THE USE OF ABDOMINAL DERMIS-FAT GRAFTS IN THE SURGICAL RECONSTRUCTION OF THE TEMPOROMANDIBULAR JOINT FOLLOWING DISCECTOMY.

A thesis submitted in total fulfillment of the requirements for the Degree of

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by

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PREFACE

i. Abstract

The surgical removal of the articular disc, otherwise referred to as discectomy, is an effective treatment for advanced stage internal derangement of the temporomandibular joint (TMJ) that fails to respond to lesser surgical and non-surgical measures. While the long term results of discectomy appear very good for relief of pain, the functional outcomes in terms of smoothness of joint action is less than ideal in cases where the disc is not replaced. Efforts to find a disc substitute that is safe and effective in facilitating the smooth, pain free function of the TMJ following discectomy has met with limited success over the last half century. The abdominal dermis-fat graft is one potential interpositional material that could be used in the TMJ. The aim of this THESIS is to determine if the autogenous abdominal dermis-fat graft is a safe and effective interpositional material when placed into the TMJ following removal of the disc. One animal and four human studies were undertaken as part of this THESIS to assess whether the abdominal dermis-fat graft satisfies the criteria for an ideal disc substitute in the TMJ. While the results show that the abdominal dermis-fat graft is largely promising as a disc substitute, there are still problems that make it less than ideal. In particular, the abdominal dermis-fat graft fails to protect the mandibular condyle from severe remodeling in about one-third of cases, and about 6.5% of cases result in the need for a total joint replacement within 4 years of the initial surgery. The abdominal dermis-fat graft is a safe and effective material for use in the TMJ but more work needs to be done to determine the factors required to improve its success in protecting the condyle from degeneration.
ii. Acknowledgements

The candidate would like to acknowledge the following individuals and institutions that helped make this THESIS possible. The experimental protocol was supervised by Professor Wayne Morrison AM from the Department of Surgery, St Vincent’s Hospital, University of Melbourne in conjunction with Associate Professor Michael McCullough from the Melbourne Dental School, Faculty of Medicine, Dentistry and Health Sciences, University of Melbourne. Assistance and advice with the experimental protocol was provided by Associate Professor John Slavin from the Department of Anatomical Pathology, St Vincent’s Hospital, University of Melbourne and Dr Nick Trost, MRI Department, St Vincent’s Hospital, University of Melbourne. The experiments were performed with the assistance of staff from the Experimental Medicine and Surgery Unit, the MRI Department and the Department of Anatomical Pathology, St Vincent’s Hospital, as well as the Oral Medicine and Pathology Department of the Melbourne Dental School, University of Melbourne. Financial support for the candidate and departments were provided by grants from the Australian & New Zealand Association of Oral & Maxillofacial Surgeons (ANZAOMS) Foundation and the St.Vincent’s Hospital Grants and Research Unit.
iii.Declaration

This is to certify that;

1. The thesis comprises only my original work except where indicated in the acknowledgements

2. Due acknowledgement has been made in the text to all other material used

3. The thesis is less than 100,000 words in length exclusive of tables, illustrations, bibliography and appendices

4. This thesis has not been submitted for the award of any other degree or diploma in any other institution.

Signed____________________________________

George Dimitroulis
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B. Addition of Appendix 6 – Candidate’s TMD publications in peer-review

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*These are the revisions recommended by Examiner No.2 which are placed in the discussion section of Chapter 9.
v. Publications

Publications arising directly from this thesis;

**Dimitroulis G.** The use of dermis grafts after discectomy for internal derangement of the temporomandibular joint


**Dimitroulis G & Slavin J.** Histological evaluation of full thickness skin as an interpositional graft in the rabbit craniomandibular joint

*J Oral Maxillofac Surg* 2006; 64: 1075-80

**Dimitroulis G.** The interpositional dermis-fat graft in the management of temporomandibular joint ankylosis


**Dimitroulis G, Trost N, Morrison W.** The radiological fate of dermis-fat grafts in the human temporomandibular joint using magnetic resonance imaging


**Dimitroulis G, McCullough M, Morrison W.** Quality of life survey comparing patients prior to and following discectomy of the temporomandibular joint

*J Oral Maxillofac Surg* 2010; 68:101-6
vi. General Aims & Overview of Thesis

Removal of the articular disc, or discectomy, is occasionally required in the surgical treatment of advanced internal derangement of the temporomandibular joint (TMJ). There is still, however, no ideal disc replacement material following TMJ discectomy that fully satisfies the criteria of long-term safety, improved joint function and protection against regressive remodeling of the condyle. While there has been much published on various grafts, little has been written on the abdominal dermis-fat graft and its use in the TMJ. The aim of the research, which is the basis for this THESIS, is to test the hypothesis that the abdominal dermis-fat graft is safe and effective as an interpositional material when implanted into a functional joint (TMJ) space. Using one animal and four human studies, this THESIS will explore the usefulness of the abdominal dermis-fat graft in facilitating the smooth pain free function of the TMJ and protecting the condyle from degeneration.

There are 10 chapters in this THESIS that will attempt to answer whether the abdominal dermis-fat graft is the ideal disc replacement material for use in the human temporomandibular joint. Chapter 1 will explore the history and background of the various treatment options for TMJ internal derangement and will specifically discuss disc substitutes used over the last half century. Chapter 2 identifies the reasons why the Candidate chose the abdominal dermis-fat graft as the subject for this THESIS. Chapters 3 (Aims & Hypotheses) and 4 (Materials & Methods) are self-explanatory. Chapter 5 is an animal study using rabbits to determine the safety and survival mechanism of the dermis-fat graft and to compare the different recipient sites for the graft (i.e. TMJ and ear) in order to see whether a functional space (i.e. TMJ) results in better survival of the graft compared to a static space (i.e. base of ear). Also to be examined in Chapter
5 is the role of the dermis component in the survival and maintenance of the fat. In the first of four human studies, chapter 6 will compare two groups of closely matched patients before and after TMJ surgery involving discectomy with interpositional dermis-fat graft from the abdomen. Using the newly devised TMJ Surgery – Quality of life questionnaire specifically developed for this project, outcome measures will be analyzed to determine if TMJ discectomy with dermis-fat grafting significantly improves the quality of life of patients, compared to those who have not had the surgery.

The fate of the dermis-fat graft in-vivo will be assessed in chapter 7 using magnetic resonance imaging of patients who have undergone the surgical procedure of TMJ discectomy with dermis-fat grafting. In particular, radiological signs of dermis-fat within the joint space will be studied and measured topographically and volumetrically over three time periods. The status of the underlying condyle, and whether the dermis-fat graft protects it from degeneration, is the subject of chapter 8. Using orthopantomograms of patients who had undergone TMJ discectomy with dermis-fat grafting, the radiological integrity of the condyles will be assessed using the “Condylar Morphology Scale” that was developed and validated in the literature as the most appropriate tool for investigating the status of mandibular condyles using tomograms. And finally, confirmation of the survival of dermis-fat grafts within the TMJ will be provided in chapter 9, where dermis-fat grafts will be surgically retrieved from the joints and histological proof of dermis-fat elements within the retrieved specimens will be sought. Based on the findings of the research undertaken for this THESIS, chapter 10 will review the validity of the hypotheses developed with respect to the clinical usefulness of the abdominal dermis-fat graft in TMJ surgery and recommendations will be made as to what the future implications are for the dermis-fat graft in TMJ surgery.
1.1 – INTRODUCTION

Our understanding of Temporomandibular joint (TMJ) disease is still rudimentary compared to that of the hip, knee and shoulder. This is partly due to the functional complexity of the TMJ that depends on the teeth and occlusion which limits and guides certain movements. The complexity of the TMJ is further compounded by the relative small size of the joint as well as the detailed surrounding anatomy which severely limits access for study (Rayne, 1987; Howerton & Zysset 1989). Our reliance on the orthopaedic literature to help shed light on the various aspects of TMJ pain and dysfunction has met with little success as the TMJ is a unique joint in the body that has few similarities with other joints in the body (Norman & Bramley, 1990).

The TMJ differs from most other joints in the body in a number of ways. Firstly, the articular surfaces are covered by fibrocartilage rather than hyaline cartilage. Secondly, both joints must function together as a unit and therefore cannot function independently. And finally, the TMJ is a ginglymoarthrodial joint capable of both rotational (i.e. hinge or ginglymal) and translatory (i.e. gliding or arthrodial) movement. In a fundamental way, the TMJ is pivotal to mandibular form and function. Disease, trauma or deformity involving one or both TMJ’s will not only have an adverse impact on mandibular function, but will, depending on the age of the patient and severity of the disorder, impact on the growth and symmetry of the lower third of the face (Dimitroulis, 1997).

There are three anatomical sites where the mandible connects to the rest of the craniofacial skeleton and these consist of two temporomandibular joints (TMJ) and the occlusal table. For many years it was thought that changes in the occlusion would have a direct effect on the structural and functional integrity of the TMJ’s. Interestingly, missing teeth and reduced vertical dimension were the earliest original theories proposed in the early part of the 20th century as the pathophysiological mechanism of TMJ pain and dysfunction (Costen, 1934). Many occlusal theories on TMJ pain and dysfunction were devised by the Dental profession which resulted in the development of occlusal splints as a means of balancing the three contact points of the mandible to the rest of the facial skeleton. It was widely thought that balancing the occlusion
would facilitate the functional equilibrium of both TMJ’s which would not only reduce the symptoms of temporomandibular disorder (TMD) but also prevent any adverse changes to the TMJ’s. Since Dentistry took on the role of research and clinical management of TMJ disorders (McNeill, 1993; Okerson, 2003), occlusion was, for a long time, the main focus of Temporomandibular Disorders (TMD) which overshadowed the importance of intra-articular pathology of the TMJ. With the passage of time, and after extensive research, there was little correlation found between occlusion and TMD (Forssell & Kalso, 2004; Hirsch, John, Drangsholt & Mancl, 2005). Infact, there is little evidence to support occlusal adjustment (Koh & Robinson, 2003) and the use of occlusal splints (Forssell & Kalso, 2004) as effective modalities in the treatment of TMD. Nevertheless, the Dental profession, undeterred by failure of the occlusal theory, still managed to bypass the TMJ and turned their attention to psychogenic and neuromuscular disorders to help explain the phenomenon of TMD.

With the introduction of TMJ arthroscopy and Magnetic Resonance Imaging (MRI), clear evidence emerged of actual joint pathology in a significant proportion of patients presenting with clinical features of TMD (Dimitroulis, 2005a). The significance of this is that a disease oriented treatment plan would include surgical intervention, which, as far as the Dental profession is concerned, is still widely considered to be a treatment option of last resort. In reviewing the literature, the aim is to critically evaluate our current understanding and surgical management of one of the most common TMJ disorders; internal derangement (ID), specifically as it relates to the articular disc and the role of autogenous grafts, in particular the abdominal dermis-fat graft, as potential replacement tissues following discectomy.

1.2 – Applied Anatomy of the TMJ

1.2.1 – Embryology

Development of the TMJ begins about the 8th or 9th week of gestation. The initial primitive (primary) joint between the mandible and the skull base is formed by the malleus (Meckle’s cartilage) and the incus which eventually go on to develop into the middle ear. The articular
disc, synovial tissues, joint capsule and articular cartilage of the definitive or secondary joint begin to develop between the 10th and 17th weeks of gestation. The TMJ develops from two cellular condensations: a temporal and a condylar blastema. The secondary cartilage growth appears by the 10th week of gestation. At 10 weeks, the mesenchyma between the condylar cartilage of the mandible and the developing temporal bone begins to differentiate. According to Molina and co-workers, (2005) the histological maturation of the articular disc begins at the 12th week and is complete by the 16th week of gestation. Complete development of the joint components occurs after the 21st week (Sperber, 1976). What role the common origin of the TMJ and middle ear has to play in some TMD symptoms is yet to be fully elucidated. The presentation of tinnitus or earache (ie. otalgia) in the absence of ear pathology is a not too uncommon symptom of TMD that has yet to be explained (Chan & Reade, 1994).

1.2.2 – POST-NATAL GROWTH & DEVELOPMENT

The condyle develops via endochondral ossification while the temporal bone (i.e. glenoid fossa) is via intramembranous ossification. In the early years (0-2 yr) the condylar neck is thick and short and engages a shallow glenoid fossa with a poorly defined articular eminence. The condylar head harbours extensive vascular channels with a thick cartilaginous cap. In childhood (3-12 yr) a more adult like configuration of the condylar process and glenoid fossa develops with a more clearly defined articular eminence. Excellent regeneration and remodeling potential is found in this age group.

According to the functional matrix theory (Moss, 1968; Moss, 1969) the condyle is considered as a site of secondary adaptation to the demands of mandibular growth rather than as the primary growth centre. The teenage years (13-18 yr) are endowed with good capacity for new bone formation but lack the excellent remodeling potential of the younger age group. In the adult, the TMJ continues to adapt to functional changes and demands of jaw function throughout life, although degenerate joint disease in the latter years appears to reflect the diminished healing capacity of the joint with age.
1.2.3 – THE CONDYLAR HEAD

The mandibular condyle is a bony process that is attached to the base of the skull by a funnel shaped capsule which encloses the TMJ. The adult condyle is roughly elliptical in the axial plane. The mediolateral dimension is approximately twice the size of its anteroposterior width. For this reason, it is rare for the condyle to penetrate into the middle cranial fossa because the medial and lateral poles are too wide and impact the lateral rim of the glenoid fossa during traumatic episodes. The mediolateral axis of the condyle is between 15° and 33° to the coronal plane which makes true joint movements difficult to replicate on a laboratory articulator.

The mandibular condyle is the key to the form and function of the mandible. Damage or disease afflicting the condyle will adversely affect mandibular function, occlusion and lower facial asymmetry (Dimitroulis, 1997). The condyle-fossa concentric relationship varies according to the size and shape of the disc, so it is not a reliable determinant of joint pathology. The surface of the condyle is made up of fibrocartilage with type 1 collagen which is similar to that found in bone. The elasticity, resistance to compression and osmotic properties of the fibrocartilage is largely due to the proteoglycan ground substance.

1.2.4 – THE ARTICULAR DISC AND ITS ATTACHMENTS

The articular disc is a flexible, biconcave fibrocartilagenous ligament which acts as a functional buffer zone between the condyle and cranial base (i.e. temporal bone) that serves to reduce joint friction, distribute loads, and reduce the incongruence between the joint’s bony surfaces. The disc divides the joint space into superior and inferior compartments. The inferior joint space allows rotation of the condyle on initial mouth opening. Further mouth opening beyond 27mm to 30mm interincisal distance is facilitated by the superior joint space that permits translation or forward sliding of the condyle over the articular eminence. Loss of translatory movement due to pathology involving the superior joint space will limit mouth opening to less than 30mm interincisal distance.
In 1954, Rees (Rees, 1954) described the gross anatomy of the articular disc as being composed of 3 zones; the posterior band (3mm thick), the intermediate zone (1.5mm thick) and anterior band (2mm thick). The normal resting position of the disc is taken as the posterior band seated at the 12 o’clock position with respect to the condyle. In centric occlusion, condylar pressure is exerted through the thin intermediate zone onto the posterior slope of the articular eminence. Varying degrees of displacement of the disc are frequently found within the non-patient population which may well be considered a variant of normal. (Dolwick & Dimitroulis, 1996). However, despite this, disc displacement continues to be thought of as the basis for internal derangement of the TMJ as we shall see later.

At the histological level, the articular disc consists of avascular collagen with some cartilaginous elements. The TMJ disc cell population is approximately 70% fibroblast like (i.e., spindle shaped) and 30% chondrocyte like (i.e., round cells) with sparse contributions from other cell types (Detamore, Hegde, Wagle et al 2005). Within the population of fibroblasts, there is a subpopulation of fibrochondrocytes which are distinguished on the basis of exhibiting chondrocytic markers but lacking visible pericellular matrix (Landesberg, Takeuchi & Puzas, 1996). It has been reported that cells towards the periphery of the disc tend to be fibroblastic while cells in the centre of the disc are more chondrocytic (Detamore, Hegde, Wagle et al 2006), the distribution of which changes as a function of the patient’s age, gender and medical condition (Nakano & Scott, 1996).

Unlike other hyaline cartilage (i.e. collagen type II), the TMJ disc is almost entirely collagen type 1, with only trace amounts of collagen type II (Milam, Klebe, Triplett & Herbert, 1991). Elastin fibers are found in much smaller amounts relative to collagen and tend to be more prevalent on the superior surface and periphery of the TMJ disc (Keith, 1979). The collagen fibril distribution within a matrix of sulphated glycosaminoglycans is designed to resist compression as well as tension forces (Allen & Athanasiou, 2006). Biomechanical experiments have demonstrated that the superior surface of the disc experiences mainly tensile stresses while the inferior surface experiences mainly compressive forces, particular in the posterior band, during the chewing cycle (Donzelli,
Gallo, Spilker & Palla, 2004). Because of its avascular nature, the disc has a very poor capacity for healing (Ten Cate 1989).

The disc is firmly attached to the medial and lateral poles of the condyle via discal ligaments and is continuous anteriorly with the anterior capsule (Wilkinson, 1988) which is attached superiorly to the anterior slope of the articular eminence. While early anatomical studies (Rees, 1954) reported a direct attachment of the anterior edge of the disc to the superior head of lateral pterygoid muscle, more recent studies have found the majority of fibres of the superior head of lateral pterygoid muscle attach to the condyle with only a few fibres found attached to the anteromedial part of the disc (Schmolke 1994, Marguelles-Bonnet, Yung, Carpentier & Meunissier, 1989). A recent cadaver study found that no fibres of the superior head of lateral pterygoid were attached to the disc but instead terminated within the capsule under the disc (Christo, Bennett, Wilkinson & Townsend, 2005). Despite this, it was also found that activation of the superior head of lateral pterygoid muscle still produced tension to the disc even though no muscle fibres were found directly attached to the disc itself. (Christo, Bennett, Wilkinson & Townsend, 2005; Wilkinson & Chan, 1988; Wilkinson, 1989). This is further supported by a recent immunohistochemical study on porcine TMJ discs which failed to find any direct evidence of actual muscle fibre insertion into the disc although a tendinous insertion could not be ruled out (Detamore, Hegde, Wagle et al 2006).

The lateral pterygoid muscle is made up of two components which contract independently during opening and closing cycles of the jaws (Juniper, 1981). However, recent data indicate that these concepts may perhaps be too simplistic as the superior head has been found to consist of three mediolaterally arranged functional zones (Phanachet, Whittle, Wanigaratne et al, 2003) that may independently contract in both opening and closing cycles of the mandible. (Murray, Phanachet, Uchida & Whittle 2004). The lack of co-ordinated activity between the superior and inferior heads of lateral pterygoid muscle was once thought to be implicated in disc displacement that resulted in clicking and/or locking of the TMJ. However, electromyographic and cadaver studies have found no relationship between the activity of the lateral pterygoid muscle and disc displacement. Instead it is
currently thought that the essential role of the lateral pterygoid muscle is in the generation of side-to-side and protrusive movements of the jaw (Murray, Phanachet, Uchida & Whittle, 2004).

Posteriorly, the disc is anchored to fibres of the bilaminar zone which is otherwise referred to as the retrodiscal tissues or posterior attachment. Scapino (1991) described the retrodiscal tissue as composed of three parts; the superior lamina which he referred to as the temporal part of the posterior attachment (TPA) and the inferior lamina which he described as the condylar part of the posterior attachment (CPA). In between these two was the intermediate part of the posterior attachment (IPA). The superior lamina (TPA) is attached to the squamotympanic fissure and is composed of fibroelastic tissue that allows disc retraction as the mouth closes and at the same instance counterbalances the contraction forces of the superior head of lateral pterygoid muscle.

Two studies, however, refute the concept of an elastic superior lamina that has a recoil mechanism to control disc movement (Wilkinson & Crowley, 1994; Christo, Bennett, Wilkinson & Townsend, 2005). The inferior lamina (CPA) is attached to the back of the condyle and is composed of compact, non-elastic collagen fibres. The region between the lamellae (IPA) is made of loose fibrofatty tissue which is penetrated by vascular elements, in particular an extensive venous plexus and neural tissue containing pain and proprioceptive fibres. The loose fibrofatty tissue acts as a space filler in regions vacated by the condyle during functional excursions. That is, most of the expansion of the bilaminar zone that occurs during condylar movements takes place in the IPA.

1.2.5 - GLENOID FOSSA & ARTICULAR EMINENCE

The TMJ articulates with the cranial base through the temporal bone, namely the glenoid fossa and the articular eminence. The glenoid fossa is a concave bony structure covered with a thin layer of articular fibrocartilage, above which lies the middle cranial fossa. While the roof of the glenoid fossa is relatively thin and easily penetrated, the raised edges of the fossa are thick and consist of compact cortical bone which can resist the impact
of the lateral and medial pole of the condyle during traumatic incidents that may force the condyle superiorly into the cranial base.

The squamotympanic fissure forms the posterior boundary of the glenoid fossa and suture between the squamous portion of temporal bone and greater wing of sphenoid forms the medial boundary of the fossa. Anteriorly it is continuous with posterior slope of the articular eminence which is covered with a relatively thick layer of fibrocartilage. The articular eminence forms the root of the zygomatic arch. The posterior slope has an average angle of 60° which guides the condylar head downwards as it translates forwards during mandibular opening. It has been speculated that the steeper the angle of the articular eminence, the greater the likelihood of anterior disc displacement. A steep eminence is thought to increase the risk of ligament elongation because of the greater condylar-disc movement required to overcome the steep angle. (Hall, Brown & Sclar 1984; Okerson, 2003). However, Alsawaf and co-workers (1989) failed to find any positive association between TMJ clicking and the slope of the eminence.

1.2.6 – The Synovium & Synovial Fluid

The synovium of the TMJ is a membrane that lines all the internal surfaces of the joint except for the disc and articular cartilage (Ten Cate, 1989). While the main function of the synovial membrane is the production of synovial fluid, the synovium is also involved in the rapid diffusion of nutrients into the joint cavity as well as phagocytosis, degradation and removal of debris out of the joint. The synovial membrane is made up of an intimal layer of synovial cells one to four cells deep. There are two types of synovial cells. Type A cells have prominent golgi apparatus while Type B have extensive rough endoplasmic reticulum scattered within their respective cytoplasm. The role of Type A synovial cells is primarily the synthesis and export of hyaluronate with a secondary phagocytic role. Type B cells basically synthesize and export protein.

Normal synovial fluid is a dialysate of plasma which is relatively impermeable to high molecular weight plasma proteins. Apart from the obvious lubrication of the joint surfaces, synovial fluid has an essential role in maintaining and protecting the articular
cartilage as well as providing essential nutrients to the chondrocytes which is facilitated by joint motion. Lack of joint motion reduces the diffusion of nutrients from the synovial fluid to the chondrocytes which make up the fibrocartilage articular surfaces. Hyaluronic acid is one of the principal components of synovial fluid and when injected into joints affected with osteoarthritis, it has been shown to improve joint mobility and suppress pain and inflammation (Neo et al, 1997). Research is striving to correlate the composition of synovial fluid with certain joint disorders. Elevated protein levels, the presence of inflammatory mediators and change in viscosity of the synovial fluid have all been speculated to reflect various disease processes occurring within the joint.

1.2.7 – Capsule & Ligaments

The TMJ is completely enclosed within a funnel shaped capsule which defines the joint boundaries. Superiorly it attached to the rim of the glenoid fossa and articular eminence and inferiorly to the neck of the condyle. The entire lateral aspect of the capsule is thickened to form the lateral ligament that helps stabilize the joint. Other ligaments which help suspend the mandible to the cranial base and provide additional support to the TMJ is the sphenomandibular and stylomandibular ligaments.

1.2.8 – Nerve & Blood Supply

According to Thilander (1964) the sensory nerve supply to the TMJ is via three branches of the trigeminal nerve; the auriculotemporal, the masseteric and deep temporal nerves. Important nerve fibres are those of pain and joint proprioception which are mainly located in the bilaminar zone and surrounding capsule. There are normally no nerve fibres on the articular surface, disc and synovium. The blood supply to the TMJ is mainly from the deep auricular branch of the internal maxillary artery. An extensive venous plexus is found in the bilaminar zone between the two laminae.

1.2.9 – Surrounding Anatomy

Joint motion is facilitated by opposing groups of masticatory muscles which open and close the jaws. In addition, there is also a group of muscles which provides stability
during jaw function. Jaw opening involves a significantly smaller force than that of jaw closure. This is reflected in the relatively small size of the lateral pterygoid, suprahyoid and digastric muscles which are responsible for mouth opening which may perhaps be assisted to some extent by the force of gravity. A considerably larger force is applied during mouth closure as reflected in the powerful muscle group of masseter, medial pterygoid and temporalis muscles responsible for this movement. Stability of the head during jaw function is essential, otherwise the head would rock back and forth with every opening/closing cycle of the mandible. Muscles which provide the stability include the sternomastoid, suboccipital and infrahyoid muscles.

While the TMJ is surrounded by an envelope of complex anatomical structures (Howerton & Zysset, 1989), the facial nerve is the most important structure that limits surgical access to the TMJ (Al-Kayat & Bramley, 1979). Cadaver studies (Dingman & Grabb 1962) have found that the distance from the glenoid tubercle to the upper branches of the facial nerve anteriorly is $2.0 \pm 0.5$ cm with the shortest distance measured at 0.8 cm. Inferiorly to the bifurcation of the main trunk of the facial nerve, the mean distance is $3.0 \pm 0.3$ cm with the shortest distance measured at 2.4 cm from the glenoid tubercle.

1.3 – TMJ INTERNAL DERANGEMENT

1.3.1 – INTRODUCTION

Internal derangement (ID) of the TMJ refers to a localized mechanical fault within the joint which interferes with its smooth function. More specifically, ID is often considered the result of disc displacement where there is an abnormal positional relationship between the disc, the condyle and glenoid fossa/articular eminence. Historically, Annandale (1887) was the first to identify disc displacement of the TMJ in 1887. However, Pringle (1918) was the first to suggest disc displacement as the cause of TMJ pain and dysfunction. In 1951, Ireland (1951) surmised the clinical features of disc displacement, and proposed its progression. After a quiet period following Ireland’s proposals, refinement of arthrography techniques in the 1970’s helped revive interest in disc displacement. Largely due to the
works of Farrar (1971) and Wilkes (1978), disc displacement became virtually synonymous with ID. This concept spawned an era of clinical practice that devised many surgical and non-surgical ways of repositioning the displaced disc which was thought to be the mainstay in reducing pain and dysfunction associated with TMJ ID (McCarty & Farrar, 1979; Dolwick & Sanders, 1985; Dolwick & Nitzan, 1990; Hall & Nickerson, 1994).

By the 1990’s, conflicting evidence began to emerge that refuted the validity and significance of disc displacement as the central focus of ID (Dolwick & Dimitroulis, 1996). Clinical studies showed that clicking, a good sign of disc displacement, was found in 30-50% of non-patient population groups, the majority of who reported no pain or mandibular dysfunction (Solberg & Clark, 1980). Furthermore, surgical procedures involving simple lavage & lysis of the superior joint space, treatment which did not reposition the disc, were found to be effective in reducing pain and improving mandibular function in patients who presented with closed lock (Nitzan, Dolwick & Heft, 1990; Nitzan & Dolwick, 1991). Even magnetic resonance imaging (MRI) of asymptomatic volunteers demonstrated that over 30% of joints that showed no pain or dysfunction had evidence of disc displacement (Kircos et al, 1987).

Based on recent clinical, radiological and arthroscopic evidence, a displaced disc may not be as pathologically significant as originally thought (Dolwick & Dimitroulis, 1996). Clinical features of internal derangement may well be due to a number of co-existing factors such as inflammation, effusion, tissue compression or stretching, poor lubrication and tissue injury or breakdown rather than just a simple matter of a displaced disc. Further research at the microscopic, ultrastructural and biochemical level is needed to elucidate the true pathological process behind ID of the TMJ.

1.3.2 – **CLINICAL FEATURES**

Joint noises, in particular clicking, are the defining clinical feature of ID. Clicking is caused by the condyle resonating against the articular disc as it recoils posteriorly as the jaw opens, or anteriorly as the jaw closes. TMJ clicking manifests itself in over one-third of the non-patient population (Elfving et al, 2002) and it is usually of minor clinical significance.
While the clicking TMJ has been the focus of a multitude of published studies, some involving very complex methodologies (Widmalm, Djurdjanovic & McKay, 2003; Huddleston et al, 2004), little practical insight as to the significance of clicks has yet been achieved. Even attempts to classify joint clicks (Prinz & Ng, 1996) has led to nothing more than an academic exercise of little clinical relevance. The real problem lies in the failure to match clicks to actual joint pathology. What further compounds this is that most researchers who study and publish on clicking TMJ’s are not surgeons. Many have, therefore, never actually seen clicking in a surgically exposed joint of a live human. Like disc displacement, perhaps a clicking joint is a variant of normal and should only be considered pathological if it is accompanied by pain and/or restricted joint function (i.e., closed lock). Joint clicking may also be problematic when it becomes audible enough for others to hear, creating a socially embarrassing situation for the patient.

Joint clicking is often considered the product of disc displacement caused by stretching of discal attachments. Pain may be the result of compression or tearing of the posterior discal attachment which gives rise to inflammation of the irritated or traumatized tissues. Chronicity is created by the release of inflammatory mediators that are incompletely scavenged or removed (Milam & Schmitz, 1995). In advanced conditions, the clicking ceases and the joint fails to translate effectively leading to closed lock of the TMJ. Closed lock, which results in limited mouth opening, is unlikely to be purely the outcome of a permanently displaced disc that fails to reduce. MRI’s have clearly demonstrated non-displaced discs in patients with painful closed lock (Hatala, Westesson, Tollents & Katzbert, 1991). This suggests that perhaps a lack of proper lubrication of the superior joint space may be a major factor in the failure of the condyle to translate forward because the disc is adhered chemically to the glenoid fossa (Nitzan, 2001). The main evidence for this is the success of hydrodilation of the superior joint space using TMJ arthrocentesis which is able to restore joint function (Nitzan & Etsion, 2002).

In advanced cases of ID, the disc is permanently displaced and often severely deformed beyond recognition. The relationship of TMJ osteoarthrosis (OA) to ID is still speculative. A recent study by Dimitroulis (2005d) showed that only one-third of joints with
advanced ID had evidence of concomitant OA. This is contrary to the previously held view that OA was the main cause of severe ID (de Bont et al, 1986; Stegenga et al, 1991) which is implied in the most widely accepted classification of ID, namely the Wilkes (1989) classification. In that classification (Appendix 1), and indeed in further modified versions of the same classification, pathology involving the condyle is clearly expressed in the description of stage IV and V levels of ID. However, what the Dimitroulis (2005d) study showed was that two-thirds of the joints with severe disc displacement and deformity showed no radiological or surgical signs of disease in the condyle as one would expect to encounter in the stage IV and V joints which was one of the inclusion criteria in this study (Dimitroulis, 2005d).

1.3.3 – **Radiological Features**

Magnetic resonance imaging (MRI) has revolutionized the radiological diagnosis of intra-articular disorders of the TMJ. For many decades prior to the advent of MRI, double contrast arthrography was the mainstay in the investigation of joint pathology involving the articular disc (Kozeniauskas & Ralph, 1988). This invasive technique, which involved injection of contrast medium into the inferior joint space, not only relied on the skill of the radiologist but also on the compliance of the patient who had to undergo this invariably uncomfortable procedure. Tomograms of the mandibular condyle were also popular but the key limitation was the lack of definition of anything other than calcified structures such as the condylar head, articular eminence and glenoid fossa (Lewis, Dolwick, Abramowicz & Reeder, 2008). Attempts to correlate measures of joint space (i.e., the distance between the condylar head and glenoid fossa) with various pathological conditions were powerfully argued but poorly matched with any substantial evidence (Fallon, Fritz & Laskin, 2006).

The introduction of computerized tomography (CT scans) in the 1970’s once again limited observation to bony structures of the TMJ. Nevertheless, the big advantage of CT scans to standard tomography was the ability to view the bony structures in coronal, sagittal and axial planes, which better defined the structural integrity of the bony anatomy from all angles. Unfortunately, soft tissue definition was still impossible to display even with injection of contrast media. For traumatic condylar injuries, tumours and ankylosis of the
TMJ, the CT scan has proved to be a useful investigative tool. As for internal derangement, CT scans were of limited use and so MRI was the next major step in diagnostic imaging for TMJ ID (Lewis, Dolwick, Abramowicz & Reeder, 2008).

With ongoing improvements in the quality and resolution of MR images, due largely to increased computing power of the machines that process the various soft tissue signals, a clearer picture of internal derangement of the TMJ can now be constructed. While the main focus of MRI interpretation is the displaced, dislocated or subluxed disc, buckling, folding, perforation and deformity of the disc can also be clearly demonstrated by most current MRI machines. Discal adhesions, oedema and various inflammatory or degenerative conditions of the discal attachments and condyle can also be observed with fluctuating spin cycles of the water molecules according to the magnetic energy imparted onto the specially constructed receiving coils. Despite these technological advances clarity of images is still problematic as the TMJ is relatively small structure compared to more commonly scanned joints such as the hip or knee which can be clearly imaged with a far better resolution (Limchaichana, Petersson & Rohlin, 2006).

Kircos and co-workers (1987) were one of the earliest research groups to show the presence of displaced articular discs in the TMJ’s of asymptomatic volunteers. It has since been repeatedly confirmed by more recent MRI studies that displaced discs do indeed show up in 20% (Haiter-Neto et al, 2002) to 50% (Emschoff et al, 2002; Larheim, Westessson & Sano 2001) of asymptomatic volunteers. Larheim (2005) points out that while disc displacement is certainly prevalent in asymptomatic non-patient populations, TMD patients with clinical features of TMJ internal derangement are more likely to present with completely displaced discs that are non-reducing (40%) compared to asymptomatic volunteers (2-3%) (Larheim, Westessson & Sano 2001). This suggests that while MRI’s are useful for imaging the TMJ, the proper interpretation of the images cannot be undertaken in isolation without the full clinical history of the patients being available.
1.3.4 – **Relationship of Internal Derangement to Osteoarthritis of the TMJ**

The TMJ articular disc and synovial lining has been the subject of several histological studies that have focused on the diseased state without adequate reference to closely matched control specimens from non-diseased joints (de Bont, Boering, Leim et al 1986; Holmlund, Gynther & Reinholt, 1992; Isacsson, Isberg, Johansson et al 1986; Isberg & Isacsson, 1986). In fact, most attempts to include control specimens have relied on autopsy material obtained from older individuals with an unknown clinical TMJ profile (Luder, 1993; Paegle, Holmlund & Reinholt, 2002). For obvious ethical reasons, control specimens from living individuals with healthy TMJ’s are impossible to obtain which is one of the major limitations of all these studies.

A study by Holmlund and co-workers (Holmlund, Gynther, Reinholt, 1992) that looked at patients with TMJ internal derangement found histological features of degeneration (i.e. myxoid and focal cystic areas) in 53% of the joints compared to 72.7% of joints found in the Dimitroulis study (Dimitroulis 2005d). Degeneration reflects a gradual process of articular disc “wear and tear” which may also be part of the ageing process (Pereira, Lundh & Westesson, 1996). Hyalinization is often considered part of the aging process where there is a marked decrease in cells and vessels that are replaced by a significant abundance of collagen (Pereira, Lundh & Westesson, 1996). When the collagen fibres have a crushed appearance it is more likely to be disease rather than age related. The presence of hyalinization, particularly in the younger patients is indicative of abnormal degenerative changes in the articular disc especially where specimens demonstrate a crushed appearance of the collagen fibres (Isacsson, Isberg, Johansson et al 1986; Isberg & Isacsson, 1986).

The presence of chondrocytes, or chondroid metaplasia, within fibrous tissue such as ligaments or tendons is normally associated with abnormal compression forces (Luder, 1993, Scapinelli & Little 1970). According to the literature, the presence of chondrocytes is most likely to be the result of abnormal forces applied to displaced discs since chondrocytes do not occur in discs that are not displaced (Mills, Daniel & Herzog, 1994; Pereira, Lundh, Eriksson & Westesson, 1996).
Early studies undertaken in the 1980’s showed inflammatory cell infiltrates were not a prominent feature of painful TMJ internal derangement (Hall, Brown & Baughman, 1984; Isacsson, Isberg, Johansson et al 1986; Isberg & Isacsson, 1986; Kurita, Westesson, Sternby et al, 1989). Later studies (Gynther, Holmlund & Reinholt, 1994; Holmlund, Gynther & Reinholt, 1992), however, found inflammation in about two-thirds of the joints studied which was greater than the 45% of joints (10/22) found with inflammation in the most recent study by Dimitroulis (2005d). Dimitroulis (2005d) also found the inflammation was of varying degrees of intensity with mixed chronic inflammatory cells diffusely infiltrating the articular disc and retrodiscal tissues and not necessarily confined to areas of increased vascularity. Other studies found predominately mild inflammation characterized by slight lymphocytic perivascular infiltrates. (Gynther, Holmlund & Reinholt, 1994; Hall, Brown & Baughman, 1984; Holmlund, Gynther & Reinholt, 1992).

Pereira and co-workers (Pereira, Lundh & Westesson, 1996) compared tissue samples from 27 TMJ pain patients (i.e. painful disc displacement) with seven asymptomatic oncology patients who agreed to donate TMJ tissue samples after death. Their results showed a difference in histology of the posterior disc attachment and capsule between painful and non-painful TMJ’s. The higher number of fibroblasts and reduction in elastin fibres along with reduction in vascularity found in the posterior disc attachment suggested a process of repair following an acute injury. Histological signs of inflammation and degeneration were notably seldom observed (Pereira, Lundh, Eriksson & Westesson, 1996).

Collapse and erosion of the articular surface of the mandibular condyle is indicative of osteoarthrosis. Osteoarthrosis is a focal degenerative disorder that primarily affects the articular cartilage and subchondral bone of synovial joints such as the TMJ (Stegenga, de Bont, Boering & Van Willigen, 1991). It has been well documented that osteoarthrosis often occurs in conjunction with internal derangement in the TMJ (de Bont, Boering, Leim et al 1986). However, the Dimitroulis study (Dimitroulis 2005d) reported only six of the 18 joints (33.3%) diagnosed with disc pathology were also found to have osteoarthrosis which included diagnostic features such as osteophytes (2 cases), collapse and erosion of articular surface (7 cases) and
subchondral sclerosis and remodelling (6 cases). Dimitroulis (2005d) showed that osteoarthrosis and internal derangement may co-exist in up to one-third of cases. The fact that osteoarthrosis was not found in all cases suggested that perhaps internal derangement may precede osteoarthrosis. This is contrary to the widely held view that subclinical osteoarthrosis may lead to pathologic tissue responses in the form of internal derangement. Hence the concept that internal derangement should be considered a sign of osteoarthrosis (de Bont, Boering, Leim et al 1986; Stegenga, de Bont, Boering & Van Willigen, 1991) rather than its cause was not borne out in the Dimitroulis (2005d) study since 14 joints appeared to show no evidence of condylar pathology at the radiological and gross inspection at the time of surgery.

1.3.5 – Molecular Biology

In the 1950’s it was claimed (Ireland, 1953) that displacement of the articular disc was the first stage in a sequence of events that led to osteoarthritis. Later reports suggested that the articular disc had a protective effect on the underlying articular tissues within the TMJ which was compromised when the disc is displaced, thereby exposing underlying tissues to excessive loads with consequent degenerative changes (Glineburg, Laskin & Blaustein, 1982; Laskin, 1978; Stevenson, Evaskus & Laskin, 1979). An alternative view proposed by various workers (de Bont, Boering, Liem et al, 1986; de Bont & Stegenga, 1993; Stegenga, de Bont, Boering et al, 1991) suggested that disc displacement was a consequence of pre-existing degenerative conditions within the TMJ. Such propositions, however, did not explain why disc displacement has been observed in both symptomatic and asymptomatic patients. Furthermore, it has also been shown that repositioning of a displaced disc is unnecessary in treating pain and dysfunction in the TMJ as results of TMJ arthroscopy and arthrocentesis have proved (Dolwick, 1995; Dolwick & Dimitroulis, 1996; Nitzan, Dolwick & Heft, 1990). As a result of these observations, investigators have turned their attention to the molecular biology of articular health and disease in order to understand the factors that lead to, or result from, internal derangement and osteoarthrosis of the TMJ (Israel, 1989; Israel, 1994; Milam & Schmitz, 1995; Milam, Zardeneta & Schmitz, 1998; Nitzan & Marmary, 1997; Nitzan & Etsion, 2002).
At the molecular level, the difference between adaptive changes and disease depends on the balance between anabolic (i.e., reparative) and catabolic (i.e., destructive) molecular events within the affected tissues. Therefore, the disease state is when tissue destruction outpaces tissue repair. The most significant finding in recent decades is the TMJ responds to a wide range of dynamic forces through its remarkable adaptive capacity (Boyne, 1967; Bradley, 1985; Dalhstrom, Kahnberg & Lindahl, 1989; Dimitroulis, 1997; Ogus, 1987). Changing load demands on the joint caused by clenching or bruxism leads to mechanical stress. The adaptive capacity of the TMJ responds to mechanical stress by metabolic events that result in remodeling within the articular tissues (Carlsson & Oberg, 1974). This may explain the structural variations found within asymptomatic joints not associated with active disease. This also explains why not all people who clench or brux go on to develop symptoms of TMJ disease (Rugh & Harlan, 1988).

In those who do develop TMJ symptoms, the joint may have a reduced adaptive potential and so responds to mechanical stress in a maladaptive way that results in disease. Increasing age is the most common factor which reduces the adaptive potential of articular tissues. Female hormones such as oestrogen and prolactin are also thought to adversely affect the adaptive capacity of the TMJ by tipping the balance of molecular events in favour of catabolic or destructive tissue degradation. Degenerative changes within joint tissues are also promoted by factors which enhance sympathetic tone such as nicotine ingestion or psychological stress resulting from chronic pain and anxiety (Milam & Schmitz, 1995).

Based on the data derived from clinical and animal research, Milam and Schmitz (Milam & Schmitz, 1995) proposed three mechanisms of injury to explain degenerative TMJ disorders. These are; direct mechanical injury, hypoxia-reperfusion injury and neurogenic inflammation. The tripartite theory proposes that excessive mechanical loading of the joint disturbs the delivery of vital nutrients to the cells within the joint and disrupts the elimination of harmful metabolic waste products. Further damage is done when the mechanical load on the joint results in intra-capsular pressure that exceeds the end capillary-perfusion pressure which disrupts the blood flow to the joint and leads to tissue
hypoxia. When the pressure is released, the resultant reperfusion of the joint in the form of a sudden surge in blood flow may result in oxygen being converted to damaging free radicals. Finally, the release of pro-inflammatory neuropeptides from mechanically stressed or irritated nerve terminals in retrodiscal tissues, especially in cases of disc displacement, can invoke an inflammatory response in surrounding tissues causing pain and swelling (i.e. dysfunction). The diagnostic spin-off from such research is the establishment of markers for TMJ disease. The main obstacle, at present, is it is still unclear which molecular and bioactive compounds are involved in joint adaptation (i.e., repair) and which are indicative of disease (i.e., tissue destruction) (Milam, Zardeneta & Schmitz, 1998).

According to Milam and co-workers (Milam, Zardeneta & Schmitz, 1998), mechanical stresses to the joint lead to the accumulation of damaging free radicals which, under normal conditions, are neutralized by scavenging mechanisms in the form of enzymes, antioxidants and some hormones (e.g., melatonin). A disease state can occur in susceptible individuals who are unable to respond to the accumulation of free radicals within the TMJ because of the intrinsic deficiency of their free radical scavenging or repair mechanisms. Milam and co-workers (Milam, Zardeneta & Schmitz, 1998) refer to this as ‘oxidative stress’ which triggers further molecular events that amplify the destruction of articular tissues and result in degenerative disease in the TMJ.

Nitzan and Dolwick (1991) first suggested the suction cup phenomenon to explain the mechanism for closed lock of the TMJ. The ‘suction cup’ theory failed because it implied excessive and sustained negative intra-articular pressures which was not physiologically possible. In response to the limitations of the original theory, Nitzan and Marmary (1997) coined the term the ‘anchored disc phenomenon’ or ADP to describe the process where the disc is stuck or adhered to the glenoid fossa, not by negative pressure, but by chemical means through surface adhesion. A similar concept of ‘lubrication deficiency’ was previously alluded to by Boering (1966), Ogus and Toller (1986) and Stegenga and co-workers (Stegenga, de Bont, Boering & van Willingen, 1991).
In an attempt to explain the adhesive forces, Nitzan (2001) took the theory of uncontrolled free radicals further by speculating that oxidative stress may also damage the lubrication system that allows the smooth translation of the disc during function of the TMJ. The phospholipids and hyaluronic acid, which are essential in an efficient system of joint lubrication, are attacked and broken down by excess free radicals. This results in damage to the joint lubrication system which leads to increase friction between the articular disc and the surrounding articular surfaces. According to Nitzan & Etsion (2002), this leads to either ADP or displacement of the articular disc. Nitzan & Etsion (2002) went on to explain that ADP occurs when the surfaces are pressed together under repetitive function load in the absence of adequate lubrication. By injecting fluid in the superior joint space, the surfaces are prized apart by hydro-dissection. This model helps to explain why simple arthrocentesis and lavage of the TMJ is effective in re-establishing joint motion in a joint with closed lock without affecting the position of the disc.

The failure of disc repositioning techniques in the past has resulted in a concerted effort by researchers to understand the physiology of joint function and dysfunction at the molecular level (Dolwick, 1995; Dolwick & Dimitroulis, 1996). Research in molecular biology may one day result in a test that will help identify those patients most susceptible to TMJ disorders (Milam, Zardeneta & Schmitz, 1998). Improvements in diagnostic and therapeutic approaches to TMJ disease are what researchers in molecular biology are attempting to achieve. With the help of molecular biology, the future of TMD management may comprise more carefully targeted and less radical treatment modalities. Histological, biochemical and molecular studies are opening up new frontiers in our understanding of TMJ internal derangement that will hopefully provide the basis for better and more effective treatment modalities in the future. Treatments such as TMJ arthrocentesis using different agents such as specific enzymes or antioxidants may well obviate the need for more radical open surgical intervention. The future holds great promise.
1.4 – SURGERY FOR TMJ INTERNAL DERANGEMENT

1.4.1. – HISTORY OF SURGICAL TREATMENT

In the first half of the 20th century, publications on TMJ surgery were sporadic which reflected the poor understanding of TMJ pathology (Burman & Sinberg, 1946; Katzberg, Keith, Guralnick et al, 1983). By the second half of the 20th century the evolution of TMJ surgery gathered momentum as improved understanding of TMJ disorders paralleled advances in diagnostic imaging (Boering, 1966; Carlsson & Oberg, 1974; Eriksson & Westesson, 1983; Isberg & Westesson, 1982; Wilkes, 1978). In recent decades TMJ arthroscopy has opened up a vast new field of molecular biology which has led to an improved understanding of the pathosis of TMJ pain and dysfunction which, in turn, has provided critical support for the role of surgery in the management of TMJ disorders.

Ankylosis and dislocation of the TMJ were both recognized as far back as the time of Hippocrates in the fifth century BC. Methods of manual reduction of dislocated jaws were described similar to the techniques used today. By the 19th century, various forms of chin straps were used to treat jaw dislocations. The 19th century also heralded the earliest TMJ operations which were predominantly performed for the release of joint ankyloses (Norman & Bramley, 1990). In 1856, a Cambridge surgeon, described the condylectomy from the level of the condylar neck to treat TMJ ankylosis (Humphrey, 1856). The procedure had evolved from the simple division of fibrous bands or osteotomy of the fused joint with attempts to create a pseudoarthrosis close to the original joint. In 1860, Verneuil (1860) reported the use of the temporalis flap as an interpositional barrier within the surgical defect created after release of the ankylosis. The high recurrence rate of re-ankylosis prompted wider gap arthroplasties in a bid to increase the distance between bone ends and help reduce new bone formation (Blair, 1914; Kazanjian, 1937). In 1914, Murphy (1914) described the use of autogenous fat as interpositional material while in 1934, Risdon (1934) employed free muscle grafts to address the problem of re-ankylosis. It wasn’t until the papers by Georgiade and co-workers (Georgiade, Altany & Pickrell, 1957) and Topazian (1964; 1966) appeared in the 1950’s and 1960’s that the wide gap
arthroplasty with interpositional grafting gained universal acceptance as the standard procedure for TMJ ankylosis management (Chossegros, Guyot, Cheynet et al, 1997; ditto 1999; Kaban, Perrott & Fisher, 1990; Norman & Bramley, 1990; Rowe, 1982).

Operative procedures for dislocation were more complex and varied and hence were not introduced until well into the 20th century. In 1951, Myraugh (1951) described the eminectomy for the treatment of condylar dislocation that was adapted by Irby (1957) in 1957 for the treatment of painful TMJ dysfunction. Later procedures which evolved for the treatment of dislocation included capsulorrhaphies, lateral pterygoid myotomies and osteotomies of the zygomatic arch and eminence to limit the translation of the condyle (Laskin, 1973; Norman & Bramley, 1990; Revington, 1986; Sanders & Newman, 1975). Anterior synovial sulcus ablation using electrocautery and lasers via surgical arthroscopic techniques have been more recent developments in the management of recurrent TMJ dislocation and hypermobility (McCain & De la Rue, 1989; McCain, Sanders & Koslin et al, 1992).

Other forms of TMJ internal derangement involving disc integrity and position were not recognized until well into the 19th Century. Surgery for TMJ internal derangement involving the disc can be traced back to a British surgeon Annandale (1887) who, in 1887, published an article describing two cases of discoplasty for the management of disc displacement in the TMJ. The first published case of discectomy for painful TMJ dysfunction was reported in the German literature by Lanz (1909) in 1909. From then until the 1950’s, discectomy remained the procedure of choice in the surgical treatment of painful TMJ dysfunction (Boman, 1947; Eriksson & Westesson, 1992; Hall, 1994; Kiehn, 1952). The refinement of x-rays of the TMJ by the 1950’s suggested that a reduction in joint space might well explain the painful TMJ dysfunction as a consequence of increased joint pressure. Pioneering surgeons of the day adopted the theory and devised techniques for increasing the joint space as a means of decompressing irritated tissues. Irby’s use of the eminectomy as a means of increasing joint space for the treatment of painful TMJ (Irby, 1957) has already been mentioned. Fred Henny, a trail-blazing pioneer of American Oral Surgery, advocated the technique of high condylectomy as a way of increasing the joint space.
space (Henny & Baldridge, 1957). Critics of the technique were quick to argue that whatever space was created by the condylectomy would be immediately lost by the superior collapse of the ramus. About the same time, a British team led by Sir Terence Ward looked at a different method for increasing the joint space without breaching the joint capsule (Ward, Smith & Sommar, 1957; Ward, 1961). Building on Campbell’s observations of condylar fractures, they described the mandibular condylotomy based on Kostecka’s original procedure for treating anterior open bite (Norman & Bramlet, 1990; Ward, Smith & Sommar, 1957). The condylotomy involved a simple osteotomy that separated the condylar process from the rest of the mandible. The idea was the surgically separated condyle would increase the joint space through sag and therefore relieve the pressure within the TMJ. What made this technique interesting was the osteotomy of the condylar neck could be undertaken as a closed procedure using the gigli saw. The fact the joint capsule was not breached was considered advantageous (Banks & MacKenzie, 1975). Nickerson and later Hall re-popularized the technique in the 1980’s with the modified condylotomy that utilized the direct intraoral approach for separating the condyle from the mandible (Hall, Nickerson & McKenna, 1993).

The 1960’s witnessed a hiatus in the evolution of TMJ surgery as the concept of myofascial pain and dysfunction syndrome developed by Laskin (1969) overshadowed developments in the intracapsular pathology of TMD (Boering, 1966). Building on Schwartz’s theory (Schwartz, 1955) of muscle pain, Laskin (1969) emphasized the importance of psychological influence and parafunctional habits that largely obscured the joint as a source of pathology. Despite this, Laskin helped establish the important distinction between muscle and joint problems that had important implications in the diagnosis and management of TMD (Dolwick, 1989; Laskin, 1969).

Proof for the role of the disc in TMJ pain and dysfunction was not available until 1970’s when TMJ arthrography techniques were improved and refined (Katzberg, Keith & Guralnick, 1983; Westesson, 1984). TMJ arthrography provided crucial evidence for the existence of intra-articular pathology such as disc displacement that could be clearly demonstrated in surgically undisturbed joints (Dolwick, Katzberg & Helms, 1983; Eriksson
The 1970’s proved to be a watershed in the history of TMJ surgery. Largely as a result of the pioneering works of Wilkes (1978), Farrar (1971) and McCarty (Farrar & McCarty, 1979; McCarty & Farrar, 1979), TMJ disc displacement was universally adopted as the mechanism which helped explain the pain, clicking and joint locking experienced in patients diagnosed with internal derangement (Dolwick, 2001; Dolwick, Katzberg & Helms, 1983; Dolwick & Riggs, 1983; Hall & Nickerson, 1994). It wasn’t long before a new generation of surgeons turned their attention to the articular disc. As a result, TMJ surgery gathered momentum in North America as various procedures were devised to reposition, repair or remove the diseased disc (Dimitroulis, Dolwick & Gremillion, 1996; Dolwick, 2001; Dolwick & Dimitroulis, 1994; Dolwick & Nitzan, 1990, 1994; Dolwick & Riggs, 1983; Dolwick & Sanders, 1985). Unfortunately, the early optimism of TMJ surgery was quickly followed by disasters in the form of alloplastic disc replacements that were implanted in thousands of patients between 1978 and 1986 (Dolwick & Aufdemorte, 1985; Dolwick & Dimitroulis, 1994; Hefeeez, Mafee & Rosenberg et al, 1987; Kaplan, Tu, Williams, 1988; Kiersch, 1984; Schellhas, Wilkes & El Beeb, 1988; Yi & Merrill, 1989). As a result, the initial euphoria of TMJ surgery turned to despair as surgeons were faced with a generation of patients who had multiply operated and painfully degenerated joints (Chuong & Piper, 1992; Henry & Wolford, 1993; Wagner & Mosby, 1990). It is often said that the TMJ surgery undertaken in the 1980’s helped create and dictate the TMJ surgery performed in the 1990’s. The dilemma faced by surgeons in the 1990’s was the increasing numbers of patients facing discectomy following initial disc preservation procedures that failed to alleviate symptoms (Dolwick, 2001) as well as the failed alloplastic implants that required urgent attention (Henry & Wolford, 1993). There was an understandable shift away from alloplastic implants to autogenous grafts such as temporalis fascia and muscle (Feinberg, 1994; Feinberg & Larsen, 1989), conchal cartilage (Hall & Link, 1989) and dermis grafts (Dimitroulis, 2005a; Georgiade, 1962) to replace missing discs. Unfortunately, long-term studies which showed good results of discectomy without disc replacement were largely ignored. Curiously, many surgeons felt disc replacement was mandatory following discectomy and so channeled their efforts to find the ideal disc...
replacement material that still remains elusive to this day (Hall, 1994; Ioannides & Freihofer, 1988; Ioannides & Maltha, 1988).

In 1975, Onishi (1975) adapted and miniaturized the orthopaedic arthroscope for use in the small dimensions of the TMJ. It took almost a decade before the therapeutic applications of TMJ arthroscopy became evident following extensive research into the diagnostic capabilities of the technique by Japanese (Murakami, Hosaka, Moriya et al, 1995) and Swedish (Holmlund, Gynther & Axelsson, 1994) researchers. Sanders (1986) and McCain (1988) published landmark papers on the therapeutic application of TMJ arthroscopy during the mid 1980’s especially in the management of closed lock utilizing the simple technique of arthrolysis and lavage of the TMJ (Clark, Moody & Sanders, 1991; Dolwick & Sanders, 1985). By the late 1980’s and early 1990’s TMJ surgery had undergone a renaissance with the adoption of minimally invasive surgery as the main surgical treatment modality of the TMJ. Complex operative or surgical TMJ arthroscopy was developed largely by the efforts of US surgeons McCain and de la Rua (1989) and others (Indresano, 2001; Ohnishi, 1991). The aim of operative arthroscopy was to emulate many of the open joint procedures that had fallen out of vogue. Through small portholes, these super talented arthroscopists attempted to show the world that most surgical procedures on the TMJ could be undertaken without the need for a formal arthrotomy (McCain, Sanders, Koslin et al, 1992). Like all new surgical techniques, the zealots who promoted them were swept up in the frenzied pace of keyhole surgery developments that were sweeping across almost all the surgical specialties. It seemed like keyhole surgery had limitless potential until the passage of time and experience carved out a well defined role with certain limitations that eventually dampened the initial enthusiasm.

While TMJ arthrography helped focus attention on the phenomenon of disc displacement as the pathology of the most common type of internal derangement, the introduction of TMJ arthroscopy and later, arthrocentesis cast doubt as to the true mechanism of TMJ pain and locking (Dimitroulis, Dolwick & Martinez, 1995; Dolwick, 1995; Dolwick & Dimitroulis, 1996; Nitzan, Dolwick & Heft, 1990; Nitzan & Dolwick, 1991; Nitzan, Dolwick & Martinez, 1991). The effectiveness of simple lavage and lysis to
treat closed lock raised important questions about the central pathosis of the most common forms of internal derangement (Dimitroulis, Dolwick & Martinez, 1995; Dimitroulis, 2002; Dolwick, 1995; Dolwick & Dimitroulis, 1996; Nitzan, Dolwick & Heft, 1990; Nitzan & Dolwick, 1991). TMJ arthroscopy and arthrocentesis also provided the opportunity for researchers to investigate and compare the synovial fluid of healthy and diseased joints (Israel, 1989, 1994, 1999; Israel, Saed-Nejad & Ratcliffe, 1991; Quinn, 1990; Yih, 1989). This ushered in a new era of molecular biology in TMJ research that helped US researchers Stephen Milam and John Schmitz (Milam & Schmitz, 1995) propose the molecular mechanisms of degenerative TMJ disease. A better understanding of the pathological mechanisms of TMJ disease was essential in devising more effective treatment modalities and helped redefine the role of surgery in TMJ pain and dysfunction (Nitzan, Dolwick & Martinez, 1991).

The multiply operated patients who continued to suffer from TMJ pain and joint dysfunction spurned a whole new industry of total prosthetic joint replacement. While total joint replacements for TMJ have been around since the 1970’s, the failure of the early prosthetic joints did not deter the development of new models and designs which are currently available on the market (Mercuri, 2000). The Christensen total joint prosthesis is perhaps the most widely used prosthesis in TMJ replacements (Mercuri, 1996). The numerous metal and plastic components trialed over the years have closely followed the evolution of joint prostheses developed in the field of orthopaedic surgery (Ryan, 1989). While numerous indications for the use of prosthetic TMJ’s have been cited in the literature, it perhaps is not surprising that most are used in patients with multiply operated joints (Mercuri, 1998; Mercuri, 2000; Quinn, 2000; Wolford, Dingworth & Talwar et al, 2003). The repercussions of early surgical disasters are still felt today as many patients with iatrogenic end stage joint disease are undergoing prosthetic joint replacements. The North American experience of unmitigated TMJ surgery has provided us with good reason to be cautious about the kind of patients we select for surgery. History teaches us that we are destined to repeat the mistakes of the past if we fail to properly reflect on what has already been achieved and where the failures have occurred (Dimitroulis, 2005b).
1.4.2. – INDICATIONS FOR SURGICAL INTERVENTION

Indications for surgery in the management of TMD may be divided into relative and absolute (Dolwick & Dimitroulis, 1994). Absolute indications are reserved for cases where surgery has an undisputed central role. Uncommon disorders such as tumours (Forsell, Happonen & Forsell, 1985; Hecker, Freeman & Quick, 1985), growth anomalies (Matterson, Profitt, Terry et al, 1985; Towers, 1976) and ankylosis (Chossegros, Guyot, Cheynet et al, 1997; Kaban, Perrott & Fisher, 1990) of the TMJ fall into this category (Norman & Bramley, 1990). Relative indications involve cases where surgery has a less clearly defined role, especially where the option of non-surgical management plays a predominant role. The relative indications for surgery in TMD management are important because they involve the most common disorders, namely, TMJ internal derangement involving disc position and integrity and osteoarthrosis. In the literature, the primary indication for TMJ surgery is invariably the failure of non-surgical therapy. Unfortunately, failed non-surgical therapy may often be the result of misdiagnosis or incomplete diagnosis which is known to occur in up to 20 percent of patients being treated non-surgically for TMD. This far exceeds the 5 percent of TMD patients often quoted in the literature as being suitable candidates for TMJ surgery (Dimitroulis, Dolwick & Gremillion, 1996; Dolwick & Dimitroulis, 1994). What the literature often fails to emphasize is that about 75 percent of patients who fail to respond to non-surgical treatment are also not suitable candidates for surgery. Furthermore, ‘failed non-surgical treatment’ as a prerequisite for surgical intervention is debatable because invasive treatment modalities such as TMJ arthrocentesis or arthroscopic lavage could well be considered as an early treatment option in selected cases such as closed lock of the TMJ (Dimitroulis, 2005b).

What distinguishes the surgical candidates from the rest of the group who have failed non-surgical treatment is the clinical and radiological presentation of the disease. The key clinical features of potential surgical candidates include symptoms of pain and dysfunction well localized to the TMJ (Dolwick & Dimitroulis, 1994). Dysfunction may include painful clicking, crepitus or hypomobility of the joint. In the absence of pain, the severity of the dysfunction must be taken into account in terms of the degree of disability reported by the patient. The difficulty lies where patients with similar levels of dysfunction
often report different degrees of disability (Duinkerke, Luteijn & Bouman et al, 1985). Surgical intervention should, ideally, be based on objective criteria such as whether a patient’s maximum interincisal mouth opening (MIO) is sufficient for routine dental care. A patient’s psychosocial and cultural background is also important in determining whether surgical intervention is appropriate as some patients may choose to avoid surgery for whatever reason. This is particularly important when one considers there are studies that show improvement in TMD symptoms without treatment (Sato, Goto, Kawamura et al, 1997). Since historical evidence suggests that TMD is not always a progressive disorder (De Leeuw, Boering, Stegenga et al, 1994; Green & Laskin, 1988), short term relief may be obtained through medication or arthrocentesis depending on the diagnosis.

Radiological evidence of disease in bone (i.e. tomograms or CT-scans) or soft tissue (i.e. MRI’s) provides the essential diagnostic ammunition in making the case for surgical intervention (Chuong & Piper, 1993; Heffez, Mafee, Rosenberg et al, 1987; Katzberg, Keith, Guralnick et al, 1983; Schellhas, 1989). The findings of radiology, however, should never be interpreted in isolation. The decision for surgical intervention must be based primarily on the clinical findings in conjunction with factors such as the impact of the disease on the well-being of the patient and the prognosis of the disease when no treatment is provided. Radiological investigations should only play a supportive role (Dimitroulis, Dolwick & Gremillion, 1995). Over reliance on imaging may lead to over treatment as there are often cases where disc displacement and condylar degeneration are found in asymptomatic patients (Dolwick & Dimitroulis, 1996; Hatala, Westesson, Tolents et al, 1991; Kircos, Ortendahl, Mark et al, 1987; Kozeniauskas & Ralph, 1988). Surgical intervention based on imaging studies without reference to clinical findings cannot be condoned. The only exception is the obvious presence of insidious tumours, which are rare (Forsell, Happonen & Forsell, 1985; Hecker, Freeman & Quick, 1985; Norman & Bramley, 1990).

The literature appears to support the view that surgery for common TMD such as TMJ internal derangement and osteoarthrosis are often considered under two conditions.
The first is when the TMD is refractory to appropriate non-surgical therapies and the second is where the TMJ is the source of pain and/or dysfunction that results in significant impairment to the patient (Dimitroulis, Dolwick & Gremillion, 1996; Dolwick & Dimitroulis, 1994). Essentially, the most important prerequisite for surgery should be an accurate and complete diagnosis. ‘Failed non-surgical treatment’ as often quoted in the literature may well be interpreted as ‘wrong diagnoses and therefore cannot be accepted as a legitimate prerequisite for surgical intervention. What this suggests is that with an accurate diagnosis, early surgical intervention may well be the most appropriate course of action, thereby eliminating the frustration of ineffective non-surgical treatment modalities.

According to the literature, internal derangement of the TMJ which presents as closed lock (i.e., disc displacement without reduction) has been shown to be effectively managed with TMJ arthrocentesis (i.e., acute onset closed lock) and TMJ arthroscopy (i.e., long standing or chronic closed lock) (Clark, Moody & Sanders, 1991; Dimitroulis, Dolwick & Martinez, 1995; Dimitroulis, 2002; Nitzan, Dolwick & Heft, 1990; Nitzan, Dolwick & Martinez, 1991; Nitzan, Samson & Better, 1997). Painful TMJ internal derangement where there is little or no restriction of mandibular function (i.e., reducing disc displacement) appears to respond to condylotomy procedures where condylar sag results in increased joint space and relief of intra-articular pressure (Banks & MacKenzie, 1975; Dolwick & Dimitroulis, 1994; Hall, Nickerson & McKenna, 1993). Arthrotomy of the TMJ is reserved for advanced stages of TMJ internal derangement (Table 1) and osteoarthrosis (Dolwick & Dimitroulis, 1994; Dolwick & Sanders, 1985).

The general quality of the literature on TMJ surgery is sub-optimal. Randomized clinical trials comparing surgical treatment of TMD with medical treatment and no treatment (i.e., placebo) do not exist. Because such studies are unfeasible, the true benefit of surgical treatment for TMD may never be conclusively established. The purists of evidence based medicine will, therefore, ignore the results of the studies on TMJ surgery because of the bias and poor design inherent in all such studies published to date. According to Reston and Turkelson (2003), one way of determining whether surgery does benefit some patients with TMD is to undertake a meta-analysis of published results.
Instead of comparing pre- and post operative figures within each study, they used published estimates of improvements in untreated patients as control values. Their meta-analysis suggests that TMJ arthrocentesis and arthroscopy are effective in the management of patients with TMJ disc displacement without reduction. Reston and Turkelson (2003) also note that while the evidence for the role of specific surgical procedures in certain patients is reliable, better designed clinical trials are needed to determine the degree or magnitude of the benefits of surgery. Even though the studies to date are suboptimal, the results cannot be ignored. Therefore, the current recommendations for surgery must rely on the best available evidence. Waiting for better designed, placebo controlled, random clinical trials will only frustrate the decision making for both clinicians and patients (Reston & Turkelson 2003).

1.4.3. **DISC PRESERVATION SURGERY**

While the removal of a fibrotic, deformed or diseased disc is justified (Hall, 1994), the preservation of a healthy, freely mobile disc is equally essential to healthy TMJ function (Dolwick & Dimitroulis, 1994; Dolwick & Nitzan, 1994; Piper, 1989). In his review of disc preservation surgery, Dolwick (2001) points out that the role of disc repositioning surgery for the management of TMJ internal derangement has significantly diminished in the light of the success of less invasive procedures such as TMJ arthroscopy and arthrocentesis (Dolwick, 1995; Dolwick & Dimitroulis, 1996). Although the literature appears to support the successful application of disc repositioning procedures in 80% to 95% of cases, Dolwick (2001) suspects the reported successes may have been overstated. Montgomery and co-workers (Montgomery, Gordon, van Sickels et al, 1992) found that while disc repositioning surgery had significantly reduced pain and dysfunction in 51 subjects evaluated up to 6 years post-operatively, they also found the improvement in disc position was short lived and not maintained over the follow-up period for most patients. While there is a small but significant minority of patients who continue to suffer from pain and joint dysfunction following disc preservation procedures, Dolwick (2001) recommends less morbid procedures (Vallerand & Dolwick, 1990) such as arthroscopy should be the preferred treatment. As far as disc preservation procedures are concerned, the goal should be the elimination of mechanical interference to smooth joint function rather than the
repositioning of the disc to a normal position (Dolwick, 1995,2001; Dolwick & Dimitroulis, 1994).

While surgical attempts in the past have focused on the preservation and repair of the diseased or malpositioned disc, studies have clearly demonstrated the limited capacity for discal healing (Montgomery, Gordon, van Sickels et al, 1992). Surgical procedures which have been advocated have included discopexy, plication, repositioning, sculpturing or even attempts to repair torn or perforated discs (Dolwick & Sanders, 1985). Grafts have also been utilized to patch up defects within the damaged disc. Incredibly, reports on such procedures often recorded greater than 80% success rates (Dolwick & Nitzan, 1990) although the criteria for success and follow up periods were inclined to be well below the acceptable standards for evidence based clinical studies.

For discs that are largely intact or normal but malpositioned, Dolwick (2001) advocates TMJ arthrocentesis or arthroscopic lavage and lysis to relieve the pain and closed lock rather than disc orientated surgical procedures. Worldwide, there are still many surgeons who continue the practice of disc preservation surgery, even though it is increasingly becoming evident that discectomy is perhaps the most appropriate way to manage a severely displaced, deformed or damaged disc that presents with pain or joint dysfunction that does not respond to less conservative treatment (Dimitroulis, 2005a).

1.4.4. – DISCECTOMY

A diseased or deformed disc that interferes with the smooth function of the joint and is beyond salvage is a candidate for discectomy. Discectomy of the TMJ has the distinction of having the longest follow up studies of any surgical procedure for the management of TMJ internal derangement with long-term (>5yr) positive outcomes (McKenna, 2001). At least four studies (Eriksson & Westesson, 1985; Silver, 1984; Takaku & Toyoda, 1994; Tolvanen, Oikarinen & Wolf, 1988) looked at patients at least 20 years or more following TMJ discectomy and found complete resolution in pain and restriction free diet in almost all patients reviewed. An interesting outcome in all
discectomy patients reviewed showed significant changes in the condylar morphology, not only of the operated joint but also evident on the unoperated joint. Agerberg and Lunberg (1971) suggested that the altered radiographic morphology in both the operated and unoperated joints were the result of altered joint loading following discectomy (Carlsson & Oberg, 1974; Takaku, Sano & Yoshida, 2000). Animal studies have found the condylar alteration following discectomy to resemble degenerative joint disease at the histological level (Hinton, 1992; Yaillen, Shapiro, Lushei et al, 1979). Clinical studies involving magnetic resonance imaging, however, lend support for the opinion that the radiographic changes of the condyle are adaptive rather than degenerative because the reduced symptoms do not correlate with the significant condylar changes seen following discectomy (Eriksson & Westesson, 1992; Hall, 1994; Hansson, Hansson & Petersson, 1983). The mechanism of pain relief and improvement in function over the long-term following discectomy is still unknown. The confusion is further compounded by the results of non-surgical studies which show a natural tendency for symptoms of internal derangement to improve with time (de Leeuw, Boering, Stegenga et al, 1994; Green & Laskin, 1988; Nickerson & Boering, 1989; Sato, Goto, Kawamura et al, 1997).

A recent 5 year follow-up study of 15 consecutive patients selected using strict inclusion criteria who had unilateral TMJ discectomies without replacement found that 87% (13 of the 15 patients) of the patients fulfilled the criteria for successful TMJ surgery (Nyberg, Adell & Svensson, 2004) as proposed by the 2nd International Consensus Meeting (Goss, 1992; Holmlund, 1993) (Appendix 2). While there are many other TMJ discectomy studies showing similar long term outcomes (Hansson, Eriksson & Westesson, 1992; Holmlund, Gynther & Axelsson, 1993; Takaku, Sano & Yoshida, 2000) most were hampered by inconsistent inclusion and success criteria. Nevertheless, the mounting evidence for positive outcomes of TMJ discectomy and the distinct lack of significant negative findings, apart from crepitus and condylar changes, appears to support the discectomy procedure as a legitimate means of treating pain and dysfunction resulting from severe TMJ internal derangement (Dimitroulis, 2005b).
With the success of TMJ discectomy, little attention has been paid to the two most important side effects, namely, crepitus and condylar changes that almost invariably follow discectomy without replacement. While early concern was focused on the condylar changes following discectomy, animal studies (Sato, Goto & Motegi, 2002) and MRI investigations (Takaku, Sano & Yoshida, 2000) showed the condylar changes were primarily a remodeling response to the changed joint dynamics resulting from a missing disc rather than degenerative changes as was earlier thought. Furthermore, crepitus and condylar changes appeared to be of little concern to patients who were assessed in the long-term follow-up studies.

Despite this, the issue of whether to replace the missing articular disc following TMJ discectomy remains a controversial area of surgery (McKenna, 2001). While the literature clearly points to the long-term success of TMJ discectomy without replacement, there is still concern about the crepitus and regressive remodeling that takes place in the condyle. Unfortunately, there is no ideal material or tissue graft that has been successful in replacing the missing disc (Appendix 3).

1.4.5. – DISC REPLACEMENT MATERIALS

Despite the success of long-term studies of TMJ discectomy, there is a perception among surgeons that disc replacement is required to help reduce the significant joint remodeling that is seen following discectomy alone (Merrill, 1986). The use of allograft materials to reconstruct or replace diseased tissues of the TMJ began with disastrous results when sialastic and then teflon-proplast implants were used to replace the articular disc following TMJ discectomy procedures in the late 1970’s and early 1980’s (Dolwick & Aufdemorte, 1985; Dolwick & Dimitroulis, 1994; Heffez, Maffee, Rosenberg et al, 1987; Kaplan, Tu & Williams, 1988; Schellhas, Wilkes & El Beeb, 1988; Westesson, Eriksson & Linstrom, 1989). Reports of inflammatory reactions associated with these allograft implants abound in the literature (Bosanquet, Ishimaru & Goss, 1991; Westesson, Eriksson & Lindstrom, 1989; Dimitroulis, 2005c). Dolwick and Aufdemorte (1985) described a foreign body reaction with giant cell infiltrate not only surrounding the sialastic implant but also in an adjacent lymph node. Chuong and Piper (1992) reported severe bone erosion with
cerebrospinal fluid leakage surrounding the TMJ Proplast-Teflon implant. In this study, the joints containing the alloplastic implants were found at operation to be severely inflamed and with signs of gross destruction of the surrounding structures. Before these implants were withdrawn from the market in 1988, it has been reported that up to 20,000 such devices were implanted in the United States alone (Spangoli & Kent, 1989). The disasters which followed the early use of alloplastic interpositional implants (Dolwick & Aufdemorte, 1985), such as sialastic (Bosanquet, Ishimaru & Goss, 1991; Westesson, Eriksson & Lindstrom, 1987, 1989) and proplast-teflon as disc replacement materials (Heffez, Maffee, Rosenberg et al, 1987; Kiersch, 1984; Wagner & Mosby, 1990), gave way to the increased use of autogenous grafts. Temporalis flaps (Feinberg, 1994; Feinberg & Larsen, 1989; Pogrel & Kaban, 1990), auricular cartilage (Hall & Link, 1989; Matukas & Lachner, 1990; Waite & Matukas, 1994) and dermis grafts (Dimitroulis, 2005a; Georgiade, 1962; McNeill, 1993; Meyer, 1988) have been reported with seemingly good results. Unfortunately, most autogenous grafts have been used to replace the initial failed alloplastic implants which means there were few cases reported of autogenous grafts placed at the time of the discectomy. According to McKenna (2001) there are too few data and too many variables to show that autogenous graft placement at the time of discectomy produces superior results to discectomy alone. This is inspite of the numerous animal studies which appear to demonstrate the benefits and advantages of the various interpositional grafts following discectomy which have so far not been adequately demonstrated in appropriate clinical studies (Thyne, Yoon, Luyk et al, 1992; Tong & Tideman, 2000; Tucker, Kennedy & Jacoway, 1990).

Several authors have described the implantation of cartilage in the TMJ. Perko was the first to report the use of fresh autogenous auricular cartilage for disc repair in 1973 (Perko, 1973). Witsenberg and Freihofer (1984), Ioannides and Freihofer (1988), Hall and Link (1989), and Matukas and Lachner (1990) described the clinical follow up of auricular cartilage grafts for the replacement of the disc. Ioannides and Maltha (1988) undertook an experimental study of disc replacement in the TMJ of guinea pigs using autogenous auricular and sternal cartilage. Tucker and co-workers (1990) reported autogenous cartilage implantation following discectomy in primate TMJ's. These authors concluded that autogenous auricular cartilage retained its viability without reactive or resorptive changes and appeared to be suitable as autogenous tissue grafts in
both experiments. Unfortunately, later studies (Yih, Zysset & Merrill, 1992; Takatsuka, Narinobou, Nakagawa et al 1996; Dimitroulis, Lee, & Dolwick, 2004) showed a tendency for the auricular grafts to fragment, proliferate and result in fibrous ankylosis of the TMJ with progressive limitation of mouth opening.

Dermis has been used for the repair of the TMJ disc as well as for the treatment of ankylosis by many authors since Loewe first introduced dermal grafting in 1913 (Meyer, 1988, 1989; Georgiade, Altany & Pickrell, 1957; Tucker, 1989; Tucker, Jacoway & White, 1986). The dermis graft was first introduced by Georgiade and co-workers in 1957 as an interpositional graft in the management of TMJ ankylosis (Georgiade, Alterny & Pickrell, 1957). In 1962, Georgiade described the use of autogenous dermis graft as a disc replacement following TMJ discectomy (Georgiade, 1962). Since then, there have only been a few clinical studies published on the use of dermis grafts for disc repair (Tucker, 1989, 1994; Tucker, Jacoway & White, 1986) and disc replacement material in the TMJ (Meyer, 1988, 1989). Data on the use of autogenous grafts at the time of primary discectomy are limited as most reports are of patients who have undergone repeat TMJ surgery following previous failed arthrotopies (Meyer, 1988, 1989). One study of 64 dermal grafts reported only 3 cases where the graft was placed at the time of the primary discectomy (Meyer, 1988). As far as can be ascertained, there has been only one clinical paper published on the use of the dermis graft at the same time as the discectomy (Dimitroulis 2005a). This clinical study of 35 joints in 29 patients forms part of this thesis (see chapter 2.1).

1.4.6. – TISSUE ENGINEERING OF THE TMJ DISC

An alternative to the use of autogenous grafts is currently being investigated by the rapidly growing field of tissue engineering. The principal elements of tissue engineering involve the creation of a scaffold, into which cells are seeded, and a biochemical or biomechanical stimulus is applied to make the cells grow and secrete substances that eventually produce the desired tissue that can be used to replace diseased or missing tissue elements in a living human being (Allen & Athanasiou, 2006).

The first attempt to investigate TMJ disc cells from a tissue engineering perspective was published in 1991 (Thomas, Grande & Haug, 1991). This was followed by another study
(Puelacher, Wisser, Vacanti et al, 1994) which investigated the biomechanical and biochemical properties of an engineered construct in the shape of a disc that was seeded with cells, which was the first study to demonstrate the feasibility of engineering a TMJ disc.

As a first step, early tissue-engineering studies focused on identifying the most appropriate scaffolding biomaterial. The results indicate that a mesh structure, in the form of a biodegradable polyglycolic acid and polylactic acid mesh were preferable to a hydrogel when working with a TMJ disc cell population (Allen & Athanasiou, 2006). It was found that cells readily attached to the polyglycolic acid meshes and not only maintained their viability, but also produced extracellular matrix (Almarza & Athanasiou, 2004).

As for the source of the cells used to seed the scaffold, an initial cell population that is highly chondrocytic may be ideal for the TMJ disc. The use of autogenous chondrocytes, however, from remote hyaline joint surfaces entails considerable morbidity. Fortunately, a fibrochondrocytic cell population may also be achieved from a fibroblastic cell line that may be procured from adult dermal fibroblasts, which, when treated with insulin growth factor and seeded on an aggrecan-coated surface, have demonstrated chondrocytic potential (French, Rose, Canseco & Athanasiou, 2004). This finding establishes a practical means of procuring autogenous dermal adult cells with relatively little morbidity compared to cartilage cells, and provides good evidence that autogenous dermis grafts may well be the ideal source of new disc cells.

With both the scaffold in place, and the cell source secured, the next step is finding the most effective trigger or biological signal that will maintain the cellularity and activate production of suitable extracellular matrix that will glue the whole tissue construct together. Growth factors such as platelet-derived growth factor, fibroblast growth factor and insulin-like growth factor are the most common biological signals utilized in tissue engineering. While constructs exposed to high levels of growth factors were found to have positive benefits as far as cellularity is concerned, little is known about the culture medium or seeding techniques that are most beneficial for the TMJ disc (Allen & Athanasiou, 2006). Another kind of biological signal that is often overlooked is the cell-to-cell interaction which
is effective when saturation cell seeding exceeds 75 million cells/ml within the polyglycolic acid scaffold (Almarza & Athanasiou, 2005). Biomechanical stimuli are also essential in maintaining cell survival and matrix production, otherwise the cartilagenous tissues begin to atrophy when not used for prolonged periods of time.

Tissue engineering an appropriate TMJ disc has gathered pace since 2000 (Allen & Athanasiou, 2006). The challenges faced by researchers include selection of an appropriate scaffold, identification of potential cell sources and the discovery of suitable biological and biomechanical stimuli that will fulfill the ultimate goal of creating a functional biological TMJ disc implant (Appendix 4).

1.4.7. – THE AUTOGENOUS FAT GRAFT

As early as 1914, Murphy (1914) described the transplantation of autogenous free fat grafts into joints. In 1925, Lexer (1925) reported that multiple small fat grafts do not survive as well as a single large fat graft when he found that the volume of the original graft can shrink as much as two-thirds of its original volume after 1 year. The shrinkage of free fat grafts was further confirmed by Peer (1950) who also found that after 1 year, free fat grafts lose, on average, 45% of their original volume following transplantation.

More recently, two studies which looked at the fate of autogenous free fat grafts used in posterior lumber spine decompression surgery confirmed that fat tissue does survive long term. In the first study (Kanamori, Kawaguchi, Ohmori et al, 2001 – Part 1), magnetic resonance imaging was used to determine that the grafted fat reduced in size to 57% after 42 days and 33% after 1 year as compared to the graft imaged 3 days following transplantation. Interestingly, the same study (Kanamori, Kawaguchi, Ohmori et al, 2001 – Part 1), also reported that the signal intensity of the fat graft was lower than that of the subcutaneous fat tissues in the first 6 weeks following transplantation but the intensity had fully recovered to normal by 1 year. This is in contrast to another study (Van Akkerveeken, Van De kraan & Muller, 1986), which used computed tomography scanning to investigate the size of autogenous fat graft measured at operation and 2 years later and found no change in the size of the fat graft in 15 of the 21 patients examined.
In the second part of the same study (Kanamori, Kawaguchi, Ohmori et al 2001 – Part 2), histological specimens were procured of the fat graft tissue on repeated lumbar surgery. At the light microscopy level, using hematoxylin-eosin stains, the histological specimens showed that the grafted fat used in the posterior lumbar surgery demonstrated reduced size and quality of the fat globules, as compared with normal fat tissue.

Other studies (Aangenskiold & Kiviluoto, 1976; Van Akkerveeken, Van De kraan & Muller, 1986) have postulated that autogenous free fat grafts prevent scar formation by acting as an effective hemostatic agent and a space filler that prevents the accumulation of blood and serum which would otherwise turn into scar or bone. This finding has led clinicians to use autogenous free fat grafts as a means of minimizing the occurrence of excessive joint fibrosis and heterotopic calcification when undertaking total joint replacements, particularly in the TMJ. (Wolford & Karras, 1997; Mercuri, Firas & Woolson 2008).

1.4.8. – THE AUTOGENOUS DERMIS-FAT GRAFT

Dermis-fat grafts are most commonly utilised as orbital implants in anophthalmic sockets in paediatric patients (Guberina, Hornblass, Meltzer et al, 1983). Dermis-fat grafts have also been used for augmentation rhinoplasties, closure of palatal fistulae and to restore the concave deformity following parotidectomy as well as to prevent Frey's syndrome (Bonanno, 1994; Mackay, Manders, Sagers et al, 1993; Vandeput, Droogmans & Tanner, 1995). According to Little (2002), the dermal layer is the vasoinductive layer for the underlying adipose graft and is usually placed facing against the subadjacent subcutaneous layer for optimal blood supply when used to augment and reconstruct major volumetric soft tissue defects. Unfortunately, no evidence to substantiate the above statement was provided. As far as can be ascertained, there has been only two reports in the literature describing the use of dermis-fat grafts as interpositional material in the surgical management of TMJ ankylosis (Dimitroulis 2004; Mehrotra, Pradhan, Mohammed et al, 2008), one of which form part of this THESIS (Chapter 2.3).
Whilst dermis grafts (Dimitroulis, 2005a) and, to a lesser extent, full-thickness skin grafts (Chossegros, Guyot, Cheynet et al, 1999) have been described in TMJ surgery, their main use has been as replacement material following discectomies. According to Dimitroulis (2004) fat grafts alone are easily fragmented but when attached to dermis the fat tends to be more stable and less likely to fragment when handled and manipulated into a cavity such as a gap arthroplasty. Dermis-fat grafts are easily sculptured with fine scissors to fit neatly into any size cavity which, as reported by Dimitroulis (2004), is the greatest advantage of this material to other interpositional materials already reported. Studies of the fate of dermis-fat grafts in non load-bearing areas such as human orbits and pigs ears have demonstrated little change in the volume of the graft (Mackay, Manders, Saggers et al, 1993). In some cases, the dermis-fat graft in paediatric patients have actually grown in volume with the growth of the patient (Guberina, Hornbluss, Meltzer et al, 1983; Mackay, Manders, Saggers et al, 1993). To date, there have been no studies undertaken on the fate of dermis-fat grafts under functional loading when placed as interpositional grafts in joints such as the TMJ.

1.5 – Literature Overview & Conclusions

Following TMJ discectomy, any potential disc replacement material must satisfy a number of essential criteria (Appendix 4). Most importantly, long-term safety of the material must be assured if we are to avoid the sialastic/teflon-proplast disasters of the 1980’s. Intrinsic properties such as adequate bulk, easy handling and the ability to be sculptured intra-operatively to fit the joint cavity are desirable characteristics of the ideal material. A material that is abundantly available and easy to procure with minimal morbidity are traits that will readily entice universal adoption of the technique with minimal training required. Surviving the functional demands of the intra-joint environment and, at the same time facilitating normal joint function with reduced joint noises dictates a material that is flexible enough to be able to adapt and change in response to the dynamic loads of the joint. The ideal material must also prevent bone formation and act as an effective barrier to joint ankylosis while protecting the underlying condyle from severe remodelling in the absence of a normal articular disc (Appendix 4).
In reviewing the literature, it is clear that there is still no ideal interpositional material that satisfies all the criteria for replacement of a missing articular disc following TMJ discectomy (Appendix 5). The alloplastic materials, in particular sialastic and proplast-teflon, caused significant foreign body reactions with severe erosion of the surrounding bone. Ear cartilage grafts were susceptible to fragmentation and ankylosis formation. Full thickness skin has been shown to develop epidermoid cysts when implanted into rabbits. Allogeneic grafts were found to be inflexible, resorbed unpredictably and had the potential for cross-infection. The use of temporalis muscle and fascia, while the most popular of all interpositional material, results in scarring and trismus from the donor site with the fascia lacking sufficient bulk and the muscle itself undergoing degenerative fibrosis under compressive load. Autogenous dermis was found to have insufficient bulk and was difficult to anchor to surrounding tissues while autogenous fat grafts were difficult to handle and often fragmented when placed into the joint cavity. Tissue engineered articular discs are still at the embryonic phase of development but the real challenge will come when researchers try to figure out how to anchor the newly developed disc to the surrounding articular structures without compromising the normal function of the joint (Appendix 5).

In our quest to find the ideal interpositional graft material to replace a missing articular disc following TMJ discectomy, the abdominal dermis-fat graft appears to offer some promise as the material of choice. Therefore, this THESIS is dedicated to establishing whether or not the abdominal dermis-fat graft can fulfill all the criteria for an ideal disc replacement material following TMJ discectomy (Appendix 4) in the management of advanced TMJ internal derangement.
CHAPTER 2
PRELIMINARY STUDIES

2. INTRODUCTION

The three studies contained in this chapter were undertaken by the candidate prior to his enrolment as a PhD student in early 2006. All three studies have been published in peer-review journals as follows;

**Chapter 2.1**
Dimitroulis G. The use of dermis grafts after discectomy for internal derangement of the temporomandibular joint

**Chapter 2.2**
Dimitroulis G & Slavin J. Histological evaluation of full thickness skin as an interpositional graft in the rabbit craniomandibular joint
*J Oral Maxillofac Surg 2006; 64:1075-80*

**Chapter 2.3**
Dimitroulis G. The interpositional dermis-fat graft in the management of temporomandibular joint ankylosis

The candidate undertook various preliminary studies on potential disc replacement materials that could be used in temporomandibular joint (TMJ) surgery. Initially, the abdominal dermis graft (Chapter 2.1) looked promising but it appeared to lack sufficient bulk and was difficult to properly anchor into the joint cavity as it failed to fill the joint space following discectomy (Dimitroulis, 2005a). It was then decided to look at full thickness skin as a potential interpositional graft because of greater bulk but, as the rabbit study clearly showed in Chapter 2.2, the full thickness skin graft had the propensity to develop epidermoid cysts when implanted into the TMJ (Dimitroulis & Slavin, 2006).
In the surgical management of TMJ ankylosis, the gap arthroplasty with a suitable interpositional graft is the mainstay in the treatment of this disorder. In a series of 11 patients with TMJ ankylosis, the candidate stumbled on the idea of leaving the subcutaneous fat attached to the dermis graft so that the entire surgical cavity created by the gap arthroplasty could be filled with grafted tissue which obviated the need to anchor the graft to the surrounding tissues. The results were positive with long-term follow-up of up to 6 years where only one of the 13 joints treated reankylosed. Chapter 2.3 contains the details of this study which was the first paper ever published on the use of abdominal dermis-fat grafts in TMJ surgery (Dimitroulis, 2004).

Following on from the success of the pilot study on the use of dermis-fat grafts in TMJ surgery (Dimitroulis 2004), the candidate decided to focus on this graft material as the basis for his PhD THESIS. The promising potential of this graft material in TMJ surgery beckoned further detailed study as to its real usefulness in clinical Oral & Maxillofacial Surgery practice.

The aim of chapter 2 is to provide some background on the candidate’s preparation for the PhD degree and the decision process used to select the dermis-fat graft for TMJ surgery as the basis for the research projects contained in this THESIS.
CHAPTER 2, PART 1

THE USE OF DERMIS GRAFTS FOLLOWING DISCECTOMY FOR INTERNAL DERANGEMENT OF THE TEMPOROMANDIBULAR JOINT

2.1.1. INTRODUCTION

The mainstay in the management of internal derangement of the Temporomandibular Joint (TMJ) continues to be non-surgical with occlusal splint therapy playing a central role as the principal treatment modality (Dimitroulis, 1998). While 80% of patients respond favourably to conservative measures, the remaining 20% are refractory cases that include those with chronic pain syndrome complicated by multiple contributing factors. Approximately 5% of patients who suffer from Temporomandibular Disorders (TMD) may require surgical intervention, in particular, those patients with symptoms of pain and dysfunction well localised to the TMJ who have otherwise remained unresponsive to conservative measures (Dolwick & Dimitroulis, 1994).

There are a myriad of surgical procedures involving the TMJ ranging from arthroscopy to open joint surgery or arthrotomy. Many open joint procedures revolve around various disc repair and preservation techniques with or without surgical contouring of the surrounding hard tissues (Dolwick & Dimitroulis, 1994). In some cases the disc may be beyond salvage so is surgically removed in a process referred to as discectomy. Discectomy is one of the oldest surgical procedures to the TMJ that was first described by Lanz in 1909 (Lanz, 1909). The procedure of TMJ discectomy has since spurned some of the longest follow-up clinical studies in the dental and surgical literature (Eriksson & Westesson, 1985; Silver, 1984; Takaku & Toyoda, 1994; Tolvanen, Oikarinen & Wolf, 1988). While the long-term reports suggest good outcomes for TMJ discectomy, it is still unknown whether the use of interpositional grafts to replace the excised disc are necessary or even warranted (MacIntosh, 2000; McKenna, 2001). Much has been published on the advantages and pitfalls of interpositional grafts such as ear cartilage (MacIntosh, 2000; McKenna, 2001; Tong & Tideman, 2000; Waite & Matukas, 1994) and alloplastic implants like teflon-proplast (McKenna, 2001; Ryan, 1994) but relatively little has surfaced in the literature on the use of
autogenous dermis grafts as disc replacement material following discectomy (Georgiade, 1962; Meyer, 1988; Meyer, 1989). The autogenous dermis graft has its own pitfalls such as possible hair growth and development of epidermoid cysts within the joint (Bonnington, Langan & Joye Jr, 1987; Muto et al, 1992; Weinberg & Kryshlalsky, 1995; Abrams, Andrews & Laskin, 1977).

The dermis graft was first introduced by Georgiade and co-workers in 1957 as an interpositional graft in the management of TMJ ankylosis (Georgiade, Altany & Pickrell, 1957). In 1962, Georgiade described the use of autogenous dermis graft as a disc replacement following TMJ discectomy (Georgiade, 1962). Since then, there have only been a few clinical studies published on the use of dermis grafts for disc repair (Tucker, 1989; Tucker, Jacowy & White, 1986; Tucker, 1994) and disc replacement material in the TMJ (Meyer, 1988; Meyer, 1989). The latter studies have mainly focused on cases of multiply operated joints where the dermis graft was used some months or years following the discectomy (Meyer, 1988; Meyer, 1989). As far as can be ascertained, there have not been any clinical papers published on the use of the dermis graft at the same time as the discectomy (McKenna, 2001). The purpose of this study is to present the clinical experience of using autogenous dermis as an immediate interpositional graft following TMJ discectomy.

2.1.2. MATERIALS & METHODS

A retrospective review was conducted on patients with internal derangement of the TMJ who underwent discectomy with immediate replacement of the excised disc with autogenous dermis graft. The basis for initial surgical consideration was TMJ pain and dysfunction that was not adequately responding to at least 6 months of non-surgical treatment such as occlusal splint therapy, medication and physiotherapy. Selection of surgical candidates was further considered on the basis that symptoms of pain and dysfunction were well localised to the TMJ (Dolwick & Dimitroulis, 1994). Of the patients who underwent TMJ surgery by the author between 1996 and 2003, twenty-nine patients were identified and included in the study based on the following selection criteria;

1. The TMJ had not undergone any previous arthrotomy (i.e., open joint) procedure.
2. Pre-operative Magnetic Resonance Imaging (MRI) evidence (fig.2.2.1) (Tasaki & Westesson, 1993) of severe internal derangement of the TMJ (ie. Wilke’s stage IV or V) (Wilkes, 1989)
3. Severely displaced and deformed or degenerate disc that was judged to be unsalvagable at the time of operation and so required removal (i.e., discectomy) (Hall, 1994)
4. An autogenous dermis graft was placed at the same operation as the discectomy procedure.

Patients with a previous history of TMJ arthrotomy, and those where discectomy and dermis grafting were performed in separate operations were excluded from the study.

Four parameters were used to measure the outcomes of surgery. Maximum interincisal opening (MIO), pain score on a visual analogue scale of 0-10, mandibular function score also based on a visual analogue scale of 0-10, and finally, a patient satisfaction score based on a descriptive scale of 0-4. The post-operative data used in this study were based on the very latest follow-up of each patient which ranged from as brief as 3 months to as long as 79 months following surgery (average 24 months).

2.1.2.1. Surgical Technique:

A standard pre-auricular incision and dissection was used to expose the TMJ capsule (Dolwick & Sanders, 1985). Through a horizontal incision across the capsule enclosing the superior joint space the disc was exposed and closely inspected for possible salvage and repair. The patients in this study all demonstrated damaged, diseased or deformed disks that were beyond repair and so discectomy was performed (Hall, 1994). After the diseased disc was removed, attention was paid to the surrounding articular surfaces of the TMJ for signs of eburnation or peeling of the fibrocartilagenous surfaces which, if present, were removed and the underlying bone smoothed over. Osteophytes at the lateral pole of the condyle were also removed where present. High condylar shaves, partial condylar amputations or decompressions and surgical recontouring of the glenoid fossa and eminence were undertaken only where indicated such as in the presence of disease or to facilitate joint function (Dolwick & Sanders, 1985).

The dermis graft was harvested from the groin through an elliptical incision (Tucker, 1989; Steinberg & Hohn, 1994). The overlying epidermis was carefully dissected free hand from the dermis with a No. 15 scalpel blade whilst the graft was still attached to the tissue bed. Once the
dermis was uncovered it was dissected free from its tissue bed and the underlying subcutaneous fat was removed with sharp scissors. With the resultant joint cavity free of disease and interferences, the dermis graft was gently inserted to cover the head of the condyle like a jockey’s cap (fig. 2.1.2). Where possible, the graft was anchored with sutures to the remnants of the lateral capsule or bilaminar zone. Unfortunately, in some cases, anchoring was difficult and often impossible so the graft was simply inserted as a space filler between the head of condyle and glenoid fossa and the lateral capsule closed over it to prevent the graft from spilling out of the joint cavity proper.

The joint was then repaired with layered closure and a barrel head bandage was applied over the surgical site for 24 hours post-operatively. The donor site in the groin was also closed primarily in layers to a linear wound that was covered with water-proof surgical dressing. Cephalosporin antibiotics were commenced at the time of surgery and continued for 3 days post-operatively. Rehabilitation involving physiotherapy was commenced 10 days following surgery to promote joint mobility and mandibular function.

**2.1.3. RESULTS**

Twenty-nine patients were reviewed for this study which involved surgery to 35 joints. Six patients had bilateral TMJ surgery although the surgery for each joint was undertaken on separate occasions at least 6 months apart. There were 25 females and 4 males with a mean age of 42 yr ± 13 yr ranging from 14 yr to 63 yr. The average duration of TMJ symptoms prior to surgery was 38 months ranging from a minimum of 6 months up to a maximum of 10 yr. Twenty-eight of the 29 patients had undergone treatment for TMD prior to surgery with the most common modality being occlusal splint therapy in 26 patients (89.7%). Medication was prescribed to 17 patients (58.6%) in the form of non-steroidal anti-inflammatory drugs (NSAID) or tricyclic antidepressants. Thirteen patients (44.8%) also had adjunctive physiotherapy. Of the 35 joints, 12 (34.3%) had undergone previous TMJ arthroscopic lysis and lavage. One patient, a 56 yo edentulous female had no previous TMD treatment prior to surgery.

The follow-up period ranged from 3 months to 79 months with a mean of 24.6 months ± 10.8mn (Table 2.1.2). The mean maximum interincisal mouth opening (MIO) prior to surgery was 29.9mm ± 6.9mm. Following surgery, the mean MIO improved to 36.6mm ± 5.7mm which equates
to a +6.7mm improvement or an average improvement of 22.4% in percentage terms. Using the visual analogue scale of 0-10 for pain and mandibular function, there was a 66% improvement in pain and 42% improvement in mandibular function following surgery. In raw figures the mean pre-operative pain score was 8.2 ± 1.7 which improved to a mean score of 1.6 ± 0.9 following surgery ($P<0.001$). As for the mandibular function score, the pre-operative mean was 4.4 ± 1.3 which improved to a mean score of 8.6 ± 1.8 following surgery ($P<0.05$). Thirty-three of the 35 operated joints (94.3%) demonstrated smooth function with no joint sounds clinically detected for the duration of the follow-up period in each individual case. All the data used in the calculation of post-operative parameters were based on the latest follow-up measurements recorded for each patient (Table 2.1.1).

Orthopantomograms, which included both mandibular condyles, were taken post-operatively in all patients. Serial post-operative tomograms demonstrated obvious remodelling of the condylar head in all patients who were followed up for at least 6 or more months after surgery. MRI’s were taken in only 7 of the 35 operated joints at least 6 months or more after surgery. Whilst all MRI’s demonstrated remodelling of the condylar head, none showed any definite evidence of the dermis graft in situ at 6 months or more after surgery. In 4 cases the radiology reports did note the presence of heterogenous material in the joint space but could not confirm if the material was dermis or just dense fibrotic tissue.

Twenty-one patients (72.4%) were free of complications while 16 complications were recorded in the remaining 8 patients (27.6%). Fifteen of the 16 complications (93.8%) were transient and resolved within 2 months of surgery. In one case, the operated joint developed an ankylosis that required further surgical intervention. The most common transient complication was wound infection/dehiscence/stitch granuloma, which developed superficially in the site of the skin incision in 3/35 joints (8.6%) and 5/35 donor sites (14.3%), all which resolved with local wound toilet and antibiotics. There were 3 cases each of transient partial deafness (8.6%) and transient malocclusion (8.6%) which resolved spontaneous within two weeks without further intervention. One case (1/35) of weakness of the frontal branch of the facial nerve (2.9%) that recovered spontaneously within 2 months was also recorded (Table 2.1.2).
As for the level of patient satisfaction following surgery, patients were asked to grade their degree of satisfaction according to the level of their pre-operative anticipated outcome of the surgery. In 27 of the 35 joints (77.1%) operated on, patients reported an excellent outcome which was defined as a satisfactory result that exceeded their expectations. In 3 of the 35 joints (8.6%), patients reported a good outcome, which was defined as a satisfactory result that met their expectations. In 4 of the 35 joints (11.4%) a less than satisfactory result was reported by patients which was defined as a mild improvement in symptoms which was below their expectations. There was no recorded “unchanged” symptoms following the surgery. However, there was one case out of 35 joints where the patient reported a deterioration of symptoms following surgery after ankylosis developed within the joint, although the pain had improved (Table 2.1.3).

2.1.4. DISCUSSION

Autogenous dermis grafts have been used in the TMJ for repair of disc perforations and as interpositional grafts in gap arthroplasties for TMJ ankylosis and following TMJ discectomy (MacIntosh, 2000; McKenna, 2001; Georgiade, 1962; Meyer, 1988; Meyer, 1989; Georgiade, Altany & Pickrell, 1957; Tucker, Jacoway & White, 1986; Tucker, 1994). Data on the use of autogenous grafts at the time of primary discectomy are limited as most reports are of patients who have undergone repeat TMJ surgery following previous failed arthrotomies (Meyer, 1988; Meyer, 1989). One study of 64 dermal grafts reported only 3 cases where the graft was placed at the time of the primary discectomy (Meyer, 1988). In short, little has been published on the placement of dermis grafts at the time of the initial TMJ discectomy (McKenna, 2001).

There was a significant improvement in all four parameters analysed in this clinical study when compared before and after surgery. Such results certainly demonstrate that TMJ discectomy has a substantial positive effect in the management of patients with advanced internal derangement of the TMJ who fail to respond to less invasive measures such as splint therapy and TMJ arthroscopy. What the data fail to show, which is the major limitation of this study, is whether there is any significant advantage of using dermis graft as opposed to no graft or indeed other grafts following TMJ discectomy (MacIntosh, 2000; McKenna, 2001; Hall, 1994). Unfortunately, it is
very difficult to directly compare the results of this study with other studies which also looked at TMJ discectomies either in animals (Tong & Tideman, 2000) or humans (MacIntosh, 2000; McKenna, 2001) since there are often no comparable inclusion criteria noted in other studies. Patients, for example, are often included in a study on the basis of the surgical procedure undertaken regardless of the clinical diagnosis (Meyer, 1988).

Nevertheless, long-term studies of TMJ discectomy without grafting have demonstrated very impressive outcomes in terms of pain reduction and improved mandibular function (Eriksson & Westesson, 1985; Silver, 1984; Takaku & Toyoda, 1994; Tolvanen, Oikarinen & Wolf, 1988). So it begs the question, does the excised TMJ disc need to be replaced at all (McKenna, 2001; Hall, 1994)? What this study found was TMJ function in the post-operative phase was remarkably smooth with no joint sounds noted by the author in 33 of the 35 joints up to 79 months following surgery. This is despite the radiological evidence which showed varying degrees of condylar head remodelling following TMJ discectomy with immediate dermis graft replacement. While MRI’s were taken in all patients prior to surgery (fig. 2.1.1), only 7 out of the 35 joints had MRI’s taken at least 6 months or more post surgery. No clear evidence of dermis graft within the operated TMJ was found in any of the 7 post-operative MRI’s (even though 4 cases were reported as heterogenous material present in the joint space), although condylar head remodelling was clearly evident (fig. 2.1.3).

How important the dermis graft is in the initial phases of healing following TMJ discectomy is yet to be determined since the limited MRI evidence from this study (fig. 2.1.3) seems to suggest the dermis graft may well just be a temporary measure which either disappears or undergoes significant fibrosis over time. Does the initial presence of the dermis graft promote favourable condylar remodelling and hence less TMJ crepitus over the long-term compared to cases of no grafting following TMJ discectomy? The present study certainly seems to suggest this. Perhaps the dermis, like a surgical dressing, facilitates the healing of the discless joint cavity in the early stages. It is then either resorbed or transformed into fibrous tissue as the joint adapts to smooth functional changes promoted by intervening soft tissue between the condylar head and glenoid fossa in the first 6 months following surgery (Stewart, Hann, DeTomasi et al, 1986). Further studies will obviously be required to answer these questions.
While the autogenous dermis graft appears to work well in filling the defect left by the excised TMJ disc (fig. 2.1.2), it is still not the ideal disc replacement for a number of reasons. The most obvious drawback is the donor site morbidity, though small, is still worth noting. The other drawback is the difficulty in anchoring the graft to remaining tissues in the disectomised joint. While dermoid cysts have been reported in dermis grafts (Bonnington, Langan & Joye Jnr, 1987; Muto et al 1992; Weinberg & Kryshlalsky, 1995; Abrams, Andrews & Laskin, 1977) there were no cases seen in this series of patients, but it is another factor that should be considered. Dermis is not a load bearing tissue and hence it may well explain the absence of dermis tissue in MRI’s taken in 7 of the 35 joints six months or more post-operatively. The only apparent advantage of dermis grafts seems to be the elimination of joint sounds such as crepitus in the disectomised TMJ when compared to results of studies where no grafts were used following disc removal (Eriksson & Westesson, 1985; Silver, 1984; Takaku & Toyoda, 1994; Tolvanen, Oikarinen & Wolf, 1988; Hall, 1994). The dermis graft easily fills up the cavity or defect left within the joint following disc removal which effectively reduces the potential dead space. The dermis may provide a scaffold for subsequent soft tissue growth and healing between the head of the condyle and glenoid fossa (Stewart, Hann, DeTomasi et al, 1986) which, in turn, may explain the smooth joint function found in 33 of the 35 operated joints in this study.

2.1.5. SUMMARY & CONCLUSION

The aim of this retrospective clinical study was to review the outcomes of Temporomandibular joint (TMJ) discectomy with autogenous dermis used as an immediate interpositional graft in patients with advanced internal derangement of the TMJ. Thirty-five joints in 29 patients who presented with advanced internal derangement of the TMJ with degenerate and irreparable disks were identified and included in the study. All patients underwent a TMJ arthrotomy (including 6 bilateral TMJ procedures) which involved removal of the disc (discectomy) and immediate replacement with autogenous dermis graft. Patients were followed up for an average of 2 years.

There was a mean +6.7mm improvement in maximum interincisal opening, a 66% mean improvement in pain ($P<0.001$) and 42% mean improvement in function ($P<0.05$) following TMJ discectomy with immediate dermis graft replacement. After an average follow-up period of 24.6
months, patients reported good to excellent improvement in their TMJ symptoms in 30 out of the 35 joints (85.7%). All patients demonstrated radiological evidence of varying degrees of condylar remodelling at 6 months or more following their surgery. Of the 7 patients who had MRI’s done at 6 months or more after their surgery, none demonstrated any radiological evidence of the dermis graft. No clinical evidence of joint sounds such as crepitus was found in 33 of the 35 operated joints. This study found that TMJ discectomy can have a significant positive effect in the management of patients with advanced internal derangement of the TMJ who fail to respond to less invasive measures such as splint therapy and TMJ arthroscopy. However, the only advantage of dermis grafts over no grafts seems to be that it can minimize or eliminate joint sounds such as crepitus in the discectomised TMJ. In this study the dermis grafts did not prevent regressive remodelling of the mandibular condyles.
Maximum Interincisal Opening (MIO)

Pre-operative average 29.9mm ± 6.9mm
Post-operative average 36.6mm ± 5.7mm
Improvement +6.7mm (22.4%)

Pain Score (Scale 0 – 10)

Pre-operative average 8.2 ± 1.7
Post-operative average 1.6 ± 0.9
Improvement -6.6 (66 %)
95% Confidence Level P<0.001

Mandibular Function Score (Scale 0-10)

Pre-operative average 4.4 ± 1.3
Post-operative average 8.6 ± 1.8
Improvement +4.2 (42 %)
95% Confidence Level P<0.05

- 33/35 joints demonstrated smooth joint function and no joint noises/crepitus

Table 2.1.1: Study parameters
Wound dehiscence/infection/stitch granuloma

<table>
<thead>
<tr>
<th>Condition</th>
<th>Count</th>
<th>Total Joints</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. TMJ</td>
<td>3 / 35 joints</td>
<td>(8.6%)</td>
<td></td>
</tr>
<tr>
<td>b. Groin</td>
<td>5 / 35 joints</td>
<td>(14.3%)</td>
<td></td>
</tr>
<tr>
<td>Transient deafness (&lt; 2 weeks)</td>
<td>3 / 35 joints</td>
<td>(8.6%)</td>
<td></td>
</tr>
<tr>
<td>Transient malocclusion (&lt; 2 weeks)</td>
<td>3 / 35 joints</td>
<td>(8.6%)</td>
<td></td>
</tr>
<tr>
<td>Transient Facial nerve weakness (&lt; 2 months)</td>
<td>1 / 35 joints</td>
<td>(2.9%)</td>
<td></td>
</tr>
<tr>
<td>TMJ ankylosis</td>
<td>1 / 35 joints</td>
<td>(2.9%)</td>
<td></td>
</tr>
</tbody>
</table>

* NB: 21 / 29 (72.4%) patients had no complications

The 16 complications occurred in the remaining 8 patients

Table 2.1.2. Surgical complications
<table>
<thead>
<tr>
<th>Level of Satisfaction</th>
<th>Number of Joints</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>0. Became worst</td>
<td>1 / 35 joint</td>
<td>(2.9%)</td>
</tr>
<tr>
<td>1. No improvement</td>
<td>0 / 35 joints</td>
<td>(0%)</td>
</tr>
<tr>
<td>2. Mild – below expectations</td>
<td>4 / 35 joints</td>
<td>(11.4%)</td>
</tr>
<tr>
<td>3. Good – met expectations</td>
<td>3 / 35 joints</td>
<td>(8.6%)</td>
</tr>
<tr>
<td>4. Excellent – exceeded expectations</td>
<td>27 / 35 joints</td>
<td>(77.1%)</td>
</tr>
</tbody>
</table>

**Table 2.1.3.** Patient level of satisfaction following surgery
Figure 2.1.1 – Pre-operative MRI of a severely deformed and displaced disc in the TMJ which was one of the essential criteria for inclusion in the study.
Figure 2.1.2 – Intra-operative view of the TMJ showing the exposed condylar head following discectomy. The dermis graft is placed nearby on the left before it is trimmed to fit the interpositional joint space vacated by the excised articular disc.
Figure 2.1.3 – Post-operative MRI of a TMJ that has had discectomy with immediate dermis interpositional graft 6 months previously. While remodelling of the condylar head is seen, there is no clear evidence of the dermis graft.
CHAPTER 2, PART 2

HISTOLOGICAL EVALUATION OF FULL THICKNESS SKIN AS AN INTERPOSITIONAL GRAFT IN THE RABBIT TEMPOROMANDIBULAR JOINT.

2.2.1. INTRODUCTION

The ideal disc replacement material following discectomy for advanced temporomandibular joint (TMJ) internal derangement has yet to be found (Dimitroulis, 2005b). Alloplastic implants such as proplast-teflon and sialastic have yielded disastrous results through foreign body giant cell reactions (Yih & Merrill, 1989). Autogenous ear cartilage grafts have also failed because of graft fragmentation and joint fusion resulting in ankylosis (Yih, Zysset & Merrill, 1992). The clinical use of the dermis graft as a disc replacement following discectomy in the human TMJ has been published (Dimitroulis, 2005a), however, one side effect of using dermis as an interpositional graft within the TMJ has been the development of epidermoid cysts (Muto, Tomioka, Michiya et al., 1992; Weinberg & Kryshlalsky, 1995; Bonnington, Langan & Joye, 1987). It has been suggested that remnants of epidermis left on the dermal grafts may well be the trigger that results in the formation of epidermoid cysts (Weinberg & Kryshlalsky, 1995). This is an important issue since the use of full thickness skin grafts as interpositional material has already been described for the treatment of TMJ ankylosis (Popescu & Vasiliou, 1977; Chossegros, Guyot, Cheynet et al., 1999). The purpose of this study is to determine the histological fate of the full thickness skin graft when placed into the TMJ using a rabbit model.

2.2.2. MATERIALS & METHODS

Fourteen New Zealand white rabbits were used in this study (Table 2.2.1). The study was approved by the Animal Ethics Committee at St.Vincent’s Hospital Melbourne in accordance with guidelines put out by the National Health and Medical Research Council of Australia governing animal experiments. Two rabbits were used as controls (Group A) whereby a sham
operation was undertaken with an incision made and immediately repaired without breaching the joint space. The temporomandibular joints (TMJ) of the Group A rabbits were used as the normal controls with which compare the surgically treated joints of the remaining rabbits. Six rabbits (Group B) had the left TMJ surgically exposed before the wound was repaired and the rabbits placed back in their cages. The remaining six rabbits (Group C) also had the articular disc of the TMJ exposed with the interpositional placement and suturing of a full thickness skin graft which was taken from the skin of their necks (fig. 2.2.1).

2.2.2.1. SURGICAL TECHNIQUE:

Anesthetic induction was via an IV bolus of 1:1 mixture of ketamine (70mg/ml) and xylozine (10mg/ml) at a rate of 1ml/kg into the ear vein. The anesthetic mixture provided 60-90 minutes of anesthesia time. Following anesthesia induction the fur in the left pre-auricular region was shaved and depilatory cream was placed to remove all the fur around the surgical site. After injection with 1ml of 2% lignocaine with 1/80,000 adrenaline, a horizontal skin incision was made from just posterior to the lateral canthus of the eye to just anterior to the external acoustic meatus. In the 2 control rabbits (Group A) the incision was immediately repaired without breaching the joint space. For the experimental rabbits (Groups B & C), the zygomatico-squamosal suture line was exposed and a section of the zygomatic process overlying the temporomandibular joint (TMJ) was carefully removed. The capsule of the TMJ was incised and the superior joint space was completely exposed to reveal the articular disc which was left intact. The surgical wound in Group B rabbits was closed immediately following exposure of the superior joint space. In group C rabbits, a full thickness skin graft was harvested from the neck, which was denuded of fur, and was carefully inserted into the superior joint space above the articular disc and secured firmly to the surrounding tissues with two or three 7-0 Prolene sutures (fig 2.2.1). The wound was closed with 4-0 vicryl sutures. The analgesic “Carprofen” was administered at the time of surgery and a follow up dose (5mg/kg SC) was given in the 6 hours following surgery. After operation the animals were fed a diet of crushed pellets and fresh vegetables for the first week and water ad libitum. Their weight was measured at two week intervals post-operatively. After a week all animals were placed back on their normal diet of hard pellets and vegetables.
Each animal was housed individually in a double pen to prevent the risk of other animals disturbing the surgical wounds. Each group of rabbits were killed by euthanasia at 4 weeks, 12 weeks and 20 weeks following surgery (Table 2.2.1). Euthanasia was administered by IV sodium pentobarbitone (2mg/kg)

Following euthanasia, the jaw joints were dissected out and placed in formalin. The specimens were decalcified prior to histological sectioning. Coronal sections were prepared of each craniomandibular joint for histological evaluation under light microscopy in the Department of Anatomical Pathology. At least 8 sections from each joint were examined and pertinent findings were recorded using digital photography

2.2.3. RESULTS

As this was a qualitative study, a statistical justification of animal numbers was not applicable. It was decided by the authors that the minimum number of animals for which useful comparisons could be made, as described above was 14 (Table 2.2.1). The mean weight of all 14 rabbits at the time of surgery was 2.44 kg +/- 0.17kg and the mean age at surgery was 4.91 months +/- 0.26 months.

**Control Rabbits (Group A-2 rabbits)** – Both rabbits suffered no adverse side effects from the anesthetic and operative procedure. Their return to normal diet was within 48 hours and their wounds healed uneventfully. Histological examination of the left TMJ’s showed a well rounded condylar head covered by healthy fibrocartilage. A dense fibrotic band of tissue representing the articular disc surrounded the condylar head with evidence of synovial lining present along the lateral margins. Beneath the fibrocartilage cap covering the condylar head was a graded layer of cartilagenous cells which in turn covered a well defined layer of cortical bone. The marrow space beneath the cortical bone was interspersed with vascular channels and islands of bone trabeculae enclosing osteocytes with occasional osteoblasts along the margins. It was apparent that the operative procedure which did not breach the joint space had no effect on the joint itself at both 12 and 20 weeks.
4 Weeks – Exposure of superior joint space, no graft (Group B-2 rabbits) - Both rabbits suffered no adverse side effects from the anesthetic and operative procedure. Their return to normal diet was within 7 days and their wounds healed uneventfully. The surgery had a significant early effect on both rabbits but they quickly adapted and by day 7, both were managing a routine normal diet with no apparent ill-effects. At the histological level it was apparent that not all the disc was preserved and remnants of surgically traumatised disc were seen in some sections. In the sections where the disc was breached, the joint space was filled with blood and fibrin. The condylar head in the regions where the disc was present appeared to closely resemble that of the control rabbits. However, where the disc was breached, the underlying condyle demonstrated an irregular outline with increased fibrosis and a marked reduction in mature cartilage. In the subarticular bone there was increased osteoblast and osteoclast activity reflecting high bone activity indicative of a remodeling rather than a degenerative process.

4 Weeks – Insertion of skin graft (Group C-2 rabbits) – Both rabbits suffered no adverse side effects from the anesthetic and operative procedure. Their return to normal diet was within 7 days and their wounds healed uneventfully. The interpositional skin graft procedure to the TMJ had a significant early effect on both rabbits but they quickly adapted and by day 7, both were managing a routine normal diet with no apparent ill-effects.

At the histological level it was apparent that not all the disc was preserved intact and remnants of traumatised disc were seen in some sections. The skin graft in both animals was seen to be adjacent to the condyle on the lateral aspect rather than over the head above the disc where it was originally sutured in place. The skin graft was obviously vital and both specimens demonstrated evidence of epidermoid inclusion cysts within the substance of each graft. There was significant atrophy and reduction in the number and size of the skin appendages such as sweat glands and hair follicles within the grafted skin compared to normal skin. No evidence of skin was detected superiorly above the head of the condyle and it appears the graft was displaced into the lateral position very early on following the surgery. The condyles in both animals demonstrated the same remodeling process of increased bone activity, fibrosis and surface
irregularity in areas where the disc was breached as that of the group B specimens without the skin graft.

12 Weeks – Exposure of superior joint space, no graft (Group B-2 rabbits) - Both rabbits suffered no adverse side effects from the anesthetic and operative procedure. Their return to normal diet was within 7 days and their final weight at sacrifice was 3500 grams (9.2%) lighter than the control rabbit sacrificed at the same time frame. In areas where the disc was surgically breached the condylar head showed marked flattening with subarticular trabeculae with increased osteoblast and osteoclast activity. The condylar surface adjacent to the area where the articular disc was missing demonstrated a marked reduction in fibrocartilage with increased bone formation (i.e., osteoid deposits) and osteoblast activity whereby most the the cartilagenous cap was replaced by bone (fig. 2.2.2).

12 Weeks – Insertion of skin graft (Group C-2 rabbits) – Both rabbits suffered no adverse side effects from their anesthetic and operative procedure. Their return to normal diet was within 7 days and their final weight at sacrifice was 5000 grams (11.8%) lighter than the control rabbit sacrificed at the same time frame. Once again the full thickness skin graft was laterally displaced relative to the condylar head. The graft tissue demonstrated significant amounts of keratin with increase fibrosis compared to the 4 week specimens. The skin appendages within the graft showed severe degeneration. Epidermal cysts were also present in both specimens (fig. 2.2.2).

20 Weeks – Exposure of superior joint space, no graft (Group B-2 rabbits) - Both rabbits suffered no adverse side effects from the anesthetic and operative procedure. Their return to normal diet was within 7 days and their final weight at sacrifice was 4500 grams (7.1%) heavier than the control rabbit sacrificed at the same time frame. There was no evidence of surgical trauma to the articular disc so the condylar morphology resembled that of the control rabbits in both cases.

20 Weeks – Insertion of skin graft (Group C-2 rabbits) – Both rabbits suffered no adverse side effects from their anesthetic and operative procedure. Their return to normal diet was within 7 days and their final weight at sacrifice was 4600 grams (9.5%) heavier than the control rabbit
sacrificed at the same time frame. Both specimens demonstrated lateral displacement of the graft as well as epidermoid cyst formation similar to the other Group C rabbits sacrificed earlier in the course of the experiment. Severe degeneration of all skin appendages was also noted in both grafts (fig. 2.2.3).

2.2.4. DISCUSSION

In clinical practice, full thickness skin grafts are rarely used to reconstruct the human temporomandibular joint. Instead, dermal grafts are preferred to avoid the risk of inclusion cyst formation which has been reported in the literature. Unfortunately, the evidence for cyst formation has largely been in the form of clinical case reports (Muto, Tomioka, Michiya et al., 1992; Weinberg & Kryshlalsky, 1995; Bonnington, Langan & Joye, 1987). What this study has clearly demonstrated is that the presence of epidermis does in fact result in epidermoid cyst formation in all grafts implanted into the TMJ of all the rabbits.

In 1902, Gluck (Gluck, 1902) first reported the use of skin grafts for arthroplasty. A scan of the literature showed 2 articles which reported the use of full thickness skin as an interpositional graft in the human TMJ (Popescu & Vasiliou, 1977; Chossegros, Guyot, Cheynet et al., 1999). Both were for the management of TMJ ankylosis. Popescu and Vasiliou published the first report in 1977 on the use of full thickness skin grafts for TMJ ankylosis (Popescu & Vasiliou, 1977). Interestingly, they reported that one of the major problems associated with this technique was the displacement of the graft due to poor suturing (Popescu & Vasiliou, 1977). In a recent study where full-thickness skin grafts were used as interpositional material in the management of TMJ ankylosis, only one case out of 31 patients developed an epidermoid cyst (Chossegros, Guyot, Cheynet et al., 1999). Popescu and Vasiliou reported no cyst formation after 4-6 years (Popescu & Vasiliou, 1977).

While no deliberate attempt was made to remove the articular disc when the full thickness skin graft was inserted, there were numerous instances where a breach in the disc was found as a
result of inadvertent surgical trauma. Interestingly, in areas where the disc was breached, the underlying condylar head demonstrated significant remodeling, supposedly as an adaptational response to exposed surface that was normally protected by the overlying articular disc. In 1963, Sprinz (Sprinz, 1963) also demonstrated gross condylar changes after menisectomy in the TMJ in rabbits. Unfortunately, because the interpositional graft had shifted to the lateral aspect of the condyle, there was no way to determine if in fact the graft may or may not have provided the protective covering necessary to prevent the extensive remodelling seen in all exposed surfaces of the condylar head where the disc was breached (fig. 2.2.2).

Cyst formation in grafted dermis is occasionally reported in the literature (Muto, Tomioka, Michiya et al., 1992; Weinberg & Kryshlalsky, 1995; Bonnigton, Langan & Joye, 1987). In the present study, epidermoid cysts were detected in all skin graft specimens that were placed as interpositional material within the rabbit TMJ (fig. 2.2.4). The two clinical studies (Popescu & Vasiiliou, 1977; Chossegros, Guyot, Cheynet et al., 1999) which used full-thickness skin grafts to treat TMJ ankylosis in humans reported only a single case of cyst formation in the grafts and yet the present study in the rabbit model demonstrated epidermoid cyst formation within all the grafted joints. The question, therefore, arises as to whether the mutilated joint (i.e. TMJ gap arthroplasty) is less likely to result in epidermoid cyst formation within the graft as opposed to a graft placed into a relatively normal joint as used in the present study. To answer this question, a further study involving skin grafts inserted into gap arthroplasties instead of normal joints is required as the dynamics of a mutilated joint would be different to that of a normal joint, and therefore the forces on the graft would be different. However, if the trigger for cyst formation in a skin graft is the dynamic forces of a functioning joint, then one would expect the cyst to form in all skin grafts placed into a functional joint, regardless of whether the joint is normal or mutilated. This is in contrast to full thickness skin such as radial forearm flaps which are used to line the cranial base following resection. The static environment in which the latter graft or flap is placed is not known to have ever resulted in epidermoid cyst formation.

The other issue is the stability of the graft when firmly sutured over the condylar head. While Popescu and Vasiiliou (Popescu & Vasiiliou, 1977) reported the problem of graft displacement in their paper, Chossegros and co-workers (Chossegros, Guyot, Cheynet et al.,
1999) did not make any mention of the possibility of graft displacement in their case series. All skin grafts in the present study were placed over the condylar head and firmly sutured to the surrounding joint capsule with non-resorbable sutures. Invariably, none of the grafts were found above the condylar head where they were originally placed. All grafts were found displaced laterally beside the condyle when the rabbits were sacrificed (figs. 2.2.2 & 2.2.3). It is unlikely the displacement of the grafts occurred at the time of specimen handling and preparation as all cysts were surrounded and set in fibrous tissue which was clearly outside the joint. This suggests the lateral displacement of the grafts was an early phenomenon which occurred very soon after surgery despite the use of non-resorbable sutures to secure the graft over the condylar head.

A recent study (Dimitroulis, 2005a) using dermis grafts in the human TMJ showed encouraging clinical outcomes. However, most of the dermal grafts were not secured into position with sutures but were passively placed within the joint space and the joint capsule was carefully repaired to prevent the graft from spilling out of the joint cavity (Dimitroulis, 2005a). While repair to the joint capsule was undertaken in all the experimental rabbits, it appears this effort together with the direct anchorage of the graft with non-resorbable sutures were insufficient to prevent lateral displacement of the grafts in the present study.

This study has shown that the autogenous full thickness skin graft does survive when implanted into the rabbit temporomandibular joint for up to 5 months (fig. 2.2.4). However, despite being secured by non-resorbable sutures over the head of the mandibular condyle, all grafts were found to be laterally displaced relative to the condylar process. While extrapolation to humans is difficult, there are 3 essential messages borne out of this study. The first is that all remnants of epidermis must be totally eliminated when using dermis grafts in human TMJ’s. Secondly, suturing the dermis graft to the surrounding tissues of the TMJ may be a waste of time as the graft may dislodge and find itself in a position other than above the head of the condyle where it was meant to be. And finally, perhaps what is required is a material to fill up the intra-articular space vacated by the excised disc rather than a disc substitute. This is where the dermis-fat graft looks very promising (Dimitroulis, 2004).
2.2.5. SUMMARY & CONCLUSIONS

The purpose of this study was to determine the histological fate of the full thickness skin graft when placed into the temporomandibular joint using a rabbit model. Fourteen New Zealand white rabbits were used and divided into 3 groups. Two rabbits were used as controls (Group A) whereby a sham operation was undertaken with an incision made and immediately repaired without breaching the joint space of the left temporomandibular joint (TMJ). In six rabbits (Group B) the joint capsule of the left TMJ was surgically breached but the articular disc was preserved and the wound was repaired. The remaining six rabbits (Group C) also had the left TMJ surgically exposed with preservation of the articular disc and the interpositional placement of a full thickness skin graft which was taken from the skin of their necks. All grafts were placed above the articular disc and head of condyle in the superior joint space and firmly secured to the surrounding tissues with non-resorbable sutures. The rabbits were sacrificed at 1, 3 and 5 months following surgery and the left TMJ’s were histologically prepared and examined under light microscopy. The condylar head in the regions where the disc was present appeared to closely resemble that of the control rabbits. However, where the disc was breached by inadvertent surgical trauma (Group B), the underlying condyle demonstrated an irregular outline with increased fibrosis and a marked reduction in mature cartilage. In the subarticular bone there was increased osteoblast and osteoclast activity reflecting high bone activity indicative of a remodeling rather than a degenerative process. The interpositional skin graft in all experimental animals (Group C) were found adjacent to the condyle on the lateral aspect rather than above the condylar head where it was originally sutured in place. Significant atrophy and reduction in the number and size of the skin appendages such as sweat glands and hair follicles was found within the grafted skin of all experimental animals (Group C) compared to normal skin. All the grafts demonstrated evidence of epidermoid inclusion cysts. The full thickness skin graft is not a suitable interpositional material for the TMJ because of the high risk of epidermoid cyst formation and the propensity for lateral displacement of the graft even when sutured into the appropriate intra-articular position.
<table>
<thead>
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<th>Group</th>
<th>4 weeks</th>
<th>12 weeks</th>
<th>20 weeks</th>
</tr>
</thead>
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<tr>
<td>Group A Controls</td>
<td>-</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Group B No Grafts</td>
<td>2</td>
<td>2</td>
<td>2</td>
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<tr>
<td>Group C Skin Grafts</td>
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</table>

**NB:** all group C rabbits demonstrated lateral displacement of the graft and epidermoid cyst formation within the graft material.

**Table 2.2.1.** Number of rabbits used in each group
Figure 2.2.1 – Interpositional full thickness skin graft (white tissue) shown covering the condylar head of the rabbit temporomandibular joint at the time of surgery.
Figure 2.2.2 – Photomicrograph depicting the condylar head on the right and the epidermoid cyst on the left with the lumen full of keratin. The condylar head shows reactive changes where the articular disc is disrupted. Skin appendages lining the epidermoid cyst are severely atrophied in this specimen 12 weeks following graft implantation. Note the lateral position of the graft (i.e. cyst) relative to the condylar head. (Hematoxylin-eosin stain; magnification x40)
Figure 2.2.3 – Photomicrograph showing another graft specimen at 20 weeks. The graft is on the right side and demonstrates obvious epidermoid cyst formation. The condylar head is on the left side and appears relatively normal as the disc was fully preserved. Note once again the lateral position of the graft tissue (i.e. cyst) relative to the condylar head. Midway down the medial lining of the cyst there are severely atrophied hair follicles visible. (Hematoxylin-eosin stain; magnification x40)
CHAPTER 2.3

THE INTERPOSITIONAL DERmis-FAT GRAFT IN THE MANAGEMENT OF TEMPOROMANDIBULAR JOINT ANKYLOSIS

2.3.1. INTRODUCTION

Ankylosis release is the oldest form of TMJ surgery that evolved from procedures during the 19th Century which consisted of simple bone division to separate the ramus from the cranial base (Kazanjian, 1937; Risdon, 1934). However, because of the high recurrence rate of ankylosis following simple bone division, the osteoarthrectomy, or the gap arthroplasty was conceived in an effort to reduce recurrence rates by increasing the distance between the osteotomized bone ends of the ramus and cranial base (Manganello-Souza & Mariani, 2003).


The first interpositional graft was developed by Eschmarc in the latter half of the 19th century who described the pterygomasseteric sling technique of suturing together the masseter and medial pterygoid muscles across a divided mandibular ramus (Moore, 1985). Since then the temporalis muscle and/or fascial flap has become the most popular interpositional grafting technique because of its simplicity and close proximity to the surgical site (Chossegros et al, 1997;
Moorthy & Finch, 1983; Pogrel & Kaban, 1990). Other interpositional grafts that have also been used in TMJ ankylosis are listed in Table 2.3.1

Dermis-fat grafts are most commonly utilised as orbital implants in anophthalmic sockets in paediatric patients (Guberina et al, 1983). Dermis-fat grafts have also been used for augmentation rhinoplasties, closure of palatal fistulae and to restore the concave deformity following parotidectomy as well as to prevent Frey's syndrome (Bonanno, 1994; Mackay et al, 1993; Vandeput, Droogmans & Tanner, 1995). As far as can be ascertained, there have been no reports in the English literature describing the use of dermis-fat grafts as interpositional material in the surgical management of TMJ ankylosis prior to 2004. The aim of this retrospective clinical study is to present the clinical experience of using dermis-fat interpositional grafts in the surgical management of TMJ ankylosis in adult patients.

2.3.2. MATERIALS & METHODS

A retrospective clinical study involving adult patients who presented with radiological evidence (ie. CT scan) of true ankylosis of the TMJ was undertaken. Only those with true osseous (fig 2.3.1) or fibro-osseous (fig 2.3.2) ankylosis directly involving the intracapsular structures of the TMJ (Table 2.3.2) were included in the study. Those with fibrous TMJ ankylosis were excluded as they were treated by arthroscopic intervention by the candidate. All patients were operated upon by the candidate between 1994 and 2001 and were followed up for a minimum of 2 years after their surgery. Through an extended pre-auricular incision (Al Kayat & Bramley, 1979) (fig 2.2.3), a gap arthroplasty was performed by excision of the ankylosed mass beginning from the condylar neck at the level of the sigmoid notch inferiorly to a minimum 10mm superior to this. Because of the close proximity to the cranial base, no attempt was made to refashion a new glenoid fossa at the same level as the original fossa. Therefore the surgically created gap was at least 5mm or more below the normal level of the original joint space. This provided an adequate safety margin which prevented inadvertant penetration into the middle cranial fossa during the excision of the ankylosis. In the two bilateral TMJ ankylosis cases (Table 2.3.3 – patients 4 & 7) autogenous costochondral grafts were also used to prevent the development of anterior open bite. In the rest of the unilateral ankylosis cases, the resultant gap was filled with autogenous dermis-fat graft procured from the patients’ groin.
(fig 2.3.4). For the two bilateral cases the dermis-fat grafts were secured to the costochondral grafts via a single suture tied around the neck of the rib covering most of the cartilagenous segment.

The donor site in the groin was repaired by primary closure after the graft was dissected free-hand from its tissue bed (fig 2.3.5). The graft was folded onto itself with the dermis surfaces apposed and the subcutaneous fat neatly trimmed to maximally fill the gap or cavity making sure that all the dead space was eliminated. The graft was passively placed into the cavity or gap (fig 2.3.6) and there was no effort made to anchor the graft or suture it to surrounding tissues unless of course costochondral rib grafts were used. The capsule was then closed and the wound repaired in layers with a barrel type pressure bandage around the head with extra padding applied over the surgical site for 24 hours post-operatively. Intermaxillary wire fixation (IMF) was only applied intra-operatively to facilitate the trimming and placement of the dermis-fat graft as well as the placement of the costochondral grafts in the two bilateral cases. Post-operatively, only light intermaxillary elastics were used for 4-6 weeks to guide the patient into their normal occlusion as post-operative jaw mobility was a key factor in the treatment process.

Physiotherapy to help mobilize the joint was commenced 7 days post-operatively and continued for 4-6 weeks. Patients were treated by various physiotherapists, some which utilised the Roccobado method while others also used adjunctive aids such as ultrasound over the surgical site. Patients were then followed up on regular but increasingly spaced visits. In this group of patients, pain was not a significant factor so the only parameters measured were maximum (interincisal) mouth opening (MMO), patient satisfaction and chewing ability.

2.3.3. RESULTS

Eleven patients were identified with true ankylosis of the TMJ (Table 2.3.3). There were 9 females and 2 males ranging from 18yr to 55yr (mean age 32.5yr). Four cases of TMJ ankylosis were the result of motor vehicle accidents while 6 cases were complications resulting from previous TMJ surgery which is referred to as ‘iatrogenic’ in Table 2.3.3. There was only one case of assault where the comminuted fractured condylar head was treated with 6 weeks of intermaxillary wire fixation. The two bilateral ankylosis cases (ie. patients 4 & 7) were the result of severe motor
vehicle accidents where both patients were fitted with cervical collars while recovering in an unconscious state in intensive care for 3 and 5 weeks respectively. Both patients sustained high level bilateral condylar injuries that were left untreated.

Six patients had osseous TMJ ankylosis (fig 2.3.1) where there was bone continuity from the base of skull at the root of the zygomatic arch to the neck of the mandibular condyle without any intervening soft tissue present (fig 2.3.3). The condylar head and glenoid fossa could not be delineated. The remaining five patients had fibro-osseous TMJ ankylosis where an obvious boundary delineating the head of the condyle from the glenoid fossa sandwiching a tightly adherent and scarred remnants of a meniscus was present (fig 2.3.2). The joint space was completely filled with scar tissue interspersed by bony bridges with little physical movement possible of the condylar head relative to the glenoid fossa.

The pre-operative inter-incisal mouth opening (MMO) ranged from 9mm to 20mm with an average MMO of 15.6mm (Table 2.3.3 – column 7). The measurements taken reflected the maximum passive opening each patient could achieve prior to ankylosis release. With active stretching and with the aid of various mouth opening devises, some of the patients were able to achieve around 25mm or more, although these openings could only be sustained for a few seconds and were often extremely uncomfortable. Following surgical release of the TMJ ankylosis, the unassisted MMO achieved ranged from 32mm to 42mm with an average 35.7mm (Table 2.3.4 – column 8).

The average follow-up period after surgical intervention was 41.5 months with the shortest follow-up 2 years and the longest 6 years (Table 2.3.3 – column 9). In the follow-up period only one patient (i.e. patient 4) suffered a re-ankylosis of the right TMJ fifteen months following the initial release which involved a costochondral graft. A further gap arthroplasty was performed with another dermis-fat graft and no further ankylosis was detected 57 months later. Coronoidectomies were only performed in 4 out of the 11 patients including the two bilateral ankylosis cases. The two unilateral cases necessitated ipsilateral coronoidectomies because the mouth opening achieved with the gap arthroplasty was judged to be insufficient at the time of surgery and so was performed during the same operation.
All patients in this study were followed up for at least 2 years after their surgery to release the ankylosis. All nine of the unilateral cases had some degree of mandibular deviation to the operated side on maximum mouth opening (Fig 2.3.7). All the nine unilateral cases had a satisfactory occlusion and were pleased with the outcome. Chewing ability was also significantly improved in all the unilateral cases.

As for the two bilateral cases, despite the costochondral grafting, major restorative dental work was required to resurrect the occlusion as both patients declined further orthognathic surgery to correct their significant malocclusion (ie. anterior open bite). Mandibular opening in the bilateral ankylosis patients was symmetrical following surgical release and each was pleased with the outcome once the occlusion was corrected. Chewing ability also improved significantly following the completion of restorative dentistry. Apart from the re-ankylosis in case 4 (Table 2.3.3), there were 2 cases of donor site wound dehiscence in obese patients which were both successfully treated with local wound toilet. No other complications were recorded.

2.3.4. DISCUSSION

Ankylosis of the temporomandibular joint (TMJ) is a rare phenomenon that results in chronic and severe limited mouth opening. In Western nations, trauma is the most common cause, particularly in untreated cases of severe comminution of the condylar head (Dimitroulis, 1997). In this study five of the eleven cases were the result of trauma, namely motor vehicle accidents and a single case of assault. Prolonged immobilisation of the injured TMJ is a significant contributing factor in the pathogenesis of ankylosis (Glineburg, Laskin & Blaustein, 1982) especially following severe trauma where the condylar head is shattered and the articular disk is torn from its position to expose the glenoid fossa to the remnants of the collapsed condylar neck (Dimitroulis, 1997). This is further exacerbated in patients with concomitant suspected cervical injuries who are fitted with a cervical collar that further restricts mandibular mobility as was the situation in cases 4 and 7 (Table 2.3.3). The integrity of the articular disk following trauma is said to be pivotal to the subsequent development of ankylosis (Kummoona, 1978; Stevenson, Evaskus & Laskin, 1979).
Iatrogenic causes of ankylosis may arise from cytotoxic medication, repeated TMJ surgery and irradiation. Repeated TMJ surgery emerged as a dilemma largely confined to Western countries following the introduction of the concept of internal derangement and disk displacement which acted as the catalyst for unmitigated surgical intervention in TMJ disorders during the 1970's and 1980's (Dolwick & Dimitroulis, 1994; Dolwick & Dimitroulis, 1996). In the present study, 6 of the eleven patients developed TMJ ankylosis as a result of previous TMJ surgery. Ankylosis is a well established complication of TMJ arthrotomy especially likely to occur following episodes of post-surgical infections. Four of the 6 iatrogenic cases reported a history of post-operative complications such as infection, while the remaining 2 iatrogenic cases with osseous ankylosis (ie. Table 2.3.3 – cases 2 & 10) also appeared to have had surgery to their condyles in addition to diskektomy. Further operative details were difficult to access as five of the 6 iatrogenic cases were undertaken by other surgeons in private practice whose files were not available for review.

Six patients had osseous and 5 patients had fibro-osseous ankylosis of the TMJ. Table 2.3.2 is a classification of TMJ ankylosis developed by the author which is a modified version of the original classification of the causes of limited mouth opening first published in 1982 by Norman Rowe (Rowe, 1982). Intra-articular (true) ankylosis is that which involves part or all of the intracapsular structures of the TMJ and may be further subdivided according to tissue type, that is; osseous, fibro-osseous or fibrous (Table 2.3.2) (Aggarwal et al, 1990; Wood et al 1988). The difference in the clinical presentation between osseous and fibro-osseous ankylosis has already been described in the results (figs 2.3.1, 2.3.2). Patients with fibrous TMJ ankylosis were not included in this study as these patients were treated with TMJ arthroscopic procedures by the author. Extra-articular (false) ankylosis may involve surrounding structures outside the capsule of the TMJ such as the facial skeleton (coronoid process, zygoma) and muscles of mastication (Table 2.3.2). None of the patients in this study had false ankylosis.

Only one of the 13 joints studied in this case series developed re-ankylosis during the follow-up period (Table 2.3.3 – case 4, right TMJ). This was a case of bilateral osseous ankylosis where costochondral grafts were used which were covered by the dermis-fat graft. Whether the dermis-fat graft slipped and exposed the cartilagenous portion of the rib graft to the glenoid fossa can only be speculated. The follow-up surgery 15 months after the initial release consisted of a
further gap arthroplasty with interpositional dermis-fat graft. There was no evidence of further ankylosis 57 months later.

As mentioned previously, surgery plays an integral role in the management of TMJ ankylosis which is determined by the age of the patient and the aetiology of the ankylosis. The two primary objectives of surgery are;

1. To establish jaw movement and jaw function by surgical release of the ankylosis.
2. To prevent relapse by interpositional grafting, early jaw mobilisation and intensive physiotherapy.

At present there is no ideal interpositional graft (Chossegros et al, 1997; Moorhy & Finch, 1983). The problems encountered with the present grafts are; muscle shrinks and fibroses (Pogrel & Kaban, 1990), fascia lacks bulk (Narang & Dixon, 1975), cartilage tends to fibrose and calcify (Sandler et al, 1997) while alloplastic implants under functional loads disintegrate and cause foreign body giant cell reactions (Sawhney, 1986; Wagner & Mosby, 1990). Although temporalis flaps are still the most popular choice of grafts (Omura, Aoki & Fujita, 1997; Pogrel & Kaban, 1990; Su-Gwan, 2001), dissecting temporalis muscle leads to scar contracture of the donor site (Pogrel & Kaban, 1990) which may further exacerbate the trismus unless an ipsilateral coronoidectomy is performed. The use of autogenous full thickness skin or dermis grafts as interpositional materials have also been published (Chossegros et al, 1999; Georgiade & Altany, 1957; Popescu & Vasiliv, 1977). As far as can be ascertained there has not been any studies published on the use of dermis-fat grafts as interpositional material in the surgical management of TMJ ankylosis prior to 2004 when this paper first appeared in the literature (Dimitroulis, 2004)

Whilst dermis grafts and, to a lesser extent, full-thickness skin grafts (Chossegros et al, 1999) have been described in TMJ surgery, their main use has been as replacement material following discectomies. Fat grafts alone are easily fragmented but when attached to dermis the fat tends to be more stable and less likely to fragment when handled and manipulated into a cavity such as a gap arthroplasty. Dermis-fat grafts (fig 2.3.5) are easily sculptured with fine scissors to fit neatly into any size cavity which, in the author’s opinion, is the greatest advantage of this material to other interpositional materials already reported. Studies of the fate of dermis-fat grafts in non
load-bearing areas such as human orbits and pigs ears have demonstrated little change in the volume of the graft (Mackay et al, 1993). In some cases, the dermis-fat graft in paediatric patients have actually grown in volume with the growth of the patient (Guberina et al, 1983; Mackay et al, 1993). To date, there have been no studies undertaken on the fate of dermis-fat grafts under functional loading when placed as interpositional grafts in joints such as the TMJ. The other advantage of dermis-fat grafts apart from the minimal donor site morbidity because of primary closure, is the hidden scar which is placed in the groin below the belt line (fig 2.3.4).

In cases where condylar reconstruction is not undertaken, most surgeons prefer to begin mobilisation of mandible immediately following surgical release (Laskin, 1978). This author, however, prefers to wait a period of 5-7 days for pain and swelling to subside before commencing mobilisation of the mandible. This delay allows early phase healing of the surrounding tissues and interpositional graft which may perhaps respond more favourably to mobilisation through pseudo-articular formation than with immediate post-operative mobilisation. The potential problem with early mobilisation is that it may provoke reactionary bleeding and create a large haematoma with delayed healing and increase likelihood of wound breakdown, disorganisation, and ossification. Besides, patients are more likely to comply with mobilisation activities when the pain and swelling have largely subsided. Physiotherapy in the post-ankylosis release phase not only helps to prevent re-ankylosis, but also has an important task in building up muscle bulk, strength and improving range of motion following a protracted period of relative inactivity of the surrounding mandibular musculature (Laskin, 1978). While no mouth-opening devices were used by any of the patients in the post-operative phase, the author concedes that such devices would certainly be useful in facilitating the jaw mobilisation process, especially for patients with limited access to physiotherapists familiar with functional jaw disorders.

Coronoidectomies are especially important if temporalis flaps are to be used as interpositional grafts, since the utilisation of temporalis grafts may result in scar contracture of this muscle which may further exacerbate the trismus (Pogrel & Kaban, 1990). Ipsilateral coronoidectomies are commonly undertaken in paediatric patients but contralateral coronoidectomies may be optional depending on the degree of mouth opening following the surgical release of the affected side. In the present study, ipsilateral coronoidectomies were undertaken in
only 4 of the 11 patients including the two patients with bilateral TMJ ankylosis. The author found that coronoidectomies were unnecessary in the remaining seven patients as good mouth opening was achieved once the ankylosis was excised as there was no clinical evidence of temporalis muscle stiffness, shortening or atrophy.

In 1990, Kaban and co-workers (Kaban, Perrott & Fisher, 1990) published an article which discussed the 7 steps of managing TMJ ankylosis. They recommended complete dissection and stripping of the pterygomasseteric sling off the ascending ramus. While this may be suitable for children, adult patients may run the high risk of avascular necrosis of the denuded ramus, so this technique was not utilised in this group of adult patients.

Multiple failed surgical procedures which result in TMJ ankylosis may lead to abnormal illness behaviour in these patients making them bitter, yet paradoxically, totally dependent on the health care system which created the problem in the first place. These patients must be carefully evaluated and managed from a psychological stand-point in the peri-operative phase of care as undiagnosed depression can be a significant obstacle in the patient’s rehabilitation following ankylosis release. Two of the 6 iatrogenic cases in this study were under the care of psychitarists for depression related to long standing TMJ pain and dysfunction. Therefore, patients with iatrogenically induced ankylosis may require additional counselling and psychotherapy to ensure a successful outcome (Dolwick & Dimitroulis, 1994).

In this study there were too few cases and no comparative data to draw any firm conclusions apart from the fact that the use of the dermis-fat graft is a safe and effective procedure in the management of TMJ ankylosis. In order to establish further credible support for this technique, future studies should focus on the fate of the dermis-fat grafts under functional load conditions. Even comparative clinical studies between this technique and the current standard practice of temporalis interpositional grafts in the management of TMJ ankylosis may be useful in determining whether this grafting technique should be universally adopted in the armamentarium of TMJ ankylosis management.
2.3.5. SUMMARY & CONCLUSIONS

The aim of this retrospective clinical study was to present the clinical experience of using dermis-fat interpositional grafts in the surgical management of Temporomandibular joint (TMJ) ankylosis in adult patients. Eleven adult patients who presented with ankylosis of the TMJ were identified and included in the study. All patients underwent a TMJ gap arthroplasty which involved the removal of a segment of bone and fibrous tissue between the glenoid fossa and neck of the mandibular condyle. The resultant gap was filled with an autogenous dermis-fat graft procured from the patient’s groin. All patients were followed up for a minimum of 2 years. Five of the 11 patients were found to have osseous ankylosis while 6 patients had fibro-osseous ankylosis. Two patients had bilateral TMJ ankylosis that were also treated with costochondral grafts which were overlaid with dermis-fat graft. The average interincisal opening was 15.6mm on presentation which improved to an average of 35.7mm following surgery. Patients were followed up from 2 to 6 years post-operatively (mean – 41.5 months) with only one re-ankylosis identified out of the 13 joints treated. This study found that the use of the autogenous dermis-fat interpositional graft is an effective procedure for the prevention of re-ankylosis up to 6 years following the surgical release of TMJ ankylosis.
Autogenous
- Meniscus *eg.*, *disk repositioning*
- Muscle *eg.*, *Temporalis, pterygo-masseteric sling*
- Fascia *eg.*, *Temporalis, fascia lata, dura*
- Skin *eg.*, *dermis, full thickness*
- Cartilage *eg.*, *ear, rib, sternum*
- Fat *eg*: *groin, buttocks*
- Combined *eg*: *muscle-fascia.*

Allogeneic (*cryopreserved, freeze-dried or lyophilized*)
- Cartilage
- Dura

Alloplastic
- Sialastic
- Acrylic
- Silicone

Xenograft (*bovine*)
- Collagen
- Cartilage

---

**Table 2.3.1.** - Interpositional grafts used in TMJ ankylosis
True ankylosis (intra-articular)
- Tissue type
  fibrous
  fibro-osseous
  osseous
- Extension (Topazian 1964)
  condyle
  sigmoid notch
  coronoid process
False ankylosis (extra-articular)
- Coronoid process
  trauma
  hyperplasia
  neoplasia
- Masticatory muscles
  Scarring - trauma, surgery
  radiotherapy
  myositis ossificans
  submucous fibrosis
  Trotter's syndrome

Table 2.3.2. - Classification of TMJ ankylosis
### Table 2.2.3 – Results - TMJ ankylosis case details

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CHAPTER 3:

AIMS & HYPOTHESES

As highlighted in chapter 1, there is still no ideal disc replacement material available that could safely and reliably be used following TMJ disectomy. Chapter 2.3 demonstrated the abdominal dermis-fat appears to be a promising graft that provides adequate bulk, is easy to handle, readily accessible, simple to harvest and abundantly available. However, there are still many unresolved questions that need to be addressed with respect to the use of dermis-fat grafts in TMJ surgery.

The aim of this THESIS is to establish whether the abdominal dermis-fat graft is a safe and effective interpositional material when implanted in the TMJ following disectomy for advanced cases of TMJ internal derangement. Using various research tools and methods involving 5 studies, supporting evidence for the following hypotheses will be sought i.e.,

The abdominal dermis-fat graft;
1. is a safe material when implanted into the TMJ and has no long-term adverse consequences (Chapter 6)
2. survives and adapts well to the functional demands of the TMJ (Chapters 5,7,9)
3. facilitates full range of pain free function of the TMJ (Chapter 6)
4. prevents remodelling and resorption of the mandibular condyle (Chapter 8)
5. acts as an effective barrier to joint ankylosis of the TMJ (Chapters 5,7,9)

Because under ordinary circumstances a research hypothesis cannot be proven, this THESIS will seek to determine whether the null hypothesis ($H_0$), that is, the dermis-fat graft is unsafe and ineffective when implanted in the TMJ, can be rejected. The aims of five studies seeking to determine the safety and effectiveness of the dermis-fat graft in the TMJ are set out below;
Chapter 5:

Using a rabbit model, this study will aim to determine three important issues. Firstly, the survival mechanism of the dermis-fat graft when implanted into the TMJ will be assessed at three time points under light microscopy. Secondly, to see what role, if any, the dermis component of the dermis-fat graft plays in the survival of the fat when implanted into the TMJ. And finally, whether a functional environment (i.e., joint space) is required to stimulate the growth and maintenance of the fat and dermis-fat graft and compare this to a static environment such as the base of the ear.

Chapter 6:

Using a specifically designed quality of life questionnaire, outcome measures comparing patients before and after TMJ discectomy with dermis-fat grafting will be used to determine if there are safety concerns or adverse long term consequences that may hinder the role of the dermis-fat graft in facilitating the smooth pain-free function of the joint.

Chapter 7:

In this chapter, magnetic resonance imaging will be used to identify the presence of dermis-fat tissue within, and surrounding, the joint space of the TMJ which may help provide evidence that the autogenous dermis-fat graft survives when implanted into the human TMJ.

Chapter 8:

Tomogram x-ray images of mandibular condyles will be used in this study to assess whether the dermis-fat interpositional graft protects the articular surfaces of the joint and prevents regressive remodelling of the condylar head following TMJ discectomy.

Chapter 9:

A unique opportunity to study the histological composition of dermis-fat grafts implanted into the TMJ will be provided by patients who return for total joint replacements. The aim of this study will be to closely scrutinize the interpositional tissue surgically retrieved from joints that had dermis-fat grafts previously implanted and to histologically determine the relative proportions of the fibrous and fat components within the retrieved specimens.
CHAPTER 4

MATERIALS & METHODS

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4.1. MATERIALS

In all experimental procedures, materials are essential in the execution of a proper scientific inquiry. Since this thesis involved surgical intervention to animals and humans, various surgical instruments, medical supplies, including pharmacological agents as well as microscopes, photography and laboratory equipment were required to undertake the studies. In this section, the materials used in the animal study which makes up part of the THESIS will be presented.

4.1.1. ETHICS CLEARANCE

The projects contained in this thesis were conducted in accordance with the St Vincent’s Hospital Code of Conduct for Scientific Research Practice. Ethics clearance for the use of animals was obtained from the Animal Ethics Committee of St Vincent’s Health in accordance with principles contained in the Act (Prevention of Cruelty to Animals Act 1986) and Code (the NHMRC Australian Code of Practice for the Care and Use of Animals for Scientific Purposes 1997).

4.1.2. SUPPLY OF RABBITS

All rabbits were sourced from a special animal breeding facility in Bellbrae, Geelong, about 80 km south west of Melbourne. The rabbits were pure bred New Zealand white rabbits and were all a minimum of 2.0kg and 3 months old before operation.

4.1.3. SURGICAL FACILITY

All surgical procedures on the rabbits were undertaken in one of the two operating suites within the Experimental Medicine and Surgery Unit of St.Vincent’s Hospital which is specifically designed for small animal surgery. Clean conditions are maintained throughout the theatre complex with a dedicated instrument sterilizing area between both operating theatres. Two operating microscopes (Carl-Zeiss x 10) are available which are particularly useful for microsurgical work. Trained animal technicians are available for surgical assistance and to help with the recovery of the animals.
4.1.4. Surgical Instruments

A basic surgical set up, similar to a minor Plastic surgery set of instruments, was fully sterilized and used for all the surgical procedures on the rabbits. The core instruments used include a scalpel handle and no.15 disposable blade, fine Tenotomy scissors, Adson’s toothed forceps, periosteal elevator, electric diathermy tip, no. 9 Frazier sucker attached to plastic disposable suction tubing, micro-needle holders, mosquito forceps and suture scissors. The surgical sites were isolated with sterile drapes and sterile gloves were used by the surgical team.

4.1.5. Drugs used in Rabbit Experiments

All the drugs used in the course of the rabbit experiments were scrutinized and recommended by the resident Veterinary Surgeon, Dr Sue Pierce, who is employed in the Experimental Medicine and Surgical Unit of St.Vincent’s hospital in Melbourne.

4.1.5.1. Drugs used to Anaesthetize Rabbits

Anaesthetic induction was achieved with an intravenous bolus of propofol at 1mg/kg. The maintenance phase of the anaesthetic involved the use of a 1:1 mixture of ketamine (100mg/ml) and xylozine (20mg/ml) at a rate of 1ml/kg which provided 1 hour of anaesthetic time that was enough for the surgical procedure to be completed.

4.1.5.3. Drugs used to Prevent and Treat Infection

A single dose of intramuscular Cephazolin (5mg/kg) is given at the time of surgery as a prophylactic against infection. No antibiotics are given post-operatively unless there are signs of infection in the surgical wounds, in which case the antibiotics are added to the water of the affected animals.
4.1.5.4. **DRUGS USED TO EUTHANIZE RABBITS**

Euthanasia was administered by intravenous sodium pentobarbitone (2mg/kg) through a vein in the ear.

4.1.5.2. **DRUGS USED FOR POST-OPERATIVE ANALGESIA**

Local anaesthetic (2% lignocaine with 1:80,000 adrenaline) was injected into the surgical sites intra-operatively which provided 1.5 hours of anaesthesia so that the rabbits woke up from their operation pain free. Caprofen (5mg/kg) was administered subcutaneously 6 hourly for the first 48 hours following surgery or longer if rabbits showed any signs of distress as a result of post-surgical pain.

4.1.6 – **REAGENTS USED FOR PROCESSING RABBIT SPECIMENS**

In the preparation of the rabbit specimens for histological evaluation, a standard procedure was followed within the Department of Anatomical Pathology at St.Vincent’s Hospital Melbourne. Various reagents were used to fix, decalcify, embed and stain the tissue specimens for histological analysis at the light microscopy level. The procedure for processing rabbit specimens is discussed in section 4.4.

4.1.6.1- **FIXATION**

The role of fixation is to maintain tissue close to its living state with minimal rearrangement of cellular components, particularly the protein component. Fixation achieves this by preventing autolysis and bacterial attack. The fixative used for the experiments in this thesis was 10% neutral buffered formalin which was made from 40% formaldehyde (2 litre conc.) mixed with di-sodium hydrogen and sodium di-hydrogen orthophosphate 90g, with anhydrous Na₂HPO₄ 130g, made up to 20 litres of tap water and phenol red dye added as a pH indicator.
4.1.6.2 – DECALCIFICATION

The process of decalcification must ensure complete removal of calcium salts, prevent distortion of cells and connective tissue, harbour no adverse reaction to subsequent staining and, most importantly, must act with reasonable speed to avoid long delays. There are many types of decalcifying agents although no single one is ideal for all cases. These include acids, ion exchange resins, electrolytic processes, and chelating agents (e.g., EDTA). The experiments undertaken for this thesis used an acid solution for decalcification of bone which was made up of the following formula; citric acid 100g, formic acid 350ml, tap water made up to 4 litres with a few drops of methylene blue added as a colour indicator.

4.1.6.3 – EMBEDDING

Embedding is used to provide structure to the tissue specimen to facilitate cutting of the specimens into extremely thin slices only a few microns thick without distorting the cells and connective tissues. Paraffin wax is used as an embedding medium and is made of a mixture of hydrocarbons produced in the cracking of mineral oil. The paraffin wax has a melting point range of 40-70°C and heating the wax too high alters its properties by altering the crystalline structure.

4.1.6.4 – STAINING

Staining is used to highlight the many different structures that make up each cell and its surroundings. The most routinely used stain for the histological specimens used in this study was the haematoxylin and eosin stain. Haematoxylin is extracted from the logwood tree (haematoxylon compechianum) and is oxidized to the reddish dye heamatein. Aluminium (a mordant) when used with haematoxylin, stains the nuclei a dark red colour. The sections are then treated with Scott’s tap water, a weak alkali consisting of sodium hydrocarbonate, magnesium sulphate and tap water, to turn the nuclei blue and to stabilize the dye. Eosin (1% alcoholic eosin solution) is a synthetic xanthene dye and together with phloxine, gives the widest range of contrast from pink for cytoplasm, through to bright red for collagen and muscle.
4.2. Surgery of the Rabbit

The New Zealand white rabbit offers a simple, readily available and inexpensive animal model for Temporomandibular joint surgery research. Relatively large numbers of rabbits can be used compared to sheep, minipigs and primates which is important as far as statistical analysis is concerned. Rabbits are not only less expensive to feed, but require much smaller facilities to house and maintain.

4.2.1. Applied Anatomy of the Rabbit

The jaw joint anatomy of the rabbit differs significantly from the Human Temporomandibular joint. Not only is the mandibular condyle more robust in the rabbit, it also articulates to the base of the cranium which forms part of the occipital bone and not the temporal bone, hence the term, ‘Craniomandibular Joint or CMJ’, is used to describe the rabbit jaw joint. Furthermore, the lateral aspect of the rabbit CMJ is bounded by the squamous bone extension of the zygomatic arch that needs to be fractured and removed in order to obtain surgical access to the CMJ. Fortunately, the rabbit CMJ, like the human, has an articular disc that covers the superior aspect of the condylar head of the mandible. Therefore, despite the comparative anatomical differences, the rabbit CMJ is still a useful model for the study of human Temporomandibular joint surgery.

4.2.2. Anaesthesia of the Rabbit

All surgical procedures on the rabbits were performed under general anaesthesia. Induction of the rabbit was achieved via an IV bolus of propofol (1mg/kg) into the ear vein with emla cream applied to the ear prior to IV access to help reduce the pain of the needle. The maintenance phase of the anaesthetic was a 1:1 mixture of ketamine (100mg/ml) and xylozine (20mg/ml) via IV access through the ear vein at a rate of 1ml/kg which provided 1 hour of anaesthesia time.
4.2.3. PREPARATION OF SURGICAL SITES

Following anaesthetic induction, the fur covering the surgical sites was removed with an electric razor and then depilatory cream was applied over the surgical sites for 2-3 minutes. The cream was wiped off with a cloth towel to reveal bare hairless skin. Antiseptic solution (1% Chlorhexidine) was applied to the bare skin and the surgical sites were isolated with sterile drapes in preparation for surgery. Local anaesthesia was injected (2% lignocaine, 1:80,000 adrenaline) into the surgical sites 2-3 minutes prior to the first incision.

4.2.4. SURGICAL DISSECTION

In the surgical approach to the rabbit CMJ a horizontal skin incision is made from just posterior to the lateral margin of the canthus of the eye to just anterior to the external acoustic meatus. In the control rabbits (Group A) the incision is extended down to the zygomatico-squamosal bone and is immediately repaired without breaching the joint space of the CMJ which lies immediately deep to the bone. For the experimental rabbits, an operating microscope (x10) was swung into position to facilitate deeper dissection. Upon exposure of the zygomatico-squamosal suture line a section of the zygomatic process overlying the CMJ is carefully removed with mosquito forceps. The capsule of the CMJ is then exposed to reveal the superior joint space with the articular disc clearly visible inferiorly. In rabbits where the articular disc was completely resected from the surrounding tissue bed, care was taken to minimise damage to the articular cartilage of the condylar head. Bleeding was managed with bipolar electrocautery. In rabbits where condylectomies were undertaken, the condylar process was forcibly dislocated inferiorly and laterally and resected about 5mm below the CMJ.

4.2.5. HARVESTING OF DONOR TISSUE

Both fat and dermis-fat were used as free, non-vascularised grafts in the experiments. These were harvested in the lower abdomen via an elliptical incision that was 2cm long and 1cm at maximum width. The epidermis layer was removed from the underlying dermis using a sharp no.15 scalpel blade. The fat attached to the under surface of the dermis was harvested to a depth of about 0.5cm. Where only fat was used, the overlying skin, including both
dermal and epidermal elements, was excised, however, the graft was still harvested in an
elliptical fashion as for the dermis-fat graft so that the dimensions were kept constant at 2cm
(length) x 1cm (maximum width) x 0.5cm (depth).

4.2.6. CLOSURE AND REPAIR OF WOUNDS

Meticulous haemostasis was achieved, using electrocautery, before each of the
wounds were repaired in layers using resorbable interrupted 4-0 vicryl sutures. The skin was
also closed with 4-0 resorbable vicryl sutures and steri-strips were placed across each
surgical wound. The abdominal graft sites were closed in a linear fashion.

4.2.7. MONITORING OF ANAESTHETIZED RABBIT

The anaesthetised rabbits were monitored for breathing, respiration rate, colour of
mucosa, heart rate as well as response to surgical stimuli.

4.2.8. RECOVERY OF THE ANAESTHETIZED RABBIT

Immediately after the surgery the rabbits were placed on a heat pad until they regain
full consciousness. Subcutaneous fluids were provided at 10mls/kg during the recovery
process.

4.3. POST-OPERATIVE CARE OF THE RABBIT

4.3.1. POST-OPERATIVE PAIN RELIEF

The analgesic ‘Carprofen” was administered at the time of surgery and a follow up
dose (5mg/kg SC) was given in the 6 hours following surgery. Evidence of pain and distress
was monitored by observing the general demeanour of the animal and their food and water
intake. Weight was measured daily in the first week then on a fortnightly basis. Because
chewing was temporarily affected by the surgical procedure to the jaw joint, the animals
were acclimatized to a soft diet of fresh vegetables and crushed pellets a few days prior to
surgery to help maintain their normal dietary intake in the immediate post-operative phase
instead of the hard pellets. Where there was intolerable pain or distress resulting in >20%
loss of weight, lethargy or abnormal behaviour, the affected animal(s) were to be culled. In this series of studies, all animals responded satisfactorily in the post-operative phase and no culling was necessary.

4.3.2. Rabbit Housing

The animals were held in the rabbit room of Experimental Medical and Surgical Unit of St Vincent’s Hospital Melbourne campus in Fitzroy. Each animal was housed individually in a double pen with daily exercise. A box and hay was provided for environmental enrichment and access to water was provided at all times. There were no special housing requirements post-operatively, but there was visual contact with other rabbits. The animals were housed in individual pens/cages to prevent the risk of other animals disturbing the surgical wounds.

4.3.3. Rabbit Diet in the Post-operative Period

There was initial difficulty in chewing ability for the first 3-7 days which necessitated hand feeding with crushed pellets in some rabbits as required. A soft diet of fresh vegetables and crushed pellets was otherwise provided. Hydration status was checked with a skin pinch test in the immediate post-operative period and continued on a daily basis until chewing returned to normal. Weight was measured daily in the first week and thereafter at 2 week intervals post-operatively.

4.4. Preparation of Specimen for Histological Examination

Rabbits were sacrificed at 4 weeks, 12 weeks and 20 weeks following surgery and the specimens were prepared for histology by the candidate, with the assistance of laboratory staff, in the Department of Anatomical Pathology of St.Vincent’s Hospital in Melbourne.
4.4.1. **RABBIT EUTHANASIA**

To facilitate euthanasia, each animal was administered intravenous sodium pentobarbitone (2mg/kg) via an ear vein. Emla cream was applied for 5 minutes prior to establishing intravenous access over the site of injection to minimize the pain of the injection.

4.4.2. **DECAPITATION**

After the rabbits were sacrificed, they were decapitated and the heads were sent over to the histopathology laboratory, Department of Anatomical Pathology at St.Vincent’s Hospital for histological processing.

4.4.3. **FIXATION**

The rabbit heads are placed in 10% neutral buffered formalin (NBF) for at least 2 weeks. Once the specimen has been formalin fixed, it is then placed into decal for softening (process known as decalcification) which varies from 1 to 3 weeks.

4.4.4. **PROCESSING**

On completion of decalcification, the softened rabbit specimen is carefully cut by the candidate (under supervision of the pathologist) and appropriate tissue sections are sampled and blocked for processing. The blocks are washed in running tap water for 10 minutes and then placed in tissue processor baskets and processed on an extended overnight cycle (approx 14.5 hours) to ensure adequate processing and wax infiltration. On completion of the processing cycle, the rabbit blocks are ready for embedding.

4.4.5. **EMBEDDING**

 Appropriately oriented rabbit tissue samples are embedded into appropriate sized moulds with hot molten wax (approx. 58-60°C) and placed on top of the mould. The mould is then placed on a cold plate for approximately 10-15 minutes to allow the wax to solidify. Once solidified, the blocked mould is removed and excess wax is scrapped off the block.
4.4.6. CUTTING

The block is trimmed on a microtome at 10 microns until the full face of the sampled tissue is reached. Paraffin ribbon sections are cut at 3 microns and floated onto a hot water bath (37-40°C). The paraffin ribbons sections are then picked up with labelled slides and placed in a heated oven (60°C) for 15 minutes. By this point, the wax should be melted leaving only the tissue section on the slide.

4.4.7. STAINING

The slide is placed on an automated stainer for H&E staining (Haematoxylin & Eosin stain). A Leica CV 5030 automated stainer machine is used which takes about 40 minutes and also provides the coverslip for each of the slides. The specimens are now ready for examination with the nuclei of cells appearing blue/black and the cytoplasm of cells show up as various shades of pink.

4.4.8. HISTOLOGICAL ASSESSMENT

Each slide was examined under light microscopy at various powers of magnification ranging from 2x up to 100x. The general presence and distribution of the various tissue elements including fat, fibrous and epithelial tissue were noted and recorded for each slide. The presence and type of inflammatory cells with evidence of necrotic tissue were of particular interest. Deposits of fat and dermal elements such as sweat glands and hair follicles as well as cyst like structures were easily identified and appropriately recorded in table format against each rabbit (Ch.5) or individual human (Ch.9).

4.4.9. QUANTITATIVE ANALYSIS

Virtual microscopy VM (quantitative) analysis: The hematoxylin and eosin stained histological slides were digitally scanned using the ScanScope T3 virtual microscopy slide scanner (Aperio, Vista, CA) and ScanScope Console software v7.00.08.1020 provided the user interface. The slides were loaded into the scanner, and ScanScope was configured to enable the
scanning of cells within a particular area of interest. Within this area, a reference point containing no cells was determined, which the software used to determine the background brightness. A macro focus point was manually set and several individual focus points throughout the slide were added to ensure optimum focus of the whole slide. Foci were carefully adjusted with the aid of a high magnification video monitor built into the ScanScope Console. A prescan was performed to ensure that the previously determined blank reference point was clear of any cells or artefact to maximise clarity of the scanned images. The digital scan at 20× magnification was then performed.

Once all the slides were scanned, the digital images were analysed using ImageScope(r) software package. The fat was selected using the "pen tool" and the "positive pixel count" algorithm was run on the selected tissue. The colour saturation threshold was calibrated for each group based on the intensity of the stain of the positive control slide in order to achieve uniformity in measuring the stain for all sections of that group. The same procedure was repeated for the (non-fat) fibrous and epithelial elements in order to determine the background stain. Number of positive pixels was then divided over the surface area to obtain the number of positive pixels per square millimetre for each slide. This value was then subtracted from that of the negative control slides to exclude background stain and provide a proportion of fat to non-fat ratio for each slide.

### 4.5 Clinical Studies

There are four clinical studies which make up this THESIS. All the human participants were patients of the candidate who presented for surgical management of TMJ internal derangement. The patients were referred to the candidate from other clinicians for surgical assessment following failed conservative therapy for TMJ internal derangement.
4.5.1. Ethics Clearance

The projects contained in this thesis were conducted in accordance with the St Vincent’s Hospital Code of Conduct for Scientific Research Practice. Ethics approval for the human studies was obtained from the Human Research Ethics Committee (HREC-A) of the Research and Grants Unit of St.Vincent’s hospital in Melbourne.

4.5.2. Patient Selection

The source of all patients involved in the clinical studies were those who underwent TMJ surgery by the candidate between 1996 and 2009. The studies were a retrospective review of patients with severe internal derangement of the TMJ who underwent discectomy with immediate replacement of the excised disc with autogenous dermis or dermis-fat grafts. The basis for initial surgical consideration was TMJ pain & dysfunction that was not adequately responding to at least 6 months of non-surgical treatment such as occlusal splint therapy, medication and physiotherapy. Selection of surgical candidates was further considered on the basis that symptoms of pain & dysfunction were well localised to the TMJ. The guidelines for inclusion in the clinical studies was based on the following selection criteria;

The TMJ had not undergone any previous arthrotomy (ie. open joint) procedure.
Pre-operative Magnetic Resonance Imaging (MRI) evidence of severe internal derangement of the TMJ (ie. Wilke’s stage IV or V – Appendix 1)
Severely displaced and deformed or degenerate disc that was judged to be unsalvagable at the time of operation and so required removal (i.e., discectomy)
An autogenous dermis-fat graft was placed at the same operation as the discectomy procedure.
Patients with a previous history of TMJ arthrotomy, and those where discectomy and dermis or dermis-fat grafting were performed in separate operations were excluded from the study.

Patients involved in the Chapter 9 study were those who presented with intolerable symptoms of pain and dysfunction following TMJ discectomy with interpositional dermis-fat
graft. These were essentially patients who failed TMJ disectomy and went on to have a total joint replacement, which gave the author the unique opportunity to retrieve and examine the dermis-fat grafts after they had been in the joint space.

4.5.3. INFORMED CONSENT

Once all the clinical data was gathered, a working diagnosis established and a treatment plan formulated, a written consent was sought from each patient prior to surgery. The basis for consent was a well informed patient who agreed to the surgical plan proposed by the surgeon. All treatment options including that of no treatment and the consequences were discussed with each patient. When informing the patient about the proposed treatment, layman’s language was used for the sake of clarity and understanding. Ultimately, it was determined that each patient reported in this series of clinical studies was able to fully comprehend the nature of the surgical procedures and the anticipated outcomes. Since general anaesthesia was used in all cases, a written consent signed by both the patient and the clinician, was a mandatory requirement prior to surgery. The written consent had the patient’s full name, a description of the proposed operation, site of operation and side, the date, the patient’s full signature and the full signature of the surgeon who had discussed the planned procedure with the patient. A list of potential risks and side effects specific to each operation that was discussed was also listed on the consent form.

4.5.3. STATISTICAL ANALYSIS

Statistical analysis of the collected data was performed using the Student t-test for normally distributed populations where the difference is only in the mean values and the Wilcoxon signed rank test where the paired differences are independent and come from a symmetrical distribution of values. All calculations were performed using Microsoft Excel spreadsheet (2007) with a p value < 0.05 considered as significant.

4.6 – TMJ SURGERY IN HUMANS

Arthrotomy refers to the direct surgical exposure of a joint. A Temporomandibular joint (TMJ) arthrotomy is technically one of the more difficult surgical dissections in the maxillofacial region. While the close proximity of the facial nerve is the main reason for the difficult surgical
access, other important anatomical structures such as the terminal branches of the external carotid artery and accompanying rich plexus of veins also add to the complexity of the dissection. With the middle cranial fossa above, and the middle ear behind the TMJ, there is little room for surgical error as both these cavities are only a few millimetres away from the joint itself. Below is a description of the standard surgical technique used to treat all patients involved in the various studies included in the thesis.

4.6.1 – Anaesthesia & Monitoring

TMJ arthroscopy was performed under general anaesthesia with propofol induction and a combination of enflurane, nitrous oxide and oxygen maintenance. The patient was ventilated through a naso-endotracheal tube to permit manipulation of the mandible that helped identify the position of the articular disc and mandibular condyle during the surgery. All patients were fully monitored with electrocardiogram, oxygen saturation and capnograph monitors. A temperature probe and blood pressure cuff were also attached to the patient during the procedure. As most procedures took less than 2 hours, urinary catheters were not required.

4.6.2 – Preparation of Surgical Site

The head was turned to the opposite side of the surgery so that the ear is 60 degrees to the perpendicular. The head was rested on a head ring covered by a waterproof drape to help stabilize it. Hair was shaved in front of the ear to the level of the superior tip of the pinna. A three inch (9-10cm) wide waterproof tape (“sleke tape”) was placed horizontally above the ear and another length of tape is placed vertically behind the ear to cover the hair.

A marking pen was used to outline the proposed incision line. The surgical site, including the adjacent ear and ear canal, was liberally prepped with aqueous betadine antiseptic solution. A sterile ear pledget with vaseline was inserted to protect the ear canal. The operative field was isolated with a turban head drape is wrapped around the head which covered the anaesthetic tube exiting the nose. A sterile plastic adhesive with a hole cut out for the ear was placed over the operative field. Marcaine (0.5%) with 1:200,000 is infiltrated into the subcutaneous tissues along the incision line and into the joint proper immediately prior to commencement of the surgery.
4.6.3 – **Preparation of Graft Donor Site**

The lower abdomen is exposed and a 6cm x 3cm horizontal elliptical incision is outlined with a marking pen about 10cm below the umbilicus. The skin is prepped with aqueous betadine solution and the surgical field is isolated with sterile drapes. About 8-10mls of 0.5% marcaine with 1:200,000 adrenaline is injected into the site approximately 5 minutes before the incision is made.

4.6.4 – **Surgical Approach to the TMJ**

A 5cm to 6cm curvilinear preauricular incision, peaked posteriorly at the level of the tragus, is made through skin and subcutaneous tissues to the level of the temporalis fascia. The preauricular incision runs around the insertion of the pinna, extending down to the lower border of the insertion of the ear lobe to preauricular skin. Superiorly, a small temporal extension of the incision is made in a forward arc about 45 degrees relative to the zygomatic arch. Sharp dissection was carried out through the various tissue layers until the superficial temporal fascia was reached. Every effort was made to dissect posterior to the superficial temporal vessels and retract these forward with the skin flap. On occasions, the superficial temporal vessels were ligated and cut when they could not be adequately mobilised away from the surgical dissection. Superiorly the flap is extended anteriorly by blunt dissection with a periosteal elevator. Inferiorly the flap was developed in a relatively avascular plane parallel to the external auditory (tragal) cartilage which runs anteromedially.

Once the temporalis fascia is exposed it is then incised in the vertical direction. Staying beneath the temporal fascia was essential to avoid the temporal branches of the facial nerve. A flap is developed forwards by blunt dissection with periosteal elevator exposing the root of the zygomatic arch. At this stage, the surgical assistant manipulates the mandible so the surgeon can palpate for and identify the position of the moving condyle. A large periosteal elevator is used to expose the lateral part of the root of the zygomatic arch as far forwards as the articular eminence. From the pocket created over the root of the zygomatic arch, the capsule of the joint was identified inferiorly by sharp and blunt dissection. A small triangular flap is then lifted and progressively rotated forwards by blunt dissection over the capsule and lateral margin of the glenoid fossa. This layer is relatively avascular, except inferiorly where branches of the superficial temporal vessels...
were encountered. Access may be extended anteriorly and inferiorly depending on the surgery to follow. At this point, more Marcaine 0.5% with 1:200,000 adrenaline is injected through the capsule.

A ‘T’ incision was made at the root of the zygomatic process of temporal bone to expose the TMJ capsule. Through a horizontal incision across the capsule enclosing the superior joint space the disk was exposed and closely inspected for possible salvage and repair.

4.6.5 – DISCECTOMY TECHNIQUE

The patients in these studies all demonstrated damaged, diseased or deformed disks that were beyond repair and so discectomy was performed. In all cases the disc is found to be unsalvageable, it is was completely excised. To begin the discectomy, both upper and lower joint spaces were exposed as follows; With the condyle distracted inferiorly, pointed scissors are used to bluntly enter the superior joint space and opened to reveal the superior surface of the articular disc. With a small blade, the opening is extended anteriorly and posteriorly by cutting along the lateral aspect of the eminence and fossa. The capsule is reflected laterally to reveal the superior joint space. A broad spoon shaped instrument such as a Seldin is then inserted into the superior joint space to help further distract the joint and expose the superior surface of the articular disc as well as the glenoid fossa and eminence.

To expose the inferior joint space an incision is made along the lateral attachment of the disc to the condyle within the inferior recess of the capsule. Brisk haemorrhage may occur if the posterior attachment of the disc is cut. A fine periosteal elevator is inserted into the inferior joint space to separate the disc from the condylar head and retract the disc superiorly to expose the articular surface of the condyle.

Once both joint spaces are exposed a vascular clamp is placed across the retrodiscal tissues. As the assistant distracts the mandible (and condyle) downwards and forwards, the posterolateral part of the disc is first excised with fine pointed scissors. The remaining anteromedial part of the disc is then clamped with Allis tissue forceps to help retract it laterally and posteriorly to facilitate
excision of the remaining part of the disc. Infiltration with local anaesthesia and judicious diathermy of bleeding points will help reduce bleeding in the resultant joint cavity.

After the diseased disc was removed with sharp dissection scissors, attention was paid to the surrounding articular surfaces of the TMJ for signs of eburnation or peeling of the fibrocartilagenous surfaces which, if present, were removed and the underlying bone smoothed over. Osteophytes at the lateral pole of the condyle were also removed where present. High condylar shaves, partial condylar amputations or decompressions and surgical recontouring of the glenoid fossa and eminence were undertaken only where indicated such as in the presence of disease or to facilitate joint function.

4.6.6 – Graft Harvest from Donor Site

An elliptical incision (6cm x 3cm) is made in the lower abdomen, approximately 10cm below the umbilicus. The incision is made through skin and subcutaneous tissue down to fat. An island of skin still attached to the fat bed is created and a No.15 scalpel blade is used to finely dissect the epidermal layer of skin off the underlying dermis. Once the epidermal layer is completely removed the remaining dermis with 2cm of fat attached is sharply dissected away from the abdominal bed and placed in saline moistened gauze. Hemostasis is obtained before the donor site in the abdomen is closed primarily with deep vickryl sutures and the skin approximated with a buried subcuticular non-resorbable suture. Steri-strips and a cuti-film dressing is applied over the wound.

4.6.7 – Graft Placement into Joint Space

The dermis-fat graft is carefully trimmed with sharp scissors and placed into the joint cavity with no particular orientation. The graft simply fills up the entire joint space created by the excised disc and is not anchored to any of the surrounding tissue. Repair of the lateral capsule helps keep the dermis-fat graft within the confines of the joint cavity.
4.6.8 – Repair and Closure of Joint

Careful attention to haemostasis is essential prior to closure. The surgical wound is repaired in layers ie; capsule, temporalis fascia, subcutaneous tissues and skin. Resorbable 4/0 vickryl sutures are used for the deep layers and 5/0 nylon is used for skin as simple interrupted sutures.

4.6.9 – Post-operative Dressing

The ear is padded with acuafavin dressing which is covered with plain gauze to form a mastoid type pressure dressing. The pressure dressing is, in turn, secured by a 10cm wide cloth bandage which is wrapped around the head and is removed the following day. Drains are rarely indicated.

4.7. Recovery Phase

Often, patients will only require an overnight stay in hospital before being discharged home. Patients who have undergone TMJ surgery usually need about 10-14 days to fully recover from the surgery before resuming normal duties.

4.7.1. Post-operative Analgesia

All patients are provided with patient controlled analgesia (PCA) devices for 24 hours following surgery, where a simple press of the button by the patient provides a pre-determined dose of narcotic, such as morphine or pethidine via an intravenous line. There are safety features such as maximum doses and timed lock outs so that patients cannot overdose themselves. Antiemetics are also prescribed in case the patient reacts poorly to the narcotic medication. After 24 hours, patients are switched to oral analgesics which are often a combination of non-steroidal anti-inflammatory medications with narcotics such as Panadiene Forte or Digesic depending on their level of pain and tolerance of the various medications. Patients will often continue the oral analgesics for about 4-5 days and thereafter reduce their intake as the surgical pain gradually subsides. By 10 days following surgery, most patients have discarded the need for analgesia.
4.7.2. **POST-OPERATIVE DIET**

Patients are provided with a fluid diet for the first 12 hours and then commenced on a soft, for non-chewing diet which is maintained for 6 weeks post-operatively. Thereafter, patients are encouraged to gradually increase their dietary range but advised to be careful if they experience pain when chewing certain foods. Most patients are back to normal chewing within 3 months, but some may take 6 months to fully recover their normal chewing ability.

4.7.3. **REMOVAL OF SUTURES**

The interrupted nylon sutures along the pre-auricular incision are removed about 5 to 7 days following surgery. The subcuticular suture in the lower abdomen, where the graft is procured, is removed 10 days following surgery.

4.7.4. **REHABILITATION**

Physiotherapy is used post-operatively to strengthen muscle activity and improve range of mandibular motion. It is usually commenced about 7 to 10 days following surgery to allow for the surgical pain to first subside before the mandible and operated TMJ is manipulated. Physiotherapy is continued for about 4 to 6 weeks until the patient is able to achieve and maintain a reasonable range of mandibular activity. The physiotherapist may also use ultrasound to help dissipate the surgical oedema from the joint and surrounding muscles. Occlusal splint therapy is resumed in the post-operative period only if the patient continues to clench or grind their teeth. The splint must be occlusally adjusted before the patient begins to wear it again about 2 weeks following surgery if required. Most patients, however, do not need to wear any occlusal device following TMJ surgery.

4.8. **OUTCOMES OF SURGERY**

An essential component of this thesis is the measure of success as determined by various outcomes that quantify the degree improvement in the patient’s well being. The criteria for successful outcomes of TMJ surgery as proposed by the Second International Consensus Meeting in April 1992 (Goss, 1992 later modified by Holmlund, 1993- Appendix 2) was used as the basis
for assessing outcomes in this thesis. The outcomes of surgery are measured by numerous parameters that consider a range of factors that include patient’s symptoms, (i.e., quality of life questionnaire), clinical signs (i.e., visual analogue scales and mouth opening) and radiological features (i.e., tomograms and magnetic resonance imaging).

4.8.1. CLINICAL PARAMETERS

There are 3 clinical parameters used in this thesis that have been universally adopted in the literature as reliable outcome measures that provide quantifiable results that measure unit differences before and after surgery; maximum interincisal mouth opening and visual analogue scales for pain and jaw dysfunction.

4.8.1.1. MAXIMUM INTERINCISAL OPENING

The most easily reproducible measure of jaw function is the maximum unassisted vertical mouth opening which is often measured as the maximum distance in millimetres between the incisal edges of the upper and lower central incisors. There are many devices that can be used to measure interincisal distance, and most are simple plastic rulers calibrated in millimetres or callipers specifically designed for such a purpose. For this thesis, a curved plastic ruler supplied by the makers of the “Therabite Device” (Jacksonville, Fl) was used as the standard instrument for all measurements of interincisal mouth opening. While lateral excursions of the mandible were also measured, the results were not included in the thesis as the author found these to be unreliable determinants of outcomes. For example, it was not uncommon to find good lateral excursions in one direction and yet the patient was unable to open wider than 28mm in the vertical direction with no lateral excursions possible in the opposite direction.

4.8.1.2. VISUAL ANALOGUE SCALES

The visual analogue scale (VAS) is a practical and simple way of recording subjective symptoms using a quantifiable unit scale that is internally calibrated to each patient. Patients are presented with a linear scale 10cm long which is graded from 0 to 10 with vertical lines 1 cm apart each representing 1 unit of the scale. The patients are then asked to place a mark, or cross, along the scale which best represents their current level of pain or jaw dysfunction with a short
explanation of what the two extremes of 0 and 10 represent (see Chapter 2.1). The level of pain and jaw dysfunction can be given a unit of measure that falls between a linear boundary of between 0 and 10, where 0, for example, denotes no pain at all and 10 signifies the most excruciating pain ever experienced by the patient. Most patients are able to easily identify the level of their experience on a simple scale of 0 to 10. While the levels may differ between individual patients, the differences in individual scores before and after treatment reflect the effectiveness of that treatment for each patient. Jaw dysfunction is described to patients as their ability to chew and whether their dietary intake involves all foods (including steaks) in which case the score is 0 for normal diet, or whether they are confined to liquid diet only because of severely limited jaw opening, for whatever reason (e.g., pain or joint ankylosis), in which case their jaw dysfunction score is 10.

4.8.2. QUALITY OF LIFE QUESTIONNAIRE

The quality of life (QoL) questionnaire is a fundamental tool for extracting information about the general health and well being of the patient as determined by the patient and not the researcher. In its various forms, the QoL questionnaire has been successfully used to determine not only the impact of the disease on patients but also the effectiveness of numerous treatments in improving their lives. Essentially, the QoL questionnaires have to be developed according to the unique characteristics of each disease process. Furthermore, where treatment outcomes are being assessed, the QoL questionnaire must cater to all potential side effects that may arise from the treatment itself that will affect the patient’s general well being. With a QoL questionnaire, patients are asked a series of questions and given 4 or 5 responses to choose from which are numerically graded from the most favourable at the top to the least favourable at the bottom. The scores are then added up to give an overall outcome measure for the specific disease or treatment. The problem with QoL questionnaires often revolves around questions which prompt ambiguous responses that may skew the results which ultimately leads to inconclusive outcomes. That is why it is important that QoL questionnaires are tested on small groups of patients to help identify any internal inconsistencies before being introduced to a larger study group. Often researchers will look for an existing QoL questionnaire that has already been tested for consistency and modify it slightly to fit their own study group. That is why this thesis contains a QoL questionnaire (see Chapter 6) that was developed specifically for TMJ surgery but was based on
an existing QoL questionnaire that was originally intended for use on head and neck cancer patients (i.e., the University of Washington QoL questionnaire – see Chapter 6).

4.8.3. **RADIOLOGY**

Radiology is an essential investigative tool that provides the researcher with a permanent snapshot of hidden parts of the body that require assessment without the need for surgical exposure. In this thesis, all patients had, as part of their diagnostic workup, an orthopantomogram (OPG) and magnetic resonance imaging (MRI) which were used to assess the preoperative status of the mandibular condyle and the disc respectively. While the CT scan is an excellent investigative tool for condylar morphology, it was considered beyond ethical boundaries to subject patients to unnecessary high doses of radiation purely for research purposes, since the OPG and MRI provided sufficient information for diagnostic purposes. Therefore, a retrospective review of existing tomograms that were taken prior to, and following TMJ surgery, were the subject of the Chapter 8 study. The orthopantomograms were considered sufficient for measuring condylar changes according to a formula first reported by Borstlap and co-workers, (Borstlap et al, 2004) (see Chapter 8).

Since a preoperative MRI was essential for diagnostic purposes in all patients, the MRI was considered safe for research and ethics clearance was obtained to investigate the fate of the dermis-fat graft within the TMJ in a randomly selected group of 15 post-operative patients. All 15 study patients were scanned on a 1.5T Avanto (*Siemens Medical, Erlangen Germany*) MR system using the standard 12 channel head coil. Patients were positioned comfortably and asked to keep their mouth closed for all but the last sequence, at which time a bite block was used to keep their mouths open as wide as comfortably possible.

After appropriate localisers to identify the TMJ, the following sequences were acquired:

1. closed mouth
   - (a) sagittal T1 & proton density (PD) turbo spin echo (TSE)
   - (b) axial T2 & T1 TSE
   - (c) coronal T1 & PD fat saturated TSE

2. open mouth
   - (a) sagittal T1 & PD fat saturated TSE
The axial and coronal sequences were orthogonal to the body axis and centred on the TMJ’s. The sagittal sequences were positioned perpendicular to the head of the mandibular condyle and parallel to the ramus. The total examination time was under 30 minutes and all patients tolerated the examination well. The MR images obtained were examined and reported by an experienced specialist musculo-skeletal MRI radiologist and recorded by the candidate. The grafts were evaluated on the following criteria;

1. signal on T1 and T2/PD images
2. presence or absence of graft tissue within the joint space. The radiological joint space was determined as the 120 degrees arc extending from the midbody of the condylar head to the glenoid fossa in the coronal and sagittal planes.
3. if present, nature of the tissue within the joint space as determined by the T1 signal characteristics as grey scales
4. volume of the fat graft (i.e., grey scale >900) within or around the joint space as calculated from the maximum diameters in the 3 orthogonal planes.

All the radiology data was interpreted with the help of an experienced radiologist who had a special interest in musculoskeletal radiology (see Chapter 7).

4.8.4. **LIGHT MICROSCOPY:**

This was used for the assessment of the presence of fat in the histological specimens in chapters 9. Under H & E stain, fat necrosis was defined as cell death, with loss of adipocyte nuclei, breakdown of cell membrane and formation of microcysts consisting of fat globules surrounded by chronic inflammatory cells, including macrophages and giant cells. Viable fat under H & E stain was identified by the presence of adipocyte nuclei with fat globules surrounded by intact cell membranes with vascular channels perforating through clumps of 6 or more fat cells and the absence of inflammatory cells.

4.8.5. **VIRTUAL MICROSCOPY - VM (quantitative) analysis:**

The virtual microscope was used in chapters 9 to quantify the amount of fat tissue present in the histological slides. The hematoxylin and eosin stained histological slides were digitally scanned
using the ScanScope T3 virtual microscopy slide scanner (Aperio, Vista, CA) and ScanScope Console software v7.00.08.1020 provided the user interface. After all the slides were scanned, the digital images were analysed using ImageScope(r) software package. The fat was selected using the "pen tool" and the "positive pixel count" algorithm was run on the selected tissue. The colour saturation threshold was calibrated for each group based on the intensity of the stain of the positive control slide, containing adipose tissue alone, in order to achieve uniformity in measuring the stain for all sections of that group. The same procedure was repeated for the (non-fat) fibrous and epithelial elements in order to determine the background stain. Number of positive pixels was then divided over the surface area to obtain the number of positive pixels per square millimetre for each slide. This value was then subtracted from that of the negative control slides, containing non-fat, fibrous and epithelial elements, to exclude background stain and provide an absolute value of the area of fat present for each slide.
CHAPTER 5

HISTOLOGICAL EVALUATION OF ABDOMINAL FAT AND DERMIS-FAT IMPLANTED IN THE EAR AND TEMPOROMANDIBULAR JOINT OF THE RABBIT

5.1. INTRODUCTION

Autologous fat grafts have been used in reconstructive surgery for over a century. Unfortunately, despite the abundance of adipose tissue that can be easily harvested from multiple sites with minimal morbidity, the results of free fat grafting have been generally disappointing (Ersek, 1991). While the fate of free fat grafts in soft tissue augmentation and contour repair for soft tissue defects has been unpredictable, the same degree of unpredictability is also encountered when fat is used to obliterate bony cavities such as the frontal sinus (Weber et al, 2002).

Interestingly, a recent radiological study by Dimitroulis, Trost and Morrison (2008) using magnetic resonance imaging (MRI) showed that non-vascularized dermis-fat grafts not only appear to survive, but the fat component also thrived in significant quantities when transplanted to the human temporomandibular joint (TMJ). This raises interesting questions as to whether the survival and growth of a non-vascularised fat graft is dependent on unique factors found only in certain recipient sites in the body, or whether the addition of dermis to the non-vascularized fat graft facilitates its survival.

Fat grafts alone are difficult to handle and impossible to sculpture to suitable sizes. Fat grafts also easily fragment when placed into confined spaces. The addition of dermis to the fat greatly facilitates the harvesting of finite quantities of fat tissue and simplifies the sculpturing of the fat which is bound to the dermis. Placement into various cavities is also expedited by the dermis which acts as a convenient carrier for the fat graft that can be easily orientated and anchored to the surrounding recipient bed when attached to dermis.

The dermis-fat graft was introduced to TMJ surgery by the candidate in 2004 when it was first described as an interpositional material for use in gap arthroplasties for the management of
TMJ ankylosis (Dimitroulis, 2004). Since 2000, the candidate has also used autogenous dermis-fat as an interpositional graft in joint cavities following TMJ discectomy (Dimitroulis, Trost, Morrison, 2008). The graft, which is harvested from the periumbilical region of the lower abdomen, was never expected to replace the missing disc but, instead, was intended as a soft tissue plug to fill the joint cavity when the disc was removed (Dimitroulis, 2008). Furthermore, in the absence of a disc, the intention was for the dermis-fat graft to provide a physical barrier between the condyle and glenoid fossa to not only prevent heterogenous bone formation, but perhaps to also prevent direct contact between the joint surfaces so as to minimize wear and tear on the articular cartilage.

While the clinical outcomes of TMJ discectomy with dermis-fat grafting have been favourable (Dimitroulis, McCullough, Morrison, 2009), little is known of the histological fate of the dermis-fat graft within the TMJ, and whether the dermis is at all essential in the growth and maintenance of the fat graft as suggested in the MRI study by Dimitroulis, Trost and Morrison (2008). Furthermore, by understanding the role of a functional joint space on the fate of the dermis-fat graft and comparing it to a non-functional tissue space such as the ear, further research can be directed to realising the unique benefits of these grafting techniques with potential uses in other parts of the body. Using a rabbit model, this study will aim to determine three important issues. Firstly, the survival mechanism of the dermis-fat graft when implanted into the TMJ will be assessed at three time points under light and virtual microscopy. Secondly, to see what effect dermis fat grafts have on bone growth using TMJ condylectomy as the basis for observation. And finally, whether a functional environment (i.e., joint space) is required to stimulate the growth and maintenance of the fat and dermis-fat graft and compare this to a static environment such as the base of the ear.
5.2. MATERIALS & METHODS

This study was approved by the Animal Ethics Committee at St.Vincent’s Hospital Melbourne in accordance with guidelines put out by the National Health and Medical Research Council of Australia governing animal experiments. Thirty-six New Zealand white rabbits were used in this study (Table 5.1). Six rabbits were used as controls (Group A) whereby a left TMJ condylectomy was undertaken with no graft material placed in any of the control rabbits. The remaining 30 experimental animals had fat (Group B – 15 rabbits – intact TMJ) or dermis-fat grafts (Group C – 15 rabbits - condylectomy) harvested from the peri-umbilical region of the lower abdomen. Each abdominal graft was divided into 2 equal parts with one part transplanted into the ear and the other part into the TMJ of each of the 30 experimental animals.

5.2.1. Surgical Technique for harvest of Abdominal Donor Grafts:
Anesthetic induction was via an IV bolus of 1:1 mixture of ketamine (70mg/ml) and xylozine (10mg/ml) at a rate of 1ml/kg into the ear vein. The anesthetic mixture provided 60-90 minutes of anesthesia time. The 30 experimental rabbits had either a fat graft (Group B – intact TMJ) or dermis-fat graft (Group C – condylectomy) procured from their lower abdomen. The fur in the lower abdomen was shaved and depilatory cream was placed to remove all the fur around the surgical site. After injection with 1ml of 2% lignocaine with 1/80,000 adrenaline, the autogenous fat and dermis-fat grafts were harvested via a 2cm x 1cm elliptical incision to a depth of 0.5cm in the lower abdomen of each rabbit (fig.5.1). The wound was primarily closed with 4/0 vicryl sutures. The skin was removed from the fat grafts but only the epidermal layer was removed from the dermis-fat grafts. The epidermal surface layer of the dermis-fat grafts was removed with a sharp scalpel that was scrapped back and forth over the skin until the underlying bleeding dermis was sufficiently exposed. Each graft (2cm x 1cm x 0.5cm) was divided into 2 equal parts (1cm x 1cm x 0.5cm) with one part (0.5cm³) inserted into the TMJ and the other (0.5cm³) into the base of the ear of each animal. The greatest cross-sectional area of each graft was 50mm².

5.2.2. Surgical Technique for the TMJ:
Following anesthesia induction, the fur in the left pre-auricular region was shaved and depilatory cream was placed to remove all the fur around the surgical site. After injection with 1ml of 2%
lignocaine with 1/80,000 adrenaline, a horizontal skin incision was made from just posterior to the lateral canthus of the eye to just anterior to the external acoustic meatus. The zygomatico-squamosal suture line was exposed and a section of the zygomatic process overlying the TMJ capsule was carefully removed. The capsule of the TMJ was incised and the superior joint space was completely exposed to reveal the articular disc. In the 6 control rabbits (Group A) a left side condylectomy was performed and the wound was immediately repaired without any graft. In the Group B rabbits (N=15) the joint was preserved and a portion of autogenous fat graft (0.5cm$^3$) was placed within the superior joint space and the wound closed in layers using 4/0 vicryl sutures. In the group C rabbits (N=15), a left side condylectomy was performed and an autogenous piece of dermis-fat graft (0.5cm$^3$) was placed in the resultant surgical cavity and the surgical wounds were repaired in layers with 4/0 vicryl sutures (fig.5.2).

5.2.3. Surgical Technique for Ear:
The experimental animals also had 0.5cm$^3$ volume of either a fat graft (Group B) or a dermis-fat graft (Group C) surgically implanted into the base of the left ear. Graft placement in the left ear was done through a 2cm longitudinal linear incision at the base of the ear with the dissection carried down to auricular cartilage. The graft was passively placed against the ear cartilage and the wound repaired with 4/0 vicryl sutures (fig.5.2).

The analgesic ‘Carprofen” was administered at the time of surgery and a follow up dose (5mg/kg SC) was given in the 6 hours following surgery. After operation the animals were fed a diet of crushed pellets and fresh vegetables for the first week and water ad libitum. Their weight was measured daily in the first week and thereafter at two week intervals post-operatively. After a week all animals were placed back on their normal diet of hard pellets and vegetables. Each animal was housed individually in a double pen to prevent the risk of other animals disturbing the surgical wounds.

Euthanasia was administered by IV sodium pentobarbitone (2mg/kg) to each group of rabbits at 4 weeks, 12 weeks and 20 weeks following surgery (Table 5.1). Following euthanasia, the animals were decapitated and conveyed to the histopathology laboratory where the left TMJ’s and ears were dissected out and placed in formalin. The specimens were decalcified prior to histological sectioning. Coronal sections were prepared of each TMJ and ear for histological
evaluation under light microscopy in the Department of Anatomical Pathology. Three sections from each joint and ear specimen were cut 3mm apart with the middle section taken through the centre of the specimen in the coronal plane. All slides were stained with hematoxylin and eosin and prepared on glass slides ready for histological examination. The findings were recorded using digital photography, light and virtual microscopy.

5.2.4. Light Microscopy:
Under H & E stain, fat necrosis was defined as cell death, with loss of adipocyte nuclei, breakdown of cell membrane and formation of microcysts consisting of fat globules surrounded by chronic inflammatory cells, including macrophages and giant cells. Viable fat under H & E stain was identified by the presence of adipocyte nuclei with fat globules surrounded by intact cell membranes with vascular channels perforating through clumps of 6 or more fat cells and the absence of inflammatory cells.

5.2.5. Virtual microscopy VM (quantitative) analysis:
The hematoxylin and eosin stained histological slides were digitally scanned using the ScanScope T3 virtual microscopy slide scanner (Aperio, Vista, CA) and ScanScope Console software v7.00.08.1020 provided the user interface. After all the slides were scanned, the digital images were analysed using ImageScope(r) software package. The fat was selected using the "pen tool" and the "positive pixel count" algorithm was run on the selected tissue. The colour saturation threshold was calibrated for each group based on the intensity of the stain of the positive control slide, containing adipose tissue alone, in order to achieve uniformity in measuring the stain for all sections of that group. The same procedure was repeated for the (non-fat) fibrous and epithelial elements in order to determine the background stain. Number of positive pixels was then divided over the surface area to obtain the number of positive pixels per square millimetre for each slide. This value was then subtracted from that of the negative control slides, containing non-fat, fibrous and epithelial elements, to exclude background stain and provide an absolute value of the area of fat present for each slide.
5.3. RESULTS (Tables 5.2, 5.3 & 5.4)

5.3.1. EAR SPECIMENS – each specimen had 3 slices done 3mm apart

4 WEEKS: 10 RABBITS

The mean size of the fat graft, which was largely necrotic, was 51.6mm$^2$. This was almost the same size as the original fat graft (ie. 50mm$^2$) that was implanted into the ear (Table 5.4, Fig 5.3a). There was no difference ($p<0.05$) in the fat necrosis and size of graft between groups B (47.8mm$^2$) and C (55.4mm$^2$) (Fig 5.3a). At the macroscopic level, obvious lumps were seen in both the group B (greatest diameter - 12.3mm ± 3.6mm) and C (greatest diameter - 15.3mm ± 5.1mm) rabbit ear specimens at the time of sacrifice (Table 5.5).

Group B - Fat Grafts: (5 Rabbits)

An average of 94.3% of the abdominal fat graft was found to be necrotic (Table 5.2) with microcysts, cavities full of fat globules but without a cell membrane or nucleas, surrounded by chronic inflammatory cells, mainly giant cells and eosinophils which appeared to have phagocytosed the necrotic fat to form the microcysts (fig. 5.5). There was extensive fibrosis arranged as septa throughout the necrotic graft. An average of 5.7% of the abdominal fat graft was found to be viable (Table 5.2) and mainly located at the periphery of the graft and adjacent to the perichondrium of the ear cartilage. A layer of myxoid degeneration was found close to the cartilage interface which may be related to the necrotic fat but difficult to clearly define. Mutinucleated giant cells (histiocytes) were interspersed within the necrotic fat with establishment of fibrotic tissue.

Group C - Dermis-Fat Grafts: (5 Rabbits)

Dermoid/epidermoid cysts were found in 4 of the 5 specimens (Table 5.3) with thickly fibrotic lining containing skin appendages, mainly hair follicles. The cyst lumen was full of keratin and some hair follicles were present. Ninety percent of the abdominal fat graft was attached to one side of the cyst and was found to be necrotic with microcysts surrounded by chronic inflammatory cells, mainly giant cells and eosinophils which have phagocytosed the necrotic fat to form the microcysts. There was extensive fibrosis arranged as septa throughout the necrotic graft. A small amount (mean 8.1%, Table 5.2) of the abdominal fat graft was found to be viable and mainly located along the outer rim of the cyst and 4-5 cells thick. Mutinucleated giant cells (histiocytes) were interspersed within the necrotic fat with early establishment of fibrotic tissue.
12 WEEKS: 10 RABBITS
The mean size of the viable fat graft was 21.9mm\(^2\) which was about 44% the size of the original fat graft (ie. 50mm\(^2\)) that was implanted into the ear (Table 5.4, Fig 5.3a). Group B had a mean size of 19.3mm\(^2\) and group C had a mean size of 24.5mm\(^2\) (fig 5.3a). At the time of sacrifice, obvious lumps were seen in both the group B (greatest diameter - 7.8mm ± 3.3mm) and C (greatest diameter - 6.4mm ± 2.9mm) ear specimens (Table 5.5).

Group B - Fat Grafts: (5 Rabbits)
While the tissue volume at the grafted site was reduced in size (Table 5.4), there were viable fat deposits present in all rabbits. Viable fat made up all of the grafted site while necrotic fat was absent (Table 5.2). Significant tissue fibrosis with very little fat was evident in 2 rabbits which may be the result of post-operative infection of the grafted site that was treated with antibiotics.

Group C - Dermis-Fat Grafts: (5 Rabbits)
All 5 rabbit specimens showed dermoid/epidermoid cyst formation (Table 5.3). The cysts walls were about 1-2 cell layers less than those in the 4 week rabbit specimens. In 3 of the specimens, the cystic contents had ruptured and elicited a chronic inflammatory response (macrophages and histiocytes) in the surrounding tissues. This appears to have had an adverse impact on the surrounding fat which was reduced to only 2-3 cells thick especially close to the cyst wall. However, there was abundant viable fat deposits found more than 3mm away from the cyst in 3 rabbits with no evidence of necrotic fat.

20 WEEKS: 10 RABBITS
The mean size of the viable, but largely fibrotic, fat graft was 35.2mm\(^2\) which was about 70% the size of the original fat graft (ie. 50mm\(^2\)) that was implanted into the ear (Table 5.4, Fig 5.3a). The group B rabbits had a mean size of 37.9mm\(^2\) and the group C rabbits had a mean size of 32.5mm\(^2\) (fig 5.3a). At the macroscopic level, it was difficult to discern a lump where the fat graft was placed in the ear. It appeared as if the lump, seen in earlier specimens was almost gone (Table 5.5).

Group B - Fat Grafts: (5 Rabbits)
At the microscopic level, fat was seen at the graft site. Compared to the normal subcutaneous fat lining other parts of the ear which had regular layers of parallel fibrous septa, the site of the fat graft showed tightly packed adipose cells with randomly projecting fibrous septa infiltrating
throughout the fat. In comparison to the 12 week group, there were pronounced levels of fibrosis interspersed throughout the fat at the grafted site.

**Group C - Dermis-Fat Grafts: (5 Rabbits)**

Dermoid/epidermoid cysts were found in 4 of the 5 specimens (Table 5.3) with a mature cyst lining demonstrating dermal appendages, in particular, hair follicles which were growing hair into the lumen of the cyst. There was 2-3 cell layer thickness of fat surrounding the outer cyst wall, but none of the specimens showed evidence of cyst rupture and inflammation of surrounding tissues. At the macroscopic level, it was difficult to discern a lump where the fat graft was placed in the ear (Table 5.5). It appeared as if the lump, seen in earlier specimens, was absent. At the microscopic level, mature fat was seen at the graft site, but well away from the actual cyst with no evidence of inflammatory cells or necrotic tissue. Compared to the normal subcutaneous fat lining other parts of the ear which had regular layers of parallel fibrous septa, the site of the fat graft showed tightly packed adipose cells with randomly projecting fibrous septa infiltrating throughout the fat. Pronounced fibrosis interspersed throughout the fat at the grafted site was present compared to the 12 week specimens.

5.3.2. **TMJ SPECIMENS** – each specimen had 3 slices done 3mm apart in the coronal plane with the middle section sliced at the centre of the specimen.

**4 WEEKS: 12 RABBITS**

**Group A - Control – condylectomy with no graft: (2 Rabbits)**

The joint showed extensive bone remodeling of the condylar stump with evidence of cartilaginous islands forming in areas above the amputated stump. There was irregular regeneration of the condylar head in both specimens which was composed predominately of a cap of fibrous tissue with early cartilaginous formation below the irregular fibrous outline. No fat tissue was seen.

**Group B - Fat Grafts – in superior joint space of intact TMJ: (5 Rabbits)**

The fat graft was dislodged laterally and was found adjacent to the condylar neck (fig.5.4). Most of the fat graft (mean 94.3%) was found to be necrotic as indicated by the presence of microcysts
surrounded by (chronic inflammatory) multinuclear giant cells and the absence of adipocytes (Table 5.2, fig.5.5). Fat globules within cytoplasm of multinuclear giant cells suggest phagocytosis of fat graft by these cells. There was fibrosis within the fat graft together with granulation tissue which was found in one large mass above the condylar head in one rabbit. A small amount of viable fat graft (mean 5.7%) was seen within the intra-articular space in all rabbits. However, most of the graft site (mean 94.3%) was necrotic fat (Table 5.2) with multinucleated giant cell histiocytes scattered between fat globules that were not surrounded by adipocytes, and interspersed with fibrous tissue septa. The mean size of the fat graft (Fig 5.3b), which was largely necrotic (mean 94.3%), was 32.5mm² which was about 65% the size of the original fat graft (ie. 50mm²) that was implanted into the TMJ (Table 5.4).

**Group C - Dermis-Fat Grafts - condylectomy: (5 Rabbits)**

Extensive areas of fat necrosis and fibrosis were found in all rabbit tissue specimens examined (fig.5.5). There was very little viable fat seen (mean 8.1%) (Table 5.2). The condylar stump surrounded by thick band of fibrous tissue was identified in 2 rabbits while the remaining 3 rabbits in the group demonstrated evidence of early regeneration of a new condyle. The appearance of the new condyle resembled a bulbous expansion of the condylar stump with active growth signified by the presence of osteoblasts within the condylar process. Immature cartilage was also seen covering the new condylar process but was irregular in appearance. Small dermoid cysts were found in 3 of the 5 rabbits (Rabbits 1C,2C & 4C, Table 5.3) with dermal elements such as hair follicles and sweat glands within the thick cyst lining. The remaining two rabbits showed no evidence of dermoid cysts in any of the sections examined (Table 5.3). Extensive scar tissue was also found throughout the joint space vacated by the excised condyle. The mean size of the fat graft (fig 5.3b), which was largely necrotic (mean 91.9%), was 31.2mm² which was about 62% the size of the original fat graft (ie. 50mm²) that was implanted into the TMJ (Table 5.4).

**12 WEEKS: 12 RABBITS**

**Group A - Control – condylectomy with no graft: (2 Rabbits)**

The joint showed regeneration of the amputated condylar process that appeared as osteoid tissue filled with osteoblasts that projected into the joint space as a bony stump. There was a very thick
process of cartilaginous growth over the bony stump which had an irregular outline. There was no evidence of fat.

Group B - Fat Grafts – in superior joint space of intact TMJ: (5 Rabbits)

Fat tissue was difficult to find in any measurable quantities. While no necrotic fat was present, there were little amounts of viable fat found (mean 9.6mm$^2$, Table 5.4). There were fibrocytes within the reactive synovial membrane. The mean size of the viable fat graft (fig 5.3b) amongst all the rabbits in this group was 9.6mm$^2 \pm 4.2mm^2$ which was about 19% the size of the original fat graft (ie. 50mm$^2$) that was implanted into the TMJ (Table 5.4).

Group C - Dermis-Fat Grafts - condylectomy: (5 Rabbits)

Well defined condylar heads were seen in 2 rabbits with poorly regenerated condylar processes in 2 other rabbits and only a condylar stump, presenting as a small bone projection of 2 mm length, surrounded by thick fibrous tissue seen in 1 rabbit (Table 5.3). Significant quantities of viable fat deposits (mean 39.5mm$^2 \pm 10.1mm^2$) were seen in all rabbit specimens filling the joint space (Table 5.4). In the rabbit specimens which showed incomplete condylar regeneration, large amounts of fat were seen within the internal spaces of the new bone which may be the new fat disrupting the formation of new bone. Dermoid cysts were seen in 3 of the 5 rabbit specimens (i.e., 6C,8C &10C, Table 5.3) with dermal elements such as hair follicle and sweat glands also visible within the cyst lining (fig. 5.6). The mean size of the viable fat graft (fig 5.3b) was 39.5mm$^2$ which was about 79% the size of the original fat graft (ie. 50mm$^2$) that was implanted into the TMJ (Table 5.4).

20 WEEKS: 12 RABBITS

Group A - Control – condylectomy with no graft: (2 Rabbits)

Both joint specimens showed an almost fully regenerated condyle which was the size of a normal condyle but with some irregularity in the outline. One of the two regenerated condyles demonstrated a bifid head. Some of the regenerated cartilaginous cap was composed of areas of immature hyaline cartilage surrounded by larger areas of fibrocartilage. The regenerated condylar stump was filled with osteoclasts compared to the normal condyle. There was no fat present.
Group B - Fat Grafts – in superior joint space of intact TMJ: (5 Rabbits)
Fat deposits were found in all joint specimens examined (fig.5.7). While the fat tissue was found lateral to the condyle, there was fat tissue also found within the joint space i.e., between the disc and condylar head as well as above the disc between the disc and glenoid fossa. The fat seemed to be adherent to the disc in some cases. Significant deposits of adipose tissue (mean 53.7mm²) completely surrounding the superior aspect of the articular disc (fig.5.8) was seen. The mean size of the viable fat graft (fig 5.3b) was 53.7mm² which was slightly larger than the size of the original fat graft (i.e. 50mm²) that was implanted into the TMJ (Table 5.4).

Group C - Dermis-Fat Grafts - condylectomy: (5 Rabbits)
One rabbit showed a poorly regenerated condyle (Table 5.3). The other 4 rabbit specimens only showed condylar stumps surrounded by a thick layer of fibrous tissue. Of the 5 rabbits in this group only one rabbit showed evidence of a large dermoid cyst with dermal elements within the lining such as hair follicles and sweat glands (Table 5.3). All the other rabbit specimens showed no evidence of dermoid cysts in any of the sections. Viable fat (fig.5.9, 5.10) was found in all specimens (Table 5.2) with only 1 rabbit showing some residual synovial lining. The mean size of the viable fat graft (fig 5.3b) was 98.7mm² which was about twice (197%) the size of the original fat graft (ie. 50mm²) that was implanted into the TMJ (Table 5.4).

5.4. DISCUSSION

This study showed that non-vascularised fat grafts do not appear to survive transplantation. Fat necrosis (fig.5.5) was histologically demonstrated in all tissue specimens from both the TMJ and ear at 4 weeks (Table 5.2). However, the dermis component of the graft seemed to survive and form cysts in both the ear and TMJ (Table 5.3). By 12 weeks, early signs of viable fat deposits appeared in both the ear and TMJ with a reduction in the presence of necrotic fat. At the 20 week stage, large amounts of viable fat were present in the TMJ (fig 5.3b) but not in the ear (fig 5.3a) specimens (Table 5.4). Fat transplanted to the ear showed histological signs of fibrosis (fig.5.5) where the fat graft was originally placed with little evidence of maintenance of the original volume of fat graft (Table 5.5). The results of the ear specimens (Table 5.5) confirm the generally poor and unpredictable nature of autologous fat grafts that tend
to resorb or fibrose following transplantation which is well documented in the literature (Billings & May, 1989; Ersek, 1991; Niechajev & Sevcuk, 1994). On the other hand, the large quantities of fat seen in the TMJ at 20 weeks (fig.5.3b, 5.7) (Table 5.4) appears to confirm the findings of Dimitroulis, Trost and Morrison (2008) who found MRI evidence of significant fat deposits surrounding the TMJ in all 15 human subjects who had undergone TMJ discectomy with dermis-fat graft replacement.

It appears from the results of this study that the recipient site plays a crucial role in the fate of non-vascularised fat grafts. In the ear, the volume of the original fat graft was not maintained and, by 20 weeks, was reduced to about 70% of the original size of the graft (Table 5.4). The only evidence that fat was implanted was found in the random orientation of the fibrous septa with increased amount of fibrosis in the grafted site compared to the adjacent normal tissue. The addition of the dermis layer to the fat yielded dermoid/epidermoid cysts (Table 5.3) within the ear that were quite independent of the fat graft. In contrast, significant quantities of viable fat were found in the TMJ of all rabbits, particularly at 20 weeks (Table 5.4). The fat that was placed into a potential space such as the superior joint space (Group B) (fig.8), was much less (53.7mm$^2$) than the fat placed into a surgically created space (Group A) (98.7mm$^2$) following condylectomy (Fig.5.3b, 5.10) (Table 5.4).

It seems apparent that the dermis component of the graft evolves quite separately to the fat and had the propensity to form cysts (Table 5.3), although these were less prominent in the TMJ by 20 weeks. The findings of this study in the Group C rabbits suggest that the fate of the fat and the dermis appear to be distinctly separate with the dermis surviving to form cysts while the fat becomes necrotic and is eventually replaced either by fibrosis in the ear or new fat in the TMJ. This is in contrast to the suggestion that the dermal layer is vasoinductive for the underlying fat tissue graft (Rowshan et al 2008) which was not found in this study. However, the propensity of the dermis component of the dermis-fat graft to form dermoid/epidermoid cysts has already been shown in a previous study (Dimitroulis & Slavin, 2006) using full thickness skin. That study showed that when full thickness skin was implanted into the TMJ, all the rabbits (100%) demonstrated cyst formation (Dimitroulis & Slavin, 2006). The fact that cysts were not found in all specimens in the present study points to the possibility that the cysts were the result of epidermal remnants that were still present when the dermis-fat graft was implanted into the ear.
and TMJ of the rabbits. It is likely that cysts failed to develop in those animals where all the epidermal elements were thoroughly removed before transplantation. Therefore, it seems the dermis has no influence on the fate of the fat graft at the light microscopy level. However, as mentioned in the introduction, from a clinical standpoint the dermis serves as a useful carrier for the fat graft which makes it easier to handle.

Since no fat tissue was seen in the control animals, it can be safely assumed that the viable fat seen in the TMJ of the 20 week rabbits was somehow derived from the original fat graft placed in the TMJ. This finding in itself is a revelation as the results of the study appear to support the host replacement theory because the original fat graft did not survive the transplantation. While the host replacement mechanism is unknown, perhaps the inflammatory reaction that surrounded the necrotic fat deposits may well have been the trigger that resulted in the process of neo-adipogenesis. That is, new fat tissue was created by recruitment of stem cells or pre-adipocytes from the tissues surrounding the TMJ which was facilitated by the inflammatory process around the necrotic fat. This is in keeping with the results of a recent study (Thomas et al 2008) which demonstrated that a state of chronic, low-grade inflammation promoted neo-adipogenesis in-vivo through the mobilisation and recruitment of a circulating population of adipose precursor cells.

The process of neo-adipogenesis appears to have occurred in the TMJ of all rabbit specimens regardless of whether the TMJ complex was left intact or a condylectomy was performed. Therefore, new fat formation did not rely on the presence of an intact TMJ complex so the surrounding tissues appear to be the determinant for new fat growth. Furthermore, growth of new fat did not depend on the creation of a cavity as fat still managed to grow around an intact TMJ (fig.5.7). In fact, the fat in the TMJ continued to grow and take up additional space in the 20 week specimens (98.7mm²) that was beyond the size of the graft (50mm²) that was originally implanted (fig 5.3b) in the group C animals. On the other hand, the fat graft failed to maintain any long term presence in the ear (Table 5.5) even though early evidence of new fat growth was seen in the 12 week group which was still present but had largely become fibrotic by 20 weeks in both groups B and C.
A significant finding derived from this study is the presence of the fat graft within the TMJ following condylectomy in the group C animals appears to have inhibited the growth of new bone in 4 of the 5 animals (fig. 5.10). Compared to the 6 group A control rabbits, where the condylar stump was seen to slowly regenerate over the 3 time periods, the experiment group of 15 group C rabbits showed initial attempts at regeneration in the 4 and 12 week stage but little sign of condylar regeneration at the 20 week stage (Table 5.3). It seems the presence of the fat graft following condylectomy in the group C animals appears to retard the regeneration of the condylar stump after viable fat begins to replace the necrotic fat in the 12 and 20 week rabbits (Tables 5.2 & 5.3). This has significant clinical implications for the management of TMJ ankylosis (Dimitroulis, 2004) and the prevention of heterotopic bone formation following prosthetic joint replacements (Mercuri et al 2008).

5.5. SUMMARY & CONCLUSIONS

The main aim of this study is to compare the fate of abdominal fat and dermis-fat grafts implanted into the Temporomandibular joint (TMJ) with similar grafts implanted into the ear in a rabbit model. Thirty-six female New Zealand white rabbits were used in this study. Six rabbits were used as controls (Group A) whereby a left TMJ condylectomy was undertaken with no graft material placed in the joint cavity. The remaining 30 experimental animals had fat (Group B – 15 rabbits – intact TMJ) or dermis-fat grafts (Group C – 15 rabbits - condylectomy) harvested from the peri-umbilical region of the lower abdomen. Each abdominal graft was divided into 2 equal parts. One part of the graft was transplanted into the ear and the other part into the left TMJ of each of the 30 experimental animals. Animals were sacrificed at 4 weeks, 12 weeks and 20 weeks following surgery. Specimens were prepared of the left TMJ and ear for histological evaluation under light and virtual microscopy. Fat necrosis was clearly demonstrated in all group B and C animal tissue specimens from both the TMJ and ear at 4 weeks. However, the dermis component of the graft in the group C animals seemed to survive and form cysts with no evidence of necrosis at any stage in either the ear or TMJ. By 12 weeks, signs of viable fat deposits appeared in both the ear and TMJ in the group B and C animals with no evidence of necrotic fat. At the 20 week stage, large amounts of viable fat were present in the TMJ but not in the ear specimens, more so in the group C animals (condylectomy) than the group B animals (intact TMJ). Fat transplanted to the ear showed significant fibrosis with a reduction in the
original volume of fat graft. In the group A control rabbits, all the missing condyles regenerated. However, in the presence of viable fat, the group C rabbits showed little regeneration of the condyles 20 weeks following TMJ condylectomy. Non-vascularised fat grafts do not survive transplantation, but appear to stimulate neoadipogenesis which is abundantly evident when implanted in the TMJ but not as abundant when implanted in the ear. The fate of the dermis component of the dermis-fat graft in the group C animals appears to be completely independent of the fate of the fat. The presence of fat within the joint space appears to disrupt the regeneration of a new condylar head following condylectomy in the group C animals. Therefore it seems that the process of neoadipogenesis inhibits the growth of new bone and cartilage within the joint space. This has positive implications when it comes to the management of TMJ ankylosis and the prevention of heterotopic bone formation around prosthetic joints.
Table 5.1. Summary of the 36 rabbits divided into 3 groups (ie. A, B and C). Each rabbit was 3 months old and weighed a minimum of 2.0kg at the time of surgery. An average of 0.5cm$^3$ of abdominal fat (Group B) or dermis-fat (Group C) graft was implanted into the left TMJ and left ear of each experimental rabbit. The animals were sacrificed at 3 time intervals viz., 4 weeks, 12 weeks and 20 weeks following surgery
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<th>Percentage proportion of</th>
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Summary of Mean Values of Necrotic Fat (percentage proportion)

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<th>Group C</th>
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<td>91.9% ± 3.5%</td>
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<tr>
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Table 5.2. Shows the percentage proportion of necrotic fat vs viable fat in the control Group A (TMJ condylectomy alone) and experimental Group B (fat graft, intact TMJ) and Group C (dermis-fat graft, TMJ condylectomy). Fibrosis indicates viable fat was present but interspersed with fibrous tissue.
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</tr>
<tr>
<td>Rabbit 7C</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Rabbit 8C</td>
<td>Yes (poor)</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Rabbit 9C</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Rabbit 10C</td>
<td>Yes (poor)</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>20 WEEKS</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rabbit 5A</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Rabbit 6A</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Rabbit 11C</td>
<td>Yes (poor)</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Rabbit 12C</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Rabbit 13C</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Rabbit 14C</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Rabbit 15C</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

**Table 5.3.** Group C rabbits which had autogenous abdominal dermis-fat grafts implanted into the ear and TMJ where the condyle was resected, compared to Group A control rabbits which just had TMJ condylectomy without a graft.
**EAR**

Mean area of fat tissue measured

4 weeks

<table>
<thead>
<tr>
<th>Group</th>
<th>Area (mm$^2$) ± SD (mm$^2$)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group B</td>
<td>47.8 ± 10.6</td>
<td>47.8 mm$^2$ ± 10.6 mm$^2$ (necrotic fat)</td>
</tr>
<tr>
<td>Group C</td>
<td>55.4 ± 7.4</td>
<td>55.4 mm$^2$ ± 7.4 mm$^2$ (necrotic fat)</td>
</tr>
<tr>
<td>Mean B&amp;C</td>
<td>51.6 ± 9.2</td>
<td>Mean B&amp;C = 51.6 mm$^2$ ± 9.2 mm$^2$ (necrotic fat)</td>
</tr>
</tbody>
</table>

12 weeks

<table>
<thead>
<tr>
<th>Group</th>
<th>Area (mm$^2$) ± SD (mm$^2$)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group B</td>
<td>19.3 ± 6.5</td>
<td>19.3 mm$^2$ ± 6.5 mm$^2$ (viable fat)</td>
</tr>
<tr>
<td>Group C</td>
<td>24.5 ± 5.3</td>
<td>24.5 mm$^2$ ± 5.3 mm$^2$ (viable fat)</td>
</tr>
<tr>
<td>Mean B&amp;C</td>
<td>21.9 ± 5.9</td>
<td>Mean B&amp;C = 21.9 mm$^2$ ± 5.9 mm$^2$ (viable fat)</td>
</tr>
</tbody>
</table>

20 weeks

<table>
<thead>
<tr>
<th>Group</th>
<th>Area (mm$^2$) ± SD (mm$^2$)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group B</td>
<td>37.9 ± 7.3</td>
<td>37.9 mm$^2$ ± 7.3 mm$^2$ (viable fat interspersed with fibrous tissue)</td>
</tr>
<tr>
<td>Group C</td>
<td>32.5 ± 8.1</td>
<td>32.5 mm$^2$ ± 8.1 mm$^2$ (viable fat interspersed with fibrous tissue)</td>
</tr>
<tr>
<td>Mean B&amp;C</td>
<td>35.2 ± 7.8</td>
<td>Mean B&amp;C = 35.2 mm$^2$ ± 7.8 mm$^2$ (viable fat interspersed with fibrous tissue)</td>
</tr>
</tbody>
</table>

**TEMPOROMANDIBULAR JOINT**

Mean area of fat tissue measured

4 weeks

<table>
<thead>
<tr>
<th>Group</th>
<th>Area (mm$^2$) ± SD (mm$^2$)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group B</td>
<td>32.5 ± 8.1</td>
<td>32.5 mm$^2$ ± 8.1 mm$^2$ (necrotic fat)</td>
</tr>
<tr>
<td>Group C</td>
<td>31.2 ± 6.3</td>
<td>31.2 mm$^2$ ± 6.3 mm$^2$ (necrotic fat)</td>
</tr>
</tbody>
</table>

12 weeks

<table>
<thead>
<tr>
<th>Group</th>
<th>Area (mm$^2$) ± SD (mm$^2$)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group B</td>
<td>9.6 ± 4.2</td>
<td>9.6 mm$^2$ ± 4.2 mm$^2$ (viable fat)</td>
</tr>
<tr>
<td>Group C</td>
<td>39.5 ± 10.1</td>
<td>39.5 mm$^2$ ± 10.1 mm$^2$ (viable fat)</td>
</tr>
</tbody>
</table>

20 weeks

<table>
<thead>
<tr>
<th>Group</th>
<th>Area (mm$^2$) ± SD (mm$^2$)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group B</td>
<td>53.7 ± 12.7</td>
<td>53.7 mm$^2$ ± 12.7 mm$^2$ (viable fat)</td>
</tr>
<tr>
<td>Group C</td>
<td>98.7 ± 23.6</td>
<td>98.7 mm$^2$ ± 23.6 mm$^2$ (viable fat)</td>
</tr>
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</table>

**FAT GRAFT AT TIME OF IMPLANTATION**

0 weeks

<table>
<thead>
<tr>
<th>Group</th>
<th>Area (mm$^2$)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group B</td>
<td>50.0 mm$^2$</td>
<td></td>
</tr>
<tr>
<td>Group C</td>
<td>50.0 mm$^2$</td>
<td></td>
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</tbody>
</table>

Table 5.4. Volumetric analysis could not be done because specimens were sectioned 3mm apart. So measurements of each specimen were taken in 2 dimensions of height and width only. The mean cross-sectional area of the fat graft at its widest point when sliced down the middle was 10mm x 5mm = 50mm$^2$ which was implanted in the ear and TMJ. Measurements recorded from the ear and TMJ specimens were through the histological sections that showed the greatest area of fat graft present for each animal.
<table>
<thead>
<tr>
<th>Time</th>
<th>Group B – Fat Grafts</th>
<th>12 weeks</th>
<th>20 weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 weeks</td>
<td>12.3mm ± 3.6mm</td>
<td>7.8mm ± 3.3mm</td>
<td>0mm</td>
</tr>
<tr>
<td>12 weeks</td>
<td>7.8mm ± 3.3mm</td>
<td>0mm</td>
<td></td>
</tr>
<tr>
<td>20 weeks</td>
<td>0mm</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Time</th>
<th>Group C – Dermis-Fat Grafts</th>
<th>12 weeks</th>
<th>20 weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 weeks</td>
<td>15.3mm ± 5.1mm</td>
<td>6.4mm ± 2.9mm</td>
<td>2.1mm ± 1.5mm</td>
</tr>
<tr>
<td>12 weeks</td>
<td>6.4mm ± 2.9mm</td>
<td>2.1mm ± 1.5mm</td>
<td></td>
</tr>
<tr>
<td>20 weeks</td>
<td>2.1mm ± 1.5mm</td>
<td></td>
<td></td>
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</tbody>
</table>

**Table 5.5:** The average maximum diameter (and standard deviation) of the soft tissue lump at the grafted site in the left ear as measured at the time the rabbits were sacrificed.
Figure 5.1: Dermis-fat graft being harvested from the lower abdomen. The skin remains attached to the fat tissue bed until the epidermal layer is removed to leave the underlying dermis before the graft is raised.
Figure 5.2: Experimental rabbit from Group B showing repaired incisions in the left TMJ and base of left ear where the abdominal fat grafts were implanted.
Figure 5.3a: Bar chart showing the mean relative area in mm² (and standard deviation) of the fat grafts implanted in the ear of the rabbits as measured on the virtual microscope. The control “A - red bar”, is the original size of the graft that was placed in the ear.
Figure 5.3b: Bar chart showing the mean relative area in mm$^2$ (and standard deviation) of the fat grafts implanted in the TMJ of the rabbits as measured on the virtual microscope. The control “red bar”, is the original size of the graft that was placed in the TMJ.
Figure 5.4: Group B rabbit TMJ specimen at 4 weeks showing extensive fat necrosis to the left of the mandibular condyle. Hematoxylin & Eosin x10
Figure 5.5: Higher power magnification in group B rabbit showing extensive fat necrosis with chronic inflammatory cells surrounding microcysts in the TMJ of 4 week rabbits. Hematoxylin & Eosin x 40
**Figure 5.6**: Extensive areas of viable fat in the TMJ of the 12 week Group C rabbit with evidence of early regeneration of condyle (right). A large epidermoid cyst is visible in the lower left part of the photomicrograph. Hematoxylin & Eosin x 10
Figure 5.7: Macro photograph showing a group B rabbit at 20 weeks with significant fat deposits above the condyle x 1 magnification
**Figure 5.8:** 20 week Group B rabbit intact TMJ specimen where fat graft was implanted in the superior joint space showing extensive viable fat deposits above the mandibular condyle

Hematoxylin & Eosin x10
Figure 5.9: Higher power magnification showing extensive viable fat deposits surrounding the TMJ of group B rabbit at 20 weeks. Hematoxylin & Eosin x 40
Figure 5.10: Significant deposits of viable adipose tissue in the TMJ of a Group C rabbit at 20 weeks. No sign of regenerating condyle is seen as the fat tissue fills the entire joint space following condylectomy. Hematoxylin & Eosin x 10
CHAPTER 6

QUALITY OF LIFE SURVEY COMPARING PATIENTS PRIOR TO AND FOLLOWING DISCECTOMY OF THE TEMPOROMANDIBULAR JOINT.

6.1 INTRODUCTION

The Oral Health Related Quality of Life (ORHQoL) has been used extensively in dental patients as a measure of impact of a disease on the subject’s perceived oral health (Slade 1998). The measurements can be used not only to compare the impact of different disease conditions, but also to demonstrate treatment outcomes as perceived by the patients (Lee, McGrath, Samman 2007, Shugars et al 2006, White et al 2003). Researchers assessing temporomandibular disorders (TMD) have used a variety of approaches to assess the impact of TMD on quality of life (QoL). Both generic oral health and condition-specific QoL tools which compare TMD not only to other oral conditions but also to different TMD diagnoses have been used (John et al 2007).

Unfortunately, previously used QoL questionnaires for oral diseases have been very difficult to administer and interpret and involved too many questions that failed to yield objective and reproducible results (Spilker, 1990). The University of Washington quality of life instrument and its modification (UW-QoL-R; Weymuller et al 2001) was chosen as the basis for development of a new TMJ Surgery specific quality of life questionnaire (TMJ-S-QoL) (fig.6.1) because it fulfilled the ideal test that was simple and quick to administer, did not require excessive training, was easy to interpret, and yielded objective results that were reproducible, reliable and had already been validated in a population of head and neck cancer patients (Weymuller et al 2000).

Surgery of the temporomandibular joint (TMJ) affects many aspects of the patients’ QoL which has, up until now, not been evaluated in the peer-review literature. There are many tools that can be used to assess treatment outcomes for a wide variety of disorders and the condition-specific QoL is a measure that encompasses many of these variables (Bowling, 2001). Variables such as pain, chewing, speech, mood and so on, are essential in understanding the patients’ view of their disorder and their perception of treatment outcomes. The aim of this study is to assess the
outcomes of TMJ discectomy for the management of Wilkes stage IV (Appendix 1) TMJ internal derangement by comparing the QoL status of pre-surgical patients with the QoL outcomes of comparable patients following TMJ discectomy using the newly developed TMJ-S-QoL tool.

6.2. PATIENTS AND METHODS

Sixty-one patients were enrolled in this study and were asked to complete a TMJ-S-QoL questionnaire. The questionnaire used in this study (fig.6.1) was adapted from a modified University of Washington quality of life questionnaire (UW-QoL-R; Weymuller et al 2001) version 4, which contained domains specific for head and neck cancer. Where the term “cancer” appeared in the original UW-QoL-R questionnaire, it was replaced with “TMJ disorder” with some questions specifically related to head and neck cancer such as shoulder, saliva, taste and swallowing, eliminated from the final questionnaire to come up with a new TMJ surgery specific questionnaire referred to as TMJ-S-QoL questionnaire (fig.6.1). The validity of the UW-QoL-R questionnaire has been confirmed by an internal review for consistency and reliability (Weymuller et al 2001).

The developed TMJ-S-QoL tool consists of 12 questions (fig.6.1). Nine questions (A-G, J, K) were directed to specific parameters (pain, diet & chewing, speech, activity levels, recreation, mood, anxiety, general health and well-being) that were comparable between the pre- and post-surgery groups. The parameters were graded 1 to 5 with 1 being the most positive outcome and 5 being the least favourable outcome. The other 3 questions (H, I, L) were either specifically targeted to the post-surgical group (questions I, L) or provided the patients with a more general response about their concerns (question H).

The patients were divided into 2 groups. The pre-surgery group (N = 29) were patients who were diagnosed with advanced TMJ internal derangement (Wilkes stage IV – Appendix 1) and were awaiting TMJ surgery. The post-surgical group (N = 32) were patients who had undergone the same surgical procedure, consisting of TMJ discectomy with interpositional dermis-fat grafting, for the management of Wilkes stage IV TMJ internal derangement. The Wilkes stage IV TMJ internal derangement is the second highest rating from I to V which represents an intermediate to late stage disease level that presents with chronic joint pain and
crepitus resulting from non-reducing disc displacement with deformity and early condylar changes (Wilkes, 1989 – Appendix 1).

Patients selected to participate in the study had suffered, or were suffering from, intolerable joint pain and joint dysfunction that failed to respond to at least 6 months of non-surgical therapy involving at least one of occlusal splint therapy, medication (antiinflammatories, analgesics, antidepressants) or physiotherapy. In about a third of the cases (21/61), TMJ arthrocentesis or arthroscopy were also tried but failed to provide patients with long term relief (i.e., > 3mn). Every patient in the study had an MRI of the TMJ which confirmed the presence of non-reducing disc displacement with disc deformity which was consistent with Wilke’s stage IV internal derangement (Wilkes, 1989 – Appendix 1) (fig.6.2).

The pre-surgical group of patients were scheduled to undergo the same TMJ surgical procedure as the post-surgery group but had not had any surgery at the time they completed their questionnaire. Those with radiological (i.e., MRI showed normal and minimally displaced discs) evidence of salvageable discs or significant condylar pathology were excluded from the study.

All the patients in the post-surgical group had undergone unilateral TMJ discectomy through a standard pre-auricular surgical approach (Dolwick & Sanders, 1985) by the candidate. The resultant joint cavity was filled with an interpositional dermis-fat graft procured from the lower abdomen as described by Dimitroulis (2004). Those who had undergone significant additional procedures to the condylar head i.e., resection or joint replacement, were excluded.

Both groups were matched with respect to age, sex (Table 6.2), clinical and radiological diagnoses as well as treatment proposed or undertaken. The age range of the pre-surgical group was 18 yr to 73 yr with a mean of 41.6yr while the age range for the post-surgical group at the time of the survey was 15 yr to 75 yr with a mean of 45.4 yr. The mean time interval between TMJ surgery and the survey in the post-surgical group was approximately 2 yr with the shortest period of 5 mn and the longest follow-up period of 6 yr (Table 6.1).

Statistical analysis was undertaken using the student t-test and Chi-square with a p-value < 0.05 considered as significant. All analyses were performed using the Microsoft Excel spreadsheet (Microsoft Office 2007).
6.3. RESULTS

All 61 patients (no surgery = 29; surgery = 32) completed the TMJ-S-QoL questionnaire. For all 9 comparable parameters of the TMJ-S-QoL questionnaire there was a mean improvement in the post-surgical group patients when compared to the pre-surgery group (Table 6.2). This improvement was statistically significant in 5 (i.e., pain, diet & chewing, mood, anxiety and general health) of these parameters (p<0.05) (fig.6.3). In 4 of the parameters (i.e., speech, level of activity, recreation, well-being) the improvement was not statistically significant (fig.6.4).

One question in the TMJ-S-QoL questionnaire (question H; fig.6.1) asked participants to indicate up to 3 issues, from a list of 8, that were upper most in their mind during the preceding month. In the pre-surgical group, all patients (29/29) reported issues of concern, in particular, pain (27/29) and chewing difficulties (24/29) (fig.6.5). In the post-surgical group 59% (19/32) indicated that they did not have any issues of concern. Of the remaining 41% (13/32), 9 postsurgical patients reported pain (28%), 8 patients reported chewing difficulties (25%) and 3 patients still had anxiety (9%) (fig.6.5), even though most of these patients (30/32) reported feeling better compared to their pre-surgical state (Table 6.3). The most significant reductions in reported concerns between the pre- and post-surgery groups were found in mood (81%), followed equally by pain (70%) and chewing/diet (70%) (fig.6.5).

When asked whether they would recommend TMJ surgery to others in a similar situation (question L; fig.6.1) over half the patients 53% (17/32) who had the surgery would recommend TMJ surgery only after splint therapy, medication and physiotherapy, while 44% (14/32) recommended TMJ surgery as the primary treatment (Table 6.4). One patient recommended surgery only as a last resort and there were no patients who would not recommend TMJ surgery to others in similar circumstances.
6.4. Discussion

Many previously published studies on TMJ surgery have looked at a heterogenous range of patients with different diagnoses undergoing a wide variety of different surgical procedures with outcomes which were difficult or impossible to properly assess (Reston & Turkelson, 2003; Dimitroulis, 2005b). This study has attempted to bring together a cohort of patients who were not only closely matched in age and gender, but also had comparable clinical and radiological presentations as well as diagnoses which required similar surgical procedures.

There is a paucity of literature involving QoL questionnaires that relate to patients who have undergone TMJ surgery. The UW-QoL-R instrument and its modifications (Weymuller et al, 2001) was modified and adapted to develop a QoL research tool specific for patients undergoing TMJ surgery, the TMJ-S-QoL (fig. 1). The results of this cross-sectional study show that the pain levels were significantly reduced in the post-surgical group, with the greatest improvement found in the diet/chewing, mood and anxiety levels following TMJ surgery. Interestingly, speech, recreation and level of activity were largely unaffected by the TMJ surgery perhaps because the level of disability reported for these parameters by the pre-surgical group were generally low compared to the more significant parameters of pain, diet, chewing, mood and anxiety.

One major limitation of the present study is that this was a cross-sectional study that looked at 2 closely matched groups of different individuals. Ideally, a longitudinal study which followed patients from pre- to post- surgery may have provided more controlled data. However, the time frame required to collect the data for a longitudinal study would span to a number of years, so the cross-sectional approach provided a convenient snapshot of findings that could form the basis for a longitudinal study.

The ORHQoL is a comprehensive tool that has been extensively used in its various forms for the study of temporomandibular disorders (John et al., 2007; Murray et al., 1996; Reisine & Weber, 1989). Previous studies, however, have focused on the ORHQoL of TMD patients with different diagnoses which compared the level of disability in those with myogenous to those with arthrogenous TMD, as well as the impact of dysfunctional pain patients with a history of
somatization and depression (John et al., 2007). The OHRQoL instrument allows the patient the freedom to report their own condition as they perceive it which is in contrast to the clinicians’ assessment of treatment outcomes (White, 1998). The data derived from the various quality of life studies, which establish and compare the impact of various disorders and diseases, also help determine and prioritize treatment needs in a time where health resources are stretched (Allen, 2003).

Unfortunately, QoL questionnaires can be very complicated and arduous to administer. Often there may be 50 to 100 questions that patients are required to answer which may result in fatigue or failure to answer all questions. Data collection and analysis of lengthy QoL questionnaires may be corrupted by similar questions that may be worded differently and hence provoke different responses from the study participants. Furthermore, some questions may invalidate the outcomes and skew the results of the entire QoL findings. In the quest to develop a QoL tool that was specific to TMJ surgery, the candidate sought to find an existing instrument that was short (<15 questions) simple and quick to administer, with questions that were easy to interpret, and results that were reproducible, reliable and valid for head and neck pathology. The University of Washington quality of life instrument and its modification (UW-QoL-R; Weymuller et al., 2001) was, in the candidates view, the most appropriate template which was used as a basis for developing the TMJ surgery specific QoL questionnaire (TMJ-S-QoL) that was used in this study (fig.6.1).

A seemingly paradoxical finding of this study was that, while 91% of the post-surgical patients felt much better following their TMJ surgery (Table 6.3), 41% still reported concerns, particularly with respect to pain and chewing ability. Further questioning (not included in results) revealed that the issues raised by the post-surgery group were comparatively minor and only mentioned because there were occasions where mild pain or minor chewing difficulties would arise but never at the levels experienced before their surgery. This suggests that even surgical treatment cannot completely eliminate all the symptoms experienced by patients prior to their treatment. There was one patient in the post-surgical group who reported poor outcomes in all parameters as a result of her surgery. While she reported feeling worse after TMJ surgery (Table 6.3), her advice for other patients in similar circumstances was that TMJ surgery should be undertaken only as a last resort (Table 6.4) rather than not at all. At the time of her survey, which
was 3 years following her TMJ discectomy, the patient was awaiting a total joint replacement for end-stage joint disease that was not diagnosed in the initial visit.

While over half (53%) of the post-surgical patients recommended TMJ surgery only after conservative measures are tried first, no patient in the post-surgical group selected the response of not recommending surgery at all. In an unexpected finding, 44% of post-surgical patients would recommend TMJ surgery as a first option for others in similar circumstances (Table 6.4). Whether these patients felt that the initial conservative measures were inappropriate and only served to delay the inevitable surgical intervention is difficult to discern based on the questionnaire used in this study. This would suggest that in hindsight, their disorder was serious enough to warrant more than just simple measures and, having gone through the experience, would have opted for surgery at a much earlier stage. It is only through studies like this that we can appreciate the effectiveness of different treatment regimes from a patients’ perspective which is an important part of modern health-care systems that are shifting more towards patient-centred services (White, 1998).

An important component of this study that should be highlighted was that autogenous dermis-fat harvested from the lower abdomen was used as an interpositional graft to fill all joint cavities following discectomy. Unfortunately, because all patients in the post-surgical group underwent the same procedure, this study could not determine any advantage of dermis-fat grafting over other interpositional grafts (McKenna 2001), or indeed, over no grafting at all (Takaku, Sano, Yoshida 2000). Therefore, the main therapeutic value of the surgery appears to be largely related to the discectomy (Dimitroulis 2005a), and any additional benefits of the dermis-fat graft remain unknown (Dimitroulis, Trost, Morrison, 2008).

TMJ discectomy is one of the few surgical procedures that can boast greater than 20 yr follow up data which demonstrate generally good outcomes (Eriksson & Westesson, 1985; Silver 1984; Tolvanen, Oikarinen & Wolf, 1988). The present study provides further proof of the positive outcomes of TMJ discectomy in a cohort of patients who were studied using the QoL tool (TMJ-S-QoL) that has not been previously used for TMJ surgery. The results suggest that TMJ discectomy with dermis-fat grafting appears to have a positive QoL effect in terms of
reducing pain levels and improving diet, chewing, mood, anxiety and general health in patients with Wilkes stage IV TMJ internal derangement.

6.5. SUMMARY & CONCLUSIONS

The aim of this study was to assess the quality of life outcomes of patients who had undergone Temporomandibular joint (TMJ) discectomy with dermis-fat grafting compared with a cohort of closely matched patients who had not had surgery. A cross-sectional study of 61 patients was undertaken. All patients completed a TMJ surgery specific Quality of life (TMJ-S-QoL) questionnaire. They were divided into 2 groups according to whether they had undergone TMJ discectomy (post-surgical group N = 32) or no surgery (pre-surgical group N = 29). The two groups were closely matched for age, sex, clinical presentation and radiological diagnoses of Wilkes stage IV TMJ internal derangement. Post- TMJ surgery patients demonstrated statistically significant decrease in pain levels (p<0.05), diet and chewing (p<0.01), mood (p<0.01), anxiety (p<0.01) and general health (p<0.05) compared to the pre-surgical patients. However, there were no statistically significant differences between the pre- and post – TMJ surgery groups as far as speech, level of activity, recreation and general well-being were concerned. The results of this study suggest that TMJ discectomy with dermis-fat grafting appears to have a positive quality of life effect in terms of reducing pain levels and improving diet, chewing, mood, anxiety and general health in patients with Wilkes stage IV TMJ internal derangement.
TMJ - Surgery
Quality of Life Questionnaire
(TMJ-S-QoL)

A. PAIN?
1. I have no pain
2. There is mild pain but I do not need medication
3. I have moderate pain which requires regular analgesics eg: Paracetamol
4. I have severe pain controlled only by strong analgesics eg: Panadeine forte
5. I have severe pain which is not controlled by analgesics.

B. DIET & CHEWING?
1. I can chew and eat whatever I like
2. I can chew most things except tough foods like steak and apples
3. I only stick to soft foods such as pasta and soft bread
4. I need to cut up all food into small pieces
5. I can only eat food that has been put through the blender

C. SPEECH?
1. My speech is normal
2. I have difficulty in saying some words
3. I have difficulty in being understood over the telephone
4. Only my friends and family can understand me
5. I cannot be understood at all

D. ACTIVITY?
1. I am as active as I have ever been
2. There are times where I can't keep up my old pace, but not often
3. I am often tired and have slowed down my activities though I still get out
4. I don't go out very often because I don't have the strength
5. I am usually in bed or chair and don't leave home

E. RECREATION
1. There are no limitations to recreation at home or away from home
2. There are a few things I can't do but I still get out and enjoy life
3. There are many times where I wish I could get out more, but I am not up to it
4. There are severe limitations to what I can do, mostly I stay at home and watch TV
5. I can't do anything enjoyable.

F. MOOD?
1. My mood is excellent and unaffected by my TMJ disorder
2. My mood is generally good and only occasionally affected my TMJ disorder
3. I am neither in a good mood nor depressed about my TMJ disorder
4. I am somewhat depressed about my TMJ disorder
5. I am extremely depressed about my TMJ disorder

G. ANXIETY?
1. I am not anxious about my TMJ disorder
2. I am a little anxious about my TMJ disorder but I am coping
3. I am very anxious about my TMJ disorder and finding it difficult coping
4. I am severely anxious about my TMJ disorder and not coping at all
H. Which issues have been upper most in your mind during the past month? (circle up to 3 answers)
   a. Nothing
   b. Pain
   c. Diet & Chewing
   d. Speech
   e. Activity levels
   f. Recreation
   g. Mood
   h. Anxiety

I. Compared to the month before you had your TMJ surgery, how would you rate your overall health-related quality of life? (Post-surgical patients only)
   1. Much better
   2. Somewhat better
   3. About the same
   4. Somewhat worse
   5. Much worse

J. In general, would you say your health-related quality of life during the past month has been:
   1. Excellent
   2. Very Good
   3. Good
   4. Fair
   5. Poor

K. Considering everything in your life that contributes to your personal well-being such as family, friends, spirituality and personal leisure activities, please rate your overall quality of life over the past month:
   1. Excellent
   2. Very Good
   3. Good
   4. Fair
   5. Poor

L. If a relative or friend had experienced TMJ problems very similar to what you had, would you: (post-surgery group only)
   1. Recommend TMJ surgery as the primary treatment
   2. Recommend TMJ surgery only if other measures such as physiotherapy and splint therapy and medications fail.
   3. Recommend TMJ surgery only as a very last resort
   4. Do not recommend TMJ surgery at all.

Figure 6.1: The TMJ Surgery specific quality of life (TMJ-S-QoL) questionnaire was adapted from the modified University of Washington Quality of Life Questionnaire (UW-QoL-R; Weymuller et al 2001) and used in this study. The responses were graded 1 to 5 with 1 rated as excellent and 5 as poor (see question K) for all questions apart from question H where patients were given a choice of upto 3 responses.
Table 6.1: Patients were divided into 2 groups according to whether they had undergone TMJ surgery (post-surgery) or were awaiting TMJ surgery (pre-surgery).
The Student t-test and Chi-square were used to analyse statistically significant differences between the pre- and post-surgical groups according to the various parameters. P value < 0.05 was taken as significant.

<table>
<thead>
<tr>
<th></th>
<th>PRE-SURGERY</th>
<th>POST-SURGERY</th>
<th>DIFFERENCES</th>
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<tr>
<td>Pain score</td>
<td>3.35 ± 0.94</td>
<td>1.50 ± 0.76</td>
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<tr>
<td>Diet / Chewing</td>
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<td>1.47 ± 0.72</td>
<td>P &lt; 0.01</td>
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<td>1.09 ± 0.39</td>
<td>NSSD</td>
</tr>
<tr>
<td>Activity</td>
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<td>1.25 ± 0.57</td>
<td>NSSD</td>
</tr>
<tr>
<td>Recreation</td>
<td>1.90 ± 0.98</td>
<td>1.19 ± 0.40</td>
<td>NSSD</td>
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<tr>
<td>Mood</td>
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<td>1.25 ± 0.62</td>
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<tr>
<td>Anxiety</td>
<td>2.03 ± 0.50</td>
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<tr>
<td>General Health</td>
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<tr>
<td>Well being</td>
<td>2.55 ± 1.09</td>
<td>1.66 ± 0.83</td>
<td>NSSD</td>
</tr>
</tbody>
</table>

NSSD – No statistically significant difference

**MEAN SCORES**
1 = Excellent, 2 = Good, 3 = Average, 4 = Poor, 5 = Very poor
See original questionnaire (Figure 1) for details of each level

**Table 6.2:** Mean values and statistical significant differences between the 2 groups according to whether they had undergone TMJ surgery (post-surgery) or were awaiting TMJ surgery (pre-surgery).
Compared to their condition prior to surgery, the post-surgical group reported that following their TMJ surgery;

- 91% (29) felt much better
- 3% (1) felt somewhat better
- 3% (1) felt about the same
- 3% (1) felt somewhat worse

*Table 6.3: Subjective outcomes of the post-surgical group (N = 32) who were asked how they felt following their TMJ surgery*
As a result of their experiences leading up to, and following their TMJ surgery, the post-surgical group indicated that their advice to others who find themselves in the similar circumstances;

- 53% (17) would recommend TMJ surgery only after splint, medication and physiotherapy fail
- 44% (14) would recommend TMJ surgery as a first option
- 3% (1) would recommend TMJ surgery only as last resort
- 0% (0) would not recommend surgery

Table 6.4: Recommendations of the post-surgical group (N = 32) who were asked to advise what course of treatment they would recommend to others who find themselves in a similar predicament
Figure 6.2: Magnetic resonance image of a TMJ in the rest position showing severe non-reducing disc displacement with a largely intact condyle that was one of the essential criteria used for inclusion of patients in this study.
Figure 6.3: Graph showing parameters with statistically significant differences (p<0.05) between pre- and post- TMJ surgery
**Figure 6.4**: Graph showing parameters which showed no statistically significant differences between pre- and post-TMJ surgery patients.
Figure 6.5: Graph showing the percentage (%) of patients from each group who were concerned about issues before surgery (blue) and following TMJ surgery (red). While all patients (100%) in the pre-surgical group reported issues that concerned them, 59% of patients in the post-surgical group reported no issues of concern (ie. nothing).
CHAPTER 7

THE RADIOLOGICAL FATE OF DERMI-FAT GRAFTS IN THE HUMAN TEMPOROMANDIBULAR JOINT USING MAGNETIC RESONANCE IMAGING

7.1. INTRODUCTION:

Discectomy has been used as a surgical treatment modality for severe internal derangement of the temporomandibular joint (TMJ) for many years with good outcomes (Dimitroulis, 2005c; Ericksson & Westesson, 1992; Holmlund, Gynther & Axelsson, 1993). Unfortunately, discectomy results in significant regressive remodelling of the mandibular condyle (Agerberg & Lundberg, 1971; Hansson, Ericksson & Westesson, 1992). Attempts to help reduce the regressive remodelling of the mandibular condyle following discectomy have been made with the use of interpositional grafts (Dimitroulis, 2005a). Unfortunately, the use of interpositional materials following discectomy has met with little success with alloplastic and various autogenous grafts failing to live up to expectations (Appendix 5). The dermis-fat graft has previously been reported for use as an interpositional material following gap arthroplasty in the management of TMJ ankylosis (Dimitroulis, 2004). The candidate has been using the dermis-fat graft as interpositional material following discectomy for severe TMJ internal derangement since 2000. While the clinical outcomes appear favourable for the use of this material in the TMJ (Dimitroulis, 2004), the fate of the dermis-fat graft within a functional joint space has never been published. The purpose of this study is to investigate the radiological fate of the dermis-fat graft within the TMJ using magnetic resonance imaging (MRI).

7.2. PATIENTS & METHODS:

The patients recruited for this study were randomly selected from a larger pool of patients who were similarly treated by the same clinician (i.e., candidate) for severe TMJ internal
derangement that was unresponsive to conservative measures (Wilkes stage IV – Appendix 1). Those who were first to respond to their written invitation to participate in the study were chosen until all 15 positions (i.e., 5 in each time group) were filled. The mean age of 45 years in this study was closely representative of a larger sample of 100 similar patients treated by the candidate with TMJ discectomy and dermis-fat interpositional grafting. The presence of only 1 male out of 15 patients was, however, unusually low for TMJ disorders even though females do out number males by relatively high ratios of up to 9:1 (Dimitroulis, 1998; Dworkin, LeResche & Von Korff, 1990).

Fifteen patients who had dermis-fat grafts placed in their TMJ following discectomy were recruited for this study. All patients had initially presented with severely deformed articular discs that resulted in persistent and intolerable pain and dysfunction of the TMJ, despite at least 6 months of conservative TMJ therapy involving occlusal splints, medication and physiotherapy. Each patient had undergone TMJ discectomy with immediate dermis-fat graft placement within the resultant joint space prior to their MRI. The dermis-fat graft was procured from the lower abdomen through an elliptical incision which was closed primarily. The covering epidermis was removed freehand by sharp dissection with a No.15 scalpel blade and discarded. The dermis-fat graft was trimmed placed into the joint cavity to fill the whole space and the surrounding capsule sutured to hold the graft in place (Dimitroulis, 2004; Dimitroulis, 2005a).

The 15 patients were divided into 3 groups of 5 patients according to the time lapse between the TMJ surgery and the MRI investigation; 0-6 months: 5 patients, 7-23 months: 5 patients and 2 or more years: 5 patients. All 15 patients who participated in the study were asymptomatic with good joint function at the time of the MRI investigation. As there were no clinical indications for scanning asymptomatic patients, ethical approval to conduct this clinical trial was obtained from the Human Ethics Committee at St.Vincent’s Hospital Melbourne. Written consent from each patient was obtained using a 6 page document that clearly outlined the risks and benefits of this clinical study. All patients underwent a standard safety screening process to identify any contraindications, such as the presence of cardiac pacemakers, before their MRI examination.
All patients were scanned on a 1.5T Avanto (Siemens Medical, Erlangen Germany) MR system using the standard 12 channel head coil. Patients were positioned comfortably and asked to keep their mouth closed for all but the last sequence, at which time a bite block was used to keep their mouths open as wide as comfortably possible.

After appropriate localisers to identify the TMJ, the following sequences were acquired;

(1) closed mouth
   (a) sagittal T1 & proton density (PD) turbo spin echo (TSE)
   (b) axial T2 & T1 TSE
   (c) coronal T1 & PD fat saturated TSE

(2) open mouth
   a) sagittal T1, PD and fat saturated TSE

The axial and coronal sequences were orthogonal to the body axis and centred on the TMJ’s. The sagittal sequences were positioned perpendicular to the head of the mandibular condyle and parallel to the ramus. The total examination time was under 30 minutes and all patients tolerated the examination well. The MR images obtained were examined and reported by an experienced specialist musculo-skeletal MRI radiologist. The closed mouth images were evaluated on the following criteria:

1. signal on T1, T2 and PD which confirmed the presence of fat as a bright signal in all sequences, as compared to muscle or scar which appears grey on all sequences and fluid which appears black on T1, white on T2 and grey on PD.

2. the radiological joint space was determined as the 120 degrees arc extending from the midbody of the condylar head to the glenoid fossa in the coronal (fig.7.1) and sagittal (fig.7.2) planes.

3. nature of the tissue within the joint space as determined by the T1 signal characteristics and measured by pixel signal intensity (i.e. grey scale; 0 = pure black & 1024 = pure white) of the interpositional tissue was classified on the T1 weighted image as;
   Grade 1 – almost equal to subcutaneous fat tissue (grey scale >900)
   Grade 2 – heterogenous or speckled compared with subcutaneous fat tissue (grey scale 300 – 900)
   Grade 3 – grey suggesting change to tissue other than fat eg., scar (grey scale < 300)
4. volume of the fat graft (mm$^3$) where the signal intensity on T1 exhibited a grey scale reading of >900, surrounding the condylar head as calculated from the maximum diameters in the 3 orthogonal planes, i.e., coronal, sagittal and axial planes

7.3. RESULTS:

There were 17 joints scanned in 15 patients; 9 left side TMJ and 8 right TMJ. Only one male made up the study group with 14 females who ranged in age from 21 yr to 59 yr. The mean age was 44.9 ± 12.5 yr. The untreated joints in the unilateral cases were also scanned and found to be normal in all cases.

The radiological presence of fat (i.e., grey scale intensity > 900) was found in close proximity to all 17 operated joints (100%) that were scanned with MRI and were lateral and posterior to the mandibular condyle. The presence of dermis, however, could not be discerned as a grey scale reading based on the resolution (i.e., 0.438mm pixel size) of the MR images obtained. While fat graft (i.e., grey scale intensity >900) was identified adjacent to the mandibular condyle in all cases (100%), fat within the experimentally defined joint space (figs 7.1 & 7.2) was seen in 5 of the 17 joints (29.4%) of which only 3 joints (18%) demonstrated fat surrounding the entire articular surface of the mandibular condyle (Grade 1). (fig.7.3) (Table 7.1). In the remainder of the joints (12/17 joints – 70.6%), the interpositional material found in the radiologically defined joint space exhibited grey scale intensities of <300 (Grade 3), suggesting a radiological tissue appearance of fibrous scar tissue.

The average size (volume) of the fat grafts (i.e., high intensity grey scales >900) measured (fig.7.5) in and around each joint was 3.10 ± 1.46 cm$^3$. There was no statistically significant difference in size of the fat grafts between each of the time periods i.e., 0-6 months, 3.70 cm$^3$ ± 1.17cm$^3$; 7-23 months, 3.18 cm$^3$ ± 1.22 cm$^3$; 2 or more years, 2.54 cm$^3$ ± 1.87 cm$^3$.

The integrity of the mandibular condyles was not recorded in this study as MR imaging of the condyle is difficult to interpret, which is better evaluated with tomograms or CT- conebeam scans. Condylar integrity is the subject of another study which is part of this THESIS (Chapter 8).
7.4. DISCUSSION:

The rationale for using dermis-fat as an interpositional graft following TMJ discectomy is three-fold (Dimitroulis, 2004). Firstly, the donor site in the lower abdomen provides ample tissue to fill the dead space left within the joint cavity following disc removal. Secondly, the dermis-fat acts as a simple space-filler for the joint cavity so as to prevent direct contact between the condylar head and glenoid fossa. And finally, the attached dermis helps to keep the fat intact to prevent fragmentation as it is carefully trimmed before placing into the joint cavity as one piece. There is no pretension that the dermis-fat will ever develop into a disc substitute since the main purpose of the graft is to completely obliterate the dead space within the joint cavity. No special effort was made to orientate the dermal surface in any particular direction within the joint cavity or to secure it to the adjacent tissues.

MRI has been used as an investigative tool in previous studies of the TMJ (Hansson, Ericksson & Westesson, 1992), however, this is the first time it has been used to assess interpositional grafts following discectomy in the TMJ. MRI studies in other parts of the body where free fat had been grafted have yielded varying results. Kanamori and co-workers (Kanamori, Kawaguchi, Ohmori et al, 2001a) assessed 22 patients who had undergone autogenous free fat grafts after posterior lumbar surgery to prevent epidural and perineural fibrosis. They found, using MRI, the grafted fat reduced in size to about 33% of the original size after 1 year. While the signal intensity of the grafted fat was lower than of normal subcutaneous fat tissue in the first 6 weeks following surgery, the intensity had recovered to normal status by 1 year after surgery (Kanamori, Kawaguchi, Ohmori et al, 2001a). Ultimately, the MRI showed the presence of grafted fat, which was confirmed histologically by the same researchers in a subsequent paper (Kanamori, Kawaguchi, Ohmori et al, 2001b).

The use of fat grafts to obliterate the frontal sinus has also been reported. An MRI study (Weber, Draf, Keeri et al, 2002) of 51 cases showed a significant decrease of fat present within the frontal sinus with time. The majority of cases (53%) depicted less than 20% fat present within the obliterated frontal sinus with a median half-life of 15.4 months (Weber, Draf, Keeri et al, 2002). This suggests that fat grafts implanted into bony cavities are less likely to survive.
compared with fat grafts implanted into tissue beds surrounded by connective tissue other than bone. The present study found no statistically significant difference in the mean size of the fat signals (i.e. grey scale >900) between the three time intervals assessed on T1 images (fig.7.5). In other words, the average size of the fat signals was found to be almost the same regardless of whether it was implanted less than 6 months ago as compared to those grafts that were placed more than 2 years previously. As this was a retrospective study, with no accurate record of the exact volume of fat graft originally placed into the TMJ, it was impossible to determine if, and by how much, the fat grafts had reduced in size with time. Apart form the pre-operative MRI scans, a further major limitation of this study was that each patient only had a single post-operative MRI scan which eliminated the possibility of longitudinal assessment of each graft with time (fig.7.3 & 7.4).

This study could not determine the origin and composition of the grey tissue (grey scale intensity <300, Grade 3) within the joint space of the 12 joints (70%) (see Chapter 9). The fat signal (grey scale intensity >900), in and around the TMJ, however, was easily highlighted by the T1 images (figs.7.3 & 7.4). Unfortunately, the presence of dermis could not be demonstrated based on the current MRI resolution (i.e., 0.438mm pixel size) available. The most remarkable finding of this study was the presence of the fat signal (grey scale intensity >900) that was visible adjacent to all the condyles. It was remarkable because the fat that was transplanted to the TMJ was not vascularized and yet the fat signal, which suggests the presence of viable fat, was found in all cases without exception, although mainly outside the joint space (Table 7.1). It appears the fate of transplanted fat may be linked to adipose precursor cells which are distributed widely in connective tissues throughout the adult body (Kawaguchi, Toriyama, Nicodemou-Lena et al, 1998). Adipose precursor cells in the surrounding connective tissue can proliferate and mature into fat cells depending on the micro-environment (Kawaguchi, Toriyama, Nicodemou-Lena et al, 1998). A study by Kawaguchi and co-workers (Kawaguchi, Toriyama, Nicodemou-Lena et al, 1998) showed that adipogenesis can be induced by subcutaneous injections of Matrigel (i.e., reconstituted basement membrane) in most parts of the body, thereby confirming the wide spread distribution of adipose precursor cells which are stimulated by the Matrigel to form fat. In another experiment by Kelly and co-workers (Kelly, Findlay, Knight et al, 2006), a murine chamber model, comprising an empty sealed space, containing a vascular pedicle was used to
assess the effect of fat grafts on inductive adipogenesis within Matrigel. The study found that when the chamber was sealed with no access to pre-existing adipose tissue there was neovascularisation but little or no adipogenesis. When a miniscule piece of non-vascularised fat was included in the sealed chamber, new fat formed and filled the space (Kelly, Findlay, Knight et al, 2006). Subsequent studies by this group (unpublished) showed that when the inserted fat graft was of allograft or xenograft origin, the new fat formed was host derived. That is, the graft was inductive to endogenous adipogenesis and not the source itself of the new graft. What these studies suggest is that the presence of transplanted fat grafts within a connective tissue environment stimulates endogenous precursor cells to proliferate and differentiate to form more adipose tissue. While the fate of the original grafted fat was unknown, perhaps the MRI study by Kanamori and co-workers (Kanamori, Kawaguchi, Ohmori et al, 2001a) may provide a clue. They showed that the fat signal intensity initially diminishes over the first 6 weeks then strengthens which may suggest the grafted fat tissue disappears and is gradually replaced by new adipose tissue which is laid down by the stimulated adipose precursor cells found in the connective tissues surrounding the TMJ. Furthermore, in their subsequent histological study of retrieved surgical specimens (Kanamori, Kawaguchi, Ohmori et al, 2001b), they found that the grafted fat used in the spine had reduced size and quality of the fat globules as compared to normal fat tissues.

In the present study 5 joints out of the 17 which were examined (29.4%) demonstrated evidence of fat within the actual joint space. For the purposes of this investigation, the radiological joint space was determined as the 120 degree arc that extended from the midbody of the condylar head to the glenoid fossa in the sagittal and coronal planes (figs.7.1 & 7.2). Using this radiological reference marker, 5 joints demonstrated fat signals within the actual joint cavity, most of which were found in the posterior part of the joint (fig.7.1) with some located mainly in the lateral aspect of the joint space (fig.7.2). Only 2 joints out of the 17 scanned showed fat tissue covering the entire condylar head and filling the entire joint space (fig. 7.3), while 12 joints had no radiological evidence of fat (grade 3) within the actual joint space. This would indicate that the articular forces imparted to the joint space may not be conducive to the survival of adipose tissue.
Where fat was not found, the interpositional material detected within the joint space was of a grey appearance with an isointensity similar to muscle on both T1 and T2 weighted images. The grey interpositional material was detected in 12 joints (70.6%) (Grade 3) and this could represent fibrotic scar or granulation tissue. However, the Chapter 9 study subsequently showed that the interpositional grey matter seen on MRI did actually contain mature adipose tissue which made up an average of 30.1% of the retrieved specimen on histological analysis which may well explain the grey appearance due to reduced adipose tissue present.

In conclusion, this MRI study found that a radiological fat signal was present in all joints regardless of the time lapse since surgery. This suggests that the fat graft itself may be replaced by adipogenesis (Chapter 5) from the surrounding connective tissue bed which may help explain the consistent finding of fat signals adjacent to all the condyles that were scanned with MRI. However, intermittent compressive forces within the actual joint space may act as a negative influence on growth and maintenance of fat tissue within the joint itself. A subsequent animal study undertaken after this study was published, which forms part of this THESIS (see Chapter 5), looks at the histological fate of the dermis-fat graft placed into a functional joint space.

7.5. SUMMARY & CONCLUSIONS

The dermis-fat graft has been previously reported for use as an interpositional material in TMJ ankylosis. It has also been used as an interpositional graft following discectomy for severe TMJ internal derangement by the candidate since 2000. The purpose of this study was to investigate the radiological fate of the dermis-fat graft within the TMJ using magnetic resonance imaging (MRI). Seventeen joints in 15 patients which had dermis-fat grafts placed in the TMJ following discectomy for severe internal derangement were recruited for this study. The 15 patients were divided into 3 groups of 5 patients according to the time lapse between the TMJ surgery and the MRI investigation, i.e., 0-6 months, 7-23 months and 2 or more years. The MR images obtained were examined and reported by a specialist musculo-skeletal MRI radiologist. The radiological presence of fat (grey scale intensity >900) was found either within the joint
(30%) or surrounding the condyle in all 17 operated joints (100%) that were scanned with MRI. The fat signal was mainly detected lateral and posterior to the mandibular condyle. The interpositional material found within the radiologically defined joint space was mainly of grey appearance (grey scale intensity <300, Grade 3) (12 joints - 70%), suggesting tissue change to other than fat i.e., scar or granulation tissue. Three joints (18%) had interpositional material entirely composed of fat signal (Grade 1), while 2 joints (12%) had heterogenous material composed of fat signal interspersed with grey tissue (grey scale intensity 300-900, Grade 2). There was no statistically significant difference in size of the fat grafts between each of the time intervals studied. This study found that fat signals were present in similar quantities surrounding all joints regardless of the time lapse since surgery. However, intermittent articular forces imparted on the joint may act as a negative influence on the growth and maintenance of fat tissue within the actual joint space itself.
<table>
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<tr>
<th>Patient</th>
<th>Sex</th>
<th>Age</th>
<th>Side</th>
<th>Age of fat graft</th>
<th>Mean Intensity of Grey Scale in joint space</th>
<th>Nature of interpositional material within joint space</th>
<th>Volume of fat graft present (cm$^3$)</th>
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<tbody>
<tr>
<td>1</td>
<td>F</td>
<td>21 yr</td>
<td>Right TMJ</td>
<td>0-6 mn</td>
<td>963 ± 46</td>
<td>Grade 1</td>
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<td>2</td>
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<td>55 yr</td>
<td>Right TMJ</td>
<td>0-6 mn</td>
<td>192 ± 68</td>
<td>Grade 3</td>
<td>4.20</td>
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<td>4</td>
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<td>F</td>
<td>57 yr</td>
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<td>7-24 mn</td>
<td>267 ± 53</td>
<td>Grade 3</td>
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<td>196 ± 39</td>
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<td>133 ± 29</td>
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<td>4.20</td>
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<tr>
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<td>7-24 mn</td>
<td>219 ± 38</td>
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<td>2.73</td>
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<td>11</td>
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<td>45 yr</td>
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<td>&gt;2 years</td>
<td>105 ± 22</td>
<td>Grade 3</td>
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<tr>
<td>12A</td>
<td>M</td>
<td>53 yr</td>
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<td>&gt;2 years</td>
<td>932 ± 51</td>
<td>Grade 1</td>
<td>2.10</td>
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<tr>
<td>12B</td>
<td>M</td>
<td>53 yr</td>
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<td>&gt;2 years</td>
<td>964 ± 36</td>
<td>Grade 1</td>
<td>5.97</td>
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<td>Left TMJ</td>
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<td>Grade 2</td>
<td>2.69</td>
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<td>14</td>
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<td>&gt;2 years</td>
<td>181 ± 37</td>
<td>Grade 3</td>
<td>2.70</td>
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<tr>
<td>15</td>
<td>F</td>
<td>45 yr</td>
<td>Left TMJ</td>
<td>&gt;2 years</td>
<td>162 ± 43</td>
<td>Grade 3</td>
<td>0.84</td>
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</table>

*The signal intensity of the fat graft was classified on the T1 weighted image as:*

*Grade 1 – almost equal to subcutaneous fat tissue (Grey intensity scale >900)*

*Grade 2 – heterogenous or speckled compared with subcutaneous fat tissue (Grey intensity scale 300-900)*

*Grade 3 – Grey suggesting change to tissue other than fat eg., scar (Grey intensity scale <300)*

**Table 7.1.** Tabled summary of the findings of the study.
Figure 7.1: A schematic diagram showing the position of the fat relative to the condyle in a sagittal section of the TMJ with the fat largely posterior to the condyle. Any graft tissue found within the 120 degree arc was considered as being within the radiological joint space.
Figure 7.2: A schematic diagram showing the position of the fat relative to the condyle in a coronal section of the TMJ with the fat largely lateral to the condyle. Any graft tissue found within the 120 degree arc was considered as being within the radiological joint space.
Figure 7.3: T1 sagittal MR image of the TMJ (closed mouth position) showing the presence of fat posterior and superior to the mandibular condyle in a patient who had a dermis-fat graft placed 4 years previously.
Figure 7.4: PD sagittal MR image of the TMJ (open mouth position) showing the presence of fat in the space vacated by the forward translation of the mandibular condyle in a patient who had a dermis-fat graft placed 3 months previously.
Figure 7.5: Histogram showing the mean volume (y-axis - cm³) of the fat (green) surrounding the condyles as measured on MRI between each of the time intervals. The vertical lines show the respective standard deviations. There was no statistically significant difference found (p>0.25) in the mean volume of fat between each of the time periods.
CHAPTER 8
CONDYLAR MORPHOLOGY FOLLOWING TEMPOROMANDIBULAR JOINT DISCECTOMY WITH INTERPOSITIONAL ABDOMINAL DERMIS-FAT GRAFT

8.1. INTRODUCTION

Discectomy of the temporomandibular joint has proven to be one of the most effective treatment modalities in the management of severe internal derangement that has failed to respond to lesser measures. The concern with discectomy is that the mandibular condyle undergoes significant remodelling and, or resorption. Infact, significant figures of the past such as Henny (Henny, 1969), Poswillo (Poswillo, 1974) and Toller (Toller, 1973) were all opposed to discectomy and highlighted the importance of an intact disc in preventing degeneration of the mandibular condyle, and that discectomy only resulted in temporary pain relief because the sensory fibres were cut. No evidence was cited for these claims. Carlsson and co-workers (Carlsson, Kopp, Lindstrom & Lundqvist, 1981) commented that due to the favourable results of discectomy, some of the radiographic findings in post-operative patients are best interpreted as functional remodelling rather than osteoarthritic changes.

In the last half century, numerous attempts have been made to replace the missing disc with alloplastic implants and autogenous grafts but with limited success (Appendix 5). The abdominal dermis-fat graft was first introduce to TMJ surgery by Dimitroulis (2004) who used it as an interpositional graft following gap arthroplasties for TMJ ankylosis. It has since been used as interpositional material following TMJ discectomy with good results (Dimitroulis, Trost & Morrison, 2008; Dimitroulis, McCullough & Morrison, 2010).

While it has been shown that the dermis-fat graft is found in significant quantities when grafted to the TMJ (Dimitroulis, Trost & Morrison, 2008; Chapter 5), the question remains as to whether the underlying condylar head is protected by the graft following discectomy. The purpose of this study is to look at the morphology of the condylar head following TMJ discectomy with abdominal dermis-fat grafts using the orthopantomogram (OPG) as the basis for investigation.
8.2. PATIENTS & METHODS

This retrospective study involved 28 patients (1 male) who had undergone TMJ discectomy with an interpositional abdominal dermis-fat graft for the management of severe internal derangement (Wilkes stage IV – Appendix 1) that failed to respond to preliminary measures ranging from occlusal splint therapy and medications to TMJ arthrocentesis and arthroscopy. The selection of the patients for inclusion in the study depended on the availability of one or more post-operative OPG x-rays that clearly showed both mandibular condyles. A total of 33 operated joints were examined including 5 cases of bilateral TMJ discectomy with dermis-fat grafts (Table 8.1, 8.2). The age range of the patients in this study was 15yr to 68 yr with an average age of 51.5 yr at the time of their TMJ surgery. The follow-up OPG x-rays were taken from 3 months to 6 yr following surgery with the mean follow-up period of 23 months (Table 8.1). Sixteen of the joints underwent additional surgical procedures to the condylar head ranging from debridement of the fibrocartilage surface to high condylar shaves where up to 3mm of the articular surface of the condyle was surgically removed. The remaining 17 joints had no condylar surgery and the pre-operative OPG x-rays showed no evidence of condylar pathology in this group (Table 8.3).

All OPG x-rays were taken with the same Siemens OPG machine at the magnification ratio of 1:1.1. The radiological status of the mandibular condyles following TMJ discectomy and dermis-fat grafting were measured using the 3-point condylar morphology scale (CMS) that was developed by Borstlap and co-workers (2004) for studying condylar changes following mandibular osteotomies and slightly modified for use in the present study.

The technical details of the CMS technique was described by Borstlap and co-workers (2004) but modified for the present study as follows; one tangent line is drawn to the posterior border of the ascending ramus (H) (fig. 8.1). Three further lines are then drawn at right angles to these tangent lines with one measuring the the most superior tip of the condylar head (a), the next line denoting the broadest part (b) of the condylar head, and the third line defining the most inferior contact of line H to the angle of the mandible (d) (fig. 8.1). The height of the posterior ramus (H) is taken from the intersection of line a to the intersection of line d. H1 denotes the
length of line H on the preoperative radiographs and H2 is the length of line H on the postoperative radiographs. Therefore, the change in ramus height is shown by the formula:

\[ H1 - H2 = z' \]

The 3-point CMS involves three grades of condylar integrity (fig. 8.1 & 8.2). A CMS score of zero (=0) represents a normal condylar appearance on OPG x-ray. It is further defined by a z’ value of 0mm and an x’ value of greater than 5mm (fig. 8.1) A CMS score of one (=1) represents condylar remodelling, depicted by minor morphological changes to the condyle. Remodelling was accepted as anything upto 3mm reduction in condylar height. It is further defined by the z’ value of 1-3mm and x’ value of 3-5mm (fig. 8.1). A CMS score of two (=2) depicts condylar resorption which was characterised by a significant alteration in condylar configuration and volume and decreased ramus height (i.e., \( H1 - H2 = z' \) is greater than 6% or greater than 3mm reduction of condylar height) (De Clerq, Neyt, Mommaerts, et al 1994; Habets, Bezuur, Van Oou, 1987; Habets, Bezuur, Naeiji, 1988). This is further defined by a z’ value of greater than 3mm and an x’ value of less than 3mm (fig. 8.1).

The condylar morphology was visually assessed and graded by the first author and an independent examiner. Changes between the preoperative H1 and postoperative H2 ramus height values gave the value of z’, and were measured against the postoperative x’ values, shown in Table 8.1, to give the CMS grade. Hence, the change in ramus height \( \Delta H \), was defined as; \( H1 - H2 = z' \), or simply the amount of condylar resorption between pre- and postoperative radiographs measured in millimetres. The interobserver coefficient proved to be within acceptable limits \( k = 0.92 \) (Cohen, 1960). A bivariate analysis of age and condylar surgery using chi-square statistical calculations were made on a Microsoft Excel spreadsheet (Microsoft Office 2007) with a p-value <0.05 considered significant.

8.3. Results

The results for each patient are listed in Table 8.1. All patients in the no condylar surgery group demonstrated radiologically normal condyles (CMS= 0) in their pre-operative OPG’s. In
the condylar surgery group, all 16 cases had radiological evidence of remodelling (CMS=1) on their pre-operative OPG’s (Table 8.3).

Using the CMS measure (fig. 8.1), 9 out of the 33 joints (27.3%) were found to be normal on postoperative OPG x-rays i.e., CMS = 0. Remodelling (i.e., CMS=1) was found in 14 joints (42.4%) following TMJ discectomy with dermis-fat graft and ten joints (30.3%) showed radiological evidence of resorption with a score of CMS = 2 (Table 8.2).

The average age of the no condylar surgery group was 37.2yr. In the cohort of 17 joints where the condyle was not surgically manipulated, normal condylar morphology (CMS=0) was found in all 17 joints (100%) on pre-operative OPG, whereas, no joints (0%) were found to be normal (CMS=0) on the pre-operative OPG in the group of 16 joints where surgery was undertaken on the condyle, but rather, all demonstrated remodelling (CMS=1). Remodelling (CMS=1) was found postoperatively in 3 joints (17.6%) where no condylar surgery was performed compared to 11 joints (68.8%) where condylar surgery was undertaken (p<0.05). Resorption (CMS=2) was measured in equal numbers of 5 joints in each group (p>0.05) regardless of whether condylar surgery was undertaken (31.2% - condylar surgery group) or not undertaken (29.4% - no condylar surgery group).

The average age of the condylar surgery group at the time of their surgery was 50.4 yr. Using the Chi-square statistical calculations for bivariate analysis of age and condylar surgery, there was a statistically significant age difference (p<0.001) between the two groups following surgery where remodelling (CMS = 1) and resorption (CMS = 2) were apparent. In other words, the group that had no condylar surgery were relatively young, with a mean age of 30.7yr for remodelling and 30.2yr for resorption, compared with the much older condylar surgery group that demonstrated remodelling (mean 48.1yr) and resorption (mean 55.6yr) (Table 8.3).

8.4. DISCUSSION

The adaptational changes of the mandibular condyle to altered joint loading has been observed in both animal experiments and clinical studies (Gazit, Ehrlich, Kohen et al., 1987; Mongini, 1990). Altered condylar position resulting directly from TMJ discectomy or indirectly
from orthognathic surgery or distraction osteogenesis, may result in changes to condylar contour or morphology either as remodelling or resorption that may be accompanied by clinical symptoms such as joint pain, joint sounds or limitation of jaw movement. Morphological changes to the condyle may also result from chronic disease such as rheumatoid arthritis, trauma, neoplasia and even orthodontic treatment alone. (Huang, Pogrel & Kaban, 1997).

The basis for assessing the radiological appearance of condylar morphology on OPG’s was first described by De Clerq and co-workers (1994) as well as Hoppenreus and co-workers (1998). This was subsequently adapted and modified by Borstlap and co-workers (2004) for studying condylar changes following mandibular osteotomies. The “Condylar Morphology Scale – CMS” as reported by Borstlap and co-workers (2004), was used as the basis for measuring radiological changes in the mandibular condyle following TMJ discectomy in the present study. The CMS fulfilled its purpose as a simple and effective means of measuring radiological changes in the mandibular condyle because of the precise and unambiguous definitions of remodelling and resorption provided by the authors of original paper that introduced the CMS to the literature (Borstlap, Stoelinga, Hoppenreij et al, 2004).

According to Borstlap and co-workers (2004), condylar remodelling is defined as a morphological change of the condyle without loss of ramus height i.e., minor bone resorption and/or apposition of the condyle. Condylar resorption is characterised by severe morphological changes with decreased condylar volume, decreased ramus height and the potential for occlusal changes. (Borstlap, Stoelinga, Hoppenreijs et al, 2004; Hoppenreijs, Freihofer, Stoelinga et al, 1998).

In the present study, 9 out of the 33 joints (27.3%) examined showed no radiological evidence of changes to the condyle (CMS=0) following TMJ discectomy with interpositional dermis-fat grafting. Essentially, the 9 patients with the radiological normal condyles had no surgical procedures undertaken to the condyle which were preserved and protected from surgical trauma during the discectomy procedures. On the other hand, all the joints where condylar surgery was performed demonstrated radiological evidence of either remodelling (68.8%) or resorption (31.2%). In other words, there were no radiologically normal condyles seen in the group where the condyle was surgically manipulated.
Condylar remodelling (CMS=1) was seen in 14 joints (42.4%) and was most prevalent in the group that involved condylar surgery (68.8%) compared to the group which did not involve condylar surgery (17.6%). Borstlap and co-workers (2004) stated that condylar remodelling may be considered as adaptive response of the condyle to the new position in the fossa following mandibular osteotomy but does not result in any occlusal changes. This may partly explain the remodelling seen in the 3 joints following discectomy and no condylar surgery, where the missing disc changes the position and dynamics of the condyle with respect to the fossa, but fails to explain why 9 joints showed no changes following discectomy. This suggests that perhaps the presence of the dermis-fat graft in a discless joint cavity may well compensate for the missing disc by providing a physical environment that minimises the change in condylar position with respect to the fossa. Direct surgical trauma to the condyle invariably leads to radiological changes, as shown in this study, which demonstrated that the changes were more likely to show up as remodelling (68.8%). Interestingly, the study clearly demonstrated that the surgically breached condyle cannot heal itself even in the presence of the dermis fat graft.

It is interesting to speculate whether, in the absence of the dermis-fat interpositional graft, more of the condyles would have progressed to resorption in the group where the condyles were surgically breached. The limitation of this study, however, fails to provide the answer because there was no comparable control group to compare relative outcomes between the current study group of patients who underwent TMJ discectomy with interpositional dermis-fat grafting and a control group where no interpositional graft was used.

Condylar resorption (CMS=2) was found in about one-third of the joints (10 out of 33 joints i.e., 30.3%), however, the most remarkable finding to arise from this study was that half the resorption cases (5 joints) were found in the group where no condylar surgery was performed. While it is easily understood why resorption would take place in patients who had undergone condylar surgery (31.2%), it was surprising to discover that an equal number of patients who had no condylar surgery (30.3%) also demonstrated radiological signs of condylar resorption (CMS=2). The results revealed that the condylar changes in the no condylar surgery group was found in the youngest patients with an average age of 30.7yr for remodelling and 30.2yr for
resorption, which was significantly younger (p<0.001) than the overall average age of 51.5yr for the entire study group. Similar cases of post-operative condylar resorption in young females were also found in studies on orthognathic surgery, particularly following mandibular osteotomies, resulting in relapse (Borstlap, Stoelinga, Hoppenreijs et al, 2004). Arnett and co-workers (1996) have speculated that condylar resorption in young females may be attributed to the modulation of biological response by oestrogen and prolactin (Arnett, Milam, Gottesman, 1996), which is provoked by the altered positional relationship of the condyle with respect to the fossa (Arnett & Tamborello, 1990). In the present study, TMJ discectomy in young adult females appears to result in significant morphological changes to the mandibular condyle even when the condyle itself is preserved and protected from surgical trauma. This experience is reflected in orthognathic surgery where the TMJ is not even surgically breached and yet severe condylar resorption is seen following mandibular osteotomies that change the occlusal dynamics and hence the functional loads in the joints (Hoppenreijs, Freihifer, Stoelinga et al, 1998). This study has identified a group of young adult female patients who exhibit unstable mandibular condyles that respond adversely to TMJ surgery that reflects the findings of studies that found a similar group of patients with equally adverse responses following indirect (i.e., mandibular osteotomies) surgical procedures (De Clercq, Neyt, Mommaerts et al, 1994; Borstlap, Stoelinga, Hoppenreijs et al, 2004; Hoppenreijs, Freihofer, Stoelinga et al, 1998). Further study is required to identify the factors involved in the development of condylar resorption following TMJ surgery and mandibular osteotomies.

Despite the lack of a comparable control group where no interpositional graft was used, the findings of this study suggest that the interpositional dermis-fat graft has a protective effect for the underlying mandibular condyle following TMJ discectomy in over half the joints (52.9%) where the condyle is not surgically manipulated. In cases where additional condylar surgery was undertaken, over two-thirds of the joints (68.8%) showed evidence of remodelling on post-operative OPG’s. This suggests that the dermis-fat graft may serve to prevent the operated condyle progressing from remodelling (CMS=1) to resorption (CMS=2) in about two-thirds of cases. About one-third of joints (30.3%) developed condylar resorption (CMS=2) following TMJ discectomy with interpositional dermis-fat grafting regardless of whether the condyle was preserved (29.4%) or surgically manipulated (31.5%). The interpositional dermis-fat graft,
therefore, failed to prevent significant condylar changes in about one-third of patients who underwent TMJ discectomy, with the youngest (mean 30.2yr) and the oldest patients (mean 55.6yr) most susceptible to condylar resorption.

8.5. SUMMARY & CONCLUSIONS

The purpose of this study was to look at the morphology of the condylar head following Temporomandibular joint (TMJ) discectomy with interpositional abdominal dermis-fat grafts using the orthopantomogram (OPG) as the basis for investigation.

This retrospective study involved 28 patients (1 male) who had undergone TMJ discectomy with an interpositional abdominal dermis-fat graft for the management of severe internal derangement. The age range of the patients was 15yr to 68 yr with an average age of 51.5 yr at the time of their TMJ surgery. A total of 33 operated joints were examined including 5 cases of bilateral TMJ discectomy with dermis-fat grafts. Sixteen joints underwent additional surgery to the condylar head, while the remaining 17 joints had no condylar surgery. The follow-up OPG x-rays were taken from 3 months up to 6 yr following surgery with the mean follow-up period of 23 months. The condyles of the operated joints were visually assessed on OPG and graded according to the Condylar Morphology Scales (CMS) where 0=normal, 1=remodelling and 2=resorption of the condylar head.

Using the CMS grading system, 9 out of the 33 joints (27.3%) were found to be normal i.e., CMS = 0. Remodelling (i.e., CMS=1) was found in 14 joints (42.4%) following TMJ discectomy with dermis-fat graft. Ten joints (30.3%) showed radiological evidence of resorption with a score of CMS = 2. No joints (0%) were found to be normal (CMS=0) in the group of 16 joints where the condyle was surgically manipulated. Remodelling (CMS=1) was found in 3 joints (17.6%) where no condylar surgery was performed compared to 11 joints (68.8%) where condylar surgery was undertaken. Resorption (CMS=2) was measured in equal numbers of 5 joints in each group regardless of whether condylar surgery was undertaken (31.2%) or not (29.4%).
The findings of this study suggest that the interpositional dermis-fat graft has a protective effect for the underlying mandibular condyle following TMJ discectomy in over half the joints (52.9%) where the condyle is not surgically manipulated. In cases where additional condylar surgery was undertaken, over two-thirds of the joints (68.8%) showed evidence of remodelling on post-operative OPG’s. The interpositional dermis-fat graft, however, failed to prevent significant condylar changes (i.e., CMS=2) in about one-third of patients who underwent TMJ discectomy, with youngest (mean 30.2yr) and oldest (mean 55.6yr) patients most susceptible to condylar resorption.
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<td>43</td>
<td>Left</td>
<td>No</td>
<td>&gt;2yr</td>
<td>57mm</td>
<td>57mm</td>
<td>6mm</td>
<td>0mm</td>
<td>0</td>
</tr>
<tr>
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<td>Right</td>
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<td>56mm</td>
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<td>27</td>
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<td>Left</td>
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<td>&gt;2yr</td>
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<td>57mm</td>
<td>4mm</td>
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<td>59mm</td>
<td>54mm</td>
<td>2mm</td>
<td>5mm</td>
<td>2</td>
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</tbody>
</table>

Table 8.1. Data of individual patients. Age is at the time of surgery. Identical patient number identifies that it is the same patient who has undergone bilateral TMJ surgery. All patients except No.3 were female. Side indicates TMJ. “No” denotes there was no condylar surgery performed and “Yes” signifies condylar surgery was performed. CMS is the condylar morphology scale (see fig.8.1) with its two components x’ and z’ which determine whether the condyle is Normal = 0 (x’>5mm, z’= 0), Remodelled = 1 (x’= 3-5mm, z’ = 1-3mm), or Resorbed = 2 (x’<3mm, z’>3mm). H1 are preoperative ramus heights and H2 are postoperative values. H1 - H2 = z’
### Condylar Morphology (N = 33 joints)

<table>
<thead>
<tr>
<th></th>
<th>Preoperative OPG</th>
<th>Postoperative OPG</th>
</tr>
</thead>
<tbody>
<tr>
<td>0. Normal Condyle</td>
<td>17 joints (51.5%)</td>
<td>9 joints (27.3%)</td>
</tr>
<tr>
<td>1. Remodelling</td>
<td>16 joints (48.5%)</td>
<td>14 joints (42.4%)</td>
</tr>
<tr>
<td>2. Resorption</td>
<td>0 joints</td>
<td>10 joints (30.3%)</td>
</tr>
</tbody>
</table>

**Table 8.2.** Results of the Orthopantomogram (OPG) x-rays showing the 3-point condylar morphology scales measured following TMJ discectomy and dermis-fat graft for each of the 33 operated joints before and after surgery.
No Condylar Surgery (N = 17 joints; mean age = 37.2yr ± 14.1yr)

<table>
<thead>
<tr>
<th></th>
<th>Preoperative OPG</th>
<th>Postoperative OPG</th>
<th>Mean Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>0. Normal Condyle</td>
<td>17 joints (100%)</td>
<td>9 joints (52.9%)</td>
<td>43.2yr ± 8.5yr</td>
</tr>
<tr>
<td>1. Remodelling</td>
<td>0 joints</td>
<td>3 joints (17.6%)</td>
<td>30.7yr ± 9.5yr</td>
</tr>
<tr>
<td>2. Resorption</td>
<td>0 joints</td>
<td>5 joints (29.4%)</td>
<td>30.2yr ± 20.7yr</td>
</tr>
</tbody>
</table>

Condylar Surgery (N = 16 joints; mean age = 50.4 yr ± 11.1yr)

<table>
<thead>
<tr>
<th></th>
<th>Preoperative OPG</th>
<th>Postoperative OPG</th>
<th>Mean Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>0. Normal Condyle</td>
<td>0 joints</td>
<td>0 joints</td>
<td>-</td>
</tr>
<tr>
<td>1. Remodelling</td>
<td>16 joints (100%)</td>
<td>11 joints (68.8%)</td>
<td>48.1yr ± 11.7yr</td>
</tr>
<tr>
<td>2. Resorption</td>
<td>0 joints</td>
<td>5 joints (31.2%)</td>
<td>55.6yr ± 8.5yr</td>
</tr>
</tbody>
</table>

**Table 8.3.** The 33 cases were further subdivided into joints which had additional condylar surgery and those joints that did not have condylar surgery.
Figure 8.1: The condylar morphology scale (CMS) modified after Borstlap et al, 2004. H = ramus height from point $a$ to point $d$; $a$ = most superior tip of condylar head, $b$ = broadest width of condylar head and $d$ = most inferior point where H meets the angle of the mandible. $x'$ = vertical distance between $a$ and $b$. The shaded area shows resorption of the condylar head defined as $z'$ that is calculated as the difference in ramus height, $\Delta H$, between the preoperative value $H1$, and the postoperative ramus height $H2$, so that $H1 - H2 = z'$. The CMS values are defined as follows; CMS 0 Normal $x'>5$mm, $z'=0$mm; CMS 1 Remodelling $x'=3-5$mm, $z'=1-3$mm; CMS 2 Resorption $x'<3$mm, $z'>3$mm. (Modified after Borstlap et al, 2004)
Figure 8.2 – Orthopantomograms showing examples of condylar morphology following TMJ discectomy with interpositional dermis-fat grafts. From left to right; the left picture shows a normal condyle (CMS = 0). Middle picture shows a condyle that exhibits radiological features of remodelling (CMS=1). The picture on the right shows condylar resorption with loss of condylar height (CMS=2).
Figure 8.3 – Orthopantomogram showing condylar remodelling on the left (CMS=1) following TMJ discectomy with interpositional dermis-fat grafting. This is compared to the normal unoperated condyle on the right.
CHAPTER 9

MACROSCOPIC AND HISTOLOGICAL ANALYSIS OF ABDOMINAL DERmis-FAT Grafts RETRIEVED FROM HUMAN TEMPOROMANDIBULAR JOINTS

9.1. INTRODUCTION

Abdominal dermis-fat grafts were first introduced to temporomandibular joint (TMJ) surgery in 2004 (Dimitroulis, 2004) for the management of joint ankylosis. Since 2000, the candidate has also used abdominal dermis-fat as interpositional grafts in the TMJ following discectomy. Animal, clinical and radiological studies, which form part of this thesis, have demonstrated positive outcomes with the use of dermis-fat grafts in TMJ surgery (Dimitroulis, Trost & Morrison, 2008; Dimitroulis, McCullough & Morrison, 2009; Chapter 5)

Over a 10 year period from 2000 to 2009, the clinical records of 8 patients were identified who had undergone a subsequent procedure to surgically retrieve implanted dermis-fat grafts from their TMJ’s. The purpose of this study is to examine the fate of the abdominal dermis-fat grafts that were implanted into human TMJ’s at the macroscopic and histological levels.

9.2. PATIENTS & METHODS

Clinical records from 123 patients who had TMJ discectomy with interpositional dermis-fat grafts, dating back to 2000, were examined and 8 patients were identified where dermis-fat grafts were retrieved from the TMJ. All patients were operated on by the candidate both at the original operation when the dermis-fat was implanted and subsequent operation where the dermis-fat was removed from the TMJ.

All 8 patients were females aged from 20yr to 63yr (mean = 45.8yr) at the time of the initial operation where the abdominal dermis-fat graft was implanted into the TMJ following
discectomy (Table 9.1). Six of the patients had the initial surgery undertaken for severe TMJ internal derangement (Wilkes grade IV- Appendix 1) that failed to respond to conservative measures, while 2 patients had the initial surgery undertaken for recurrent synovial chondromatosis. MRI’s and OPG’s were taken for all patients preoperatively to confirm the presence of Wilke’s stage V (Wilkes, 1989 – Appendix 1) articular disease that denotes advanced degenerative joint disease affecting the mandibular condyle. In all 8 cases, radiological signs of fat was seen surrounding the condyle, however, the intra-articular space showed only grey matter (Dimitroulis, Trost, Morrison, 2008) where the dermis-fat graft had been placed and no sign of disc that was removed in a previous operation. All patients suffered from intolerable symptoms of severe osteoarthritis (i.e., well localised joint pain, joint crepitus and reduced joint mobility – Wilke’s stage V) and returned for condylectomy with joint replacement either with autogenous costochondral rib graft or alloplastic joint (Biomet – Lorenz TMJ prosthesis). All cases were unilateral with 6 right and 2 left TMJ’s involved. Severe degenerative joint disease was histologically identified in all resected condylar specimens.

In each patient, the interpositional dermis-fat graft was carefully removed from the TMJ and photographed. All retrieved dermis-fat grafts were measured in 3 dimensions of length, breadth and thickness using a surgical grade ruler that was marked in millimetres. The measurements were taken on fresh specimens before being placed in fixative solution of formalin for transport to the histopathology laboratory. The specimens were processed in the histopathology laboratory and stained with hematoxylin and eosin and mounted on glass slides for examination under light microscopy. Three sections were prepared for each specimen 3mm apart, with the middle section taken at the centre of the specimen in the longitudinal direction. The ratio of fat tissue to non-fat tissue on each prepared histological slide was measured using the Virtual microscope.

**Virtual microscopy VM (quantitative) analysis:** The hematoxylin and eosin stained histological slides were digitally scanned using the ScanScope T3 virtual microscopy slide scanner (Aperio, Vista, CA) and ScanScope Console software v7.00.08.1020 provided the user interface. After all the slides were scanned, the digital images were analysed using ImageScope(r) software package. The fat was selected using the "pen tool" and the "positive pixel count" algorithm was
run on the selected tissue. The colour saturation threshold was calibrated for each group based on the intensity of the stain of the positive control slide, containing adipose tissue alone, in order to achieve uniformity in measuring the stain for all sections of that group. The same procedure was repeated for the (non-fat) fibrous and epithelial elements in order to determine the background stain. Number of positive pixels was then divided over the surface area to obtain the number of positive pixels per square millimetre for each slide. This value was then subtracted from that of the negative control slides, containing non-fat, fibrous and epithelial elements, to exclude background stain and provide a proportion of fat to non-fat ratio for each slide.

A single slide, taken from the middle of the specimen and bisecting this specimen longitudinally was used to derive the ratio of fat to non-fat tissue for each specimen. The ratio was calculated as follows;

\[
\frac{\text{Positive pixel count of fat}}{\text{Positive pixel count of non-fat}} \times 100 = RATIO(\%)
\]

### 9.3. RESULTS

Dermis-fat grafts were surgically retrieved from 8 joints out of 123 patients who underwent TMJ discectomy within interpositional dermis-fat grafting by the candidate between 2000 and 2009. The dermis-fat grafts were retrieved after a time ranging from 8 mn to 46 mn (mean = 22.3mn) following initial implantation into the TMJ (Table 9.1).

Thick rubbery tissue was found interposed between the condylar head and glenoid fossa in all joints (fig.9.1) with fat tissue clinically evident in all tissue specimens that were carefully excised from the joint cavity (fig. 9.2). There was no clear evidence of any joint space as the interpositional material was loosely adherent to all the articular surfaces. However, it was relatively easy to peel off the graft tissue from the articular surfaces of both the glenoid fossa and condylar head. The interpositional material retrieved from the joint was a rubbery consistency (fig. 9.3) and filled the entire joint cavity between the condylar head and glenoid fossa/articular eminence. When removed from the intra-articular space, the tissue remained firmly intact as a
single entity with clear borders that easily separated from the surrounding tissue bed (figs. 9.2., 9.3).

The average size of the retrieved grafts was 16mm (+3.2mm) x 14mm (+2.7mm) x 7mm (+1.9mm) with a mean volumetric dimension of 1.57cm$^3$ ± 0.38cm$^3$ (Table 9.1). This compares to the average size of the original dermis-fat grafts when first placed into the TMJ of 20mm (+4.1mm) x 15mm (+3.5mm) x 8mm(+2.3mm) with a mean volumetric dimension of 2.4cm$^3$ ± 0.5cm$^3$. Only tissue interposed between the condyle and glenoid fossa were removed (fig 9.1) and any other parts of the graft that was not within the joint space was left behind.

The interpositional tissue retrieved from all joints demonstrated histological evidence of mature adipose tissue surrounded by irregularly arranged collagen fibres with dermal elements such as sweat glands (fig. 9.4) and hair follicles. There was no evidence of dermal cysts or necrotic fat in any of the specimens examined. Using the data derived from the virtual microscope, the mean ratio of fat tissue to non-fat tissue was 31.3% ± 5.7% and was never more than 40% of the histological specimen (Table 9.1).

9.4. DISCUSSION

Abdominal dermis-fat grafts were initially used to fill gap arthroplasties following TMJ ankylosis release because of the large cavity that was surgically created. Because of the difficulty of securing the dermis graft within a discectomised joint space (Dimitroulis, 2004), it became apparent to the candidate that perhaps what was needed was not a disc replacement material but a material that actually fills up the entire joint space and eliminates the potential dead space. The dermis-fat graft has proved to be an excellent space filler for joint cavities as it can be easily sculptured and trimmed to fit any size or shape of joint cavity. Preliminary attempts to use fat grafts alone resulted in fragmentation of the fat tissue. However, when the fat was left attached to the dermis it became much easier to trim and surgically position within the joint cavity without fragmentation.
Unfortunately, dermis-fat grafts do not always protect the mandibular condyle from osteoarthritis (Chapter 8). This study identified that in 6.5% (8/123 cases) of patients who underwent TMJ discectomy with dermis-fat grafting over a 10 year period from 2000 to 2009, severe osteoarthritis developed with intolerable symptoms necessitating a second operation to resect the condyle and undertake a joint replacement. The second operation gave the author the unique opportunity to assess the status of the original dermis-fat graft that was placed in the joint between 8 to 46 months earlier. Interestingly, the dermis-fat graft was found to be firmly positioned and filled the entire joint cavity with no identifiable potential joint space (fig. 9.1). The graft permitted free movement of the condylar head while acting as a physical barrier preventing direct contact of the condyle with the glenoid fossa.

Since all patients were consented for joint replacement surgery, the consent also included the removal of all material within the joint space that would interfere with the placement of the joint prostheses. Upon removal of the graft it was clearly found to be vital and healthy with a soft rubbery texture which was elastic and compressible (fig. 9.2). As far as general physical properties were concerned, the grafted tissue was much more elastic and compressible than a native articular disc (fig. 9.3).

Subsequent histological examination of the dermis-fat grafts showed evidence of skin appendages such as sweat glands and inactive hair-follicles within the dermis component. Fat, however, was less abundant as when the grafts were first placed into the TMJ 8 to 46 months previously (Table 9.1), but there was adipose tissue scattered within all the excised interpositional specimens which made up no more than 40% of the total area of specimens examined (fig. 9.4). In a radiological study by Dimitroulis and co-workers (Dimitroulis, Trost & Morrison, 2008) they found MRI evidence of abundant fat deposits that were largely found beyond the confines of the joint cavity, with mainly grey matter interposed between the articular surfaces of the condyle and glenoid fossa. In the present study, the grafted material retrieved from the joint cavity demonstrated histological evidence of adipose tissue in all graft specimens, albeit in relatively small quantities (<40%) compared to the mean of 90.2% \pm 6.3% of fat that made up the original dermis-fat graft that was initially placed into the joint cavity. No attempt was made to retrieve extraneous soft tissue beyond the confines of the joint cavity which may explain why
an average volume of 1.57 cm$^3$ of graft material was retrieved compared to the original 2.4 cm$^3$ of dermis-fat graft that was placed in the original operation, and 3.1 cm$^3$ of fat identified surrounding the condyle in the MRI study by Dimitroulis and co-workers (Dimitroulis, Trost & Morrison, 2008). This study showed that the dermis-fat graft adapts to fill up the entire joint space with a marked reduction in the ratio of fat to fibrous/dermal tissue. Pre-operative MRI’s of all 8 cases showed evidence of fat tissue in the surrounding tissue bed favouring more adipose tissue growth and less fibrous tissue as found in the MRI study (Dimitroulis, Trost & Morrison, 2008) where most of the adipose tissue was found beyond the confines of the joint space.

There were no dermoid cysts found in any of the graft tissue specimens examined, which were found in the rabbit study in Chapter 5 of this THESIS when dermis-fat was grafted to the TMJ. It appears that while dermoid cysts may arise in the early phase, they rapidly disappear with time as the functional environment of the joint restricts the growth of any cyst and perhaps bursts them with the constant compressive load. Alternatively, the lack of epidermal tissue results in no cyst formation (Dimitroulis & Slavin, 2006).

This case series allowed a unique opportunity to observe the fate of the dermis-fat graft retrieved from functional TMJ’s between 8 and 46 months after initial placement into a discectomised joint cavity. The evidence derived from this study shows that abdominal dermis-fat grafts transplanted to the TMJ do thrive and adapt well to the confines of the joint cavity, allowing functional movement of the joint. However, this study also showed that 6.5% of patients who undergo TMJ discectomy with dermis-fat grafting fail within 4 years of the initial surgery and go on to have a total joint replacement.

9.4.1. Technique of attaching graft to condylar head

In a paper by Dimitroulis (2005a), he discussed the difficulties of attempting to suture the dermis graft to surrounding tissues in a discectomized joint cavity. The grafts were difficult to anchor and the few MRI follow-ups showed that the grafts had migrated either anteriorly or posteriorly to the condylar head with no radiological evidence of the graft being over the head where it was originally positioned. Others have secured the grafts, whether alloplastic or
autogenous, either to the glenoid fossa or directly to the condylar head by a suture that actually passes through the condylar head and over the interpositional material.

Unfortunately, there are no studies to date that have properly assessed the various techniques of anchoring interpositional graft materials in the TMJ joint space following discectomy. Only anecdotal discussions have been presented with no scientific evidence on how effective each of the anchorage techniques have been. The Mitec anchor implant which secures the articular disc to the back of the condyle, has only been used for existing discs and not with interpositional grafts (Mehra & Wolford, 2001).

The difficulty of securing interpositional grafts to the TMJ is compounded by the complex biomechanics of the TMJ which is discussed below.

9.4.2. TMJ Biomechanics and its effects on Interpositional grafts

The TMJ has complex functional movements that involve rotation, translation and lateral actions that place considerable demands on the articular disc. The broad range of joint movements is achieved by the rather complex ligamentous attachments of the disc to the condylar head as well as the glenoid fossa. This not only allows the disc to move together with the condylar head, but also permits subtle discrepancies so that the disc can independently adjust to the various forces (Tuitj, Koolstra, Lobbezoo & Naeije, 2010) that condylar movement imparts to the disc which is controlled by the proprioceptive fibres in the surrounding joint ligaments. The elastic bilaminar zone attached to the posterior margin of the disc (Paegle, Holmlund & Reinholt, 2002) allows for controlled elastic traction of the disc that limits extreme forward movements and aids in controlled posterior motion of the disc during mouth closure.

Unfortunately, apart from intra-articular pressure measurements (Nitzan, 1994) and few kinetic studies of disc function (Tuitj, Koolstra, Lobbezoo & Naeije, 2010), we still do not have enough knowledge about how to replicate the disc attachments on a biomechanical model that functions in vitro the same way it would function in vivo. This brings us to the immense difficulty in trying to not only devise a suitable interpositional material that has the same physical properties as a natural articular disc (Athanasiou, 2006), but also if such a disc is ever technologically possible, then how we could possibly anchor it to the TMJ so that it responds to the physiological demands of normal joint function such as chewing or talking.
The integrity of the bilaminar attachment to the disc is critical to the health and well-being of the joint. Stretching, tearing and perforations of the bilaminar disc attachment are responsible for TMJ internal derangement. Remarkably, little attention has been given to the bilaminar tissues (Paegle, Holmlund & Reinholt, 2002) as published studies have concentrated on the integrity and position of the disc with occasional reference to the bilaminar attachment (Katzberg, Tallents, 2005).

From a biomechanical perspective, the bilaminar attachment is crucial to the normal function of the articular disc. As far as interpositional grafts are concerned, if we cannot replicate the physical properties of the bilaminar attachment, then the normal functional movements of a native disc cannot be achieved with any type of interpositional material. In other words, the crude anchorage techniques now available are unlikely to restore normal physiological function to the TMJ regardless of the interpositional materials used. For these reasons, the dermis-fat graft has consistently been referred to in this THESIS as a space filler rather than a disc replacement material because it is not anchored to the surrounding joint structures when placed into the joint cavity. As a space filler, the fundamental purpose of the dermis-fat graft is to provide a soft tissue barrier to prevent direct contact between the opposing articular surfaces without necessarily replicating the natural biomechanical properties of a normal articular disc.

9.4.3. Retrieval of Dermis-Fat suggests success

This study (Chapter 9) showed that the dermis-fat graft implanted in the TMJ appears to survive as a thick rubbery material with significantly reduced fat tissue. Evidently, the graft has been naturally engineered as a response to the compressive loads of the joint cavity by increasing its fibrous tissue content at the expense of adipose tissue.

This finding suggests an adaptive response where the dermis-fat interpositional graft undergoes metaplasia that bestows favourable properties of an appropriate soft tissue buffer between the condyle and glenoid fossa and articular eminence. What both chapters 8 and 9 showed, however, is that the presence of a seemingly appropriate interpositional graft does not always protect the underlying condyle from degenerative changes. This suggests that the condyle may undergo degenerative changes that are largely intrinsic rather than as a response to external factors such as a displaced disc which has been previously shown by Dimitroulis (2005d). So
why were perfectly healthy interpositional dermis-fat grafts removed in the eight patients who were considered clinical failures and required total joint replacements?

9.4.4. Definition of Failure

In this study, clinical failure was defined as a combination of persistent, well localised, intolerable TMJ pain in conjunction with radiological signs of severe condylar degeneration of the operated joint. Surgery was not undertaken for those patients who exhibited only one of the two criteria for failure. In the absence of condylar degeneration, patients with diffuse chronic pain were referred to specialist Pain clinics for chronic pain management. Those with severe condylar degeneration, and without symptoms of pain ie. osteoarthrosis, were simply monitored with no further surgical intervention. Consequently, only those patients with osteoarthritis, suggesting an inflammatory condition of the condyle, were considered failures and returned to the operating room for retrieval of the dermis-fat grafts and condylar resection with total joint replacement (see below).

Chronic pain is a disabling disorder which normally requires counselling and pharmacotherapy and other conservative measures when no physical condition is identified as the cause of the pain. Temporomandibular disorders are notoriously difficult to properly diagnose which is reflected in the complex and confusing Research Diagnostic Criteria for Temporomandibular disorders (RDC-TMD) (Dworkin & LeResche, 1992) generally used by TMD researchers who have little appreciation of surgical disorders affecting the TMJ. Not surprisingly, the RDC-TMD emphasizes the psychological aspects of pain as being fundamental to the pathogenesis of TMD with joint internal derangement and osteoarthrosis/arthritis making up a very minor part of the classification (Sessle, 2010). As a surgeon, it is imperative that a physical cause for chronic pain is thoroughly explored and eliminated before the patient is referred for chronic pain management. For that reason, the diagnosis of osteoarthritis was pivotal in selecting those patients who would most benefit from a total joint replacement because of a physical rather than a psychological disorder.

Patients with a history of reactive arthritis, idiopathic condylar resorption and connective tissue autoimmune diseases, including rheumatoid arthritis, where excluded from the study. There is an important distinction between osteoarthritis, which is a degenerative disorder of articulating bone and cartilage, and osteoarthritis, which is a localised
inflammatory process that is often painful for the affected individual. Studies such as that by Gynther and co-workers (Gynther, Holmlund, Reinholt & Lindblad, 1997), have shown that while both rheumatoid arthritis and osteoarthritis exhibit similar tissue reactions, the inflammatory and degenerative changes seemed to develop faster in rheumatoid arthritis. Rheumatoid arthritis demonstrates radiological signs of destructive erosion of the joint surface while osteoarthritis is more likely to show osteophytes and subchondral destruction in the form of cystic cavities beneath the articular cartilage layer (Gynther, Tronje & Holmlund 1996).

Patients in this study who exhibited localised joint pain together with radiological signs of osteoarthritis were those that returned for total joint replacement on the pretence that the osteoarthritis was the source of the chronic pain that required surgical intervention to remove the diseased condyle.

Total joint replacements, whether autogenous or alloplastic, are not used to treat chronic pain but to replace missing tissue to prevent malocclusion and lower facial asymmetry when the mandibular condyle is resected. Unfortunately, the disasters of the past with respect to early TMJ prosthetic joint replacements are difficult to erase from the psyche of current TMJ specialists who experienced them (Driemel, Braun, Muller-Richter, Behr et al, 2009). Fortunately, advances in materials science and technology have made the use of alloplastic total joint replacements more reliable and predictable. If we look at the current success of our Orthopaedic colleagues, the future for TMJ total joint replacements holds great promise.

9.5. SUMMARY & CONCLUSIONS

The purpose of this study was to examine the fate of the abdominal dermis-fat grafts that were implanted into human TMJ’s at the macroscopic and histological levels. Clinical records of 123 patients who underwent TMJ discectomy with dermis-fat grafting over a 10 yr period (2000 – 2009) were reviewed and 8 patients were identified who had the dermis-fat graft surgical removed from their TMJ at a subsequent operation. The retrieved grafts were assessed at the macroscopic and histological levels for size, consistency and cellular composition. The dermis-fat grafts were retrieved after a time ranging from 8 mn to 46 mn (mean = 22.3mn) following initial implantation into the TMJ. The graft material was a rubbery consistency and filled the
entire joint space between the condylar head and glenoid fossa/articular eminence. The average size of the retrieved grafts was 16mm x 14mm x 7mm with a mean volumetric dimension of 1.57cm$^3$ ± 0.38cm$^3$. The interpositional tissue retrieved from all joints demonstrated clear histological evidence of mature adipose tissue interspersed with dermal elements such as sweat glands and hair follicles that were atrophied, although the ratio of fat to non-fat tissue was significantly (p<0.01) less (mean 31.3% ± 5.7%) than in the original graft (mean 90.2% ± 6.3%). There was no evidence of dermal cysts or necrotic fat in any of the specimens examined. This study showed that abdominal dermis-fat grafts transplanted to the TMJ do thrive and adapt well to the confines of the joint cavity, allowing functional movement of the joint. However, in this study, the dermis-fat graft failed to protect the condyle against further deterioration in 6.5% of cases which went on to have total joint replacements.
<table>
<thead>
<tr>
<th>Patient</th>
<th>Age at time of initial surgery (years)</th>
<th>Time elapsed when graft retrieved (months)</th>
<th>Side of operation</th>
<th>Reasons for Initial Operation</th>
<th>Size of graft retrieved from TMJ (cm³)</th>
<th>Ratio of fat tissue to non-fat tissue</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20 yr</td>
<td>19mn</td>
<td>Right TMJ</td>
<td>Internal Derangement</td>
<td>1.95cm³</td>
<td>32.3%</td>
</tr>
<tr>
<td>2</td>
<td>44yr</td>
<td>36mn</td>
<td>Left TMJ</td>
<td>Internal Derangement</td>
<td>1.19cm³</td>
<td>28.4%</td>
</tr>
<tr>
<td>3</td>
<td>45yr</td>
<td>15mn</td>
<td>Right TMJ</td>
<td>Recurrent Synovial Chondromatosis</td>
<td>1.65cm³</td>
<td>38.9%</td>
</tr>
<tr>
<td>4</td>
<td>63yr</td>
<td>24mn</td>
<td>Left TMJ</td>
<td>Recurrent Synovial Chondromatosis</td>
<td>0.96cm³</td>
<td>21.7%</td>
</tr>
<tr>
<td>5</td>
<td>25yr</td>
<td>8mn</td>
<td>Right TMJ</td>
<td>Internal Derangement</td>
<td>1.64cm³</td>
<td>34.6%</td>
</tr>
<tr>
<td>6</td>
<td>61yr</td>
<td>20mn</td>
<td>Right TMJ</td>
<td>Internal Derangement</td>
<td>2.01cm³</td>
<td>26.1%</td>
</tr>
<tr>
<td>7</td>
<td>59yr</td>
<td>10mn</td>
<td>Right TMJ</td>
<td>Internal Derangement</td>
<td>1.29cm³</td>
<td>31.3%</td>
</tr>
<tr>
<td>8</td>
<td>49yr</td>
<td>46mn</td>
<td>Right TMJ</td>
<td>Internal Derangement</td>
<td>1.87cm³</td>
<td>37.2%</td>
</tr>
</tbody>
</table>

Table 9.1. Summary of patients who had dermis-fat grafts surgically retrieved from the TMJ after a period of 8 to 46 months following initial TMJ discectomies with interpositional abdominal dermis-fat grafts.
Figure 9.1: Intra-operative photograph showing dermis-fat graft covering the condylar head two years after it was first implanted into the TMJ
Figure 9.2: Macroscopic view of dermis-fat graft specimen surgically removed from a TMJ 3 years after it was initially implanted into the joint cavity following TMJ disectomy. Note the mature yellow adipose tissue held tightly together by fibrous bands.
Figure 9.3: Side-on view of a dermis-fat graft specimen retrieved from a TMJ 15 months following implantation into the joint. Note the smooth surface texture that lay against the articular surface of the glenoid fossa. Some adipose tissue is evident on the left side of the specimen.
Figure 9.4: Photomicrograph of dermis-fat graft retrieved from the TMJ 8 months after it was first implanted into the joint cavity. Note the mature adipose tissue interspersed with numerous sweat ducts and other dermal elements. (Hematoxylin & Eosin x40)
CHAPTER 10

CONCLUSIONS AND FUTURE DIRECTIONS

The studies undertaken as part of this THESIS demonstrated that abdominal dermis-fat is a promising graft material that satisfies most, but not all of the criteria for an ideal interpositional graft following Temporomandibular joint (TMJ) disectomy. Chapters 6 and 7 provided evidence to support the long-term safety of the dermis-fat in the discless temporomandibular joint cavity. Chapters 2.3 and 5 showed that the presence of dermis-fat is an effective barrier to joint ankylosis as it prevents new bone formation. This was especially evident in the animal study (Chapter 5) where new condyles failed to regenerate in the presence of fat in the young adult rabbit. Chapters 5, 7 and 9 showed that abdominal dermis-fat does survive when transplanted to the TMJ although the rabbit model (Chapter 5) suggests that initial necrosis of the fat component of the graft is eventually replaced by neoadipogenesis.

While the average size of the dermis-fat graft initially placed in the joint cavity following disectomy was 2.4cm$^3$, the grafts that were subsequently retrieved in Chapter 9 measured an average 1.57cm$^3$. This would suggest in-vivo shrinkage of the graft by about one-third of the original volume that was placed. However, the MRI study in Chapter 7 demonstrated that the fat present surrounding the mandibular condyle was measured at 3.1cm$^3$ which was almost one-third (29%) larger than the original size of the dermis-fat graft that was initially placed into the joint. This would indicate that the graft had actually grown in-vivo which could only be explained by the process of neoadipogenesis that was suggested by the rabbit study in Chapter 5. The large discrepancy between the average sizes of the grafts found on MRI (i.e., 3.1cm$^3$) in Chapter 7 compared to the average size of the grafts that were surgically retrieved (1.57cm$^3$) in Chapter 9 may perhaps be explained by the possibility that only the graft material interposed within the joint space was excised and that a large component of the dermis-fat graft outside the functional joint cavity (about 50%) was left in-situ. If that is the case, then the results of Chapter 9 would help explain the composition of the “grey matter” found within the actual joint space on MRI in Chapter 7. Effectively, the grafts retrieved in Chapter 9 were the “grey matter” seen on MRI in
Chapter 7 which demonstrated extensive collagen fibres that were interspersed with islands of mature adipose tissue and remnants of dermal elements such as sweat glands and hair follicles as seen under light microscopy (fig 9.4). The ratio of fat to non-fat tissue in the retrieved specimens in Chapter 9 were no more than 40% of the total specimen which would explain the absence of a strong fat signal in the “grey matter” that was readily found interposed within the actual joint space on MRI in Chapter 7. The results of Chapter 9 indicate that the dermis-fat graft undergoes increased fibrotic changes over time in response to the functional demands of the joint environment in which it occupies. However, all the retrieved specimens demonstrated evidence of the basic fat and dermal elements, albeit in lesser quantities compared to the graft that was originally implanted.

While the discectomy procedure is largely responsible for the resolution of joint pain and dysfunction, chapter 6 showed the abdominal dermis-fat was a safe procedure and helps promote smooth, pain-free joint function. Finally, chapters 8 and 9 revealed that the dermis-fat graft is not always successful, as the dermis-fat fails to protect the condyle from further degeneration in one-third of cases and the ultimate fate of a joint replacement in 6.5% of cases. Despite some short-comings, we can safely reject the null hypothesis ($H_0$), since the evidence presented in this THESIS supports the safety and effectiveness of the dermis-fat graft as an interpositional material in the TMJ.

While the studies presented in this THESIS have been largely positive, there are still concerns that make the dermis-fat graft a less than ideal interpositional material for use in discectomized joint cavities. A major concern would be if the dermis-fat graft itself had contributed to the degeneration of the one in three condyles that was found in the radiological study in Chapter 8. Fortunately, other studies in this THESIS (Chapter 2.3, 6, 7) have provided supporting evidence for the long-term safety of the dermis-fat graft. Therefore, it is likely the degeneration of the mandibular condyles found in chapters 8 and 9 were triggered by unknown intrinsic reactions within the condyles and not related to the presence of the dermis-fat graft. Furthermore, the process of idiopathic condylar resorption, which occurs in joints of young females where the disc is present and intact, lends further weight to the idea that condylar degeneration may be linked to intrinsic factors.
A second concern with respect to the dermis-fat is the need to harvest the graft from a distant site which creates the problem of additional donor site morbidity. Even though the harvest technique is relatively simple and the donor site morbidity and potential risks are relatively small, there is still the need to focus on a material that eliminates the requirement for a second surgical procedure. What the dermis-fat graft has shown is that it is capable of not only thriving and adapting to the joint cavity, but is also effective in preventing joint ankylosis, promoting pain free, smooth joint function and, in two-thirds of cases, can prevent severe degeneration of the condyle following TMJ discectomy. Therefore, rather than engineering an exact replica of a TMJ disc which would be almost impossible to securely anchor in a functional joint space, perhaps there should be a concerted effort made to develop a graft material with properties that are very similar to abdominal dermis-fat i.e., a soft but firm material that handles easily and can be sculptured at the time of surgery to fit any volume and shape of joint space, and which adapts and responds to the demands of joint function without fragmentation or degeneration over time (Appendix 4). A material that resembles abdominal dermis-fat but developed or grown in the laboratory will mark the next major step in the on-going search for the ideal disc replacement material following TMJ discectomy.


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Appendix 2: *Criteria for Successful Outcome of TMJ Surgery as proposed by the Second International Consensus Meeting in April 1992 (Goss., 1993) and modified by Holmlund (1993).*

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**CRITERIA FOR SUCCESSFUL TMJ SURGERY**

I. Mild intermittent pain of no concern to patient

II. Range of motion greater than 35mm for vertical and 6mm for lateral & protrusive excursions

III. The ability for patient to enjoy regular diet, at worst avoiding tough, hard foods

IV. Stabilization of possible degenerate imaging changes

V. Absence of significant complications

VI. Absence of symptoms for at least 2 years.

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Appendix 3: Interpositional Materials used to replace the Articular Disc following Discectomy of the Temporomandibular Joint.

<table>
<thead>
<tr>
<th>GRAFT</th>
<th>EXAMPLES</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Replacement</td>
<td>-</td>
<td>Good results with up to 30 years follow up</td>
</tr>
<tr>
<td>Alloplastic</td>
<td>Sialastic</td>
<td>Foreign body giant cell</td>
</tr>
<tr>
<td>reaction</td>
<td>Teflon-proplast</td>
<td>Bone destruction</td>
</tr>
<tr>
<td></td>
<td>Methylmethacrylate</td>
<td>Chronic inflammation</td>
</tr>
<tr>
<td></td>
<td>Fossa prosthesis</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Metal/plastic</td>
<td></td>
</tr>
<tr>
<td>Allogeneic</td>
<td>Cartilage</td>
<td>Lyophilized, freeze-dried, cryopreserved. Risk of</td>
</tr>
<tr>
<td></td>
<td>Dura</td>
<td>Creutzfeldt-Jakob disease.</td>
</tr>
<tr>
<td>Xenograft</td>
<td>Collagen</td>
<td>Bovine source</td>
</tr>
<tr>
<td></td>
<td>Cartilage</td>
<td></td>
</tr>
<tr>
<td>Autogenous</td>
<td>Muscle</td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>e.g. Temporais</em></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fascia</td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>e.g. Temporais</em></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Pericranial</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Fascia lata</td>
<td></td>
</tr>
<tr>
<td>Cartilage</td>
<td></td>
<td>Surprising and fibrous ankylosis</td>
</tr>
<tr>
<td></td>
<td><em>e.g. Ear</em></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Rib</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Sternum</td>
<td></td>
</tr>
<tr>
<td>Skin</td>
<td></td>
<td>Epidermoid cyst formation</td>
</tr>
<tr>
<td></td>
<td><em>e.g. Full thickness</em></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Dermis</td>
<td></td>
</tr>
<tr>
<td>Fat</td>
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<td></td>
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<tr>
<td></td>
<td><em>e.g. Groin</em></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Buttocks</td>
<td></td>
</tr>
<tr>
<td>Combined</td>
<td><em>e.g. Muscle-fascia</em></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Dermis-fat</td>
<td></td>
</tr>
</tbody>
</table>
Appendix 4: Criteria for the Ideal Interpositional Material used to replace the Articular Disc following Discectomy of the Temporomandibular Joint.

Criteria for the Ideal TMJ Disc Replacement Material

Long term safety
- data >2 years available

Adequate bulk
- fills up the whole joint cavity

Good handling properties
- remains intact during transfer
- easy to sculpture during operation
- can be easily moulded to fit the entire joint space

Easy to procure
- simple & quick operation
- minimal morbidity

Abundantly available
- excess tissue available than what is required
- can be harvested from multiple sites

Survives the intra-joint environment
- able to adapt to the functional joint demands
- does not fragment or degenerate over time

Facilitates normal joint function
- reduces joint noises
- permits full range of joint motion
- allows pain free joint function

Prevents bone formation and joint ankylosis
- acts as an effective barrier to calcification
- eliminates heterotopic bone formation

Protects condyle from severe remodelling
- provides a buffer between the articular surfaces
- counteracts the process responsible for condylar degeneration
Appendix 5: Limitations of existing Interpositional Material used to replace the Articular Disc following Discectomy of the Temporomandibular Joint.

Limitations of Existing TMJ Disc Replacement Material

- Foreign body reactions (*sialastic, proplast/teflon*)
- Fragmentation & ankylosis (*ear cartilage*)
- Fragmentation & poor handling (*fat*)
- Epidermoid cyst formation (*full thickness skin*)
- Insufficient bulk (*fascia*)
- Difficult to anchor (*dermis*)
- Potential cross-infection & unpredictable resorption (*allogeneic grafts*)
- Fibrosis & trismus (*temporalis muscle*)
- Untested (*tissue engineering*)
Appendix 6 – Publications of Candidate on TMD in peer-reviewed Journals


Dimitroulis G. The prevalence of osteoarthrosis in cases of advanced internal derangement of the temporomandibular joint: a clinical, surgical and histological study Int J Oral Maxillofac Surg 2005d; 34: 345-9


Dimitroulis G & Slavin J. Histological evaluation of full thickness skin as an interpositional graft in the rabbit cranio-mandibular joint J Oral Maxillofac Surg 2006; 64:1075-80


