Systematic Review

Review of biomechanical experimental studies on different plating techniques of mandibular condyle fractures

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ABSTRACT

Mandibular condyle fractures are one of the most frequent injuries of the facial skeleton. The option for open treatment of mandibular condyle fractures has become more favorable since osteosynthesis materials were developed in the past few decades. However, the rigid fixation techniques of treating condyle fractures remain one of the controversial issues in maxillofacial trauma. These injuries are currently treated by plate-screw osteosynthesis and, depending on the case, the bone segments are fixed by one or two miniplates. Several techniques and plate types like adaption miniplates, minidynamic compression plates, resorbable plates and double plates have been evaluated biomechanically in various experimental and clinical studies. The biomechanical and physical behavior of mandibles have been investigated by different approaches. It can be divided into computer biomodels (e.g., finite element analysis) and physical models. Physical models allow testing on a gross level to give fatigue performance and fracture strength. The aim of this article is to carry out a review of the literature which deals with biomechanical evaluation made with physical models of plating techniques of mandibular condyle fracture. Based on the results of these studies, osteosynthesis with two miniplates seems to be the most stable way of treating mandible subcondylar fractures, and PLLA plates were not strong enough compared with metal plates.

Keywords: Biomechanics, mandibular condyle, plating techniques, stability

INTRODUCTION

Fractures of the mandibular condylar processes are the most common fractures in the mandible and maxillofacial region.[1-3] These fractures account for between 25 and 35% of all mandibular fractures.[4,5] The anatomical basis of the mandible ensures the dissipation of forces along the mandible, allowing the weakest part at the condylar neck to fracture, thus preventing transfer of forces to the cranium.[6] This is the reason for the high incidence of condylar fractures.[6] The therapeutic aims in condylar fracture management are to re-establish anatomy before trauma, to provide fracture stabilization and to restore the functionality with the least morbidity.[7]

Mandibular condyle fractures represent one of the most controversial issues in literature with regard to classification and diagnosis, especially with regard to recommended treatments.[8] These fractures can be treated in a conservative technique (closed reduction) or by surgery (open reduction).[2,5] There are various methods of open reduction and osteosynthesis for the condylar process.[2] These include fixation with Kirschner wires, intraosseous wiring, miniplates and lag-screws.[2] Treatment of condylar fractures with rigid internal fixation has made significant advances over the past years due to improved understanding of biomechanical principles and advances in plate and screw fixation devices.[7,9] However, there seems to be no consensus regarding the choice of the best type of osteosynthesis.[10] The literature shows that the technique most frequently used is the positioning of a single plate, although complications concerning plate fracture or screw loosening have been reported by various authors.[11-13] On the other hand, some of studies have demonstrated the greater stability of the double plate compared to the use of the single plate in the fixation of mandibular condyle fractures.[10,11,13,14]

Experimental investigations are used to quantify and evaluate function in an *in vitro* environment to better understand the biomechanics of mandibular fixation and to develop fixation devices and techniques.[1,15] Biomodeling describes the ability to replicate the morphology of a biological structure.[16] Researchers use computer-based and physical biomodels to design and analyze objects in order to understand physical principles. Computer modeling has allowed simulation of the forces acting on the mandible and approximate calculations of these forces at various points throughout the mandible. Physical models range from simple bone models mounted on a testing jig to more complex biomodels rendered in solid form. These models can be produced by engineering technologies such as rapid prototyping techniques, which replicate the morphology of the mandible.[16,17]

With regard to laboratory studies on rigid internal fixation techniques for mandibular condyle fractures, there are few studies that show the biomechanical behavior of the different forms of rigid internal fixation.[1,2,4,7,9,10,13,18,19] The aim of this study is to provide information about the traditional and alternative plating techniques for mandibular condyle fractures and review existing literature to provide a comparison of these systems' biomechanical characteristics.

MATERIALS AND METHODS

Using the PubMed search engine, a Medline search was carried out with the key words "biomechanics", "condyle fractures", "osteosynthesis", "rigid fixation", "miniplate", "mandible" and "stability", as well as combinations of these key words. This search was not limited by time.

The inclusion criteria are papers published in journals, indexed in MedLine, in which biomechanical testing studies were conducted using different plating techniques for mandibular condyle fractures. Although the physical models such as animal bone, cadaveric bone and polyurethane mandible replicas were included in the study, computer models were not included in this review. The inclusion criterion was limited to articles written only in English.

RESULTS

The total number of papers that met the inclusion criteria was 10. Only one study[20] was conducted on condyle head fractures to evaluate biomechanical stability. The other nine studies[1,2,4,7,9,10,13,18,19] were conducted on condyle neck fractures [Table 1]. The studies were conducted with synthetic mandibles,[1,2,9,10,19] pig,[7,18,20] sheep[4] and only one human cadaver.[13] Six studies[1,2,7,9,13,19] compared the biomechanical stability on different miniplates made by titanium. The other four studies[4,10,18,20] were conducted on titanium and resorbable systems.

DISCUSSION

Biomodeling describes the ability to replicate the morphology of a biological structure.[16] Animal tissue, synthetic materials and other materials have been used in biomechanical research.[15] Human bone substitutes used for research should closely approximate the mechanical behavior of the human mandible under the conditions of the investigation and reduce concerns involving the economic, ethical and health considerations associated with the use of cadaveric tissue.[1,15] Human cadavers are subject to natural variation that may affect outcomes, and formalin fixation alters the physical properties of human bone.[9] Human cadaver is used in only one study in the literature for comparison of biomechanical stability for mandibular condyle fractures.[13] According to Lauer,[7] porcine mandibles offer more realistic conditions concerning the anchorage of screws and the creation of the fracture as well as with the transmission of the load compared to synthetic bone.

Synthetic polyurethane resin replica hemimandibles were used due to their standardized size and anatomical shape, density, hardness, elasticity coefficient and similarity to the human mandible.[9] For this reason, from the literature we can observe that most studies used synthetic mandible models.[1,2,9,10,19]

The mandible is subjected to forces produced by the muscles of mastication and by reaction forces acting through the teeth and temporomandibular joints.[16] However, the actual forces being applied to the condylar neck in terms of maximum force and direction of force have not yet been completely identified.[18] Koolstra *et al*,[21] estimated joint reaction forces relative to the corresponding bite forces using a three-dimensional mathematical model of the human masticatory system. Some of the authors used Koolstra's mathematical study to decide the direction of the force.[10,13,19]

In 1997, the first *in vitro* study associated with mandible condyle fractures were performed by Ziccardi *et al*.[19] They evaluated the biomechanical stability of the Wurzburg lag screw plate and a four-hole miniplate. Their testing was performed using polyurethane mandible replicas and servo hydraulic testing machine. Loading was performed according to the Koolstra's mathematical analysis. Ziccardi *et al*, found the Wurzburg lag screw to be superior in stability to the 4-hole miniplate. Additionally, they also mentioned that the failure strength of both systems were not enough for functional loading of the temporomandibular joint.

A study was carried out by Haug *et al*,[9] of the mechanical behavior of four different single plating techniques including a zygomatic dynamic compression plate, a minidynamic compression plate (DCP), a locking adaption plate and an adaption plate with six screws each. Forces in four different directions and torsion were applied. They evaluated the yield load, yield displacement and stiffness, which are clinically important variables. Yield load is the load at which the system begins to permanently deform, yield displacement is the displacement at which permanent deformation begins and stiffness is that rate of change of stress as

Table 1: Literature review of the biomechanical experimental studies on different plating techniques of mandibular condyle fractures

Author/year	Model material	Force direction	Plating technique
Ziccardi *et al.*[19]	Synthetic	Anterio- posterior*	Wurzburg lag screw plate 4 hole miniplate system
Choi *et al.*[13]	Formalin-fixed cadaver	Anterio- posterior*	4 hole miniplate 4 hole minidynamic compression plate 4 hole 2.4mm plate Double miniplate
Haug *et al.*[9]	Synthetic	Posterior to anterior Lateral to medial Medial to lateral Torsional	No fixation 6 hole 2.0 mm zygomatic dynamic compression plate 6 hole 2.0mm locking adaptation plate 6 hole 2.0mm adaptation plate 6 hole 2.0mm minidynamic compression plate
Tominaga *et al.*[10]	Synthetic	Anterio-posterior*	Single 4-hole mini adaptation plate Double 4-hole mini adaptation plate Single four-hole minidynamic compression plate Eckelt lag screw Wurzburg lag screw plate Double 4-hole biodegradable miniplates (PLLA)
Asprino *et al.*[1]	Synthetic	Anterior to posterior Medial to lateral	Control group One adaptation plate _ 6-mm screws One adaptation plate _ 8-mm screws Two adaptation plates _ 6-mm screws
Lauer *et al.*[7]	Porcine models	Anterior to posterior Posterior to anterior Lateral to medial Medial to lateral	Delta plate Trapezoid plate Dynamic compression plate Double miniplate
Alkan *et al.*[4]	Sheep models	Anterio- posterior*	Miniadaptation plate Minicompression plate Biodegradable miniplate.
Gealh *et al.*[2]	Synthetic	Anterior to posterior Medial to lateral	Double 4-hole miniplates Two overlaid 4-hole miniplates
Pilling *et al.*[18]	Pig models	Anterior to posterior Posterior to anterior Lateral to medial Medial to lateral	Eckelt lag screw Single 4-hole miniplate Single 4-hole miniplate with bar Double 4-hole miniplates 4-hole minicompression plate Zygoma compression plate Condylus fracture plate Square 4-hole plate Single 4-hole resorbable miniplate Double 4-hole resorbable miniplates

*Koolstra mathematical model

a function of strain which meant resistance to motion of the fixed site. They suggest that none of the systems evaluated were ideal for the treatment of mandibular condyle fractures, but that the mini DCP is the closest to an effective means for reconstruction.

Alkan *et al*,[4] also compared single plate systems. The authors investigated the biomechanical behavior of three osteosynthesis systems used for the fixation of subcondylar fractures. The authors used 15 sheep hemi mandibles and tested them with compression forces by an Instron servo hydraulic mechanical testing unit. They stated that the titanium miniadaptation plates, minicompression plates, and the absorbable miniplates did not differ significantly in their biomechanical behavior.

After biomechanical studies that compare the single plate systems were analyzed, several authors reported that these systems did not show ideal fixations for a biomechanical perspective.[9,10,18,19] Additionally, Tominaga *et al*,[10] suggested that biodegradable plates could be used in this area if they can be applied as double plating. Hammer *et al*,[11] reported, based on their clinical observation, that a high failure rate was observed with a single miniplate. *In vitro* strain measurements in the condylar process showed that the highest level of tensile strain occured on the on the anterior and lateral surfaces and the highest compressive strain was shown to occur on the posterior surface.[12,13] Therefore, the two miniplates applied at the posterior and anterior border of the condylar neck seem to have the beneficial effect of restoring the tension and compression trajectories.[13,22] Choi *et al*,[13] showed that double adaptation plating proved 4 times stronger than single plating. In this study, authors compared the biomechanical stability of four different plating techniques (four-screw monocortical miniplate, bicortical mini DCP, 2.4-mm plate and a double monocortical miniplate). They found the mean loads for permanent deformation were 15 N for the single miniplate, 29 N for the mini DCP, 44 N for the 2.4-mm plate and 93 N for the two miniplates. They conclude the double miniplate to be the most stable fixation system.

Tominaga *et al*,[10] conducted a study showing that double-plate systems are more stable. The authors tested a single four-hole miniadaptation plate, double fixation with the same plates, single four-hole mini DCP, Eckelt lag screw system, Wurzburg lag screw plate system and double four-hole biodegradable miniplates made of poly L-lactide (PLLA). Eighteen synthetic mandibles were used, perpendicular or oblique experimental condylar fracture lines created and the plates fixed. They reported that, in perpendicular fracture, double adaptation plate and Eckelt lag screw showed higher levels of stiffness, whereas double PLLA was almost at the same level of single DCP. In oblique fracture, double adaptation plate showed the highest strength.

The loads across the fracture depend on variables such as position of the fracture and the bite point.[23] Wagner *et al*[24] and Throckmorton *et al*,[12] showed that the largest possible load on a treated mandibular fracture to be a singular occlusal contact on the contralateral molar region. They reported that a force of up to 210 N can be exerted on the osteosynthesis.

A maximal load capacity of the osteosynthesis should exceed these reported values in order to enable early functional rehabilitation of the joint independently of the patient's compliance and occlusal state.[18] In 2009, Pilling *et al*,[18] compared the biomechanical stability of 10 different plating techniques (The Eckelt lag screw, one or two 2.0-mm miniplates, one miniplate with bar, minicompression plates, zygoma compression plates, condylus fracture plates, square four-hole plates, and either one or two resorbable four-hole miniplates). They used a total of 164 fresh mandibles from minipigs. They reported that forces being applied from anterior to posterior showed the lowest value of 88.3 N for single resorbable plates and the highest mean value of 549.1 N for osteosynthesis with two titanium miniplates. The double resorbable plates resisted a mean maximum force of up to 172.5 N. Consequently, these results suggest that some types of osteosynthesis may be unstable, particularly a single resorbable plate. This discourages its use in mechanically heavily loaded areas.

The biomechanical stability of specially designed plates such as delta and trapezoid were compared by Lauer *et al*.[7] They used the delta plate, the trapezoid plate, the DCP and double miniplates as osteosynthesis materials, and each group was subjected to linear loading in anterior-to-posterior, posterior-to-anterior, lateral-to-medial, medial-to-lateral directions by a mechanical testing machine. They found that statistically significant differences were noted between the fixation groups in all four directions. According to their results rigid internal fixation with double miniplates showed the best stability in all directions except posterior to anterior. In this direction, the delta plate resisted the highest loads. In the three other directions, the delta plate was second best with data similar to double miniplates but lower in magnitude.

According to Ellis,[25] if the plate is loaded beyond the screw/bone anchorage's limit, the screws can become loose and lead to fracture instability. A way to prevent this biomechanical failure is to provide more holding force by the screws. This can be achieved by using bicortical rather than monocortical engagement of the threads, using larger diameter screws, and/or by using more screws on each side of the fracture. In 2009, Asprino *et al*,[1] compared the biomechanical behavior of the plating techniques fixation with a 4-hole plate and 6-mm screws, a 4-hole plate and 8-mm screws and double 4-hole plates with 6-mm screws. According to their results, lengthy screws, with bicortical engagement, can increase the stability at fixation of mandibular condylar process fractures.

Although double plate applications are more stable than single plate applications for mandibular condyle fractures, applying the double plate is not always possible. Shinohara and Martini[26] aimed to increase the functional stability of high fractures of the mandibular condyle, with minimum cost to the patient. Keeping this in consideration. Gealh *et al*,[2] described the use of a simple technique for the fixation of mandibular condyle fractures by using two plates overlaid. Authors compared the mechanical resistance of two separate plates and two overlaid plates. Forty synthetic polyurethane replicas of human hemimandibles were used to carry out the study. The fixation techniques were two separate four-hole plates with eight screws, and two overlaid four-hole plates with four screws. Load values and peak displacement were measured. They concluded that the use of a fixation system with two separate plates showed greater resistance in anteroposterior and mediolateral directions than a system of two overlaid plates. In situations where it is not possible to fix two separate plates in condylar fracture, and other fixation materials are not available (such as locking system plates and compression miniplates), the authors advocate that overlaid plates have shown themselves to be a good fixation alternative.

Of the reviewed literature, nine out of 10 compared plating techniques on subcondylar fractures or condyle neck fractures. Only one article compared stabilization of resorbable pins and titanium screws on diacapitular fracture.[20] Schneider *et al*,[20] reported that fixation with pins resisted mean shear forces of 310 N until the pins fractured, whereas fixation with titanium screws failed at 918 N when the screws pulled out of the bone.

CONCLUSIONS

Mandibular condyle fractures represent one of the most controversial issues in the relevant literature, especially with regard to recommended treatment. Therefore, it is necessary to carry out *in vitro* experimental studies to obtain better biomechanical performance in the rigid internal fixation of condylar fractures and to enable the development of ideal materials and techniques. According to biomechanical studies in literature related to miniplate fixation of mandible condyle fractures, single plates cannot provide enough stability in terms of biomechanics. However, double adaptation plating show sufficient resistance to motion and failure strength for immediate function. Resorbable plate is not strong enough compared to metal plates. According to some of authors, biodegradable plates can be used in this area if they can be applied as double plating. In addition to specially designed plate systems such as trapezoid and delta plates, two overlaid plate techniques serve as biomechanical alternatives for stabilization of condyle fracture.

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