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Biomechanical stability analysis in the plate-niting of the mandibular angle

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The purpose of this study was to compare the biomechanical stability of two types of plating (osteosynthesis) used to fix fractures of the mandibular angle. The fixation systems included: (1) a single six-hole miniplate; (2) two miniplates – six-hole as before and an additional four-hole miniplate. All plates and screws used in this experiment were made of stainlees steel (Champy type). A simple angle fracture was made in the mandible models at a standardized location. The stability of the fixations was measured using the holographic interferometry method. Displacements of mandibular bone fragments were examined.

Key words: mandible, miniplate, displacement analysis

1. Introduction

Surgical methods of stabilizing craniofacial bones are modelled in accordance with a basic rule in general orthopaedic surgery. There are clear indications for the use of miniplate osteosynthesis for fractures of the mid-face [2], [6]–[11], [13]. The qualities and clinical effects of stabilization depend on the kind of fracture and biomechanical conditioning (geometrical features of miniplates and their mechanical properties) and techniques of stabilization together with the skills of the operator.

There are still improvements in the treatment of mandibular fractures, which depend on the arrangement of the bone fragments in their anatomical position and their immobilization until the beginning of concrescence. Existing, practical techniques of stabilizing fractures of the mandible internally are mostly based on clinical experience.

Most frequently observed are fractures the crevice being located in the angle region of the mandible [4], [5]. For this case surgeons usually use two straight miniplates: 6-hole miniplate (as princial plate) and 4-hole miniplate (as an additional helping plate).

Because of the lack of publications concerning the biomechanic conditions occurring during the work of the broken mandible, stabilized with miniplates, the authors undertook investigations in order to qualify dislocations and deformations for these techniques of stabilizing the fracture fragments. Determination of biomechanic conditions is of vital importance for the recognition of secondary displacements of the bone fragments due to the action of forces originating from different muscular groups, which will presumably lead to a better and more correct stabilization [12].

The values of forces initiated by temporal and masseteric muscles (but not those of the temples and flanks), assumed in this work, are greater than the forces which occur when mandible is broken [3], [14]. This may not adequately represent the physiologic load of a broken mandible.

Holographic interferometry was used to study these dislocations and deformations, because it makes it possible to measure the examined object as a whole [1], [8].

2. Material and methods

The aim of this investigation was to qualify dislocations and deformations of jaws stabilized by implants in the course of biting. Two identical models of jaws were analysed, in which a cut simulated an oblique break adjacent to the angle of the mandible. Such breaks are most often observed in clinical practice. The direction of the crevice determines the dislocation of blocks, resulting from the activity of the muscles and movement of the mandible, as well as from the influence of the weight of osseous blocks. A model of the mandible was made of epoxy resin imitating a real human jaw.

The fracture in the mandible was joined with stabilizers of Champy plates with four or six holes made of AISI 316L steel, arranged as follows:

- two lines of plates, with four and six holes jointly,
- a single six-hole plate.

The system of burdening thus designed permitted simulation of the operation of two main muscular groups (temporal and mandibular muscles) acting on both sides, according to the physiological and biomechanical circumstances of mastication (figure 1). In such a system of burdening the dislocations of two bone fragments of the mandible stabilized with miniplates were analysed. Investigation was carried out for three kinds of loads of the mandible, i.e., applied to the incisors and to the left and right fangs (figure 2), making use of the optical holographic interferometry.

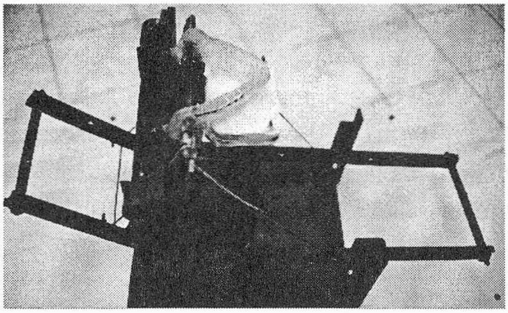


Fig. 1. View of the burdening system

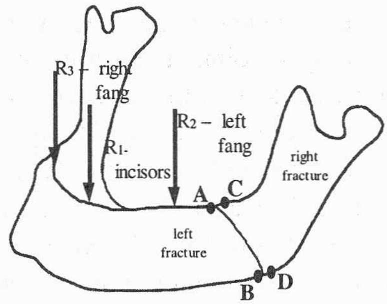


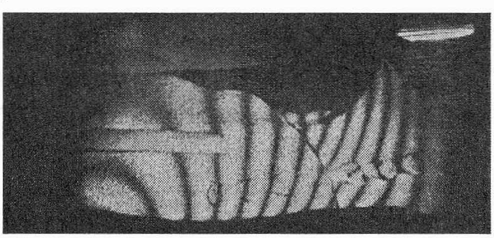
Fig. 2. Points along the edge of the fracture and points of applying the load

3. Results

The investigation and analysis of dislocations and deformations of a mandible stabilized with plates were carried out for the following loads: temple F_S = 80 N and masseteric F_Z = 50 N [15], [16]. Then, in this model, the load on the temple muscle was increased successively: F_{S1} = 1.8 N, F_{S2} = 2.7 N, F_{S3} = 4 N. In order to avoid too large deformations occurring in the mandible at increased loads the following ones were assumed: 0.8 N, 1.3 N, 2.7 N. The load on the mandible was constant due to the role of temporal muscles in the mechanism of transferring the forces [15], [16].

Based on the interferograms obtained different parameters were determined characterizing the dislocations of fractures in the mandible, which changed according to the circumstances and depending on the kind of fracture. Examples of the holographic interferograms obtained are presented in figure 3.

a



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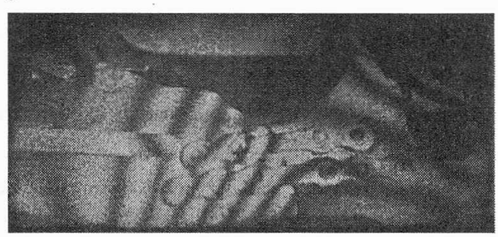


Fig. 3. Holographic interferograms registered for the model of a mandible:
a) support on the right fang $F = 80$ N, $\Delta F = 0.8$ N, b) support on the incisors $F = 80$ N, $\Delta F = 2.7$ N

The values of dislocations of definite points were determined at the boundary of the fracture on the right and left fangs of the mandible. Points *A*, *B*, *C* and *D*, at which the dislocations were measured, are shown in figure 2.

Tables 1 and 2 present the results of measurements of dislocations of the determined points depending on the way of stabilization, places of applying force on the teeth and the values of an increase of force of the mandibula. The maximum value of dislocations of points A and B in the case of joining with one plate only is attained at the highest values of the load $\Delta F_{S3} = 4$ N when the support of the teeth is situated on the right fang ($A = 15.42 \cdot 10^{-7}$ m, $B = 28.27 \cdot 10^{-7}$ m),), the least one when the support is on the left fang ($A = 11.56 \cdot 10^{-7}$ m, $B = 5.91 \cdot 10^{-7}$ m). The greatest dislocations of points C and D are to be observed if the incisors are supported ($C = 20.56 \cdot 10^{-7}$ m, $D = 10.28 \cdot 10^{-7}$ m), point C attaining its maximum of dislocation compared with other points and at the support of the left fang ($C = 33.41 \cdot 10^{-7}$ m) (table 1).

Table 1. Values of dislocations at selected points at the edge of the fracture depending on the place of applying the force on the teeth. A single six-hole plate and double stabilization with miniplates of steel with four and six holes

	Support on the incisors				Support on the right fang				Support on the left fang			
	Dislocations at selected points on the edge of the fracture [10^{-7} m] Stabilization with a six-hole miniplate											
	A	B	C	D	A	B	C	D	A	B	C	D
ΔF_{S1}	7.71	11.56	11.56	6.42	12.85	17.99	10.28	7.71	3.85	6.42	12.85	4.62
ΔF_{S2}	12.85	20.56	21.84	10.28	12.85	20.56	12.85	7.71	6.42	3.85	23.13	5.14
ΔF_{S3}	14.13	23.13	20.56	10.28	15.42	28.27	15.42	11.56	11.56	5.14	33.41	5.14
	Dislocations at selected points on the edge of the fracture [10^{-7} m] Stabilization with a miniplate with four and six holes											
	A	B	C	D	A	B	C	D	A	B	C	D
ΔF_{S1}	7.71	19.27	8.73	8.22	8.99	15.93	7.96	7.45	7.71	16.44	7.19	6.42
ΔF_{S2}	12.85	29.04	13.87	14.90	12.85	28.27	8.99	10.28	20.56	29.55	10.28	11.05
ΔF_{S3}	12.85	31.61	14.90	15.93	13.10	33.41	13.62	12.85	25.70	39.83	13.36	12.85

Points A and B joining two plates shift most for $\Delta F_{S3} = 4$ N, when the support of the teeth is situated on the left fang ($A = 25.70 \cdot 10^{-7}$ m, $B = 39.83 \cdot 10^{-7}$ m). The least dislocations occur at the support on the incisors ($A = 12.85 \cdot 10^{-7}$ m, $B = 31.61 \cdot 10^{-7}$ m) (table 1).

The support of the stabilized mandible on the left fang is characterized by considerable differences of dislocations between the respective points: it is to be observed, however, that points B and D (on the bottom edge) shift imperceptibly in relation to points A and C.

From analyses of dislocations of points A, B, C and D one can infer that the best stabilization of the mandibles (i.e. without great differences of the values of dislocations between points AB and CD) is observed in the case of stabilization with two miniplates.

Based on the magnitude of dislocations of points A, B, C and D, the dislocations of the mandible were determined, depending on the way of exerting forces on the teeth.

The magnitudes of dislocations were determined for the maximum increase in forces of temporal muscles ΔF_{S3} = 4 N. In the case of smaller forces the dislocations are smaller (table 1).

If we accept that a negative value of dislocation indicates the opening of a gap, whereas a positive value indicates its tightening, one can notice that only the mandible stabilized with a single miniplate will open itself on one side and tighten on the other. A one-sided opening of the mandible supports the incisors ($AC = -6.43 \cdot 10^{-7}$ m) and the left fang. In order to support the left fang the upper gap (*AC*) remains open ($AC = -21.85 \cdot 10^{-7}$ m), whereas its bottom part (*BD*) remains almost in the same place, reaching only a slight displacement equal to $BD = 0.77 \cdot 10^{-7}$ m.

A one-sided opening of the gap occurs also at the supports on the incisors and right fang ($AC = -2.05 \cdot 10^{-7}$ m, $AC = -0.52 \cdot 10^{-7}$ m) (table 2).

In the case of stabilization of the mandible with two miniplates at each support considered the blocks are tightened, the most steady pressure occurring at the support on the right fang ($AC = 23.13 \cdot 10^{-7}$ m, $BD = 25.70 \cdot 10^{-7}$ m).

Measurements of dislocations by means of holographic interferometry have shown that in both examined configurations of a mandible stabilized with one or two miniplates, there are dislocations of the blocks, which are the greatest at a maximum increase of the forces of the temporal muscles, amounting to ΔF_S = 4 N (at a constant acting force of the temple muscles F_S = 80 N).

Table 2. Dislocations between points *AC* and *BD* depending on the place of applying forces on the teeth, at a maximum increase of the forces of the temple muscles ΔF_{S3} = 4 N

Open gap	Support on the incisors	Support on the right fang	Support on the left fang
Stabilization with a six-hole miniplate of steel AISI 316L			
AC [10^{-7} m]	–6.43	2.57	–21.85
BD [10^{-7} m]	12.85	16.71	0.77
Stabilization with a four- and six-hole miniplate of steel AISI 316L			
AC [10^{-7} m]	–2.05	–0.52	12.34
BD [10^{-7} m]	15.86	20.56	26.98

Next, dislocations along a straight line were analysed, passing through the centre along the mandibles between the stabilizing plates (two joining plates). In the system with one six-hole plate the position of the straight line does not change and coincides with the axis of the openings of the plates. For analysis two characteristic points were selected situated on both sides of the edge of the fracture. The analysed points are presented in figure 4.

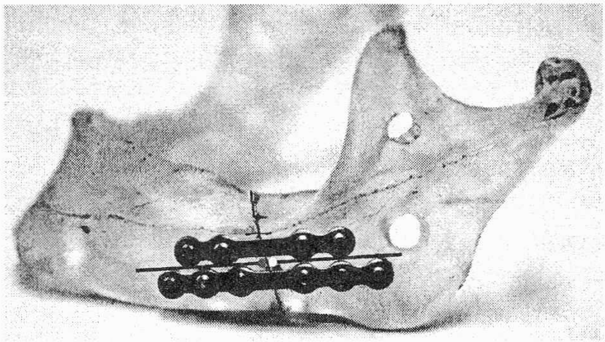
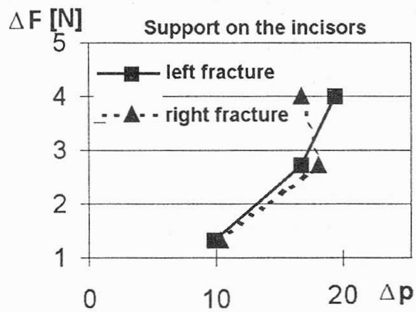
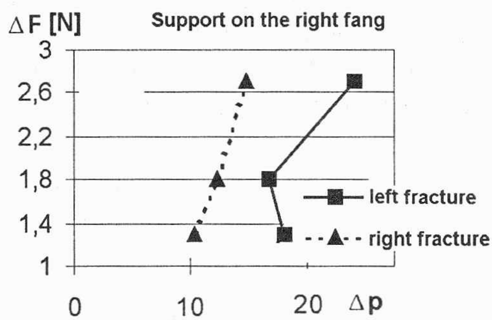


Fig. 4. Points situated along a straight line
at the opposite ends of the edge of the fracture

Graphs of dislocations of the proposed points depending on the increase of forces, the temple muscles of the mandible, on the kind of its load and model of stabilization have then been set up (figures 5 and 6).





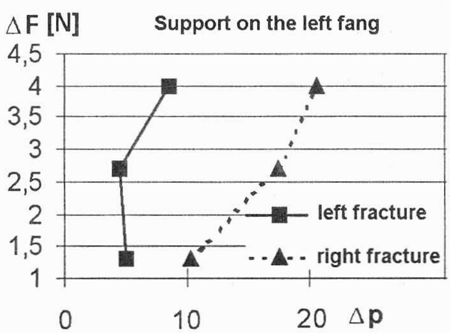
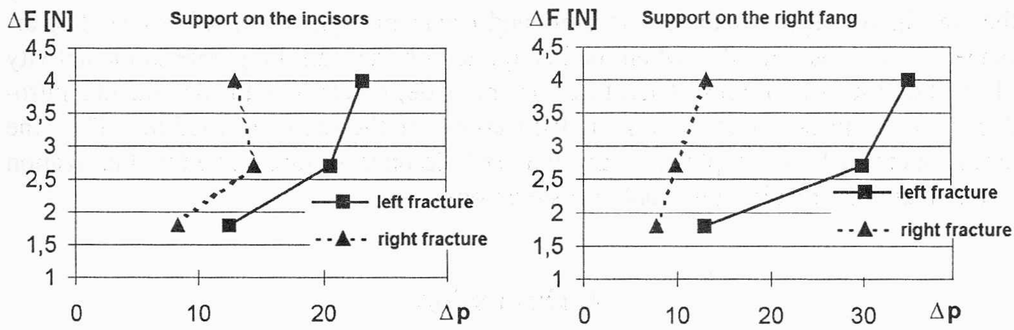


Fig. 5. Graphs of dislocations of the points along a straight line on the right and left fracture of the mandible. Stabilization with a single six-hole miniplate made of AISI 316L steel, ΔF – increase of the force of the temple muscles [N], Δp – dislocation [10^{-7} m]

If the mandible is stabilized with a six-hole miniplate of AISI 316L steel, the dislocation of the right fracture tends to deform itself uniformly, no matter which kind of support has been applied. This is indicated by the curve of dislocations of this fracture. The values of dislocations range from 10 to $20 \cdot 10^{-7}$ m, growing with an increase of the force of temple muscles. The left fracture, however, does not behave in this way and changes distinctly depending on the kind of support and the values of F_S.



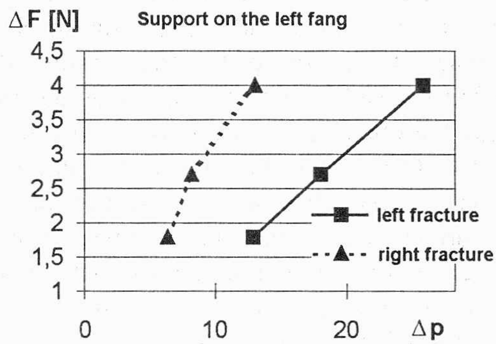


Fig. 6. Graphs of dislocations of the points along the straight line on the right and left blocks of the mandible. Stabilization with four- and six-hole miniplates made of AISI 316L steel, ΔF – increase of the force of temple muscles [N], Δp – dislocation [10^{-7} m]

At the support on the incisors the right and left fractures are deformed in a similar way, i.e., the dislocation curves of the left and right fractures attain identical values of dislocations in the range ΔF_S = 1–2.7 N. In the case of an increase of F_S, the dislocations of the right fracture decrease, whereas those of the left one grow.

While supporting the left fang, the deformations of the right fracture grow steadily in the range from 10 to $14 \cdot 10^{-7}$ m, while the dislocations of the left fracture (above ΔF_S = 1.8 N) grow stepwise from 17 to $25 \cdot 10^{-7}$ m.

In the case of a mandible stabilized with two miniplates supported on the left fang, the dislocations of fractions are linear. They occur within the range of $7–28 \cdot 10^{-7}$ m, both the left fraction and the right one having lower values of dislocations and being characterized by an identical course of curved dislocations.

At the support on the right fang there occur very large dislocations, especially of the left fraction, whose value of dislocations grows in the interval of loads ΔF_S = 1.4–2.7 N from 12 to $30 \cdot 10^{-7}$ m and ΔF_S = 2.7–4 N from 30 to $38 \cdot 10^{-7}$ m. It is therefore to be supposed that the load of the mandible supported on the right fang yields large instability of the given system.

The support on the incisors brings about dislocations which grow in the range from 7 to $20 \cdot 10^{-7}$ m on both fractions for loads of ΔF_S = 0.5–2.7 N. Above this limit, on the left fraction slight dislocations have been recorded, whereas the dislocations on the left fraction undergo a reduction (figure 6).

The quality of stabilization, and thus the magnitude of dislocations are affected by the way in which the mandible is burdened (incisors, right fang, left fang). The arrangement is most unstable when load is applied on the right fang, due to the activity of the large arm of forces. Therefore, on this side, together with the fracture introduced there appear large values of dislocations of the osseous fractions. Thus the arrangement of two miniplates: four- and six-hole ones, ensures a better stabilization of the mandible, resulting in smaller dislocations.

4. Discussion

The course of healing is influenced by the anatomical arrangement of the osseous blocks and compact adhering to the surface of fraction. A straight cut of the mandible changes the profile of the fracture line, if compared to actual ones, which are most often meshed in both the side-line and the upper one. The investigation has shown that the obtained dislocations of fractures for different techniques of joining are not large. They cannot be compared with those required, as in hitherto existing observations of the clinical concrescence of mandible bones, dislocations conditioning a correct concrescence have not been determined so far.

The investigation has shown that a more convenient variant of stabilizing the fractions of the mandible is to join them with two miniplates. Slight (tensile and compressive) dislocations obviously favour the concrescence due to the electromechanic effects and the generation of flow potentials, which contribute to the transportation of mineral components to the bones. The junction with one plate can cause considerable dislocations of the fractures or even deteriorate the osseous concrescence if insufficient techniques of joining the miniplate with the bone are applied.

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