making this index particularly well suited to the evaluation of plaque reducing agents or procedures. This index can also be applied to a partial mouth scoring. When the facial and lingual/palatal surfaces of anterior and posterior teeth are included partial mouth scoring with this index provides a reasonable reflection of the full mouth plaque accumulation (Mandel 1974). Fischman (1986) has suggested that the Turesky et al. (1970) Plaque Index satisfies the guidelines of the Council on Dental Therapeutics of the American Dental Association for acceptance of products for the management of dental plaque and gingivitis. The Turesky et al. (1970) modification of the Quigley & Hein Plaque Index (1962) is recognized as a reliable index for measuring plaque removal after toothbrushing (Robinson et al. 2005). In a statement by Sicilia et al. (2002) the standardization of indices used in clinical trials was recommended and it was further suggested that the plaque index of Turesky et al. (1970) be used as a common index for assessing plaque removal in future studies.

Table 5: The Turesky et al. (1970) Modification of the Quigley & Hein Plaque Index (1962)

0	No plaque.
1	Separate flecks of plaque at the cervical margin of the tooth.
2	A thin continuous band of plaque (up to 1 mm) at the cervical margin.
3	A band of plaque wider than 2 mm but covering less than a third of the crown.
4	Plaque covering at least one third but less than two thirds of the crown.
5	Plaque covering two thirds or more of the crown.

The comprehensive nature of the Turesky et al. (1970) index could be further enhanced when the facial and lingual/palatal surfaces are scored at three points each as opposed to merely scoring the mid-points. This allows an individual evaluation of the approximal aspects of the teeth that have been shown to harbor residual plaque after toothbrushing with a manual toothbrush (Cumming & Loe 1973, Lang et al. 1977, Rugg- Gunn et al. 1979).

Figure 4: Turesky et al. (1970) modification of the Quigley & Hein (1962) Index (World Health Organization Oral Health Country/Area Profile Programme).



7. Studies Evaluating the Effects of Toothbrush Bristle Wear and Time-in-use on Plaque Removal Efficacy

7.1 Introduction

With use, toothbrush filaments have reduced elasticity which is apparent by single fibers deviating from their original direction and the shape of the brush-head changing. This results in signs of toothbrush wear such as splaying and matting of the bristles (Rawls et al. 1993). The removal of supragingival plaque is the primary criterion of toothbrush efficacy. The effect of toothbrush bristle wear on plaque removal efficiency is clinically relevant to support scientifically valid recommendations on toothbrush renewal that are linked to performance. The wear patterns induced over time and the effects of bristle wear on plaque removal may in fact be quite unique to the brush style. Therefore; clinical

trials should investigate different styles of brush such as manual and powered toothbrushes. There are currently a limited number of published studies that have addressed this important subject (Pugh 1978, Kreifeldt et al. 1980, Glaze & Wade 1986, Daly et al. 1996, Sforza et al. 2000, Galgut 2001, Tan & Daly 2002, Warren et al. 2002, Conforti et al. 2003). These studies have found conflicting results and have principally examined manual toothbrush wear. A single clinical trial (Conforti et al. 2003) has studied the effects of bristle wear of a modern rotation oscillation powered toothbrush.

These studies will be reviewed individually to determine the influence of toothbrush bristle wear and time-in-use on plaque removal efficiency for both manual and powered toothbrushes.

7.2 Pugh (1978)

One factor implicated in toothbrush wear is the magnitude of force used during toothbrushing. Pugh (1978) measured the forces generated during unsupervised toothbrushing of 47 subjects via a strain gauge attached to the handles of manual toothbrushes. He determined that the peak forces generated during brushing ranged from four to 20 N independent of the manual strength or gender of the subjects. It is possible that the additional weight of the strain gauge may have altered the habitual brushing technique of the study subjects. It can be concluded that there are unique differences in toothbrushing force amongst individuals.

In the same study, Pugh (1978) found that the amount of wear as determined by visual examination of the bristles, did not affect the ability of the brush to remove "cosmetic stains" (a black dye consisting of 4-methylcatechol and p-phenylenediamine) from mounted extracted teeth until the brushes were "severely worn". However, this discovery is of questionable clinical significance as the cleaning of black dye from extracted teeth *in vitro,* does not correlate to cleaning true extrinsic stains on the natural dentition *in vivo*. Of note was the finding in this study that the subjective visual assessment of toothbrush wear was inconsistent among fifteen judges who did not agree on the assignment of worn toothbrushes to eight arbitrary groupings of bristle wear. This indicates that it may be difficult for people to correctly judge when their personal toothbrush is "severely worn".

7.3 Kreifeldt et al. (1980)

Kreifeldt et al. (1980) initially collected 72 worn manual toothbrushes for examination. It is not described how long these brushes had been in use. The bristles were examined microscopically and it was found that they displayed matting and bristle taper from 0.011 inches at the fixed end to 0.008-0.006 inches at the free end. This was then used as a model for artificial wear produced firstly, by clamping new manual brushes between two plates for a period of 24 hours to cause matting. Secondly, the brushes were rubbed against a ribbed stainless steel surface with pumice slurry for varying intervals to induce bristle taper. The brushes were subsequently allocated to five categories according to the degree of matting and taper. Twenty-four female dental hygiene students were randomly allocated a brush from a different category on each of three clinic visits after a period of 24hours of plaque accumulation. A pre-brushing plaque score was taken initially and then

consecutive plaque scores at four 32.5 second brushing intervals were completed to assess the amount of plaque removed during each period. The plaque scores, determined by a single hygienist, were given at four sites on eight study teeth per subject.

Kreifeldt et al. (1980) concluded that "worn toothbrushes produce statistically significant and large decreases in plaque removal ability depending upon their state of wear." The reproducibility of plaque scoring was not tested in this study merely the "subjective scoring error". When a consecutive plaque score increased (being technically impossible) a "subjective scoring error" was recorded. It is therefore; possible that the results are inherently inaccurate if the hygienist had a low level of reproducibility across the study. It is not stated whether there is a "washout" period between the three clinic visits or whether the baseline plaque scores were comparable for each session. Each study subject tested a brush from only three of the five wear groupings. This means that personal differences in brushing technique rather than bristle wear alone could have influenced the plaque reduction scores achieved.

Caution must be taken when interpreting the results of this study. *In vitro* mechanically produced toothbrush wear is by nature "artificial" and may not be an accurate representation of the character and pattern of wear produced by an individual's home toothbrushing routine. The arrangement of the dental arch, personal brushing technique, and the time and force used in toothbrushing may all influence the rate and character of bristle splaying. It has been suggested that the wear pattern developed on a toothbrush

may be an adaptive modification of the brush to an individuals' brushing technique and dental anatomy (Tan & Daly 2002).

7.4 Glaze & Wade (1986)

Glaze and Wade (1986) investigated the effects of different toothbrush renewal intervals on oral hygiene effectiveness. They compared plaque removal in two groups of pre-clinical dental students over a ten week period. Group one used a new single manual toothbrush for the ten week study period and group two changed brushes fortnightly. Plaque scores (Podshadley & Haley 1968) and the Gingival Index (Loe & Silness 1963) was recorded on six teeth (16, 21, 14, 36, 41 & 44) for all subjects at baseline and at fortnightly intervals. The mean increase in toothbrush surface area over the ten weeks in group one was 68.1%, indicating progressive wear, yet the difference in plaque removal between the two groups did not reach statistical significance until week ten. This suggests that effective plaque removal is maintained until pronounced toothbrush wear has occurred. Both study groups showed a mean increase in plaque scores from baseline to ten weeks signifying that a component of the elevated plaque levels was unrelated to the wear status of the brushes and may have been the result of decreased interest or time spent in toothbrushing by the study subjects over the ten week period. The gingival index was not statistically different for either group at baseline or at any stage throughout the study. Both groups maintained a low level of clinically detectable gingival inflammation in spite of differences in plaque scores. This questions the threshold of plaque removal that is clinically significant to gingival health.

In this study toothbrush wear was determined in two ways: (a) toothbrushes were individually measured and categorized according to a criterion of progressive wear; (b) toothbrushes were evaluated measuring the increase of the area of the brushing surface using a caliper. The first method of measurement was subjective. The second method was likely to over-estimate toothbrush wear because brushing surface area was calculated by multiplying the highest measurement of length by the highest of width.

Toothbrush wear varied considerably from person to person in both study groups. Whilst this study indicates that toothbrush wear results in decreased plaque removal overall, on an individual basis 26% of the brushes in group one were still graded as being in good condition and removing plaque effectively at the end of the ten weeks. This supports the concept that toothbrush wear is highly individual.

7.5 Daly et al. (1996)

Two studies on the effect of toothbrush wear on plaque removal have been done by the Daly group. In the first study (Daly et al. 1996), 22 dental students were issued with a manual toothbrush, which they were to use exclusively for the nine week study period according to their normal technique, duration and frequency. At baseline, after an initial plaque score was given, each subject was given a professional prophylaxis to remove all plaque and calculus deposits. This routine was repeated at three, six, and nine weeks. For the 20 subjects that completed the study mean plaque scores decreased in each of the three week experimental periods, despite progressive toothbrush wear. Toothbrush wear was measured by computer image analysis of scanned tracings of the toothbrush heads. A

high degree of reproducibility was achieved as reflected by the low coefficient of variation of the tracing (2.5%) and scanning analysis (1.1%). Unlike visual assessment (Pugh 1978) this technique is objective and has a superior accuracy than hand measurements with calipers (Glaze and Wade 1986). There was a mean increase in toothbrush wear of 23% with a range varying from 0% to 100% over the nine weeks. When the plaque scores for the ten subjects with the highest toothbrush wear were compared to the ten with the lowest wear there was no significant difference between the two subgroups, suggesting that plaque removal was not affected by toothbrush wear.

The decrease in plaque scores over the nine weeks could have been a reflection of the three weekly professional cleaning that reduced the plaque score to zero baseline levels at each study interval. This would have negated the accumulation of any residual plaque that was not removed during the participant's home toothbrushing. Alternatively this result may have been attributable to the heightened awareness of oral hygiene of the study subjects due to participation in a research project where their plaque control was repeatedly examined. This may be especially true as the study subjects were dental students. This phenomenon of superior performance resulting from being studied is known as the 'Hawthorne Effect". The overall improvement in oral hygiene by participants over the nine weeks may have actually over-ridden any potential decrease attributable to toothbrush wear. It is also a relatively short study period when compared to the reported toothbrush replacement times of three to six months of the majority of the general population (Dean et al. 1992). It is possible that the impact of toothbrush wear on plaque removal is not seen until after nine weeks (Glaze & Wade 1986).

7.6 Tan & Daly (2002)

This study is the second clinical trial by the Daly group designed to investigate the effects of wear on a manual toothbrush. The study sample was made up of 40 adults (aged between 21-64 years) receiving treatment at a public dental hospital. By using general dental patients they eliminated the potential bias in the previous sample group of university dental students who may have had elevated oral hygiene awareness. For inclusion the subjects had to be free of plaque retaining factors such as orthodontic appliances or prostheses. The study teeth had to be "caries free, without restorations and to have probing depths of less than four millimeters on the facial and lingual aspects". These inclusion criteria were designed to eliminate as many confounding factors on plaque accumulation as possible between the subjects. The sample size is double the number of the 1996 study so affording greater power to this clinical trial.

Toothbrush wear was generated by three months routine home use. A period of three months is appropriate as this is the time frame most commonly recommended for toothbrush renewal by dental professionals (Abraham et al. 1990, Daly & Marshall 1996, Leichter & Pack 1999, Daly et al. 2000). Each subject was issued with a manual toothbrush and asked to use it exclusively for 12 weeks. There was no log book or record taken to ensure that the test brush was used exclusively. In order to simulate the normal pattern of toothbrush use, no instructions were given as to the frequency or duration of toothbrushing. This has greater clinical relevance than mechanically induced toothbrush wear (Kreifeldt et al.1980). Toothbrush wear was calculated in the same manner as the previous study. This was done by tracing the outline of the toothbrush bristles on

standardized photographs of the brush heads and using a computerized image analysis program to calculate the surface area of the scanned images. A high degree of accuracy was achieved for the tracing and scanning procedures as reflected by the low standard deviations of the reproducibility experiments.

Subjects attended the clinic on two occasions for test toothbrushing with either their 3-month-old brush or a new toothbrush. The cross-over design allowed each patient to act as their own control so the brush head becomes the variable factor rather than the brushing ability of the study subject. Patients were required to abstain from all oral hygiene for 48 hours prior to performing toothbrushing in the clinic. A period of 48 hours has been shown to allow for maximum plaque growth without inducing gingival inflammation (Lang et al. 1973). It was established that the pre-brushing plaque scores for the two clinic visits were not significantly different which is crucial for the consistent comparison of plaque removal for both toothbrushing trials.

Supervised toothbrushing was completed over an interval of 60 seconds without a mirror. The results of the study may have been altered with a longer brushing interval as only 54% of plaque is removed after 60 seconds of professional brushing with a manual toothbrush yet 67% is removed at two minutes (Van de Weijden et al. 1993). However, a one minute interval accurately reflects normal toothbrush habits as adults will spend on average between 30 and 60 seconds on toothbrushing with a manual toothbrush (Saxer et al. 1998). It is possible that the effect of being observed could alter the normal brushing

technique of the participants yet by standardization of the clinic visits the effect would presumably be the same for both brushes.

Plaque scores (Turesky et al. 1970) were recorded both pre- and post-brushing on the mid-facial and mid-lingual/palatal surfaces of the twelve test teeth. The disadvantage of this scoring system is that the approximal areas were not evaluated. Therefore; the impact of bristle splaying, thinning and distortion in this vital area was not considered in this trial. Plaque scoring was completed by a single blinded examiner and 84.8 % reproducibility (per surface scored) was achieved. This means that there was approximately 15 % error inherent in the results. Plaque scores were combined to give a mean for each subject before and after brushing for each brush and an overall mean for the study sample calculated for both the new and the worn toothbrushes. By examining means for the study sample, individual differences are reduced in importance and variations tend to be eliminated (regression to the mean). Therefore, the data analysis will be biased towards the null hypothesis that there is no difference between new and 3-month-old toothbrushes.

The used toothbrushes exhibited increased brushing surface areas (BSA) ranging from 1.5 % to 144.4 %. The overall mean increased surface area was 63.1 %, which is very similar to that reported by Glaze & Wade (1986). Plaque scores are non-parametric statistics so the data analysis was calculated on the percentage plaque score reductions. This study showed that the percentage reductions in plaque scores achieved when brushing with new toothbrushes were not significantly different from those achieved with

3-month-old toothbrushes. This was true of 3-month-old brushes exhibiting minor wear (BSA 1-50%), moderate wear (BSA 51-100%), or marked wear (BSA 101-150%). Thus toothbrush wear did not affect plaque reduction in this study sample.

7.7 Galgut (2001)

The varying rate of manual toothbrush wear in a group of 102 individuals over a six month period was studied by Galgut (2001). The correlation between toothbrush wear and Plaque Index (Turesky et al. 1970) and the Gingival Index (Loe & Silness 1966) was also examined. It is not specified which teeth (full mouth or partial mouth scoring) or sites were examined and scored. The study subjects were recruited from the waiting list at a dental hygiene school and ranged in age from 19-52 years. Of the 102 study subjects 79 were female and only 28 were male. It is not stated whether the participants had fixed or removal prostheses or other plaque retentive factors and their periodontal status is not defined. Toothbrush wear was determined by visually observing the brush heads for "distortion of the filaments that was greater than one mm from the vertical" which is less accurate than direct measurement. Subjects and toothbrushes were assessed at two, four, 12 and 24 weeks. Patients were given four brushes at baseline and asked to replace the brush when it showed signs of wear; this means that the assessment of toothbrush wear was done by the patient themselves. At each examination the worn brushes were checked and replaced with new brushes. At the completion of the study the subjects were divided into either "rapid" or "slow" wearers, defined arbitrarily by the number of replacement toothbrushes used over the 24 weeks. Rapid wearers (58% of subjects) used more than three replacement toothbrushes and slow wearers (42% of subjects) used less than three

replacement toothbrushes during the 24 week study. Toothbrush replacement was determined by the participants. There was no control group or gold standard for comparison and interpretation of the result and there was a disproportionate number of women to men in the study sample. This is selection bias in the study sample as it has been shown that women replace their toothbrushes more frequently than men (Grundy & Wetherill 1979, Leichter & Pack 1999). The frequency of toothbrush replacement was highly variable. In total 44% of people did not require a replacement brush at any time throughout the six month study.

Most toothbrush wear occurred in the initial phases of the study and decreased over the 24 weeks. Fifty one percent of all replacement brushes issued were allocated in the first four weeks of the study. This may reflect a decrease in toothbrushing over the six month study period due to the waning enthusiasm of participants. This is supported by the steady increase in plaque scores over the six months for both study groups. When toothbrush wear was compared to plaque levels the "rapid wearers" had higher scores, although this was not statistically significant by the end of the six month study period. The Gingival Index (Loe & Silness 1963) of all subjects decreased steadily from baseline to 24 weeks for both groups indicating a decrease in gingival inflammation over the study in spite of an increase in plaque scores. When toothbrush wear was related to variation in Gingival Index levels there was no statistically significant difference between the "slow" and "rapid" wearers over the 24 weeks of the study.

7.8 Sforza et al. (2000)

Sforza et al. (2000), designed a study of 20 university students (of non medical faculties) aged between 20 and 32 years of age, to determine the influence of wear on a manual toothbrush after three months of continual home use compared to monthly toothbrush replacement in terms of plaque and gingival indices. One study group was instructed to use the same manual toothbrush for the three month study period. The second group was allocated a new brush at each monthly examination. The Gingival Index (Loe & Silness 1963) and the Plaque Index (Silness & Loe 1964) were recorded for 12 test teeth at four sites (mesial, distal, buccal, lingual/palatal) at monthly intervals. The wear of the toothbrush was determined by caliper measurement under magnification. Toothbrush wear was measured monthly and a wear index allocated according to Rawls et al. (1989). This method will result in an over-estimation of toothbrush wear as calculations are determined from the maximum measurements of length, width and height. There are no reproducibility scores given for these measurements so the inherent error is unknown. Subjects were given oral hygiene instruction initially and at each clinic visit and were instructed to brush three times a day during the study. A keen awareness of oral hygiene and the high frequency of toothbrushing may not reflect the subject's normal pattern and toothbrush wear could have been more rapid as a result.

Over the three month study period there was a statistically significant increase in the wear index of the first group, yet there was no correlation between wear index and plaque index. The results obtained suggest that there is no difference in plaque removal and resulting gingival index between those subjects using a brush continually for a three

month interval as compared with those changing their brush at monthly intervals. This suggests that plaque removal is influenced by factors other than toothbrush wear. The frequency of daily brushing and the high level of oral hygiene awareness may have had more influence on the plaque accumulation and gingival status of the subjects than the effects of the toothbrush wear. Furthermore, it cannot be excluded that the plaque removal efficiency of a toothbrush may already be reduced after one month of use. In order to show a clear distinction to the 3-month-old brush comparison with a brand new toothbrush would have been a superior study design.

7.9 Warren et al. (2002)

In 2002 Warren et al. published a two part study completed at the Oral B laboratories in Boston, USA, investigating the effect of toothbrush wear on plaque removal efficacy. Studies that are completed "in house" by the manufacturer cannot be considered truly independent and without bias (Boardman 2002). The source of recruitment and the mean age of the sample population is undisclosed so the generalizability of the study result is unknown. In the "single use" part of the trial 74 participants were enrolled, however, patients with dentures or fixed prostheses were not excluded. These could act as plaque retentive factors and may affect the homogeneity of study subjects. Subjects were asked to attend on two occasions at least one week apart. The subjects were not given an initial supra-gingival scale and prophylaxis to establish a zero plaque score at baseline. Hence the presence of heavy calculus deposits may also have influenced plaque removal during toothbrushing across the sample to varying degrees. At each visit subjects were given either a new toothbrush or one that had been subjected to *in vitro* mechanical wear on a

proprietary scrubbing machine that was reportedly "equivalent to 3-months use". Previous unpublished studies were used to calculate the degree of bristle wear equivalent to "3-months use". The nature of these studies or the validity of the methods used is unknown so the direct comparison to wear induced by *in vivo* toothbrush use cannot be made. It has been shown that toothbrush wear is extremely variable between individuals (Dean 1992, Galgut 2001, Tan & Daly 2002). There is likely to be little correlation between the artificially induced laboratory wear and toothbrush wear resulting from three months of home use. Plaque scores were given according to the Rustogi Modified Navy Plaque Index (Rustogi et al. 1992) however; no reproducibility data is given for the examiner so the accuracy of the data is unknown. The first part of the study concluded that the mean plaque reduction achieved with a new brush was significantly greater ($p<0.0001$) than the mechanically worn brush for whole mouth, marginal and approximal surfaces.

In the second part of the trial called the "three month study" the study sample was divided into two parallel groups. The population from which the study sample was recruited is not defined. The age range and characteristics of the subjects is unknown. There is no description of the dental or periodontal status of the individuals or whether the study teeth had caries, restorations, periodontal loss of attachment or any other factors that could influence plaque retention or the ability to give an accurate plaque or gingival score. Each participant was issued either a new Oral-B® Indicator P40 toothbrush or one that had mechanically induced wear. The new toothbrush group was issued a replacement toothbrush every month. All subjects attended the clinic at six and 12 weeks and a plaque

score (RMNPI) and gingival score according to the Lobene Modified Gingival Index (LMGI) (Lobene et al. 1986) were recorded after one minute of toothbrushing. There is no evidence of calibration or reproducibility testing for the recorded clinical indices so the accuracy of the results is unknown.

Prior to each visit subjects were asked to refrain from all oral hygiene for the preceding 23-25 hours. It has been shown that maximum plaque accumulation occurs after a period of 48 to 94 hours (Furuichi et al. 1992) so a longer period of abstinence from oral hygiene may have altered the study outcomes. A percentage reduction from baseline in mean whole mouth plaque scores and gingival indices was calculated. Both groups had reductions, however; the group using the new brush had greater reductions in the whole mouth, marginal and approximal plaque scores (RMNPI) at six and 12 weeks. The difference between the groups for gingival scores (LMGI) did not reach statistical significance. Whilst the difference in plaque score reductions reached statistical significance gingival health remained unaffected so the clinical significance is questionable.

The toothbrushes in the worn brush group had mechanical wear at baseline and were then subjected to further wear induced by twelve weeks of home use. It seems likely that these brushes would have had extreme bristle wear; however, this cannot be established as there is no measurement of toothbrush wear for the individual toothbrushes in this study. Therefore, the study outcomes cannot be correlated to any particular degree of toothbrush

bristle splaying, distortion or wear. This makes it difficult to draw any meaningful conclusions from the data.

7.10 Conforti et al. (2003)

All previous published studies on toothbrush wear have used conventional manual toothbrushes. The mechanical action of rotation oscillation powered toothbrushes may have a direct effect on the degree and pattern of toothbrush wear generated with use, therefore, the results of manual toothbrush wear studies may not be directly applicable to a powered toothbrush. Conforti et al. (2003) completed two studies at the Oral–B laboratories Boston, USA. Examiner independence can be questioned as this was a manufacturer sponsored study completed "in house". The first part of the study involved a manual toothbrush (Oral B ® Cross Action) and the second a battery powered rotation oscillation toothbrush (Braun Oral B ® Battery D4 toothbrush). Wear was generated by a period of three months twice daily brushing at home. Following the home use phase, plaque removal efficacy was compared with a new brush of the same make and type in a single-use, cross-over study design.

(1) Study One: Manual Toothbrush

In the manual toothbrush study 46 subjects were recruited. No details of the sample population used for recruitment were given so the generalizability of the study result is unknown. Power calculations were not provided and so it is not possible to determine if the sample size has sufficient power to detect a difference. Eligible participants were required to have "at least 18 scorable teeth" (not including third molars, teeth with

orthodontic appliances, bridges, crowns or implants). However, it was not defined which teeth were to be scored nor whether the same number and position of teeth were scored in each subject. There was no exclusion of teeth with carious lesions, class five restorations or periodontal loss of attachment. This a flaw in the study as it affects the homogeneity and consistency of the study sample.

Participants were randomly assigned to one of two treatment sequences, new/worn or worn/new for the two trial appointments and were asked to abstain from all oral hygiene procedures for 23-25 hours prior to their first clinic visit. Pre- and post-brushing plaque scoring was completed after disclosing with erythrosine using the Proximal Marginal Plaque Index (PMI) (Benson et al. 1993) but it was not revealed how many examiners were completing the plaque scores or whether the examiners were blinded. No reproducibility data or calibration results were provided. Subjects brushed for one minute with their assigned toothbrush and toothpaste but it was not stated whether or not the tooth-brushing was completed with the aid of a mirror which could lead to an improved performance due to the visibility of the disclosed plaque. Further, it has not been stated whether toothbrushing was supervised by an independent person or whether the examiners were present. One week's washout period was allowed between clinic visits.

Toothbrush wear was determined by visual examination and rated according to a five point wear index from zero (no wear) to four (extreme wear). This is a subjective assessment and will be less accurate than the measurement of toothbrush surface area used in other toothbrush wear studies (Daly et al. 1986, Tan & Daly 2002). Three

examiners completed the wear assessment yet there was no inter- or intra-examiner reproducibility data given.

This study found that both the worn and the new manual toothbrushes significantly reduced pre-brushing plaque scores. The difference in percentage plaque reduction of the new and 3-month-old brushes did not reach statistical significance for whole mouth or marginal scores. This result is consistent with the findings of Tan & Daly (2002) who showed that bristle wear generated by three months home use had little effect on the plaque removal of manual toothbrushes; however direct comparison with this study is difficult as different plaque indices were used. Furthermore, Tan & Daly (2002) did not examine approximal sites. In this clinical trial when approximal sites alone were examined, the 3-month-old toothbrush removed 29% of plaque compared to the new brush which removed 32% of plaque. Whilst this difference was statistically significant it is unlikely this result has any clinical significance.

(2) Study Two: Powered Toothbrush

The second study was similar in design to the first; however, battery powered toothbrushes rather than manual toothbrushes were evaluated for plaque removal after three months wear. A study sample of 46 adult subjects was generated yet the study population was undefined and therefore the profile of the participants is unknown. Further deficiencies in the study were: there were no power calculations given to establish that the study sample had sufficient numbers to detect a difference between the worn and the new toothbrushes; the inclusion criteria did not define the caries experience

or periodontal status of the subjects; the study teeth were not identified; and subjects were not given any supragingival scaling at baseline to establish a zero calculus and plaque score. The potential variation in the level of hard deposits across the study sample could bias the results as calculus deposits will be plaque retentive and will be stained by the disclosing solution during plaque assessment.

Toothbrush bristle wear was assessed visually using the five point wear scale, as in the first study. This was a subjective assessment completed by three different examiners without inter- or intra-examiner reproducibility data being given. Wear assessment based on visual inspection is less accurate than the method of tracing the outlines of the toothbrush heads and calculating the surface area of the tracing via a computerized program as per the method described by Tan & Daly (2002).

Plaque removal was tested at two clinic visits after abstinence from all oral hygiene measures for 12-18 hours. This is a much shorter period of plaque accumulation than in the first part of the study (23-25 hours). It has been shown that the degree of plaque accumulation at 12 hours is significantly lower than at 48 hours (Lang et al. 1973). Lang et al. (1973) demonstrated that at 12 hours plaque is rarely detected on the facial tooth surfaces and only the molar teeth regularly harbor plaque. The degree of pre-brushing plaque may have substantially affected the results of this clinical trial which was specifically designed to investigate subtle differences in plaque removal between the worn and new brush heads.

Whole mouth plaque scoring was completed after disclosing according to the Turesky modification (Tureskey et al.1970) of the Quigley & Hein Plaque Index (Quigley & Hein 1962) on six sites per 18 study teeth. The number of examiners completing the plaque scores was not stated nor whether the examiners were blinded. No reproducibility data or calibration results were given. Toothbrushing was for a two minute interval but it is not stated whether subjects were allowed to use a mirror or whether the rinsing protocol was standardized. Details of the randomization procedure for toothbrush allocation were not provided.

It was shown that brushing for two minutes with either a new or a 3-month-old brush head significantly reduced plaque scores in the study sample. The direct comparison of the efficacy of the new and worn brush heads revealed that for all surfaces examined, there was no statistically significant difference in reduction of plaque scores. Subgroup data analysis was completed for 15 brushes out of a total of 46 (32%) considered to have "extreme wear" defined as an allocated wear rating of three (heavy wear) and four (extreme wear). It was only in this subgroup of subjects that a statistically significant difference in percentage reduction of plaque scores was found between the new and the 3-month-old brush heads at whole mouth and approximal surfaces. At the approximal sites, the worn brush head had a mean 16 % reduction in plaque scores versus 19% for the new brush head. For the full mouth scores, the worn brush had 34% reduction in plaque scores and the new brush head achieved a 37% reduction of plaque scores. A 3% difference in plaque score reductions is of questionable clinical significance. Caution

must be exercised when interpreting there results as a subgroup of 15 subjects may have insufficient power.

7.11 Discussion

Overall the results of studies investigating the effect of toothbrush age and wear on the capacity to remove plaque have drawn conflicting conclusions (Table 6). The inconsistencies in results may be explained by the variation in study designs. Factors that may affect the clinical outcome include the choice and number of study subjects, how the toothbrushes are worn, the measurement of toothbrush wear, the surfaces examined, the plaque index used and whether there are single or multiple examiners and their level of reproducibility for plaque scoring. Two methods of wear have been used in the studies published to date, namely wear generated artificially (Kreifeldt et al. 1980, Warren et al. 2002) and wear generated from routine home use (McKendrick et al. 1971, Glaze & Wade 1986, Daly et al. 1996, Sforza et al. 2000, Galgut 2001, Tan & Daly 2002, Conforti et al. 2003). Bristle splaying and deformation produced *in vitro* may be greater and more uniform than the highly individual patterns of wear that are the result of routine self performed plaque control (Daly et al. 2002, Glaze & Wade 1986, Dean et al. 1992). Studies using mechanically generated toothbrush wear have shown a statistically significant difference in plaque removal between new and worn toothbrushes (Kreifeldt et al. 1980, Warren et al. 200) which may reflect an artificially elevated degree of bristle wear. The clinical significance and practical application of studies examining *in vitro* toothbrush wear may be questioned as they may not accurately represent *in vivo* toothbrush patterns of use.

The terms approximal, interproximal, interdental and proximal are often used interchangeably leading to some confusion in the correct interpretation. The access of toothbrush bristles is restricted to the "approximal" areas defined as 'the visible spaces between the teeth that are not directly under the contact point' (Egelberg & Claffey 1998). Some studies have argued that the effects of toothbrush wear on plaque removal are more significant at approximal surfaces than for whole mouth plaque scores (Warren et al. 2002, Conforti et al. 2003). The estimation of plaque accumulation at approximal sites has limitations namely that wider sites are clearly visible whereas approximal spaces with papillae may be inaccessible to the eye (Morita et al. 1998). The term "interproximal" refers to 'the sites directly under the contact point of adjacent teeth' (Egelberg & Claffey 1998). The true interproximal areas are inaccessible to the toothbrush regardless of the design or method of brushing (Hansen & Gjermo 1971, Yankell et al. 1980, Bergenholtz et al. 1984).

Careful selection of the study sample is important to eliminate bias in the results. The study sample should be representative of the population to whom the results are directly applicable. When looking at toothbrush wear the results should reflect the general population at large, covering if possible a broad age and gender distribution. Several studies have used university undergraduate dental students or dental hygiene students (Kreifeldt et al. 1980, Daly et al. 1996, Glaze & Wade 1986). An elevated awareness of oral hygiene may have influenced the level of plaque removal during the studies. Two studies had a sample population drawn from university students of non-medical faculties

(McKendrick et al. 1971, Sforza et al. 2000). These subjects could have superior plaque removal compared to an older sample population due to improved manual dexterity (Marchini et al. 2006). The clinical trials that have selected the study subjects from a wide age range have the greatest external validity (Galgut 2001, Tan & Daly 2002, Warren et al. 2002, Conforti et al. 2003).

As the time period for manual toothbrush renewal most often recommended by dental professionals is two to three months (Abraham et al. 1990, Daly & Marshall 1996, Leichter & Pack 1999, Daly et al. 2000), a study period of three months would appear to be the most appropriate if the findings are to be interpreted as the evidence base for recommendations on toothbrush renewal. Recently published studies examining plaque removal by manual toothbrushes after a three month period of routine home use do not support the reduced efficacy of worn brushes (Sforza et al. 2000, Tan & Daly 2002, Conforti et al. 2003). However; only a single investigation has studied plaque removal using a powered toothbrush with a brush head worn over a period of three months routine home use (Conforti et al. 2003). They concluded that the plaque removal of the worn and the new brush heads were not significantly different thereby, reflecting the findings of manual toothbrush studies (Sforza et al. 2000, Tan & Daly 2002, Conforti et al. 2003).

Table 6: Summary of the Results of the Toothbrush Wear Studies

Study	Sample Size	Findings	Study Population Recruitment and Age.	Type of Wear
McKendrick et al. (1971)	65	The length of time of toothbrush replacement did not affect oral cleanliness or periodontal status for both manual and powered toothbrushes.	University students. Age range18-33 years.	Subjects replaced toothbrushes at their own request over a two year period after normal home use.
Kreifeldt et al. (1980)	24	Worn manual toothbrushes had statistically significant decreases in plaque removal ability.	Dental hygiene students. Age range 18-19 years.	Wear artificially produced to give controlled reproducible amounts of bristle matting and tapering. The brushes were divided into five groups from new to heavy matting.
Glaze & Wade (1986)	40	Greater increase in plaque scores from two to ten weeks in the group using a single manual toothbrush than the group with two weekly toothbrush replacements.	Students enrolled at the Royal Dental Hospital of London School of Dental Surgery. Age range 19-26 years.	Ten weeks of home use. No instructions given on frequency or duration.
Daly et al. (1996)	22	No significant differences in plaque scores between high wearers and low wearers of a manual toothbrush at three, six, or nine weeks.	Second year dental students attending the University of Sydney. Age range 19-22 years.	Toothbrush wear after routine home use (no instructions given on frequency or duration) assessed at three, six and nine weeks.

Sforza et al.(2000)	20	At three months no significant difference detected in PI and GI between the continuous use of a manual brush group and the monthly manual brush replacement group.	University students from a non-medical background. Age range 20-32 years.	Three months home use. Subjects given instructions to brush three times per day.
Galgut (2001)	107	Subjects divided into rapid and slow wearers. After six months the difference in plaque scores was not significant between the groups.	Patients seeking treatment at a dental hygiene school. Age range 19-52 years.	Manual toothbrushes used at home (standardized instructions given) and replaced when brushes showed signs of wear as assessed by visual assessment by examiner.
Tan & Daly (2002)	44	No significant difference in % plaque score reduction between new and 3-month-old manual toothbrushes.	Subjects recruited from patients attending a public dental hospital. Age range 21-64 years.	Wear induced by a three month interval of routine home use. No instructions given on frequency or duration.
Warren et al.(2002)	74	Significant difference in mean plaque reduction of new manual toothbrush for whole mouth, marginal and approximal surfaces as compared to worn manual toothbrushes.	No data given on recruitment. Age range 18-65 years.	*In vitro* mechanical wear produced by a scrubbing machine.
Conforti et al. (2003) Part One	46	No significant difference in whole mouth % plaque score reduction between new and 3-month-old manual toothbrushes.	No data given on recruitment. Age range 18-70 years.	Three months twice daily brushing at home.
Conforti et al. (2003) Part Two	46	No significant difference in % plaque score reduction for all surfaces between new and 3-month-old powered toothbrush heads.	No data given on recruitment. Age range 18-70 years.	Three months twice daily brushing at home.

8. Conclusion

It has been shown that toothbrush wear increases with time of use and that the pattern of wear is highly variable (Rawls et al. 1989, Calgut 2001). Toothbrushing habits differ among individuals with regard to technique, time, force, frequency and the type of brush used (Pugh 1978, Grundy & Wetherill 1979, Dean et al 1992). This suggests that the pattern of wear produced in a three month period of home brushing will be unique to each person. In addition, individual dental anatomical features such as the number of teeth, arch shape and size, tooth size and inclination, cusp and incisal edge sharpness and interdental embrasure sizes have all been suggested as factors which might influence the degree of brush head wear (Tan & Daly 2002).

It has been shown in studies that dental professionals most frequently recommend a manual toothbrush replacement time of two to three months to their patients (Abraham et al. 1990, Daly & Marshall 1996, Leichter & Pack 1999, Daly et al. 2000) and a three month toothbrush renewal interval is also quoted in the manufacturer's instructions accompanying toothbrush products (Braun Oral-B ®). Published manual toothbrushing studies have established that plaque removal is not reduced after a three month period of home use (Sforza et al. 2000, Tan & Daly 2002, Conforti et al. 2003). In contrast, studies examining "extreme" manual toothbrush wear (Galgut 2001) or artificially produced manual toothbrush wear (Kriefeldt et al. 1980, Warren et al. 2000) have demonstrated a reduced plaque removal efficacy. Time in use is clearly not the sole determinant of the effective lifespan of a toothbrush. Based on the scientific evidence reviewed it can be

concluded that manual toothbrush renewal is not indicated after a set time period of three months of routine home use, to maintain plaque control in the average person.

A recent Cochrane systematic review designed to compare manual and powered toothbrushes with respect to removal of plaque and gingival health found evidence to support greater plaque removal and reduction of gingivitis for powered toothbrushes with a rotation oscillation action (Robinson at al. 2005). This evidence will lend support to the growing popularity of powered toothbrushes for self performed plaque control. The pattern and rate of bristle wear on powered toothbrushes may be significantly different to a manual toothbrush due to the different degree of force applied to the teeth, bristle number and arrangement and automated brushing action. The direct comparison of data based on manual toothbrushes to powered toothbrushes may be invalid. Currently only a single published study exists on the effects of bristle wear generated by three months home use on plaque removal with a rotation oscillation powered toothbrush (Conforti et al. 2003). This manufacturer-sponsored study did not find a statistically significant difference in percentage plaque score reduction between the new and 3-month-old toothbrush heads. However; the authors reported a statistically significant difference in a small subgroup of subjects with the highest rating of bristle wear. Definitive recommendations should not be made on the basis of a single clinical trial, especially one with several deficiencies in the reported methodology. It is therefore essential that independent and well designed clinical research be undertaken to further define the association of plaque removal efficacy and bristle wear resulting from a period of three months routine home use on a rotation oscillation powered toothbrush.

9. References

Abraham, N., Cirincione, U. & Glass, R. (1990) Dentists' and hygienists attitudes toward toothbrush replacement and maintenance. *Clinical Preventive Dentistry* **12**, 28-33.

Alexander, J. F., Saffir, A. J. & Gold, W. (1977) The measurement of the effect of toothbrushes on soft tissue abrasion. *Journal of Dental Research* **56**, 722-727.

American Dental Association. (2004) Cleaning your teeth and gums (oral hygiene) Overview. *American Dental Association Website* http:/www.ada.org/public/topics/cleaning.asp (accessed 20th May 2006).

Ainamo, J. & Bay, I. (1975) Problems and proposals for recording gingivitis and plaque. *International Dental Journal* **25**, 229-230.

Axelsson, P., Nystrom, B. & Lindhe, J. (2004) The long-term effect of a plaque control program on tooth mortality, caries and periodontal disease in adults. Results after 30 years of maintenance. *Journal of Clinical Periodontology* **31**, 749-757.

Baab, D. & Johnson, R. (1989) The effect of a new electric toothbrush on subgingival plaque and gingivitis. *Journal of Periodontology* **60**, 336-341.

Bakdash, B. (1995) Current patterns of oral hygiene product use and practices. *Periodontology 2000* **8**, 11-14.

Benson, B. J., Grossman, E., Mankodi, S. & Sharma, N. C. (1993) Development and verification of the proximal/marginal plaque index. *Journal of Clinical Dentistry* **14**, 14-20.

Bergenholtz, A., Gustafsson, L., Sergerlund, N., Hagberg, C. & Ostby, P. (1984) Role of brushing technique and toothbrush design in plaque removal. *Scandinavian Journal of Dental Research* **92**, 344-351.

Bergstrom, J. (1973) Wear and hygiene status of toothbrushes in relation to some social background factors. *Swedish Dental Journal* **66**, 383-390.

Bergstrom, J. & Lavstedt, S. (1979) An epidemiological approach to toothbrushing and dental abrasion. *Community Dentistry and Oral Epidemiology* **7**, 57-64.

Boardman, T. J. (2002) Statistical issues in assessing powered toothbrushes. *Advances in Dental Research* **16**, 4-5.

Borutta, A. (1997) Plaque removal efficiency of a newly developed powered toothbrush in the primary dentition of pre-school children. *Journal of Clinical Dentistry* **8**, 151-155.

Bosman, C. W. & Powell, R. N. (1977) The reversal of localized experimental gingivitis. A comparison between mechanical toothbrushing procedures and a 0.2% chlorhexidine mouthrinse. *Journal of Clinical Periodontology* **4**, 161-172.

Breitenmoser, J., Mormann, W. & Muhlemann, H. R. (1979) Damaging effects of toothbrush bristle end form on gingiva. *Journal of Periodontology* **50**, 212-216.

Brothwell, D. J., Jutai, D. K. & Hawkins, R. J. (1998) An update of mechanical oral hygiene practices: evidence-based recommendations for disease prevention. *Journal of the Canadian Dental Association* **64**, 295-306.

Checchi, L., Minguzzi, S., Franchi, M. & Forteleoni, G. (2001) Toothbrush filaments end-rounding: a stereomicroscope analysis. *Journal of Clinical Periodontology* **28**, 360-364.

Checci, L., Farina, E., Felice, P. & Montevecchi, M. (2004). The electric toothbrush: analysis of filaments under stereomicroscope. *Journal of Clinical Periodontology* **31**, 639-642.

Clerehugh, V., Williams, P., Shaw, W. C., Worthington, H. V. & Warren, P. (1998) A practice – based randomized controlled trial of the efficacy of an electric and a manual toothbrush on gingival health in patients with fixed orthodontic appliances. *Journal of Dentistry* **26**, 633-639.

Conforti, J., Cordero, R., Liebman, J. & Bowman, J. (2003) An investigation into the effects of three months' clinical wear on toothbrush efficacy: results from two independent studies. *Journal of Clinical Dentistry* **14**, 29-33.

Cumming, B. R. & Loe, H. (1973) Consistency of plaque distribution in individuals without special home care instructions. *Journal of Periodontal Research* **8**, 94-100.

Da Costa, C. C., Da Costa Filho, L. C., Soria, M. L. & Mainardi, A. P. (2001) Plaque removal by manual and electric toothbrushing among children. *Brazilian Oral Research* **15**, 296-301.

Daly, C. & Marshall, R. (1996) Attitudes to toothbrush renewal: A survey of Australian periodontists and dental hygienists. *Periodontology* **17**, 118-121.

Daly, C., Chapple, C. & Cameron, A. (1996) Effect of toothbrush wear on plaque control. *Journal of Clinical Periodontology* **23**, 45-49.

Daly, C., Marshall, R. & Lazarus, R. (2000) Australian dentists' views on toothbrush wear and renewal. *Australian Dental Journal* **45**, 254-256.

Davies, R. M. (2006) Dental Health and Practice. *Word of Mouth*. British Dental Health Foundation, Warwickshire, England.

Dean, D. (1991) Toothbrushes with graduated wear: correlation with *In Vitro* cleansing performance. *Clinical Preventive Dentistry* **13**, 25-30.

Dean, D., Beeson, L., Cannon, D. & Plunkett, C. (1992) Condition of toothbrushes in use: Correlation with behavioral and socio-economic factors. *Clinical Preventive Dentistry* **14**, 14-18.

De La Rosa, M. R., Guerra, J., Z., Johnston, D. A. & Radike, A. W. (1979) Plaque growth and removal with daily toothbrushing. *Journal of Periodontology* **50**, 661-664.

Egelberg, J. & Claffey, N. (1998) Role of mechanical dental plaque removal in prevention and therapy of caries and periodontal diseases. Consensus Report of Group B. In: Lang, N., Attstrom, R. & Loe, H., eds. *Proceedings of the European Workshop on Mechanical Plaque Control.* London: Quintessence, 169-172.

Esposito, M., Worthington, H. V., Coulthard, P. & Jokstad, A. (2003) Interventions for replacing missing teeth: maintaining and re-establishing healthy tissues around dental implants (Cochrane Review). In: *The Cochrane Library* **4**. Chichester, UK: John Wiley & Sons, Ltd.

Fischman, S. L. (1986) The current status of indices of plaque. *Journal of Clinical Periodontology* **13**, 371-374.

Fischman, S. L. (1997) The history of oral hygiene products: How far have we come in 6000 years? *Periodontology 2000* **15**, 7-14.

Fraleigh, C., McElhaney, J. & Heiser, R. (1967) Toothbrushing force study. *Journal of Dental Research* **46**, 209-214.

Frandsen, A. (1985) Changing patterns of attitudes and oral health behavior. *International Dental Journal* **35**, 284-290.

Frandsen, A. (1986) Mechanical oral hygiene practices. In dental plaque control measures and oral hygiene practices. Eds Loe, H. & Kleinmann, D. V., pp. 93- 116. Oxford-Washington, D. C.: IRL Press.

Furuichi, Y., Lindhe, J., Ramberg, P. & Volpe, A. R. (1992) Patterns of denovo plaque formation in the human dentition. *Journal of Clinical Periodontology* **19**, 423-433.

Galgut, P. (2001) The influence of toothbrush wear on the variables of plaque and gingivitis in clinical trials. *Journal of Dental Hygiene.***75 (2)**, 150-155.

Glass, R. & Martin Lare, M. (1986) Toothbrush contamination: a potential health risk? *Quintessence International* **17**, 39-43.

Glaze, P & Wade, B. (1986) Toothbrush age and wear as it relates to plaque control. *Journal of Clinical Periodontology* **13**, 52-56.

Greene, J. C. & Vermillion, J. R. (1960) The Oral Hygiene Index: a method for classifying oral hygiene status. *Journal of the American Dental Association* **61**, 172- 179.

Greene, J. C. & Vermillion, J. R. (1964) The Simplified Oral Hygiene Index. *Journal of the American Dental Association* **68**, 7- 13.

Grundy, M. & Wetherill, S. (1979) Toothbrush usage and factors in toothbrush wear. *British Dental Hygienists Association* **18**, 17-24.

Grossman, E. & Proskin, H. (1997) A comparison of the efficacy and safety of an electric and a manual children's toothbrush. *Journal of the American Dental Association* **128**, 469-474.

Haffajee, A., Thopson, M., Torresyap, G., Guerrero, D. & Socransky, S. (2001a) Efficacy of manual and powered toothbrushes (I). Effect on clinical parameters. *Journal of Clinical Periodontology* **28**, 937-946.

Haffajee, A., Smith, C., Torresyap, G., Guerrero, D. & Socransky, S. (2001b) Efficacy of manual and powered toothbrushes (II). Effects on microbiological parameters. *Journal of Clinical Periodontology* **28**, 947-954.

Hansen, F. & Gjermo, P. (1971) The plaque removing effect of four toothbrushing methods. *Scandinavian Journal of Dental Research* **79**, 502–506.

Hawkins, B. F., Kohout, F. J., Lainson, P. A. & Heckert, A. (1986) Duration of Toothbrushing for effective plaque control. *Quintessence International* **17**, 361-365.

Heasman, P., Wilson, Z., Macgregor, I. & Kelly, P. (1998) Comparative study of electric and manual toothbrushes in patients with fixed orthodontic appliances. *American Journal of Orthodontics and Dentofacial Orthopedics* **114**, 45-49.

Heasman, P., Stacey, F., Heasman, L., Sellers, P., Macgregor, I. & Kelly, P. (1999) A comparative study of the Phillips HP 735, Braun/Oral B D7 and the Oral B 35 Advantage toothbrushes. *Journal of Clinical Periodontology* **26**, 85-90.

Hellstadius, K., Asman, B. & Gustafsson, A. (1993) Improved maintenance of plaque control by electrical toothbrushing in periodontitis patients with low compliance. *Journal of Clinical Periodontology* **20**, 235-237.

Hellstrom, M., Ramberg, P. & Krok, L. (1996) The effect of supragingival plaque control on the subgingival microflora in human periodontitis. *Journal of Clinical Periodontology* **23**, 934-940.

Hugoson, A. & Koch, G. (1979) Oral health in 1000 individuals aged 3-70 years in the community of Jonkoping, Sweden. *Swedish Dental Journal* **3**, 69-87.

Ho, H. P. & Niederman, R. (1997) Effectiveness of the Sonicare sonic toothbrush on reduction of plaque, gingivitis, probing pocket depth and subgingival bacteria in adolescent orthodontic patients. *Journal of Clinical Dentistry* **8**, 15-19.

Howorko, N., Gutek, M., Naidoo, S. & Hoover, J.N. (1993) Effectiveness of an electric toothbrush on plaque removal in periodontal patients. *American Journal of Dentistry* **6**, 49-51.

Jepson, S. (1998) The role of manual toothbrushes in effective plaque control: advantages and limitations. In: Lang, N., Attstrom, R. & Loe, H., eds. *Proceedings of the European Workshop on Mechanical Plaque Control.* London: Quintessence, 121- 137.

Johnson, B. D., & McInnes, C. (1994) Clinical evaluation of the efficacy and safety of a new sonic toothbrush. *Journal of Periodontology* **65**, 692-697.

Jongenelis, A. P. & Wiedemann, W. (1997) A comparison of plaque removal effectiveness of an electric versus a manual toothbrush in children. *Journal of Dentistry for Children* **64**, 176-182.

Jung, M., Kockapan, C. & Wetzel, W. E. (2003) Bristle end rounding of manual toothbrushes and reproducibility of end rounding classification. *American Journal of Dentistry* **16**, 299-304.

Jung, M., Soyden, N., Rubbert, F. & Wetzel, W. E. (2005) Quality of bristle end-rounding on replaceable heads of powered toothbrushes. *Journal of Clinical Periodontology* **32**, 604-609.

Kinnane, D. F., Jenfins, W. M. M. & Paterson, A. J. (1992) Comparative efficacy of the standard flossing procedure and a new floss applicator in reducing interproximal bleeding. *Journal of Periodontology* **63**, 757-760.

Kolenbrander, P. E. (2000) Oral Microbial Communities: Biofilms, Interactions, and Genetic Systems. *Annual Review of Microbiology* **54,** 413-437.

Kreifeldt, J., Hill, P., & Calisti, L. (1980) A systematic study of the plaque removal efficiency of worn toothbrushes. *Journal of Dental Research* **59**, 2047-2055.

Kressin, N. R., Boehmer, U., Nunn, M. E. & Spiro, A. III (2003) Increased preventive practices lead to greater tooth retention. *Journal of Dental Research* **82**, 223- 227.

Lang. N. P., Cumming, B. R. & Loe, H. (1973) Toothbrushing frequency as it relates to plaque development and gingival health. *Journal of Periodontology* **44**, 396- 405.

Lang, N. P., Cummings, B. R. & Loe, H. (1977) Oral hygiene and gingival health in Danish dental students and faculty. *Community Dentistry and Oral Epidemiology* **5**, 237-242.

Lazarescu, D., Boccaneala, S., Illiescu, A. & De Boever, J. (2003) Efficacy of plaque removal and learning effect of a powered and a manual toothbrush. *Journal of Clinical Periodontology* **30**, 726-731.

Leichter, J. & Pack, A. (1999) The attitudes of New Zealand dentists and dental hygienists towards toothbrushes and toothbrushing. *Journal of the New Zealand Society of Periodontology* **84**, 14-17.

Litonjua, L. A., Andreana, S. & Cohen. R. E. (2005) Toothbrush abrasion and non carious lesions: evolving concepts. *Compendium of Continuing Education in Dentistry* **26**, 767-768.

Lobene, R. R., Weatherford, T., Ross, N. M., Lamm, R. A. & Menaker, L. (1986) A modified gingival index for use in clinical trials. *Clinical Preventive Dentistry* **8**, 3-6.

Loe, H., Theilade, E., & Jensen, S. (1965) Experimental gingivitis in man. *Journal of Periodontology* **36**, 177-187.

Loe, H. & Silness, J. (1963) Periodontal disease in pregnancy. I. prevalence and severity. *Acta Odontologica Scandinavica* **21**, 533-551.

MacGregor, I. D. (1984) Toothbrushing efficiency in smokers and nonsmokers. *Journal of Clinical Periodontology* **11**, 321-330.

Mandel, I. D. (1974) Indices for the measurement of soft accumulations in clinical studies of oral hygiene and periodontal disease. *Journal of Periodontal Research* **9**, (Suppl. 14), 7-30.

Mantokoudis, D., Joss, A., Christensen, M. M., Meng, H. X., Suvan, J. E. & Lang, N. P. (2001) Comparison of the clinical effects and gingival abrasion aspects of manual and electric toothbrushes. *Journal of Clinical Periodontology* **28**, 65-72.

Marchini, L., Viera, P. C., Bossan, T. P., Montenegro, F. C. & Cunhan, V. P. (2006) Self reported oral hygiene habits among institutionalized elderly and their relationship to the condition of oral tissues in Taubate, Brazil. *Gerodontology* **23**, 33-37.

Massassati, A. & Frank, R. M. (1982) Scanning electron microscopy of unused and used manual toothbrushes. *Journal of Clinical Periodontology* **9**, 148-162.

McAllan, L. H., Murray, J. J., Brook, A. H. & Crawford, A. N. (1976) Oral hygiene instruction in children using manual and electric toothrushes. Benefits after six months. *British Dental Journal* **140**, 52-56.

McCraken, G., Janssen, J., Swan, M., Steen, N., de Jager, M. & Heasman, P. (2003) Effect of brushing force and time on plaque removal using a powered toothbrush. *Journal of Clinical Periodontology* **30**, 409-413.

McKendrick, A., McHugh, W. & Barbenel, L. (1971) Toothbrush age and wear. An analysis. *British Dental Journal* **130**, 66-68.

Morita, M., Nishi, K. & Watanabe, T. (1998) Comparison of 2 toothbrushing methods for efficacy in supragingival plaque removal: the Toothpick method and the Bass method. *Journal of Clinical Peridontology* **25**, 829–831.

Murray, P. A., Boyd, R. C. & Robertson, P. B. (1989) Effects on periodontal status of rotary electric toothbrushes versus manual toothbrushes during periodontal maintenance. II. Microbiological result. *Journal of Periodontology* **60**, 396-401.

Nelson Filho. P., Macari, S., Faria, G., Assed, S. & Ito, I. Y. (2000) Microbial contamination of toothbrushes and their decontamination. *Pediatric Dentistry* **22**, 381-384.

Nolte, W. A. (1982) Oral Microflora. *Oral Microbiology*,. W. A. Nolte, ed, pp. 192- 228. St. Louis: Mosby.

Pretara-Spanedda, P., Grossman, E., Curro, F. A. & Generallo, C. H. (1989) Toothbrush bristle density: relationship to plaque removal. *American Journal of Dentistry* **2**, 345-348.

Podshadley, A.G. & Haley, J.V. (1968) A method for evaluating oral hygiene performance. *Public Health Reports* **83**, 259-264.

Polson, A. M. (1997) The research team, calibration, and quality assurance in clinical trials in periodontics. *Annals of Periodontology* **2**, 75-82.

Pugh, B. (1978) Toothbrush wear, brushing forces and cleaning performance. *Journal of the Society of Cosmetic Chemists* **29**, 423–431.

Quigley, G. & Hein, J. (1962) Compressive cleansing efficiency of manual and power brushing. *Journal of the American Dental Association* **65**, 26-29.

Quirynen, M., Vervliet, E., Teerlinck, J., Darius, P. & van Steenberghe, D. (1994) Medium and long term effectiveness of a counter-rotational electric toothbrush on plaque removal, gingival bleeding, and probing pocket depth. *International Journal of Periodontics and Restorative Dentistry* **14**, 364-377.

Ramberg, P., Lindhe, J. & Eneroth, L. (1994) The influence of gingival inflammation on de novo plaque formation. *Journal of Clinical Periodontology* **21**, 51- 56.

Rapley, J. W. & Killoy, W. J. (1994) Subgingival and interproximal plaque removal using a counter-rotational electric toothbrush and a manual toothbrush. *Quintessence-International* **25**, 39-42.

Rawls, H., Mkwayi-Tulloch, N., Casella, R. & Cosgrove, R. (1989) The measurement of toothbrush wear. *Journal of Dental Research* **68**, 1781-1785.

Rawls, H., Casella, R. & Mkwayi-Tulloch. (1993) An *in vitro* and *in vivo* study of toothbrush bristle splaying. *Journal of Dental Research* **72**, 947-952.

Reitman, W. R., Whiteley, R. T. & Robertson, P. B. (1980) Proximal surface cleaning by dental floss. *Clinical Preventive Dentistry* **2**, 7-10.

Renton-Harper, P., Addy, M. & Newcombe, R. (2001) Plaque removal with the uninstructed use of electric toothbrushes: comparison with a manual brush and toothpaste slurry. *Journal of Clinical Periodontology* **28**, 325-330.

Robinson, H. B. (1946) Toothbrushing habits of 405 persons. *Journal of the American Dental Association* **33**, 1112-1117.

Robinson, P. G., Deacon, S. A., Deery, C., Heanue, M., Walmsley, A. D., Worthington, H. V., Glenny, A. M., Shaw, W. C. (2005) Manual versus powered toothbrushing for oral health. *The Cochrane Database of Systematic Reviews* 2005, Issue 2. Art. No.: CD002281. DOI: 10.1002/14651858.CD002281.

Rustogi, K. N., Curtis, J. P., Volpe, A. R., Kemp, J. H, McCool, J. J. & Korn, L. R. (1992) Refinement of the Modified Navy Plaque Index to increase plaque scoring efficiency in gumline and interproximal areas. *Journal of Clinical Dentistry* **3,** (supplement C), 9-12.

Rugg-Gunn, A. J., Macgreggor, I. D., Edgar, W. M. & Ferguson, M. W. (1979) Toothbrushing behavior in relation to plaque and gingivitis in adolescent school children. *Journal of Periodontal Research* **14**, 231- 238.

Saxer, U. B., Barbakow, J. & Yankell, S. L. (1998) New studies on estimated and actual toothbrushing times and dentifrice use. *Journal of Clinical Dentistry* **9**, 49-51.

Saxton, C. A. (1973) Scanning electron microscope study of the formation of dental plaque. *Caries Research* 7, 102- 119.

Schemerhorn, B. & Zwart, A. (1996) The dentin abrasivity potential of a new electric toothbrush. *Journal of Dentistry* **9**, 19-20.

Sforza, N., Rimondini, L., di Menna, F. & Camorali, C. (2000) Plaque removal by worn toothbrush. *Journal of Clinical Periodontology* **27**, 212-216.

Sicilia, A., Arregui, I., Gallego, M., Cabezas, B. & Cuesta, S. (2002) A systematic review of powered vs. manual toothbrushes in periodontal cause-related therapy. *Journal of Clinical Periodontology* **29**, 39-55.

Silness, J. & Loe, H. (1964) Periodontal disease in pregnancy. II Correlation between oral hygiene and periodontal condition. *Acta Odontologica Scandinavica* **22**, 112-135.

Silverman, J., Rosivack, R. G., Matheson, P. B. & Houpt, M. I. (2004) Comparison of powered and manual toothbrushes for plaque removal by 4- to 5- year-old children. *Pediatric Dentistry* **26**, 225-230.

Silverstone, L. M. & Featherstone, M. J. (1988) A scanning electron microscope study of the end rounding of bristles of eight tooth-brush types. *Quintessence International* **19**, 87-107.

Sjogren, K., Lundberg, A. B., Birkhed, D., Dudgeon, D. J. & Johnson, M. R. (2004) Interproximal plaque mass and fluoride retention after brushing and flossing- a comparative study of powered toothbrushing, manual toothbrushing and flossing. *Oral Health and Preventive Dentistry* **2**, 119-124.

Smulow, J., Turesky, S. & Hill, R. (1983) The effect of supragingival plaque control on anaerobic bacteria in deep periodontal pockets. *Journal of the American Dental Association* **107**, 737-742.

Stalnacke, K., Soderfeldt, B., Sjodin, B. (1995) Compliance in use of electric toothbrushes. *Acta Odontologica Scandanavica* **53**, 17-19.

Tan, E. & Daly, C. (2002) Comparison of new and 3-month-old toothbrushes in plaque removal. *Journal of Clinical Periodontology* **29**, 645-650.

Taji, S. S. & Rogers, A. H. (1998) ADRF Trebitsch Scholarship. The microbial contamination of toothbrushes. A pilot study. *Australian Dental Journal* **43**, 128-130.

Tawse Smith, A., Duncan, W. J., Payne, A. G. T., Thomson, W. M. & Wennstrom, I. (2002) Relative effectiveness of powered and manual toothbrushes in elderly patients with implant supported mandibular over dentures. *Journal of Clinical Periodontology* **29**, 275-280.

Thompson, W. & Walter, S. (1988) Kappa and the concept of independent errors. *Journal of Clinical Epidemiology* **41**, 969-970.

Thienpont, V., Dermout, L. R. & Van Maele, G. (2001) Comparative study of 2 electric and 2 manual toothbrushes in patients with fixed orthodontic appliances. *American Journal of Orthodontics and Dentofacial Orthopedics* **120**, 353-360.

Trimeneers, L. M., Wijgaerts, I. A., Grognard, N. A., Dermaut, L. R. & Adriaens, P. A. (1997) Effect of electric toothbrushes versus manual toothbrushes on removal of plaque and periodontal status during orthodontic treatment. *American Journal of Orthodontics and Dentofacial Orthopedics* **111**, 492-497.

Turesky, S., Gilmore, N. D. & Glickman, L. (1970) Reduced formation by chloromethyl analogue of vitamin C. *Journal of Periodontology* **41**, 41-43.

Vandekerckhove, B., Quirynen, M., Warren, P. R., Strate, J. & Van Steenberghe, D. (2004) The safety and efficacy of a powered toothbrush on soft tissues in patients with implant-supported fixed prostheses. *Clinical Oral Investigations* **8**, 206-210.

Van der Weijden, G. A. & Hioe, K. P. A. (2005) A systematic review of the effectiveness of self performed mechanical plaque removal in adults with gingivitis using a manual toothbrush. *Journal of Clinical Periodontology* **32** (Suppl. 6): 214-228.

Van der Weijden, G., Timmerman, M., Nijboer, A., Lie, M. & Van der Velden, U. (1993) A comparative study of electric toothbrushes for the effectiveness of plaque removal in relation to toothbrushing duration. Timer study. *Journal of Clinical Periodontology* **20**, 476-491.

Van der Weiijden, G., Timmerman, M., Piscaer, M., Ijzerman, Y., Warren, P. & van der Velden, U. (1994) The long-term effect of an oscillating/rotating electric toothbrush on gingivitis. An 8-month study. *Journal of Clinical Periodontology* **21**, 139-145.

Van der Weijden, G., Timmerman, M. & Reijerse, E. Toothbrushing force in relation to plaque removal. (1996) *Journal of Clinical Periodontology* **23**, 724-729.

Van der Weijden, G.A., Timmerman, M.F., Danser, M. M. & Van der Velden, U. (1998a) The role of electric toothbrushes: Advantages and Limitations. In Lang, N., Attstrom, R. & Loe, H., eds. *Proceedings of the European Workshop on Mechanical Plaque Control.* Berlin: Quintessence, pp. 138-155.

Van der Weijden, G., Timmerman, M. F., Danser, M. M. & Van der Velden, U. (1998b) Relationship between the plaque removal efficiency of a manual toothbrush and brushing force. *Journal of Clinical Periodontology* **25**, 413-416.

Van der Weijden, G., Timmerman, M., Piscaer, M., Ijzerman, Y., Van der Velden, U. (2004a) Plaque removal by professional electric toothbrushing compared with professional polishing. *Journal of Clinical Periodontology* **31**, 903-907.

Van der Weijden, G., Timmerman, M., Versteege, P. & Van der Velden, U. (2004b) High and low brushing force in relation to efficacy and gingival abrasion. *Journal of Clinical Periodontology* **31**, 620-624.

Van Houte, J., Gibbons, R. J. & Banghart, S. B. (1970) Adherence as a determinant of the presence of Streptococcus salivarius and Streptococcus Sanguis on the human tooth surface. *Archives of Oral Biology* **15**, 1025-1034.

Verran, J. & Leahy-Gilmartin, A. A. (1996) Investigations into the microbial contamination of toothbrushes. *Microbios* **85**, 231-238.

Vowles, A. D. & Wade, A. B. (1977) Importance of filament diameter when using bass brushing technique. *Journal of Periodontology* **48**, 460-463.

Walsh, M., Heckman, B., Leggott, P., Armitage, G., & Robertson, P. (1989) Comparison of manual and power toothbrushing, with and without adjunctive oral irrigation, for controlling plaque and gingivitis. *Journal of Clinical Periodontology* **16**, 419-427.

Warren, P., Hartmut, L. & Chater, B. (1998) Electric toothbrush use. Attitudes and experience among dental practitioners in Germany. *American Journal of Dentistry* **11**, S3- S6.

Warren, P. R., Smith Ray, T. & Cugini, M. (2000) A practice-based study of a powered toothbrush: Assessment of effectiveness and acceptance. *Journal of the American Dental Association* **131**, 389-393.

Warren, P., Jacobs, D., Low, M., Charter, B. & King, D. (2002) A clinical investigation in to the effect of toothbrush wear on efficacy. *Journal of Clinical Dentistry* **13**, 119-124

Willershausen, B. & Waterman, L. (2001) Longitudinal study to assess the effectiveness of electric and manual toothbrushes for children. *European Journal of Medical Research* **6**, 39-45.

Williams, S.A. & Curzon, M.E.J. (1990) The interrelationship between caries, oral cleanliness and the use of fluoride toothpaste. *Caries Research* **24**, 413 (Abstract 66).

Wolff, K. A., Olin, D. S., Keenan, K., Harde, K. A. & Backdash, B. (1996) Sonic toothbrush efficacy in maintenance of implants in a prospective study. *Journal of Dental Research* **75**, (Abstract 426).

World Health Organization Country/Area Profile Programme, Department of Noncommunciable Diseases Surveillance/Oral Health. WHO Collaborating Centre, Malmo University, Sweden. http://www.whocollab.od.mah.se/exp/ohigv60.html. (accessed 15th March 2006).

Ximenez-Fyvie, L., Haffajee, A. & Som, S. (2000) The effect of repeated professional supragingival plaque removal on the composition of the supra- and subgingival microbiota. *Journal of Clinical Periodontology* **27**, 637-647.

PART B:

SCIENTIFIC PAPER

COMPARISON OF NEW AND 3-MONTH-OLD BRUSH HEADS IN THE REMOVAL OF PLAQUE USING A POWERED TOOTHBRUSH.

Accepted for publication in the Journal of Clinical Periodontology
2nd October 2006

COMPARISON OF NEW AND 3-MONTH-OLD BRUSH HEADS IN THE REMOVAL OF PLAQUE USING A POWERED TOOTHBRUSH

Louise M E Hogan [1,2], Christopher G Daly [1] and Brad H Curtis [3].

[1] Discipline of Periodontics, Faculty of Dentistry, University of Sydney, Sydney;

[2] Periodontics Unit, Westmead Centre for Oral Health, Westmead Hospital, Westmead;

[3] Community Oral Health and Epidemiology, Faculty of Dentistry, University of Sydney, Australia.

Key words: Powered toothbrush; toothbrush wear; plaque removal; oral hygiene.

Abstract

Aim: To compare the effectiveness of new and 3-month-old worn brush heads in plaque removal using a rotation oscillation powered toothbrush.

Methods: A single examiner blinded, randomized, cross-over study was conducted in which 34 adults attended the clinic on two occasions following 48-hour periods of no oral hygiene. Following plaque scoring, subjects brushed for 2 minutes with either a new brush head or with the brush they had used for 3 months and plaque was then rescored. Bristle wear was assessed by measuring brushing surface areas on digital images.

Results: Mean plaque score percentage reductions with new brush heads were not significantly different from those achieved with 3-month-old heads for total surfaces (new=38.1%; worn=37.1%; P=0.83) and approximal surfaces (new=31.3%; worn =30.8%; P=0.9). Brushing surface area increases of the 3-month-old heads ranged from 0-135% (mean 26.9%). Compared with new brush heads, no significant differences were found for plaque score reductions for heads with minor, moderate or marked wear.

Conclusion: Rotation oscillation powered toothbrushes with 3-month-old brush heads exhibiting various degrees of wear were as effective as new brush heads in plaque removal. Bristle age and wear on a powered toothbrush may not impede the effectiveness of plaque removal.

Clinical Relevance

Scientific rationale for study: Clinical studies of manual toothbrushes have shown that 3-month-old toothbrushes are as effective in plaque removal as new brushes. However, there is a lack of evidence regarding the efficiency of new and 3-month-old worn brush heads on a powered toothbrush.

Principal findings: There was no difference in plaque removal efficiency between new and 3-month-old brush heads on a rotation oscillation powered toothbrush.

Practical implications: Bristle wear induced by a period of 3-months home use on a powered toothbrush does not impede plaque removal efficiency. Replacement of powered toothbrush heads every 3 months may not be warranted.

Introduction

Effective oral hygiene performed regularly by the patient disrupts the plaque biofilm on the tooth surface and is considered an important factor in helping to reduce the incidence of dental caries and chronic periodontal disease in both the short and long term (Axelsson et al. 2004). For both manual and powered toothbrushes, the plaque biofilm is disrupted and removed from the tooth surface by the mechanical cleaning action of the bristles. Once these bristles become worn, it has been assumed on the basis of *in vitro* (Kreifeldt et al 1980) and *in vivo* studies (Glaze & Wade 1986) that toothbrushes have a reduced capacity to remove plaque and require replacement. Also, surveys of dental professionals have found that the majority identify splayed bristles as the main sign of toothbrush wear and recommend replacement of manual brushes every 2 to 3 months (Abraham et al. 1990, Daly & Marshall 1996, Daly et al. 2000). However, growing evidence from more recently published studies indicates that the wear status of a manual toothbrush may not be critical in effective plaque removal (Daly et al. 1996, Sforza et al. 2000, Tan & Daly 2002). In these studies, there was no difference in efficacy of plaque removal between new brushes and brushes that had been used routinely at home for periods of 9-12 weeks. In contrast, several studies which have compared new manual toothbrushes with brushes that have been artificially worn *in vitro* have found a statistically significant difference (Kreifeldt et al. 1980, Warren et al. 2002). It is possible that extreme wear may be produced artificially that does not reflect the normal situation *in vivo*.

A recent Cochrane report found evidence to support a modest superiority in plaque removal for powered toothbrushes with a rotation-oscillation action as compared with

manual brushes (Robinson at al. 2005). Although manufacturers of powered toothbrush heads recommend in their labelling that the heads should be replaced every 3 months, there is little scientific data available to support that this will assist in plaque removal. Studies of manual toothbrushes may not be directly applicable to powered toothbrushes as dissimilar bristle arrangement and reduced force applied to the teeth during use (Van der Weijden et al. 1996) may result in a different pattern and rate of bristle wear.

Only one study to date has examined the effects of wear on plaque removal using a modern powered toothbrush (Conforti et al. 2003). This clinical trial found no significant differences for whole-mouth or approximal plaque scores for new as compared with 3-month-old brush heads. However, in a subgroup whose bristle wear was judged as being "heavy" or "extreme", the new brush heads achieved a higher plaque reduction for both the full mouth and approximal plaque scores. Given that this research was carried out by a toothbrush manufacturer and private research institutions, there is a need for independent, university-based studies to further investigate the effect of brush head wear on plaque removal with powered toothbrushes to assist dental professionals in giving evidence-based advice to their patients.

The aim of this study, therefore, was to test the hypothesis that there is no difference in plaque removal between a new and a 3-month-old brush head using a rotation-oscillation powered toothbrush. A second aim was to examine the relationship between brush head wear and plaque removal on a powered toothbrush.

Materials and Methods:

Experimental Design

A single (examiner) blinded, randomized, cross-over clinical trial was conducted with adult participants. Ethical approval for the study was given by the Sydney South West Area Health Service Ethics Review Committee and by the Human Research Ethics Committees of the University of Sydney and the Western Sydney Area Health Service. Research was conducted in accordance with the World Medical Association Declaration of Helsinki (version VI, 2002 http://www.wmanet/e/policy/b3.htm accessed 31st March 2005). Volunteers were given written and verbal explanations regarding participation in the study and were required to sign a witnessed consent form.

Population Screening

Thirty-five volunteers were sought amongst staff and adult patients of the Westmead Centre for Oral Health and the Sydney Dental Hospital. All participants were required to be non-smokers and to not require antibiotic prophylaxis for the study treatment. For eligibility for inclusion in the study, subjects were required to have a central or lateral incisor, first or second pre-molar, and first or second molar present in each quadrant. These teeth constituted the 12 test teeth for the study. These teeth had to be caries-free, without restorations on facial, lingual/palatal or approximal surfaces and to have probing depths <4mm. Participants were excluded if they were wearing oral prostheses, orthodontic brackets or appliances.

Toothbrush

The toothbrush used in this study was a Braun Oral-B® D9 electrically rechargeable rotation-oscillation powered toothbrush (Braun GmgH, Kronberg, Taunus, Germany; Oral- B Laboratories, Gillette, Mississauga, ON, Canada) with an oscillating frequency of 63Hz and oscillating angle of 55°. The brush-heads used were Oral-B FlexiSoft® EB 17-8 (Oral- B Laboratories, Gillette). The brush head had the following specifications: diameter 13.2mm; 26 tufts in total (10 Indicator, eight Flexi-Soft, eight white) made up of monofilaments each with a diameter of 0.006mm. The monofilament length was 8.3mm for the "Interdental Tips" and 7.2mm for all other monofilaments.

Experimental Steps

Each subject was issued with a powered toothbrush and a new brush head with written directions on its use. They were instructed to use the allocated powered toothbrush and brush head exclusively for the next 3 months (12 weeks) but were not directed on the frequency or duration of daily tooth brushing. At this initial appointment, each patient was given a supragingival scaling and polishing to remove supragingival deposits and extrinsic stains. At the end of the 3-month period, the worn brush heads were returned in containers to prevent accidental distortion of the bristles during transport. The brushing surface of each brush head was then photographed.

Assessment of plaque removal by the used, as compared with the new brush heads, was then performed in an examiner-blinded cross-over study. Each subject tested both the worn and a new brush head. Subjects attended the clinic for two plaque assessment visits,

each a minimum of 2 weeks apart. Before each visit, they were instructed to refrain from all mechanical or chemical oral hygiene procedures for 48 h and to bring their fully charged toothbrush handle with them to the clinic.

At each of these visits, subjects rinsed for 15 s with 5 ml of erythrosine solution (1% w:v) to disclose plaque and then rinsed with 20ml of water for 20 s. The pre-brushing plaque was then scored by the examiner. Subjects were then given either a new brush head or the brush head that they had used previously for 3 months. A coin toss performed by a dental assistant was used to determine random allocation of the brush head. A measured amount of toothpaste to cover the diameter of the brush head was then placed on the brush and subjects were instructed to brush without a mirror for 2 min. At the completion of brushing, the subjects rinsed with 20ml of water for 20 s. The examiner, who had been absent from the clinic during the brush head allocation and brushing, then returned for re-disclosing and re-scoring of plaque. At the subject's second plaque assessment visit, identical procedures were followed, except that the brush head allocation was reversed.

Plaque Scoring

Plaque was scored at six sites (mesial, mid and distal of the facial and lingual/palatal aspects) on each of the 12 test teeth (one incisor, one pre-molar, one molar in each quadrant) using the Turesky et al. (1970) modification of the Quigley & Hein (1962) plaque index (PI). The mesial and distal sites on each of the facial and lingual/palatal surfaces constituted the approximal tooth surfaces for the purposes of plaque scoring. These sites are the visible spaces between the teeth that are not directly under the contact

point (Egelberg & Claffey 1998, Van der Weijden 1998). Plaque was disclosed before scoring by rinsing with erythrosine solution. All plaque scoring was performed by one examiner (LH) who was calibrated for plaque scoring before commencement of the study. Reproducibility during the study was assessed continuously by re-scoring 12 sites selected randomly by the dental assistant at each subject's examination.

Brush Head Wear

Toothbrush wear was assessed by measurement of the brushing surface area. Standardized digital photographs of each brush head were obtained using a customized jig for mounting a digital camera (Cannon ® DC 8.1 V, Cannon Inc., Tokyo, Japan) and a powered toothbrush handle (Braun Oral-B® D9, Braun GmgH, Kronberg, Taunus, Germany) onto which brushes could be fitted (Fig. 4). The digital images were downloaded onto a computer (Toshiba ® Satellite A10, Toshiba Corp., Tokyo, Japan). The outline of the brushing surface area on each of the bitmapped images was traced and the surface area within the outline was determined using NIH image software (Image J, public domain Java image program, Research Services Branch, National Institute of Mental Health, Besthesda, Maryland, USA). The reproducibility of the tracing procedure was assessed by preparing 20 tracings of each of five brush heads and calculating the means (± SD's) for each brushing surface area. The reproducibility of the image analysis was determined by calculating the surface area of a randomly selected image 20 times.

Statistical Analysis

The null hypothesis was that a new brush head on a powered toothbrush is no more effective at reducing plaque scores than a 3-month-old brush head. The Turesky et al. (1970) modification of the Quigley & Hein (1962) PI has a range of values from zero to five in numbers. As plaque scores were recorded at six sites on each of the 12 test teeth in each patient, a total score of 30 was possible for each tooth whilst a minimum score of zero (0 x 12 study teeth) and a maximum score of 360 (30x12 study teeth) was attainable for each subject. The efficiency of plaque removal was determined by comparing the total plaque score before brushing and after brushing and calculating the difference expressed as a percentage reduction. The desired sample size was calculated under the following parameters:-

1. Based on previous studies of manual (Tan & Daly 2002) and powered toothbrushes (Conforti et al. 2003), a mean reduction in plaque scores of 20% was considered relevant and a standard deviation of 30% considered likely.

2. We sought Type 1 error probability for a two-sided test of 5%.

3. Power 90% - For paired tests, it is the probability of correctly rejecting the null hypothesis of equal population means, given n pairs of patients and a Type 1 error probability α (chosen as 5%).

Using PS ® Power and Sample size calculator (V1.1.31 Department of Biostatistics, Vanderbilt University School of Medicine, Nashville, USA), a projected sample size of 26 subjects (paired data) was calculated. To allow for losses to follow-up, 35 subjects were recruited. The pre-brushing scores for each of the two plaque assessment visits of

the patients after 48-h periods of no oral hygiene were compared using a paired *t* -test. The differences between the "before" and "after" brushing scores, expressed as percentage reductions in plaque scores, were used as the variable of response for comparison of the new and 3-month-old brush heads. For each patient the percentage plaque score reductions achieved with each brush were compared using a paired- t-test.

Results:

Subjects

Thirty-four of the 35 subjects (11 male, 23 female; aged 18-65 yrs) completed the study. The 34 subjects comprised 24 patients, seven dental assistants and three dentists. The drop-out subject was a female patient, aged 30 years, who was excluded due to failure to attend for the plaque assessment visits. At the first plaque assessment visit, random allocation resulted in 18 subjects being allocated a new brush head and the other 16 subjects being allocated their 3-month-old brush head. No adverse events such as gingival abrasion were reported by, or observed in, any of the subjects at any of the clinic visits.

Measurement Reproducibility

During the plaque scoring calibration exercises before study commencement, the examiner achieved a reproducibility of 86%. During the study, plaque was re-scored on 816 sites selected randomly. A reproducibility of 90% and a *k* score of 0.87 were achieved. Brush head wear was measured by outlining the perimeter of the brushing surface area and then calculating the area within the perimeter by computerized image analysis. The coefficient of variation for the outlining procedure was 1.3% and the coefficient of variation for image analysis was 0%.

Plaque Scores

Each subject was required to abstain from all oral hygiene procedures for a 48-h period preceding each of the two plaque assessment visits. No statistically significant differences

were found between the pre-brushing plaque scores for both 48-h periods (p=0.14). Before brushing with the new brush heads, the mean (± SD) total plaque score was 257.9 (± 43.54), whilst before brushing with the 3-month-old brush heads it was 272.0 (± 34.45). The percentage reductions in plaque scores achieved when brushing with the new brush heads were not significantly different from those achieved with the 3-month-old brush heads for any of the tooth surfaces (Table 1). The mean (± SD) percentage plaque score reductions on facial surfaces were 46.2% (± 22.6) for the new brush heads and 44.6 % (± 22.2) for the 3-month-old brush heads (p= 0.76); on the lingual/palatal surfaces, they were 26.8% (± 18.2) for new and 27.4% (± 19.6) for 3-month-old brush heads (p= 0.90); and on the approximal surfaces (ie mesial and distal sites), they were 31.3% (±19.1) for new and 30.8% (± 18.6) for 3-month-old brush heads (p= 0.90). Overall, no differences were found in plaque score reductions for total tooth surfaces with the new brush heads (38.1% ± 18.1) or with the 3 month-old brush heads (37.1 %± 18.5; P= 0.83).

Brush head Wear

The 3-month-old brush heads exhibited increased brushing surface areas ranging from 0 to 135 %. The overall mean increase (± SD) in the brushing surface area of the used brushes was 26.9% (± 32.4%). The 3-month-old brush heads showed a wide variation in bristle wear (Fig. 1). The effect of brush head wear on plaque removal was investigated by assessing percentage plaque score reductions achieved with brushes exhibiting varying degrees of wear in comparison with the plaque score reductions achieved by the same patients when using new brush heads. No significant differences in percentage plaque score reductions were found between new brush heads and 3-month-old brush heads

exhibiting minor wear (0-10%, n= 14, p= 0.74), moderate wear (11-40%, n=11, p= 0.57) or marked wear (41-135%, n=9, p= 0.24) (Table 2). Plaque removal efficiency of the 3-month-old brush heads did not decrease with increasing bristle wear for either total surfaces (Fig. 2) or approximal surfaces (Fig. 3).

Table 1. Comparison of percentage plaque score reductions for the new and the 3- month-old brush heads.

Surface	**Plaque score reductions New brush-head (%)** Mean *(± SD)*	**Plaque score reductions Worn brush head* (%)** Mean *(± SD)*	**Difference in plaque score reductions** (P value)
Facial (mid & approximal)	46.2(± 22.64)	44.6(± 22.29)	0.76
Facial (mid-tooth)	70.3(± 26.40)	67.1(± 24.45)	0.60
Facial (approximal)	38.5(± 24.66)	37.0(± 23.60)	0.80
Lingual/Palatal (mid & approximal)	26.8(± 18.26)	27.4(± 19.67)	0.90
Lingual/Palatal (mid)	43.4(± 28.58)	44.2(± 31.02)	0.91
Lingual/Palatal (approximal)	23.9(± 18.23)	23.3(± 18.96)	0.90
Mid (lingual/palatal & facial)	57.5(± 22.25)	56.0(± 23.26)	0.78
Approximal (lingual/palatal & facial)	31.3(± 19.1)	30.8(± 18.69)	0.90
All surfaces	38.1(± 18.10)	37.1(± 18.57)	0.83

Table 2. Total plaque score reductions expressed as a percentage (mean ±SD) are shown for 3-month-old (worn) brush heads and new brush heads in the same subjects (*n*=34).

Brushing surface area increase of worn* brush heads (%)	**Number of subjects** (N)	**Total surfaces mean** (±SD) **plaque score reduction with worn brushes** (%) (±SD)	**Total surfaces mean** (±SD) **plaque score reduction with new brushes** (%) (±SD)	*t value* ***(df)*** **(95%CI of difference)** *P value***
0 – 10	14	34.3 (±16.16)	35.9 (±19.53)	$t_{13} = 0.34$ *(-8.6 to 11.7)* $p = 0.74$
11 – 40	11	33.1 (±22.51)	38.1 (±20.54)	$t_{10} = 0.59$ *(-14.0 to 24.0)* $P = 0.57$
41-135	9	46.3 (±15.23)	41.4 (±13.44)	$t_8 = -1.27$ *(-13.7 to 4.0)* $p = 0.24$

* 3 months old
** Paired t-test (New – Worn); NS = P>0.05

Table 3. Approximal plaque score reductions expressed as a percentage (mean ±SD) are shown for 3-months-old brush heads as compared with new brush heads in the same subjects (*n*=34).

Brushing surface area increase of worn* brush heads (%)	**Number of subjects** (N)	**Approximal mean(±SD) plaque score reduction with worn brushes** (%) (±SD)	**Approximal mean (±SD) plaque score reduction with new brushes** (%) (±SD)	*t value* ***(df)*** **(95%CI of difference)** *P value***
0 – 10	14	28.07 (±14.82)	28.11 (±20.53)	$t_{13} = 0.01$ *(-10.7 to 10.8)* **$p = 0.99$**
11 – 40	11	25.41 (±22.81)	30.36 (±20.41)	$t_{10} = 0.57$ *(-14.4 to 24.3)* **$p = 0.58$**
41-135	9	39.11 (±17.60)	37.06 (±13.66)	$t_8 = -4.22$ *(-13.3 to 9.2)* **$p = 0.68$**

* 3 months old
** Paired t-test (New – Worn); NS = P>0.05

Figures:

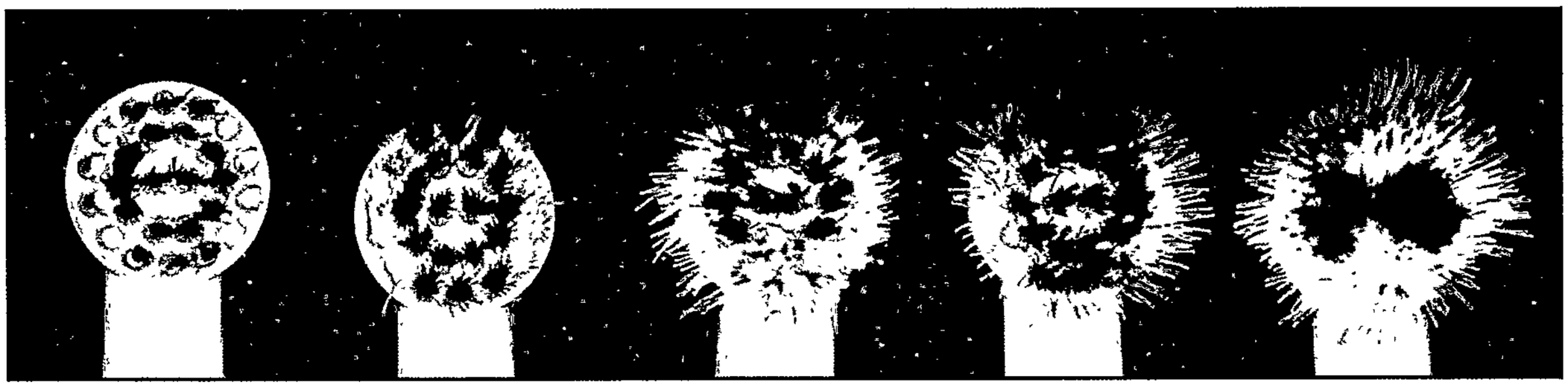


Fig. 1. Three-month-old brush heads exhibiting variations in bristle wear. The percentage increase in brushing surface area for the illustrated brush heads was (from left to right) 0%, 16%, 46%, 72% and 94%.

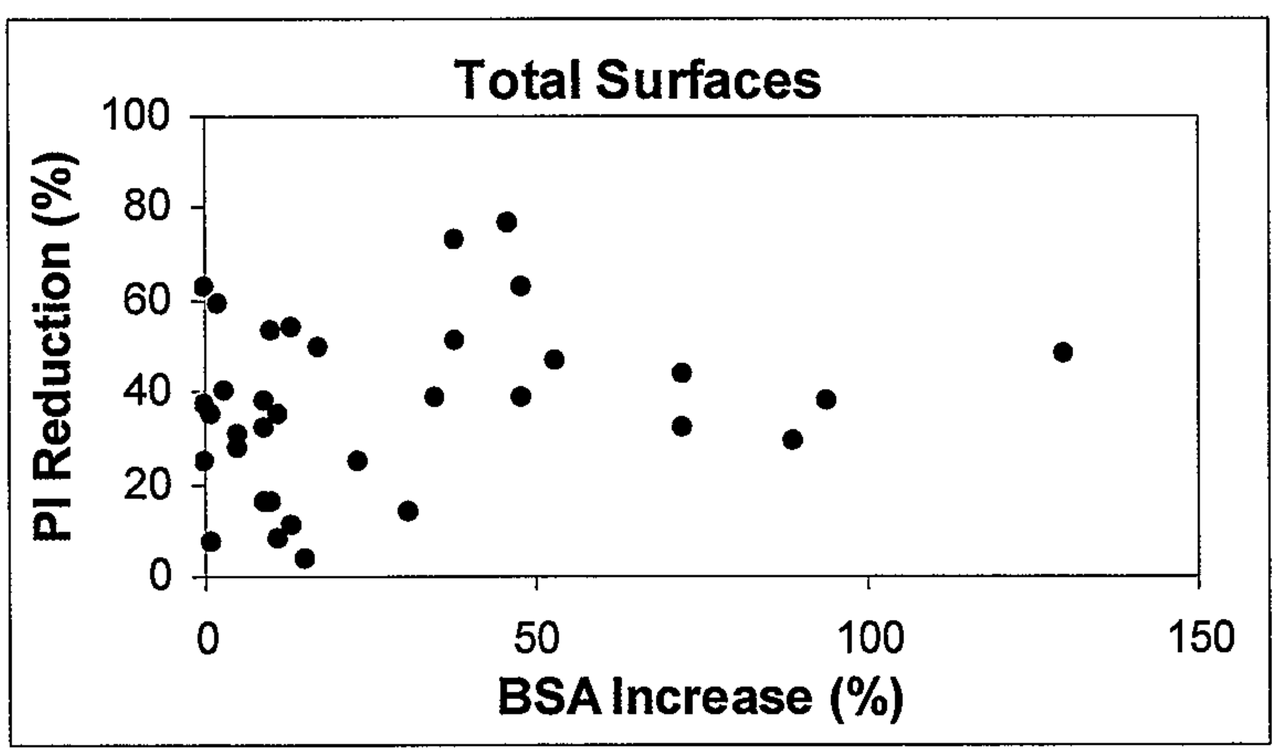


Fig. 2. The percentage plaque score reductions for total surfaces achieved with each of the 3-month-old brush heads are shown in relation to the increase in the brushing surface area (BSA) of each brush head ($n = 34$).

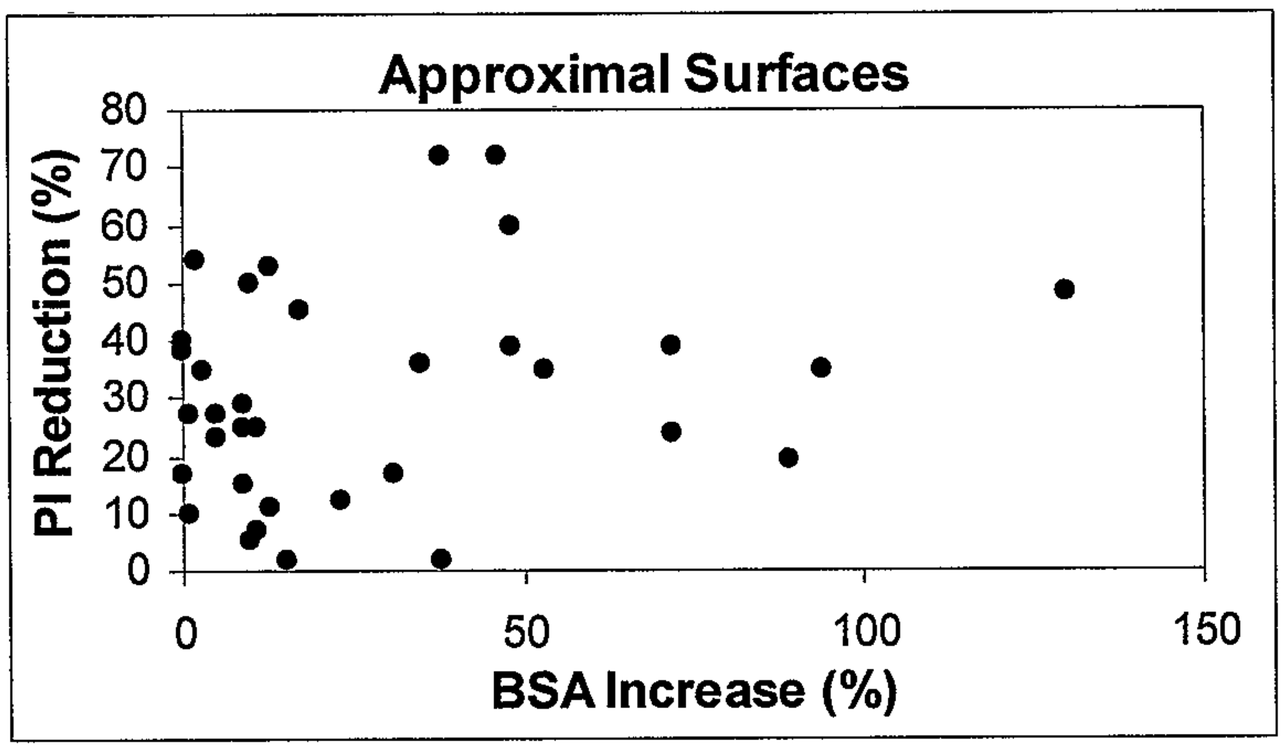


Fig. 3. The percentage plaque score reductions for approximal surfaces achieved with each of the 3-month-old brush heads are shown in relation to the increase in the brushing surface area (BSA) of each brush head (n =34).

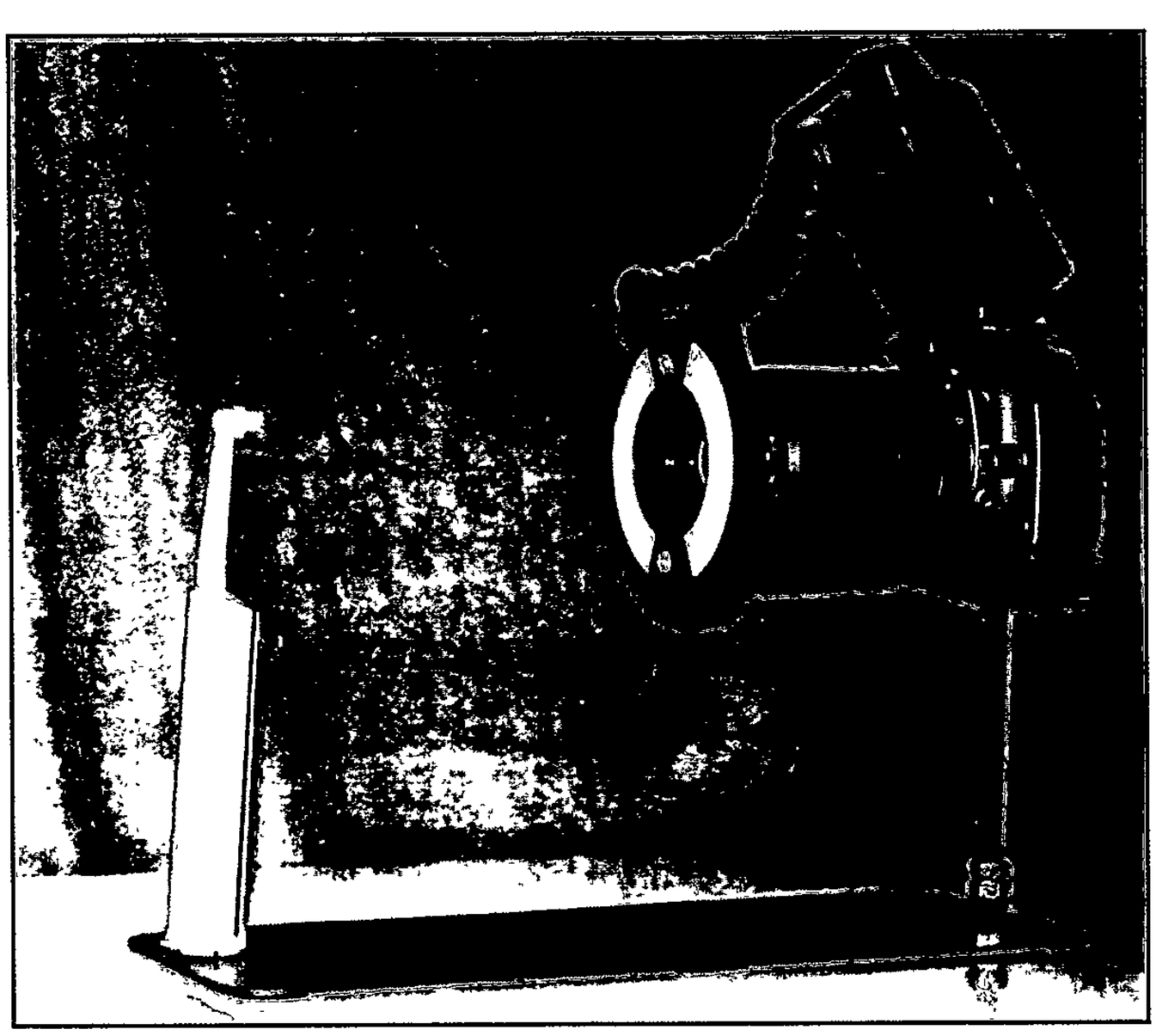


Fig. 4. Customized jig for taking standardized digital photographs of the brush heads.

Discussion:

This study found that 3-month-old, worn brush heads were no less effective than brand new brush heads when used on a rotation-oscillation-powered toothbrush to remove 48-h-old plaque. In this cross-over study, each subject tested both brush heads. This avoided any differences in brushing style that might occur when two different groups of subjects are utilized and allowed a direct comparison between 3-month-old and brand new brush heads in the same patient. In designing the study, selection of parameters was made as follows: (1) A rotation-oscillation-powered toothbrush was utilized as this is the only type of powered brush identified in a Cochrane Review as removing more plaque than manual brushes (Robinson et al. 2005) and this type of brush was used in the only other study published to date on the effect of age and wear on plaque removal by powered brushes (Conforti et al. 2003); (2) The 12 test teeth were the same as those used in previous studies investigating plaque removal by three-month-old and new manual tooth brushes (Sforza et al. 2000, Tan & Daly 2002); (3) The duration of brushing at the clinical visits was 2 min. as this interval has been well documented as being ideal for plaque removal using a rotation-oscillation-powered toothbrush (van der Weijden et al. 1993); and (4) The Turesky et al. (1970) modification of the Quigley & Hein (1962) PI was used since this index has been proposed as a consensus PI for toothbrush studies (Sicilia et al. 2002). The utilization of the 12 test teeth, apart from following the established protocols of previous studies (Daly et al. 1996, Sforza et al. 2000, Tan & Daly 2002), was necessary as the selection criteria for scoreable teeth to be caries-free, without restorations on facial, lingual/palatal or approximal surfaces and to have probing pocket depths of ≤4mm would have prevented recruitment of sufficient adult subjects

including periodontal patients unless a younger, dentally unrestored and dentally fir population was used.

Plaque removal effectiveness of the new and 3-month-old brush heads was expressed as mean percentage plaque score reductions according to the Turesky et al. (1970) modification of the Quigley & Hein (1962) PI. This index is recognized as a reliable index for measuring plaque removal after toothbrushing (Robinson et al. 2005). A major disadvantage of most plaque indices, including the Turesky one, is that they are subjective. This underpins the need for intra- and inter-examiner calibration and reproducibility exercises to be performed as part of any clinical trial assessing plaque removal with toothbrushing. In the current study, all plaque scoring was done by a single examiner who achieved a *k* score of 0.87. A *k* score above 0.75 is considered substantial (Thompson & Walter 1988). In the only other study investigating the effect of brush head age and wear on plaque removal with a rotation-oscillation-powered toothbrush (Conforti et al. 2003), no information was given on the number of examiners performing the plaque scoring or on the level of plaque scoring reproducibility.

It has been shown that plaque removal is least effective on the approximal and lingual surfaces after manual toothbrushing (Cumming & Loe 1973, Lang et al. 1977, Rugg-Gunn et al. 1979). This was confirmed in the present study, with the highest mean percentage plaque removal achieved at the mid-facial sites and the lowest from the approximal lingual/palatal sites regardless of whether a new or a 3-month-old brush head was used. It is possible that the low percentage plaque score reductions were influenced

by subjects brushing without a mirror. However, it is more likely that the inclusion of approximal plaque scoring accounted for the overall low percentage plaque reductions. This was due to two approximal but only one mid-site being scored on each tooth surface. Thus, the reduced plaque removal at approximal sites (approximately 31% plaque score reduction; Table 1) as compared with mid-sites (>55% plaque score reduction; Table 1) would be expected tp have a marked effect on total plaque scores. Overall, both the new and 3-month-old brush heads were more effective on the facial than on lingual/palatal surfaces (Table 1).

Our findings are in agreement with studies of manual toothbrushes which have reported that 3-month-old brushes are no less efficient in removing plaque than brand-new ones (Sforza et al. 2000, Tan & Daly 2002). A shortcoming of the manual toothbrush studies was that neither assessed plaque removal at approximal sites. It has been suggested that the main advantage of a powered toothbrush over a manual toothbrush is their superior plaque removal at approximal sites (Egelberg & Claffey 1998, Van der Weijden 1998, Van der Weijden & Hioe 2005). Therefore, in the present study and that of Conforti et al. (2003), plaque removal at approximal sites was assessed in addition to plaque removal on mid-buccal and mid-lingual/palatal surfaces. Neither study found a statistically significant difference in plaque score reduction at approximal sites for the 3-month-old brush heads as compared with new brush heads. However, in the Conforti et al. (2003) study, 15 of the 46 subjects whose used brush heads were given the highest wear grading had lower percentage plaque reductions after brushing with the 3-month-old brush heads at approximal sites. Unfortunately, the grading of brush head wear in the Conforti et al.

(2003) study was performed subjectively by three examiners evaluating the worn brush heads on a five-point visual scale. No inter- or intra-examiner reproducibility scores were presented for this exercise and therefore the degree of accuracy in assessing brush head wear in that study cannot be determined. In the present study, in which brush head wear was objectively assessed by digitally measuring the brushing surface area of the worn brush heads in a highly reproducible and accurate manner, no reduction in plaque removal efficiency was found for brushes with mild, moderate or marked wear at approximal sites (Table 3) as compared with brand new brush heads. Overall, plaque removal efficiency did not deteriorate with increasing bristle wear (Table 2).

We observed a wide variation in the brushing surface areas of the 3-month-old brush heads with surface area increases ranging from 0% - 135%. A similar variation in bristle wear has been identified in studies of manual toothbrushes (Bergstrom 1973, Daly et al. 1996, Mckendrick et al. 1971, Sforza et al. 2000, Tan & Daly et al. 2002) and it is generally assumed that individuals who brush with the highest force produce the highest bristle wear (Pugh 1978). It has been shown that considerably less force is used with a rotation-oscillation-powered brush as compared with a manual toothbrush but there is still a wide variation in the brushing force of individuals using powered brushes (Van der Weijden et al. 1996). Although it is possible that brand-new brushes may lead to more gingival abrasion than a worn brush in which bristles have become splayed and softened, no gingival abrasion was found for either brush. The incidence of gingival abrasion occurring with rotation-oscillation-powered brushes has been reported to be low and similar to that found with a manual toothbrush (Van der Weijden et al. 1994).

Within the constraints of this clinical trial, it is concluded that 3-month-old brush heads are as effective as new brush heads in plaque removal on a rotation-oscillation-powered toothbrush even when the brush heads display marked wear. Taken together, the findings of this study and those investigating 3-month-old manual toothbrushes (Sforza et al. 2000, Tan & Daly 2002) suggest that toothbrush bristle wear per se should no longer be considered a valid reason for toothbrush head renewal. These findings challenge the recommendations of toothbrush manufacturers that powered toothbrush heads need to be replaced every 3 months and should assist dental professionals in making evidence-based recommendations to patients.

References:

Abraham, N., Cirincione, U. & Glass, R. (1990) Dentists' and hygienists attitudes toward toothbrush replacement and maintenance. *Clinical Preventive Dentistry* **12**, 28-33.

Axelsson, P., Nystrom, B. & Lindhe, J. (2004) The long-term effect of a plaque control program on tooth mortality, caries and periodontal disease in adults. Results after 30 years of maintenance. *Journal of Clinical Periodontology* **31**, 749-757.

Bergstrom, J. (1973) Wear and hygiene status of toothbrushes in relation to some social background factors. *Swedish Dental Journal* **66**, 383-390.

Conforti, J., Cordero, R., Liebman, J. & Bowman, J. (2003) An investigation into the effects of three months' clinical wear on toothbrush efficacy: results from two independent studies. *Journal of Clinical Dentistry* **14**, 29-33.

Cumming, B. R. & Loe, H. (1973) Consistency of plaque distribution in individuals without special home care instructions. *Journal of Periodontal Research* **8**, 94-100.

Daly, C. & Marshall, R. (1996) Attitudes to toothbrush renewal: A survey of Australian periodontists and dental hygienists. *Periodontology* **17**, 118-121.

Daly, C., Chapple, C. & Cameron, A. (1996) Effect of toothbrush wear on plaque control. *Journal of Clinical Periodontology* **23**, 45-49.

Daly, C., Marshall, R. & Lazarus, R. (2000) Australian dentists' views on toothbrush wear and renewal. *Australian Dental Journal* **45**, 254-256.

Egelberg, J. & Claffey, N. (1998) Role of mechanical dental plaque removal in prevention and therapy of caries and periodontal diseases. Consensus Report of Group B. In: Lang, N., Attstrom, R. & Loe, H., eds. *Proceedings of the European Workshop on Mechanical Plaque Control*, Berlin: Quintessence, pp. 169-172.

Glaze, P & Wade, B. (1986) Toothbrush age and wear as it relates to plaque control. *Journal of Clinical Periodontology* **13**, 52-56.

Kreifeldt, J., Hill, P., & Calisti, L. (1980) A systematic study of the plaque removal efficiency of worn toothbrushes. *Journal of Dental Research* **59**, 2047-2055.

Lang, N. P., Cummings, B. R. & Loe, H. (1977) Oral hygiene and gingival health in Danish dental students and faculty. *Community Dentistry and Oral Epidemiology* **5**, 237-242.

McKendrick, A., McHugh, W. & Barbenel, L. (1971) Toothbrush age and wear. An analysis. *British Dental Journal* **130**, 66-68.

Pugh, B. (1978) Toothbrush wear, brushing forces and cleaning performance. *Journal of the Society of Cosmetic Chemists* **29**, 423-431.

Quigley, G. & Hein, J. (1962) Compressive cleansing efficiency of manual and power brushing. *Journal of the American Dental Association* **65**, 26-29.

Robinson, P. G., Deacon, S. A., Deery, C., Heanue, M., Walmsley, A. D., Worthington, H. V., Glenny, A. M. & Shaw, W. C. (2005) Manual versus powered toothbrushing for oral health. *The Cochrane Database of Systematic Reviews* 2005, Issue 2. Art. No.: CD002281. DOI: 10.1002/14651858.CD002281.

Rugg-Gunn, A. J., Macgreggor, I. D., Edgar, W. M. & Ferguson, M. W. (1979) Toothbrushing behavior in relation to plaque and gingivitis in adolescent school children. *Journal of Periodontal Research* **14**, 231-238.

Sforza, N., Rimondini, L., di Menna, F. & Camorali, C. (2000) Plaque removal by worn toothbrush. *Journal of Clinical Periodontology* **27**, 212-216.

Sicilia, A., Arregui, I., Gallego, M., Cabezas, B. & Cuesta, S. (2002) A systematic review of powered vs. manual toothbrushes in periodontal cause-related therapy. *Journal of Clinical Periodontology* **29**, 39-55.

Tan, E. & Daly, C. (2002) Comparison of new and 3-month-old toothbrushes in plaque removal. *Journal of Clinical Periodontology* **29**, 645-650.

Thompson, W. & Walter, S. (1988) Kappa and the concept of independent errors. *Journal of Clinical Epidemiology* **41**, 969-970.

Turesky, S., Gilmore, N. D., Glickman, L. (1970) Reduced formation by chloromethyl analogue of vitamin C. *Journal of Periodontology* **41**, 41-43.

Van der Weijden, G. A. & Hioe, K. P. A. (2005) A systematic review of the effectiveness of self performed mechanical plaque removal in adults with gingivitis using a manual toothbrush. *Journal of Clinical Periodontology* **32** (Suppl. 6): 214-228.

Van der Weijden, G., Timmerman, M., Nijboer, A., Lie, M. & Van der Velden, U. (1993) A comparative study of electric toothbrushes for the effectiveness of plaque removal in relation to toothbrushing duration. Timer study. *Journal of Clinical Periodontology* **20**, 476-491.

Van der Weijden, G., Timmerman, M. & Reijerse, E. (1996) Toothbrushing force in relation to plaque removal. *Journal of Clinical Periodontology* **23**, 724-729.

Van der Weijden, G., Timmerman, M., Reijerse, E., Danser, M., Mantel, M., Nijboer, A. & van der Velden, U. (1994) The long-term effect of an oscillating/rotating electric toothbrush on gingivitis. An 8-month clinical trial. *Journal of Clinical Periodontology* **21**, 139-145.

Van der Weijden, G.A., Timmerman, M.F., Danser, M. M. & Van der Velden, U. (1998) The role of electric toothbrushes: Advantages and Limitations. In Lang, N., Attstrom, R. & Loe, H., eds. *Proceedings of the European Workshop on Mechanical Plaque Control.* Berlin: Quintessence, pp. 138-155.

Warren, P., Jacobs, D., Low, M., Charter, B. & King, D. (2002) A clinical investigation in to the effect of toothbrush wear on efficacy. *Journal of Clinical Dentistry* **13**, 119-124.

Acknowledgements:

The authors acknowledge a grant from the Dental Board of New South Wales to support this investigation.