
Volume 42 Issue 6 September 2014 ISSN 1010-5182
ELSEVIER
Journal of
Cranio-Maxillo-Facial
Surgery
Official Journal of the
European Association for Cranio-Maxillo-Facial Surgery
www.jcmfs.com

Journal of Cranio-Maxillo-Facial Surgery 42 (2014) 730–737

Contents lists available at ScienceDirect

Journal of Cranio-Maxillo-Facial Surgery

journal homepage: www.jcmfs.com

“A” shape plate for open rigid internal fixation of mandible condyle neck fracture

Marcin Kozakiewicz [a,*], Jacek Swiniarski [b]

[a] Department of Maxillofacial Surgery (Head: Marcin Kozakiewicz), Medical University of Lodz, Zeromskiego 113, 90-549 Lodz, Poland
[b] Department of Strength of Materials and Structures (Head: Zbigniew Kolakowski), Technical University of Lodz, Stefanowskiego 1/15, 90-924 Lodz, Poland

A R T I C L E I N F O

Article history:
Paper received 2 May 2013
Accepted 4 November 2013

Keywords:
Mandibular condyle neck
Fracture treatment
A-shape plate

A B S T R A C T

Introduction: Reduction of the fracture is crucial for proper outcome of the treatment. The stability of reduction is closed connected to the method of its fixation. The topic of condylar fracture osteosynthesis still remains highly controversial and challenging. That is why authors decided to propose novel design of the fixating plate and the example of its application. The aim of this study was to present A-shape plate dedicated to rigid fixation of mandible condyle neck fracture.
Material and methods: A-shape condylar plate (ACP) design is prepared of 1.0 mm thick titanium alloy (grade 5) sheet: posterior and anterior bars are reinforced by widening to 2.5 mm and anatomically curved along the compression and traction lines in ramus and condylar neck. Superior three-hole-group has triangular organization and located on the level of condylar head. The inferior extensions of the bars are equipped in three holes located at each of lower tails. Connecting bar (2.0 mm wide) connects the first hole of each lower tails closing upper part of ACP in triangular shape. The connecting bar runs along compression line of condylar neck. Holes in ACP has 2.0 mm diameter for locking or normal screws. Height of ACP is 31 mm. The proposed new type of plate was compared by finite element analysis (FEA) to nowadays manufactured 9-hole trapezoid plate as the most similar device. ACP design was evaluated by finite element analysis (FEA) and later applied in patient affected with high condylar neck fracture complicated by fracture of coronoid process.
Results: FEA revealed high strength of ACP and more stabile fixation than trapezoid plate. The result was caused by multipoint fixation at three regions of the plate and reinforced bars supported by semi-horizontal connecting bar. Clinical application of ACP was as versatile as makes possible to simultaneous fixation of high condylar neck and coronoid process fracture.
Conclusion: Application of proposed A-shape condylar plate would be possible in all levels of neck fractures and can be use for stabilization additionally existed coronoid process fracture.

1. Introduction

Mandibular condyle fractures are among the most frequently encountered injuries for patients who suffer facial trauma, and rigid internal fixation of the facial skeleton has become an accepted (Chossegros et al., 1996; Rasse, 2000; Wilk, 2003) and even expected treatment modality (Haug et al., 2002). The main focus has shifted somewhat from the debate of open versus closed treatment to more specific surgical questions (Abdel-Galil and Loukota, 2009). Ideas for rigid internal fracture fixation in the condylar area (base, middle, high neck, and head) have significantly changed in last decade (Schneider et al, 2008), but the question of how to stabilize the reduced fracture in the best way is still open (Aquilina et al., 2013). The topic of condylar fracture osteosynthesis still remains highly controversial and challenging.

The aim of this study was to present an A-shape plate specifically for rigid fixation of mandible condyle neck fracture.

2. Materials and methods

2.1. The plate

The design of A-shape condylar plate (ACP) is shown in Fig. 1. Total ACP height is 31 mm and width is 19 mm. The thickness of the plate is 1.0 mm of titanium alloy grade 5 (Ti6Al4V). According to known compression and traction lines in the mandibular ramus (Meyer et al., 2002) two main bridges in the A-shape condylar plate

* Corresponding author. Tel.: +48 42 6393738-9; fax: +48 42 6566547.
E-mail address: marcin.kozakiewicz@umed.lodz.pl (M. Kozakiewicz).

1010-5182/$ – see front matter © 2013 European Association for Cranio-Maxillo-Facial Surgery. Published by Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jcms.2013.11.003

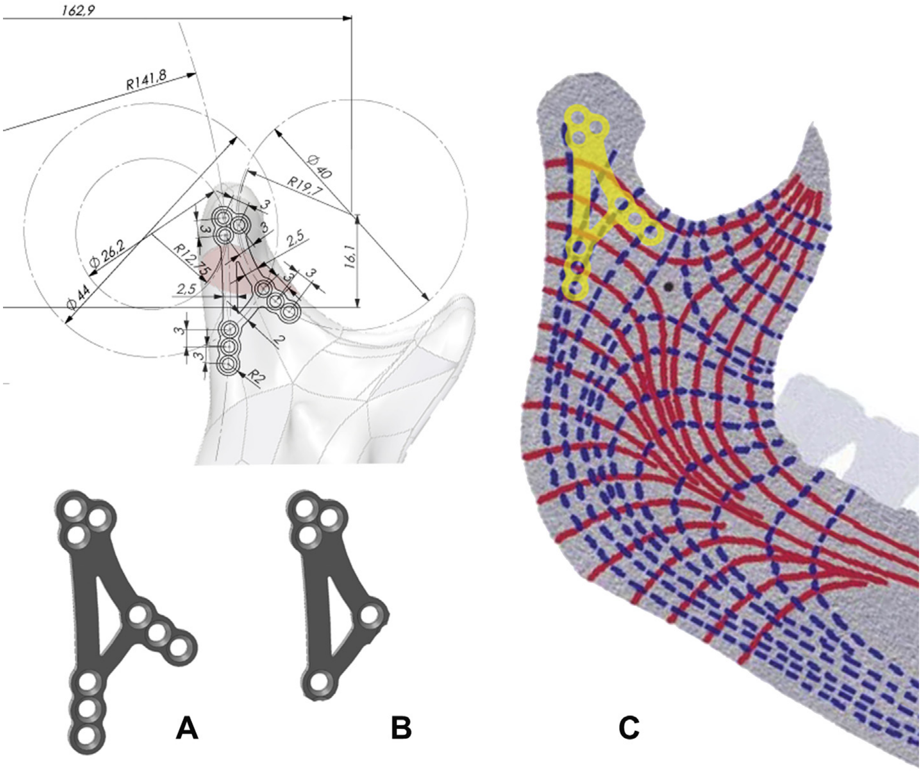

Fig. 1. Design of the A-shape condylar plate. Posterior and anterior bars are reinforced and anatomically curved. Superior three-hole-group has triangular organization. The bars are equipped in three holes located at each of lower tails. A – Full dimension plate of height 31 mm and wideness 19 mm. B – Plate can be intra-operationally reduced to triangle shape by cut off the lower tails. C – A-shape condylar plate imposed on stress distribution pattern in the mandibles (according to Meyer et al., 2002). Bars of the plate run along compression (blue) and traction (red) lines. Note: dimensions in millimetres, R-radius, design here is for right condylar neck fixation.

(ACP) are parallel to posterior border of the mandibular ramus [compression area] and along the sigmoid notch [traction area], respectively. Their width is 2.5 mm. There are three linearly located holes are on inferior tails of the bridges. Superiorly, the bridges converge and on top the 3-hole-group has a triangular organization. The 2.0 mm wide bar connects inferior parts of the bridges. The connecting bar runs along the compression line of condylar neck. All the holes have locking threads.

2.2. Material properties

For verification of the material properties of titanium alloy Ti6Al4V grade 5 a static tensile test according to ISO 6892-1 was performed. Three samples of the alloy were tested to breaking point. The test was performed in a universal tensile test machine (Instron 5989 with extensometer, Zwick/Roell).

2.3. Finite element analysis

The newly designed ACP (as above) was compared to the 9-hole-plate Medartis trapezoid condylar plate [Condylus Fragment Plate M-4858]. In both a locking screw system was used. For the boundary conditions the incisor teeth were fixed in three directions but could rotate, and the condyle could translate on the plane surface of a support. The loads used were for a mouth closing to 5 mm on an incisive tooth which is the condition that causes the most critical situation on the condyle (Mesnard et al., 2011, 2010), and which presents most tension and displacement in the condyle. The muscular actions applied here were similar to the ones presented in the dentomaxillofacial literature (Iwasaki et al., 2003; Ramos et al., 2011) and five principal muscles were included in the loading configuration (Fig. 2C): deep masseter: M1-left side, M2-right side (vector: $X = 7.776$ N, $Y = 127.23$ N, $Z = 22.68$ N), superficial masseter: M3-left side, M4-right side (vector: $X = 12.873$ N, $Y = 183.5$ N, $Z = 12.11$ N), medial pterygoid: M5-left side, M6-right side (vector: $X = 140.38$ N, $Y = 237.8$ N, $Z = -77.3$ N), temporalis: M7-left side, M8-right side (vector: $X = 0.064$ N, $Y = 0.37$ N, $Z = -0.13$ N) and medial temporal: M9-left side, M10-right side (vector: $X = 0.97$ N, $Y = 5.68$ N, $Z = -7.44$ N). These applied insertion muscles zones (Mesnard et al., 2011) and insertion centres of the muscles (Mesnard et al., 2010) have been based on MRI observations.

Finite element models are useful tools for demonstrating the biomechanical behaviour of complex structures (Hart et al., 1992; Field et al., 2009; Ichim et al., 2007). The FEM used in the present study was composed of tetrahedral linear elements with 4 nodes and 5,200,000 degrees of freedom (DOF) (Fig. 2C). The model constructed had no dentition because the presence of teeth has marginal influence on the biomechanics and behaviour of the mandibular condyles (Korioth et al., 1992; Ramos et al., 2011). This hypothesis was validated through experimental studies (Mesnard et al., 2010). For the convergence tests, the maximal displacements and the maximal equivalent strains were assessed in the regions where the rosettes were placed on the mandible. The convergence rate for the displacements and the equivalent strains was reached for a mesh of more or less 40,000 DOF. It was considered the convergence for 25,000 DOF (Hart et al., 1992) and a model with 47,525 elements (Lovald et al., 2009). The FEM was built and solved with Ansys R14.5 (Ansys Inc. www.ansys.com).

The simulations took into account the mechanical properties of mandibular cortical bone, which was considered to have a Young's modulus of 14.7 GPa and a Poisson coefficient of 0.3, similar to

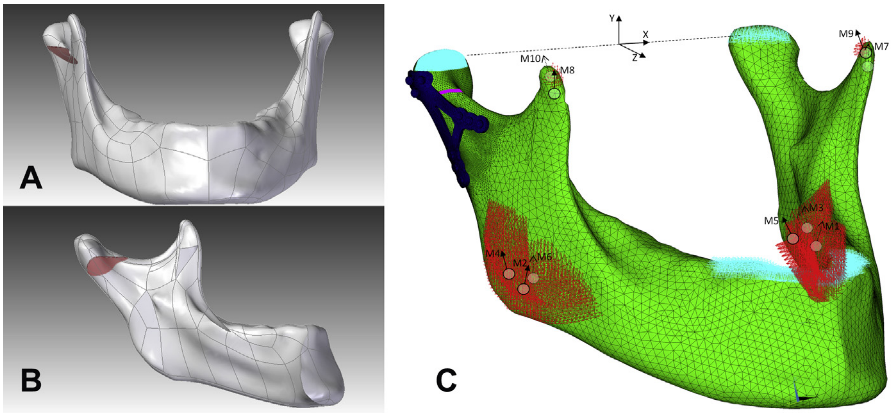

Fig. 2. Assumptions of the finite element analysis. A – Design of high condylar neck fracture (frontal view). B – Location of the fracture line in lateral view. C – Finite element model.

models used by other authors (Motoyoshi et al., 2009; Ichim et al., 2007; Field et al., 2009; Ramos et al., 2011) for experimental validation. The width of a fracture line after open reduction was simulated as 0.32 mm. The A-shape condylar miniplate and reference trapezoid plate were fixed with 9 screws (Fig. 2). The Young's modulus (titanium alloy) and Poisson coefficient of the Ti6Al4V implant and screws were 104 GPa and 0.3 respectively. Resolution of the mesh in thickness of the plates was a minimum of 5 layers of elements.

The implant was applied to the right side of the mandible (Fig. 2C). The implant position with respect to the mandible was defined by the level of the fracture. The high condylar neck fracture (Krenkel, 1997) was chosen according to one observed in a clinical example for open rigid internal fixation by the A-shape condylar plate (Fig. 2 A,B). To simulate the behaviour of the screws they were considered to be completely surrounded by cortical bone. The screw-implant contact was modelled as a touching contact situation. No contact between the implant and bone (0.3 mm distance) was modelled. This lack of contact was important for test of plates as a load bearing device. Stress and displacement in the fracture line were analyzed on the external surface of the mandible and plates (Figs. 3a, 4 and 5).

2.4. Clinical application

Ethic Committee approval was obtained for human treatment with A-shape condylar plates (RNN/738/12/KB).

A 37-year-old female presented following a road traffic collision. She had a high condylar neck fracture (according to Krenkel's classification) on the right side, complicated by coronoid process fracture ipsilaterally, (Fig. 9A, C) together with a laceration of the lower cheek and mental skin on the left side. In addition she had a right sided skin wound in the parietal and occipital region, cervical spine torsion and loss of consciousness, contusion of right shoulder, dislocated fracture of proximal part of left humeral bone and a dislocated fracture in the proximal 1/3 of fibula. After wound closure and stabilization of general status, consultation of neurosurgeon, maxillofacial surgeon, ophthalmologist, laryngologist, and orthopaedic surgeons, the humerus and fibula fractures were treated with open reduction and rigid internal fixation.

Eight days later, under general anaesthesia, a preauricular approach was performed on the right side. The condylar head was found dislocated antero-medially (Fig. 6). Downward wire traction was applied to a 2.0 mm diameter 8 mm long screw placed in the mandibular ramus. The condylar head was reduced (Fig. 7) and fixed by one A-shape condylar plate. Three screws were used in the proximal fragment, two screws were in the ascending ramus along the posterior border, and the coronoid process was fixed by the last two screws along the sigmoid notch (Fig. 8). Only 2.0 mm diameter and 6 mm long screws were used. The wound was closed watertight layer by layer.

3. Results

3.1. Material properties

It was established for investigated titanium alloy grade 5: Young's modulus 104 GPa, yield stress 934 MPa, ultimate tensile stress 1650 MPa and elongation to break approximately 10%.

3.2. Finite elements analysis

All models showed that after loading the distribution of stress spreads along the posterior border of ascending ramus and toward the sigmoid notch crest. It matches the normal biomechanical behaviour of the mandible during function.

Distribution of equivalent stress according to von Misses hypothesis of the FEA model of a mandible with a high condylar fracture reveals maximum equivalent stress in the A-shape plate but not in the bone. The maximum equivalent stress $\sigma_{red\ max} = 704$ MPa is located in the miniplate. The area of maximum equivalent stress is very limited and is caused by the mechanical solution in which the screw–plate interface is sharp. Equivalent stress in the last part of the ACP is lower than 300 MPa. This value is for titanium grade 5 is three times lower than yield stress. The bridge connecting the main arms of ACP is the stiffening element which lowers the flexibility of the ACP to bending and torsion loadings (Fig. 3a D and 3a E). The highest equivalent stress in the connecting bridge is not exceeded $\sigma_{red} = 30$ MPa. Distribution of equivalent stress in cortical bone showed a maximum stress $\sigma_{red\ max} = 96$ MPa. In close up observation it was well demonstrated that the area of the maximal stress is extremely limited to part of the hole edge in the condyle fragment of cortical bone. The highest equivalent stress in the screws is $\sigma_{red\ max} = 379$ MPa, less than half the yield stress of Ti6Al4V grade 5, which is $R_{02} = 934$ MPa. Comparison to the most similar plate i.e. Condylus Fragment Plate M-4858 is presented in Fig. 3b. The plate has a load bearing role [$\sigma_{red\ max} = 925$ MPa], with a value very near to the limit of titanium alloy yield stress. Moreover, high stress is observed in the plate around holes and connecting bridges over fracture line. That trapezoid

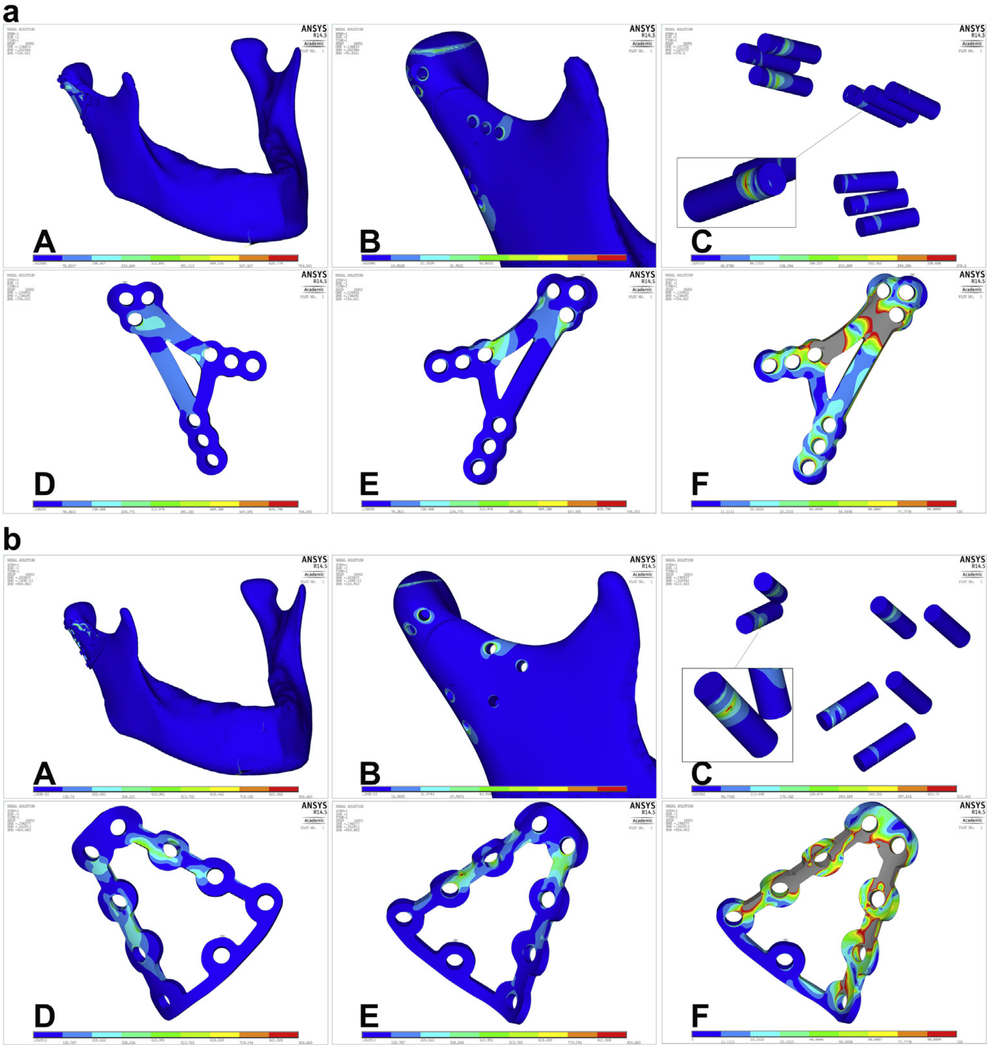

Fig. 3. a Distribution of equivalent stress according to von Misses hypothesis of finite element analysis of A-shape condylar plate used for internal rigid fixation. A – plate acts load bearing role; B – stress in bone of condylar process; one hole in superior part reveal stress of approx. 100 MPa; there are located in superficial bone; inferior six holes are loaded in balanced way; C - equivalent stress in screws; stress is respectively located as in bone; areas in contact to superficial cortical bone are the most stressed region in the screws; its maximum value is lower than half of required force according to yield stress of used titanium alloy; D - stress observed in the outer surface of the plate; anterior main bridge of the plate is stress up to 260 MPa; maximum stress is noted next to inferior group of the holes in anterior part; E – stress revealed on bone faced surface of the plate; anterior main bridge is on the stress up to 300 MPa; maximum stress is in inferior group of holes (700 MPa); it is lower than yield stress of used titanium alloy; F – evaluation of role of the connecting bar; relatively small stress is transmitted by the bar (minimal observed in experiment), but it supports the integrity of the both main bridges and superior three-hole-group. b Comparison to most similar miniplate – trapezoid-shape. A – plate acts load bearing role [925 MPa], near to border value of titanium alloy yield stress [934 MPa]; B – stress in bone of condylar process; anterior hole in condylar fragment reveals stress of approx. 140 MPa. Next in lower fragment the most upper and anterior hole shows approx. 130 MPa equivalent stress; there are located in superficial bone; C – equivalent stress in screws; stress is respectively located as in bone; areas in contact to superficial bone are the most stressed region in the screws; its maximum value is higher than for ACP screw system; D – stress observed in the outer surface of the plate; anterior part of the frame is stress up to 925 MPa; maximum stress is noted next to superior anterior hole located over fracture line; it should be pointed that concentration of stress is observed around holes over the fracture line. E – stress revealed on bone faced surface of the plate; anterior/lower and posterior/upper part is on the higher stress up to 925 MPa; it is near yield stress of used titanium alloy in regions over the fracture line; F – evaluation of role of the lower frame; small stress is transmitted by the frame.

plate fixation presents mean relative displacement of fracture fragments along the fracture line as: 116.3 ± 14.7 μm, versus A-shape condylar plate: 64.5 ± 4.8 μm tabl. 1 and fig. 5.

3.3. Clinical application

Stable osteosynthesis was achieved (Figs. 8, 9B and 9D). One plate fixation of two fractures was possible (high condylar neck and coronoid process). Two screws were put in lower ramus part of the plate along the posterior border, three screws into condylar head, and two screws stabilized the coronoid process fragment. The postoperational course was uneventful. The patient was discharged from the Department of Maxillofacial Surgery after 3 days.

4. Discussion

There is discussion in the clinical literature about how to approach the reduction of condylar fractures. Inferior condylar neck fractures benefit from open reduction with internal fixation by an intraoral approach whereas in high condylar neck fractures the retromandibular or transparotid approach shows the best results. Fractures of the condylar head were previously almost all treated by closed reduction [Handschel et al, 2012]. Results of surgical treatment of condylar process fractures are superior to the results of conservative treatment, and the procedure is safe with the transparotid surgical approach and good surgical technique [Vesnaver et al., 2012]. The current meta-analysis data suggest that open reduction with internal fixation for condylar fractures may be as good or better than

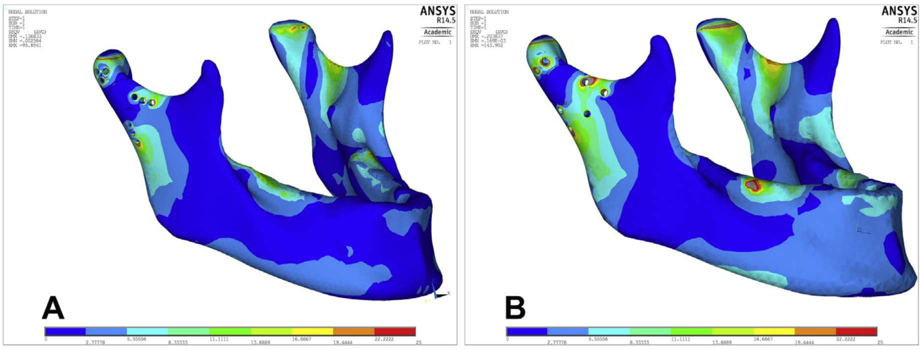

Fig. 4. Bone equivalent stress after rigid fixation in two methods. A – fixing by A-shape condylar plate: wide free of stress area around fracture line; high stress area around the upper and the most lower screws. B – application of trapezoid plate [Condylus Fragment Plate M-4858]: wide free of stress area around fracture line and wide spreading the stress in base of the condyle in posterior buttress of ramus; high stress distribution toward sigmoid notch.

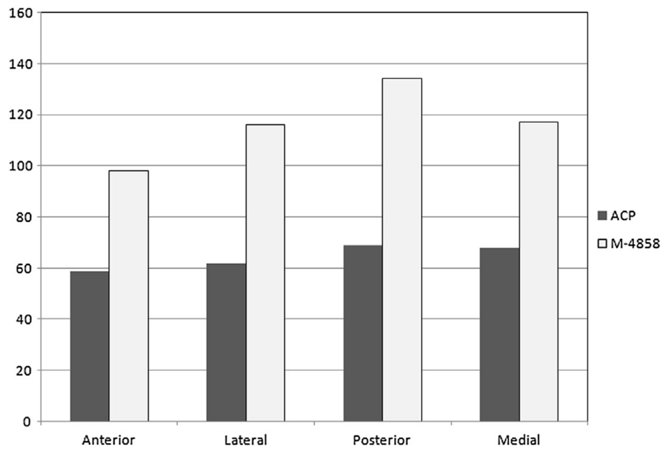

Fig. 5. Relative movement between fracture fragments in both pattern of internal fixation studied. A-shape condylar plate (ACP) predicts the less movement when compared with trapezoid plate (M-4858). Results in micrometres.

conservative management. The morbidity associated with the operation is low. However, the available evidence is of poor quality and not strong enough to change clinical practice [Kyzas et al., 2012].

The major principle in all fracture treatment is prefect reduction, but generally it cannot be maintained post-operationally without suitable fixing materials. Fracture of a plate has been described (Wagner et al., 2002). It is supposed that the main reason was improper reduction, but also the load-bearing plate construction would be helpful (Kleinheiz and Meyer, 2009). Thus, reduction and fixation are involved with each other.

Location of the plates is determined by the lines of force distribution in the ramus. According to Meyer (Meyer et al., 2002) tension is the highest along the sigmoid notch and compression is the highest along posterior border of ramus. Both the bundles of lines meet in upper part of condylar neck. Concerning the worse forces i.e. stretching, the ideal site for fixed lower and intermediate high fracture would be the area just below the sigmoid notch. Unfortunately, the bone at that site is thin and it would be difficult to stabilize torsion caused by lateral forces. This is why the second plate location is recommended along the posterior border of the ramus. It is a gold standard for ORIF of condylar neck (Choi and Yoo, 1999).

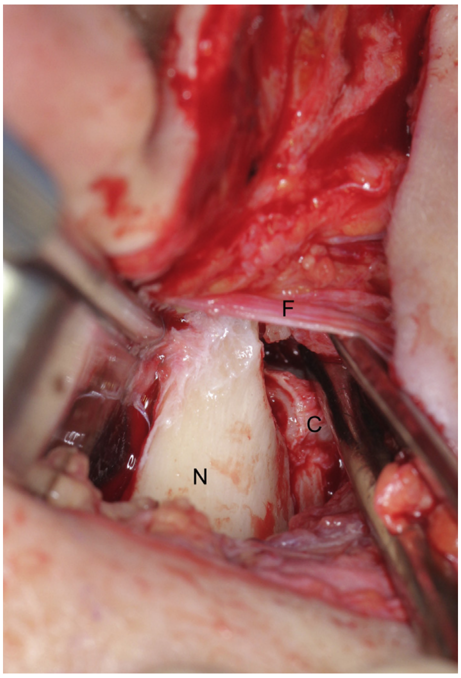

Fig. 6. Intra-operational view – right side, high condylar neck fracture. Preauricular approach. Antero-medial dislocated proximal fragment of condylar process. N-neck of the condyle; C – condylar head; F – facial nerve.

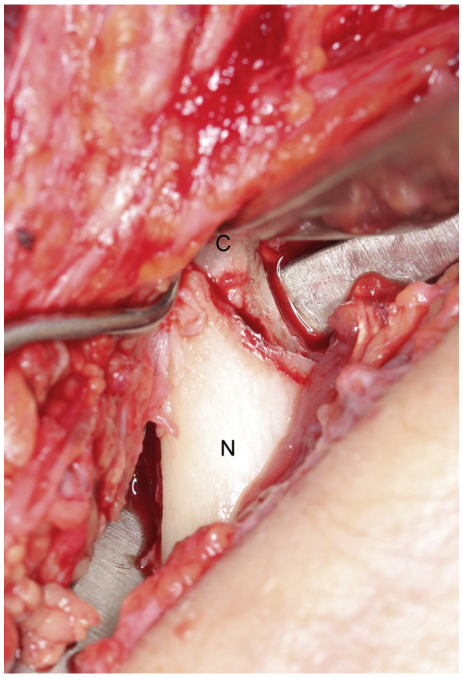

Fig. 7. Reduced condylar neck fracture. N-neck of the condyle; C-condylar head.

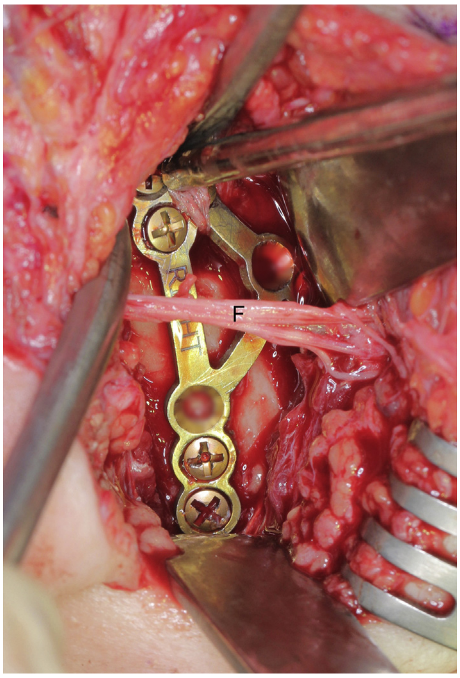

Fig. 8. Rigid internal fixation by A-shape condylar plate and 2.0 mm screws. F – facial nerve.

Difficulties in extraoral surgical approaches determined miniaturization of the plates which could combine strength and possibility of intraoral endoscopic installation or would limit the extension of skin approach. Nowadays a series of trapezoid (Medartis, Synthes, KLS Martin) and triangle plate (Medartis) are available. Generally, plates dedicated for endoscopic oral approach (four-hole plates) are too small to be used for management of all types' condylar region fractures, but mainly for intermediate high neck fracture fixation. There are bigger plates, such as 9-hole trapezoid (Medartis) and lambda plates (Synthes). The first one is very versatile in intermediate and lower fractures of the neck, but comminuted fractures need additional plates. Moreover, the two upper holes are distant each other. The lambda plate is useful in all level fractures of the neck, but sometimes in high fractures only 2 designed holes are not enough for stabilization of the reduced proximal fragment.

The above principles (reinforcement, multipoint fixation, three dimensionally stable) led to the design and construction of the A-shape condylar plate. The goal of reinforcement was reached by wider bars located along physiological lines of compression and traction forces. The increased width of the bar is 2.5 mm and there is no hole set in the bar. Next, double bars: anterior and posterior, supports two areas of the condylar neck. Multipoint fixation is achieved by 9 holes located in top and two tails of the plate, which is combined with 3-D stabilization accomplished by the inferior connecting bar (2.0 mm wide). Finite element analysis revealed that there were no regions in the ACP where maximal equivalent stress was higher than threshold values for the material used. Three screws in proximal (condyle) fragment made it rigid in all directions.

The anatomical design caused the side orientation of the plate, thus there is the need for two types of A-shape condylar plates.

The new ACP revealed higher equivalent stress than reference Medartis plate. On the one hand, ACP acts as a more load bearing device than reference, but the material properties ensures that the plate strength is suitable for such as role. On the other hand, load bearing is better for immobilisation of the reduced bone fragments. It eliminates micromovements more efficiently, and encourages fracture healing.

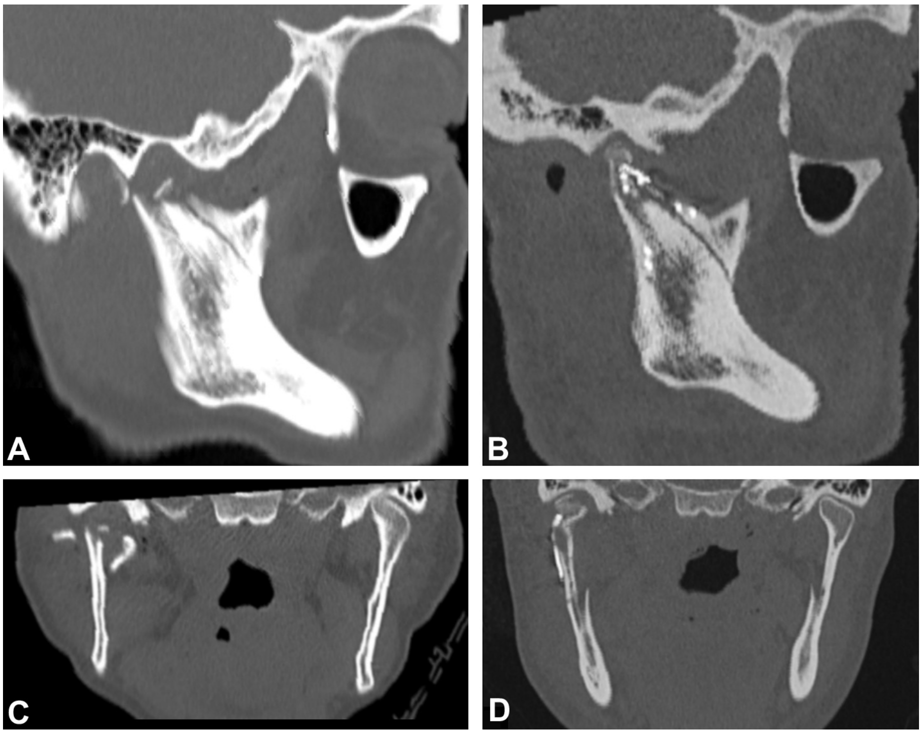

Fig. 9. Computerized tomography of A-shape condylar plate clinical application (in coronal view). A – comminuted high condylar neck fracture complicated by coronoid process fracture, external acoustic meatus is closed (sagittal view). B – after open rigid internal fixation, 3 screws in proximal fragment, 2 screws in distal fragment and also 2 screws fixed coronoid process (sagittal view). C – comminuted high condylar neck fracture (coronal view). D – reduction and fixation led to restore height of the mandibular ramus (coronal view).

In the trapezoid plate [Condylus Fragment Plate M-4858] the concentration of stress is observed around holes over the fracture line [approx. 900 MPa]. These holes without screws are the most intense and hazardous part of the plate. A plate brake has been seen in such as regions [Wagner et al., 2002]. For a fracture to occur additional unfavourable circumstances, eg. improper reduction, extensive biting by the patient, are necessary, when the plate braking will occur at the hole without the screw just over the bone fracture line.

Evaluation of stability in the region of the fracture line fixed by plates [ACP or M-4858] revealed the opportunity to take stress from bone to miniplate, and distribute it to numerous screws [for example 9]. It should be noted that the higher stress is observed in model with M-4858, than in ACP. Analysis of bone fragment movements revealed that reference trapezoid plate causes enlargement of fracture fissure after loading twice as much as the ACP. It is expressed mostly in the posterior border of the condylar neck i.e. compression region of loaded mandible. It was demonstrated [Aquilina et al., 2013] that plate fixation with 4 screws in condylar fragment [proximal] is much more stable than two-screw fixation. Mean relative displacement of fracture fragments along the fracture line in one plate [2 upper screws] is 115.4 ± 3.0 μm versus two plates [4 upper screws]: 29.9 ± 3.7 μm or 46.4 ± 2.2 μm - configuration depended [Aquilina et al., 2013]. In the A-shape condylar plate [3 upper screws] 64.5 ± 4.8 μm was reached and respectively in trapezoid-shape plate M-4858 [2 upper screws] 116.3 ± 14.7 μm. Stabilization in distal fragment of neck fractures [mandibular ramus] is relatively easy as clinical experience shows, but the condylar head is sometimes a challenge. This leads to the conclusion that the number of screws in proximal fragment is essential for rigid internal fixation.

Rigid internal fixation with double mini plates showed the best stability (over the trapezoid plate, delta and dynamic compression plate) 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 (Lauer et al., 2007). Proposed ACP provides 3-D stability by combine the advantages of above plates, especially trapezoid and double miniplates. The locking system of the plate has, despite of improvement of plate durability in hole surrounding regions, the advantages of greater primary stability and decreased likelihood of screw loosening.

Advantages of the A-shape condylar plate:

1. meets requirement of fixation along compression and traction lines in ramus and condylar neck,
2. provides anatomical reduction, functional and stable osteosynthesis within one-plate application,
3. no compression plate (locking system) protects bone fragments displacement during fixation,
4. durable construction,
5. possible fixation of multiple fractures (i.e. both condylar and coronoid processes),
6. can be adjusted i.e. shorten by cutting off unnecessary lower tails.

Disadvantages:

1. relatively large size (if dimensions are not adapted by cut off the lower tails),
2. metal implant,
3. need bone drilling,
4. one plate for left side and another type for right side.

5. Conclusion

Application of proposed A-shape condylar plate would be possible in all levels of neck fractures of mandible and can be use for stabilization additionally coronoid process fractures.

Funding

Source of support in the form of grant of Medical University of Lodz: 503/5-061-02/503-01, 502-03/5-138-03/502-54-084.

Conflict of interest

The authors have declared no conflict of interest.

Acknowledgements

Ledo Co (www.ledo.pl) for support in CAD and CAM of the A-shape condylar plate. ChM Co (www.chm.eu) for titanium alloy raw material, surface conditioning and laser marking of the prototype plates.

References

Abdel-Galil K, Loukota R: Fractures of the mandibular condyle: evidence base and current concepts of management. Br J Oral Maxillofac Surg 48: 520–526, 2009
Aquilina P, Chamoli U, Parr WCH, Clausen PD, Wroe S: Finite element analysis of three patterns of internal fixation of fractures of the mandibular condyle. Br J Oral Maxillofac Surg 51: 326–331, 2013
Choi BH, Yoo JH: Open reduction of condylar neck fractures with exposure of the facial nerve. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 88: 292–298, 1999
Chossegros C, Cheynet F, Blanc JL, Bourezak Z: Short retromandibular approach of subcondylar fractures: clinical and radiologic long-term evaluation. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 82: 248–252, 1996
Field C, Ichim I, Swain MV, Chan E, Darendeliler MA, Li W, et al: Mechanical responses to orthodontic loading: a 3-dimensional finite element multi-tooth model. Am J Orthod Dentofacial Orthop 135: 174–181, 2009
Handschel J, Rüggeberg T, Depprich R, Schwarz F, Meyer U, Kübler NR, et al: Comparison of various approaches for the treatment of fractures of the mandibular condylar process. J Craniomaxillofac Surg 40: e397–e401, 2012
Hart TR, Hennebel V, Thongpreda N, Van Buskirk WC, Anderson RC: Modelling the biomechanics of the n audible: a three-dimensional finite element study. J Biomech 25: 261–286, 1992
Haug RH, Gilman P, Peterson GP, Goltz M: A biomechanical evaluation of mandibular condyle fracture plating techniques. J Oral Maxillofac Surg 60: 73–80, 2002
Ichim I, Kieser JA, Swain MV: Functional significance of strain distribution in the human mandible under masticatory load: numerical predictions. Arch Oral Biol 52: 465–473, 2007
Iwasaki LR, Baird Brian W, McCaIl Jr WD, Plickel Jeffrey C: Muscle and temporomandibular joint forces associated with chin cup loading predicted by ical modeling. Am J Orthod Dentofacial Orthop 124: 530–540, 2003
Kleinheiz J, Meyer C: Fractures of the mandibular condyle: basic considerations and treatment. London: Quintessence Publishing Co, Ltd, ISBN: 13:978-1-850-97180-1, 2009
Korioth TW, Romilly DP, Hannam AG: Three-dimensional finite element stress analysis of the dentate human mandible. Am J Phys Anthropol 38: 69–96, 1992
Krenkel C: Treatment of mandibular-condylar fractures. Atlas Oral Maxillofac Surg Clin North Am 5: 127–155, 1997
Kyzas PA, Saeed A, Tabbenor O: The treatment of mandibular condyle fractures: a meta-analysis. J Craniomaxillofac Surg 40: e438–e452, 2012
Lauer G, Haim D, Proff P, Richter G, Pradel W, Fanghänel J, et al: Plate osteosynthesis of the mandibular condyle. Ann Anat 189: 412–417, 2007
Lovald ST, Wagner JD, Baack B: Biomechanical optimization of bone plates used in rigid fixation of mandibular fractures. J Oral Maxillofac Surg 67: 973–985, 2009
Mesnard M, Ramos A, Ballu A, Morlier J, Cid M, Simoes JA: Biomechanical analysis comparing natural and alloplastic temporomandibular joint replacement using a finite element model. J Oral Maxillofac Sung 69: 1008–1017, 2011
Mesnard M, Ramos A, Lokhov VA, Ballu A, Nyashin Yi, Simfies JA: Muscular and articular forces exerted on the mandible. In: 1st International conference on biodenlal engine ring. Porto, Portugal: CRC Press (Taylor 8 Francis), 199–204, 2010 ISBN: 978-0-415-57394-8
Meyer C, Kahn JL, Boutemi P, Wilk A: Photoelastic analysis of bone deformation in the region of the mandibular condyle during mastication. J Cranio-Maxillofac Surg 30: 160–169, 2002
Motoyoshi M, Ueno 5, Okazaki K, Shimuzi N: Bone stress for a mini implant close to the roots of adjacent teeth-3D finite element analysis. Int J Oral Maxillofac Surg 38: 363–368, 2009

Ramos A, Completo A, Relvas C, Mesnard M, Simoes JA: Straight. Semi-anatomic and anatomic TMJ implants: the influence of condylar geometry and bone fixation screws. J Cran Maxilllofac Surg 39: 343–350, 2011
Rasse M: Neuere Entwicklungen der Therapie der Gelenkfortsatzbruche der Mandibula. Mund Kiefer Gesichtschir 4: 69–87, 2000
Schneider M, Erasmus F, Gerlach KL, Kuhlisch E, Loukota RA, Rasse M, et al: Open reduction and internal fixation versus closed treatment and mandibulomaxillary fixation of fractures of the mandibular condylar process: a randomized, prospective, multicenter study with special evaluation of fracture level. J Oral Maxillofac Surg 66: 2537–2544, 2008
Vesnaver A, Ahčan U, Rozman J: Evaluation of surgical treatment in mandibular condyle fractures. J Craniomaxillofac Surg 40: 647–653, 2012
Wagner A, Krach W, Schicho K, Undt G, Ploder O, Ewers R: A 3-dimensional finite-element analysis investigating the biomechanical behavior of the mandible and plate osteosynthesis in cases of fractures of the condylar process. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 94: 678–686, 2002
Wilk A: La chirurgie du condyle mandibulaire. Resume Rev Stomatol Chir Maxillofac 104: 121–122, 2003