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Lag screw effect on the biomechanical torsion stability in the I.S.I. monocortical mandible angle system

by

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Submitted in partial fulfillment of the requirement for the degree:

MSc Odont in Oral Surgery

Department of Maxillo Facial and Oral Surgery
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Declaration

I, Hendrik Petrus Ehlers, declare that this research dissertation is my own work and has not been presented for any degree at another University:

Signed………………………………..

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Supervisor: Prof. F.J. Jacobs

Department: Maxillo-Facial and Oral Surgery

Qualification: MSc Odont in Oral Surgery

SUMMARY

In a recent *in vitro* biomechanical stability study by F.J. Jacobs, a unique, patented inclined screw insertion (I.S.I.) mandibular angle, intra-oral trauma-plate was evaluated for torsion and compression stability and compared to conventional plating of simulated angle fractures in polyurethane mandibular replicas.

This *in vitro* comparative pilot study is an extension of the above-mentioned study. Similar I.S.I. mini-plates with 45º inclined screw holes in quadrant 3 (Fig 1), were used but in the one sample 13mm-long lag screws were used to transect the fracture lines where in the other group non-lagging screws of similar length were used to fixate simulated mandibular angle fractures in polyurethane mandible replicas. A uniquely designed and manufactured jig, incorporated in a Zwick machine, was utilized to apply torsion forces within clinical relevant load values. The load-displacement values for torsion forces was determined and compared for the two groups. It was established that

lag screws significantly improved the torsion stability of the lag-plate group to that of the non-lag group.

During the stability testing, two factors were identified, which had a critical influence on the compression generated by the lag screw between the fracture fragments. An adequate amount of bone must be maintained between the first screw hole, directly distal to the fracture line, and the fracture line. All screws must be inserted in the correct sequence in order to insure sufficient compression between the fracture fragments as a result of the lag-effect.

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Die effek van `n grypskroef op die biomeganiese torsie stabiliteit in die I.S.I monokortikale kaak-hoek sisteem

deur

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Leier: Prof. F.J. Jacobs

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Kwalifikasie: MSc Odont in Mondchirurgie

OPSOMMING

In `n onlangse *in vitro* studie deur F.J. Jacobs, is `n gepatenteerde, unieke geanguleerde miniplate, waarvan die skroefgate geanguleer is, die sg. Inklineerde Skroef Inplasing (I.S.I.) kaak-hoek, intra-orale traumaplaat geevalueer vir torsie en kompressie stabiliteit en vergelyk met konvensionele plate op gesimuleerde kaakhoek frakture in poli-uretaan mandibular replikas.

In hierdie *in vitro* loodstudie, is I.S.I. miniplate met skroefgate wat teen 45º geanguleer is, gebruik in kombinasie met `n enkele 13mm lange grypskroef ("lag screw") om gesimuleerde kaakhoek frakture in poli-uretaan mandibula replikas te fikseer. Deur gebruik te maak van `n spesiaal ontwerpte en vervaardigde monterings-apparaat wat binne in `n Zwick masjien geïnkorporeer word, is die I.S.I gefikseerde replikas onderwerp aan torsie kragte, binne klinies relevante ladingswaardes. Die verplasings en

ladingswaardes is geregistreer en vergelyk met identiese I.S.I miniplate sonder `n grypskroef.

Die loodstudie resultate het getoon dat die frakture wat gefikseerd is met die I.S.I. miniplaat-grypskroef kombinasie betekenisvol beter stabiliteit toon as die frakture wat met slegs die miniplaat, sonder `n grypskroef, gefikseerd is vir klinies relevante ladings- en verplasingswaardes.

Tydens biomeganiese toetsing van die mandibula replikas, is twee faktore wat `n kardinale rol speel in die stabiliteit wat verkry word deur `n miniplaat grypskroef kombinasie te gebruik, geïdentifiseer. Voldoende hoeveelheid been tussen die eerste skroefgat, direk distaal van die fraktuurlyn, en die fraktuurlyn asook die korrekte volgorde waarin die skroewe geplaas word, moet gehandhaaf word om maksimale kompressie van die fragmente deur die grypskroef te verseker.

Deur `n I.S.I miniplaat, met geanguleerde skroefgate van 45º, te kombineer met `n grypskroef, kan die stabiliteit van die gefikseerde mandibulere kaakhoek betekenisvol verbeter word en verleen dit meer stabiliteit wanneer vergelyk word met frakture gereduseer met `n I.S.I miniplaat sonder grypskroef plasing.

Table of Contents

List of Figures, Tables and Graph……………….……………………………………12

CHAPTER 1: Introduction…………………………..……………………………14

CHAPTER 2: Aim ……………………………………………….……….………...17

CHAPTER 3: Literature Review …………………………………………………18

3.1 The application of a lag screw as a treatment modality for mandibular fractures ….……………………………………………………………….…18

3.1.1 Technical aspects of lag screw application……………………………………...18

3.1.2 Lag screw application in mandible fractures……………………...…………20

3.1.3 Advantages of lag screw application…………………………………………22

3.1.4 Disadvantages of lag screw application………………………………………...23

3.1.5 Contra-indications of lag screw application...…………………………………..23

3.1.6 Lag screw mini-plate combinations…………………………………..………24

3.1.7 Conclusion……………………………………………………………………....26

3.2 The application of mini-plates in the treatment of mandibular angle fractures……………………………………………………………………..…26

3.2.1 Unique properties of mandibular angle fractures……………………………….27

3.2.2 AO/ASIF (Arbeitsgemeinschaft für Osteosynthesefragen/ Association for the Study of Internal Fixation) guidelines for the treatment of mandibular angle fractures…………………………………………………..28

3.2.3 Champy technique……………………………..…………………………30

3.2.4 Compression vs. non-compression plates…………..……………………..31

3.2.5 Screw length…………………………………………..………………...31

3.2.6 Plate position………………………………………..………………..33

3.2.7 One plate vs. two plate treatment……………………………………….34

3.2.8 Conclusion……………………………………………………………...36

3.3 Applied biomechanics of the mandible…………………………………..….36

3.3.1 Biomechanical properties of a normal mandible………………………...37

3.3.2 The biomechanical behavior of a mandibular angle fracture…………………...38

3.3.2.1 Classification of movement of fracture segments………………………………38

3.3.2.2 The effect of bite (load) point on the movement of mandibular angle fracture segments………………………………………………………42

3.3.3 The effect of masticatory muscle function on the fracture segments of mandibular angle fractures……………………………………………….…43

3.3.4 The effect of dentition on a mandible fracture…….…………………….....43

3.3.5 Bite forces……………………………………………………………….44

3.3.6 Conclusion……………………………………………………………...45

3.4 The osteology of the mandibular angle and the inferior alveolar nerve: Anatomical considerations for the treatment of mandibular angle fractures ………………………………………………………..….46

3.4.1 Cortical thickness in the mandibular angle……………………………………..46

3.4.2 Thickness of the mandible…..………………………………………………..48

3.4.3 Course of the inferior alveolar canal……………………………………….....49

3.4.4 Conclusion……………………………………………………………...50

CHAPTER 4: Experimental Procedures…..…………………………………………...52

4.1 Experimental Design…...……………..…………………………………………..52

4.2 Equipment and Materials...…………..……………………………………………52

4.2.1 Biomechanical testing device…...…………………...…………………………52

4.2.2 Zwick testing machine………...……..…………………………………….....54

4.2.3 Polyurethane mandibles...…...…………………………………………………..54

4.2.4 Acrylic templates…………...…………………………………..………………55

4.2.4.1 Sectioning template………..……………………………………………….55

4.2.4.2 Mini-plate positioning template………..………………………………………..56

4.2.5 Drill guide……...…………………………………………………………….....57

4.2.6 Mini-plates and Screws…………...…………………………………………..57

4.2.7 Torque screwdriver………..……………………………………………….58

4.3 Experimental Technique……...……………………………………………….....58

4.3.1 Preparation of Samples…...…………………………………………………..58

4.3.2 Testing of samples…………….....……………………………………………59

4.3.3 Standardization of experiment………………………………………………..61

4.4 Data Evaluation………...……………………………………………………63

4.5 Alterations to original protocol methodology…...……………………………….63

CHAPTER 5: Results……………………………………………………………….65

5.1 The non-lag test samples ……………………………………………...………65

5.2 The lag test samples …..…………………………………………………………...67

5.3 Comparison results of lag group and non-lag group…………...…………………..69

CHAPTER 6: Discussion…………..………………………………………………72

6.1 Plate position…………………...……………………………………………..72

6.2 Screw length………………...…………………………………………………...73

6.3 Screw placement………………..…………………………………………75

6.4 Clinical relevance of the study…………………………...……………………...76

6.4.1 Polyurethane mandible replicas…………………………………………………76

6.4.2 Force application………………………………………………………………..77

6.4.3 Distance of the gap between fracture fragments………………………………..78

CHAPTER 7: Conclusion………………………………………………………..…80

CHAPTER 8: References……………………………………………………………..81

CURRICULUM VITAE………………………………………………………………89

List of Figures, Tables and Graphs

Figure 1: Screw quadrant angle orientation……….………………………………….16

Figure 2: Fracture of the cortical bone plate……………………………………….24

Figure 3: Lag screw with biconcave washer……………………………………….25

Figure 4: Champy’s ideal lines of osteosynthesis………………………………….29

Figure 5: Positive bending movements of mandibular fractures...……………………39

Figure 6: Negative bending movements of mandibular fractures…………………….39

Figure 7: Positive torsion movements of mandibular fractures…………………..….40

Figure 8: Negative Torsion movements of mandibular fractures……………………..40

Figure 9: Positive shear forces of mandibular fractures………………………………41

Figure 10: Negative shear forces of mandibular fractures……………………………41

Figure 11: Cross sections made to determine the cortical thickness of the mandible…………………………………………………………………47

Figure 12: Comparison of the mean thickness of the bucal cortical bone plate in different mandibular areas….……………………..…………………47

Figure 13: Comparison of the mean thickness of the lingual cortical bone plate in different mandibular are………………..…………………48

Figure 14: Biomechanical testing device…………………………...………………53

Figure 15: Zwick testing machine……………………………………………………..54

Figure 16: Polyurethane mandible replicas……………………………………………55

Figure 17: Mini-plate positioning template……………………………………………56

Figure 18: Pre-fabricated drill guide……………………………..………………57

Figure 19: I.S.I. mini-plate with 45° angled screw holes………………...……………57

Figure 20: Torque screwdriver……………………………………………...…………58

Figure 21: Biomechanical testing of samples……………………………………………60

Figure 22: Biomechanical testing device incorporated in the Zwick machine…..……61

Table 1: Load-displacement values for torsion in the non-lag group………………..65

Graph 1: Load-displacement in the non-lag group……………………………..……66

Table 2: Load-displacement values for torsion in the lag group……………………67

Graph 2: Load-displacement in the lag group………………………………………..68

Table 3: Mean load-displacement values for torsion in the lag and non-lag group….69

Graph 3: Mean load-displacement values for torsion in the lag and non-lag group….70

Table 4: P-values………………………………………………………………………71

Figure 23: Corical bone destruction…..…………………………………………..…72

Figure 24: Calculation of the required length of a lag screw…………………………74

Figure 25: Separation of the fracture fragments by the lag screw……………………..76

Chapter 1 Introduction

One of the great challenges in maxillo-facial and oral surgery is the treatment of mandibular angle fractures. The incidence of mandibular angle fractures varies between nine and 27% of all mandible fractures.[1-4] The high fracture tendency of the mandibular angle can be attributed to the presence of third molars, a thinner cross-sectional area and complex biomechanical force distribution in the area. The change in shape from horizontal to vertical also subjects the mandible to more complex forces.[5] Furthermore, fractures of the mandibular angle show a high incidence of postoperative complications.[6]

Various compression and non-compression fixation techniques have been developed in order to improve the stability of a treated mandibular angle fracture and to reduce the postoperative complications. One such compression technique is the insertion of a lag screw as a method of internal fixation of a mandibular angle fracture.[7]

One of the negative aspects of a lag screw used without a plate, as a treatment modality of mandibular angle fractures, is the high amount of compressive forces exerted by the head of the lag screw on the cortical bone plate, on tightening of the screw. These forces can cause micro fractures in the cortex and subsequent disintegration.[8,9] Studies have been conducted on lag screw washers and plates in order to overcome this problem.[8,9]

Another challenge in the open reduction and internal fixation of a mandibular angle fracture is the positioning and fixation of mini-plates. The fixation screws have to be inserted perpendicular to the mini-plate, demanding a transbuccal approach, increasing the risk of postoperative complications such as haematoma formation, increased operation time, scar formation and injury to the facial nerve.

Inclined screw insertion (I.S.I) plates, a new concept in mini-plate design, were recently developed for the treatment of mandibular angle fractures[10]. In a previous study I.S.I plates with screws inserted at 45°, 60° and 75° angles were tested for stability and compared. This study has been the only study up to date, which was conducted on I.S.I plates with plate hole angle orientation varying in quadrant orientation for the two segments of the plate (proximal segment in quadrant one and distal segment in quadrant three) describing quadrant insertion angles with plate placement in the tension line on the superior buccal aspect of the external oblique line [10]. This concept of inclined screw insertion and the screw angle orientation with regards to the plate-hole and plate, can be explained with the aid of the following sketch (Fig.1).

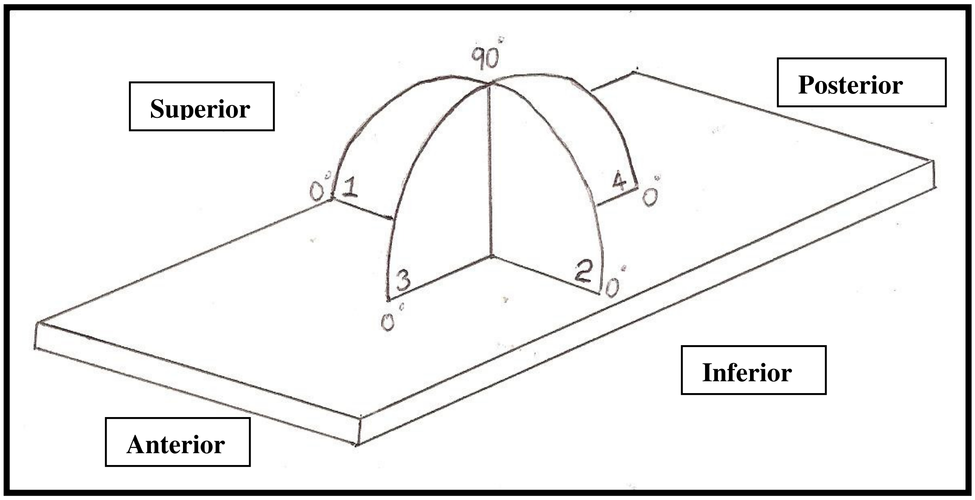


Figure 1: Screw quadrant angle orientation

The various angles of screw placement can be described with semi-circles at right angles to each other drawn over the plate-hole with the first semi-circle diagonal to the long axis of the mini-plate and plate-hole. A perpendicular line (representative of conventional screw insertion) will divide the semi-circle in quadrants 1 and 2. The second semi-circle is drawn perpendicular to the first semi circle (parallel to the long axis of the plate) and will divide the plate into quadrants 3 and 4 by the same perpendicular line representative of a 90° crew insertion. The angle 0° will be at the plate surface.

In the I.S.I plate, the screws inserted in the segment of the plate distal to the fracture line, are inserted in quadrant 3. The screws inserted in the plate segment proximal to the fracture line are inserted in quadrant 1.

The design of the I.S.I plates and the plate-hole and quadrant screw inclination simplifies mandibular angle fractures treatment via an intra-oral approach and creates lag screw potential without risk of cortical bone plate fractures during tightening of the lag screw.

The purpose of this *in vitro* pilot study was to combine lag screw application at 45º in mini-plate fixation and compare the biomechanical torsion stability with that of similar ISI (45º) plating without lagging.

Chapter 2 Aim

The aim of this comparative *in vitro* pilot study is to determine the significance of improvement in biomechanical torsion stability tendency when utilizing lag screws in I.S.I 45° plates in the treatment of mandibular angle fracture simulations. The insertion of a 13mm long screw in hole three of an I.S.I (45º) fixation plate converts it into a lag-plate which will create a compression effect, provided that prior to the insertion of the lag screw, at least one screw of 5mm length is inserted on each side of the fracture line. The biomechanical torsion stability of these I.S.I (45º) lag plates will be compared to I.S.I (45º) non-lagging plates. Although the sample size of this study is small it should demonstrate a tendency towards torsion stability improvement or no improvement. It is expected that lag screw implementation might indicate plate geometric changes to accommodate its insertion without fracture-line destruction. All possible variables are standardized in the comparative I.S.I pilot study with the only variable, the lag-screw implementation in the one test sample.

Chapter 3 Literature Review

3.1 Lag screw application as a treatment modality of mandibular fractures

The term lag screw refers to a technique as well as a type of screw.[11] The application of the lag screw refers to a technique where a screw is applied through the fracture line transecting both fracture fragments in order to achieve interfragmentary stability through compression.[12,13] However the screw thread engages only in the distal fracture fragment.[13]

A true lag screw only has threads on the portion of the screw, which will be inserted in the fracture fragment distal to the fracture line. Tightening of the screw will result in compression between the fracture fragments as these threads will engage the far cortex and the screw head will seat against the near cortex.[12]

The use of lag screws as a treatment modality for mandibular fractures was first described by Brons and colleagues in 1970.[14] In 1981 Niederdellman described a method of internal fixation of mandibular angle fractures using a single lag screw.[15]

3.1.1 Technical aspects of lag screw application

A correct point of entry in the bone and alignment of the drill is crucial and may lead to complications if executed incorrectly.[7] For mandibular angle fractures the ideal angle between the cortex and the path of screw insertion should be 10° to 20°.[7] For fractures of the anterior mandible the surgeon should strive towards inserting the screw perpendicular to the fractureline.[11]

A large screw gliding hole, with the same diameter as the external diameter of the screw, is drilled on the outer fracture segment.[12,13] A smaller hole, the compression hole, is drilled in the inner cortex with the same diameter as the internal diameter of the screw so that only the distal fragment is engaged by the screw thread.[12,13] A single screw is applied through the fracture and tightened in order to compress the fragments together. Without a gliding hole the two fragments will be transfixed, but not compressed.[13] The screw must not be torqued higher than 30 to 40N-cm. Torquing any higher may lead to fracturing of the fragments due to the wedging effect of the screw head or failure of the bone in which the gliding screw is drilled.[13]

A sufficient amount of bone should be present between the head of the screw and the fracture line as this bony ridge provides the support to the head of the screw. Destruction of this bony ridge will lead to insufficient support of the head of the lag screw and subsequent insufficient rigidity of the fracture.[7] The head of the lag screw must rest on cortical bone. Over tightening of the screw should be avoided as this might lead to micro-fractures in the cortical bone plate.[7] In order to ensure maximum stability, the lingual cortex of the proximal segment should be penetrated by the lag screw. [7]

A fracture of the anterior mandible undergoes shearing and torsional forces during function. One bone screw may not provide adequate stability and therefore a minimum of two lag screws is advocated.[11] In the case where an anterior mandible fracture is in combination with a condyle fracture, the surgeon should take care to avoid splaying of the mandible when the screws in the anterior mandible are tightened. This can be avoided by examining the lingual cortex after tightening of the lag screw.[16]

In the event of instability an additional screw or a mini-plate must be inserted in order to resist rotational forces along the long axis of the first screw. A countersink is utilized in order to allow flush adaptation of the screw head to the surface of the mandible.[12]

3.1.2 Lag screw application in mandible fractures

Lag screws can be used as an alternative for mini-plates and screws in the treatment of mandibular fractures, especially for fractures in the anterior mandible. However, due to the fact that they are inserted via an intra-oral approach and must be inserted at the correct angle, they have limited use in the mandible and can be too technically demanding for certain fractures in the posterior mandible.[12]

Factors limiting the use of a lag screw are fracture localization, fracture gap pattern, regional anatomy, type of fracture and the surgeon's experience in using lag screws.[13] A reliable intact cortical bone for anchoring is essential.[13]

Fractures of the anterior mandible are an ideal indication for a lag screw due to three factors. The curvature of the mandible allows placement of the lag screw across the symphysis. Secondly the thick cortices of the anterior mandible provide extremely good support and fixation of the lag screw. Thirdly, the absence of a neurovascular bundle and the accessibility of the fracture site make it an ideal situation where a lag screw can be used.[11, 13] However it can be used as treatment of certain angle fractures.[13] In clinical retrospective studies conducted, authors found the lag screw technique to be extremely successful in the treatment of fracture in the anterior mandible.[11,16]

The lag screw was commonly used in the past in the treatment of mandibular condyle fractures.[17] The screw is inserted inferior to the condyle, which makes the opening of the capsule unnecessary, thus permitting a less traumatic procedure.[12] Eckelt developed a lag screw for the reduction and fixation of condyle fractures.[18] An intra-oral lag screw method was also described by Kitayama.[19] Ziccardi and colleagues compare the biomechanical stability between condylar neck fractures treated with a four-hole mini-plate and similar fractures treated with a Wurzburg lag screw plate system. They found the Wurzburg lag screw plate system to provide more stability compared to a fracture treated with a miniplate.[20]

In mandibular angle fractures, if used with the right indications, solitary lag screws have been found to be a successful treatment option which can provide enough stability to withstand the functional loading of the mandible.[21-23] However a lag screw can only be applied when the fracture line runs from ventromedial to dorsolateral. This is the only situation in which an acceptable angle can be achieved between the fracture and the screw.[13] The use of this technique, in the angle of the mandible, requires more skill than any other area.[7]

Lag screws are less useful in the body of the mandible than elsewhere in the mandible. The reason is because the fractures in this area are not usually located in the sagittal plane as most fractures in this area occur without much obliquity.[24] In a clinical study conducted by Ellis he found that lag screw fixation of a mandibular body facture was a reliable and successful technique when there was sufficient obliquity of the fracture.[24] However, a second lag screw can seldom be placed due to the presence of the neurovascular bundle of the inferior alveolar nerve. It is therefore an area where a combination between a lag screw and plate should be used.[24]

3.1.3 Advantages of lag screw application

Because the time consuming task of adapting a mini-plate is eliminated, the technique can be applied more rapidly which will restrict long theatre procedures.[7,11,12,24] Lag screw placement is a low cost procedure and requires few instruments.[7,11,13] The material can be removed easily and the close approximation of fragments due to the large amount of compression generated can be achieved, which will lead to complete adaptation of the fracture surfaces.[12,13] Due to the compression generated, displacement of fracture segments seldom occurs whilst applying lag screw fixation. A lag screw also permits more rapid application of fixation without reduction in rigidity.[20,24]

The use of lags screws means that reduction of the fracture fragments is more anatomically accurate.[7] Less extensive degloving of the soft tissue is necessary as the technique does not require large incisions or dissections.[21] It has the ability to apply great amounts of compression between fragments which will promote bone healing and reduce the tendency towards lingual and alveolar gaps as often encountered with plates.[7,8]

3.1.4 Disadvantages of lag screw application

The compression forces which are generated on tightening of the screw can lead to high compression forces on the screw head which can cause the screw head to penetrate the cortical bone or cause the cortical bone plate to crack.[12] This problem can be overcome by combining the lag screw with a washer or mini-plate.

In the case of angle fractures the screw can only be applied through a transbuccal approach which could lead to scarring or facial nerve damage.[7] Although the technique requires few instruments, these instruments are technique-specific and cannot be used in other applications.[7] It is an extremely technique sensitive procedure with a high risk of burr fractures.[7,16]

3.1.5 Contra-indications of lag screw application

The application of a lag screw in the event of bone loss or in comminuted fractures will lead to displacement of the bone fragments, overriding of fracture segments and shortening of the fracture when compression is applied, which will lead to postoperative occlusal problems[7,12]

Where the continuity of the buccal cortex is disturbed, the cortex will not provide enough support for the screw head to ensure proper compression of the fragments.[7,11]

Anatomical structures should also be taken into consideration as the presence of the neurovascular bundle of the inferior alveolar nerve in the path where the screw will be inserted will increase the risk of nerve damage with the use of a lag screw.

3.1.6 Lag screw mini-plates combinations

When a mandible fracture is fixated by means of a lag screw, the head of the lag screw transmits the tensile forces to a small area in the cortical plate. This may cause the cortex to crack and cause the concave head of the screw to penetrate the cortical plate which will lead to loss of retention.[8,9] Countersinking of the screw will decrease the thickness of the supporting cortex which could increase the possibility of a fractured cortical plate. This will then lead to the screw head resting on cancellous bone which provides inadequate support to the screw head.[7,8,11]

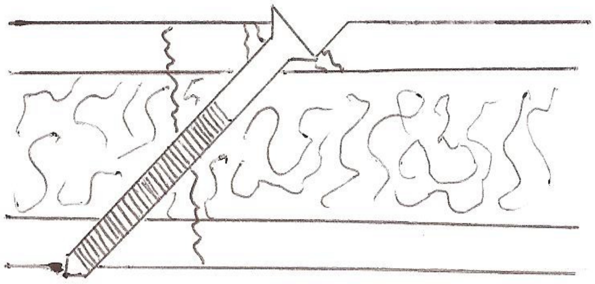


Figure 2: Cortical bone plate fracture

Various studies have been conducted in order to provide a washer or plate which will increase the supporting area to the screw head, prevent fracture of the cortical plate and remove the need for countersinking.[8,20]

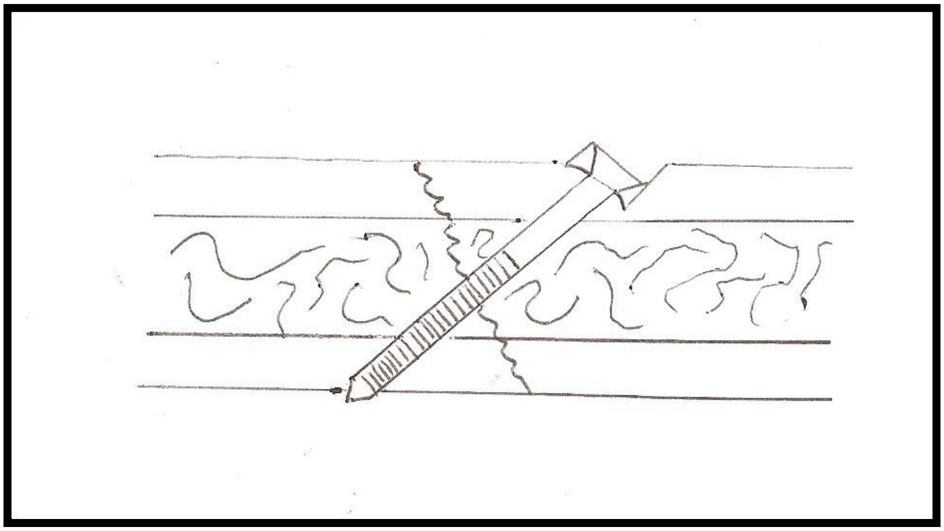


Figure 3: Lag screw with biconcave washer

Combining a lag screw with an angled hole mini-plate or washer eliminates localized crushing forces under the screw head and will transform it into pressure that is better tolerated.[9,12,20] Furthermore, more stability can be provided by combining a lag screw with a mini-plate across the fracture line. The additional screws inserted through the mini-plate will also prevent rotation.[24] A lag screw with a concave head placed perpendicular to the bone at a tensile force of 1000N will create pressure of 120MPa on the cortical plate. This is close to the maximum compressive force of cortical bone. If the screw is inserted at an angle to the cortical plate, only part of the head will be in contact with the cortex and will apply pressure of 240MPa on the cortical plate.[8] Terheyden and co-workers designed a self-adapting washer used in conjunction with a lag screw, which reduced the pressure applied by the lag screw head on the cortical bone to 27MPa. They also found that the stresses in the screw were reduced.[8] Lag screws combined with washers or mini-plates can be torqued to double the value of a solitary lag screw.[20]

In condylar neck fractures it has been proved that a lag screw in combination with a plate, for example the Wurzburg lag screw plate, provides more stability when compared to a fracture treated with a four hole mini-plate.[20]

3.1.7 Conclusion

Lag screws are seldom used in modern maxillofacial surgery as a treatment modality for mandibular fractures. Mini-plates and screws tend to be the more popular treatment modality. By combining a lag screw with an I.S.I mini-plate, the positive aspects of both modalities can be utilized.

3.2 Application of mini-plates in the treatment of mandibular angle fractures

The goal of rigid internal fixation as treatment of mandibular angle fractures is to provide immediate function and stability of the fracture fragments in order to promote bone healing with minimal postoperative complications. To achieve this, appropriate stability must be ensured by the method of treatment. This pursuit of stability gave rise to the treatment modality of internal fixation with plates and screws.

Open reduction with internal fixation using bone plates in the treatment of mandibular fractures was first described by Schede in 1888.[25] The plate and screw method has several advantages when compared to maxillomandibular fixation, such as early functioning of the mandible with reduction in atrophy of the masticatory muscles and temperomandibular joint dysfunction; improved oral hygiene; better nutritional intake; better communication as well as improved airway management due to a shortened state of mandibular immobilization.[26] Various principles, materials and plate designs have evolved over the years into the different plating techniques used by surgeons today.

3.2.1 Unique properties of mandibular angle fractures

The mandibular angle fracture has certain properties which will have an influence on the treatment options of a fracture in this region. It has a thin cross-section, when compared to areas on more anterior locations of the mandible, which provides less surface contact area to allow stabilization between the fragments.[27] The angle has less surgical accessibility when approached transorally.

Optimal stabilization by means of maxillomandibular fixation is more difficult due to the fact that most angle fractures are situated posterior to the molars, which will complicate stability in the event of an unstable fracture. The presence of third molars in the fracture line increases the risk of fractures in this area and may complicate treatment by hindering reduction, decrease the contact area between fragments; reduce vascularity and increase the risk of postoperative infection.[27]

Biomechanically the angle fracture has the highest bending and shear forces movements when compared to fractures in other regions of the mandible.[28] Furthermore the presence of teeth and the position of the inferior alveolar nerve provides a challenge to the surgeon when placing plates and screws in this area of the mandible.[29]

All these above-mentioned factors will influence the number of plates used as well as the position of these plates in the treatment of these fractures.

3.2.2 AO/ASIF (Arbeitsgemeinschaft für Osteosynthesefragen/ Association for the Study of Internal Fixation) guidelines for the treatment of mandibular angle fractures

AO/ASIF for decades recommended the use of a 6-hole mini-plate fixated with bicortical screws at the inferior border of the mandible combined with a 4-hole mini-plate inserted with monocortical screws just inferior of the roots of the teeth.[27] They propagated the use of rigid plates in order to prevent interfragmentary mobility.[5]

Historically the AO/ASIF principles were:[5]

1. Anatomic reduction
2. Rigid fixation
3. Atraumatic surgical technique
4. Immediate surgical function

There are certain challenges when using the AO technique. Surgical accessibility when using a transoral approach tends to be difficult. To overcome this problem a transbuccal approach has to be used, which is associated with certain problems such as damage to the marginal mandibular branch of the facial nerve, infections and scarring. Furthermore, the thin crossection of the bone at the inferior border of the mandible leads to less available surface area for fragment approximation.[27,30,31]

3.2.3 Champy technique

Champy and colleagues tested a method that was based on a modified version of the Michelet technique. Their technique consisted of monocortical juxta-alveolar and sub-apical osteosynthesis without compression and intermaxillary fixation in order to fixate and treat mandible fractures.[32]

Biomechanical studies by Champy and colleagues suggested that masticatory forces on the mandible created elongation strains at the alveolar border and compression strains along the lower border of the mandible. The transition between these two forces was identified as the "line of zero force" which was situated along the inferior alveolar nerve.[33]

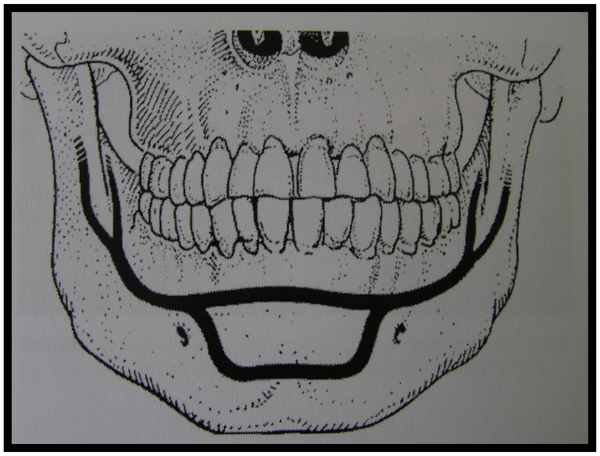


Figure 4: Champy's ideal lines of osteosynthesis

Studies on the photo elasticity of a model of araldite showed that a plate screwed at the lower border does not re-establish the stress distribution that existed before the section of the model, but when a plate is inserted at the upper border of the model, the stress distribution is nearly the same as inside the model. When this finding was applied to the mandible they found that the fixation of a fracture along the alveolar border is stronger than the fixation along the inferior border and will better re-establish the mechanical properties of the mandible.[32]

In view of their research, they suggested the ideal lines of osteosynthesis.[32]
In the case of angle fractures they suggested that the best site for plating is on the ventral side of the oblique ridge of the mandible, but a plate positioned lower on the lateral surface of the mandible at the dento-alveolar junction anterior to the canal of the inferior alveolar nerve will also be sufficient to withstand the strain created by masticatory muscles.[32] The masticatory forces will create a natural strain of compression along the lower border of the mandible, which will make the use of a compression plate in the area unnecessary.[32]

It must be stressed that the studies done by Champy were done on two-dimensional models and that a two-dimensional model does not illustrate the effect that forces on the contra-lateral side may have on the fracture.[29]

Advantages of the Champy technique[27]

- The surgeon uses a minimum amount of material to fixate the fracture.
- Monocortical screws pose lower risk of damage to the inferior alveolar nerve.
- The transoral approach can be used which will decrease the risk of scar formation and facial nerve injury. There is less soft tissue trauma and the technique is much quicker.

Limitations of the Champy technique[27]

- Reduction of an unfavourable fracture can be difficult via the transoral approach.
- Because monocortical mini-plates do not allow primary bone healing, this technique is not recommended in all types of fractures, especially in patients who cannot be followed up.

3.2.4 Compression vs. non-compression plates

In the 1950s compression plate techniques were first described in orthopedics.[34,35] These techniques made use of eccentrically placed screws in order to generate compression along the fracture line. This compression provides increased stabilization and allows primary bone healing.[36] Non-compression plates simply fix the two fragments without supplying any compression between the fragments.[36] In the 1970s Schmoker and co-workers developed compression plates for the treatment of mandibular fractures.[37]

In an *in vitro* study conducted by Shetty and colleagues, they compared different compressive systems to adaptive systems. They found that mandibular angle fractures fixed by compressive systems had much greater stability than those fixed with adaptive systems. The adaptive system permits more motion at the fracture site and cannot provide surety that the alignment of the fracture segments will be maintained. [38]

3.2.5 Screw length

Mini-plates used in the treatment of mandible fractures may be secured with screws that penetrate only one mandibular cortex (monocortical) or both cortical plates (bicortical).[36] In different studies, authors found bicortical screws to provide more stability and decrease the postoperative complications.[39-41]

Turgut and colleagues conducted a comparative *in vitro* study using sheep mandibles. The stability between mandibular angle fractures treated with a bicortical dual mini-plate; a single plate positioned at the upper border of the mandible fixed with monocortical screws; a reconstruction plate and a mandibular angle fracture treated with biplanar dual-mini-plate where the upper plate was fixed with monocortical screws and the lower plate with bicortical screws were compared. These authors described the bicortical dual mini-plate method as treatment where the lower plate as well as the proximal three holes of the upper plate were fixated by bicortical screws. They found that by applying bicortical screws rather than monocortical screws in the proximal three holes of the upper plate the stability of the treated fracture can be increased.[39]

In an *in vitro* study conducted by Haug and colleagues, the stability of mandibular angle fractures treated with different plating techniques were compared. No significant differences in the stability between the different groups were found and similar resistances to vertical forces were achieved in all the groups. However, all the failures that were observed in this study occurred in the plates fixated with monocortical screws. These authors postulated that the thickness of the plates made no difference in the resistance to vertical deformation but that monocortical screws appear to be the weak link in the system.[40]

In a different study by Haug and colleagues bovine ribs were used to determine the effect that screw number and length may have on the weight bearing ability of fractures treated with tension band plating. They found that increasing the number of screws per segment caused an increase in the weight resisted by the fracture up to three screws. More than three screws per segment did not lead to an increase in the weight bearing ability of the fracture. Furthermore these authors found that for a 2mm mini-dynamic compression plate an increase in screw length led to an increase in the weight bearing ability of the fracture. However, screw length did not play a role in the amount of weight resisted for a 2mm adaptation plate.[41]

3.2.6 Plate position

Mandible fracture plates can be positioned in one (monoplanar) or two dimensions (biplanar).[36] With the monoplanar placement of the plates, two plates are placed on the lateral surface of the mandibular angle. With biplanar placement of the plates, one plate is placed medial to the oblique ridge of the mandible and the other plate on the lateral surface of the mandible. Various studies have proved biplanar plating to be superior in stability to monplanar plate placement.[31,36,42]

Fedok and colleagues did an *in vitro* study on the effect of different plate positions as well as plating techniques on the stability of treated mandible fractures.[36] By making use of polystyrene mandibles they compared five different treatment techniques by testing their stability in an experimental jig. They compared samples with the following plate positions: monocortical/biplanar, bicortical/monoplanar, monocortical/monoplanar, bicortical/biplanar and a single plate positioned lingual to the oblique ridge. These authors found that the group with biplanar placement of the plates showed more stability than the groups treated with monoplanar placement. They stated that biplanar plate placement provides a three-dimensional framework that neutralizes superior distraction forces as well as torsional forces, which explained their observations. The group that showed the greatest stability was the group treated with bicortical/biplanar plate placement.[36] This study proved that plate position as well as plating technique is of great importance in the stability of a treated mandibular angle fracture.

These same results were obtained in two other separate *in vitro* studies where different plating techniques were compared. The biplanar plate placement was found to have more favorable biomechanical properties than monoplanar plate placement.[31,42]

Kroon and co-workers compared two different monoplanar plating techniques. They found that when a single plate is positioned ventral to the oblique line, the plate appears to be less resistant to bending forces. The plate positioned buccal to the oblique line is more resistant to vertical loading forces but still allows slight lateral movement.[29]

3.2.7 One plate vs. two plate treatment

Authors vary greatly in opinion on the number of plates that should be used when treating mandibular angle fractures. In various *in vitro* studies, models where the fractures were fixated by mini-plates positioned at the superior as well as the inferior border proved to be more stable than the models where the fractures were fixated by a single mini-plate positioned at the superior border.[29,30,39,43-45]

The results of clinical studies comparing complication rates are controversial. Schierle and co-workers found no significant difference in the complication rates when comparing single and two plate fixation of mandibular angle fractures.[43] However in a clinical study conducted by Ellis, different treatment methods for mandibular angle fractures were compared and it was found that two plate techniques have a higher complication rate than single plate techniques. This author found the rate of major complications to be inversely proportional to the rigidity of the fixation applied.[5] The contrasting *in vivo* study conducted by Levy and colleagues compared the complication rate of mandibular angle fractures treated with a single mini-plate and those treated with two mini-plates. Their results proved that two mini-plates were more effective in the treatment of mandibular angle fractures and associated with less postoperative complications.[46]

One should keep in mind that several authors who postulate the use of two mini-plates base their opinion on biomechanical *in vitro* studies.[29,30,39,43-45] The incidence of complications differs in a clinical scenario.[5,43,46] There are various reasons why results obtained in clinical studies differ. Treatment in one country differs from treatment in another, the etiology of the fractures differs and authors also differ in opinion on what constitutes a complication.[5] Another factor to take into consideration is the horizontal or vertical favourability of an angle fracture, which will determine whether a fracture will require placement of one or two mini-plates. The load bearing nature of a fracture will dictate the use of reconstruction plates. Fractures that require placement of two mini-plates or reconstruction plates are generally more unfavourable and more prone to postoperative complications.

Biomechanical factors are not the only aspects to be taken into account and there are many others to be considerred.[5] Scierle suggested that although a single mini-plate at the external oblique ridge gives excellent results, each case must be evaluated individually to evaluate if a second plate at the inferior border is indicated.[43]

The controversial results obtained in various studies indicate that there is no fixed rule for the use of one or two plates when treating mandibular angle fractures. The stability of a plating technique should be evaluated intraoperatively to determine whether one or two mini-plates are indicated. A second plate (bi-plating) is indicated in another plane (bi-planar) if the superior border plate renders insufficient stability of the fragments in a medio-lateral dimension (vertically unfavourable angle fractures).

3.2.8 Conclusion

The mandibular angle cannot only be seen as a region that is always in tension on the upper border and compression at the lower border, as this only applies to forces in a single specific plane. Forces in other directions could also lead to significant changes or movement and should be viewed in a three-dimensional model.[38] In a clinical situation the choice of plating method will depend on the requirements of the local situation, the surgeon's familiarity with the specific technique, the availability of instruments and material and the cost of the treatment as well as the specific outcome.[38]

3.3 Applied biomechanics of the mandible

Mandibular angle fractures are associated with the highest incidence of post-surgical complications of all mandible fracture types.[5,6] The biomechanics of the mandibular function play a significant role in the complication rate experienced in the treatment of mandibular angle fractures.[47] It also relates to the predilection of the mandibular angle for fractures.[48]

In order to successfully treat mandibular angle fractures one has to have proper knowledge of the forces applied to the mandible. The bite forces, as well as the forces exerted by the masticatory muscles on the fracture segments are of utmost importance when the treatment of the fracture is planned and will play an important role in the success of the treatment.

To determine the limits of mechanical properties for plate systems, the number and positioning of plates used when treating a mandible fracture as well as the magnitude and direction of the load across a fracture line have to be understood.[28] These loads will also play a significant role in the geometric design of mini-plates and the anatomical position placement in load sharing fracture treatment.[28,49]

3.3.1 Biomechanical properties of a normal mandible

The biomechanics of the mandible are determined by two factors: the forces exerted by the masticatory muscles and the direction of muscle pull. The bite force applied to the mandible is a result of the summation of the vectors of forces exerted by each masticatory muscle. These vectors summate to form a single force vector which acts perpendicular to the occlusal plane.[50] During normal masticatory function, tension occurs at the level of the dentition as well as compression along the inferior border of the mandible.[51] Biomechanically the angle can be considered as a lever which makes it more prone to fractures.[5]

3.3.2 The biomechanical behaviour of a mandibular angle fracture

Mandibular angle fractures are biomechanically complex due to disruption of the major stress-bearing areas of the mandible.[51]

Factors that play a role in the biomechanics of a mandible fracture are:

1. The site of fracture.[28,49,52]
2. The bite point position (load point).[28,49,52]
3. Bite forces.

Studies have been performed mainly on two dimensional models in the past.[53,54] However, more resent studies performed on three-dimensional models have given a much more complex and realistic understanding of the pattern of the biomechanical forces within the mandible.[28,52] The shape of the mandible and actions of the muscles and joints determine the biomechanical behaviour of the mandible.

3.3.2.1 Classification of the movement of fracture segments

Tams and co-workers classified the displacement of fracture fragments in a mandibular fracture, based on the load point on the occlusal surface, as follows:[28,49]

- Positive bending movement:

  Increased distance or tension between the fragments at the alveolar side accompanied by a simultaneous decreased tension or compression at the lower border of the mandible.[28 49]

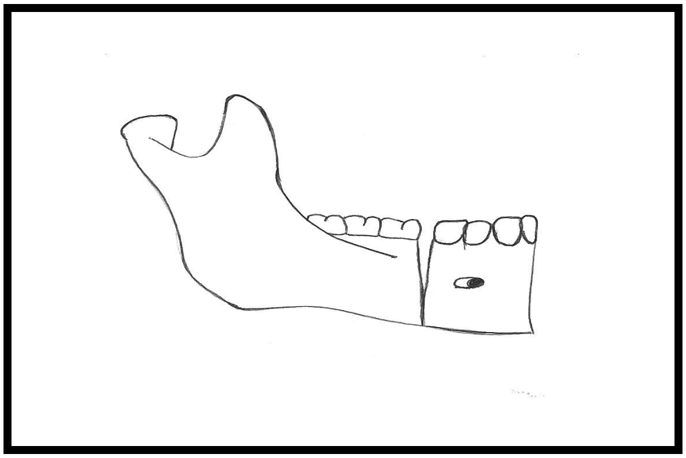


Figure 5: Positive bending movement of a mandibular fracture

- Negative bending movement:

  Decreased tension or compression at the alveolar side accompanied by a simultaneous increased distance or tension between the fragments at the lower border of the mandible.[28,49]

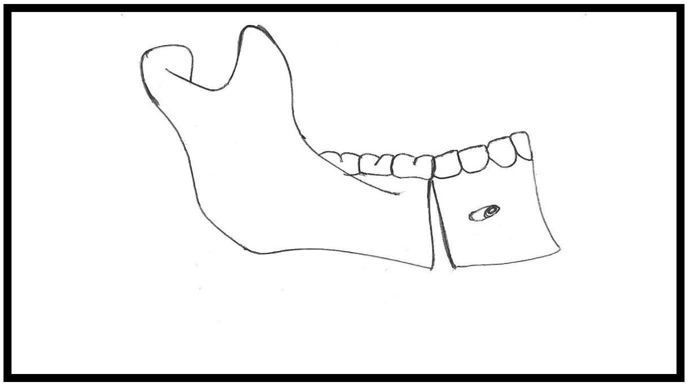


Figure 6: Negative bending movements of a mandibular fracture

- Positive torsion moment:

  Lingual displacement of the border of the proximal fragment with simultaneous buccal displacement of the border of the distal fragment.[28,49]

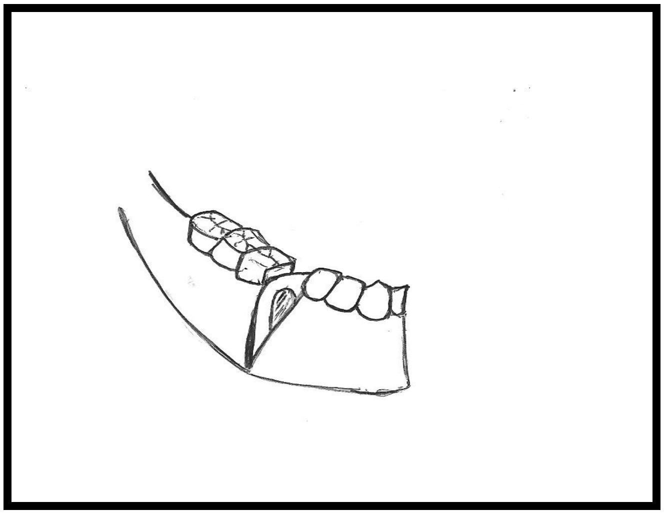


Figure 7: Positive torsion movement of a mandibular fracture

- Negative torsion moment:

  Buccal displacement of the border of the proximal fragment with simultaneous lingual displacement of the border of the distal fragment.[28,49]

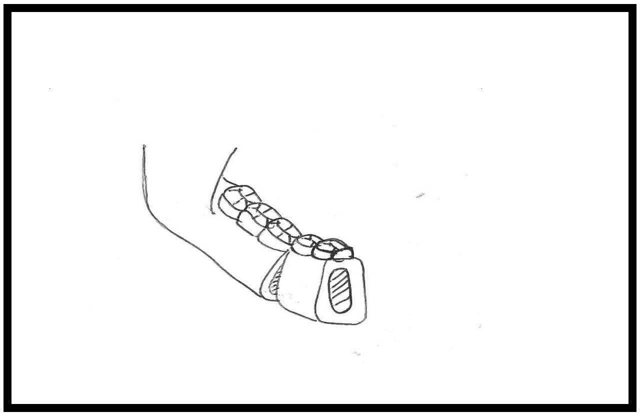


Figure 8: Negative torsion movement of a mandibular fracture

- Positive shear forces:

  Superior displacement of the distal fracture segment.[28]

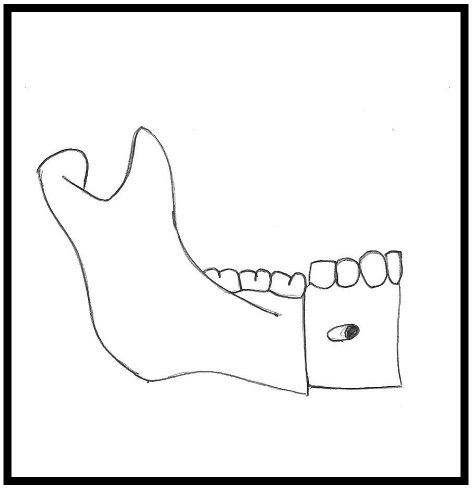


Figure 9: Positive shear forces of a mandibular fracture

- Negative shear forces:

  Superior displacement of the proximal fracture segment.[28]

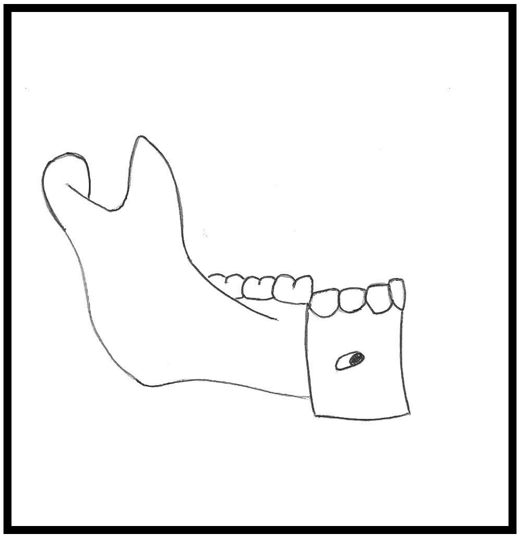


Figure 10: Negative shear forces of a mandibular fracture

3.3.2.2 The effect of bite forces and bite (load) point on the movement of mandibular angle fracture segments

Research was conducted by Tams and co-workers on resin mandibles in order to determine the biomechanics of different fracture sites.[28,49] They made two very important observations. The magnitude of the force applied to the mandible and the site where force is applied both play an important role in the movement of the fracture segments.[28,49]

When a fixed force is applied to angle fractures there are high positive bending movements with a maximum value when the bite point is on the canine of the non-fractured side. Bite points on the second and third molars on the fractured side are characterized by negative bending movements of the fracture with a maximum for the third molar. The positive bending movements are much higher than the negative bending movements. For fixed bite forces the angle fracture fragments have the highest positive bending movements and small torsion movement when compared to other types of mandible fractures. The angle has the highest shear forces of all types of mandible fractures with a maximum positive bending force on the angle which is 4 times higher than the maximum negative bending forces (negative bending movements are usually found for bite points close to the fracture line.)[28,49]

When simulated biting forces are being used, the angle fractures still have the highest positive bending movements when compared to fractures in other areas of the mandible.[49] The highest positive bending movement is observed when the bite point is on the first molar on the non-fractured side.[49]

Tams and co-workers classified mandible fractures into two groups according to their biomechanics:[28]

1. The anterior mandible, which consists of the anterior body and symphysis (area of the mandible anterior of the second molars). These fractures have high negative bending movements and high torsion movements.
2. The posterior mandible, which consists of the angle and posterior body (area of the mandible posterior to the second molar.) These fractures have high positive bending movements, small torsion movements and high shear forces.

3.3.3 The effect of the masticatory muscle function on the fracture segments of a mandibular angle fracture

Forces exerted by the elevator muscles of mastication tend to cause problems in a mandibular angle fracture. In a horizontally unfavourable fracture these muscles displace the distal segment superiorly. If the fracture is vertically unfavourable, these forces will also cause medial movements of the proximal fracture segments.[55]

3.3.4 The effect of dentition on a mandibular fracture

Occlusal relationship has both a protective and a negative effect on a treated mandibular fracture. In the case of a full dentition with an adequate occlusal relationship, bite forces will be evenly distributed in the dentition, which can prevent displacements of the fixated fracture segments. However, a full dentition can also cause the patient to exert higher bite forces during mastication, which can have a negative effect on the prognosis of the treatment. Crunching and clenching during sleep or when lifting heavy objects contribute to unacceptable loading risks on a treated mandibular fracture as well as insufficient compliance by the patient.[56]

3.3.5 Bite forces

The forces exerted on a treated mandibular fracture originate from the action of the masticatory muscles during mastication. The bite force applied to the mandible is a result of the summation of the vectors of forces exerted by each masticatory muscle. These vectors summate to form a single force vector which acts perpendicular to the occlusal plane.[50] *In vivo,* the bite forces are different for bite points in the molar, pre-molar, canine and incisor regions. During the healing period the average biting forces on incisors, canines, premolars and molars have been shown to be 0.7:0.8:1.1:1.4.[49] There is a small difference in muscular activity between the working side and the non working side during mastication.[57] However the bite forces do not have a uniform magnitude but increase from the incisor region to the molar region.[58]

In their research, Gerlach and Swarz found the bite forces of a normal human to be:[59]

- 185.3 ± 81.3N between the incisors.
- 190.1 ± 82.88N between the canines.
- 250.7 ± 75.9N on the left and 211.9 ± 109.3N on the right for molars.

There are a significant reduction in the bite forces of a patient in the first six weeks after treatment.[58,59] These bite forces slightly increase during the first three weeks after treatment. After four weeks there is no change in bite forces, but a drop after five weeks with an increase after six weeks can be observed.[59] Normal bite force values will only return to normal three months postoperatively.[59] For the incisor bite forces there was no difference in bite forces between a treated patient and a normal person after six weeks but a significant reduction in bite force in the molar area.[58] The bite force in the molar area of the fractured side shows a much bigger reduction than that of the non-fractured side both before and after six weeks.[58]

The reason for the decrease in bite forces after five weeks may be due to the regeneration of the inferior alveolar nerve and re-innervation of the periosteum which can bring along the return of pain sensation.[59] The reduction in bite forces in a patient with a mandibular fracture can also be attributed to trauma to the masticatory muscles either during surgery or by the injury itself. Neuromuscular mechanisms of the masticatory muscles cause muscle splinting in order to prevent pain or further damage to the bone and muscles, which also contributes to reduced bite force in a treated mandible fracture.[58] Furthermore, the willingness of the patient to bite hard may have decreased.[59]

3.3.6 Conclusion

The mandible is not just a simple beam and must be seen as a three dimensional model. There are a variety of force vectors from the muscles and temperomandibular joint which act on the mandible. It is important to understand what movement can be expected at a certain fracture site in order to plan where the mini-plates and screws used to treat the fracture have to be positioned.

3.4 The osteology of the mandibular angle and the inferior alveolar nerve: anatomical considerations for the treatment of mandibular angle fractures.

In order to successfully treat a mandibular angle fracture and to minimize permanent post-operative complications, proper knowledge of the anatomy of the mandibular angle region is critical. The anatomy will determine critical aspects of the treatment such as plate position and screw length.

3.4.1 Cortical thickness in the mandibular angle

In a study conducted by Smith and colleagues on dried mandibles, it was determined that the thickness of the cortical bone plate varied in different areas of the retromolar area of the mandible. A sample of fifty (50) mandibles were cut cross-sectionally in 3 areas:

a. At the distal root of the second premolar.
b. At the distal root of the third molar.
c. Just anterior of the anterior border of the ramus.

The cortical bone plate on the lingual, as well as the buccal cortex, was measured at the external oblique ridge as well as 5mm above the inferior border of the mandible.[60]

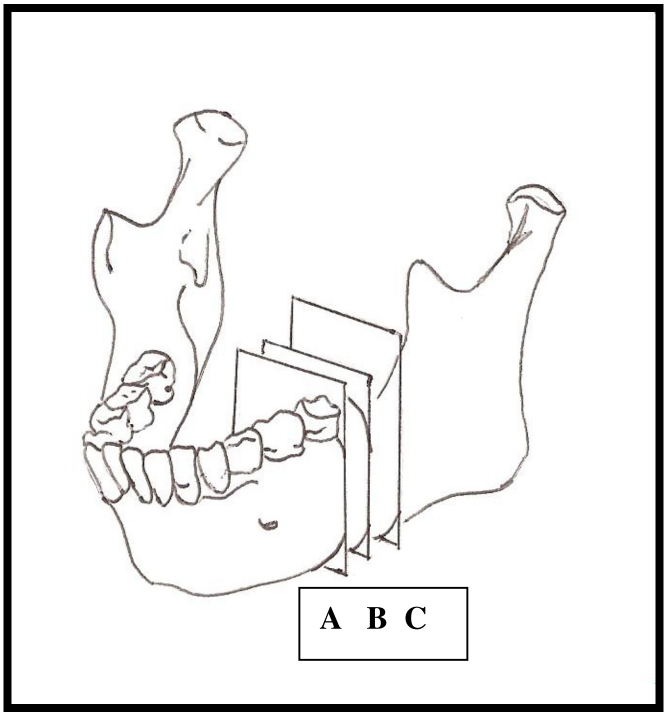


Figure 11: Cross-sections made to determine the cortical thickness of the mandible

The buccal cortex at the external oblique ridge is thicker than the cortical bone plate 5mm above the inferior border of the mandible. It has a mean thickness of 3.0 to 3.5mm compared to the mean thickness of 2.2 to 2.5 mm at the inferior border.

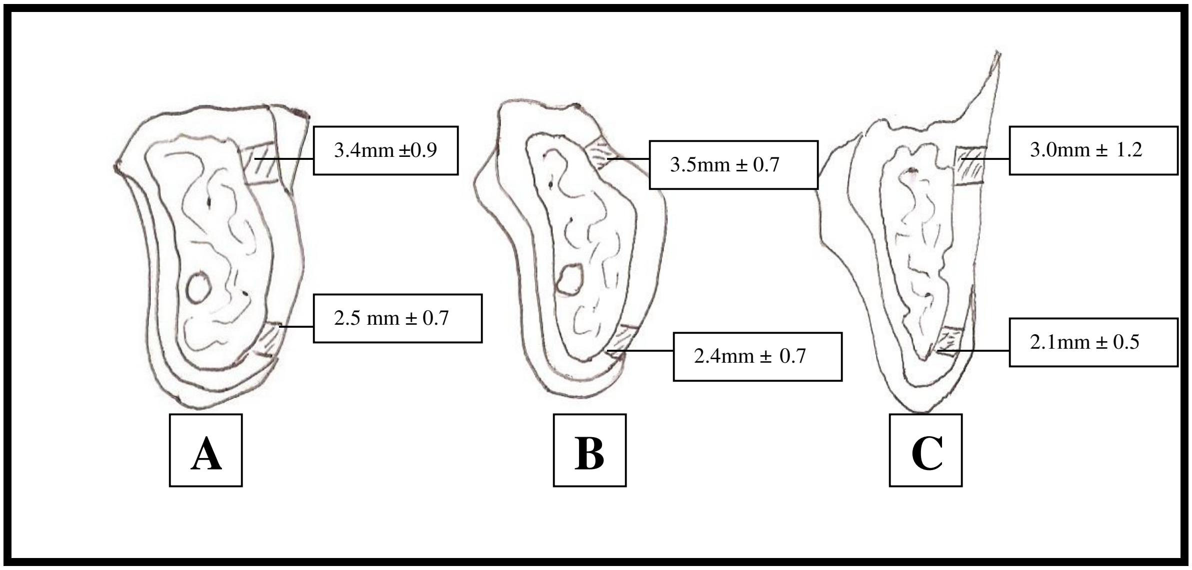


Figure 12: Comparison of the mean thickness of the buccal cortical bone plate in different areas of the mandible

The lingual cortex is thinner than the buccal cortex by 1.1 to 1.4mm at the external oblique ridge and by 0.5 to 0.7 mm at the inferior border. It is also thicker at the external oblique ridge when compared to the lingual bone plate 5mm above the inferior border of the mandible. It has a mean thickness of 2.1 to 2.3mm at the external oblique ridge and a mean thickness of 1.6 to 1.9mm at the inferior border.

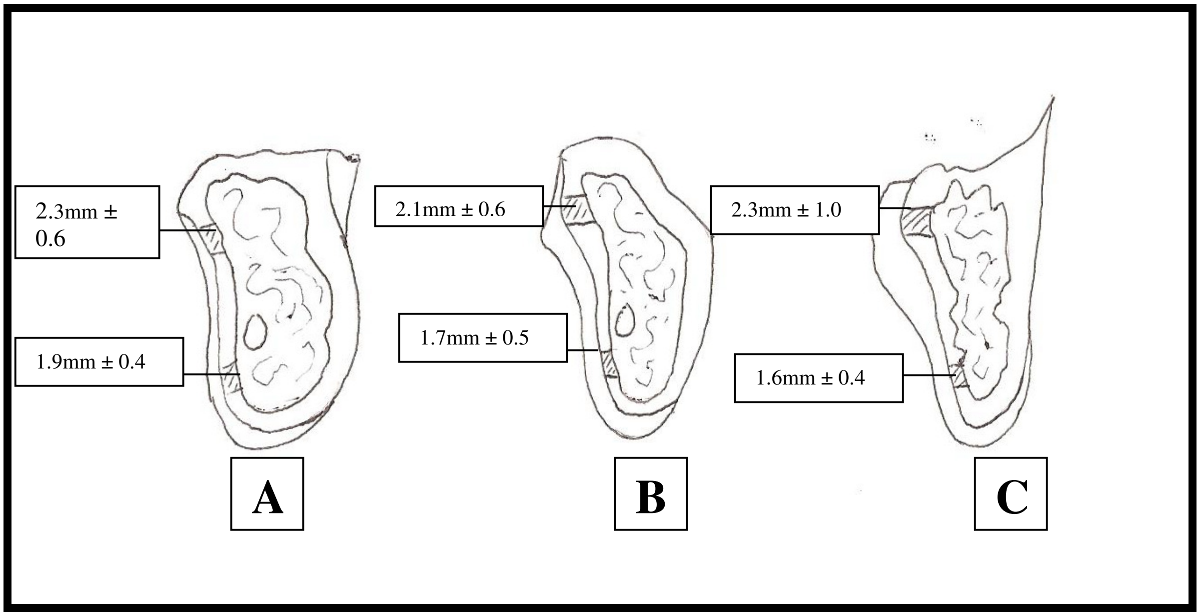


Figure 13: Comparison of the mean thickness of the lingual cortical bone plate in different areas of the mandible

These results were supported by other authors.[61]

3.4.2 Thickness of the mandible

In the same study by Smith and colleagues, the thickness of the mandible at the external oblique ridge and 5mm above the inferior border of the mandible where compared.[60]

The mandible was significantly thicker at the external oblique ridge than 5mm above the inferior border. The mandible at the external oblique ridge had a mean thickness of 13.3 to14.9mm whereas it was 6.4 to 9.5mm at the inferior border.

At the external oblique ridge the bone was thickest at the level of the distal root of the third molar and thinnest at the level of the posterior root of the second molar. At 5mm above the inferior border of the mandible, the mandible was thickest at the level of the distal root of the second molar and thinnest just anterior to the most anterior part of the ramus.

3.4.3 Course of the inferior alveolar canal

Ysuji and colleagues evaluated CT-scans of 35 patients in order to determine the position and course of the inferior alveolar canal. They found the mandibular canal to be positioned more lingually than buccally at all sites.[62] In a previous similar study by Yamamoto the same observation was made.[63] Rajchel found that the distance between the buccal cortex and the inferior alveolar canal is greatest at the level of the first and second molars and smallest at the level of the third molars.[64]

In the study by Ysuji and co-workers the CT-scans were made with sections parallel to the occlusal plane at standardized locations in order to determine the course of the mandibular canal. These sections were taken in a plane at the bottom point of the mandibular foramen; at a point where a line drawn from the posterior point of the second molar intersects with the mandibular angle and the mandibular canal at a point where a line drawn from the center of the second molar intersects with the inferior mandibular margin and at a midpoint between the level at the mandibular foramen and the level of the mandibular angle.

The authors found that a bone marrow space between the buccal cortex and the canal was present in 77.1% of the cases. Although there was a difference in the incidence, these results were similar to the results found in a study by Yamamoto, who found a space between the buccal cortex and the inferior alveolar canal in 75 % of his cases.[63] Fusion of the canal and the buccal cortex was present between the level of the mandibular foramen and the mandibular angle in 10% of the cases, at the level of the angle in 4.3% of the cases, at the level of the foramen, the midpoint and angle in 4.3% of the cases, at the level of the mandibular foramen and midpoint in 1.4% of the cases, at the midpoint and mandibular angle 1.4% of the cases and in 1.4% at the level of the inferior border and angle.[62] In the majority of patients there was sufficient bone between the buccal cortex and the inferior alveolar canal and they would not have any risk of damage to the neurovascular bundle with insertion of a monocortical screw in the buccal cortex during internal fixation of a mandibular angle fracture.

3.4.4 Conclusion

Taking the above-mentioned anatomical aspects into consideration, the assumption can be made that mini-plates used in the internal fixation of mandibular angle fractures can be positioned on the buccal or lingual aspects of the external oblique ridge as well as on the buccal aspect of the inferior border of the mandible without any risk of neurovascular damage. Of these two areas on the mandibular angle, the buccal cortical plate on the buccal aspect of the external oblique ridge will provide the thickest cortical bone plate to secure the monocortical screws used to fixate the mini-plate. In an anatomical point of view the ideal position for a mini-plate in the treatment of a mandibular angle fracture will be on the external oblique ridge or onto the lateral side of the oblique ridge as postulated by Champy.[65]

Chapter 4 Experimental procedures

4.1 Experimental design

The experiment was conducted in the form of a comparative *in vitro* pilot study in which an experimental group (lag effect) was compared to a control group (no lag effect).

52 Mandibles (n=52) were tested with 26 samples in the control group and 26 samples in the experimental group. Lag effect was created in the experimental group by inserting a lag screw in the first hole distal to the fracture line. No lag effect was created in the experimental group. Rotational forces with load-values, within clinical relevant range, were exerted on the reduced fracture and the load-displacement values was measured in each group and compared.

1.2 **Equipment and Materials**

4.2.1 Biomechanical testing device

The *in vitro* study was conducted making use of a jig manufactured and designed by F.J. Jacobs for previous biomechanical studies on polyurethane mandibles at the University of Pretoria[10]. The device was designed for the purpose of applying torsional, tension and compressive forces on synthetic mandibles.

The device consists of two vertical plates which provide the points of fixation for the synthetic mandible. One plate is fixated in order to provide a point of rigid fixation and stability to the tested mandible. The second platform also provides a point of fixation of the mandible, but is mobile and is connected to a pulley. It allows rotation of the distal fracture fragment. The pulley consists of a disc with a diameter of 4cm on a horizontal axis. A cable fixated to the pulley is attached to the load pin of the Zwick machine. Tension exerted by the load pin on the cable causes rotation of the pulley and subsequent torsional forces on the synthetic mandible.

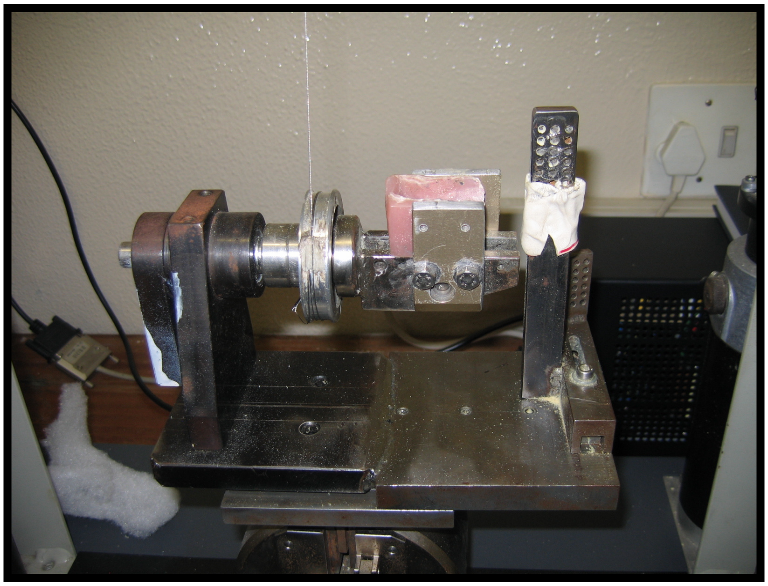


Figure 14: Biomechanical testing device

The rotation force can be calculated using the formula:

$T_m = r \times F$

Where T_m = torsion (Nm)

r = radius of the wheel (mm)

F = the upward force via the cable (N).

If the radius is constant ($T_m = F$), then the rate of force delivery is determined by the crosshair speed of the Zwick testing machine at 1mm/min.

4.2.2 Zwick testing machine

A Zwick testing machine (Ulm, Germany) was used to apply rotational forces to the synthetic mandible. Rotation was exerted at a constant rate of 1mm/min on the cable by the load cell via the load pin. The load cell has a 50 N limit. Cable pull produced a clockwise rotation on the distal fragment of the polyurethane mandible used and was registered as torsion/Newton by the load-cell via a computer.

Figure 15: Zwick testing machine

The experimental jig was incorporated into the Zwick machine by means of adaptor plates.

4.2.3 Polyurethane mandibles

52 polyurethane mandible replicas (Synbone, Lanquard, Switzerland) were used in this study with 26 mandible replicas in the experimental group and 26 mandible replicas in

the control group. These mandible replicas have a rigid outer cortex as well as a softer medullary component in order to simulate a human mandible. They have an elastic modulus of 1/10 of normal human bone. These uniform synthetic mandibles were used to eliminate the variability associated with frozen cadaver mandibles and to prevent physical changes such as drying during the thawing phase.

Figure 16: Polyurethane mandible replica

4.2.4 Acrylic templates

Two pre-fabricated acrylic templates were used in order to ensure uniformity in the position of the fracture line as well as the position of the mini-plate between the different samples. They were manufactured on an intact synthetic hemi-mandible and were produced out of polymethylmethacrylate.

4.2.4.1 Sectioning template

A sectioning template was used to standardise all separation cuts in the polyurethane mandibles. The template fitted tightly on the lateral surface of the synthetic mandible and had a groove on the superior as well as the inferior border to provide a uniform sectioning guideline in all the samples. The mandibles were sectioned through the mandibular angle, along a line connecting the superior and inferior grooves of the template, distal to the 3rd molars in order to simulate a vertically and horizontally unfavourable fracture.

4.2.4.2 Mini-plate positioning template

An acrylic positioning template was used to prepare the screw holes to ensure that every mini-plate was placed in a uniform position on all the mandible replicas.

Figure 17: Mini-plate positioning template

The template fitted tightly on the lateral surface of the synthetic mandibles.

A slot was cut in the template at the position of the 2nd line of osteosynthesis on the lateral aspect of the external oblique ridge, according to Champy[32], which accommodated the mini-plate.

4.2.5 Drill guide

A drill guide was used to insure that all the pilot holes were drilled at a standardised angle of 45º

Figure 18: Pre-fabricated drill guide

4.2.6 Mini-plates and screws

In order to fixate the simulated fractures, I.S.I. (inclined screw inserted) system 6-hole curved mini-plates with 45^0 angle holes (Stryker-Leibinger, Germany) were used in the experimental group as well as in the control group.

Figure 19: I.S.I. mini-plate with 45º angled screw holes

The mini-plates were fixated with self-tapping screws, 2mm in diameter. In the experimental group 5mm screws were inserted in all the holes, except the hole proximal to the fracture line. 13mm screws were inserted in the remaining hole across the fracture line to create a lag effect. In the experimental group 5mm screws were inserted in all the holes. No lag effect was created in the control group.

4.2.8 Torque screwdriver

All the screws were tightened to the same standardized pre-loads of 25Ncm using a calibrated torque screwdriver of certified calibration (Torq).

Figure 20: Torque screwdriver

4.3 Experimental technique

4.3.1 Preparation of the samples

In order to obtain uniformity between all the samples, the synthetic hemi-mandibles were prepared using the same technique for every specimen. All separation cuts (fracture stimulations) were made on identical positions on all specimens utilising the acrylic sectioning-template. The mini-plates were positioned on the superior border, on the lateral aspect of the oblique ridge of the mandible according to Champy's ideal lines of osteosynthesis.[32] The acrylic positioning-template was utilized to ensure uniformity of the plate positions.

A pilot drill with a 1.5mm diameter was used to drill the pilot holes for the insertion of the screws. The pilot hole proximal to the fracture line was drilled at a minimum distance of 5mm from the fracture line in order to prevent destruction of the cortex with subsequent reduction in the amount of support provided by the cortex to the screw. Pilot drilling was angulated at 45º, standardized and guided by making use of a pre-fabricated drill guide.

5mm screws were inserted in all the screw holes of the control group. Screws were first inserted in the screw-holes of the mini-plate in the proximal segment followed by the screws in the distal fragment. In the experimental samples 5mm screws were inserted in the same sequence as in the control group except in the hole directly distal to the fracture line. A 13mm lag screw was inserted, after the other screws were tightened, in the hole directly distal to the fracture line in order to prevent separation of the fracture segments. All screws were tightened to a standardized pre-load of 25 N/cm using a calibrated torque screwdriver. In the experimental group all screws were inserted and tightened before insertion of the lag screw in order to prevent distraction of the fragments with insertion of the lag screw.

4.3.2 Testing of the samples

The ramus of each of the synthetic hemi-mandibles was fixated to the fixated vertical plate in order to prevent the proximal fracture segment from moving. The distal fragment was fixated to the remaining vertical plate, which was connected to the wheel of the pulley, in order to allow rotation of the distal fracture fragment. The testing jig was then inserted into the Zwick machine and the cable from the pulley connected to the load pin.

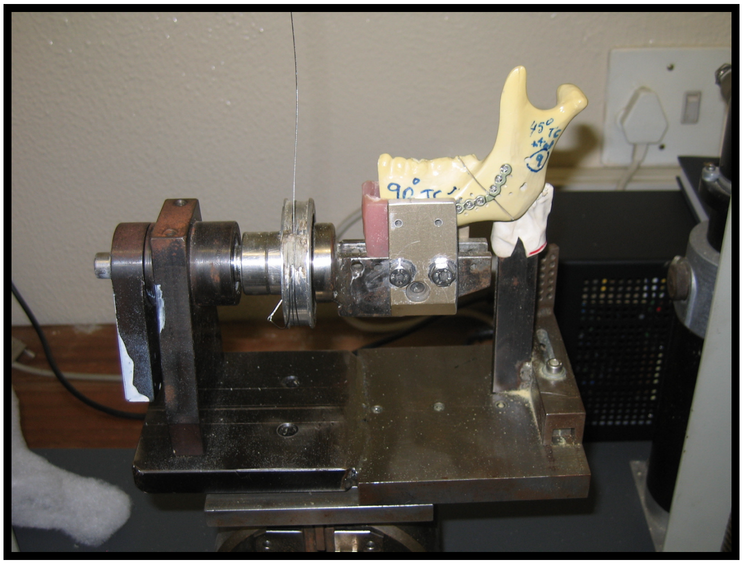


Figure 21: Biomechanical testing of samples

The Zwick machine exerted a progressive tensional force at a rate of 1mm/min via the load pin and cable onto the wheel, which led to the clockwise rotation of the wheel and subsequent rotation of the distal fracture fragment. A progressive force of up to 50N was applied to the specimens. Since the elastic modulus of the polyurethane mandibles is 1/10 of the human mandible, 1N in the test modulus is equal to 10N clinically. The displacement values of the fracture fragment, relative to the forces exerted on the fragments, were registered by the Zwick machine on a computerized chart recorder.

Figure 22: Biomechanical testing device incorporated in the Zwick machine

Prior to every test the Zwick machine was calibrated to show a zero deflection value on the chart recorder.

4.3.3 Standardization of the experiment

The following aspects of the *in vitro* experimentation were standardized:

- Polyurethane mandible replicas (Synbone, Lanquard, Switzerland) with stimulated outer cortex and inner medullary component were used in all the experiments.
- All separation cuts (fracture stimulations) were made on identical positions on all specimens using the acrylic sectioning template.

- All the mini-plates used to fixate the fractures were I.S.I. at 45° in a 6-hole plating system.
- In the control group of 26 I.S.I. plates (n=26), all screws were of the same length (5mm) and diameter (2mm). In the experimental group of 26 I.S.I. plates (n=26) all screws were of the same length (5mm) and diameter (2mm) except the lag screw of 13mm length and 2mm in diameter, which were inserted in the screw hole directly distal to the fracture line. In the experimental group all the lag screws were 13mm in length and 2mm in diameter.
- All the screws and plates used in this study were manufactured of the same material and were of the same fabrication.
- All the mini-plates were placed on the same location on all the replicas according to the Champy osteosynthesis line on the lateral aspect of the external oblique ridge using an acrylic positioning template.[53]
- All the screws were inserted in a uniform sequence. All screws were inserted in the most proximal and most distal holes of the mini-plate prior to the lag screw across the fracture line.
- All the screws were tightened to the same insertion torque of 25Ncm using a calibrated torque screwdriver of certified calibration.
- All pilot holes were drilled using a 1.5mm diameter drill and prepared at a pre-determined depth.
- All screws were inserted at 45° angles using a pre-fabricated drill guide.

- All biomechanical testing was done by the same operator, using the same experimental jig and Zwick machine.

4.4 Data collection

Load-displacement values were recorded by the Zwick machine on a computerized chart, where the displacement of the fragments was plotted against the amount of force exerted on the specimens. After completion of the experiment, these values were presented in tabulated form. Statistical analysis was performed on the tabulated results and represented graphically.

4.5 Alterations to original protocol methodology

Due to financial constraints and availability of I.S.I plates, the proposed sample size was reduced from 60 mandibles to 54 (n=54) with 26 samples in the experimental group and 26 samples in the control group.

In order to prevent damage to the screw heads, the planned pre-load with which the screws were tightened, was reduced to 25Ncm.

Damage of two polyurethane mandible replica samples in the non-lag group during biomechanical testing resulted in exclusion of the samples from the total sample size for final statistical analysis.

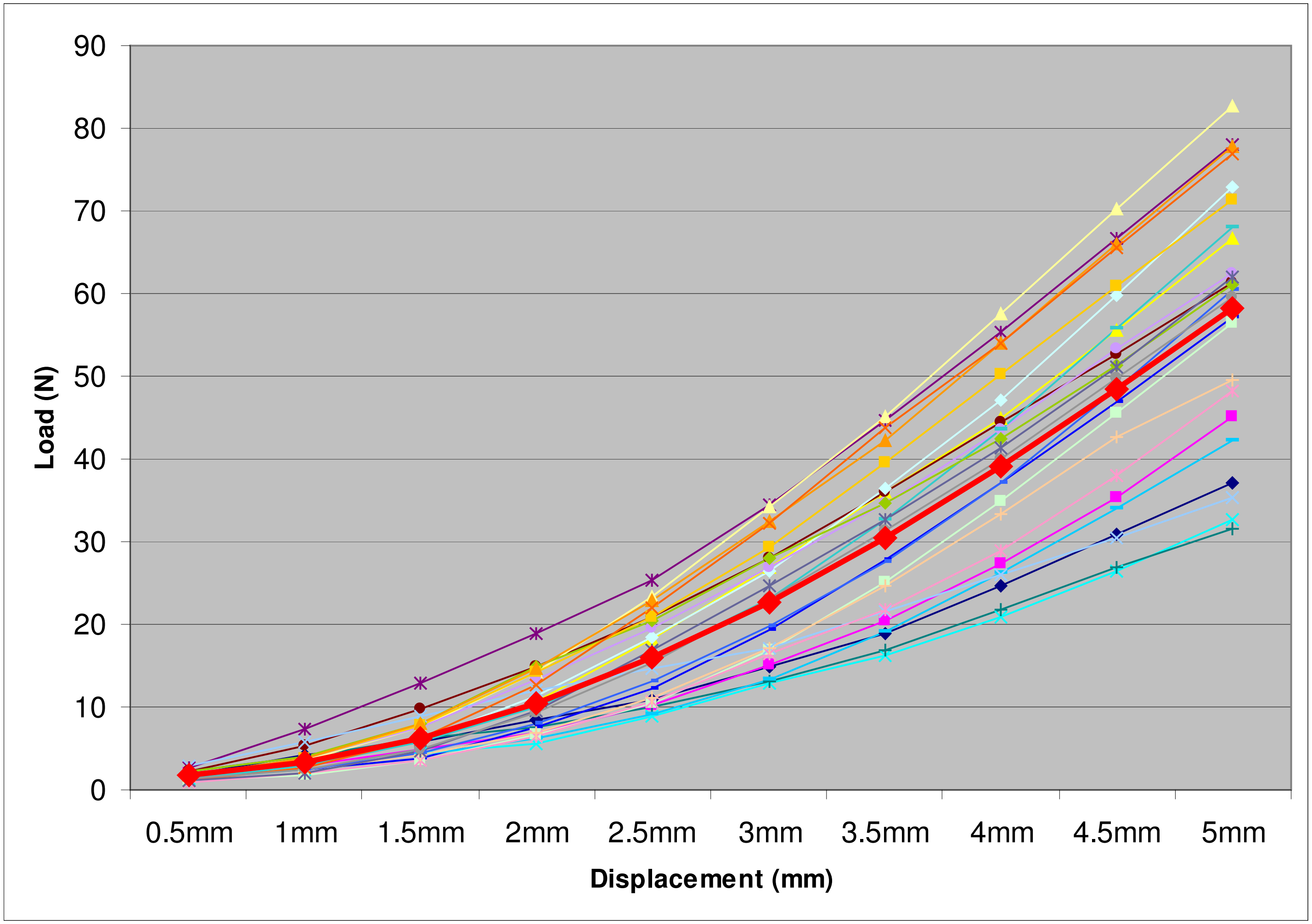
The lag screw length was increased from 9mm to 13mm in order to allow sufficient transection over the fracture line.

Chapter 5 Results

5.1 The non-lag test sample

Table 1: Load-displacement values for torsion in the non-lag group

	Displacement (mm)										
Sample Nr	**0.5mm**	**1mm**	**1.5mm**	**2mm**	**2.5mm**	**3mm**	**3.5mm**	**4mm**	**4.5mm**	**5mm**	
1	1.7	4.2	5.7	8.4	11	14.9	19	24.6	30.8	37.2	**LOAD IN NEWTONS**
2	2	3	4.9	7	10.3	15.2	20.4	27.3	35.4	45.2	
3	1.7	3.1	6	10.7	18.2	26.9	36	45	55.6	66.6	
4	1.3	2.4	4.4	5.6	9	12.9	16.3	20.9	26.5	32.6	
5	2.7	7.3	12.8	18.8	25.3	34.5	44.6	55.4	66.7	78	
6	2.3	5.3	9.7	15	21	27.9	36.1	44.5	52.6	61.3	
7	2.3	4	6.2	7.5	9.9	13.1	17	21.8	26.8	31.5	
8	1.6	2.4	3.8	7.5	12.2	19.3	27.8	37.2	47	57.2	
9	1.6	2.5	4.2	6.2	9.2	13.4	19.2	26.3	34	42.3	
10	1.5	2.9	6.1	11.4	18.5	26.4	36.5	47.2	59.7	73	
11	1.1	1.8	3.6	6.6	10.5	16.8	25.1	35	45.6	56.5	
12	1.8	3.6	7.6	14.3	23.4	34.2	45.1	57.5	70.2	82.6	
13	2.8	5.7	8.8	12	14.6	17.1	21.5	26.1	30.5	35.3	
14	1	1.9	3.6	6.4	10.7	16.4	21.8	29	38	48.3	
15	1.4	3.8	7.6	13.3	19.6	26.8	34.6	43.6	53.3	62.4	
16	1.5	2.5	4.3	7	11.1	17.2	24.6	33.4	42.6	49.6	
17	1.5	2.4	4.4	7.9	13.1	19.7	27.6	37.2	48.4	60.5	
18	1.3	2.8	5.8	9.9	16.1	23.1	32.7	43.6	55.7	68	
19	2.2	4	8.1	14.8	20.5	27.9	34.7	42.4	51.4	61.2	
20	1.8	3.7	7.8	14.2	21	29.4	39.6	50.2	60.8	71.4	
21	1.7	3.7	8.1	14.7	22.8	32.5	42.2	54	65.9	77.8	
22	1.1	2.7	6.2	12.7	21.9	32.2	43.7	53.9	65.5	76.8	
23	1.2	2.1	4.6	9.6	17	24.6	32.7	41.3	51.2	62	
24	1.4	2.5	5	9.4	15.4	23.2	31.4	40.1	49.8	59.6	
Average Load (N)	**1.7**	**3.3**	**6.2**	**10.5**	**15.9**	**22.7**	**30.4**	**39.1**	**48.5**	**58.2**	

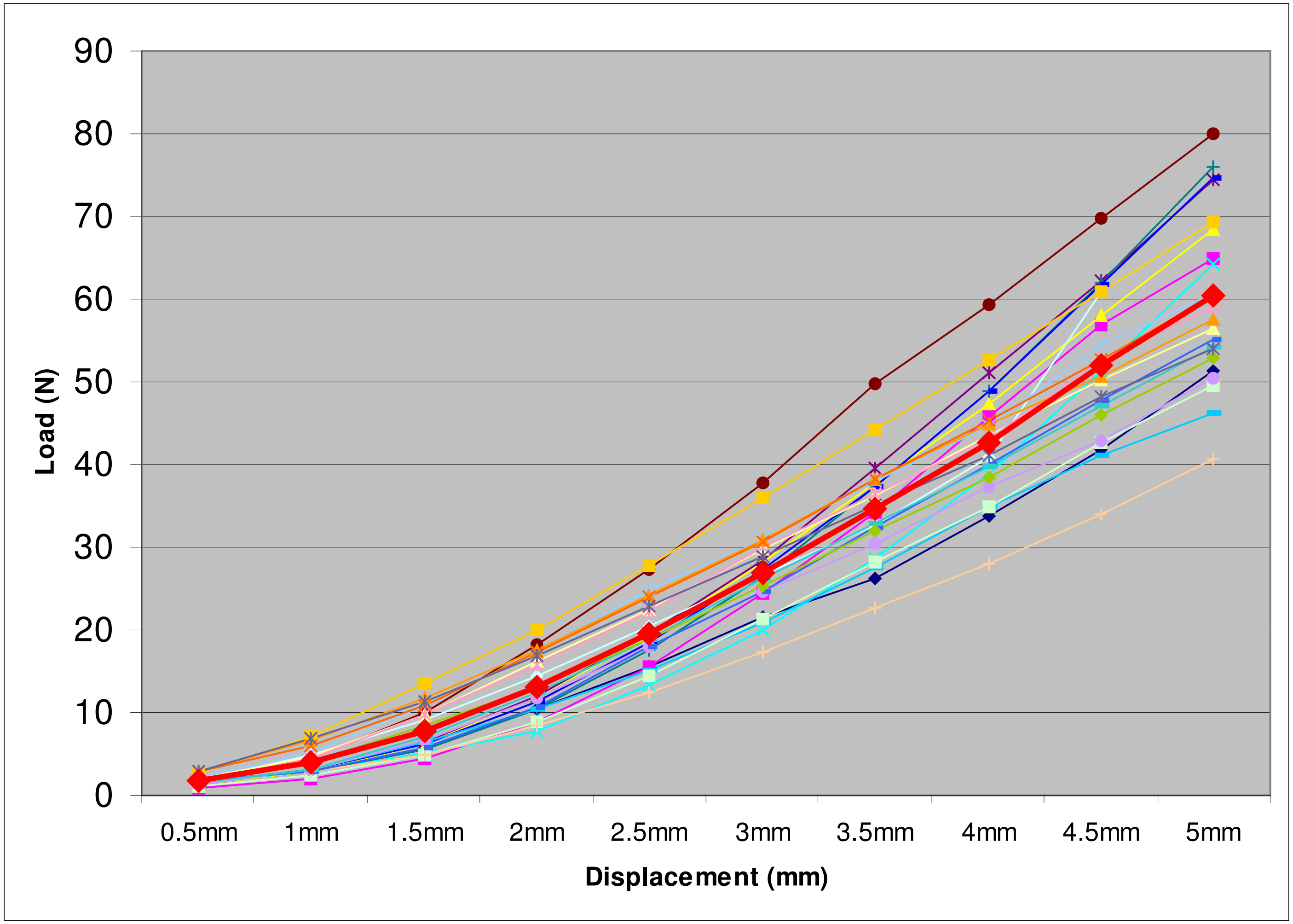


Graph 1: Load-displacement in non-lag group

5.2 The lag test sample

Table 2: Load-displacement values for torsion in the lag group

	Displacement (mm)										
Sample nr	**0.5mm**	**1mm**	**1.5mm**	**2mm**	**2.5mm**	**3mm**	**3.5mm**	**4mm**	**4.5mm**	**5mm**	
1	1.4	2.8	5.6	10.4	15.6	21.5	26.2	33.8	41.7	51.4	
2	1	2.1	4.4	8.9	15.5	24.5	34.3	45.7	57	64.8	
3	1.4	2.8	6.2	12	19.2	28.2	37.7	47.4	57.9	68.5	
4	1.6	3	5.2	7.8	13.4	19.9	28.6	38.8	51.3	64.2	
5	1.5	3.1	6.4	12	19.5	28.4	39.5	51.1	62.3	74.4	**L**
6	1.6	4.4	10	18.2	27.3	37.8	49.7	59.4	69.8	80	**O**
7	1.7	3	5.6	10.5	17.5	26.5	37.4	49	62.1	75.9	**A**
8	1.5	3.2	6.2	11.4	18.4	27.3	37.4	49	61.8	74.6	**D**
12	1.4	3.1	6.5	10.5	15.2	21	27.6	34.8	41.1	46.2	
13	1.8	4.8	9.1	14.5	20.4	26.7	32.7	40.8	61	69.3	**I**
14	1.1	2.4	4.8	9	14.5	21.3	28.3	35	42.6	49.6	**N**
15	1.9	4.6	9.8	16.3	22.4	29.7	36.2	43.6	50.3	56.4	
16	2.2	5.1	11	17.4	24.9	31	38.1	44.7	54.5	60.7	**N**
17	1.6	4.5	9.7	15.7	22.2	29.9	36.4	43.1	52.6	59.2	**E**
18	1.3	3.1	6.7	11.8	18	24.6	30.4	37.4	42.9	50.5	**W**
19	1.8	3	4.8	8.5	12.5	17.3	22.6	27.9	34	40.6	**T**
20	1.7	2.8	5.7	10.6	17.9	24.7	32.4	40.1	47.7	55.2	**O**
21	1.5	3.2	7.1	12.4	19	26.2	33	39.8	47.1	54.3	**N**
22	1.7	4.1	8.4	13.2	19	25.3	31.9	38.5	46.1	53	**S**
23	2.7	7.2	13.6	20.1	27.8	35.9	44.3	52.6	61	69.3	
24	3	6.6	11.8	17.6	24.2	30.9	38.2	44.9	50.7	57.6	
25	2.8	6	11	17.3	24.1	30.7	38.2	45.3	52.6	60.4	
26	3	6.9	11.4	16.9	23	29	35.2	41.1	48.2	54.1	
Average Load (N)	**1.79**	**3.99**	**7.87**	**13.17**	**19.63**	**26.88**	**34.62**	**42.77**	**52.01**	**60.44**	



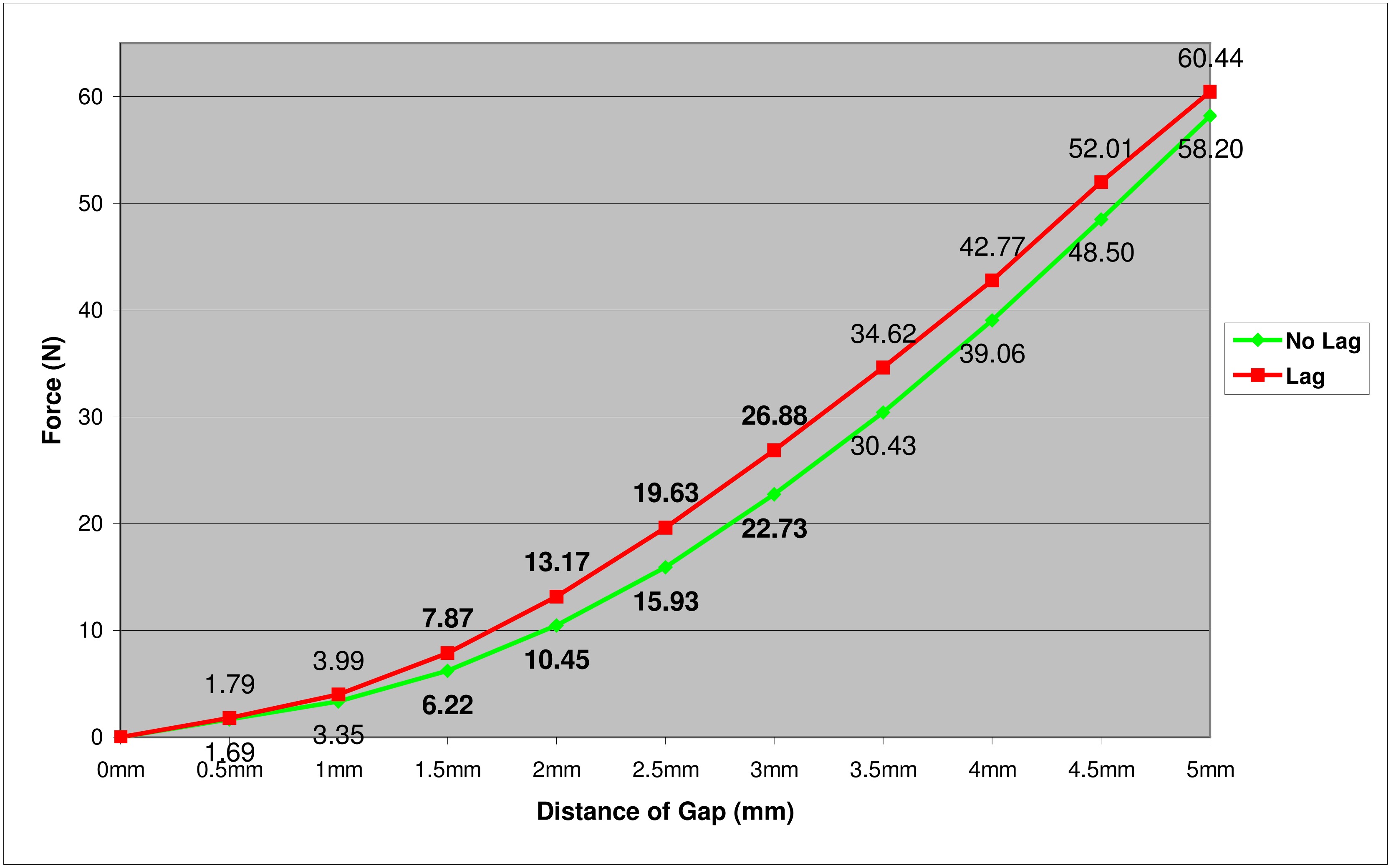
Graph 2: Load-displacement in lag group

5.3 Comparative results of lag-group and non-lag group

By comparing the load-displacement data of the sample group stabilized with a lag screw and the sample group stabilized without a lag screw, it was found that the fractures stabilized with a lag screw proved to be more stable for the rotational forces applied. In order to create a gap of equal size between the fracture fragments of the samples, increased rotation force had to be exerted on the samples stabilized with lag screws when compared to the samples stabilized without lag screws.

Table 3: Mean load-displacement values for torsion in the lag and non-lag group

	Displacement (mm)											
Group	**0mm**	**0.5mm**	**1mm**	**1.5mm**	**2mm**	**2.5mm**	**3mm**	**3.5mm**	**4mm**	**4.5mm**	**5mm**	
Non-Lag	0	1.7	3.3	6.2	10.5	15.9	22.7	30.4	39.1	48.5	58.2	**Load (N)**
Lag	0	1.8	4.0	7.9	13.2	19.6	26.9	34.6	42.8	52.0	60.4	



Graph 3: Mean load-displacement values in the lag and non-lag group

The biomechanical testing for torsional forces showed that the samples stabilized with a lag screw proved to be more stabile than the samples treated without lag screws. The results showed significant differences between the lag group and the non-lag group in the range of force values, causing the distance in the fracture gaps to be between 0.5mm and 3mm.

Table 4: P-values

Distance of gap	0mm	0.5mm	1mm	1.5mm	2mm	2.5mm	3mm	3.5mm	4mm	4.5mm	5mm
P-value	-	0.5052	0.1226	0.0276	0.0129	0.0103	0.0241	0.0695	0.1759	0.284	0.5555

▨ **P- value smaller than 0.05 indicates a significant difference in stability between the lag and non-lag group**

Taking into consideration that the elastic module of the polyurethane mandible replicas used in this study, is 1/10 of a normal mandible, 1N of load force in this experiment has a clinical relevance to a rotation force value of 10N.

Chapter 6 Discussion

6.1 Plate position

In this study all simulated fractures were fixated by means of an I.S.I. plate and all screws were inserted at an angle of 45º. The inclination of the screw, make the cortex between the first hole distal to the fracture line and the fracture line prone to disintegration.

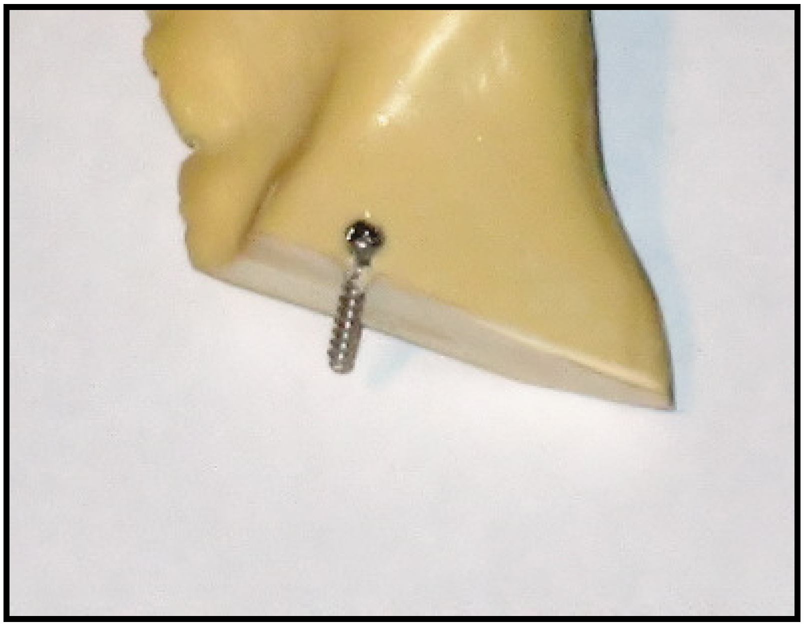


Figure 23: Cortical bone destruction

Disintegration of the cortical segment may lead to reduced support of the screw head and subsequent reduced compressive forces over the fracture line when a lag screw is inserted[7-9].

In order to prevent destruction of the cortical segment the mini-plate must be positioned in such a way that the cortex situated between the first hole (distal to the fracture line) and the fracture line is of sufficient thickness to prevent disintegration with drilling and insertion of the screw. It was determined, in this study, that the first hole distal to the fracture line had to be at a minimum distance of 5mm from the fracture line in order to prevent cortex destruction, when pilot drilling at 45°. It is recommended that this be the minimum amount of cortex that should be maintained between the first hole and the fracture line to ensure adequate support to the lag screw.

6.2 Screw length

The initial planned length of the lag screw of 9mm was found to be inadequate and did not allow sufficient lagging across the fracture line. The lag screw length was increased to 13mm.

The minimum prerequisite length for a lag screw in order to allow the screw to reach the fracture line can be calculated by making use of trigonometry. Taking into account that the minimum recommended distance between the fracture line and the first hole in this study was 5mm and that all screws were inserted at a 45° angle, these two values can be used to determine the minimum required length of the lag screw.

If **A** is the first hole distal to the fracture line and **ED** is the fracture line, we know that the recommended distance of **AE** for this study is 5mm. If **AC** is the screw length and **B** is the point where the screw crosses the fracture line, and we know for this study that all screws were inserted at a 45° angle, the angle **EAB** is also a known value of 45°.

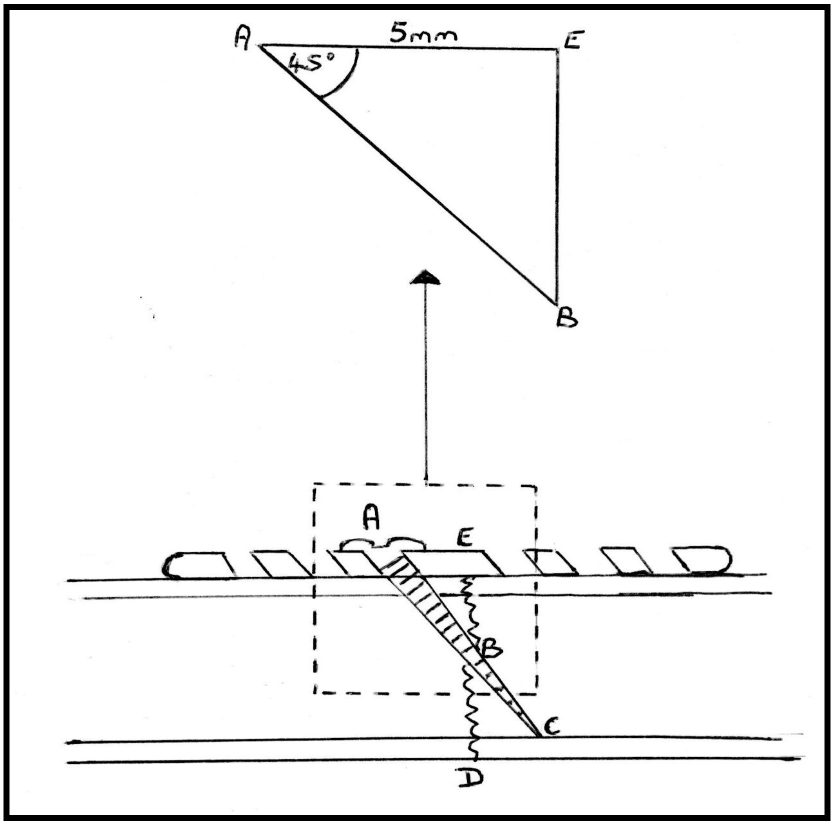


Figure 24: Calculation of the required length of a lag screw

To determine the minimum length of a lag screw in order to cross the fracture line, the length of **AB** must be determined. With the known values of **A** and **AE,** the length of **AB** can be determined by making use of the following trigonometrical equation:

$$\text{Cos } A = AE / AB$$

$$\text{Cos } 45^\circ = 5\text{mm} / AB$$

$$0.70710678 = 5\text{mm} / AB$$

$$AB = 7\text{mm}$$

In order for the first screw proximal to the fracture line to lag across the fracture line, it must be longer than 7mm. Jacobs defined this phenomenon as screw tip travel[10].

In order to maximise the stability and compressive forces across the fracture line supplied by the lag screw, the lag screw can be inserted bicortically. Taking into account that the average thickness of the mandible at the level of the oblique ridge is between 13.3mm and 14.9mm[60], the lag screw inserted in the hole distal to the fracture line at a 45° angle must be 18mm or longer in order to be inserted bicortically, when calculated trigonometrically.

In order to allow 5mm or more lag into the proximal fragment, the lag screw inserted in the first hole distal to the fracture line, when used in conjunction with an I.S.I. 45° mini-plate, must be 12mm or longer.

6.3 Screw placement

A problem that arose during experimentation was the separation of the fragments with insertion of the lag screw. The initial protocol for the study indicated that the most proximal and distal screws would be inserted prior to the lag screw, where after the remainder of the screws will be inserted at random. With the preparation of the samples for biomechanical testing, it was found that the two screws inserted prior to the insertion of the lag screw did not provide enough stability to the fracture fragments in order to prevent them from separating with insertion of the lag screw.

With insertion of the lag screw in the pilot hole of the distal fragment, pressure is exerted by the tip of the screw on the proximal fracture fragment, which can cause the fragments to separate, rather than be compressed. This phenomenon is in total contrast to the initial purpose for which a lag screw is applied, namely compression of the fracture fragments.

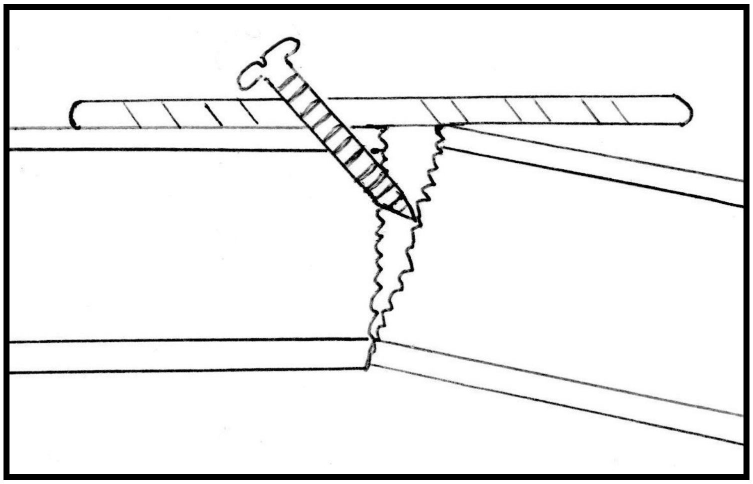


Figure 25: Separation of the fracture fragments by the lag screw

This problem was successfully overcome, in this study, by inserting all screws prior to insertion of the lag screw. Another possible solution would be to drill the pilot hole through both fracture fragments.

6.4 Clinical relevance of the study

6.4.1 Polyurethane mandible replicas

Simulation of the mandibular angle fracture was created using a small saw blade. This caused the edges of the fracture fragments to be smooth. However, in a clinical situation, the edges of the fracture fragments will be irregular.

Compression between the fracture fragments created by a lag screw will cause interdigitation of these irregular fracture lines which will increase the stability of the treated fracture.[66] Therefore, in clinical scenarios, the stability created by a lag screw, will be higher than *in vitro* studies where polyurethane mandible replicas are being used.

Polyurethane mandible replicas have an elastic modulus of 1/10 of a normal mandible. When compared to a normal mandible, 1N force exerted on a polyurethane mandible replica represents 10N in the clinical situation.

6.4.2 Force application

Normal bite forces in a healthy human being range from 185N between the incisors up to 250N between the molars.[59] However these bite forces are significantly reduced in a patient with a mandibular fracture 6 weeks after treatment.[58, 59]

The load application in this study was in the range of 100 to 500N. The mean load-displacement data indicated that the mandibles stabilized with a lag screw were proved to show more stability through the whole range of forces exerted on the samples when compared to the samples treated without lag screws.

The mandible replicas treated with lag screws proved to be significantly more stable than the fractures fixated without lag screws in the range of 78N – 260N, which falls into the range of normal biting forces under clinical conditions.

6.4.3 Distance of the gap between the fracture fragments

The difference in stability between the lag group and the non-lag group proved to be significant for a fracture gap of between 1.5mm and 3mm. In order to create a gap of 1.5mm between the fracture fragments of the mandibles stabilized with a lag screw, a load force of 78N was required and for the non-lag a force of 62N to create a fracture gap of the same magnitude. The improvement in stability provided by the lag screws is obvious. The lag screw samples demonstrated a 16N rotation load force increase for a fracture gap displacement of 1.5mm compared to the non-lag group.

A load force of 268N had to be exerted on the average mandible in the lag group to create a fracture gap distance of 3mm, compared to the 227N load force needed to create a fracture gap size of the same magnitude in the non-lag specimen group. The lag group could withstand a rotation force load increase of 41N, when compared to the non-lag samples for a fracture gap of 3mm.

When compared to the mandibular fractures stabilized without a lag screw, the average mandible fracture in the lag group could withstand significantly more load force before a fracture gap of the same magnitude could be measured within the range of 1.5mm to 3mm.

The clinical relevance of the above mentioned observation can be indicated by comparing these findings with studies conducted by Goodship and Kenwright on tibial fractures[67,68]. They established that micro movement larger than 2mm inhibited bone healing in tibial fractures.[67,68]

Chapter 7 Conclusion

Recent studies conducted on a patented I.S.I. mini-plate system formed the basis of this study. The angled screw application delineates lag screw application in combination with ISI mini-plates and renders it a lag-plate for the treatment of mandibular angle fractures. This previous ISI-study set the platform for the current pilot study investigating lag screw effect on the torsion stability of inclined screw plating at a screw angle of 45º.

Mandibular angle fractures stabilized with the I.S.I. 45º mini-plate and a lag screw, showed significantly superior stability within clinical relevant parameters when compared to the samples treated without the I.S.I. mini-plate lag screw combination.

The incorporation of a 13mm screw creates lag potential and converts the ISI plate into a lag-plate with superior biomechanical stability, when compared to non-lag plates and therefore conventional plating systems with screws placed at right angles to the plate surface

Geometric plate design factors and screw length consideration are of paramount importance when pursuing optimum stability in inclined lag-screw insertion plating.

Chapter 8 References

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Curriculum vitae

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PERSONAL PROFILE

Contact Details	Cell: 082 341 8860 Work: 012 546 6863 Fax: 012 259 1384
Date of Birth	25 July1978
Nationality	South African
ID Number	7807255092083
Age	31 Years
Home Language	Afrikaans
Marital Status	Married
Health	Excellent health
Occupation	Dentist
HPCSA Number	DP 0083216
Interests	Hunting; Scuba Diving; Reading; Jogging

EDUCATION AND QUALIFICATIONS	
Secondary Education	Senior Certificate with endorsement Silverton High School, Pretoria Afrikaans HG; English HG; Mathematics HG; Science HG; Biology HG; Accounting HG
Tertiary Education	BChD University of Pretoria 2003
Tertiary Education Post Graduate	Dip. Odont (Oral Surgery) University of Pretoria 2005
Primary subjects	The following primary subjects were completed: Anatomy – University of Pretoria Physiology – University of Pretoria Pharmacology – University of Pretoria Pathology – University of Pretoria
Additional Subjects	Research Methodology
Tertiary Education Currently	MSc Odont in oral surgery University of Pretoria
Research	• Protocol has been approved by the research committee of the University of Pretoria • Research Topic: Lag screw effect on the biomechanical torsion stability in the I.S.I. monocortical mandible angle system • Research has been completed • Disertation will be handed in • Research Leader: Prof. F.J. Jacobs • Reference: Prof. F.J. Jacobs 083 453 0939
Additional Courses Completed	• Advanced Trauma Life Support (ATLS) • Basic Life Support (BLS) • Advanced Cardiovascular Life Support (ACLS) • Advanced Medical Life Support (AMLS)

WORK EXPERIENCE	
1. Institution	University of Pretoria
Job Title	Session doctor in the department of maxillo- facial and oral surgery
Period	November 2005
Main Responsibilities	• Clinical training of pre-graduate students • Presentation of lectures • Treatment of patients in the dept. Maxillo- facial and oral surgery • Sessions as **medical officer** in the department Maxillo-facial and oral surgery of the University of Pretoria – October 2008 4 Years
Reference	Prof. K. Butow 012 319 2232
2. Institution	Ifafi Tandheelkundige Praktyk
Job Title	Owner
Period	1 January 2005 to date 5 Years
Main Responsibilities	• Restorative dentistry • Removable prosthetics • Periodontal treatment • Crown and bridge work • Removable prosthetics • Endodontic treatment • Oral surgery ○ Removal of impacted third molars ○ Apisectomies ○ Extractions and surgical removal of teeth ○ Biopsies ○ Preprostetic surgery ○ Closure of oral antral fistulas ○ Removal of roots in antrum ○ Management of soft tissue trauma ○ Treatment of TMJ disorders
3. Institution	Ellisras Hospital
Job Title	Community Service in rural area
Period	1 January 2004 to 31 December 2004
Main Responsibilities	• Set up and manage a new clinic • Treatment of facial fractures

	• Treatment of soft tissue trauma • Biopsies • Removal of impacted third molars • Surgical removal of teeth • Dental extractions • Management of oral pathology • Prostodontics • General restorative dentistry • Minor Orthodontic treatment • Treatment of TMJ disorders • Assistance of general medical practitioners with general surgery Dr Minaar 082 442 3166
4. Institution	Cornwall View Dental Practice
Job Title	Oral Surgery
Period	Once a week from January 2006 to January 2007 1 Year
Main Responsibilities	• Surgical removal of teeth and root rests • Surgical removal of impacted 3^{rd} molars • Closure of oral antral fistulas • Biopsies • Pre-prostetic surgery e.g. alveolotomies, removal of tori • Dental extractions
Reference	Dr Du Toit 012 345 5600
5. Oral Surgery References	Oral surgery cases are referred to me by the following dentists for treatment: • Dr Nel The Village, Moreleta Park 072 123 3496 • Dr Raats Hartbeespoort 082 486 6546 • Dr De Wet 073 284 4465 • Dr. R. Naude Danmed Medical Centre 012 386 1355 • Dr. T. Taylor 082 708 4706

	These cases include: • Surgical removal of teeth and root rests • Surgical removal of impacted 3rd molars • Closure of oral antral fistulas • Biopsies • Pre-prostetic surgery e.g. alveolotomies, removal of tori • Dental extractions • Removal of root in antrum Hereto attached is a logbook of the surgical procedures performed by me
6. Assistance of Maxillo facial and oral surgeons	Assistance of Maxillo facial and oral surgeons during surgery in theatre
Period	November 2005 up to date
Reference	4 Years Dr. M Swanepoel 082 561 2290 Dr. Harmse 012 807 1121 Dr. Hoogendijk 083 230 6332 Hereto attached is a list of assisted surgeries, the hospital where the surgery took place as well as the surgeon assisted.

AWARDS	• Ross Barrowman Prize – to the student who obtained the best results in removable partial dentures 2003 • Brooklyn surgical centre floating trophy – to the student who achieved the best results in the clinical part of the examinations in Odontology, Oro-Facial Surgery, Dento-Facial Anomalies and Prosthetics 2003 • Swann-Morton Award – to the student who performed the best during the co-assistance period of Oro-Facial Surgery 2003
Personal Skills and Competencies	• Language Advanced level o English o Afrikaans • Computer Skills Advanced level o MS Office • Leadership Skills o Member of the student representative council, Primary School o Excellent leadership qualities o Chairman of the board of deacons of the Reformed church