DIAGNOSTIC IMAGING
OF THE
TEMPOROMANDIBULAR JOINT

Malcolm Iain Coombs,
B.D.S., L.D.S.
University of Sheffield
D.C.R.
College of Radiographers
London

A treatise submitted in partial requirement for
the Degree of Master of Dental Surgery.

Department of Oral Medicine and Oral Surgery,
Faculty of Dentistry,
University of Sydney.
1986.
## CONTENTS

Acknowledgements iv.

Preface v.

Introduction vii.

Chapter 1 Historical Background 1.

Chapter 2 Anatomy of the Temporomandibular Joint 10.

- Craniomandibular articulation 12.
- Components of the temporomandibular joint 13.
- Temporal component 13.
- Condyle 16.
- Articular disc 19.
- Capsule and temporomandibular ligament 22.
- Neurovascular supply 24.
- Function 24.
- Remodelling of the joint 27.

Chapter 3 Indications for Diagnostic Imaging 33.

Chapter 4 Radiographic Imaging Methods 38.

- Conventional methods 42.
- Radiation dosages 44.
- Current techniques 46.
- Sagittal projections 47.
- Transcranial view 49.
- Head positioners 52.
- Transpharyngeal views 55.
- Anterior-posterior views 58.
- Axial views 62.
- Tomography, General considerations 64.
- Correction for condylar inclination 68.
- Panoramic radiography 72.
- Panoramic sonography 84.

Chapter 5 Arthrography 87.

- Indications 91.
- Technique 93.
- Interpretation 100.
- Complications 102.

Arthroscopy 104.
Chapter 6 Computerised Tomographic Imaging 107.

- Basic principles.......................... 108.
- Reformation.................................. 119.
- Reformations used for visualizing TMJ...... 123.
- Advantages and disadvantages of CT........ 127.
- Soft tissue imaging......................... 132.
- Radiation dosages.......................... 136.
- Three dimensional image reconstruction.... 140.
- Appendix, CT of the TMJ, a protocol........ 151.

Chapter 7 New Imaging Techniques I 156.

- Nuclear Magnetic Resonance Imaging.... 157.
- Basic Principles............................ 157.
- Magnet design................................ 158.
- Clinical application......................... 168.
- Technique modifications.................... 170.
- Surface coils................................ 171.
- Temporomandibular joint.................... 175.
- Contraindications........................... 183.

Chapter 8 New Imaging Techniques II 186.

- Nuclear Medicine........................... 186.
- Basic principles............................ 186.
- Clinical uses................................ 193.
- Facial development......................... 204.
- SPECT........................................ 212.

Chapter 9 NonInvasive Methods 216.

- Ultrasound.................................. 216.
- Principles of ultrasound................... 217.
- Maxillofacial uses........................... 223.
- Temporomandibular joint................... 223.

- Thermal Imaging............................ 237.
- Thermal detection........................... 238.
- Medical thermography....................... 240.
- Clinical techniques......................... 242.

Conclusion 247.

Bibliography 253.
ACKNOWLEDGEMENTS

The author wishes to express his appreciation to the following for their assistance in the preparation of this treatise.

The Department of Defence and Director of the Royal Australian Army Dental Corps for allowing me the time to further my studies.

My wife Heather for her patience and long suffering, my family for the support they have given me and to my father W.H.J. Coombs, F.C.R., A.R.P.S. a pioneer in the field of radiology to whom I dedicate this treatise.

Prof. M. Jolly and his staff of the Oral Medicine, Oral Surgery department, Sydney University for taking me under their collective wings, particularly Les Oliver, senior lecturer, my supervisor, for his guidance and encouragement.

A/Prof. G. Stacy and staff of the Oral and Maxillofacial department, Westmead Hospital for their help, assistance and use of patient material.

A/Prof. C.A. Helms, Department of Radiology, University of California, San Francisco for the magnetic resonance imaging illustrations in Chapter 7.

Dr. E. Crocker, Director of department of Ultrasound and Nuclear Medicine, Westmead Hospital for his time and the use of equipment in his department.

Dr. J. Read, Staff Radiologist, and the staff of the CT department, Westmead Hospital for allowing me a free rein of their new equipment.

Dr. R. Cooper, Director of Nuclear Medicine, Royal North Shore Hospital for illustrations in Chapter 8.

Dr. E. Boscamp, Philips, Eindhoven, Holland for supplying me with information on the use of surface coils and hard copy of magnetic resonance imaging.

Mr. B. Waters, Department of Dental Radiology, Westmead Hospital for his assistance in the TMJ radiography.

Messrs. R. Johnson and R. Vanluen, Audio-visual dept., Sydney Dental Hospital and Mr. P. Woods, Audio-visual dept., Westmead Hospital for providing me with the excellent illustrations; the seemingly impossible was accomplished.
PREFACE

During the last twenty three years of practising dentistry, I have noticed a steady increase in the number of patients seeking treatment, or being referred to specialist centres for treatment of facial pain and temporomandibular joint problems. This increase appears to have expanded over the last ten years.

This review of Diagnostic Imaging of the Temporomandibular Joint arose from treatment of a patient with post traumatic joint trismus which had been considered 'hysterical' in origin. After linear tomography, a radiographic report indicated no abnormality apart from a narrowing of the joint space and a slight morphological difference in the shape of the condylar heads. Subsequent examination using computerised tomography showed bilateral fractures of the condylar heads and bony ankylosis.

The face and jaws present unusual difficulties in radiographic examination as we have the situation of hard and soft tissues and airspaces in a unique combination. Their exact relationships had only been determined by dissection of cadavers until Wilhelm Conrad Roentgen announced to the world his discovery of xrays. This prompted a Professor Morton in the U.S.A. to make the comment 'the covered now has been uncovered, the concealed has now been revealed and the invisible now
visible' (Blackman 1959). The progress of improving ways to look into and through the human body from this time moved relatively slowly as scientific theory was hampered by the limitations of technological development in the electronics industry. Then with the advent of the space age and man's ability to leave the confines of gravity came the need for smaller and lighter equipment to control his machines. From this programme came the silicon chip and the micro computer. Theory could now be put into practice and this has since revolutionized the ability of man to visualize that which is within his body more effectively and to change the whole process of radiology to that of diagnostic imaging.

This text is a resume of the radiographic techniques, a review of the current imaging methods available to the oral and maxillofacial surgeon when assessing and treating disorders of the temporomandibular joint, with some speculation as to the future techniques that may prove useful in providing a clearer picture of this area and thus an accurate diagnosis of the patient's problem.

Malcolm I. Coombs
INTRODUCTION

Temporomandibular joint problems have always been in existence but may not have been recognised as such, the patient seeking treatment from medical practitioners for such complaints as headaches, migraine, neck and facial pains. Many were told that their problem was "all in the mind", so consequently they learned to live with the pain until it became debilitating and treatment such as alcohol injections or trigeminal nerve resection was performed as a last resort.

With the increase of knowledge and an improvement in ways of obtaining this knowledge, the dental profession became more able to diagnose and treat temporomandibular joint problems which previously would have been overlooked. There is now more interplay between the professions as treatment of the temporomandibular joint is considered to be multidisciplinary, with medical and dental practitioners as well as physiotherapists becoming involved.

A great deal has been published over the years on the temporomandibular joint since Costen put forward his theories in 1934 in relation to loss of vertical dimension. His observations were correct but in recent years his conclusions have been found to be otherwise. Costen's ideas were superseded in 1955 when Schwartz proposed the theory on temporomandibular joint pain dysfunction syndrome, which, after Laskin in 1969, was changed
to myofascial pain dysfunction syndrome.

Some of the conclusions drawn from this mass of published literature have been incorrect and have not necessarily corresponded with the clinical findings. This in turn has led to misinterpretation. However a much clearer picture as to the structure and components of the masticatory apparatus is now available as a result of work done by Sicher in 1949, Rees in 1954, with Du Brul's additions to Sicher's work in 1980 (Bell 1982a).

Treatment over the years has been very varied ranging from bite appliances, rehabilitation of the occlusion and dentition, injections of sclerosing solutions, and more recently cortisone injections, physiotherapy, psychotherapy, surgery and drug therapy with indomethacin, diazepam and carbamazepine. There have been a wide variety of surgical procedures which include removal of impacted wisdom teeth, partial or total condylectomy, and removal or surgical repair of the disc. With the advent of microsurgery much more definitive surgical treatment is available provided there is accurate diagnosis of the problem.

As more knowledge of the temporomandibular joint is obtained so better treatment will evolve. The accuracy of diagnoses has depended upon a variety of factors. Clinical history continues to be the key, now assisted
by a range of radiographic techniques such as plane, panoramic, tomographic and arthrogramic radiography. There is now an expansion of the knowledge being gained concerning the joint with the use of computerised tomography, magnetic resonance imaging, nuclear medicine, digital subtraction and fluoroscopy. The information gained from these areas is now giving a greater insight into problems of the temporomandibular joint, making it possible to study joint function, to diagnose and to predict the need and outcome of surgery to the joint.
Chapter 1

HISTORICAL BACKGROUND

In November 1895 Wilhelm Conrad Roentgen, professor of physics at the University of Wurtzburg announced the discovery of x-rays (Britannica 1974, Fortier and Glover 1982). This has been heralded as one of the most revolutionary achievements in the history of medical science (Fortier and Glover 1982). Within two weeks of this announcement two dentists, Dr. Otto Walkoff in Braunschweiz, Germany and Dr. Frank Harrison of Sheffield, England, produced the first radiographic pictures of teeth (Fortier and Glover 1982, Berry 1982, Blackman 1959). They cut down unexposed photographic plates to approximately 2 x 3 inches, wrapped them in black paper, placed them in the mouth and with an exposure time of twenty five minutes, produced the first pictures showing the teeth within the bone. These pictures were of no diagnostic value.

Blackman (1959) reports that in January 1896 Harrison informed a meeting of the British Medical Association that he had constructed a vacuum tube for the use in taking dental x-rays. This was followed in April 1896 by Dr. Charles Clarke, who announced to the Odontological Society in London results of experiments using the 'new method of x-rays' to produce images of teeth. Some of his first radiographs are preserved in the Odontological Museum of the British Medical Association. Clarke
became the first radiologist to the Royal Dental Hospital. In June 1896 Harrison submitted to a British Medical Association meeting x-ray photographs taken from dry and live specimens, with an exposure time of ten minutes, showing the structure of the teeth. Although poor in definition they showed enamel, dentine and pulp canals. All present at the meeting agreed that the new photographic process would be of greatest use in dentistry.

On 4 June 1896 Harrison recorded the first comments on radiation hazards as related to dentistry when he reported that one of his male assistants who had been exposed many times with exposures of 10 - 20 mins. over a period of one month, had developed a burning sensation over the right side of his face in the area directly subjected to the x-rays. The assistant had stopped shaving because of the tenderness of his skin. His description was as follows:

'The skin gradually increased in redness, became deeper in colour and eventually presented an appearance of local erysipelas with a sharp line of demarcation. Subsequent days showed change; first the hair follicles of the beard and right side of moustache began to pustulate. A few days later the redness became less marked, the skin commenced to desquamate and hair over the affected area began to fall out. Eventually the right
side of the face became quite bald and the skin glossy and wrinkled'.

The whole incident caused a furore at the time and stimulated a great deal of interest. However, the panic slowly disappeared when it was found that the introduction of an aluminium filter placed in the line of the x-ray beam reduced the liability of x-ray burns. Harrison himself developed a radiation burn on his finger caused by the practice of holding the film in the patient's mouth during exposure to x-rays (Figs. 1-1, and 1-2).

From 1897 the development of dental x-ray equipment was taken up by a variety of manufacturers and the production of x-ray apparatus with a greater and more stable output concurrent with the development of improved gas tubes was achieved. Slowly exposure times were reduced and this was accompanied by the appearance on the market of special celluloid D film for intra-oral radiography. It is interesting to note that each packet of dental films carried a slip of paper from the manufacturers suggesting that in order to prevent gagging when the film was placed in the mouth, the oral cavity should first be sprayed with cocaine as a preliminary routine.

The intra-oral radiograph is somewhat limited in its overall coverage of the maxillo-mandibular structures so conventional extra oral radiographs were used.
Fig. 1-1. Harrison (about 1906) holding film in his patient’s mouth and showing his home-made x-ray machine.

Fig. 1-2. Radiation burn on Harrison’s finger.
to achieve better coverage. However, these radiographs are plagued by distorted images, lack of definition and superimposition of anatomical structures (Blackman 1959).

Langland, Langlais and Morris (1982a) in their book Principles and Practice of Panoramic Radiology review the development of panoramic radiography. In 1933/34 Dr. H. Numata of Japan was the first to propose and experiment with rotational panoramic radiography. He placed a curved film in the mouth lingual to the lower teeth and used a slit of a narrow x-ray beam that rotated around the patient's head to expose the film. Some twelve years later Dr. Yrjo Veli Paatero of the Dental Institute, Helsinki University, proposed, experimented and demonstrated a slit beam method of panoramic radiography. It was similar to that of Numata in placement of the film but the patient moved instead of the source. At this time panoramic radiography began to follow two pathways:

1. using an intra oral source
2. an extra oral source with moving patient, x-ray source, film or a combination of the three.

Intra oral source

In 1943 Horst Berger took out a patent for a machine with an x-ray tube that could be inserted into cavities of the human body, but in 1946 Dr. Walter Ott,
a Swiss dentist developed an x-ray tube that could be introduced into the patient's mouth. This was later modified by Dr. Sidney Blackman, England, about 1960, and was known as the panograph. However, this method has not developed much further apart from refinements to the equipment. Only three companies now manufacture this type of equipment under the names of Panoramix, Status X, and Stat Oralix.

Extra oral source

This was known as rotational panoramic radiography and became the more popular method. In 1949 Paatero observed that panoramic radiographs could be taken with a parabolographic technique by placing the film extra orally, the film and patient revolved at the same velocity on a single vertical axis while the x-ray source remained stationary. This made it possible to radiograph the curved surfaces of the jaws by laying them out as a flat plane giving a panoramic view. This technique was subsequently called panoramic tomography, from panoramic - an unobstructed, complete view of the region in all directions, and tomography - an x-ray technique for taking radiographs of layers of tissue in depth, without interference of tissue above and below the level of the layer of tissue in question. Between this time, through to the 1950s, work was done in Washington, London and Helsinki by Paatero in conjunction with others. One such
person was Blackman who went on to work in conjunction with Watson and Son Ltd. to manufacture and produce a model known as the rotograph. Following this a great deal of the early work in England was done at the Royal Dental Hospital, London on such a machine (Semple and Gibb 1985).

The first orthopantomograph suitable for taking clinical radiographs was completed by Paatero in 1959. By 1960 it had proved to be clinically acceptable. In this system the patient either stands or sits immobile while the x-ray source rotates behind the neck and a curved film cassette moves around the face rotating upon its own axis. A narrow beam of radiation is directed through the patient and a second slit into the film. It revolves around three successive rotational axes; one for the anterior portion of the jaws and two eccentric axes for each side of the jaws. Since that time many different panoramic machines became available but in the mid 1970s Morris and Hudson in U.S.A. designed the Tomorex machine which was unique in that it allows a panoramic film to be taken of an injured patient in the prone position. In 1980 a similar machine was developed in Finland designed to receive a patient in the prone position and also capable of taking short arcs as well as full panoramic views, known as panoramic zonography. It employs a narrow angle tomographic arc and strives to scan the whole object undistorted and sharply defined.
It permits uncomplicated positioning of the patient by the use of light beams and is capable of producing symmetrical pre and post operative radiographs and a Water's view of the mid face. Panoramic radiography has developed rapidly since the late 1940s when Paatero began experimenting with slit beam rotation methods to produce panoramic radiographs of the jaws. It has proved an excellent screening and diagnostic aid for both the medical and dental professions (Langland et al 1982a).

Tomography as such has been in existence almost as long as conventional radiography but only came into its own with the development of faster film speeds, intensifying screens and more efficient x-ray machines that were developed during the 1930s. It can now be divided into three main categories:

1. conventional tomography
2. computerised tomography
3. emission tomography.

The principles of conventional tomography can be implemented in several different ways. The x-ray tube and the film can move synchronously in a straight line in opposite directions, in parallel planes or alternatively in opposite directions in parallel planes with other motions such as circular, cross, spiral, trispiral, hypocycloidal and other multidirectional movements. The blurring of objects outside the focal plane is
accomplished most effectively by the more compound movements of the tube and film. The choice of tomographic technique to be used should be determined by the specific diagnostic task and the anatomical site under investigation.

With the advent of the space programme came the micro-chip and the computer moved from a large room-filling mass of equipment to small compact units capable of a multitude of functions. It has now become possible to measure accurately the extent of x-ray transmission through an object and numerically transform that information into a density scale and thus into pictures as in computerised and emission tomography.
Chapter 2

ANATOMY OF THE TEMPOROMANDIBULAR JOINT

General

Christensen (1969) made the following comment when discussing the diagnosis and treatment of disturbances the temporomandibular joint:

'It is essential that the clinician has a very clear understanding of the basic anatomical features of the functional activity of the region, which involves not only the normal and correct functioning of the joint but also the various dysfunctions applicable to the region with the dental background inevitably associated with the production of these dysfunctions, and especially the treatment required to restore normal function'.

The point of junction between two objects is known as the point of articulation and when used anatomically in relation to bony structures it is known as a joint. Orthopaedically joints are classified as being either diarthrodial or synarthrodial (Bell 1982b).

A synarthrodial joint is a fibrous joint where two bony parts are united by a band of fibrous tissue which allows little or no movement. This type of joint is commonly called a suture. Examples are the articulation between the cranial bones and also that of the pubic symphysis. A diarthrodial joint on the other hand allows a wide range of movement between the opposing bones. The
actual articular surfaces between the bones are covered with tissue capable of withstanding considerable pressure but at the same time allowing movement. It should be noted that the direct pressure bearing areas do not have any nerves or blood vessels supplying them. However, this avascular area requires nutrition. This is supplied by a fluid known as synovial fluid which bathes the internal surfaces of the joint. The presence of the fluid necessitates the joint to be encapsulated, this being achieved by means of a fibrous capsule that is attached around the periphery of the joint. The inner-surface of the capsule is lined by the synovial membrane which secretes the synovial fluid that feeds and lubricates the nonvascularized tissue. The capsule has both a good blood and nerve supply. It should be noted that if the pressure is removed from the avascular areas there is a proliferation of blood vessels into these areas. Diarthrodial joints are therefore classified as synovial joints and can be subdivided into simple, that is between two bones, or compound, between three or more bones.

In synovial joints the articular surfaces are usually covered by a thin layer of hyaline cartilage known as articular cartilage which is avascular and non innervated in its central area, the peripheral part having both blood and nerve supply. In some joints the synovial
capsule is divided by a wedge shaped crescent of fibrocartilage known as a meniscus. This structure does not necessarily divide the joint space into two compartments or restrict the free flow of the synovial fluid. It helps to facilitate movement of the bony parts but does not act as a true articular surface. Such structures are found, for example, in the knee joints.

By definition, the temporomandibular joint is a synovial joint and is, therefore, diarthrodial. However, the temporomandibular joints have several characteristics which make them different from other synovial joints. The joint is considered to be of the compound type, the articular disc having the functions of a third bone having two articular surfaces above and below (Bell 1982a). Sicher (1962) considers it to be a hinge joint with a movable socket thus making it a double joint, the lower part being the hinge or ginglymoid and the upper being arthrodial in type. Thus the temporomandibular articulation is classified as a ginglymo-arthrodial joint.

Craniomandibular articulation

DuBrul (1980) considers that the articulation between the mandible and base of the skull should be termed the craniomandibular joint, as the adult mandible is a single bone with identical types of joint at either end, neither of which can move without affecting the other.
He considers the term temporomandibular joint has developed from anatomical dissections being carried out unilaterally and only in the sagittal plane. However, for the purpose of this thesis the term Temporomandibular Joint (TMJ) is being used, as most radiographic techniques used look at each joint separately.

Components of the temporomandibular joint

In 1954 Leonard A. Rees published a very clear picture of the joint and its component structures which still form a basis for an explanation of the functional anatomy of the joint. He describes the joint as consisting of five parts:

1. articular fossa and eminence
2. condyle
3. articular meniscus or disc
4. capsule
5. temporomandibular ligament.

Temporal component

The articular surface of the temporal bone comprises basically of two parts, the concave area of the articular or glenoid fossa posteriorly (Fig. 2-1) and the convex surface of the articular eminence anteriorly (Fig 2-2). The surface is bounded by the anterior margin of the squamotympanic fissure posteriorly and the tubercle of the eminence anteriorly. The medial border is bounded by the suture between the squamous part of the temporal
Fig. 2-1. Concave articular or glenoid fossa.

Fig. 2-2. Convex articular eminence.
bone and greater wing of the sphenoid bone. The lateral border is made up of a raised, narrow crest joining the articular tubercle at the root of the zygomatic arch in front, to the postglenoid process behind. The bone of the articular fossa is very thin and superiorly forms part of the floor of the middle cranial fossa. DuBrul (1980) considers this clear evidence that the articular fossa, despite the fact that it contains both the disc and the head of the condyle, is not stress-bearing or a functional part of the craniomandibular articulation; that part being between the condyle and disc, on one hand, and the articular eminence with its extended planes, on the other. The angle of the slope of the articular eminence varies from individual to individual and changes with age, particularly in patients with disease of the joints.

The surface of the articular fossa is covered by a thin layer of fibrous tissue which is thickened anteriorly as it extends over the articular eminence. Between the bone and this fibrous tissue lies a layer of fibrocartilage. This is separated by an illdefinible band of cells known as the proliferative zone (Blackwood 1976). Toller (1974), following microscopic examination of tissue taken from joints during surgery and from fresh cadavers indicates another layer of faintly fibrillar material between the fibrous layer and the synovial
cavity. This smooth-surfaced layer varies in thickness, between 1 to 3 microns. He considered it to correspond with the lamina splendens described in other joints. The articular surface of this zone is smooth, while the undersurface follows the undulations of the fibrous layer and in effect smooths out any irregularities that may occur. The cells near the articular surface have a reduced amount of cytoplasm as compared with the cells of the non load-bearing areas of the joints.

Condyle

The adult mandibular condyle is basically elliptical in shape with its largest diameter being mediolateral in direction and shortest diameter in an anteroposterior direction. Rees's (1954) description of the condyle was very simple, likening it to a gable roof because of the transverse ridge with anterior and posterior downward slopes. He also noted that the lateral and medial poles were below the articular surface and marked by distinct bony tubercles, necessary for the attachment of the capsule and meniscus (Fig. 2-3).

Yale et al (1966) after assessing several collections of skulls developed a classification for the types and angles of mandibular condyles. After assessing 1560 dried skulls they indicated that the average mediolateral length was 20 mm and that the anteroposterior length was between 8 to 10 mm. They describe the
Fig. 2-3. Mandibular condyle 1. anterior view 2. posterior view.

Fig. 2-4. This lateral pole could be mistaken as an osteophytic spur on a panoramic radiograph.
superior surface of the condyle as being convex more so in the anteroposterior direction than in the mediolateral direction. Looking at the different areas of the condyle it was noted that the posterior surface was also convex whereas the anterior condylar surface could be either convex, flat or concave. On many of the condyles examined there was a pronounced ridge running mediolaterally on the antero-inferior limit of the articulating surface. This ridge is the upper limit of the pterygoid fovea, which is the depression on the anteromedial aspect of the condyle at the junction with the neck. It is at this point that the lateral pterygoid muscle is attached.

It should be noted that this ridge should not be mistaken as an osteophytic spur. On certain views, such as panoramic or transpharyngeal via the sigmoid notch, the lateral part of this ridge can be incorrectly identified as osteophytic lipping or beaking (Fig. 2-4).

The axes of the condyles are not parallel to each other or perpendicular to the anatomical sagittal plane. Extension of these axes medially will cause them to meet just anterior to the foramen magnum at an angle varying between 140° to 160° degrees. Yale et al (1969), working on dry skulls and Taylor et al (1972), working on sub-mentovertex radiographs found that the long axes of the condyles intersected with the coronal plane, intermeatal
level, at an angle varying between 15 to 22.5 degrees. The mean is considered to be about 20 degrees.

Radiologists consider this angle to be important and will take a submentovertex film initially before completing a radiographic survey of the joints. It is required to adjust the head to obtain the correct angulation prior to performing TMJ tomography. This is known as corrected tomography and will be discussed in more detail under radiographic techniques.

Like the articular fossa the articular surface of the condyle is covered by fibrous tissue. On the posterior aspect the fibrous tissue is thin and is bound directly to the bone. However, over the convex surface of the condyle this fibrous tissue is much thicker with an interposing layer of fibrocartilage between it and the sub-articular bone. The fibrous layer and fibrocartilage are separated by the cells of the proliferative zone, which with age becomes less distinct. However, it retains its activity throughout life and is responsible for remodelling and repair of the articular surfaces. In the normal joint the mineralized articular surface is smooth but can become irregular with age or osteoarthritic changes. Radiographically smooth, intact bony margins usually indicate a healthy joint.

Articular disc

The articular disc or meniscus is made up of dense
fibrous tissue, being elliptical in shape. Rees (1954), described the disc as being of unequal thickness throughout and exhibiting four clearly defined transverse zones:

1. anterior zone
2. intermediate zone
3. posterior zone
4. bilaminar zone.

It is made up of the thin intermediate zone with the thickened anterior and posterior bands, the posterior band being approximately twice the width of the anterior band. Posteriorly the disc divides into an upper layer, which is attached to the anterior margin of the squamo-tympanic fissure and a lower layer which is continuous with the periosteum on the posterior surface of the condyle. The posterior region is sometimes known as the retrodisical pad (Blackwood 1976) or the bilaminar zone (Rees 1954). It contains elastic fibres in the upper layer, while the lower layer is chiefly fibrous tissue. Anteriorly the meniscus is attached to the articular eminence above and to the articular margin of the condyle below. Centrally the fibres of the disc merge and fuse with the fibres of the lateral pterygoid muscle anteriorly and medially (Fig. 2-5 and 2-5a).
Fig. 2-5. Sagittal section through the TMJ showing the different aspects of the joint.

Fig. 2-5a. Keyed photograph of fig. 2-5 indicating the various components of the TMJ.

1. temporal bone
2. upper joint space
3. bilaminar zone
4. anterior zone
5. lower joint space
6. condylar head
7. fibres of lateral pterygoid muscle.
Rees (1954) likened the shape of the meniscus to that of a schoolboy's peaked cap closely covering the head of the condyle with the peak extended forwards. Medially and laterally the meniscus fuses with the capsule and together they are attached to the respective poles of the condyle. The inferior attachments of the disc form the enclosure of the inferior joint space (Fig. 2-6).

Capsule and temporomandibular ligament

According to Rees (1954) the fibres of the capsule and the two parts of the bilaminar zone are inseparable and can only be distinguished by the fact that the capsular fibres run directly from the neck of the condyle upwards and backwards to the temporal bone.

Anteriorly there is no capsule as the disc fuses with the fibres of the lateral pterygoid muscle. The upper and lower attachments of the disc thus form the boundaries of the synovial cavities.

The capsule itself is a thin structure particularly on the medial aspect and is separated from the disc by an extension of the upper synovial cavity. The lateral wall is also thin behind but is strengthened forward by the temporomandibular ligament. This ligament reinforces the lateral wall of the capsule and is intimately bound to it. It is made up of dense, flat, fibrous sheets of tissue which pass forwards and upwards from the neck of
Fig. 2-6. Lateral view of the TMJ showing the meniscus with the superior and inferior attachments defined with pins.

Fig. 2-7. Showing the capsule and temporomandibular ligament.
the condyle below the lateral pole to the root of the zygomatic arch (Rees 1954) (Fig 2-7).

Neurovascular supply

The blood supply to the joint is from the maxillary artery via the deep auricular branch. The pterygoid plexus of veins is in close association with the medial aspect of the joint. The posterior part of the disc and capsule has a rich plexus of blood vessels but as mentioned previously the central part of the disc is avascular.

The innervation of the joint comes from the auriculo temporal branch of the mandibular division of the trigeminal nerve. The capsule and periphery of the disc contain free nerve endings but the central area of the disc has no nerve supply.

Function

In order to be successful in imaging the joint, particularly in arthrography and CT scanning, a basic knowledge of the normal movement and function of the joint is considered necessary. The basic movements of the mandible are depression and elevation, that is opening and closing movements of the jaw, along with lateral or side to side movements, protrusion and retrusion. These movements are all controlled by the muscles of mastication.
Rees (1954) divides the movements of the joints into six phases:

1. occlusal phase
2. retruded opening phase
3. protrusive opening phase
4. extreme protrusive opening phase
5. closing phase
6. retrusive closing phase.

A summary of joint function is as follows; opening from centric occlusion is started by contraction of the lateral pterygoid muscles causing a slight rotation and translation of the condyles within the lower joint space.

On further opening the movement is transferred to the upper joint space so that the condyles and discs slide together in a downward and forward action along the articular eminence. This movement is effected by continued contraction, particularly the superior fibres of the lateral pterygoids, relaxation of the masseters, medial pterygoids and temporalis muscles, and contraction of the anterior belly of digastric, mylohyoids and geniohyoid muscles.

In extreme opening the condyles and discs move forward on to the base of the articular eminence. However there is a great deal of variation as to how far this forward translation of the condyles and discs can take place.
Closing of the jaw is a reverse process with the condyles and discs being returned to the articular fossae by contraction of the masseter, medial pterygoid and temporalis muscles with corresponding relaxation of the lateral pterygoids and submandibular muscles. At all times the disc follows the movement of the condyle and its return to the articular fossa is aided by the action of the elastic fibres in the bilaminar zone.

With lateral or side to side and rotational movements the condyle on the side to which the movement is taking place remains fixed in the articular fossa by the contraction of the muscles on that side. The opposite condyle and disc are drawn downward and forward on to the articular eminence by the contraction of the medial and lateral pterygoids of that side. The reverse process takes place with movement of the jaw to the opposite side.

Protrusion of the jaw is caused by both condyles and discs being pulled forward on to the articular eminence by the action of the medial and lateral pterygoids together, the jaw being supported by the tonic contraction of the other elevator muscles. Retrusion is caused by relaxation of the pterygoid muscles and contraction of the horizontal fibres of the temporalis muscle. The movements of the condyles and discs during the processes of mastication, deglutition and speech are a complex combination of the above mentioned phases.
Remodelling of the joint

Blackwood (1976) describes three types of remodelling which take place continuously throughout life on the articular surfaces of the joints. They are:

1. Progressive - addition of tissue to the articular surface which increases the vertical dimension of the joint.

2. Regressive - removal of tissue from the articular surface which results in a decrease in the vertical dimension of the joint.

3. Peripheral - addition of tissue along the margins of the articular surface which results in osteophytic or lipping formation.

These changes are considered a method of compensation for changes in dentition caused by occlusal wear or loss of teeth. Oberg et al (1971) and Blackwood (1976) consider there is a direct relationship between the extent of remodelling and the number of missing teeth. Oberg found that there was an increase in remodelling with age from the age of 20 years, that arthritic changes occurred more in women than men at a 2:1 ratio and that there was a significant difference between the groups studied to suggest that the risk of arthrosis of the TMJ would be greater in persons who have lost several teeth than in those who have not.

More recently attempts have been made to show that
the TMJ is a loaded joint by radiographically evaluating the trabecular pattern of the condyles to determine how they varied between three different classifications of bite. The article by O'Ryan and Epker (1984) discussed variations in TMJ function and morphology for skeletal class I, skeletal class II open bite and skeletal class II deep bite dentofacial forms.

The differences were explained on the basis of accepted principles of biomechanics and how they influenced cartilaginous growth and bone remodelling. The conclusion was that variations in TMJ morphology and function are predictable based on these biomechanical principles which govern adult skeletal morphology but until these variations are fully appreciated care must be exercised in the clinical, radiographic, arthrographic and histological determination of problems with the TMJ (O'Ryan and Epker 1984).

The argument that the magnitude and direction of force exerted upon the joints alters with different occlusal arrangements and skeletal patterns is possible but the author considers that there is more scope for further research in this field.

Kozam (1985), Professor of Anatomy at the New Jersey Medical School, recently published an article concerning the morphology of the TMJ, the shape and contour of which are determined in part directly by
heredity and indirectly by the size and shape of the teeth and their orientation in the dental arch.

When the crowns of the permanent teeth erupt they are fully calcified and as hard as they will ever be. Bony joints and their surrounding soft tissue on the other hand will not take on their full shape until adulthood. Therefore, they will contour themselves to the final relationship of the teeth in the arch.

Joint remodelling continues until the relationships of the teeth in the dental arches have stabilized to the least traumatic working conditions, this being finalized during adulthood. The type of bite determines the resulting type of joint during the developmental stages of the temporal bones and condylar processes. Once the mature joint is formed there is little or no remodelling with alterations of the occlusion.

Kozam went on to discuss three types of normal joint as previously identified by Riesner:

1. joint with moderate overbite
2. joint with diminished overbite
3. joint with deep overbite.

The first is associated with patients who are able to perform all mandibular movements comfortably and have an evenly developed musculature.

The second type of joint is found in patients who are able to make wide lateral excursions during the
growth period, develop a shallow glenoid fossa and have a flatter than average posterior incline to their articular eminence. The upper fibres of the lower belly of the lateral pterygoid are more developed than the lower fibres.

In the third group are patients who are not able to make significant lateral excursions without interference. In these patients powered depression and elevation of the jaw is dominant with the compensating occlusal curve either reduced or absent. The joint itself shows marked convexity of both the articular eminence and the condylar head. The lower fibres of the inferior belly of the lateral pterygoid muscles are overdeveloped with opening and closing movements being dominant over lateral excursions. The greater use of the lower fibres during development produces a tilt of the condylar heads. The meniscus tends to be compressed and acts as a cushion between the condyle and articular eminence.

Little or no remodelling occurs in the joint after extraction or replacement of teeth and dental restorations. Changes that occur are usually found in the bone and not the fibrocartilage covering the articular surfaces. When chewing patterns are changed rapidly as a result of significant restorative changes the joint quickly reaches the limits of its adaptive parameters before producing discomfort as a prelude to tissue destruction. Kozam calls this the first defensive step.
The second defensive step is the commencement of changes in the neural and muscular activity patterns. This neuromuscular accommodation is manifest as a change in the masticatory pattern as the body tries to eliminate the discomfort even if it is subliminal in nature.

When a clinician suggests to a patient that the discomfort is just an adjustment period then he is asking that patient to alter his neuromuscular patterns until a more comfortable one is found. The main problem is that it is impossible to determine where this neuromuscular adjustment ends and damage to the ligaments, bone and fibrocartilage occurs.

Kozam concluded that occlusion determines the shape of the joint during development and growth stages but is not strictly true for changes that occur in the adult joint. Following narrow parameters joint and tissue destruction occurs rather than accommodation in the adult. Joint accommodation is really a neuromuscular adaption. When this adaption fails then pathological conditions start to appear in the muscles and tendons or in the bone, cartilage and ligaments of the joint proper.

It is at this point when the patient seeks treatment that the nature and location of the pathological condition must be accurately determined. Only when this occurs can the correct therapy be planned. Speculative
treatment can, in the long run, only lead to patient disappointment and add another dimension to the problem.
Chapter 3

INDICATIONS FOR DIAGNOSTIC IMAGING

The incidence of clinical problems associated with the temporomandibular joint is now considered to affect more than 28% of the adult population (Solberg et al 1979).

The symptoms may vary from single joint noises through a variety of manifestations which include earache, headache, pre-auricular pain, clicking of the joint, intense intracapsular pain, muscle spasm and locking of the joint. The problem may become so intense as to totally disable the patient. (Ricketts 1953, Laskin 1969).

The evidence for the apparent cause of the problem and that which can be observed pathologically may appear contradictory. In some cases the joint symptoms are associated with a specific pathological condition including displacement of the meniscus and a variety of arthritic changes. In other cases there may be symptoms but no specific pathology is detectable. However, the relationships within the joint may be considered to be suspect. For example, regions within the joint may appear to be too narrow or too wide, the articular eminence may be considered to be at too steep an angle and again in other cases the joint can appear to be quite normal (Krietziger and Mahan 1975, Blaschke et al 1980, Carlsson 1980, Hall et al 1984).
When pathology within the joint is found it is now possible to treat the problem by direct surgical intervention. This is only indicated when all other forms of conservative treatment have failed and radiographic evidence indicates that extensive changes within the condylar head have occurred. Problems which have a high psychosomatic basis should not be considered for surgery unless the patient has undergone extensive psychiatric evaluation. There are a range of surgical procedures now available for treatment of the temporomandibular joint. These include procedures related to the disc varying from simple repositioning, plication, to meniscectomy and procedures affecting the hard tissues of the joint such as high condylar shave, condylectomy, reshaping the articular eminence and the use of rib grafts. More recently the use of prostheses such as silastic sheet grafts and implants as well as metallic implants have been used, and in certain areas microsurgery is now being practised for repair of soft tissue damage (Henny 1984).

Over the years there have been many ways of classifying disorders of the temporomandibular joint. Weinmann and Sicher (1951) for example, classified TMJ disorders as follows:

1. vitamin deficiencies
2. endocrine disorders
3. arthritis.
Several years later Sicher (1954) recognised masticatory muscle spasm as a common cause of TMJ dysfunction. This was followed some two years later when Schwartz used the term temporomandibular joint dysfunction syndrome to point out the difference between the acute masticatory muscle pain and that caused by organic disorders of the joint itself.

By 1960 Bell (Taylor et al 1972) had sorted TMJ complaints into three categories:

1. intracapsular conditions
2. capsular conditions
3. extracapsular conditions.

By 1970 Bell had re-classified TMJ problems into six categories:

1. spontaneous dislocation
2. traumatic joint
3. masticatory pain-dysfunction syndrome
4. temporomandibular arthritis
5. chronic hypomobility
6. developmental anomalies and neoplasms.

For the next 10 years or so work on TMJ problems was devoted almost exclusively to muscular disorders but Farrar (1971) proposed that some problems were related to disc interference and not solely muscular disorders. Bell, since then, has again revised his original classification by logically grouping into broad categories...
those conditions that present similar symptoms. These categories are then subdivided into areas that are dis-similar and clinically identifiable. Bell feels that this acts as a plan to help the clinician arrive at a precise diagnosis of the patient’s problem and as such is a valuable diagnostic aid. His classification now divides the clinical symptoms into five basic groups:

1. acute muscle disorders
2. disc-interference disorders
3. inflammatory disorders
4. chronic mandibular hypomobilities
5. growth disorders.

In his book Clinical Management of Temporomandibular Joint Disorders (1982c) Bell also comments on the radiographic confirmation of joint conditions as related to the clinical features, that is, the position of the condylar head in the glenoid fossa. It can be summarized as follows:

1. Acute muscle disorders may show restricted movement of the condyle or gross malocclusion particularly related to spasm of the elevator and/or the lateral pterygoid muscles.

2. Disc-interference disorders which he subdivides into four classes, and spontaneous anterior dislocation.
   a. class I and II may show positive radiographic changes in the presence of malocclusion
b. class III may show positive changes in width of disc space or within the subarticular bone

c. will show no changes

d. may show positive changes for gross dislocation.

3. Inflammatory disorders may show radiographically if there is restricted movement, changes in the bone or in the disc space.

4. Chronic mandibular hypomobility may show location of the cause particularly if there is restriction of movement, for example in ankylosis.

5. Growth disorders will show structural alterations particularly in relation to rapid osseous changes, therefore radiology is essential for an accurate differential diagnosis.

In order to provide an adequate diagnosis and treatment it is necessary to be able to visualize the joint effectively. It is the responsibility of the clinician, the radiologist and the radiographer to work together to efficiently display, where possible, the cause of the appropriate symptoms.
Chapter 4  

RADIOGRAPHIC IMAGING METHODS

General

'The TMJ remains an elusive structure to examine radiographically' (Langland et al 1982a).

The underlying problem is that though the joint is easily accessible and close to the skin it is small and lies in close proximity to several areas of radiographically dense bone. These are the petrous temporal bones (Fig 4-1), the mastoid processes and the articular eminences of the malar bones (Fig. 4-2) all of which obscure the joint when viewed from different directions. Other bony projections involved, particularly if they are enlarged, are the styloid processes and pterygoid plates, (Fig. 4-3 and 4-4).

Radiographic procedures of the joint are generally considered to fall into the following categories:

1. Conventional methods
   - plane film radiography

2. Tomography - linear
   - pluri-directional
   - panoramic

3. Contrast procedures - arthrography

4. Special procedures - computed tomography
   - magnetic resonance
   - nuclear scanning
Fig. 4-1. Transcranial view across calvarium showing
1. roof of glenoid fossa 2. petrous pyramid.

Fig. 4-2. Lateral view of the TMJ showing associated
dense bony structures 1. articular eminence 2. mastoid
process.
Fig. 4-3. Para view with contralateral TMJ obscured by 1. enlarged pterygoid plate 2. styloid process.

Fig. 4-4. Transpharyngeal view with condyle to be viewed partially obscured by enlarged pterygoid plate.
- ultrasound
- thermal imaging.

In the first three procedures there are different ways of visualizing the TMJ. They vary in relation to the plane in which the joint is viewed; lateral or sagittal to frontal or coronal views.

It is proposed to discuss the first two procedures in this chapter, with parts 3 and 4 being subject matter for subsequent chapters.

In radiography of the TMJ it is essential to develop a good technique to produce the information required on the condyle, glenoid fossa, articular eminence, meniscus and joint space as well as the structures governing the relative positions of the components of the joint. Otherwise the picture will be not only useless but also very misleading (Poyton 1982). Various radiographic techniques have been developed and are now considered to be part of the diagnostic armamentarium. These techniques are widely used but have failings, the main one according to Bronstein et al (1981) being that the information they yield can be difficult to interpret.

The projections devised have been developed with the problems of superimposition in mind but whatever technique is used it is essential to show the correct relationships (Poyton 1982). These various projections
do not always show the condyle exactly along its transverse axis i.e. between the lateral and medial poles of the condyle, which is considered the most valuable view for the diagnostician. The clinician must be aware that the contours of the articular surfaces can be distorted by the radiographic projection. As these limitations occur with each projection, in terms of visualization and distortion, then ideally a selection of views should be taken to rule out the possibilities of joint pathology (Griffiths 1983).

Conventional methods

Standardization of views is highly desirable and accuracy is essential. The most commonly used projections according to Poyton (1982) are:

1. transcranial - 25 degree tube tilt
2. transpharyngeal - Parma projection
3. PA mandible - 30 degree tilt
4. tomography.

Other conventional views available are transpharyngeal or infracranial, transorbital, various anterior and posterior views (Townes' and reverse Townes’) and submentovertex, all of which are concerned with the bony structures of the joint. On the other hand contrast arthrography with or without tomography and fluoroscopy is a more specialized technique for viewing and diagnosing derangements of the meniscus.
The panoramic projection can produce good views of the craniomandibular articulation but standardization and accuracy are difficult to achieve. It has proved to be an ideal screening film for a preliminary survey and should an abnormality be detected then a more specialized view of the joint can be taken with, if necessary, use of contrast media injected into the joint as in arthrography.

The conventional radiographic views of the TMJ only detect and evaluate deviations in the hard tissues of the joint, principally that of the condyle. Several studies have been carried out over the years comparing the different techniques and their variations. The conclusions were that whatever technique is used a minimum of two views at right angles projecting through the articular surfaces are necessary (Quantrill and Lewis 1974). The jaw positions closed (centric occlusion), open and at rest (centric relation) should be included in a radiographic examination. Routine views should include transcranial or transpharyngeal, lateral tomographs, occipitomental and Townes' projections. All authors agreed that each technique had its limitations and that no one technique was better than the other. It is important to select the one that most clearly demonstrates the desired information (Zech 1959, Klein et al 1970, Smith and Harris 1970, Quantrill and Lewis 1974).
Other techniques may be employed to deal with specific conditions but where possible all additional observations should be bilateral so that both joints can be compared with each other (Poyton 1982).

The selection of the projections should be based upon the clinical findings and the nature of the suspected pathology. Limitations may also be imposed by the type of radiographic equipment available and the expertise of the radiographer in that field. The radiation dose produced by each technique, though relatively low, has also to be considered due to the cumulative effects of multiple views especially when treating children and females of child-bearing age.

Radiation dosages

Currently most radiological examinations of the TMJ are made on film using standard dental x-ray machines or using a machine specifically designed for plane tomography and this has led to an increased awareness of the potential radiation hazards to the patient.

To date very little work has been done on the radiation dosages produced during radiography of the TMJ. However, Brooks and Lanzetta (1985), carried out a project to ascertain the radiation dosages to the head during TMJ radiography using four techniques:

1. transcranial
2. transpharyngeal (Parma projection - through the sigmoid notch)
3. transorbital

4. lateral tomography.

They used standard dental x-ray equipment, with a kVp of 90 and 70, and a cephalometric machine capable of linear tomography. The radiography was carried out on a tissue-equivalent phantom head with lithium fluoride thermoluminescent dosimeters previously calibrated with a cobalt 60 beam irradiator. A total of thirty dosimeters were used, located at selected points on the phantom head and chosen to represent such areas as the point of entry of the central beam for each technique, bone marrow, thyroid and salivary glands and lens of the eye.

It was found that the skin doses for the various areas ranged from 112 mrad for the transorbital projection to 990 mrad for the Parma projection and was related to the point of entry of the central beam. Doses to the pituitary were on average 5.8 mrad (range 2.3 to 11.5), except for the Parma projection, without coning, which was 18.2 mrad and for the lateral tomograph 26.5 mrad. The transorbital projection was the only one to produce any significant radiation to the lens of the eye, which was 112 mrad and 170 mrad for 90 kVp and 70 kVp respectively. This compares with the eye dosage figures of 112.36 mrad reported by Weissman from his comparative study of dosages during dental radiography.
using special views (Weissman 1973). The lateral tomograph produced the highest dosage to the pituitary gland and bone marrow of the skull whilst the Parma projection gave the highest dosage to the parotid gland.

The radiation dosage to the tissues during TMJ radiography can be further reduced by observing the following:

1. strict collimation of the x-ray beam to improve picture quality and reduce scatter radiation

2. use of faster film-screen combinations such as rare earth screens

3. reduction of number of views to minimum required to maintain diagnostic requirements.

Current techniques

The final selection of the technique to be used is usually influenced by the clinician's preference for a specific view and is related to how he feels he can interpret the data produced. Some prefer the transcranial views because they feel it shows the complete joint on a single view, whereas others prefer tomograms because there is an absence of superimposed tissue even though the views are segmental in nature.

Madsen (1966) proposed that the ideal radiographic technique for producing images of the TMJ should include:

1. demonstration of all aspects of the joint with limited distortion
2. demonstration of both joints simultaneously
3. the patient comfortable and in a natural posture
4. sufficient accuracy to be able to reproduce the same images on subsequent occasions.

The present techniques available are unable to satisfy all these ideals. In conventional radiography, the radiation beam passes through all structures between it and the film resulting in superimposition of the various structures. However, different techniques have been developed to minimize the effects of superimposition from remote bony areas. These enable imaging of the joint of interest from a position which is most useful in determining any abnormalities that may be present.

Sagittal projections

These views are produced by the central ray being at right angles to the sagittal plane of the patient. They are usually called true lateral jaw or lateral cephalographs (Fig.4-5a/b). They are commonly used in orthodontic and orthognathic work for evaluation of the various aspects of the hard and soft tissues of the craniofacial structures, and are usually taken with the patient's head stabilized in a device known as a craniostat and are therefore accurately reproducible. These views should never be used for evaluation of the TMJs.
Fig. 4-5a. True lateral view of TMJs as seen on a cephalogram showing superimposition by base of skull.

Fig. 4-5b. True lateral view of TMJs, left condyle and lateral border of glenoid fossa marked for ease of interpretation.
for the following reasons:

1. There is direct superimposition of both condyles, rami and body of the mandible over each other.

2. If it were possible to view the condyles they would be in an oblique view as their transverse axes are not at right angles to the sagittal plane.

At times this view is used mistakenly to show subcondyalar fractures, producing a film that is diagnostically useless as far as detail is concerned. A better projection for this is the oblique lateral view which can be modified to show four basic areas:

1. mandibular molar region
2. maxillary posterior teeth
3. mandible as far anteriorly as the canine tooth
4. superior aspect of ramus, neck of the condyle and TMJ with the medial pole uppermost. This only produces a clear view of the joint if the mouth is open.

Transcranial view

Over the years several different techniques of this projection have been proposed by Lindblom, Grewcock, Gillis and others. The basic difference between each is the angulation and point of entry of the central ray (Lewis 1964). Basically the transcranial projection is a form of lateral skull view and is the view most commonly used to avoid superimposition of the condyles over
Fig. 4-6a. Transcranial view of TMJ, open position. Joint marked to indicate plane of condyle and position of medial and lateral poles.

Fig. 4-6b. Transcranial view of TMJ, closed position.

Fig. 4-6c. Key to markers on TMJ.
1. lateral border glenoid fossa and articular eminence
2. square – lateral pole
3. triangle – medial pole
4. transverse axis of condyle.
over each other and the other dense anatomical structures, in particular the petrous pyramids of the petrous temporal bone (Fig. 4-6a/b/c).

This is achieved by placing the film against the side of the face to be radiographed, parallel to the mid-sagittal plane, then rotating the patient’s head bringing the nose towards the film by no more than 15 degrees. The x-ray beam is then projected from the contralateral side at a point above and behind the external auditory meatus. This ensures that the central ray passes over the contralateral petrous pyramid and usually through the anteromedial apex of the ipsilateral pyramid. However it can pass under or over depending upon the vertical angulation of the central ray.

The central ray is, as close as possible, parallel to the transverse axis of the condyle in question, but hits the articular surface at an oblique angle. Therefore, the shadow of the condyle and also the fossa registered on the film does not represent a true picture of the joint, in particular the profile of the articular surface of the condyle. This view puts the lateral pole higher than the medial pole therefore producing a misleading profile. The clinician thus sees the surface of the lateral pole instead of the central load-bearing part of the condyle where morphological anomalies are most likely to occur.
Head positioners

The evidence from the various surveys indicates that no one TMJ radiographic technique is superior to another and that no one method is suitable for all occasions. This resulted in many dentists feeling that TMJ radiographs had little clinical value for diagnosis and treatment planning due to their inaccuracy and variability. It was not considered possible to reproduce successive radiographs of the same joint.

Weinberg (1970) carried out a feasibility study on dry skulls which indicated the error between pairs of TMJ radiographs was so small that further clinical experimentation was desirable. Twenty eight pairs of TMJ radiographs were taken a week apart with the patients' jaws in acquired centric occlusion to reduce any gross errors that may be introduced. The x-ray cone position was standardized by means of a small piece of cardboard 2 1/2 inches by 3/4 inch which was placed anterior to the ear on the mid-tragus line, the cone being centred through the other end of the cardboard with a fixed cone angle to the film of 75 degrees. He observed that the study provided evidence that the TMJ space could be duplicated using a simple technique and that it should prove useful in evaluation of the joint. It was found that this method of duplicating radiographs could be performed with a high degree of accuracy and provided a valuable
tool in the diagnosis and treatment of TMJ problems.

As a result of this work Weinberg went on to inves-
tigate the factors which influence the quality and cha-
racter of TMJ radiographs and to develop a technique
that would guarantee good consistent results. His previ-
ous work had shown that changes in the head position
and/or location of the x-ray tube did not appreciably
change the dimensions of the joint space due to the 14:1
ratio between x-ray source to film and the object to
film distances. The original technique did not have any
control over the superimposition of the cranial struct-
ures because of the source/object to film ratio (14:1).
The dense cranial structures, being nearer to the sou-
rc e, will move a greater distance in relation to the TMJ
with only small movements of the head. This, therefore,
makes it essential to stabilize the head during TMJ
radiography in order to obtain good diagnostic quality
films. Using the 'auditory axis', that is a line drawn
between the centres of the auditory meatus on each side
as the base line, a head positioner was constructed to
fix the patient's head. The patient's head was placed in
a horizontal position with his lower ear over a fixed
auditory guide on a plastic table which also carried the
film. A second plastic sheet containing a series of
holes was hinged over the patient's head and positioned
using a movable auditory rod. An angulation of 75 deg-
rees was used for the x-ray tube point at the joint to
be radiographed. The positions of the guides and tube were noted on the head positioner for future reference. Because of these known positions it was then possible to adjust the patient's head to obtain the optimum results with superimposition being kept to a minimum.

The most important factor in any form of radiography is to control the radiation dosage to the patient so by using a fixed position it is possible to reduce the amount of radiation used and the area irradiated by means of collimation. This has a twofold benefit. Firstly as mentioned, to reduce the radiation and secondly, as there is a reduction in the area of exposure there is a reduction in the scatter from the denser bony tissues. This reduces the background 'fogging', improves the contrast and the diagnostic quality of the film (Weinberg 1972).

Since then several different techniques have been developed, for example Buhner (1973) and Preti et al (1984) but all use the auditory axis and are variations of the same principle. All agree that some form of head positioner is necessary to produce consistent and satisfactory radiographs of the TMJ. Mikhail and Rosen (1979) in their work on myofascial pain-dysfunction syndrome concluded that the use of a head positioner for TMJ radiography provided a valuable aid to the diagnosis and treatment planning particularly when extensive restorative procedures were necessary. TMJ radiographs
being taken before and after the restorative procedures were found useful in treatment planning and in documenting the results, bilateral condylar symmetry being the ultimate aim (Fig. 4-7a/b).

Transpharyngeal views

Other views which by-pass the petrous pyramids are the transpharyngeal projections, known as the McQueen, the Parma or infracranial view. These projections view the joint from below the base of the skull through the pharyngeal tissues. The central ray is projected from the contralateral side below and anterior to the joint, the film being placed against the joint in question parallel to the mid-sagittal plane. The ipsilateral condyle is viewed through a 'window' made by the sigmoid notch of the mandible on the contralateral side. The ray is oblique to the transverse axis of the condyle and strikes the joint from an inferior medial aspect, the effect being to elevate the medial pole. The articular surface of the condyle is usually obscured by the lateral border of the glenoid fossa so it is better to view the condyle with the mouth open (Fig. 4-8). As with the transcranial views the image is therefore distorted and a true sectional contour of the condyle and joint is not achieved.

Another transpharyngeal projection is obtained by aiming the central ray from a point below the external
Fig. 4-7a. Standard series of views taken with the head positioner below in closed, rest and open positions.

Fig. 4-7b. Denar Accurad head positioner attached to a standard dental x-ray machine.
Fig. 4-8. Transpharyngeal view through sigmoid notch 'Parma projection', mouth open. Medial pole above and behind lateral pole.

Fig. 4-9. Transpharyngeal view, tube centred below and behind angle of mandible, both condyles (arrowed) can be viewed.
auditory meatus of the contralateral side behind the posterior border of the ramus of the mandible. This particular transpharyngeal projection views the joint through the joint space over the medial pole. The ipsilateral joint can also be seen by this method projected into the cranial vault showing the joint space over the lateral pole. Therefore, with this projection it is possible to view both condyles together (Fig. 4-9).

Anterior-posterior views

These projections include such views as Townes’ and reverse Townes’ (Fig. 4-10) showing the posterior-superior articular surfaces, transorbital (Fig. 4-11) showing the anterior-superior articular surface and the Waters’ or occipitomental projections (Fig. 4-12a/b) showing the anterior-inferior surfaces. All views taken in the AP or PA direction, with the exception of the transorbital, have the advantage of viewing the joints bilaterally at the same time and can therefore evaluate bilateral symmetry and condylar neck fractures (Fig. 4-13). The problem with these views is that they only visualize the condyle if the patient’s head is angled sufficiently, or the mouth is open thus distracting the condyles out of the fossae to eliminate superimposition by the mastoid processes which are immediately posterior to the joints (Fig. 4-14). This will also pose a problem if the patient has limited opening.
Fig. 4-10. Reverse Townes' projection radiograph.

Fig. 4-11. Transorbital projection radiograph.
Fig. 4-12a. 60° occipitomental view, used mainly for maxillofacial region, TMJs obscured by coronoid process.

Fig. 4-12b. 75° occipitomental view, TMJs obscured by ramus of mandible.
Fig. 4-13. PA mandible projection showing fractured right neck of condyle.

Fig. 4-14. Enlarged PA projection of left TMJ showing superimposition of the mastoid process.
The main disadvantage of plane film projections is that there is a distorted view of the condyle. Erosion or pitting of the articular surface may be undetectable which in turn may lead the clinician into a false diagnosis. Even employing the popular transcranial view with its anatomical and morphological findings, failure to identify bony pathology has been reported as high as 50% (Oberg et al. 1971).

Eckerdal and Lundberg (1975) reported that a change of 5 degrees in positioning of the patient can produce a significant variation in the interpretation, by different clinicians, of the joint and its relationships.

Axial views

Identification and orientation of the transverse axes of the condyles can be achieved by use of the submentovertex view along with mandibular symmetry. To obtain optimal results in transcranial radiography the central ray should be directed parallel to the condylar axis and at right angles to the same axis in lateral tomography (Omnell and Petersson 1976, Rozencweig and Martin 1978).

The submentovertex view (Fig. 4-15) is more often used as a locating film for the other views, in particular transcranial projections and lateral tomography (Lysell and Petersson 1980).
Tomography

General considerations

The equipment used in transcranial radiography falls within the range of the general dental practitioner in relation to size and cost but tomography, by contrast, involves the use of equipment that is too large and complex for the average dental surgery (Fig. 4-16). Tomographic procedures fall, therefore, within the field of medical and dental radiologists working in hospital or large radiological facilities. This does not preclude their availability to the general dental practitioner who will find that it can play a valuable role in his diagnosis and treatment of TMJ patients. Nevertheless, for him to take full advantage of its benefits he must understand the general principles and limitations.

Tomography is a technique whereby sectional radiographs of the body can be taken as if the patient had been cut into a series of very thin slices. This method of radiography is very useful in visualizing structures deep within the body that are obscured by the more superficial layers. Since its inception in the early 1930s tomography has been known by different names, planigraphy, laminography and zonography.
Fig. 4-16. Polytome U3 x-ray machine used for pluri-directional tomography.
In 1962 the International Commission of Radiological Units and Standards decided on the official terminology as follows:

1. tomography - the body-section technique
2. tomogram - the body-section radiograph
3. zonography - thick section tomography using an exposure angle of 10 degrees or less.

In plane or conventional radiography we see a two-dimensional image of the whole of a three-dimensional object, whereas with tomography we are seeing the image of a two-dimensional plane, section, or slice from within a three-dimensional structure (Coen 1974, Rosenberg and Silha 1982).

Tomography uses the principle of simultaneous movement of the x-ray tube and the film about a focal plane, the axis of which is located, as far as TMJ radiography is concerned, in the condyle being examined. This produces a series of sagittal sections, but in the case of coronal sections the axis of the focal plane corresponds with the line joining both condyles. The resulting image represents a thin plane or slice through the joint which is sharply defined in comparison with the surrounding structures which are 'blurred out'. Superimposition and image distortion are greatly reduced using tomography.

There are three factors that influence the thickness and quality of the image slice:
1. exposure angle

2. source to film distance

3. path of tube travel.

1. The angle through which the x-ray source travels is known as the exposure angle and it is this angle which governs the thickness of the section or slice through the subject: the smaller the angle the thicker the slice or the wider the angle the thinner the slice. The thinner the slice the better the radiographic detail.

2. Another factor that influences the slice thickness is the source to object and object to film distances ratio. However, the thickness of the slice is determined by altering the exposure angle as the source-film distance on most machines is fixed.

3. The main factor influencing the quality of any tomographic image is that of the direction or path the tube travels, either linear or pluridirectional.

Linear tomography is in many ways superior to the conventional radiographic techniques in showing bony details (Lindvall et al 1976, Eckerdal and Lundberg 1979). Eckerdal showed tomography to be more reliable than transcranial techniques in portraying joint relationships. However, linear tomography (Fig. 4-17a/b) is considered inferior to the pluridirectional methods due to the pronounced streaking that occurs when the long axis of an object is parallel to the path of the tube.
travel. Little or no streaking occurs when the path of
travel is perpendicular to the long axis of the object.
The more complex the pluridirectional movement of the
tube the more efficient the method in reducing streaking
and thus improving the diagnostic quality of the film
(Fig. 4-18a/b).

The hypocycloidal movement is considered the most
effective of the pluridirectional movements, particular-
ly with regard to the detection of bony defects (Ecker-
dal 1973, Rosenberg and Silha 1982). Pluridirectional
movements such as trispiral and hypocycloidal have a
slice thickness of 1-2 mm and are considered ideal for
TMJ work (Rozencweig 1975).

Correction for condylar inclination

Selection of the correct plane can be critical. If
the slice does not pass through the area of pathosis a
false negative diagnosis may occur. In some cases the
pathology has remained undetected because of its orien-
tation even when the slice has passed through the patho-
logically involved tissues. In order to prevent this
occurrence multiple slices are necessary but as radia-
tion dosage for a single slice is of the order of 1-10
rads per slice, depending upon the exposure technique,
beam geometry and film/screen speed, the dosage may be
considered prohibitive because the final image only
represents a small percentage of the tissues subjected
to radiation (Rozencweig and Martin 1978).
Fig. 4-17a. Linear tomogram through coronal plane showing blurring effect of this type of radiograph.

Fig. 4-17b. Sagittal plane, lateral linear tomogram showing blurring effect of this type of radiograph.
Fig. 4-18a. Coronal plane through TMJs using hypocycloidal technique.

Fig. 4-18b. Lateral view through left TMJ using corrected hypocycloidal technique.
Bussard et al (1980), basing their work on a retrospective study by Yune et al (1973) of patients with TMJ dysfunction which revealed that more pathological changes were evident when 'corrected axis' lateral tomography was used, found that radiologists and radiographers were ignorant of the technique. The rationale is to manoeuvre the head so as to align the central tomographic beam with the transverse axis of the condyle. This puts the slices at right angles to the anterosuperior articular surface thus increasing the sensitivity in detecting small defects. This produces a true end-on view of the joint whereas the unaligned view shows the condyle obliquely producing an altered projection which can lead to a misdiagnosis. The clinician appears to be looking at the anterior condylar surface but is in fact only viewing the anterior surface of the lateral pole.

Three methods have been developed to determine the required degree of rotation of the head:

1. nonmeasurement correction
2. standardized correction
3. individualized correction.

1. With the nonmeasurement correction the patient's head is placed on the table and rotated so that the temple, zygomatic arch and/or mandible are flat against the table. This technique is very dependent on the skill and experience of the radiographer.
2. The standardized method approach has the head rotated the same amount for each patient, usually between 15 - 20 degrees and is set by means of a protractor.

3. The individualized method is the most accurate and is carried out by determining the angle of inclination of each condyle from a submentovertex radiograph (Fig. 4-19). This requires a head angle indicator and holder to maintain the patient’s head static during exposure (Fig. 4-20). The main problem with this technique is that it is time consuming and subjects the patient to extra radiation exposure (Coin 1974, Stanson and Baker 1976). Rozencweig and Martin (1978) feel very strongly about the use of the individualized correction technique in tomography for patients with TMJ pain and dysfunction: 'rigorous observance of the critical angles is essential'.

Regardless of which method is used it should be emphasized that all lateral TMJ tomography should be corrected and that nothing can be gained without some degree of head rotation.

Panoramic radiography

This is a specialized form of tomography which includes the whole of the maxillae, mandibular bones and teeth which lie in the focal trough. Virtually all present day panoramic machines are capable of producing views of the TMJ. The standard and special panoramic
Fig. 4-19. Submentovertex radiograph with angles of inclination marked.

Fig. 4-20. Showing head clamp and protractor used for individually corrected TMJ tomography.
views provide a simple and effective method of screening the area of the TMJ. Most gross bony pathological disorders can be detected or dismissed using panoramic films.

In cases of myofascial pain dysfunction of short duration no changes are likely to be seen, or there may be a lack of concentricity of the condyle in the fossa and a unilateral lack of translation on opening. If this is the case then use of tomographic arthrograms may show anterior displacement or perforation of the meniscus.

In the case of long standing myofascial pain dysfunction degenerative changes may be seen. For other changes such as neoplasms, ankylosis or any condition that may require surgery on the joint then other more definitive radiography of the TMJ is necessary (Langland et al 1982).

In TMJ pantomography the appearance of the temporomandibular joints varies depending upon the patient's position in the machine. Therefore, in order to evaluate the joint correctly a three-dimensional analysis of its structure is necessary. This is usually done by positioning the joints for both the oblique or standard view and profile or open mouth view, with normal radiographic variations being easily noted from the differences between the images. Positioning errors which cause lack of sharpness and distortion of the joint structure are easily seen. The type of pantomographic machine used
will also determine the joint image variation. It is necessary for the clinician to know what the normal radiographic features are for the particular machine being used (Chomenko 1980).

Each machine has its own focal trough or zone of sharpness so the position of the joints within this trough is the key to understanding the variations as only structures within this zone will be in focus. All others on either side will be 'blurred out' and distorted. Different machines have been modified by their manufacturers in order to accommodate what they consider normal variations in the patients' jaw sizes.

Chomenko (1980) recommended combined examination of oblique and profile views for visualizing the TMJs. On the standard view only the mediolateral aspect of the joint is viewed, the condyle, glenoid fossa and articular eminence being projected onto the film obliquely so that their true relationship is not seen (Fig. 4-21a). The special, profile or open mouth view demonstrates the actual condyle fossa relationship as well as the anterior and posterior joint structure (Fig. 4-21b).

Chomenko (1982) carried out a comparative study of the oblique and profile views on normal average sized TMJs of a dried skull using an orthopantomograph machine (Seimens Corp.). The skull, with markers on the medial and lateral poles of the condyle, and on the medial and
Fig. 4-21a. Standard panoramic radiograph showing TMJs, indicators show medial pole (arrow) above and behind lateral pole in mouth closed position.

Fig. 4-21b. Special panoramic projection viewing the TMJs along their transverse axes.
lateral borders of the articular eminence was positioned in the machine as per the instructions in the operating manual of the orthopantomograph, the standard or 'N' position and special or 'S' position. A comparison of the appearance of joint structure between the two methods was reported on and the results were as follows:

1. In profile view, the condyle is narrower and more curved than on the oblique view.

2. The articular space and surfaces are more clearly defined on the oblique view.

3. The actual relationships between the condyle, fossa and articular eminence are only seen on the profile view.

4. The medial structures of the joint are projected about the lateral structures in both views; horizontal separation of the condyle and articular eminence is reduced in the profile view.

5. The medial and lateral cortices of the condyle form the posterior and anterior outlines respectively on the oblique view. In profile view, the posterior and anterior cortices appear at the anterior and posterior outline of the condyle respectively.

6. The tympanic plate is superimposed over the mandibular fossa and medial condyle on the profile view.

A similar experiment was carried out by the author using a dry skull with normal condyles, the left joint
being marked as described in Fig. 4-6c. The skull was set up on a photographic tripod in a Siemens OPG 5 machine according to the instructions in the operating manual (Fig. 4-22). Specially constructed acrylic bite blocks were used to hold the jaws in the open and closed positions respectively. Standard 15 second exposures were made at 55 kVp and 15 ma on Kodak DF 96 film using Dupont standard H.plus intensifying screens. The cassettes were loaded with two films to reduce the effect of the screens and to compensate for the lack of soft tissue on the skull which would have an effect during normal working procedures with patients.

The results obtained were as follows:

1. In the oblique view, the condyle appeared broader than in the profile view with the medial pole above and behind the lateral pole (Fig. 4-21a).

2. The articular space and fossa were obscured by the lateral border of the fossa.

3. In the profile view, the condyle appeared to have rotated so that the incident ray had passed along the transverse axis of the condyle. However the medial pole was still slightly above and behind the lateral pole (Fig. 4-21b). This position is the better one of the two to observe the condyle.

4. The separation of the condyle and the articular eminence was reduced in the profile view, there being
some overlap on the superior surface of the condyle.

These results were very similar to those of Chomenko (1982) with the exception of the position of the anterior and posterior cortices (item 5 Chomenko) the author considering they appear as the anterior and posterior borders respectively. This difference may be due to a misprint in Chomenko's article.

Other differences could be attributed to the use of different machines, the authors' being a later model than Chomenko's and the use of a slightly different vertical angulation, 7 degrees on the OPG 5, 9 degrees on the OPG used by Chomenko.

The images produced and the position of the anatomical structures will vary with the direction of the incident beam to the joint. The vertical direction is fixed (7 or 9 degrees) for both the oblique view and the profile view. Therefore, their vertical projections will be the same. However, as the jaw opens for the profile view the head of the condyle moves in a horizontal direction. As a result those structures on the same horizontal plane in the different projections will appear in a different relationship on the profile film. Structures closer to the source of radiation will appear more superior and apparently further away. The incident ray's horizontal direction will produce a wide condyle in the standard projection as it passes through the
joint at an oblique angle striking the medial part of the joint first and appears on the film to be the posterior border of the joint. Thus the lateral pole appears anteriorly and can be mistaken for osteophytic beaking (Fig. 2-4).

By contrast, when the TMJ is projected in the profile view the incident ray passes the posterior aspect of the joint first and the anterior structures last. Chomenko (1982) also found that the tympanic plate could be projected over the fossa and the medial part of the condyle. He also felt that the joint should be viewed in the profile position as small changes in the anteroposterior position of the condyle could be observed.

Chomenko (1982) also compared results from three different panoramic machines which had differing focal troughs and planes in focus. He found that image visibility and size of structure would only vary from radiograph to radiograph when the TMJ remained in the zone of sharpness. If it was outside this zone then distortion and blurring of the image occurred. The difference between the images from each machine was a reflection of their different focal troughs and planes of focus, particularly where the focal trough is narrow (Lund and Mason-Hing 1975).

The three machines compared were the Panorex (S.S. White Dental Mfg. Co.), the Panelipse (General Electric Co.) and the Orthopantomograph (Siemens Corp.). It was
found that the images of the TMJ produced by the Panorex were frequently poorer than either the Panellipse or the Orthopantomograph machines as the joints tend to lie outside the focal plane and on the edge of the focal trough (Fig. 4-23). In practice the differences produced by the different machines were less severe than those caused by the incorrect positioning of the patient by the operator.

Conclusions

The value of panoramic radiography for visualizing the TMJ is dependent upon it being placed accurately in the focal trough.

The standard projections are best for showing the medial and lateral cortices of the condyle, the articular space and surfaces.

The profile projection is best for demonstrating the anterior and posterior cortices and the position of the condyle.

Image discrepancies are easily seen when the normal radiographic features of the joint are not shown. A TMJ positioned too far in front of the focal trough will appear shortened and slightly blurred, but a TMJ positioned too far behind the focal trough will be elongated and very blurred.
Fig. 4-23. Position of the focal trough (FT) and plane of focus (P) in relation to the mandible for each machine.
Panoramic zonography

Normally panoramic radiography is carried out with the patient standing or seated in the machine. In 1980 Siemens developed the Zonarc (Fig. 4-24), a panoramic planigraphic unit for taking panoramic radiographs with the patient supine and this was used essentially in casualty work. It has five standard programmes with space reserved in the control table for two optional ones. As these programmes are stored in removable micro-pressor memory, they can be changed or replaced. Thus the Zonarc can be kept up-to-date in accorance with clinical requirements. The programmes are as follows:

1. middle third of facial anatomy
2. temporomandibular joints lateral view
3. cervical vertebrae
4. optic foramina
5. standard panoramic view of maxillae, mandible and oblique projection of the TMJs.

In June 1985, addressing the British Society of Dento-maxillo-facial Radiologists in London, Professor Rottke of Hamburg, West Germany, gave a report 'A Two Year Review of the Siemens Zonarc'. He reported that of the programmes available the lateral view of the TMJ (Fig. 4-25) had been used most frequently (43%) followed by the basic dental view, then mid-face tomography and finally the sagittal view of the TMJ. This latter was
Fig. 4-24. Siemens' 'Zonarc' panoramic planigraphic unit.

Fig. 4-25. Temporomandibular joints - lateral view as taken using the 'Zonarc'.
carried out with a 6% frequency. It was also found that the sagittal TMJ view did not compare favourably with the reverse Townes' or transorbital views. It was concluded that the Zonarc was a valuable adjunct to maxillofacial radiology (Rottke 1985).
Chapter 5

ARTHROGRAPHY

General

The conventional radiographic techniques discussed in the previous chapter do not detect the soft tissue parts of the joint. Despite the fact that the meniscus is a fibrocartilaginous structure it is not usually viewed on radiographs mainly because of the superimposition of the bony parts of the joint. This difficulty has been overcome by the use of arthrography.

Norgaard was the first to use arthrography on the TMJ, publishing the first article on the subject in 1944 and following it with his thesis in 1947, which is considered the definitive work on the subject (Toller 1974). However arthrography of the TMJ was never a popular technique, probably because of the technical difficulties encountered during the introduction of contrast medium into a joint space as small as that of the TMJ and difficulties in interpreting arthrograms (Toller 1974). Work carried out by Campbell at Queen Victoria Hospital, East Grinstead between 1954 and 1965 concluded that the procedure should not be performed if an alternative way of obtaining the necessary information was available. The procedure caused extreme pain and there was difficulty in entering the lower joint space, the author injecting extra-articularly on several occasions.
There was the fear of infection, damage to blood vessels and that the patient's disability could be made worse by the injection of the medium into the joint space (Campbell 1965).

Campbell also thought that the study of some arthrograms was worthwhile but there were occasions when they gave no more information than that which appeared on the standard radiographic views and there was no justification to subject patients to such a procedure. It is only in the last ten years that more arthrography has been done and there has been a resurgence in the use of the technique. This has coincided with the improved tomographic and fluoroscopic techniques and as a consequence there have been more reports of the results achieved (Blaschke et al 1980, Ioannides and Scaf 1985).

Arthrography of the TMJ is now being employed in many radiology facilities and hospitals on a regular basis to visualize the soft tissues of the joint, specifically the meniscus and its posterior attachments. Arthrography over the years has created some controversy over the indications for its use but most of the more recent articles indicate that it is diagnostically effective and has a low incidence of complications (Farrar and McCarty 1979, Dolwick et al 1979, Blaschke et al 1980, Bronstein et al 1981). Blaschke after five years experience in performing TMJ arthrography indicated the following:
1. The method is safe, provided all reasonable precautions are taken.

2. It should not cause undue pain for the patient if correctly performed and adequate post-operative precautions are carried out.

3. It is very useful in providing essential diagnostic information if meniscus derangement is suspected.

4. It can be carried out as an outpatient procedure taking a relatively short time.

Other authors, such as Murphy (1981) and Doyle and Hase (1983), agree with this philosophy but make the proviso that the operator should be 'thoroughly conversant with the technique'.

It must be remembered that arthrography is an invasive procedure and can be very painful at times. The use of arthrography should be carefully considered against the patient's clinical symptoms and the possible results obtainable. The procedure should not be carried out unless the clinician has a good understanding of the technique and there is a diagnostic need for further information.

The main reason for the new found popularity is that it has proved successful in demonstrating anterior disc displacements in patients with signs and symptoms of TMJ pain and dysfunction. Wilkes (1978) based his
findings on the examination and treatment of 400 cases of varying TMJ disorders, carrying out arthrography on most of his patients, many of them bilaterally. This helped to act as a control in the cases of unilateral symptoms as it became possible to compare the joint in question with an asymptomatic or 'normal' joint. He found in patients with TMJ pain-dysfunction syndrome a variety of internal derangements, the most common being displacement of the articular disc related to damage to the posterior attachment of the disc. Direct surgical examination confirmed the arthrographic findings.

Further studies by Katzberg et al (1980) on a series of 104 examinations found arthrography reliable in detecting internal derangements of the TMJ, 40 of which were confirmed by surgery. Bronstein et al (1981) reported an exact correlation between surgical observations and those made arthrographically in 34 cases of suspected disc derangement.

Perhaps the most important clinical information required from TMJ arthrography is the position of the meniscus in relation to the articular surface of the condyle during opening and closing movements of the mandible. It will also provide information concerning the morphology of the meniscus in sagittal view and if there is perforation of the disc or the joint capsule. The position of the disc is determined in an antero-
posterior direction. Arthrographic examination will also assess movement or lack of movement of the meniscus relative to the condyle during the different stages of jaw movement. This type of dynamic information can be obtained by viewing the procedure directly on a fluoroscope or by videoing the images for later consideration. All this will help the clinician particularly in cases of anterior displacement, reduction of which may occur as the jaw opens. Usually the patient hears a click and at the same time a 'jerk' is seen on the fluoroscope in the condyle/disc movements.

Indications

As previously indicated in this chapter most of the patients having TMJ arthrography present with signs and symptoms of internal derangements and there is a high degree of correlation between the clinical and arthrographic findings. Similarly correlation between radiographic observations and the direct findings during surgery are of the order of 90% for most studies (Moloney 1985). As a result of these findings there appears to have been a reappraisal of the indications for TMJ arthrography, particularly as more clinicians feel they can adequately diagnose internal derangements without arthrography. For example an arthrogram should no longer be necessary to confirm a displaced disc which reduces, whereas to have one for a disc that displaces without reduction is a
more difficult decision especially if the patient is to have surgery.

It is necessary for the surgeon to have a definitive diagnosis if there is any doubt as to the presence or form of a suspected internal derangement. Therefore the surgeon must exercise a proper clinical judgement in obtaining an arthrogram, particularly if the patient's problem is more related to pain rather than an actual TMJ dysfunction. The necessity for the use or otherwise of arthrography would appear to depend entirely upon the surgeon and how he feels about operating either with or without it.

There were no specific guide lines or recommendations as to when or when not to use arthrography until those made to the American Dental Association President's Conference in 1983. They were as follows:

1. that TMJ arthrography be considered a special diagnostic method with limited indications

2. that the general dental practitioner should not order arthrography during the early stages of management of a TMJ patient, except in unusual circumstances

3. that it be used if the patient fails to respond to conservative treatment

4. that it be used to rule out suspected internal derangements.

Moloney (1985) felt that arthrography should be
reserved for patients with strong indications of internal derangement where conservative treatment had failed to relieve their symptoms after what he called an 'adequate duration' but gave no indication as to what time frame he considered that to be. He also considered patients with persistent pain, all pre-surgical cases and any cases where acute rupture of the meniscus was suspected should have arthrography as part of their examination.

Technique

Arthrography is an invasive procedure which is difficult and demands a high level of skill on the part of the operator (Doyle and Hase 1983).

Toller (1974), Wilkes (1978), Blaschke et al (1980), Zetz et al (1982) and Doyle (1983) have described in detail their techniques for injection of radiopaque medium into the joint spaces. Toller describes how to inject both joint spaces, the inferior one first, whereas Wilkes canulated the upper joint space first, similarly with Blaschke. However, Zetz describes a technique for injecting the lower joint space first with the needle being inserted through the anterior lateral portion of the external auditory canal, the point of the needle passing upward and inward at angles of 20 and 30 degrees respectively until it encounters the posterior slope of the condyle. The other techniques use a preauricular approach.
Basically, the technique is aseptic and performed under local anaesthesia, the patient lying prone with his head turned so that the joint under examination is uppermost. Blaschke and Wilkes used 20 or 22 gauge angiocatheters, whereas Zetz and Doyle used a 25 gauge needle. After the needle has been inserted the patient is asked to open his mouth to check the position. The needle moves with the condyle head if located correctly. It is essential that the radiopaque medium used be water soluble and the amount injected be approximately 1ml. Wilkes felt that it was essential to use cannulae, so that the volume of fluid could be adjusted during the procedure thus preventing extravasation which can occur during functional movements of the joint, rather than simply using a needle.

All the authors felt that it was necessary to use fluoroscopic techniques to observe the positioning of the needle and flow of the radiopaque medium into the joint space thus avoiding any problems such as extravasation. Zetz et al suggested that if an extracapsular spill occurs then the needle should be withdrawn and then be reinserted after about 15 minutes. Radiography of the joint should be carried out as soon as possible after injection of the contrast medium as there is a tendency for it to be absorbed rapidly because of the
vascularity of the area. Once the contrast has been injected visualization of the joint is carried out by any of the methods described in the previous chapter with the mouth in the open and closed positions (Fig. 5-1a and 5-1b). For the reasons also mentioned in the previous chapter lateral tomography is the preferred method of examination. More recently CT assisted arthrography has also been used but further work in this field is required (Katzberg et al. 1981).

Once radiography is completed then a dynamic study of the joint movements can be carried out fluoroscopically (Fig. 5-2). The meniscus can be seen separating the upper and lower compartments either or both of which are filled with contrast medium. By videoing the fluoroscopic examination the joint dynamics can be revued continuously and comparison can be made as treatment of the patient progresses. Arthrography with high speed cineradiography (250 frames/sec and 500 frames/sec) is another method of observing the dynamics of the meniscus (Isberg-Holm and Westesson 1982). These are the only methods available by which the clinician can study the dynamics of the joint tissues as ultrasound at present is unable to produce effective pictures of the joint even in real time viewing. This particular aspect will be discussed later in the section on ultrasound.
Fig. 5-1a. Transcranial projection of TMJ arthrogram in closed position showing radiopaque dye in the inferior joint space.

Fig. 5-1b. Transcranial projection of TMJ arthrogram in the open position.
Fig. 5-2. Series of views taken from a fluoroscopic examination of the left TMJ. The two single views at the bottom of the series are the scout views in the open and closed position taken prior to injection of the radiopaque dye.
A more recent modification of arthrography was described by Westesson (1983) known as the double-contrast technique which he based on a method that is used for other joints in the body where it had proved superior to the single-contrast method. The development of this technique for the TMJ was carried out initially on autopsy specimens but the results were such that the method is now applied to patients with TMJ problems. This technique uses cannulae and in its initial stages is similar to the basic methods previously described. However, once cannulation is completed the patient is transferred to the tomographic unit and is seated with the head immobilized in a cephalostat in the position previously determined by preoperative radiography. A further small amount, $0.3 \text{ ml}$ to $0.5 \text{ ml}$, of contrast medium is injected into both spaces respectively with the patient's mouth at maximum opening and tomography is performed. The patient then closes his mouth, the contrast medium being allowed to reflux and further views are then taken.

Most of the medium is then aspirated and air is injected to both spaces simultaneously until elastic resistance is experienced. The amount of air injected varies in relation to the joint position and ranges from $0.2 \text{ ml}$ to $0.6 \text{ ml}$ and $0.1 \text{ ml}$ to $0.4 \text{ ml}$ for the upper and lower spaces respectively. The air is gently pressurized
but allowed to move freely in and out of the spaces during the whole of the examination. The idea of this technique is to ensure that the medium covers all surfaces of the joint and meniscus.

Video fluoroscopic techniques are now being used with arthrography to treat patients who are having splint therapy for TMJ pain and dysfunction. Follow-up arthrography was carried out within 4 weeks of starting splint therapy, contrast being introduced into the lower joint space. A fluoroscopic videotape recording, arthro-tomography and spot film radiography was then performed to establish the joint relationships.

If it is found that splint therapy has not recaptured the meniscus then arthrographically assisted splint registration is performed immediately. This is done by ascertaining the position of the 'clicks' then getting the patient to open his mouth. The meniscus moves anteriorly but as the jaw moves forward the meniscus is reduced. At this point the mouth is closed into an edge to edge position and the mandible is slowly retruded until an optimal condyle disc position is obtained. While this position is maintained rapid self curing material is placed between the teeth. Elimination of the click is confirmed by getting the patient to open and close his mouth fully. The treatment is then completed by fabricating a more permanent splint using the
bite registration obtained by fluoroscopic arthrographic observations (Manzione et al 1984, Tallents et al 1985).

Splint therapy is not always successful and may even be a contributing factor to the progression of the disease. Manzione et al (1984) feel that the results obtained using this technique have raised the question of the accuracy of clinical judgement alone in the treatment of displaced discs. They feel that wrongly initiated treatment will allow or even be a factor in progression of the disease. They feel that elimination of the click is not always a good sign as it may even show displacement without reduction. Final evaluation of this form of treatment will depend upon continued use in assessing splint therapy and results obtained from a long-term follow up study.

Interpretation

Arthrography is basically the artificial opacification of the joint spaces using a medium that is radiographically opaque. When both joint spaces are opaque the clearly defined radiolucent space represents the meniscus and its posterior attachment. The structure of the meniscus is not seen and if only one space contains contrast medium then the meniscus represents the boundary of the pool of dye.

Perhaps the key to interpreting TMJ arthograms is an understanding of the anatomical relationships and
contours of the various surfaces of the joint. The thin intermediate zone of the meniscus has a concave inferior surface whereas the posterior zone has a convex inferior surface (Rees 1954). In the normal joint the posterior zone remains above and behind the vertex of the condyle, relative to the stage of jaw opening. The intermediate zone remains between the bony articulating surfaces during all stages of joint movement. If the convexity indicating the posterior zone is seen anterior to the condyle this indicates that the meniscus is displaced anteriorly. The general principle that the intermediate zone should remain between the bony articulation during movement is well established clinically (Wilkes 1978, Dolwick et al 1979, Blaschke et al 1980).

The exact location of the meniscus can be determined when both joint spaces are opaque, an important point when diagnosing cases of nonreducing displacements.

The most common abnormal finding arthrographically is that of the anteriorly displaced disc. Depending upon how severe or how chronic the problem, along with anatomical and mechanical factors, the question is whether or not the disc will reduce to a normal condyle-disc relationship during movement of the mandible. Should the meniscus not reduce it will form a constant mass anterior to the condyle presenting a mechanical obstruction
to forward movement. These two conditions correspond to the clinical observations of clicking and closed locking respectively. The clinician must therefore carefully assess if a reduction takes place, when and to what extent it occurs in order to be able to produce an effective treatment.

Another use of area arthrography for the clinician is in determining perforation of the meniscus. This is achieved by filling the lower joint space with contrast medium and observing radiographically the passage of that contrast medium through the disc into the upper joint space.

It should be noted that arthrography is of no use in the investigation of bony defects because opacification of the joint spaces obscures the bony surfaces of the joint. The clinician should have pre-arthrographic views taken if bony defects are suspected. Investigations on young adults by Katzberg et al (1983) found that there was evidence of TMJ arthritis in conjunction with anterior displacement of the meniscus.

Complications

Arthrography is an invasive procedure and requires considerable technical expertise. Three common errors occur:

1. injecting too low on the condyle and therefore depositing the solution outside the capsule
2. improper positioning of the needle leading to injection into the wrong space

3. placing both needles in the same space.

Other complications to be considered are allergic reactions to the radiopaque medium. This is considered rare but caution is essential particularly if the patient has a history of sensitivity to iodine containing products. Infection is an ever present danger so it is necessary to observe a strict sterile procedure. There is a transient alteration in the patient’s occlusion due to the increase of fluid in the joint spaces. There can also be a temporary facial nerve paralysis caused as a result of the local anaesthetic which occurs in about 20% of cases (Zetz et al 1982). Post operative pain is usually relative to the patient’s pain threshold and can usually be well controlled with suitable analgesics. Zetz suggests the use of aspirin or aspirin containing analgesics because of its anti-inflammatory properties. Blaschke also suggests the use of ice packs to reduce pain and oedema.

The contrast medium in the joint is slowly absorbed by the synovial membrane and excreted by the kidneys. Failure to achieve successful results can prevent further examination of the joint for a minimum period of 2 weeks to allow for the injected medium to fully disperse. There is always a risk that the examination will aggravate the TMJ problem (Blaschke et al 1980).
ARTHROSCOPY

Arthroscopy is the technique of direct visual examination of the internal surfaces of a synovial joint. It has come to the fore in recent years particularly since the development of the fibre optic light system and the ability to produce a very intense light without the production of a great deal of heat. This technique has been used greatly in work on the knee and shoulder joints but very little appears in the literature concerning its use in the TMJ.

Japanese workers appear to lead the field in this area. Ohnishi, according to Holmlund and Hellsing, (1985) is considered to be the first to publish a report on TMJ arthroscopy using a needle arthroscope with a 2 mm diameter cannula. The needle arthroscopes were first developed for examination of the smaller joints such as the toe, ankle and finger.

More recently work on arthroscopy of the TMJ has been published by Hellsing et al (1984), Murakami et al (1984), and Holmlund and Hellsing (1985). The great advantage of this technique is that the joint surfaces can be viewed directly and the findings recorded either by means of a still camera or on videotape. The procedure is carried out under local anaesthesia. This is preferable to general anaesthesia as it allows full control of the jaw movements essential to permit access.
and to observe the relationships of the joint structures during function. A sharp tipped trocar enclosed in a 2.4 mm cannula is used to puncture the joint capsule, which has been distended with isotonic saline solution. Once access is acquired the sharp trocar is replaced by a blunt one to prevent damage to the internal structures. This is then exchanged for a fibre optic telescope to view the internal surfaces of the joint and can then be attached to either the still camera or the video system to obtain a permanent record. Throughout the examination the joint cavity is irrigated and distended using saline at a gravity pressure of 100 cm water (Hellsing et al 1984).

This initial report was related to two patients with chronic TMJ conditions, facial pain and clicking respectively. The clicking was assumed to be related to anterior meniscus displacement based on clinical history. However arthroscopic examination found observable degenerative changes within the joint. Similarly in the case of chronic pain severe arthrotic changes were observed. In both these cases no structural changes were observed radiographically and as a result a diagnosis of chronic pain with a psychogenic base could have mistakenly been made. As a result of this Hellsing concluded that clinical and radiographic guidelines for TMJ diagnosis may be insufficient and that direct viewing may be
performed to elicit information not achievable by other techniques.

The case presentation by Murakami et al (1984) was one of suppurative arthritis of the TMJ which was diagnosed by arthroscopy. Direct drainage and irrigation of the joint cavities with antibiotic solution, followed by opening exercises, produced an excellent result.

Holmlund and Hellsing (1985), comparing two arthroscopes, carried out a series of TMJ arthroscopic examinations on 54 cadavers. They found a 100% diagnostic accuracy and their findings were in close agreement with observations made during later dissection of the specimens. They found that the selected puncture site for arthroscopy was about 12 mm anterior to the tragus (range 0-17 mm) and 2 mm below the tragal canthus line (range 0-6 mm). The average depth of puncture was 27 mm (range 18-33 mm). They found that the anterior part of the upper joint space and the wall close to the puncture site was difficult to examine but all other areas could be clearly visualized.

Although an invasive technique with possible complications, when used skilfully arthroscopy is relatively atraumatic. It should not be ignored as a possible aid in diagnosing conditions of the TMJ.
Chapter 6

COMPUTERISED TOMOGRAPHIC IMAGING

An increasing number of oral surgeons and other members of the dental profession have recently been looking at and assessing the more modern and up to date imaging techniques. Perhaps the most successful technique for imaging the TMJ to date has been computerised tomography (CT). This is proving to be far superior to conventional radiography.

Work on the theory of x-ray transmission was started in London in the mid 1960s, by Dr. Godfrey Hounsfield. It led to the first computed tomography system at the Atkinson Morley Hospital in 1971. For his work in this field Hounsfield received the Nobel Prize for Medicine in 1979 (Trapnell 1985).

The initial use for the first generation of scanners was in the study of the brain and skull through to its base. Computerised axial tomography (CAT) scanning had a profound effect upon neuroradiological diagnosis. Intracranial lesions were accurately displayed and the critically ill patients could be examined without fear of aggravating their condition. This very significantly reduced the invasive type of investigation such as occurred in pneumoencephalography (Ambrose 1973).

The ultimate progression was to produce scanners which could view the whole body. The newer generations
of scanners have now made it possible to view accurately the facial structures in greater detail in either axial, coronal or even direct sagittal section (Manzione and Katzberg 1984) with the ability to reconstruct electronically a slice along a pre-set plane (Miller et al 1985). Computed tomography is now playing a much greater part in the treatment of patients in maxillofacial surgery (Ames et al 1980, North and Rice 1981, Frame and Wake 1981 and 1982, Fujii et al 1981 and 1983).

Basic principles

Since the appearance of the first generation scanners capable of viewing only the calvarium, modifications, development and innovation have proceeded rapidly increasing the capabilities of these machines both in their clinical application and their use in diagnosis. However, the basic principles of scanning have remained the same.

The unit consists of a motorised couch on which the patient lies, which moves in and out of an aperture centred in the scanning gantry (Fig. 6-1). Within the gantry is an x-ray source and collimators mounted on a mobile frame. These are precisely fixed and aligned to a block of extremely sensitive crystal radiation detectors. The part of the patient being examined is interposed between the x-ray source and the detectors. The mobile frame is capable of making exact linear movements
Fig. 6-1. GE 9800 CT machine showing motorized couch and aperture in scanning gantry.
so enabling a series of tightly collimated x-ray beams to pass across an axial section of the patient (Fig. 6.2). This slice ranges from 13 mm wide in the original machines down to 1.5 mm in the latest generation of scanners. This is known as the scan-slice thickness. The x-ray beam passing through the patient is monitored by the radiation detectors. The resultant profile is recorded and stored for processing either in the computer or on disc. This raw data consists of attenuation coefficient values calculated for very small volumes of tissue, not a value for the whole tissue mass. A single scan produces a two dimensional array of attenuation coefficient values measured in Hounsfield units (H) (Hounsfield 1973).

A series of scans produces a three dimensional matrix of such values. The computer then translates the attenuation coefficient values into grey levels which are given CT numbers or values. Thus a picture is produced with bone having a CT number of the order 800 - 900 H and being bright white on the monitor screen. The soft tissues such as connective tissue, muscle, tendon and cartilage have varying shades of grey with CT numbers ranging between -50 to +250 H, fat being the darkest on the screen, apart from fluid and space, with a CT number of less than -50 H units. The array of the data, now in the form of small points known as pixels which
Fig. 6-2. Simplified diagram explaining the scan sequence during an examination of the head, modified from Hounsfield (1973). Following completion of this sequence the couch moves the required distance to give the slice thickness and the process is repeated until completion of the examination.
are varying shades of grey, is projected onto the screen of a television monitor (Fig. 6-3). The effect is to produce a computed picture which represents an anatomical cross section through which the x-ray beams have passed during the scan. The actual shades of grey that make up the image are assigned by the computer and are not directly representative of the tissues.

In order to obtain these composite pictures a series of exposures takes place as the radiation source and receptors in the frame rotate around the patient. During scanning the mobile frame moves through an arc of 180 degrees stopping every 2 - 10 degrees, depending upon the machine, to irradiate the patient who, as stated previously, is situated in the centre of the gantry. A complete rotation of a single scan now takes between 1.3 - 9 seconds to complete. After completion of the first scan the patient is moved on the motorised couch so that the layer adjacent can be scanned.

These scans can be carried out either contiguously or with an overlap depending on the investigation required. The process is repeated to obtain a series of sections until the area under investigation is covered. The number of slices required for the facial region varies depending upon the thickness of the slice and the area under examination. It has been found by personal experience using the GE 9800 machine with 1.5 mm slices
Fig. 6-3. Television monitor and control panel of a GE 9800 CT machine.

Fig. 6-4a. Patient lying positioned for a normal axial scan.
Fig. 6-4b. Standard scout view for the axial scan.

Fig. 6-4c. Standard 1.5 mm axial scan through the TMJs.
contiguously, between 18 - 25 slices are required to image the craniomandibular articulation depending whether the mouth is open or closed for the examination. Normally axial views are taken with the patient lying on his back with the orbitomeatal line parallel to the plane of the scan (Fig.6-4a/b/c). It is also possible to take direct coronal and sagittal scans provided the patient can tolerate the positioning of the head. For the coronal scan the patient lies either prone or supine with the head tilted backward, chin extended forward so that the plane of scan is between 60 and 90 degrees to the orbitomeatal line (Fig.6-5a/b/c). For the sagittal scan the patient lies on his side with his head either hanging downward just forward of his shoulder or with his head lifted up in close apposition to his upper shoulder. The plane of scan is perpendicular to the orbitomeatal line at an angle of about 80 degrees to the vertical. In order to complete the correct positioning the gantry is then tilted by 20 degrees (Fig. 6-6a/b/c). However, because of the data obtained, should the initial axial scan not be in the optimal plane for demonstration of the suspected pathosis then sections in alternative planes can be produced from the original data by a process known as reformation.
Fig. 6-5a. Patient positioned for a direct coronal scan.

Fig. 6-5b. Scout view for direct coronal scan.
Fig. 6-5c. Image produced by a direct coronal scan.

Fig. 6-6a. Patient positioned for direct sagittal scan.
Fig. 6-6b. Scout view for direct sagittal scan.

Fig. 6-6c. Direct sagittal view before being flipped for easier viewing.
Reformation

Reconstructed images can be obtained from the three-dimensional matrix of attenuation produced from a series of axial scans stacked one upon the other. Any plane of reconstruction requires at least one line of display data from each axial scan. The horizontal plane of the reconstruction is always identical to the plane in which the original axial scans were obtained. There are four planes commonly used for reconstruction:

1. coronal
2. sagittal
3. paraxial
4. oblique.

The coronal plane separates the body into anterior and posterior parts and is at right angles to the axial scan from which it is taken and uses data from left to right of the scan (Fig. 6-7).

The sagittal plane separates the body into right and left parts and is at right angles to the axial scan. Reconstructions in this plane use data from the anterior to the posterior aspects of the scan (Fig. 6-8).

The paraxial plane is at right angles to the axial scan but at an oblique angle to the coronal and sagittal planes. Any degree of angulation can be used (Fig. 6-9a/b).
Fig. 6-7. Coronal reformation from an axial scan showing both joints.

Fig. 6-8. Sagittal reformation of fractured left condyle.
Fig. 6-9a. Paraxial reformation from an axial scan, parallel to transverse axis of right condyle.

Fig. 6-9b. Paraxial reformation from axial scan taken at right angles to the transverse condylar axis.
The oblique plane is any plane which is not at right angles to the axial scans and can be selected from any of the other planes of reconstruction which are at right angles to the axial scan (coronal, sagittal or paraxial). The data is obtained from each pixel of the axial scans not directly below each other.

The most common reformations used are the coronal and sagittal because they relate directly to conventional anatomical planes, whereas paraxial and oblique planes are less easy to relate to the conventional planes of anatomy. The voxels (A voxel = pixel x scan thickness) are not aligned in columns or rows so therefore the definition or clarity is reduced (Readman 1984).

It must be noted that at present time the reconstructions in other planes do not have the same resolution as the planes parallel to the scan slice. Reconstructions should, ideally, be built up from a large number of contiguous slices. However it is found in practice that slices have a finite thickness which may be several millimetres and are not always contiguous. This means that the quality of the reconstruction is determined by the thickness of the slice and the interval between slices. Therefore thin slices and shorter intervals improve the image quality. The slice thickness will also affect the quality of the direct scans as there is a trade off between the higher resolution of
the thin slices and the improved contrast-to-noise ratio of the thicker slices. The slice thickness must be weighed against other factors such as x-ray exposure and convolution filter to obtain the most favourable balance for each clinical application. The optimum balance for application to the head and neck region is considered to be a slice thickness of 1.5 mm, an exposure of 480 mAs, a field of view of 24 cm and a scan time of 9.6 secs (Zonneveld and Vijverberg 1984, Readman 1984).

For optimum results it is therefore necessary to maximise patient orientation prior to commencement of scanning. The problem of potential movement by the patient during the relatively long period (9 seconds/slice on a GE 9800) can be greatly reduced by careful positioning of the patient and the use of suitable head restraints (Fig. 6-10). The great danger with direct coronal scans is of the patient swallowing and thus moving his head position. Should this happen the whole programme has to be repeated, similarly during the direct sagittal scans of the TMJ with the mouth open (Fig. 6-11).

Reformations used for visualizing the TMJ

Work carried out in the CT department of the Westmead Centre by the author and Dr. John Read (Staff radiologist) lead to the development of a protocol for reformations from axial scans (Appendix chapter 6).
Fig. 6-10. Patient's head resting in padded holder, held by velcro straps to help prevent movement.

Fig. 6-11. Paraxial reformation distorted (arrows) by movement of patient during normal axial scan.
The work was carried out using a GE 9800 CT scanner on 3 dry skulls and 10 patients (to date) with a variety of joint problems. It was found that a more accurate picture of the joint could be built up using paraxial planes than the recommended coronal and sagittal views described in the machine's operating manual.

Corrected axis tomography has been used as a technique for producing more diagnostically accurate lateral tomograms of the TMJ (see chapter 4). Working on this principle the author carried out a series of paraxial reformations along the transverse axis of the condyles as determined from the axial scans of the patients. The lateral projections of the condyles were produced by carrying out paraxial reformations taken at right angles to the transverse axis of the condyles and not along the anatomical sagittal plane. It was found that in all cases a more accurate picture of the joint and its pathosis could be built up and that any measurements of the bony parts of the joint were accurate to within one pixel (0.35 mm) (Table 1).

Paraxial reformations parallel or at right angles to the transverse axis of the condyle give a complete picture of the joint particularly of the space and meniscus as they cut these structures at right angles. This reduces the averaging of the Hounsfield numbers for
these particular areas and gives a more accurate attenuation value for the soft tissues involved. The true coronal and sagittal planes cut through the joints at oblique angles and in the case of the TMJs do not follow the recognised anatomical configurations of the joint.

In order to select the plane for reconstruction, the axial scan with the TMJs at maximum size is chosen from the series of axial scans. This individual scan is projected upon the monitor screen. It is then enlarged and the required plane of reformation is selected using parallel cursor lines to outline the area to be reconstructed. Once the parameters have been set the required slice thickness is fed into the computer and reformation of the appropriate number of slices is carried out automatically.

It was found that the ideal slice thickness for both the normal axial scan and the reformations was 1.5 mm contiguously which gave a minimum of seven slices in each of the paraxial planes of reconstruction. The TMJ is a small structure and is therefore ideally suited for this technique as the patient can usually remain still during the scan period.

The main disadvantage for this technique was found to be the time required to complete the reformations, up to two hours depending upon the clinician's requirements. This situation is even more critical if a second
computer console is not available as it will necessitate reformations to be stopped during normal scanning. Alternatively it has to be carried out between patients which in a busy CT department is not always possible. This leads to the added problem of storage space on the working discs. However with the continued improvement of computer software and programming these problems should be minimized.

Advantages of CT

CT overcomes the many disadvantages of the conventional radiographic views, the main one being that superimposition does not occur and all tissues irradiated can be displayed. With the fine collimation beam scatter is kept to a minimum and the operator can select the position of the scan so as to avoid the major sensitive organs and tissues. When making multiple scans it has been found that the radiation exposure level at any point of the surface does not rise significantly above that for a single scan. The radiation exposure for an examination which covers both TMJs has been estimated at between 2-5 rads (Maué-Dickson et al 1979, McCullough and Payne 1978, Trefler and Haughton 1981).

Disadvantages of CT

Like the other radiographic techniques there is the difficulty in visualising soft tissue and of assessing three dimensional structures and their relationships
when the information is on a two dimensional display
device such as a TV monitor screen or film. This is
overcome to a certain extent by having a section by
section series and the use of reformation.

The presence of metallic objects within the area to
be examined will cause considerable 'scatter' and the
appearance of linear artifacts will spoil the image
quality so much so that they can be confused with patho-
logical lesions such as fracture lines. Coronal and
sagittal scans are particularly vulnerable to this prob-
lem as the plane of the scan can pass through the molar
region where amalgam restorations may be present. This
can be reduced in the coronal scan by moving the chin in
or out so that the orbitomeatal base line is no longer
horizontal. Other metallic objects which may cause dis-
tortion and artifacts within the slice are metal bone
plates, large transosseous wires and metallic foreign
bodies (Fig.6-13).

As with conventional tomography certain pathologi-
cal information may be missed if the plane of the sec-
tions is inappropriate and even when such information
is present it could be missed by the clinician who may
be unfamiliar with the projection he is viewing. The
easiest projection obtainable in CT is the axial view
but this produces a view with which most clinicians are
unfamiliar. Suggestions have been put forward recently
by various workers as to a technique which will allow
direct sagittal sections to be taken (Manzione et al
1983 and 1984, Sartoris et al 1984). However the design
of current CT machines does not lend itself to modifica-
tion. Even in the up to date machines that have gantry
tilt, direct sagittal views are difficult to obtain
because of patient positioning, the patient having to
lie on his side with head tilted awkwardly either
upward or downward (Fig. 6-7a).

A very recent article by Manco and Messing (1986)
working on evaluation of splint therapy using direct
sagittal CT describes a technique of patient placement
which is more comfortable and less demanding for the
patient physically. They studied 887 TMJs of 445 pa-
tients referred to them with anterior displaced discs, of
whom 202 were receiving splint therapy.

Examination of the joints was carried out in both
the open and closed positions using a 'statistics cir-
cle' which is a soft tissue imaging technique similar to
'blink mode'. Direct sagittal scans were performed using
a Siemens Somatom DR2 scanner, and the following techni-
que. A trolley was placed parallel to the CT couch on
the side of the TMJ to be examined. A patient backboard
was then placed diagonally across both the couch and
trolley with one end entering the aperture of the gantry
but not crossing the plane of irradiation. The backboard
was attached to the motorized couch of the scanner. To position for the above technique the patient lies prone on the backboard, shoulders at the top edge, his arm on the side to be examined extended through the aperture of the gantry, the other arm at his side. The head is tilted away from the extended arm and positioned parallel to the plane of scan using the beam localizer lights. The patient’s eye is not placed in the plane of irradiation (Fig. 6-12). The foot of the backboard is raised from the trolley so that the board and patient only are resting upon the motorized couch. This will allow the patient to be moved sequentially through the gantry as in a normal CT examination. The scan sequence is from the lateral to the medial aspect of the joint.

The joints were studied separately with a scan slice thickness of 2 mm which gave approximately five scans per joint. A mouth prop was not used unless pre-click scans were required. The radiation skin dose was estimated to be 2.5 rads per scan and a maximum dose of 5.9 rads per patient with a scan time for bilateral joints of approximately 25 mins.

Manco and Messing concluded that direct sagittal CT was an ideal imaging modality for splint evaluation as it served to confirm or disprove the clinical diagnosis. They felt that this technique was superior and more acceptable to the patients than arthrography which had
Fig. 6-12. Position of the patient during direct sagittal scanning, modified from Manco and Messing.
been previously described by Manzione et al (1984) as a method for studying disc splitting.

Soft tissue imaging

The range of Hounsfield units of attenuation representing different soft tissues within the joint overlap, making it difficult to distinguish between them. However a number of clinicians have experimented with CT to find a way of determining the location of the meniscus within the joint (Helms et al 1982 and 1983, Manzione et al 1984, Fjellstroem and Olofsson 1985). The joint meniscus is usually displaced in an anteromedial direction as a result of the pull from its attachment to the lateral pterygoid muscle. The meniscus having a cartilagenous content will have a higher Hounsfield unit than the muscle tissue and surrounding fat which lies between the superior and inferior bellies of the lateral pterygoid muscle. Theoretically this could be detected in two ways because of the difference of CT numbers - either by direct inspection or by the CT 'blink mode' (Helms 1983). The 'blink mode', or identification mode as it is known on some machines, for example GE 9800, allows the operator to define a range of CT numbers. These are displayed in a scan section by spots of increased brightness which rapidly 'blink' on and off, giving the appearance of a white spot on the screen within the tissues to be identified (Fig.6-14).
Fig. 6-13. Artifacts caused by amalgam fillings in the molar region on a direct coronal scan.

Fig. 6-14. Direct sagittal scan in 'blink mode'.
Early attempts to calculate the various structures of the TMJ using CT had limited but encouraging success. These were aided by the use of contrast medium injected into the lower joint space (Katzberg et al 1981). It was, however, considered better to evaluate the meniscus of the TMJ without contrast medium and thus eliminate the need for an invasive technique. The size of the meniscus is not considered a limiting factor as the modern scanner can resolve structures as small as \( \phi 0.25 \text{ mm} \) (Merritt et al 1984).

Helms et al (1983) compared CT scanning of the TMJ with arthrographic and operative findings. In patients with clicking joints it was found necessary to observe the joints with the patient's mouth open to a point just prior to the click occurring. The information obtained from the scans was studied in parasagittal reformation through both condyles. At least four reformation through the condyle of each joint were obtained, one through the lateral pole, one centrally and two medially as most displaced menisci are pulled anteromedially. The 'blink mode' was then used to determine any differences in tissue density anterior to the condyle. If no difference in density was detected the CT was considered normal. It was found using the 'blink mode' that the anteriorly displaced meniscus could be identified as the surrounding tissue was of a lower density being muscle.
and fat. In their research Helms et al (1983) studied several patients arthrographically and found the meniscus displaced which was later confirmed during surgery in all cases. Likewise with the patients studied by CT alone displaced menisci were again confirmed by surgery. It was also possible to study the contralateral joints simultaneously using CT for evaluation. The symptomless joints were interpreted as normal whereas patients with bilateral symptoms were found to have abnormal joints. It was not possible to obtain arthrographic or surgical confirmation that the symptomless joints were normal so accuracy of the CT scans in these cases can only be speculative. However, the indications are that evaluations of soft tissue structures within the TMJ are possible and that the advantage of CT over arthrography is that it is non-invasive and as a result there is a reduction in the morbidity. It is also possible to examine both joints simultaneously with less hazardous radiation exposure to the patient than occurs during a combination of plane radiography and arthrotomography. All tissues are visualized during CT whereas a separate assessment of the bony structures is required before arthrography is performed. Like multidirectional tomography CT scanning can show a variety of joint manifestations such as joint space narrowing, osteophytosis and other signs of degenerative joint diseases. CT
can show the whole of the joint whereas hypocycloidal tomography only shows the central 2/3 rds. of the joint clearly (Eckerdal 1973). Westesson (1983) has suggested that double contrast arthrography be preceded by transcranial radiography to outline the lateral poles of the condyle under examination.

Radiation dosages

McCullough and Payne (1978) experimenting on radiation dosage for a variety of CT machines found that the dose values in CT scanning depended upon four factors:

1. single-scan image quality
2. detection efficiency
3. details of the scan motion
4. multiple-scan geometry.

The lower limits of patient dosage are directly related to the requirements for single-scan slice image quality, that is, noise, axial resolution and slice thickness. They found that improvements in image quality such as thinner slices, increased axial resolution (smaller pixels) or increased contrast resolution (reduced scan noise) usually required an increase in patient dosage. In their studies they found patient dosage from clinically used CT scanning techniques to range from 2 - 5 rads for five or more slices per study. They could not determine whether a different generation of scanner produced a higher quality image with a reduced dosage to the patient.
Scatter radiation to the patient appeared small and could be reduced by the use of lead aprons (0.25 mm lead equivalent) placed under and over the patient. Dosages to the ovaries during head scans were 0.066 to 0.022 mrad per scan and to the eyes about 120 mrad at 140 kVp, 20 mA, single scan, at normal scan time. It was also estimated that the dosage at the isocentre of the patient was reduced by between 30-60% of the maximum surface dosage. The scatter dosage at one metre from the scan slice was estimated to be about 1-2 mrad.

A comparative study between conventional tomographs and computed tomography was carried out on a phantom head and an adult cadaver head to determine:

1. relative radiation dosage to the patient during single and multiple tomograms utilizing both modalities

2. subjective and objective image quality between the different systems.

The results were published by Maue-Dickson et al in 1979. In their research they utilized one conventional tomography unit and four CT units. The dosimetry and subjective image quality was collected on the cadaver head while the objective image data was obtained on a specially designed water phantom head.

Radiation exposure was measured on the cadaver and phantom heads during single and multiple tomograms by
each of the five units using lithium fluoride thermoluminescent dosimeters previously calibrated with a Cobalt 60 radiation source. The dosimeters were placed in two locations on the cadaver head:

1. on or under the eyelids
2. a short distance from the x-ray beam.

On the phantom head the dosimeters were placed above or below the head in direct line with the centre beam.

For subjective image quality the cadaver head was scanned using diagnostic settings for the various units. The CT units used either 10 mm or 13 mm scan slices whereas the conventional tomographic machine used 1 mm sections in the trispiral mode.

For objective image quality the phantom head was imaged on each of the CT units and the images viewed by a panel of observers. However it was found that valid objective comparison of image quality between conventional and CT units was difficult because of system differences and was not possible with the equipment being used.

On evaluation of the study there was a major difference between conventional tomography and CT. In single sections radiation dosage levels for all units was comparable. In multiple scans with conventional tomography x-rays passed through all layers of the head irrespective of which layer was in focus and scatter was quite
considerable. By comparison, in the CT scan series there was only a small increase in radiation exposure and scatter was kept to an absolute minimum by adequate collimation and dosage was found not to increase significantly regardless of the number of sections scanned. Dosage ranged from 1.1 to 5.0 rads per single scan and was found in the CT units never to increase by more than a factor of 2 irrespective of the number of scans.

However with the conventional tomography the radiation dosage increased almost arithmetically with the number of sections, 40 rads for 70 slices. It was found that the image quality increased with increased radiation exposure up to a certain point where it plateaued. As a result of their work Maue-Dickson et al made the suggestion that by utilizing a combination of computed and conventional tomography reduction of the total exposure to the patient without loss of diagnostic value could be achieved. They felt CT clearly had an advantage over conventional scans when multiple sections were required because the dosage was noncumulative. They considered it feasible to detect small structures with CT, but not see them in detail, since the minimum scan slice was 5 mm thick. Such structures were then better visualized by conventional tomography with a slice thickness of 1 mm.

With the latest generation CT scanners it is now
possible to have a scan slice of 1 mm in series whereas most conventional tomography units have a section thickness of 1 mm but with separation of 2-3 mm between sections. As mentioned previously radiation is almost noncumulative with CT scanning, the maximum dosage being about 7.7 rads, irrespective of the number of slices and so a combination of the two techniques is now considered unnecessary.

Fjellstroem and Olofsson (1985) used Helms' work as a basis for their own research into examination of the joint meniscus using CT. They used a later generation scanner than Helms and so had greater success in the location of the anteriorly displaced meniscus. All workers in this field concluded that CT was a valuable diagnostic tool using selected cases. The main disadvantage in relation to CT is the financial consideration (a CT examination being twice the cost of an arthrogram unless done bilaterally). The CT could not determine perforation of the disc or show dynamic function of the meniscus as can be seen using arthrography in combination with video fluoroscopy.

Three dimensional image reconstruction.

Until recently medical imaging has always represented a three-dimensional object as a two-dimensional image, resulting in important diagnostic information being obscured and that which could be seen gave no indication
as to the depth of the lesion. This was initially over-
come by taking plane radiographs from different angles,
at least two at right angles. The position of the lesion
could then be visualized in relation to surrounding
anatomical structures. With the development of the dif-
ferent forms of tomography visualizing deeper lesions
improved. However it still left a great deal to be
desired because of the blurring effect and thus it was
impossible to produce an artifact free film. CT has now
provided us with a means of producing accurate two-
dimensional images without the associated blurring or
superimposition, so much so that it is possible to
identify accurately small structures (Nelson 1984).
However complete diagnosis requires more information so
making it necessary to obtain multiple slices with perhaps enhancement using a contrast agent such as an-
giografin injected intravenously. This then introduces
limitations because of increased radiation dosage and
invasion of contrast media into the tissues.

As previously mentioned it is possible to view the
TMJ in different planes, i.e. coronal, sagittal and
parasagittal, using the process of image reformation
from the original axial scan. This gives the clinician
the opportunity to view the joint in a three-dimensional
manner provided he is fully aware of the anatomical
relationships of the region involved. Although only a
modern concept, three-dimensional imaging as a means of diagnosing pathosis has been demonstrated. Herman and Coin (1980) demonstrated the use of three-dimensional imaging to diagnose and demonstrate the existence of long exostoses extending into the neural canals of the human spine. These exostoses were not visible on conventional radiographs because of the surrounding vertebral bone. It was noted that the bony contours were not necessarily obvious on the individual CT views but could be viewed in retrospect after being shown by three dimensional image reconstruction. Surgery was planned on the basis of the three dimensional images and confirmed the accuracy of the diagnosis (Herman and Coin 1980).

As a result of this, the possibility of using medical three dimensional imaging was considered as a method of improving evaluation of the meniscus of the TMJ. Roberts et al (1984) published a very good synopsis of the technical background of the technique for producing three dimensional images based on CT data. They indicated the three stages necessary in the collection, construction and display of three-dimensional images:

1. collection of the data using CT or other imaging systems (The other system indicated here would be Magnetic Resonance Imaging).

2. two-dimensional image processing which can be broken down into:
3. three-dimensional image processing which consists of:
   a) boundary surface detection
   b) surface shading
   c) image manipulation
   d) image dissection.

Using this technique Roberts and his co-workers used blocks of tissue approximately 5 cm anteroposteriorly by 5 cm mediolaterally and 8 cm caudocranially containing an intact TMJ taken from cadaver specimens. These were then enclosed in plastic boxes with the orientation marked to allow correct positioning in the CT scanner. A lateral radiograph was taken of each block to check the orientation. Two sets of images were taken using different window levels and ranges to demonstrate the effect of varying parameters. A series of these images were then used to produce a motion picture rotating around the horizontal and vertical axes through 360 degrees at an interval of 2 degrees.

The images produced showed small anatomical details of the bony parts of the area, for example the pterygoid-mandibular fossa and the insertion of the lateral pterygoid muscle into the subcondylar fossa. They found that
the spatial relationships of the condyle and the articular eminence could be visualized very clearly by rotation of the images. It was also found that the meniscus could be displayed but it was difficult to tell whether this was real or artifact due to the close proximity of the joint surfaces at the area in question. It has been found that increasing the joint space overcomes this problem (Christiansen and Thompson 1984).

In Roberts's studies the meniscus could clearly be seen in relation to the articular surface of the condyle, the glenoid fossa and the articular eminence. Whether such good results could be obtained if the meniscus were displaced would be debatable as the CT attenuation levels of the meniscus and where it merges with the fibres of the tendon of the lateral pterygoid muscle are almost identical, thus making it difficult to define any boundaries between them. However subsequent studies have indicated that it is possible (Thompson et al 1984).

Roberts et al felt that this technique had several potential applications in relation to clinical diagnosis and further research, namely:

1. Direct observation of hard and soft tissue without distortion due to invasive processes e.g. biopsy, dissection or arthrography. The ability to rotate the images, to add or to subtract parts permits more complicated relationships to be studied.
2. Contiguous structures can be separated and their hidden surfaces examined in detail.

3. The structures imaged are represented by a three dimensional matrix of CT attenuation values, the spatial coordinates of which are known, therefore accurate volumetric measurements can also be determined. This will allow tissue changes and remodelling of the bone to be monitored accurately without invasion.

These applications are particularly relevant to radiographic interpretation of pathology of the TMJs in which the clinician needs to assess the relative positions of the condyle, glenoid fossa and articular eminence, the position of meniscus and size of the joint space, and evidence of pathological bony changes such as remodelling.

Limitations related to this technique appear to be of a technical nature.

1. Dimensions of the smallest voxel are formed by the particular scanner used. For example in the GE 8800 machine the voxel size is $0.1875 \times 0.1875 \times 1.5$ mm. This defines the lower limit of the dimensions used. Therefore any structure of this order can be detected but anatomical detail cannot be defined. This will mean that the technique can only be applied to relatively large changes in morphology and structure.
2. Image distortion is thought to be due to characteristics of the algorithms used in section reconstruction and relationship to the specimen orientation and the orientation of the voxel matrix. These can possibly be considered as being negligible but are subject to experimental confirmation.

3. Orientation of the specimens is critical if they are thick (3 or 5 mm sections) or if they are used to determine structural relationships in which critical dimensions are less than a single section. This applies particularly to the TMJ if the plane of the section is parallel to that of the joint surface because it is possible to encompass both surfaces and the meniscus in the same section. An average attenuation value for bone, cartilage and fibrous tissue will be formed and no distinction between the structures can be made. This makes identification of the boundary surfaces for the purpose of separation very difficult and thus will lead to errors or produce surface artifacts. It is therefore better to use sections perpendicular to the joint surfaces. In TMJ examinations, the commonly used scan is an axial section. For three-dimensional imaging of the joint the parasagittal or paraxial scans are preferred. It is not always possible to obtain such sections because of the difficulty of position for the patient and of gantry design (Osborne and Anderson 1978, Manzione et al 1983). Direct coronal scans could be used
as they also cut the joint space at right angles and therefore are ideal for surface separation. Because of the head positioning required this becomes a problem for older patients. The cuts for a true coronal scan pass through the posterior part of the pituitary fossa and has also to be considered because of radiation dosage problems. This latter problem can be avoided by using a modified coronal section or sub-coronal view. This view is considered hard to interpret and it is difficult at the time of scanning to decide on the locations of the first and last scan-slice.

4. For general work the standard window levels for bone and soft tissue are acceptable but as greater accuracy is needed for detecting bony pathosis the window level is critical. At this time the actual window level for depicting the surface of the bone is unknown. However, gross remodelling could easily be detected with the resolution of present scanners. Improvements in this area and in that of computer software together with more research are required to detect the actual threshold level for changes in bone surface morphology.

Roberts et al (1984) concluded that three-dimensional imaging provided an excellent method for viewing the TMJ in vitro and there appeared to be no reason to believe that this could not be applied to in vivo situations. This method of imaging could be used to gather
accurate in vivo data, in particular of the articular surfaces which can only be obtained currently by the use of arthroscopy.

The joint meniscus had also been demonstrated in vitro and there is no reason to suppose that this could not occur in vivo. The anterior displaced disc can be demonstrated by using soft tissue scans and 'blink mode' (Christiansen 1984) but it was felt that the distinction between the lateral pterygoid tendon insertion into the meniscus and the meniscus itself was not accurate enough to permit imaging and separation of these structures. Further work in this field by Ram et al (1985) working on cadaver specimens concluded that three dimensional imaging and three dimensional movie evaluations produced a lower percentage of false negative diagnoses and that correct and accurate diagnosis by this method was more consistent.

Current work in the use of the computer aided design (CAD) and computer aided manufacturing techniques (CAM) linked with computed tomography is being used as a method of producing three-dimensional images (Johnson 1984).

The CAD/CAM system was first developed in the military aircraft manufacturing field to analyze aircraft fuselage surfaces giving engineers the ability to move aircraft structures about in order to ascertain their
aerodynamic capabilities. This system was then utilised by surgeons who found it easier to relate their surgery to three dimensional images rather than mentally stack CT scan-slices.

CAD/CAM has given the clinician the ability to make realistic surgical simulation using three dimensional images of their patient's anatomy. Work in this field in St. Louis, New York and Boston has revolutionized the surgical planning of total hip replacement surgery. The design of the prosthesis, its subsequent manufacture and surgical simulation have made things easier for both the surgeon and his patient alike. Custom-made orthopaedic implants have lead to improved fitting of the prostheses and a greatly reduced failure rate where standard manufactured implants have failed.

Professor Micheal W. Vannier of Washington University has pioneered the application of CAD/CAM to the planning of maxillofacial surgery. CAD is used to provide the surgeon with accurate measurements of distance from the surface and volume of lesions. To obtain these measurements from standard CT scans alone would be time consuming or even impossible. By using anatomical landmarks a three dimensionally reconstructed image is formed from CT views of the patient. Simulated surgery is performed using normal anatomy to form the corrected facial features. Measurements are then taken from the
images produced before and after simulated surgery and a plan is developed to obtain the desired results and the surgeon then follows the plan. No reference was made in the articles in relation to using this technique of imaging or planning for surgery on the TMJ, but because of its current uses in orthopaedic work and in maxillofacial reconstruction it seems reasonable to assume there is nothing to prevent its use in this area.
Chapter 6
Appendix

CT of the Temporomandibular Joint

Protocol

A working protocol was developed for use at the Westmead Centre by the author and Dr. John Read (staff radiologist) for CT examination of the TMJs designed to assist the clinician, radiologist and radiographer. This protocol will be subject to review to produce the most effective diagnostic views and further improve the technique.

Clinical problem

1. INTERNAL DERANGEMENTS: Study objective is to image the meniscus and assess the severity of displacement. (Note CT will not demonstrate perforations).

2. ASSESSMENT OF BONY STRUCTURES: Clinical problems include trauma, bony ankylosis and arthritis. Soft tissues are not the objective. (Note joint movement is better assessed clinically or fluoroscopically).

Scan area, plane, slices (collimation x spacing)

1. INTERNAL DERANGEMENT STUDIES: Perform at least 18 contiguous slices (non contrast) 1.5 x 1.5 mm AXIALS. -20° to OML (lower orbital margin to top edge EAM is the upper margin of the scan area).

The mouth is opened to a point just before the 'click' is experienced (or 18 - 20 mm if no clicking
Appendix cont.
sensation is reported) and the position is held by the
countdown closing on bilaterally placed bite blocks.

2. BONE STUDIES:

Axial scans:

1.5 x 1.5 mm NON CONTRAST.

-20° to OML (orbito mental line)

at least 18 contiguous slice from top
dge of EAM down. (external auditory meatus)

Direct coronal scans:

1.5 x 1.5 mm NON CONTRAST.

to cover full width of TMJs.

Note the mouth is kept closed throughout.

Technical information for GE 9800

Scout view: 120 kVp @ 40 - 100 mA

-100 -> 150

azimuth 90°

ref. OML

Matrix: 512

SFOV: Head (scout field of view)

DFOV: To fit the condyles (diagnostic field)

SCANS: Axials 1.5 x 1.5 mm

140 kVp 170 mA 3-4 secs

Algorithm (attenuation value window)

Internal derangements: for soft tissue only.

Bone studies: for bone only.
Appendix cont.

Special instructions

1. INTERNAL DERANGEMENT STUDIES: Print axial images as 2 on 1 format with DFOV 21 and bone window only. Select appropriate axial scan for reformation. Print 7 paraxial reformations through each mandibular condyle as per diagram below using 'BLINK MODE WINDOW' approx 75 H.U. and level 80 - 110 H.U. (radiologist or clinician to be present during printing of these views).

Paraxial reformations

Parallel to the short axis of the mandibular condyles.

Used in BOTH

i. internal derangement studies

ii. bone studies
Appendix cont.

Paraxial reformations
Parallel to long axis of
the mandibular condyles.
Used on bone studies only.

2. BONE STUDIES: Print axial and direct coronal images as a two on one format on bone window setting. Print 7 paraxial reformations parallel to the transverse diameters of each condyle and 7 paraxial reformations at right angles to the transverse axis and axial scans and parallel to the AP diameter of each condyle (see above diagrams) on bone windows only. With these reformations it is possible to measure each condyle at its widest point as shown below. This was carried out on the CT scans of the dry skull and found to be accurate to one pixel (Table 1). It is, therefore, possible to produce pre-surgical dimensions of the joint thus enabling the surgeon to accurately prepare for the operation.
Appendix cont.

Maximum transverse diameter

AXIAL SCAN

MID-RIGHT CONDYLE.

MIDLINE PARAXIAL REFORM OF TMJ.

Under normal circumstances paraxial reformations of the joint will be performed, unless otherwise requested, along the transverse axes of the condyles and at right angles to them. These reformations give a truer picture of the TMJ space and its relationship to the condylar head. All reformations will be automatically performed according to the above protocol. If any variation of plane is required it should be discussed with the radiographer and the request form completed accordingly.

TABLE 1.

<table>
<thead>
<tr>
<th>Skull</th>
<th>Transverse axis CT</th>
<th>Actual cm</th>
<th>AP axis CT</th>
<th>Actual cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.86</td>
<td>1.90</td>
<td>0.95</td>
<td>0.95</td>
</tr>
<tr>
<td>2</td>
<td>2.00</td>
<td>2.10</td>
<td>1.20</td>
<td>1.09</td>
</tr>
<tr>
<td>3</td>
<td>1.83</td>
<td>1.95</td>
<td>1.05</td>
<td>0.96</td>
</tr>
</tbody>
</table>

155
Chapter 7

NEW IMAGING TECHNIQUES I

General

As mentioned earlier a range of imaging procedures have been developed over the last 2 - 3 decades which have corresponded to the development of the micro-chip and computer. The micro-computer is the main stay upon which these techniques work. Along with this technical expansion the development of new materials has made it possible to put into practice theories that have been known for many years but handicapped by the lack of necessary equipment.

Some of the imaging methods to be discussed are not available in Australia at present and publications in relation to their uses, particularly related to the TMJ, are not freely available. However, the author would like to acknowledge the assistance given to him by some of the pioneer workers in these fields. The areas to be covered in chapters seven, eight and nine are as follows, and will be discussed in the following order:

1. nuclear magnetic resonance imaging - chapter 7
2. nuclear medicine - chapter 8
3. ultrasound - chapter 9
4. thermal imaging - chapter 9.

Note: The resume of the basic principles of Magnetic Resonance Imaging (MRI) in this treatise was developed from selected abstracts from Nuclear Magnetic Resonance Imaging. S.W. Young 1984.
NUCLEAR MAGNETIC RESONANCE IMAGING

Basic principles

The principles of Nuclear Magnetic Resonance (NMR) were first described by Block and Purcell in 1946 for which they received the Nobel prize in 1952. Medical NMR imaging is a way of making pictures of sections of the body that appear somewhat similar to CT scans and has been used in several countries around the world since 1973. Presently there are some 150 units in use.

Until recently reports on its use have been limited but more and more articles are now appearing in a wide variety of journals. The current feeling is that it is superior to other imaging modalities, even CT scanning in certain areas. For example, NMR scans are free from artifacts produced on CT scans by dense bone and metallic objects.

The information density in the NMR signal is greater than that available in an imaging modality like CT because it is based on four separate components:

1. density of the nuclear species, usually hydrogen which is composed of a single proton - 'H'
2. The two relaxation times - T1
3. - T2
4. motion or flow.

CT radiographic images are however based mainly on one tissue characteristic - electron density.
Another important aspect of NMR imaging that is encouraging its clinical use is that it does not use any ionizing radiation and is therefore free from the hazards of x-ray damage to vital tissue (Young 1984).

The phenomenon of NMR relies on the properties of certain atomic nuclei and the way in which they behave when placed in a strong magnetic field. The imaging of these dominant atomic nuclei is directly related to the single protons within the water and fat of the body, that is, the hydrogen atom. There are other nuclei such as phosphorus 31 and carbon 13 but they are masked by the sheer numbers of the hydrogen nuclei.

When a strong magnetic field is applied to a magnetic nucleus the latter behaves rather like a child's top - if a top is spun its axis moves around an imaginary vertical axis to the ground, in the same way the magnetic moment of the magnetic nucleus is said to 'precess' around the direction of the applied magnetic field. If the strength of the magnetic field is increased the rate at which the nucleus precesses increases, and conversely if the magnetic field is reduced the rate at which the nucleus precesses is also reduced (Fig. 7-1).

In practice NMR is not done on one nucleus but on many nuclei all of which will have different angles of precession at any given instance. Some will point along the direction of the applied magnetic field and the
Fig. 7-1. As a child’s top (T) spins around its axis (A) it also wobbles around an imaginary axis (G) this being the applied force of the gravitational field. Likewise the proton (P) as it spins on its own axis (A) will rotate around the axis of the magnetic force of the applied magnetism (M).
remainder will point in the opposite direction. There is a slight excess of individually aligned nuclei, the sum of their magnetic moments producing a magnetisation (M) of the sample, or in a medical case, of the tissues of the patient. Thus we are left with a small magnetisation which is rather weak. NMR is intrinsically a rather insensitive technique.

The signals from NMR need to be generated in order to build up the images. This is done by applying a radio signal to the patient. The radio wave applied is such that it oscillates along a direction at right angles to the steady magnetic field. The result is that the magnetisation is tipped through any angle we choose — in fact the pulse of the radio wave is of an appropriate length to tip the magnetisation through 90 degrees and it is that component which then generates the signal. When the radio signal is removed the resultant magnetism has to return to its state of equilibrium along the static field and so it relaxes. The next stage is a process of relaxation and generation from a latent signal (Fig. 7-2a/b).

The component at right angles to the steady field gradually decays becoming smaller and the component parallel to the steady field grows back to its original value. The decay of the transverse component of magnetisation is characterized by a time constant called T2 —
Fig. 7-2a. Radio wave (RW) tips the magnetic field through 90 degrees from the applied magnetic field (M).

Fig. 7-2b. Radio wave (RW) is stopped. The resultant magnetism has to return to a state of equilibrium. During this phase of relaxation $T_1$ grows back to its original value whilst $T_2$ decays, gradually becoming smaller.
and is known as the spin-spin relaxation time. T2, therefore, defines the decay of the transverse component of magnetism and the other relaxation time T1 defines the recovery of the magnetism along the direction of the steady field.

When generating the signal required to build up an NMR image the magnetic moment has to be tipped through an angle - typically through 90 degrees but this is not essential. We then have to acquire the signal that follows the stopping of the disturbing pulse. This signal is recorded and there is a small delay time in order for recovery to continue and each tissue will have its own relaxation time. These tissue relaxation times are intrinsic to the particular tissue and distinguish one tissue from another (Fig 7-3).

The relaxation then causes the transverse component to decay at the same time that the magnetism grows back along the steady field and while that is happening a signal is produced that also decays as the transverse component (T2) decays (Fig. 7-4). This acquired signal is recorded, digitised and fed into the computer giving the signal that produces the picture.

The signal is very weak and buried in random noise so it needs to go through a process known as averaging. This is achieved by repeating the process over and over
Fig. 7-3. When the radio pulse (RW) tips the magnetic field through 90 degrees a latent signal is generated which becomes the acquired signal (AS) when the RW pulse ceases. It is this acquired signal that produces the MRI picture.

Fig. 7-4. As the magnetism grows back along the static applied magnetic field the acquired signal generated decays as the transverse component T2 decays. The longer the T2 curve the stronger the NMR signal.
again then adding all the signals together until eventually the signal required grows and the signal to noise ratio increases. The next stage is known as 'Fourier transformation' - a mathematical process which converts the acquired signal into time domains. The signal as a function of time is changed into a spectrum signal as a function of frequency and will generally contain a number of peaks related to the different nuclei in the sample. In the case of proton imaging there is one peak that dominates over the others and that is the peak for water. In some tissues there will also be a peak for fat, but these are the only peaks used at present in NMR imaging. Other peaks are currently used in NMR spectroscopy.

If the whole process is taken a stage further and a radio pulse is given to tip the magnetisation through 180 degrees and then allowed to relax, then at any given time during the relaxation phase we can stop or sample the magnetisation. To stop this a second radio pulse is used which can tip the present residual magnetism back through 90 degrees. The signal produced is then proportional to the residual magnetization so in effect measuring how much the magnetization recovers during the interval between the two pulses. Following this there is a waiting period for the system to recover again. This stage of the recovery is dead time, that is - negative
lost time. The T1 sequence is rather an inefficient way of acquiring signals but there are ways and means of improving the efficiency. One of the reasons why the earlier workers in the field were not successful in producing some of the early T1 images was that they were too impatient and did not wait long enough for the system to recover before repeating the process. Consequently the images produced lost a great deal of their intrinsic contrast.

If the process is repeated for different recovery times then the signal will vary as a function of the recovery time. The short recovery time will produce a negative signal getting smaller and smaller, passing through zero then increasing in a positive sense. In order to measure the path of T1 it is necessary to fit the magnitude of those signals to an exponential function so that a graph of T1 is derived. This is all done on an imaging machine by the computer. All that is required is to specify the type of sequence on the keyboard for the T1 image and the computer essentially does this and gives T1 a value for each pixel representing the tissues being imaged.

NMR is inherently a three-dimensional system as the signals are obtained from the total volume of the subject that is enclosed within the transmitter and receiver coils. It is, therefore, necessary to reduce the
volume from which the signals come to defined points or planes. This can be done by one of two methods as follows:

1. Selective irradiation, which is done by using a specially adjusted radio frequency pulse that consists of a very narrow band of frequencies. The effect is that only those nuclei lying within a single plane and perpendicular to the direction of the plane will exhibit resonant frequencies corresponding to those of the initial radio pulse. This means that a thin isolated slice of the subject can be irradiated and the thickness or position of the plane can be altered by changing the width of the slice or by moving it contiguously electronically.

2. A second method devised at Nottingham University, UK is to impose an oscillating magnetic field in order to select a plane. This is achieved by reversing the plane of selection field gradient, the fulcrum of which is on one plane within the magnetic field. The signals from outside this plane are variable and do not have any effect on the intensity of the image.

The main disadvantages of whole volume methods are that a huge amount of data is produced. This requires a much longer time for collection, a computer that can handle the data and also have a large storage capacity. Two-dimensional images usually require less time to
collect but do not have the imaging capacity of the three-dimensional images. After collection the three-dimensional image can be dissected and reformed in any plane the clinician desires in exactly the same way as CT. The one distinct advantage that NMR has over CT in this area of imaging is that reformed images are equal in all dimensions and there is no loss of image quality similar to that which occurs with CT reformations. This means that two-dimensional images of any selected slice thickness can be reformed any time after the initial data has been obtained. With the three-dimensional data it has been found that different surfaces can be detected mathematically thus enabling the clinician to determine the size, shape and volume of the organs or pathological lesions.

As mentioned previously the signal to noise ratio of an NMR image can be improved by increasing the strength of the magnetic field. As the field strength increases so the rate of precession of the nuclei increases linearly, and a higher radio frequency pulse is required to tilt the nuclei. This in turn leads to a further problem in that the higher the frequency of the transmitted and emitted radio signals the more easily they are absorbed. Therefore in imaging the whole body, attenuation becomes a limiting factor when the frequency exceeds 15 megahertz and a field strength of 0.3 tesla.
Magnet design

There are currently two common designs of magnet:

1. the four-coil, air-core, ambient temperature
2. large bore, helium-cooled superconducting.

Systems of the conventional nonsuperconducting magnets are usually satisfactory for whole body imaging at field strengths less than 0.2 tesla, with a power consumption of 50 kilowatts. The superconducting magnets on the other hand are initially more expensive to install but have low operating costs. They generate stronger but more stable fields and can image nuclei other than hydrogen, such as phosphorus 31 which needs a field strength of 0.9 tesla at 15 megahertz. NMR imaging machines need a gradient coil system to create linear field gradients which need to be altered rapidly for plane selection (Pykett 1982, Young 1984, Naughton et al 1984, Thornton 1984).

The standard NMR units look very similar to CT units. The patients lie on a couch which moves in and out of the centre of a large gantry. This gantry is more bulky than those used in CT and carries the magnetic coils (Fig. 7-5).

Nuclear Magnetic Resonance (NMR) imaging is now becoming known as Magnetic Resonance Imaging (MRI). This is for two reasons. Firstly it is now generally recognised that the signal may not always be nuclear and
Fig. 7-5. GE 'SIGNA' a superconducting 1.5 tesla magnet showing magnet and patient couch.

Fig. 7-6. Parasagittal MRI, produced on a similar type of machine as illustrated above, through left TMJ. Arrow. image of condyle seen as cancellous bone (white) surrounded by cortex (black) A. anterior.
secondly, in the U.S.A., the word nuclear is thought to have misleading implications for the patient, particularly in the light of current feelings related to the use of radioactive products (Thornton 1984). From this point, in this dissertation, NMR will be referred to as MRI in relation to medical imaging.

Clinical application

Systematic data published since the early 1980s has indicated that MRI is a good technique for the detection of pathological lesions in various parts of the body. Early clinical results suggested that it was particularly useful in locating necrotic tissue, ischaemia caused by mechanical obstruction to the blood supply, neoplastic and degenerative changes of various types. This is due to the fact that the soft tissue contrast is superior to that of the other various x-ray techniques and so detection of lesions is high (Pyket 1982).

Currently MRI is considered superior to other imaging modalities for specific areas. These include detection of multiple sclerosis, detection of oedema and haemorrhage, and characterization of intracranial tumours (Kelly et al 1985).

In the practice of medical imaging the cost and time factors need consideration when deciding which modality to use. Such things as involuntary movements of the patient and of the tissues being studied have to be
considered. The head, for example, is particularly easy to examine under MRI as it can be held still for the duration of the scan. The heart, however, beats continuously, and therefore needs a high speed imaging technique or a means by which the operator can 'gate' or synchronise the information collected over a series of cardiac cycles.

Technique modifications

The technique of enhancing images by the use of contrast media has long been known in radiology and is used with great effect to obtain further information not always visible on standard views. The contrast medium or dye can either be taken orally, by enema or by injection usually intravenously. Contrast injected intravenously is used to enhance soft tissue studies in CT. In like manner it is also possible to enhance MRI by the use of 'tracers' which can be administered orally or by injection. These tracers are not radiopaque substances but contain paramagnetic ions such as iron (Fe++), gadolinium (Gd++) and manganese (Mn++).

These ions contain unpaired electrons thus giving them a magnetic moment. They will, therefore, tend to align themselves in the static field of an MRI system and increase the local magnetic field which in turn
modifies relaxation times of the NMR sensitive nuclei. The resulting changes of local image intensity would allow the paramagnetic ions to be mapped in the same way radioactive tracers are mapped in nuclear medicine.

In experimental work manganese chloride has been used intravenously in rabbits and dilute ferric chloride orally in human subjects. The main problem with these ions is that under normal conditions they are toxic when used intravenously in humans. In order to reduce this toxicity the substances have to be chelated, for example, iron to ethylenediaminetetraacetic acid and gadolinium to diethylenetriamine pentaacetic acid (Carr et al 1984).

MRI scanners are large and costly to run and ideally used for imaging large volumes. However, the medical field has now looked into the use of surface coils which were originally used in NMR spectroscopy. Depending on the clinical application two types of scanner can be used:

1. whole body scanners
2. small part scanners, with specialized shaped ones being produced for specific areas for example spinal column and female breast (Braun and McCarthy 1985, Boskamp 1984 and 1985).
Surface coils

In MRI the use of surface coils rather than whole body coils has been found to produce improved signal to noise ratio. This improvement enables a higher spatial resolution of up to 0.3mm to be obtained (Boskamp 1984).

The main disadvantage of surface coils is that they only cover a small area, depth of resolution being equal to the radius of the coil, and so have a limited field of view. It is also necessary to have a second coil to produce excitation. This second coil must be capable of producing a homogeneous radio frequency because exact 90 and 180 degree pulses are required over the whole scan. The homogeneity of the surface coil radio frequency field is not as exact so this allows the coil to be adapted to the area being examined.

Having two coils working on the same resonance frequency leads to a problem of coupling. During excitation a large current can be developed in the surface coil which distorts the radio frequency magnetic field. This problem has now been overcome by either reducing the mutual inductance or by maximizing the impedance of the surface coil during excitation. Boskamp solved the problem by using an electronic detuning method. He has developed a series of coils for use on different parts of the body, such as breast, eye, ear, scrotum, knee and elbow (Boskamp 1985) (Figs. 7-7, 7-8).
Fig. 7-7. Sagittal MRI of left TMJ produced using saddle type surface coil.

Fig. 7-8. Sagittal MRI of left TMJ showing 1. cortex of articular eminence 2. cancellous part of condyle surrounded by cortex (arrow) 3. articular disc 4. lateral pterygoid muscle 5. external auditory meatus.
In his work he uses only the surface coil as receiver and a saddle coil for excitation, with the surface coil being adapted to the anatomical region to be examined. This close positioning increases sensitivity, optimizes the patient's comfort and reduces examination times, for example 4 minutes for an eye examination. The reduction in the time taken for the examination is essential as MRI is sensitive to patient movement which changes the image and would necessitate repeating the examination. Some authorities use surface coils for detection and full sized units for excitation (Hayes 1984).

Temporomandibular joint

Currently there is very little written in the literature concerning MRI of the TMJ. Helms et al (1984) using a superconductive magnet at a field strength of 0.35 tesla, with the radiofrequency coil acting as both transmitter and receiver, imaged three patients with known anteriorly displaced discs (previously diagnosed by arthrography). They obtained a series of parasagittal images of both TMJs with the mouth partly open to accentuate the displaced disc (Fig. 7-6).

It is known that dense cortical bone has very little free hydrogen and is therefore magnetically stable, producing no image and therefore a black area on the
film corresponding to the cortex of the condyle, articular eminence and petrous temporal bone. On the other hand, however, the cancellous bone contains marrow and fat both of which contain a large concentration of available hydrogen ions and therefore emits a strong signal which appears on the film in varying shades of grey to white.

Helms et al also found an area anterior to the condyle which produced a positive signal and concluded it to be the anteriorly displaced disc. Because of the large system they used there was lack of spatial resolution and so they were not able to see the meniscus in its normal position between the condyle and the glenoid fossa (Figs. 7-9, 7-10).

Helms and his co-workers concluded that MRI had the ability to image the joint and the chief advantage over CT and arthrography was that it was non-invasive and did not use ionising radiation. They also found that MRI had the ability to image in any direct plane and reconstruct in different planes without loss of definition. This latter was another distinct advantage over CT. The spatial resolution of MRI was inferior to CT and arthrography and like CT could not detect perforation of the meniscus or view the joint dynamically. MRI at this time was limited by the equipment used but Helms et al felt that it had the potential to replace CT in the diagnosis
Fig. 7-9. Parasagittal MRI through right condyle in a patient with pain and click. A. anterior C. condyle appears black as scan slice is through cortex L. lateral pterygoid muscle Arrow, area of high intensity which indicates anteriorly displaced disc.

Fig. 7-10. Parasagittal MRI of a normal right TMJ. A. anterior E. articular eminence C. condyle both E and C black due to low intensity of signal. No disc tissue can be seen.
of internal derangements and would probably replace arthrography.

Katzberg et al (1985) reported their findings of an experiment carried out by them on four patients, three of whom were asymptomatic and one with a displacement with reduction, diagnosed arthrographically. The examination was carried out using a 1.5 tesla unit to generate the signal and a 6.5 cm diameter surface coil in a wooden frame attached to the table in such a way that it could be pressed against the patient's temporal region. Initially 'fast scans' were used to orientate the area to be imaged, scan time being of the order of 52 seconds. Once established then 'slow scans' were carried out, these being of the order of 4 to 5 minutes.

Images of both right and left joints were taken on one patient and the right joint only on the other two asymptomatic patients. Images with the jaw closed and at maximum opening were taken on all patients. Bilateral views were taken on the symptomatic patient, the affected side being arthrographed some three weeks prior to the MRI examination. Sagittal images were taken and the meniscus could clearly be seen on all patients. Distinction between the lateral pterygoid, meniscus and the bilaminar zone could be identified. In the normal joints the meniscus appeared as having biconcave surfaces, a thick anterior part, a thin central part and a thick
posterior part which was immediately superior to the condyle in the normal closed position. It was also noted that with MRI distinction could be made between the posterior band and the bilaminar zone, the latter showing whiter than the grey of the disc on the film. This was probably due to the higher fat and water content of the bilaminar zone. The attachments of the lateral pterygoid, superior head into the disc and inferior head into the head of the condyle, could be distinguished. A description of the meniscus was as follows:

'The disc tissue appears to be very pliable as its superior surface actually assumes a convex configuration with the jaw closed. As the jaw opens, the body of the disc assumes a horizontal orientation and the biconcave configuration again becomes obvious'.

The lateral pterygoid fat pad appears as a bright structure anterior to the anterior band, similar to that as described by Manzione et al following their work on CT (Manzione et al 1984).

Correlation between the arthrogram and MRI was found to be accurate in relation to the joint with the anterior displacement, with the meniscus being found anterior to the head of the condyle when the jaw was in the closed position. On examination with the jaw open the meniscus resumed its normal position in relation to
the condyle, the latter being close to the apex of the articular eminence. It was noted, however, that the distinction between the posterior zone of the meniscus and the bilaminar zone was not as obvious as in patients with normal joints. This was thought to be related to abnormal changes, either histological and/or biochemical, taking place in the tissues.

Katzberg and his co-workers concluded that MRI had an imaging capability that was not previously available. It was noninvasive and had no radiation dangers. It promised the potential for tissue differentiation to such an extent as to enable assessment of the histological and biochemical changes known to occur in the joint with disc displacements. This in turn could allow pre-treatment diagnosis and enable the clinician to assess his treatment progress. This ability to observe such changes as remodelling and healing of the disc would improve the understanding of the conditions and help in deciding whether the treatment should continue to be conservative or whether surgery is needed.

They felt that MRI using surface coils provided an effective noninvasive means of clearly depicting the various tissues of the joint. It would allow more work to be carried out for visualization of the normal joint which was not previously possible because of the inherent problems of our current imaging modalities. MRI
of the TMJ was considered to be ideal for the diagnosis and treatment of such complex problems.

A larger survey recently reported in the literature was conducted by Harms et al (1985). In this a total of 115 TMJs in 67 patients were surveyed using a high resolution surface coil as receiver and a standard whole body MRI scanner as transmitter. Five millimetre sections with two-dimensional multisection were imaged. The findings were correlated with clinical and standard radiological examinations and surgical confirmation of the MRI results was made on 15 patients.

The anatomical structures of the joint were well delineated in relation to the signal they produced and even though cortical bone has little or no signal, bony abnormalities such as osteophytes could be seen because of their surrounding soft tissue which produces an intermediate signal with T1 weighted images. They found that T2 weighted images were useful in showing fluid and inflammatory changes due to the increase of mobile protons.

In some patients with joint symptoms it was possible to show a normal meniscus but it was noted that there was presence of inflammation in the retrodiscal area. The ability to detect the presence of fluid and/or inflammation in a symptomatic joint which has a normal meniscus can radically change the clinical management of the patient's problem.
In cases of anterior displacement without reduction the meniscus could be seen anterior to the condyle with the mouth open and closed, and confirmation of this was found during surgery. With anterior displacement with reduction the meniscus was seen anterior to the condyle in mouth closed views and in a normal relationship in mouth open views.

Harms et al reported the ability of MRI to detect other pathological changes such as perforations, fibrous adhesions and ankylosis of the joint all of which were confirmed surgically. It was also noted that post operative views could be taken to confirm the healing processes or otherwise. They found that surgical implants had no effect on the images but orthodontic appliances did produce severe artifacts. Fortunately when TMJ imaging under normal conditions is carried out such appliances are sufficiently remote from the joint so as not to affect the final images.

Harms and his co-workers concluded that the direct surface coil imaging could be obtained in any plane without loss of image quality. The soft tissue anatomy of the joint could be imaged without introduction of contrast media, as in arthrography, and could also detect the presence of inflammatory changes which to date has been impossible to achieve except by means of nuclear medicine techniques.
They found that the only limitation MRI had was being unable to carry out dynamic studies as in arthrofluoroscopy and that patient movement severely degraded the images. It was also possible to miss small perforations of the meniscus since separation of the meniscus fragments would not be seen. As the MRI technology improves so the section thickness will decrease and spatial resolution will improve.

Contraindications

Since MRI uses no form of ionizing radiation to produce good quality images it has been assumed that it is harmless. This can be an undesirable assumption. Researchers in the field of biomagnetic effects have looked at three specific areas related to MRI and they can be considered under the following headings:

1. the effects of static magnetic fields
2. the effects of rapidly switched or varying magnetic fields
3. the radiofrequency heating effect.

Of these, the effects of radiofrequency and ferromagnetic materials in magnetic fields have received the most attention.

Ferromagnetic materials can represent a hazard to both patient and operator when working around magnets of such strength. However, this can be kept to an absolute minimum if not eliminated completely by very careful
questioning of the patients and the use of metal detectors prior to scanning. To prevent apathy developing continual warning should be carried out for personnel working around scanners regarding the dangers of even the smallest ferromagnetic object on their person. Some concern over the heating effect in surgical clips during scanning was discussed by Davis et al (1981) and found to cause no problems. The main problem with the clips was that they could move during scanning and produce artifacts which could lead to possible misdiagnosis.

A study of metal surgical implants and other materials such as dental amalgam and 14 carat gold was carried out by New et al (1983). They found that a real danger existed with aneurysm clips. The torque forces applied during scanning were sufficient to cause movement of the clips and this could lead to haemorrhage.

The induced ferromagnetism was shown to be directly related to the composition of the alloys from which the clips were made - the higher the ferromagnetic properties of the material present the greater the production of artifacts. Dental amalgam and gold were found not to produce any artifacts and there was no heating effects due to eddy currents set up in the metal by the radio-frequency signal. However, stainless steel dentures and orthodontic appliances produced extensive artifacts in MRI scans of the facial region but there were no heating effects (New et al 1983, Harms et al 1985).
Perhaps the greatest problem for potential MRI patients is to those who have implanted pacemakers. They can be affected by both static and varying magnetic fields and contain enough ferromagnetic material to cause them to move within the patients chest. Patients with pacemakers should therefore be excluded from MRI examinations.

Dr. Gerald Wolf, president and medical director of the Pittsburg NMR Institute commented that concerns over MRI were purely theoretical and that radiofrequency heating was not a problem at the field strengths used. They had treated some 75,000 patients with MRI and had found no untoward side effects (Vinocur 1985).
Chapter 8

NEW IMAGING TECHNIQUES II

General

In the next two chapters we shall consider the application to the TMJ of three imaging techniques developed for and used very effectively in other areas of medicine and how they may help the clinician in his diagnosis and treatment of joint problems.

The use of these imaging modalities has expanded so much over the last decade that most hospitals have departments devoted solely to them, either individually or together but usually separate from the main x-ray departments even though the schools of radiography are responsible for training in these fields.

NUCLEAR MEDICINE

Basic principles

Nuclear medicine is the collective term for an area of medical science devoted to the use of radioactive isotopes which are tagged to pharmaceutical products injected into the body and allowed to collect in specific areas where they emit a radioactive signal which can then be monitored.

An isotope is defined as one or more forms of the same element having the same atomic number but each differs due to varying numbers of neutrons in the nucleus. There may be different radioactive forms of the
same element but they will all have the same chemical properties. The term radioisotope is usually reserved for the unstable forms of an element and all unstable forms of different elements are known as radionuclides. All nuclides with an atomic number greater than 82 are radioactive because they contain an unstable number of protons or neutrons. It is possible to produce artificially unstable nuclides from stable ones. Each radionuclide has its own decay pattern, the initial nuclide being known as the parent nuclide. The nuclide left after decay is the daughter nuclide, which if in turn unstable has its own decay pattern different from the parent.

A number of factors must be considered in relation to measurement and protection during the use of radioactive materials, such as type and energy of the radiation, its penetration power and half-life. The half-life (T1/2) can be considered in three ways:

1. radioactive or physical half-life
2. biological half-life
3. effective half-life.

The amount of radionuclide used is usually measured as a multiple of the Curie (Ci), which is, by definition the unit of radioactivity in which the number of disintegrations per second is $3.7 \times 10^{10}$. The amount of radionuclide used in the clinical field is measured in millicuries (mCi) or microcuries (uCi).

187
The biological half-life in relation to nuclear medicine is defined as the length of time required for one half of the dose of the substance to be excreted through the normal processes and should be identical for all isotopes of that substance.

The effective half-life is a combination of the physical and biological half-lives and must be known in order to calculate the dosage of the radiopharmaceutical. The effective half-life is the time taken for the radioactivity within the body to decay by half. As external detection is necessary it is important to know that the radionuclide is a gamma emitter and to study its gamma-spectrum. The ideal range of emissions should be between 90 and 500 Kev because lower energies would be absorbed by the tissues and higher energies would cause problems of collimation and scatter within the scintillation crystal.

The most common and readily available radionuclide used is technetium 99m. It is easily produced and chemically will link with a whole range of pharmaceuticals. It has ideal characteristics for dosimetry, physical half-life of 6 hours, and a short biological half-life. It is readily excreted by various routes depending upon how it is given. It is favourable from the radiation point of view as it is a pure gamma emitter, with a low energy level of 140 Kev making it easy to image as it does not require a great deal of lead shielding.
Nuclear medicine is synonymous with photography in that it uses a camera sensitive to gamma rays as opposed to light. This gamma camera is large because of the lead shielding to combat random and scattered radiation and weighs in the region of half a ton. The heart of the camera is a sodium iodide crystal about 1.5 cm thick and 35 cm diameter in front of which is a lead grid or collimator (Fig. 8-1). The property of the crystal is that it 'simulates' when struck by gamma rays, these simulations being picked by a series of photomultiplier tubes and converted into electrical impulses. The signal so produced is then modified electronically to produce a readable image on a photographic plate or on a cathode ray tube. There are basically two types of device used in imaging the distribution of radionuclide through the body, the moving rectilinear scanner and the scintillation camera (Fig. 8-2). The latest introduction to nuclear medicine is a gamma camera that revolves around the body. The information gained from the camera is fed into a computer to which it is linked and which can then produce axial, coronal or sagittal enhanced reformations of the radionuclide scan (Fig. 8-3a/b). This process is known as single photon emission computerized tomography (SPECT) and is considered to give greater sensitivity to the scans (Manning 1980).
Fig. 8-1. Diagrammatic representation of a Gamma camera, modified from Manning (1980).

Fig. 8-2. GE MaxiCamera 400 moving rectilinear scanner.
Fig. 8-3a. Example of axial reformed nuclear scans of a case exhibiting condylar hyperplasia of the right condyle. 'Hot spot' shows clearly in images 15 and 16.
Fig. 8-3b. Enlargement of image 16, fig. 8-3a, showing 'hot spot' on the computer reformed axial bone scan using process known as single photon emission computerized tomography (SPECT).
Clinical uses

There are a whole range of investigations for which radionuclide imaging can be used in the medical field; organ function, absorption studies, investigation of the rate of change in radioactivity, dilution studies, organ imaging and in-vitro testing. The most common use which can be related to the TMJ is that of bone scanning.

Alexander (1976) was one of the first to discuss the use of bone scanning in diagnosis of lesions in the maxillofacial region, the various indications being neoplastic disease, trauma, inflammation and metabolic diseases. Bone scanning is based on the use of organic phosphates labelled with a radionuclide. The most frequent to be used is technetium 99 methylene diphosphonate (99mTcMDP) which when injected intravenously circulates through the body, is metabolised by the bone cells within two hours and becomes incorporated into areas where new bone is being formed or resorbed whether normally or abnormally (Matterson et al 1985). For example in Paget's disease a bone scan (Fig. 8-4) will show bone activity long before any changes can be seen on a standard radiograph when the disease is already established.

Alexander also mentioned special uses for bone scanning in the maxillofacial region:

1. demonstration of myositis ossificans
2. assessment of bone grafting
3. evaluation of bone grafting and ridge augmentation

4. sinus disease

5. joint scanning.

At this point he did not elaborate on joint scanning as it was an article of a general nature.

Alexander et al (1979) cited two cases of bone scanning related to the TMJ. One was a chronic sclerosing osteomyelitis with a pathological fracture and pain in the right joint during treatment of the fracture and the second a patient with pain in the right TMJ, limited opening and a radiographic diagnosis of degenerative joint disease.

The article described the use of a specially constructed marker which when placed in the external auditory meatus (EAM) during scanning produced a deficit on the film which corresponded to the patient's EAM thus making it easier to locate the TMJ. This was done because of the difficulty in locating normal anatomy on a bone scan and the inherent resolution of the scan.

In the first case, following closed reduction of the fracture and fixation with elastic traction, pain developed in the right joint. A bone scan showed an increase in the osteogenic activity in the right joint as compared to the left side. When the fixation was removed the pain disappeared and subsequent scintograms
Fig. 8-4. Left lateral planar bone scan of patient with Paget's disease.

Fig. 8-5. Position of patient in relation to gamma camera for a lateral planar bone scan of left TMJ.
also showed a progressive decrease in activity in the joint. The diagnosis was considered to be an increase in bone activity as a consequence of the elastic traction.

In the second case clinical history and radiographic examination indicated degenerative disease of the right TMJ. A bone scan was performed to confirm or rule out active disease. The scan confirmed the diagnosis of degenerative joint disease which was successfully treated conservatively.

The only conclusions drawn in this article were related to the use of the anatomical marking device. However it would appear that there could be a place for bone scanning in relation to certain problems of the TMJ.

Although bone scanning had proved to be a useful diagnostic modality in the location of benign and malignant disease, its application at this time to the diagnosis of oral disease had been limited, the TMJ having rarely been evaluated. This was considered by Goldstein and Bloom (1980) when a study on nine patients was carried out. The patients were evaluated using limited bone scans and the results correlated with radiographic and microscopic findings on all patients.

All nine patients had a detailed clinical history, evaluation of occlusion, pantomograms, tomograms, periapical dental and transcranial radiographs. All were
treated surgically at which time a small biopsy was taken. In addition to the standard evaluation a bone scan was carried out using 20 mCi of 99mTcMDP injected intravenously. After 2 to 4 hours 500,000 count scintigrams were taken in the anterior, left and right lateral projections (Figs. 8-5, 8-6).

The results were divided into three groups according to the radiographic, scintigraphic and histological findings, as follows:

Group 1. One patient had normal findings for all areas of evaluation but had a six month history of intermittent pain in the right joint. Surgical finding was a perforated meniscus.

Group 2. Four patients had abnormal scintigrams and histology with normal radiographs. In three out of the four patients histology of the condyle was normal, but all had pathosis of the glenoid fossa. The fourth patient had pathosis of both condyle and glenoid fossa, the biopsy showing periosteal necrosis and osteosclerosis in the fossa and degeneration with fibrosis of the marrow spaces in the condyle.

Group 3. Four had abnormal findings in all areas of evaluation, the pain being present from between 3 to 8.5 years. Surgery confirmed degenerative changes in both glenoid fossae and condyles of all patients. Histological findings showing osteosclerosis of all fossae, and
Fig. 8-6. Series of anterior, right lateral, and left lateral planar bone scans showing bilateral activity in both condyles, particularly in the lateral views.
fibrosis of the condylar marrow spaces.

There are many causes of facial pain ranging through mechanical, infective, congenital, neoplastic and in some cases psychogenic. The diagnosis of TMJ problems is always difficult and more so when radiographic evaluation is normal. It should be noted that in four out of the eight patients with bone disease the radiographic evaluation was normal. In eight of the nine patients bone scanning showed evidence of abnormality and in the single case of perforated meniscus there was no histological evidence of osseous changes, therefore the bone scan would be expected to be normal.

Goldstein and Bloom (1980) concluded that in cases of facial pain with normal radiographs a limited bone scan appeared to be a useful method for detecting early degenerative changes in the TMJ. On the evidence of this small sample this would appear so.

In a more recent study on 125 patients with TMJ problems who had bone scans as part of their diagnostic work-up and compared against radiographic and arthrographic evaluation, it was suggested that bone scans were not a reliable aid to diagnosis (Craemer and Ficara 1984).

Craemer felt that insufficient work had been done and the evidence presented was only on limited numbers of patients. The purpose of his research was to evaluate
of patients. The purpose of his research was to evaluate the usefulness of the bone scan as a diagnostic aid for diseases of the TMJ, and correlate it with radiographic and arthrographic examinations, also taking the patient's age into consideration.

Craemer's study was carried out on a group of 125 patients, ages ranging between 16 to 67 years, consisting of 45 males and 80 females. The presenting symptoms varied through a range of problems such as painful TMJs, inability to open or close the mouth, joint noises and pain in facial muscles. Occlusal evaluation was done on 106 patients; 38 had tomograms, 78 had transcranial radiographs and 21 patients received arthrography. All patients were given a bone scan. This consisted of an intravenous injection of 15 mCi of 99mTcMDP, the joints being scanned 2 to 4 hours later with a high resolution collimated gamma camera.

Of the 38 tomograms 12 were normal and 26 showed obvious bony changes such as erosions, osteophytes and abnormal radiolucencies or radiopacities. When compared with the bone scans, of the 26 abnormal tomograms only 7 were positive giving a 73% false negative result for the scans. Five of the 12 normal tomograms had positive scans which Craemer felt indicated the bone scans detected osseous changes that were either physiological in nature or too small to show radiographically.
All 78 transcranial radiographs showed some form of abnormality such as abnormal joint spaces, abnormal condylar position in the open and closed positions, and osseous changes. Only 10 had positive bone scans giving an 82% false negative result.

Fourteen of the 21 arthrograms showed an abnormality such as a perforated or an anteriorly displaced meniscus. Three of the 14 had positive bone scans and 2 of the 7 normal arthrograms were positive scans which were considered to indicate an abnormal osseous process not related to the normal functions of the joint.

Craemer appeared to be in two minds about the results of the bone scans as compared with the patient's occlusion and went on to discuss the role of age in relation to the bone scans. He found a higher percentage of positive scans (54.5%) in the 16 to 20 years age group, the smallest percentage (8.9%) in the 31 to 45 years group.

The final evaluation was comparing the symptomatic joints with the bone scans. Of the 25 examined 15 (60%) were positive and therefore identified correctly as symptomatic joints.

Craemer acknowledged the usefulness of bone scanning as a well recognised diagnostic tool in the maxillofacial region particularly in relation to the conditions put forward by Alexander (1976). It must be remembered
that a bone scan is nonspecific in nature and demonstrates osteoblastic activity. The increase of positive scans in the 16 to 20 age group could be attributed to normal physiological growth taking place. He went on to comment that a bone scan may have some value in the diagnosis of arthritic conditions of the joint. Because of cost and possibility of excessive radiation to the patient, bone scanning for diagnosis and treatment of conditions of the joint should not be used. He felt that his study had sufficient numbers to demonstrate conclusively that the bone scan was not a diagnostic aid in TMJ disorders.

Craemer made the following conclusions:

1. that bone scans were of little value and should not be used in diagnosis of TMJ disorders

2. that there was no correlation between radiography, arthrography and the results of the bone scans

3. that the increased uptake of radionuclide in younger patients probably represents normal ossification of the developing TMJ

4. that further research into the use of bone scans with TMJ disorders was unnecessary.

It is felt that certain observations should be made on Craemer's article at this time. There is a lack of consistency as 125 patients were examined but a variety
of radiographic techniques (38 tomograms, 78 transcranial and 21 arthrograms apparently chosen at random) were used for comparison with the bone scans on all patients.

It is a pity that so many of the radiographic evaluations were done using transcranial projections, all of which, according to the author's interpretation, had abnormalities present and that negative scans were false negatives. The inference was that the radiograph was the method of choice in determining joint pathology. There are many references indicating that radiographic changes within the joint are not necessarily associated with symptoms such as pain (Toller 1973, Kopp and Rockler 1979). The use of the transcranial film to show normal and symptomatic joints has been studied in depth and now considered an unreliable technique (Mikhail and Rosen 1979, Blaschke and Blaschke 1981).

In this study it is noted that 60% of the positive scans were associated with symptomatic joints which seems more indicative of change in bony morphology than was evident radiographically but Craemer failed to comment on that fact.

He also failed to mention that not all patients with TMJ related symptoms and facial pain dysfunction need radiographic assessment provided an adequate clinical history is obtained. Similarly a bone scan is not
required for every patient, but it can indicate changes within the joint before changes can be seen radiographi-
cally and is therefore an additional diagnostic techni-
que now being used widely in clinical practice.

Facial development

Another area in which nuclear bone scanning is being used in relation to the TMJ is that of assessment of facial growth particularly in relation to maxillo-
facial surgery and the correction of facial deformities such as mandibular asymmetry. Evaluation of facial growth has, over the years, been carried out by using the following methods:

1. serial observation, correlation of the patient's age with growth history and patterns of close relatives

2. comparing hand-wrist radiographs against known standards

3. superimposition of serial cephalograms. This last method is the most direct way of assessing facial growth. None of these methods can predict accurately the growth pattern and subject the patient to a great deal of radiation as they require several radiographs over a period of several months.

Mandibular asymmetry can be caused by a number of factors but one that is commonly seen is that of unila-
teral condylar hyperplasia. In this condition one
condyle grows faster than the other or may continue to
grow beyond the age when normal growth ceases.

Beirne and Leake (1980) appear to be among the
first to report the use of a nuclear bone scan in the
detection of a hyperactive condylar growth centre. They
used technetium 99m pyrophosphate in a 14 year old girl
with facial asymmetry after clinical and radiographic
examination had determined an enlarged right condyle.
The bone scan showed growth taking place in both con-
dyles but with greater activity on the right side. Right
condylectomy was performed and histological examination
of the growth plate indicated activity and a rapid cell
turnover. The bone scan permitted immediate evaluation
and treatment of the problem which prevented further
development of the asymmetry and malocclusion.

The uptake of 99mTcMDP into bone is a reflection of
the blood flow and metabolic activity of the area.
Therefore nuclear bone scanning with this radiopharma-
ceutical should be a good method of assessing skeletal
growth particularly in relation to the mandible.

Kaban et al (1982) using this theory developed
standards of uptake based on age and skeletal matura-
tion. They studied the uptake of 99mTcMDP on 34 pa-
tients, ranging in age from 15 months to 22 years, who
were being scanned for acute pathological conditions of
the extremities. None of the patients had facial defor-
nities and were on the whole relatively healthy. The
uptake pattern was correlated against mandibular growth, chronological and skeletal age.

The dose of 200 uCi/kg of 99mTcMDP was injected intravenously, scanning taking place 3 to 4 hours later. Anteroposterior (AP), submental and lateral head views were taken but the condylar region was hard to visualize on the AP and submental view because of the superimposition of the petrous temporal bone and mastoid process. The ideal view was the lateral with the neck hyperextended to separate the ramus and condyle from overlap of the vertebral column. This was achieved by the use of a head holder made specially for the purpose.

Right and left lateral images were taken and the information fed into a computer. Uptake in the fourth lumbar vertebra was also taken and used as a standard reference. From the counts taken a ratio between the point on the mandible and the count for the lumbar vertebra was established.

The ratios for the right and left condyles in symmetric patients were found to be equal to within +/- 5%. There was found to be a decrease in the ratios with age in the condylar region from more than 2:1 in the first two years of life to 1:1 or less for patients over 20 years of age. Once the ratio between the condylar region and the lumbar region was below 1 it was assumed that growth was completed. If this is the case then it
means scanning could be a means of detecting the time of growth cessation. This would prove to be extremely useful in the timing of surgical procedures. This preliminary investigation studied exclusively the condylar region because of its importance as a growth centre and enough data were collected to make this technique clinically useful.

After establishing these normal uptake patterns Cisneros and Kaban (1984) carried out a study to apply them in the assessment of 21 patients with mandibular asymmetry. Diagnoses included 5 patients with generalized mandibular asymmetry, 6 with hemifacial microstomia and 10 with condylar hypo or hyperplasia. The technique was as previously described and the results were expressed as a ratio of the uptake in the condyle to that of the lumbar vertebra. The ratio of uptake and right and left differences for three mandibular regions (condyle, ramus and body) were computed for each patient, the results then being compared with normal data for age and sex.

The results showed that in patients with asymmetry the ratios for the affected and unaffected mandibular regions were lower than the expected mean for age and sex. However the differences between the two sides in the condylar regions were greater regardless of the condition diagnosed.
The ratios of radionuclide uptake in patients with facial asymmetry decreased with increasing age as found in the previous study of the normal population. However, the ratios were found to be lower for age bilaterally even on the normal side. This was considered to be due to the fact that the mandible is one bone with left and right sides functionally related unlike any other bone in the body. A condition affecting facial growth on one side would be expected to have considerable effect on function and growth on the normal side.

Cisneros and Kaban concluded that on the basis of the data collected in this study scintigraphy has become, as far as they were concerned, a standard part of the diagnostic work-up and treatment planning for patients with facial asymmetry. It can be used to demonstrate equalization of growth and indicate the end stage of the deformity. It can determine the normal and abnormal side in difficult cases and the effects of functional and surgical therapy can be evaluated using scintigraphy as part of the follow up treatment. They also felt that there was no reason why the technique could not be expanded to assessment of growth in the other facial bones.

As treatment of mandibular asymmetry can involve orthognathic surgery it is very important to know if the condition is still active and whether growth is
progressing in the condyles. A series of study models
taken over a period of time can be used to elicit the
information but this takes time and if the patient is
also undergoing orthodontic treatment this can defeat
the purpose of taking serial study models.

Basing his work on the previously published studies
by Beirne and Leake (1980) and Kaban and Cisneros (1982
and 1984), Pogrel (1985) conducted a pilot study into
the differences between the uptake of radionuclide in
the condyle in normal patients and ones with diagnosed
unilateral condylar hyperplasia.

Pogrel scanned the TMJs of 30 patients under the
age of 45 years who were undergoing bone scans for a
variety of nonmalignant conditions. These patients had
no previous history of TMJ conditions and were all
asymptomatic. There were 18 male and 12 female patients
and they all were studied using a gamma camera linked to
appropriate computer hardware. The TMJs were isolated
and separate counts were done so that the results could
be compared for each pair of joints, counts being car-
rried out every 2 mins for a 30 minute period.

The results showed that there was only a small
percentage difference in activity for most of the pa-
tients. Twenty one were between 0 to 5 % whilst 9 were
in the 5 to 10 % range, no single case exceeding 10 %.
Of the 9 who were in the higher range 4 were teen-agers
and, therefore, it would be safe to assume that growth would still be taking place.

A further 6 cases were scanned. These patients were diagnosed with mandibular asymmetry thought to be caused by unilateral condylar hyperplasia. Of these, 2 showed a difference in condylar activity of 10%. In the other 4, activity ranged from 17 to 135%, all of whom were under 22 years of age. It was assumed that the 2 with the difference of less than 10% had completed their active growth phase.

In the case of the 4 over 10% it was believed that the hyperplastic growth was still active. These patients were given the choice of waiting for activity to cease or having condylar surgery to remove the hyperplastic tissue followed by orthognathic surgery.

It would appear from this study that even though normal activity is shown the uptake of radionuclide is not equal. In the normal patients the difference was less than 10% and then only slightly higher in those where active normal growth was taking place. It is also assumed that if activity is greater than 10% then this may indicate some disease process. It must be remembered that a bone scan will also show other related activities such as infection, inflammation, neoplasms and other problems that may cause bone activity. The use of the bone scan should always be coupled with the clinical
history and it would appear to be of great benefit as an aid to diagnosis of active unilateral condylar hyperplasia. The presence of active unilateral growth may be an indication for surgery.

A recent article in the literature by Matterson et al (1985) reporting on 2 cases where bone scanning was used in the differential diagnosis and assessment of condylar hyperplasia concluded that bone scanning was a safe noninvasive method, readily available to the clinician and should be considered a useful way of determining growth activity in the condyle when patients with condylar hyperplasia were being assessed for either surgery or orthodontic treatment.

So far we have only considered the use of radionuclide scanning in relation to the hard tissues of the TMJ but many of the patients seeking treatment have a variety of symptoms such as joint pain, clicking during opening and closing movements, locking and limited opening. When these patients are assessed and their history leads the clinician to a diagnosis of internal derangement they are referred for arthrography. Usually anterior displacement of the meniscus is demonstrated, which is now considered an important aetiological factor leading to osteoarthritic degeneration in the articular cartilage and subchondral bone (Katzberg et al 1983).

Planar bone scanning has been shown to be superior
to the various standard radiographic techniques in the early detection of disease in the TMJ (Goldstein and Bloom 1980), and arthrography is commonly used to confirm diagnosis of internal derangement.

**Single photon emission computed tomography (SPECT)**

A comparative study into the diagnostic accuracy of planar scintigraphy, single photon emission computed tomography (SPECT), radionuclide angiography, arthrography and conventional radiography was carried out on 36 patients with TMJ dysfunction as part of their preoperative testing programme by Collier et al (1983).

A total of 23 patients with unilateral TMJ symptoms and 13 with bilateral symptoms were independently evaluated using the above mentioned methods. Of the 36, 33 were female and 3 were male. The age range was 18 to 55 years with a mean of 32, all of whom had been given a thorough clinical examination.

Radionuclide angiography was performed after intravenous injection of 25 mCi 99mTcMDP, which consisted of 10 sequential 3 second anterior view images followed by a 5000 count image. Three hours later left lateral and right lateral planar scans of the head were performed using a gamma camera with high resolution collimator. A SPECT examination followed using a rotating gamma camera with low energy general purpose collimation. From this 64 projections over 360 degrees were acquired for 20
seconds per projection and then reformation of axial, coronal and sagittal views was performed.

After the bone scanning was completed the patients were referred for conventional radiographs and arthrography. The arthrography was by standard technique of injection of contrast media into the lower joint space under fluoroscopy. Dynamic video studies were taken along with spot radiographs.

The radionuclide angiography, bone scans and SPECT views were examined by three nuclear medicine physicians and each technique was evaluated separately and without knowledge of the arthrographic or radiographic studies. These latter were examined by a radiologist skilled in TMJ evaluation also without knowledge of the nuclear medicine results.

Based upon the severity of the symptoms, clinical examination and arthrography all patients underwent surgery with meniscus resection and insertion of a silastic prosthesis. A total of 49 joints were treated, 23 unilateral and 13 bilateral. Using the surgical findings as a base line the diagnostic sensitivity of the various methods described was calculated using the chi-square test. For the purpose of this study the 23 untreated joints were considered to be normal, that is a joint without symptoms severe enough to warrant surgery.
The overall results for surgically proved disease were as follows:

1. arthrography, the most sensitive with a value of 0.96
2. SPECT - 0.94
3. planar scintigraphy - 0.76
4. radionuclide angiography - 0.35
5. combined radiographic techniques - 0.04.

There were 2 false negative results with arthrography and 3 with SPECT. However, one of the arthrographic negatives was shown positive by SPECT. The confidence level for arthrography and SPECT for confirmed TMJ disease was 95% from planar scintigraphy and 99.9% from that of radionuclide angiography and conventional radiography. Collier et al concluded that SPECT, when compared with the other methods used in this study, was the technique of choice for noninvasive imaging of joints with internal derangement.

A recent article was published in the Australian Dental Journal by Ryan et al (1985) on the use of bone scanning as an aid to diagnosis. This was part of a series on internal derangement of the TMJ submitted by Moloney. He, along with co-authors Ryan, Collier and Messer have republished the work by Collier et al (1983). They draw the same conclusions in relation to the use of SPECT but suggest for further comparative
studies in the light of current work on the use of CT scanning and MRI as noninvasive modalities in the diagnosis of internal derangement of the TMJ.
Chapter 9

NONINVASIVE METHODS

ULTRASOUND

General

The generation of ultrasound in solids and liquids was first achieved in 1917 by the French physicist, Langevin, who had the idea of using piezoelectric effects to excite a quartz crystal electrically causing mechanical oscillation at one of its resonant frequencies. This developed rapidly because of the naval application to echo sounding. During this work it was noticed that small fish were killed by the sound beams. This lead to its use in the medical field for tissue destruction as in the breakdown of cancerous tissue or tissue modification as in the breakdown of adhesions formed as a result of injury (Hill 1983).

These early ill-controlled applications in medicine were largely discontinued by 1939. Work done by McDonald in Glasgow in the mid 1940s and development of the pulse-echo technique by Wild and Reid in 1952 revived its use. The development of diagnostic ultrasound machines was hampered, as in other areas, by the limitations of electronic technology. However, development over the last ten years has corresponded to that of other radiographic methods if not over taking them in certain areas. As with CT, ultrasound also produces anatomical cross-
sections of soft tissue but without the same spatial resolution, so these modalities have moved in different directions (Chiver 1983).

Ultrasound has moved into 'real time' visualization with the advantage of lower cost, quicker examination time and the ability to repeat examinations without radiation hazard to the patient. It has proved extremely useful in the field of obstetrics and pre-natal examination.

Principles of ultrasound

Basically, ultrasound techniques involve the generation of sound which has a higher frequency than that detectable by the human ear, that is, frequencies above 20,000 cycles per second. Most machines now used for medical diagnostic purposes work on a range of frequencies above $1 \times 10^6$ cycles/sec (1 megahertz) to $15 \times 10^6$ cycles/sec (15 megahertz). The ultrasonic waves are generated when an electrical impulse is applied to a crystal which contracts and expands at a rate synchronous with the externally applied voltage.

This crystal is said to have a piezoelectric effect. Conversely, if a sound wave of appropriate frequency hits the crystal then it will begin to vibrate producing a voltage proportional to the sound wave (Buddenmeyer 1975, Wells 1983).

The ultrasonic scanner generates the electrical
impulses that are converted into high-frequency sound waves by a transducer which contains the crystal. This transducer acts as both transmitter and receiver. The sound waves leave the transducer in the form of 'acoustic wave packets' which pass into the tissues under examination (Fig. 9-1). Because of the sound waves' high frequency, air is not a good transport medium so the transducer must be acoustically coupled to the skin by means of either a water bath or a gel (Buddemeyer 1975, Crocker 1979).

When the transmitted sound passes into the tissues the waves will either be absorbed, reflected or deflected in a manner dependent upon the acoustic properties of the tissue. The product of the tissue density and the velocity of the sound wave is known as the acoustic impedance and varies from tissue to tissue. Therefore, the reflected signal from the tissues will vary in strength. As the echoes return to the transducer they are converted back to electrical energy. This electrical impulse is carried to a receiver unit where it is amplified, processed and then displayed on a monitor screen either as a graph, 'A mode' signal or as a bright spot on a time base, 'B mode' signal (Fig. 9-2) (Crocker 1978 and 1979, Price et al 1980).

With the computer equipment now available it is possible to update the incoming sound information at a
Fig. 9-1. Diagrammatic representation of an ultrasonic echoscope, modified from Crocker (1978).

Fig. 9-2. Diagrammatic representation of 1. A mode 2. B mode traces, modified from Crocker (1978).
sufficiently rapid rate to allow visualization of physiological movement within the field being scanned. This process is known as 'real time' imaging (Leopold 1980).

Reflected echoes can be displayed in several different ways:

1. A mode or amplitude mode
2. B mode or brightness mode
3. M mode or movement mode
4. C mode or coronal mode.

The most commonly used is 'B mode' (Crocker 1978, Leo and Rao 1975). In 'B mode' scanning, the intensity of the reflected sound is represented as different levels of brightness on a grey scale. It is the accepted theory that the spatial distribution and texture of the echoes in such a grey scale image assist in distinguishing between the tissue types (Price and Jones 1980).

The image is obtained by moving the transducer across the tissue being examined. The echoes returning from a number of interfaces will appear as a number of spots of differing brightness on the oscilloscope screen. By using a storage oscilloscope and moving the transducer many times across the screen a series of B scans are obtained and a two-dimensional echographic section through the tissue is acquired (Fig. 9-3) (James et al 1980). A permanent record of the pictures produced this way can be made by photographing the oscilloscope.
Fig. 9-3. Diagrammatic representation of a B mode linear scan through a circular structure. Movement of the transducer indicated by the arrows, modified from Crocker (1979).

Fig. 9-4. Diagrammatic representation of an A mode scan of the preauricular area over the TMJ after Spranger (1978). 1. skin and underlying tissue 2. lateral ligament 3. capsule 4. lateral part of condyle 5. mid-central parts of the joint 6. medial part of condyle 7. temporal bone.
image, feeding the signals into an appropriate video recording system or by use of high speed cinematography.

Early use of ultrasound concentrated on investigation of the deep structures of the chest and abdomen but as equipment has improved it can now be used on more superficial structures and specialized instruments have been developed for this purpose. Conventional machines usually require a working frequency range of 2 to 5 megahertz to achieve penetration. Superficial structures are examined with higher frequency transducers of up to 15 megahertz. It should be noted that the higher the frequency the better the resolution but there is a reduction in the penetration. The average frequency used is around 8 megahertz (Leopold 1980).

Ultrasound measures the anatomical position of surfaces and structure characterization arises through differences in acoustic impedance. Ultrasound is strongly reflected at boundaries between soft tissue and gas or bone. Structures of a few millimetres thick can be resolved in soft tissue in the interior of the body. As ultrasound does not penetrate into gas or through bone it will suffer high attenuation and has proven to be of more use in the study of soft tissue, especially the abdominal cavity. With the development of smaller transducers and higher frequencies more superficial scanning has been achieved (Jackson and Kouris 1983).
Maxillofacial uses

A great deal has been published on ultrasound techniques in diagnostic medicine which is suggestive of its widespread use, the value of the techniques and the need for further development. It is not until recent years that ultrasound has started to be used in maxillofacial surgery. One of the two most recent articles published by Jones and Frost (1984), relates to the imaging of soft tissue masses in the neck. They concluded that for examination of these, ultrasound could be a valuable diagnostic aid and was particularly useful in localizing lesions for biopsy. The second relates to the examination and assessment of facial swelling particularly in postoperative oedema caused as a result of third molar surgery (Wilson and Crocker 1985). Both parties felt that further work was needed to fully investigate the potential that ultrasound might play in oral and maxillofacial surgery.

Temporomandibular joint

A thorough search of the literature has revealed only two articles on the use of ultrasound on the temporomandibular joint. The first was by Spranger (1978), as part of an article in which he considered ultrasound scanning of the teeth, maxillary sinus and other jaw related structures.

He felt that x-ray examination of the joint was
never able to analyze the parafunctional and dysfunc-
normal processes. To do so would subject the patient to heavy doses of radiation. It was for this reason that ultrasonic techniques were investigated regarding their usefulness in functional diagnosis of the TMJ.

Spranger, using 'A mode', produced an oscillogra-
phic picture of echoes of the preauricular region along a direction to the sella turcica. He concluded that the peaks of the 'A mode' graph corresponded to the various structures encountered when passing from the skin laterally to the temporal bone medially (Fig. 9-4) as follows:

1. skin and soft tissues of the preauricular region, parotid gland and masseter muscle
2. temporomandibular or lateral ligament
3. connective tissue of the capsule and synovial fluid
4. lateral pole of the condylar head
5. mid-central parts of the condylar head
6. synovial fluid and medial part of the capsule
7. lateral pterygoid muscle
8. temporal bone.

The visualization of the above mentioned structures relates to the depth of the tissue that can be scanned. Some of these layers are self limiting as far as the type of tissue is concerned.
Apart from mentioning the use of a 12 MHz transducer early in his article in relation to the scanning of teeth there is no comment as to the equipment that was used when examining the joint. He did however discuss the technique used.

Spranger felt that the indication for ultrasonic imaging of the TMJ involved the evaluation of functional behaviour. Movement can only be recognised as such when a reference point can be compared with the distance travelled by the moving point. He considered that the more life-like the image then a better comparison between reference points could be achieved. By building up a series of two-dimensional images it was possible to keep a check on the movements.

A series of scans were carried out in the vertical plane and the parts visualized were basal part of the temporal bone, mandibular fossa, condyle and neck of condyle. This examination was carried out with the mouth closed and then open. A series of scans were carried out from which a picture of the joint was built.

This process was repeated taking horizontal sections with the zygomatic arch, articular eminence in front of the condylar head and the basal part of the external auditory meatus, the styloid process and the mastoid bone behind. Spranger commented that as long as 'sonic contrast' from the bones could be expected then
images could be obtained.

In the ultrasonic images produced the superficial tissues appeared fused together because of the way the unit parameters had been set. The setting was in such a way that central limitation of the strongly reflective bone of the joint was clearly visible. This meant that the low energy of the echoes from the surrounding tissues were inadequate for proper visualization. This in turn meant that the visualization of the border layers came from the tissues of the TMJ capsule and thus a comparison of the images produced, one with another, was possible and therefore allowed interpretation.

Spranger concluded that visualization of the temporo-mandibular joint was possible with the mouth in any position from fully open to fully closed and permitted immediate establishment of a diagnosis for the patient.

The images obtained from the vertical examination when built up permitted an interpretation of the harmonious movements of opening whilst the horizontal examination permitted interpretation of lateral deviations of the condyle.

In each case, the images were measured with the aid of a grid and unlike other diagnostic measures the configuration of the soft tissue could be established metrically using the grid.
In studying this article the author found difficulty in determining the correlation between the images printed and the diagrammatic interpretation of them. The general nature of the article was such that a large number of assumptions had to be made. However it forms the basis for further research work in this field.

The second article by Campbell (1984) raised the point that if ultrasound could be used as an imaging modality for the TMJ it would be more convenient, less expensive and above all noninvasive. The purpose of his study was to explore the feasibility of and technical factors for clinical imaging of the TMJ with ultrasound.

His work was carried out on cadaver specimens using a high resolution 'real time' scanner with a 10 MHz probe and a static scanner with a 7.5 MHz transducer to delineate the sonographic anatomy of the meniscus and related structures of the TMJ. Initially an isolated meniscus was suspended in a water bath and imaged in both sagittal and coronal planes. The next stage was to image an intact meniscus in a dry skull orientated in both the normal and displaced positions. The whole was suspended in a coupling medium and imaged. The final stage was dissection of the TMJs from a cadaver specimen, with soft tissue and muscles attached. This was then used to determine functional movements of the
joint. Static two-dimensional 'B mode' and 'real time' images were taken to determine the soft tissue and bony anatomy.

The results of the scans were found to be favourable. The meniscus alone appeared as a rim of echogenic tissue due to its concavo-convex shape. The echographs of the skull and attached meniscus showed the zygoma, articular eminence, condyle and coronoid process as well as the meniscus both in the normal relationship and in the displaced position. In the cadaver specimen the condyle, joint space and meniscus could be seen.

Campbell found that the interpretation of the images was enhanced when they were recorded parallel to two specific tissue planes. The semiaxial plane of pogonion to vertex of the skull was best for recording the meniscus in its long axis. The oblique coronal plane from outer canthus to mandibular angle was best for showing the zygomatic arch, articular eminence, meniscus and condyle. He felt that recording in both planes was necessary for best visualization of the disc.

Campbell concluded that it was possible to detect the anatomy of the the TMJ with the currently available ultrasound equipment and that further work in this field was necessary.

A pilot study on two patients was carried out by the author along with Dr. E.F. Crocker, Director of
Ultrasound at Westmead Hospital to determine the feasibility of ultrasound as a method of diagnosing problems of the TMJ.

One patient had clinically normal asymptomatic joints. The second had a click on the left side but was asymptomatic on the right. The clinical diagnosis of this patient was a left anterior displaced meniscus with reduction.

Two machines were used on two separate occasions, the first being a SKI-200 multifocus mechanical sector scanner with an integrated water delay mechanism (Fig. 9-5). The transducer element is mounted in a self contained water bath enclosed by a thin, pliable plastic membrane mounted on the end of the hand held probe (Fig. 9-6). This was coupled directly to the skin in the preauricular region over the TMJ which had been previously located by palpation.

The transducer provided a 28 degree sector angle, operated at 12 frames per second with a frequency of 8 MHz. It was focused at 2.5 cm from the face of the water bath, scanning being possible to 5.0 cm. The field of view was 2.5 cm at the skin surface and 5.0 cm at the depth of the field. Axial resolution was 0.25 mm, lateral resolution was variable according to the focal zone, 3 mm at skin level and 5 mm at 5.0 cm depth.

The second machine used was a Diasonics, multifocus
Fig. 9-5. SGI-200 multifocus mechanical sector ultrasound scanner with integrated water delay mechanism. Positioning of the transducer and examination was monitored on the television screen above the trolley.
Fig. 9-6. Transducer is mounted in a self contained water bath (arrow) on the end of a hand-held probe. Transducer in position for sagittal TMJ examination, mouth closed position.
mechanical sector scanner with a 32 degree sector angle, with the transducer focused 4.5 cm from the face. Field of view was 2.5 cm at the skin to 5.0 cm at depth. Depth of resolution was only 3.5 cm due to it being a 10 MHz transducer. This also had an integrated water bath surrounded by a flexible plastic membrane at the end of a hand held probe. The probe on the second machine was about half the size of that of the first machine. It was coupled directly to the skin.

Due to the heavy work load of the ultrasound department and available time on the second machine this study was limited to the two patients.

The healthy joints were scanned first on the SKI-200 machine using 'real time' to visualize the movements of the condyle. It was possible to follow the movements of the condyles as the scanning was taking place. Freeze images of the scan were of no diagnostic value. It was possible to detect the condyle and articular eminence because of their relationship during functional movements but it was not possible to detect the meniscus or other soft tissue of the joint apart from the attached muscle tissue.

Visualization of the symptomatic joint was carried out in the same manner and then compared with the normal joint on the other side. Similar results were obtained as with the first case. The main difference was that it
was possible to detect the point of the 'click' or recovery of the meniscus. The forward and downward progression of the condyle appeared to 'jump' during its movement. It was impossible to obtain a diagnostically acceptable freeze image of this point of recovery of the meniscus and viewing only occurred during 'real time' imaging.

The whole study was repeated using the 10 MHz machine which gave better definition of the tissues but did not penetrate as far into the joint. With this machine it was possible to define more clearly some of the soft tissue interfaces and on some of the images the lateral pterygoid muscle could be shown. The lateral edge of the meniscus and capsular tissue could also be seen more clearly provided the line of the scan was parallel to the edge of the meniscus. Unfortunately this particular machine was only in use for a very short time and it was not possible to carry out further studies with it.

The conclusions drawn from this small study were that it was possible to detect the actions of the muscle masses, for example the masseter and lateral pterygoid. The lateral pole of the condyle could be visualized and its movements followed in 'real time' imaging and it was thought possible to determine the interface image caused by the lateral border of the meniscus (Figs. 9-7 and 9-8).
Fig. 9-7. Freeze image from the Diasonics machine of the left TMJ in sagittal plane with the arrows indicating the anterior and posterior borders of the condylar head. The bright area between them is the soft tissue over the lateral pole of the condyle.
Fig. 9-8. Freeze image of the left TMJ taken when patient has mouth fully open showing 1. lateral pterygoid muscle 2. soft tissue over the lateral pole of condyle 3. skin, underlying tissue and masseter muscle 4. shadow probably caused by the articular eminence.
The freeze images taken of certain aspects of the scan when observed later were found to be of no clinical value. When shown to other clinicians they found it impossible to determine what the images were or what the different shadows represented. In order to interpret the images it was necessary to have viewed the 'real time' scans.

It is felt that 'real time' imaging could provide a method of viewing the functional movements of the condyle or at least the lateral pole and that it would need finer probes to be able to distinguish the joint space and meniscus. When considering ultrasound it must be remembered that the shape of the fossa and articular surface of the condyle, concave and convex respectively, are such that the sound waves will not be reflected back at right angles and thus will produce scatter of the echoes and cause interference. Also the lateral border of the fossa is inferior to the apex of the condyle and roof of the fossa and will, therefore, act as a bony barrier to the sound waves.

With the advent of more sophisticated machines it may be possible to use ultrasound as a noninvasive means of visualizing the TMJ. However, at present it would appear from the evidence presented that it has a strictly limited use.
THERMAL IMAGING

Note: The resume of the basic principles of Thermal Imaging in this treatise was developed from selected abstracts from Thermal Imaging. Jones. C.H. 1983. In Jackson (Editor). Imaging with non-ionising radiations.

General

All objects are emitting and absorbing infrared radiation continuously. The radiant energy is emitted over a broad wavelength band with maximum emission occurring at a wavelength dependent upon the surface temperature of the object. Hot bodies and fires emit at wavelengths of a few microns whereas the human body with a surface temperature of 35°C will emit most copiously at wavelengths of 10 microns. Most detectors currently in use are sensitive to a radiation range of 3 to 15 microns.

Fundamental to an understanding of the thermal emission of solids is the concept of a black body, which by definition is a body which absorbs all radiation that strikes it irrespective of wavelength. If placed in an enclosure of uniform temperature it would come to a state of equilibrium at that temperature and would therefore emit the same amount of radiation as it absorbs (Kirchoff’s law 1860).

On the other hand all bodies only absorb a fraction of the radiation falling on them. This depends upon the physical properties of the body and the wavelength of
the radiation. If we consider the amount of radiation emitted from the sun we can see by the different colours of objects that not the same amount of radiation is emitted from each of them despite the fact they are all bathed in the same amount of light.

Thermal detection

There are three groups of detectors used for measuring infrared radiation:

1. thermal detectors
2. photon detectors
3. liquid crystal.

Thermal detectors such as thermocouples are dependent upon the heating effect of radiation, whereas the photon detectors depend upon the photo-electric effect, such as photoconductive materials.

A more modern method of temperature detection is the use of liquid crystals which are a class of organic compounds that possess ordered fluid phases and combine solid-like optical properties with fluid-like flow. Some liquid crystals are colour-temperature sensitive and can be used to visualize surface temperature distributions. The most common is the cholesteric liquid crystal which is colour-temperature sensitive in the cholesteric phase. This phase exists within a specific temperature range and is exhibited by esters of cholesterol. When viewed on a black background they give rise to
iridescent colours, the change of dominant colour being affected by very small changes in temperature (Fig. 9-9).

This high sensitivity has made liquid crystals very useful in mapping different areas of temperature in the same region. It can be used by mixing a range of crystals together and in very thin sheets. This has been used extensively in the medical field particularly as an alternative to infrared thermography in breast cancer studies.

This method has two major disadvantages:

1. Direct contact and pressure on the plate can influence the temperature.

2. It is not always possible because of the shape of the object to get uniform contact and so areas are missed and a false reading is obtained.

Thermographic systems

Most systems are made up of three parts:

1. the scanning system which views the area under examination and focuses the radiation

2. the detector

3. the display system.

Numerous scanning methods have been employed with various configurations of detector used. Single detector scanning systems usually include the use of oscillating mirrors, rotating prisms and multi-sided mirror drums.
The build up of the thermographic image is synchronized with the scanning of the patient. Most of the modern systems use indium antimonide or cadmium mercury telluride detectors in either their photoconductive or photovoltaic mode (Fig. 9-10).

The signal from the detector is amplified and modified to produce an image on a TV monitor. The resulting picture shows the temperature differences in varying shades of grey, hot spots being either black or white depending upon the system used. More up-to-date machines now use colour display systems. Finally, there is a means of obtaining a permanent record of the thermogram, usually a high-quality photographic unit.

Medical thermography

Thermally, the human body has an 'inner core' where heat production takes place with the temperature falling gradually with increase of distance from the centre. This core temperature is maintained around 37°C, with the skin of the extremities being the coolest part.

The surface temperature distribution is characteristic of the individual and depends upon several factors both physical and physiological. The skin is the interface between the deeper tissues and the environment, therefore it plays a very important role in controlling the body temperature. It should be noted that infrared thermography shows the surface thermal patterns, although these are the result of many factors.
Fig. 9-9. Example of the use of liquid crystal as a method of monitoring body temperature of a patient.

Fig. 9-10. Diagrammatic representation of the various types of infrared scanning systems (Jones 1984).
Since body temperature is maintained by tissue metabolism and blood flow in the skin and subcutaneous tissues, a study of skin temperature is a reflection of physiological changes, particularly those concerned with thermoregulation and metabolism. Skin temperature can be measured by using thermistors and/or thermocouples, but they are not suitable for mapping changes in temperature over large areas.

As blood perfusion plays an important role in modifying the skin temperature, then thermography must be an indicator of this effect and will reflect blood flow in the tissues, thermal conductivity, and metabolic heat generation.

In the clinical environment, thermography should be carried out in a draught-free room with an ambient temperature of 20°C. It is easier to standardize the technique at this temperature. The skin of the patient should be cooled uniformly for a period before the examination starts. This accentuates the thermal pattern which remains constant throughout the examination because it takes approximately 40 minutes to reach equilibrium and an examination is completed in about 15 minutes.

Clinical techniques

Among the most important clinical uses are:
1. screening for malignant disease

2. delineation of the extent of suspected or known disease

3. identification of areas of abnormal temperature which reflect functional impairment in underlying tissue

4. monitoring the effects of various forms of therapy, for example, reconstructive surgery

5. assessing the prognosis of certain disease processes

6. identification of functional deficiencies and vascular disorders

7. studying the effects of chronic and acute trauma

8. physiological assessment of energy metabolism and peripheral vascular investigations.

Jones (1984) reported that a great deal of work in this field had been carried out but much of it was of little value because of lack of adequate preparation of the patient, thermal calibration and clinical assessment.

One area in which thermography can be used in relation to the TMJ is in the assessment of arthritis. Arthritis is frequently a chronic inflammatory condition and since heat is one of the classical symptoms of inflammation, thermography has proved to be a method of
demonstrating localized inflammation and evaluating treatment. Pain is a dominant factor which may be controlled by analgesic drugs but it has been shown that even though the pain has been removed the inflammation still continues.

Pain is associated with greater heat production and this heat production may in turn lead to higher skin temperature over the affected area (Fig. 9-11). A review of the literature has found only one article associated with the TMJ and that was a study comparing muscle of mastication in normal subjects and those with dysfunction syndrome (Berry and Yemm 1971).

In their study Berry and Yemm compared 15 normal subjects against 15 with mandibular pain dysfunction. No details of the patients were given save they had attended for treatment of pain over the masseters. In the results both groups showed differences in temperature between the two masseters and it was noted that 11 out of 15 dysfunction patients showed a higher temperature over the affected side. They then stated in summary that variations in skin temperature of about 5°C existed between the different areas and that in the cases of dysfunction the skin temperature over the painful area had a higher temperature than the unaffected side.

Except for two other articles reviewed, one related to unilateral chewing (Berry and Yemm 1974) and one
Fig. 9-11. Example of an infrared thermogram taken on a patient with pain in the left cheek. Pale yellow surrounded by red indicates the area involved.
related to chronic pain syndromes (Uematsu et al 1981), there appears to have been no further work in this area. Both these indicated difficulty with thermography and negative results were reported.

Currently work is being carried out at Prince Henry Hospital, Sydney by Dr. Peter Drummond on migraine, headaches, and facial pain using thermography but as yet no results have been published.

It would appear that at this time there is no real use for thermal imaging in the diagnosis of problems related to the temporomandibular joints.
CONCLUSION

This treatise has been produced in an attempt to give the reader an opportunity to compare the different techniques of visualizing the TMJ in one book and so obtain an overall concept of the best method of imaging the joint and its surroundings.

Whenever there is reason to suspect that organic pathological conditions are present, it is generally considered that radiographs of the TMJ are required. The more conventional methods such as transcranial, transpharyngeal and panoramic techniques can be used as a way of screening the joint. These methods are of limited value in evaluating TMJ problems.

Technically the TMJ is one of the most difficult parts of the body to visualize clearly by radiographic means because of the superimposition of surrounding bony structures. When a screening film shows a possible abnormality another method of visualizing the joint should be considered. Tomography should be reserved for this situation but linear tomography is now considered too crude for evaluating the complex structures of the TMJ because of blurring and distortion. Similarly, as distortion is inherent in panoramic radiography, this method is not suitable for detailed visualization of the TMJ.

Pluridirectional tomography is the best of the conventional methods and should be considered as part of
the armamentarium for imaging the joint. However it does have the draw-back of producing high radiation dosages to the patient.

The search for better ways of visualizing the TMJ has lead to a revival in the use of arthrography, although it should be considered a special diagnostic tool with limited indications. It should be reserved for patients with suspected internal joint derangements in whom nonsurgical therapy of long standing duration has not resolved the symptoms and surgery is contemplated, in patients with painful limited opening if dislocation of the meniscus is suspected and if the resulting information will radically alter the treatment.

Arthrography can be used with conventional radiographic methods, tomography or, more effectively, with fluoroscopy during which dynamic studies of the joint can be performed and recorded.

Computed tomography appears to have some value in replacing arthrography and can be used as an alternative method for diagnosis of articular disc displacement using the soft tissue identification or 'blink mode'. The preliminary work already done in this field indicates there is potential for this technique. Further work in this area and improved computer software should prove to be very useful.

The CT scan, as well as being a practical option to
the arthrogram, has proved to be an ideal method for imaging the hard tissues of the joint because it is noninvasive and provides a reduced amount of radiation to the patient when compared with all other radiographic techniques.

Three-dimensional imaging and displaying of the TMJ in vivo from CT data with no additional radiation risk to the patient has been attempted and is obviously still in its early stages. Here again with the continued improvement in software and future research this area of imaging could prove very useful in assisting the clinician in his diagnosis of the patient's TMJ problems.

The use of magnetic resonance imaging, particularly with the use of surface coils is now developing and this has the advantage over other imaging techniques in that it is noninvasive and no radiation is involved. The great advantage it has over CT and arthrography is that it is possible to visualize the meniscus and surrounding soft tissues with greater ease and clarity.

A further advantage of MRI is the ability to image directly from the stored information in any plane that is required by the clinician whereas with CT the reformed image loses quality and therefore spatial resolution. Information from MRI can be obtained by scanning the patient in only the one position whereas with CT the patient has to be placed in different positions some of
which can be very uncomfortable.

MRI has the potential to replace CT in the diagnosis of internal derangements of the TMJ and to eliminate the painful invasive procedures of arthrography. Its greatest disadvantage at this time is the cost of setting up such equipment and of running it. However, this will no doubt be resolved as equipment and techniques are improved. There is still a great deal of scope for research in this field.

Despite the apparent controversy in the literature as to the efficacy of nuclear medical scans it is considered that bone scanning now has a place as an aid to early diagnosis of conditions of the TMJ which can only be shown by other methods when the problem is in an advanced state. It would also appear that single photon emission computed tomography holds the key to this method of imaging and will come to the fore as more research is done in this field.

At this stage of their development the author feels that the use of ultrasound and thermography is of little use as imaging modalities for the TMJ but as changes occur in equipment and techniques then as noninvasive methods there may be a place for them.

It is considered that the greatest potential for imaging all components of the TMJ lies in the fields of magnetic resonance imaging and nuclear medicine with
certain areas of x-ray computed tomography. It must be remembered that when a patient seeks treatment for pain and discomfort in the TMJ region the clinician should determine whether the problem is within the joint itself or a condition affecting the surrounding structures.

It would appear that there is no simple correlation between the problem within the joint, and the symptoms experienced by the patient. The manifestation of TMJ problems may differ greatly from patient to patient and also may vary at different times within the same individual. One patient with the same condition as another may experience a great deal of discomfort whereas the other may have very few symptoms and in some instances may suddenly become asymptomatic.

It is generally agreed that the present methods of diagnosing disease of the TMJ are inadequate. Before a diagnosis can be made the total picture as determined by the history, clinical examination of the patient and all other pertinent information is necessary. Once all this has been determined the best technique of imaging the joint can be decided in order to confirm or change the clinical findings. The most modern and up to date technique available should be used.

It is hoped that future readers will use this review of the current literature as a basis for further thought on how the TMJ can be visualized most effective-
ly and be stimulated into seeking better ways of clarifying, diagnosing and treating effectively the patient suffering from problems related to the temporomandibular joint.
BIBLIOGRAPHY

Alexander, J.M.
Radionuclide bone scanning in the diagnosis of lesions of the maxillofacial region.

Alexander, J.M., Fratkin, M.J., Hall, D.L.
Temporomandibular joint marking for radionuclide bone scintigraphy.

Ambrose, J.

AMES, J.R., Johnson, R.P., Stevens, E.A.
Computerized tomography in oral and maxillofacial surgery.

Beirne, O.R., Leake, D.L.
Technetium 99m pyrophosphate uptake in a case of unilateral condylar hyperplasia.

Bell, W.E.

Bell, W.E.
Clinical Management of Temporomandibular Disorders.

Bell, W.E.
Clinical Management of Temporomandibular Disorders.
Chicago, Year Book Medical Publishers,Inc., pp 5-8, 1982(b).

Bell, W.E.
Clinical Management of Temporomandibular Disorders.
Berry, D.C., Yemm, R.
Variations in skin temperature of the face in normal subjects and in patients with mandibular dysfunction.

Berry, D.C., Yemm, R.
Changes in facial skin temperature associated with unilateral chewing.

Berry, H.M.
Radiologic Anatomy of the Jaws.
Philadelphia, University of Pennsylvania Press.

Blackman, S.
Dental radiology, past, present and future.

Blackwood, H.J.J.
London, Heinemann Medical Books Ltd.

Blaschke, D.D., Blaschke, T.J.
Normal TMJ bony relationships in centric occlusion.

Blaschke, D.D., Solberg, W.K., Sanders, B.
Arthrography of the temporomandibular joint: Review of current status.

Boskamp, E.

Boskamp, E.
Improved surface coil imaging by decoupling of excitation coil and receiver coil in MR tomography. Radiology, received for publication October 1985.

Braun, M., McCarthy, A.L.
NMR images produced in a substantially non-uniform field.
Bronstein, S.L., Tomasetti, B.J., Ryan, D.E.  
Internal derangements of the temporomandibular joint: Correlation of arthrography with surgical findings.  

Brooks, S.L., Lanzetta, M.L.  
Absorbed dose from temporomandibular joint radiography.  

Buddemeyer, E.U.  
The physics of diagnostic ultrasound.  

Buhner, A.G.  
A headholder for orientated temporomandibular joint radiographs.  

Bussard, D.A., Kerr, G., Hutton, C., Yune, H.  
Technique and use of "corrected axis" tomograms of the mandibular condyles.  

Campbell, J.H.  
Ultrasound imaging of the temporomandibular joint: Feasibility studies in cadaver specimens.  
Case reports and scientific sessions 66th. annual meeting.  

Campbell, W.  
Clinical radiological investigations of the mandibular joints.  

Carlsson, G.E.  
Mandibular dysfunction and temporomandibular joint pathosis.  

Iron and gadolinium chelates as contrast agents in NMR imaging: Preliminary studies.  
Chiver, R.C.
Ultrasonic imaging and analysis of tissue texture.
In Jackson (Editor), Imaging with non-ionizing radiations.
London, Surrey University Press.
pp 50-84, 1983.

Chomenko, A.G.
Comparing normal pantomographic jaw anatomy.

Chomenko, A.G.
Structure of the TMJ as viewed on the pantomograph.

Christensen, F.G.
Some anatomical concepts associated with the temporomandibular joint.

Christiansen, E.L., Thompson, J.R.

Cisneros, G.J., Kaban, L.B.
Computerized skeletal scintigraphy for assessment of mandibular asymmetry.

Coen, C.G.
Tomography of the temporomandibular joint.

Internal derangement of the temporomandibular joint: Detection by single-photon emission computed tomography.

Craemer, T.D., Ficara, A.J.
The value of the nuclear medical scan in the diagnosis of temporomandibular joint disease.

Crocker, E.F.
Grey scale ultrasound: Its impact on clinical basis.
Crocker, E.F., Jellins, J.
Grey scale ultrasonic examination of the thyroid glands.

Davis, P.L., Crooks, L., Arakawa, M., McRae, R.,
Kaufman, L., Margulis, A.R.
Potential hazards in NMR imaging: Heating effects of changing magnetic fields and RF fields on small magnetic implants.

Dolwick, M.F., Katzberg, R.W., Helms, C.A., Bales, D.J.
Arthrotomographic evaluation of the temporomandibular joint.

Doyle, T., Hase, M.
The clicking painful temporomandibular joint: Use of arthrography in diagnosis.

DuBrul, E.L.
St.Louis, C.V. Mosby Co.

Encyclopaedia Britannica.
Chicago, Benton.

Eckerdal, O.
Tomography of temporomandibular joint: Correlation between tomographic image and histologic sections in a three-dimensional system.

Eckerdal, O., Lundberg, M.
The structural situation in temporomandibular joints: A comparison between conventional oblique transcranial radiographs, tomograms and histologic sections.

Farrar, W.B.
Diagnosis and treatment of anterior dislocation of the disc.
Farrar, W.B., McCarty, W.L.
Inferior joint space arthrography and characteristics of condylar paths in internal derangements of the TMJ.

Fjellstroem, C-A., Olofsson, O.
Computed tomography of the temporomandibular joint meniscus.

Fortier, P., Glover Jr., J.A.
St.Louis, C.V. Mosby Co.
pp 3-12, 1982.

Frame, J.W., Wake, M.J.C.
The value of computerized tomography in oral surgery.

Frame, J.W., Wake, M.J.C.
evaluation of maxillofacial injuries by use of computerized tomography.

Fujii, N., Yamashiro, M.
Computed tomography for the diagnosis of facial fractures.

Fujii, N., Yamashiro, M.
Classification of malar complex fractures using computed tomography.

Goldstein, H.A., Bloom, C.Y.
Detection of degenerative tissue of the temporomandibular joint by bone scintigraphy: Concise communication.

Griffiths, R.H.
Report of the President's conference on the examination and management of temporomandibular disorders.

Hall, M.B., Gibbs, B.B., Welsch, A.G.
Association between prominence of the TMJ eminence and meniscus.
Harms, S.E., Wilk, R.M., Wolford, L.M., Chiles, D.G., Milam, S.B.
The temporomandibular joint: Magnetic resonance imaging using surface coils.

Hayes, C.
Surface coil imaging. In Magnetic Resonance Imaging of the Temporal Bone.
Milwaukee, General Electric.

Hellsing, G., Holmlund, A., Nordenram, A., Wredmark, T.
Arthroscopy of the temporomandibular joint: Examination of 2 patients with suspected disk derangement.

Helms, C.A., Morrish Jr., R.B., Kircons, L.T., Katzberg, R.W., Dolwick, M.F.
Computed tomography of the meniscus of the temporomandibular joint: Preliminary observations.

Helms, C.A., Katzberg, R.W., Morrish, R., Dolwick, M.F.
Computed tomography of the temporomandibular joint meniscus.

Helms, C.A., Richardson, M.L., Moon, K.L., Ware, W.H.
Nuclear magnetic resonance imaging of the temporomandibular joint: Preliminary observations.

Henny, F.A.
St. Louis, C.V. Mosby Co.

Herman, G.T., Coin, C.G.
The use of three-dimensional computer display in the study of disk disease.

Hill, C.R.
Biological effects of ultrasound. In Goldberg and Wells (Editors), Ultrasonics in Clinical Diagnosis.
3rd. edition.
London/New York, Churchill Livingstone.
pp 228-236, 1983.
Holmlund, A., Hellsing, G.
Arthroscopy of the temporomandibular joint. An autopsy study.

Hounsfield, G.N.
Computerized transverse axial scanning (tomography)
Part 1. Description of system.

Ioannides, C., Scaf, J.
Perforation of the intra-articular disc diagnosed by arthro-tomography of the temporomandibular joint.

Isberg-Holm, A.M., Westesson, P-L.
Movement of the disc and condyle in temporomandibular joints with and without clicking. A high-speed cinematographic and dissection study on autopsy specimens.

Jackson, D.F., Kouris, K.
The role and potential of new imaging methods. In Jackson (Editor), Imaging with non-ionising radiations.
London, Surrey University Press.
PP 1-49, 1983.

James Jr., A.E., Goddard, J., Price, P.R., Jones, T.B., Powis, R.L.
Advances in instrument design and image recording.

Johnson, R.S.
3D surface imaging brings CT scans to life.

Jones, C.H.
Thermal imaging. In Jackson (Editor), Imaging with non-ionizing radiations.
London, Surrey University Press.
pp 151-216, 1983.

Jones, J.K., Frost, D.E.
Ultrasound as a diagnostic aid in maxillofacial surgery.
Kaban, L.B., Cisneros, G.J., Heyman, S., Treves, S.
Assessment of mandibular growth by skeletal scintigraphy.

Katzberg, R.W., Dolwick, M.F., Helms, C.A., Hopens, T.,
Bales, D.J., Coggs, G.C.
Arthrotomography of the temporomandibular joint.

Katzberg, R.W., Dolwick, M.F., Keith, D.A., Helms, C.A.,
Guralnick, W.C.
New observations with routine and CT-assisted arthrography in suspected internal derangements of the temporomandibular joint.

Katzberg, R.W., Keith, D.A., Guralnick, W.C., Manzione, J.V., Ten Eick, W.R.
Internal derangements of the temporomandibular joint and arthritis.

Magnetic resonance imaging of the temporomandibular joint meniscus.

Kelly, W.M., Brant-Zawadzki, M., Norman, D., Kyos, B., Newton, H.
Advantages of magnetic resonance imaging (MRI) Vs computerized tomography (CT) for detection and characterization of intracranial tumours.

Klein, I.E., Blatterfein, L., Miglino, J.C.
Comparison of the fidelity of radiographs of mandibular condyles made by different techniques.

Kopp, S., Rockler, B.
Relationship between radiographic signs in temporomandibular joint and hand joints.

Kozam, G.
The temporomandibular joint from the viewpoint of the anatomist.
Krietziger, K.L., Mahan, P.E.

Langland, O.E., Langlais, R.P., Morris, C.R.

Langland, O.E., Langlais, R.P., Morris, C.R.

Laskin, D.M.

Leo, F.B., Rao, G.U.V.

Leopold, G.R.

Lewis, G.R.


Lund, T.M., Mason-Hing, L.R.

Lysell, L., Petersson, A.

262
Madsen, B.
Normal variations in anatomy, condylar movements and arthrosis frequency of the temporomandibular joints.

Manco, L.G., Messing, S.G.
Splint therapy evaluation with direct sagittal computed tomography.

Manning, D.J.
The construction and operation of modern gamma camera systems: a teaching article.

Manzione, J.V., Seltzer, S.E., Katzberg, R.W., Hammerschlag, S.B., Chiango, B.F.
Direct sagittal computed tomography of the temporomandibular joint.

Manzione, J.V., Tallents, R., Katzberg, R.W., Oster, C., Miller, T.L.
Arthrographically guided splint therapy for recapturing the temporomandibular joint meniscus.

Manzione, J.V., Katzberg, R.W., Brodsky, G.L., Seltzer, S.E., Mellins, H.Z.
Internal derangements of the temporomandibular joint: Diagnosis by direct sagittal computed tomo-
graphy.

Matterson, S.R., Proffit, W.R., Terry, B.C., Staab, E.V., Burkes Jr., E.J.
Bone scanning with 99m technetium phosphate to assess condylar hyperplasia.

Maue-Dickson, W., Telfer, M., Dickson, D.R.
Comparison of dosimetry and image quality in computed and conventional tomography.

McCullough, E.C., Payne, J.T.
Patient dosage in computed tomography.
Merritt, G., Farman, A., George Jr., D., Chu, A., Blair, R.
Computerized tomography, panoramic dental radiography and lateral oblique projections for mandibular cortical and medullary defects: A comparative study.

Mikhail, M.G., Rosen, H.
The validity of temporomandibular joint radiographs using the head positioner.

Miller, D., Dawes, A.T., Cowie, J.W.
CT-routine examination of the petrous temporal bone using high-resolution multiplanar reconstruction techniques.

Moloney, F.
Internal derangements of the temporomandibular joint. I. Clinical and radiological diagnosis.

Murakami, K-I., Matsumoto, K., Iizuka, T.

Murphy, W.A.
Arthrography of the temporomandibular joint.

Naughton, A., Hart, C.W., Jenkins, J.P.R., Isherwood, I.
"Teach-in" on magnetic resonance imaging.

Nelson, T.R.
Computers hold the key to medical imaging's future.

Potential hazards and artifacts of ferromagnetic and nonferromagnetic surgical and dental materials and devices in nuclear magnetic resonance imaging.

Norgaard, F.
Arthrography of the mandibular joint.
North, A.F., Rice, J.
Computed tomography in oral and maxillofacial surgery.

Oberg, T., Carlsson, G.E.; Fajers, C.M.
The temporomandibular joint. A morphologic study on a human autopsy material.

Omnell, K.A., Petersson, A.
Radiography of the temporomandibular joint utilizing oblique lateral transcranial projections.

O'Regan, F., Epker, B.N.
Temporomandibular joint function and morphology: Observations on the spectra of normalsy.

Osbourne, A.G., Anderson, R.E.
Direct sagittal scans of the face and paranasal sinuses.

Pogrel, M.A.
Quantitative assessment of isotope activity in the temporomandibular joint regions as a means of assessing unilateral condylar hypertrophy.

Poyton, H.G.
Oral Radiology.
Baltimore, Williams and Wilkins.
pp 311-328, 1982.

Preti, G., Arduino, A., Pera, P.
Consistency of performance of a new craniostat for oblique lateral transcranial radiographs of the temporomandibular joint.

Price, R.R., Jones, T.B., Goddard, J., James Jr., A.E.
Basic concepts of ultrasound tissue characterization.

Pykett, I.L.
NMR imaging in medicine.
Sci.Amer. 246: 54-64, 1982.
Quantrill, J.R., Lewis, J.E.S.
The interpretation of temporomandibular joint radiographs.

Ram, C., Pettigrew, J.C., Roberts, D., Udupa, J.
Comparative evaluation of condyle pathology via 3D image reconstruction.

Readman, L.P.
Reconstruction technique in high resolution computed tomography.

Rees, L.A.
The structure and function of the mandibular joint.

Ricketts, R.M.
Laminography in the diagnosis of temporomandibular joint disorders.

Roberts, D., Pettigrew, J., Udupa, J., Ram, C.
Three-dimensional imaging and display of the temporomandibular joint.

Rosenberg, H.M., Silha, R.E.
TMJ radiography with emphasis on tomography.

Rosencweig, D.
Three-dimensional tomographic study of the temporomandibular articulation.

Rosencweig, D., Martin, G.
Selective tomography of the TMJ and myofacial pain-dysfunction syndrome.

Rottke, Dr.Dr.
A two year review of the Siemens Zonarc.

Ryan, D.E., Collier, B.D., Messer, E., Moloney, F.
Internal derangements of the temporomandibular joint. II. Use of bone scanning as an aid to diagnosis.
Sartoris, M.D., Neumann, M.D., Riley, R.W.
The Temporomandibular Joint: True sagittal computed
tomography with meniscus visualization.

Semple, J., Gibb, D.
The place of rotational tomography in dentistry. 1.
History and development of rotational tomography.

Sicher, H.
Problems of pain in dentistry.

Sicher, H.
Temporomandibular articulation: Concepts and misconceptions.
1962.

Smith, N.J.D., Harris, M.
Radiology of the temporomandibular joint and condylar head.

Solberg, W.K., Woo, M.W., Houston, J.B.
Prevalence of mandibular dysfunction in young adults.

Spranger, H.
Ultrasonography of the jawbone, temporomandibular joint and teeth. In M. de Vlieger (Editor), Handbook
of Clinical Ultrasound.
New York, John Wiley and Sons.

Stanson, A.W., Baker Jr., H.L.
Routine tomography of the temporomandibular joint.

Tallents, R.H., Katzberg, R.W., Miller, T.L., Manzione,
J.V., Osler, C.
Evaluation of arthrographically assisted splint therapy in treatment of TMJ disk displacement.

Taylor, R.C., Ware, W.H., Fowler, D., Kobayashi, J.
A study of temporomandibular joint morphology and
its relationship to the dentition.
Thompson, J.R., Christiansen, E., Hasso, A.N., Hinshaw Jr., D.B.
Temporomandibular joints: High resolution computed tomographic evaluation.

Thornton, M.
An ABC of NMR. A guide to the physics and terminology.

Toller, P.A.
Osteoarthrosis of the mandibular condyle.

Toller, P.A.
Temporomandibular capsular rearrangement.

Toller, P.A.
Opaque arthrography of the temporomandibular joint.

Trapnell, D.H.
Diagnostic radiography: Computerised tomography and maxillofacial injuries. In Rowe and Williams (Editors), Maxillofacial Injuries.

Trefler, M., Haughton, V.M.
Patient dose and image quality in computed tomography.

Uematsu, S., Hendler, N., Hungerford, D., Long, D., Ono, N.
Thermography and electromyography in the differential diagnosis of chronic pain syndromes and reflex sympathetic dystrophy.

Vinocur, B.
MRI INSIGHTS. Concern over the bioeffects lingers despite appearance of safety.

Weinberg, L.A.
An evaluation of duplicability of temporomandibular radiographs.
Weinberg, L.A.
Technique for temporomandibular joint radiographs.

Weinmann, J.P., Sicher, H.
Pathology of the temporomandibular joint. In Sarnat (Editor), The Temporomandibular Joint.
Illinois, Thomas Springfield.
pp 45-81, 1951.

Weissman, D.D.
Comparative absorbed doses in dental radiographs.
III. Special projections.

Wells, P.N.T.
Physics and instrumentation. In Goldberg and Wells
(Editors), Ultrasonics in Clinical Diagnosis. 3rd.
edition.
London/New York, Churchill Livingstone.
pp 1-30, 1983.

Westesson, P.-L.
Double contrast arthrotomography of the temporoman-
dibular joint: Introduction of an arthrographic
 technique for visualization of the disc and artic-
 ular surfaces.

Wilkes, C.H.
Arthrography of the temporomandibular joint in
 patients with the TMJ pain-dysfunction syndrome.

Wilson, I.R., Crocker, E.F.
An introduction to ultrasonography in oral surgery.

Yale, S.H., Allison, B.D., Hauptfuehrer, J.D.
An epidemiological assessment of mandibular condyle
 morphology.

Young, S.W.
Nuclear Magnetic Resonance Imaging.
Basic principles.
Selected abstracts.

Yune, H., Hall, J.R., Hutton, C.E., Klatte, E.G.
Roentgenologic diagnosis in chronic temporomandib-
ular joint dysfunction syndrome.
Zech, J.M.
A comparison and analysis of three technics of taking roentgenograms of the temporomandibular joint.

Zetz, M.R., Irby, W.B., Doles, L.R.
A simplified method for injection or aspiration of the temporomandibular joint.

Zonneveld, F.W., Vijverberg, G.P.
The relationship between slice thickness and image quality in CT.