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Original paper

Application of holographic interferometry and speckle photography in the evaluation of mandible stabilization techniques

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Application of the holographic interferometry and speckle photography in the primary stability determination of a mandible undergoing the bilateral sagittal split osteotomy (BSSO) is described. Measurements were carried out on Synbone models of human mandibles representing three different techniques of stabilisation. The maximum value criterion of the cut edge displacement components was used for the evaluation of the devices applied (miniplates and bicortical screws). A hybrid technique (miniplate with bicortical screw) of the mandible stabilisation is proposed.

Key words: *mandible osteotomy, stability, holographic interferometry, speckle photography*

1. Introduction

Rigid internal fixation for mandible osteosynthesis, after the bilateral sagittal split osteotomy (BSSO), at present constitutes the basic type of the osteosynthesis ([1]–[6]). The stabilisation is achieved using bicortical screws or/and miniplates. In those cases, the primary stability of fixation is the function of many factors, including the structure of the implant, its material, positioning in relation to the proximal and distal segments of the mandible as well as the location of the fractures. This requires examining the osteosynthesis stability achieved with the help of different types of implants. Clinical trials concern mainly the interaction between human organism and implants, including the assessment of long-term effects of the stabilisation, whereas the examinations of the osteosynthesis stability performed on mandible preparations and models allow assessment of such parameters as, e.g., displacements of crack's edges [5], comparing the stiffness of joining segments of the mandible using bicortical screws and four-hole miniplate [6], selection of the amount of miniplates [7], and determination of their strength [8]–[11]. In the case of evaluating the primary osteosynthesis stability, the measuring techniques most often applied enable the measurement of the displacements of crack edges (e.g., using extensometr [5] or magneto-resistance sensors [12]), the strain determination of the mandible (e.g., strain gauges and electronic speckle pattern interferometry (ESPI) [13], and photoelastic coating technique [14], [15]). In this paper, the results of the in vitro primary stability osteosynthesis of the mandible segments after BSSO, performed using three different techniques, are described. Their evaluation is based on maximum, relative displacements of the segments (gap changes), i.e., on the bone healing process and deformations of stabilising miniplates.

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2. Material and methods

The tests were carried out on anatomically correct, standardized mandible models (Synbone, Switzerland) made of modified polyurethane resin. The model was shown in figure 1.

Fig. 1. View of the mandible model (Synbone)

Three models were subjected to bilateral sagittal split osteotomy double-sided, according to the Obwageser technique with Dal Pont's modification [16], [17], and the fourth model (reference) enabled us to compare the results to the conditions of a healthy mandible.

The geometrical model of the mandible, with marked lines of the cut corresponding to the osteotomy technique applied, is shown in figure 2.

The following items were used for the stabilisation:

- the four-hole miniplates, fixed with Ø 2 mm × 5 mm screws (M2),
- the six-hole miniplates, fixed like M2 model (M3),
- the bicortical screws Ø 2 mm × 13 mm (M4).

The models prepared for tests (after BSSO) are shown in figure 3.

All the models were loaded statically according to the ARMSTRONG's scheme [18] corresponding to the mandible incisal loading (figure 4). The load F is the resultant of forces generated by the muscles acting on the angle of the mandible (masseter) and coronoid process (temporal muscle).

In order to determine relative displacements of the mandible segments, the optical methods of the measurement, i.e., speckle photography (SP) [19] and holographic interferometry (HI) [20], were employed. The surfaces of the models were covered with white paint to get an appropriate contrast of speckle and interference images.

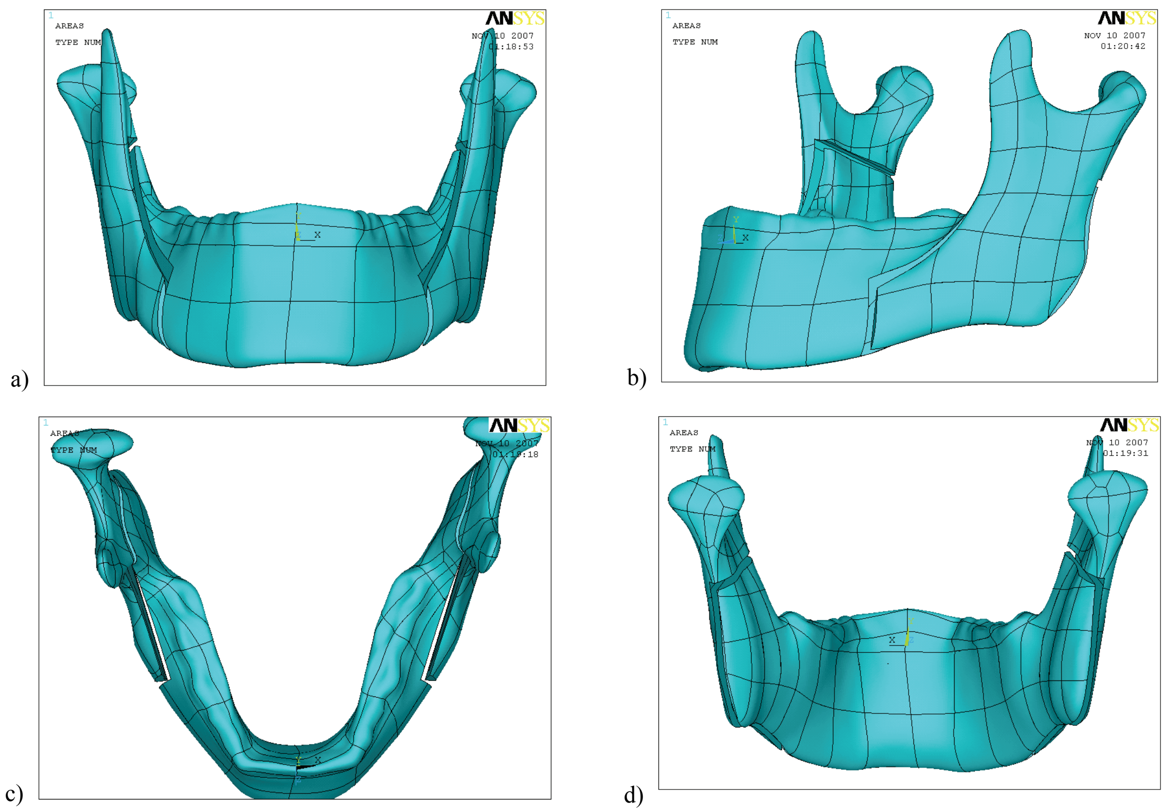
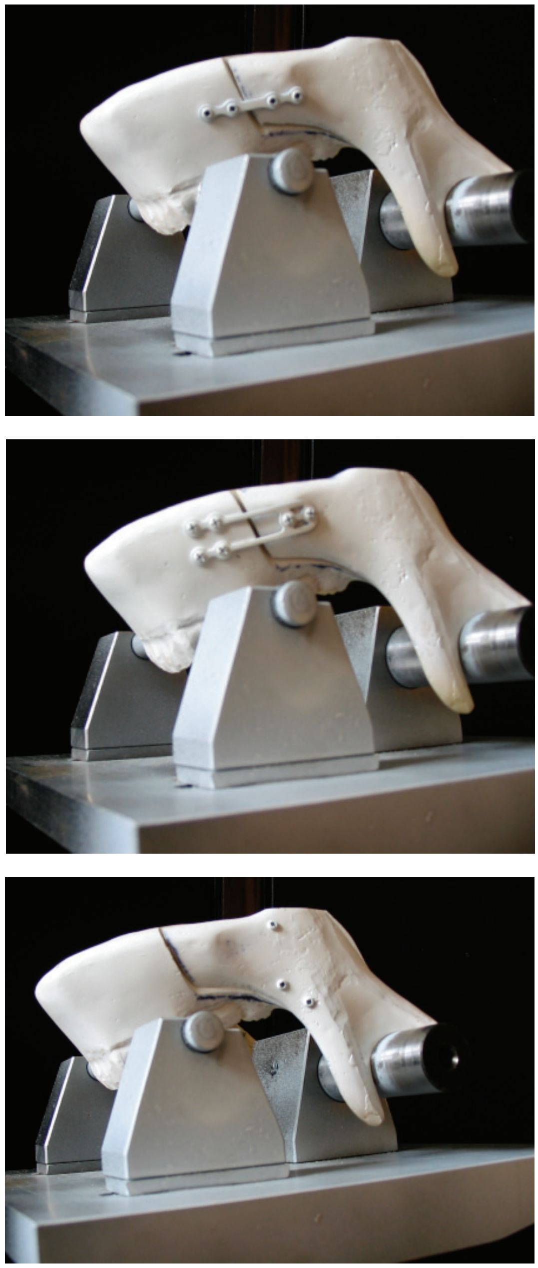


Fig. 2. Model of the mandible after BSSO – geometrical model:
a) front view, b) side view, c) view from above, d) rear view



a) b) c)

Fig. 3. View of models after BSSO:
a) four-hole miniplate – M2,
b) six-hole miniplate – M3, c) bicortical screws – M4

Fig. 4. Scheme of the mandible model loading

In the first phase of the experiment, the components u_x and u_y of displacement were measured using speckle photography. The specklegrams were recorded using double-exposure technique for the increase of the force F equal to 5 N, and for the model of M1 (reference) – 20 N. The preliminary loading was 50 N. A scheme of the optical system used in the specklegram registration is shown in figure 5.

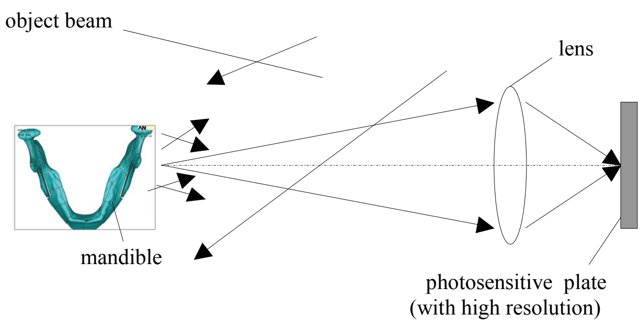


Fig. 5. Scheme of specklegram registration

In the second phase of experiment, the component u_z of the displacement of mandible segments was measured using holographic interferometry. All the models were being subjected to the same scheme of loading (described above) and the interferograms in the optical system shown in figure 6 were registered using the double-exposure technique. The load increase ΔF between exposures was 3 N (for preliminary loading equal to 50 N).

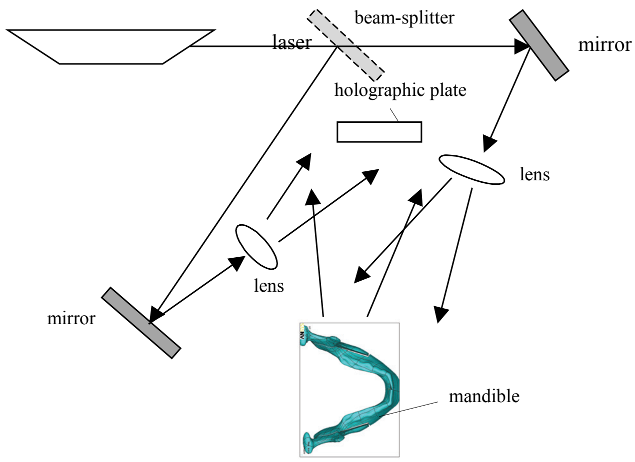


Fig. 6. Scheme of the optical system
for holographic interferogram registration

The systems used for specklegrams and interferograms registration were equipped with the argon gas laser emitting at the wavelength λ = 514. 5 nm. The photosensitive (holographic) plates with the resolution above 3000 lines/mm were used.

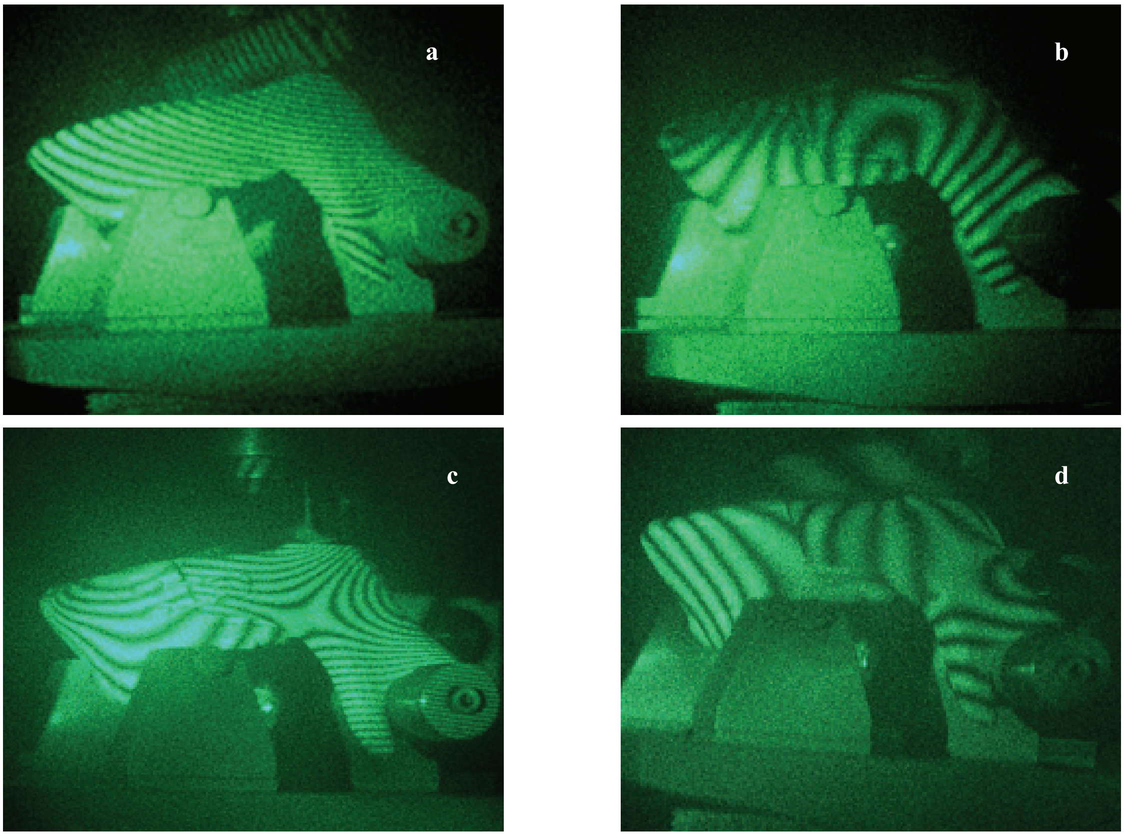


Fig. 7. Images of interference fringes (for $\Delta F = 3$ N): a) model M1, b) model M2, c) model M3, d) model M4

3. Results

The specklegrams were analyzed using a point-by-point technique in the optical system presented in figure 8. A parallel beam of the coherent light passing through the small area of the specklegram generates the specific interference image – parallel and equidistant fringes. The distance a between fringes depends on the value of the displacement vector $\vec{d}$ in xy plane, and its direction (determined by the angle Θ) is perpendicular to the direction of the action of the vector $\vec{d}$. The values of the vector $\vec{d}$ and the displacement components u_x and u_y are determined by the following equations:

$$|\vec{d}| = \frac{\lambda \cdot \sqrt{4 \cdot L^2 + a^2}}{2 \cdot M \cdot a} \cong \frac{\lambda \cdot L}{M \cdot a}, \tag{1}$$

$$u_x = |\vec{d}| \cdot \cos\Theta \cong \frac{\lambda \cdot L}{M \cdot a} \cdot \cos\Theta, \tag{2}$$

$$u_y = |\vec{d}| \cdot \sin\Theta \cong \frac{\lambda \cdot L}{M \cdot a} \cdot \sin\Theta, \tag{3}$$

where:

L – the distance between specklegram and screen,

M – the magnification of the object picture on the specklegram.

The components u_x and u_y were calculated for the points shown in figure 9.

The components of the vector $\vec{d}$ were calculated for $\Delta F = 5$ N and scaled linearly for the $F = 450$ N. This level was accepted for the maximum load of the mandible during the incisal edge loading. In all the three cases of the stabilisation, the changes of the crack configuration between A and B segments were observed. The results of the differences Δu_x and Δu_y in calculations are presented in the table.

Table. Differences Δu_x and Δu_y (mm)

Differences	M2	M3	M4
Δu_x ($A1$–$B1$)	–0.286	–0.541	–0.894
Δu_x ($A2$–$B2$)	0.111	0.101	–0.045
Δu_y ($A1$–$B1$)	–0.583	–0.368	–0.631
Δu_y ($A2$–$B2$)	–0.740	–0.429	–0.405

In order to determine displacements in the z direction (perpendicular to the xy plane), the analysis of the holographic interferograms was provided. Interference

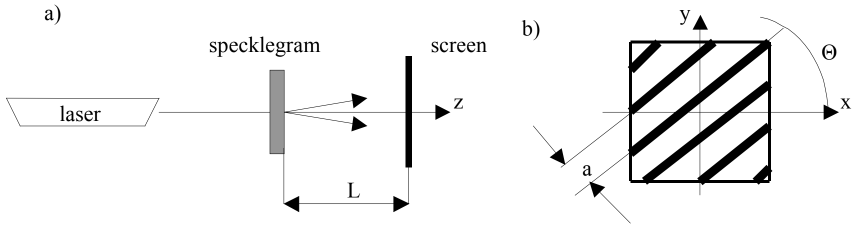


Fig. 8. Optical system for point-by-point specklegram analysis

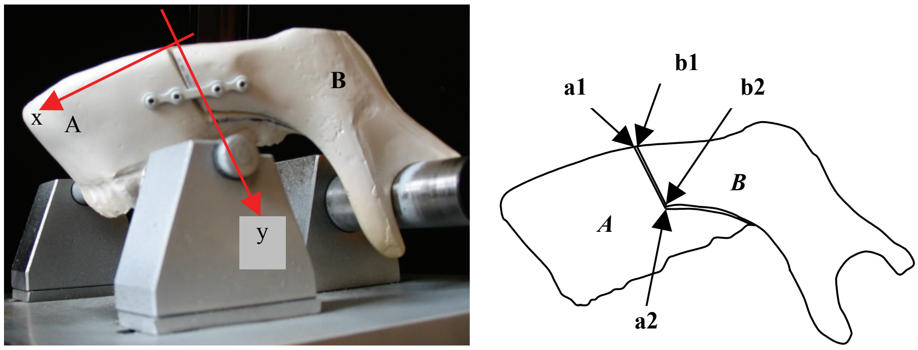


Fig. 9. Coordinate system (on the left) and location of the points analysed (on the right)

fringe images were recorded in the optical system for hologram reconstruction (figure 10).

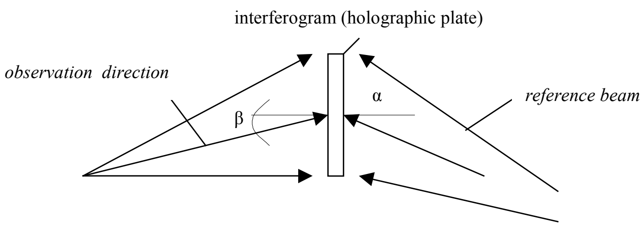


Fig. 10. Scheme of the interferograms' reconstruction

The displacement component u_z is determined by the equation:

$$u_z = \frac{N\lambda}{\cos\alpha + \cos\beta}, \tag{4}$$

where N is the fringe pattern order.

If the reference beam, making an angle α with the holographic plate during interferogram registration, and an angle β between the plate and observation (object beam) direction are small, equation (4) can be reduced to:

$$u_z = \frac{N\lambda}{2}. \tag{5}$$

For the quantitative analysis of the holographic interferograms registered during the present experiment, formula (5) was used.

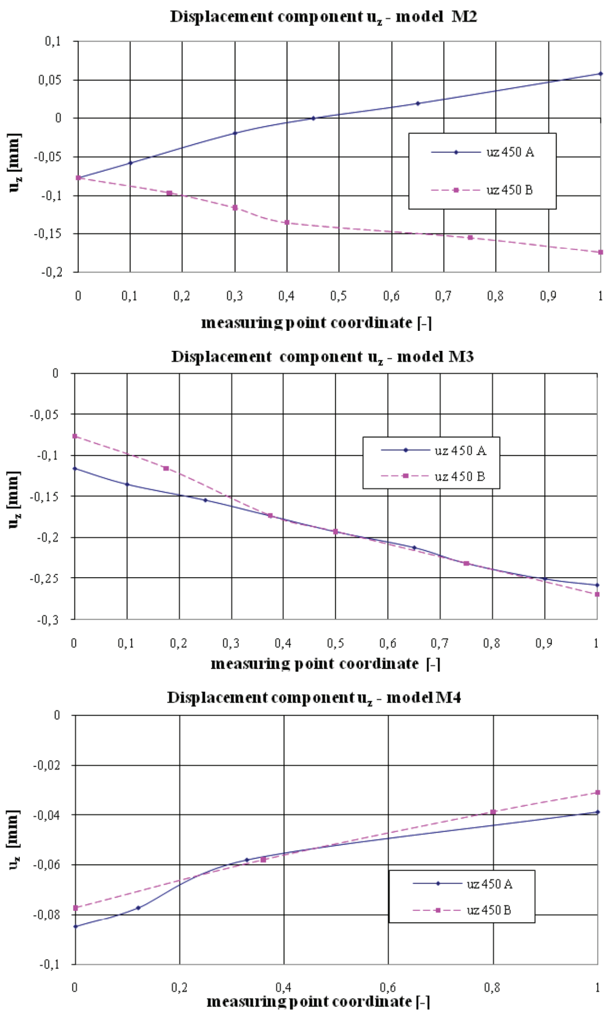


Fig. 11. Distributions of the component $u_z(y)$ – the mandible models after BSSO

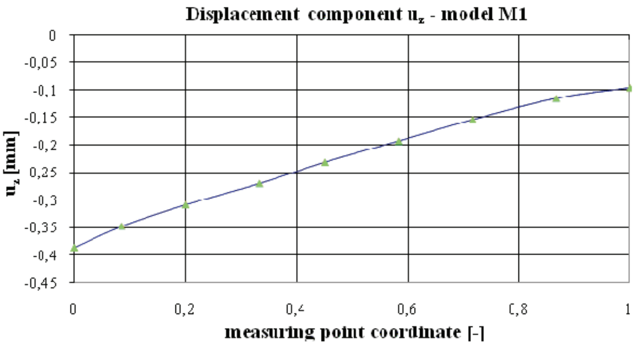


Fig. 12. Distribution of the component $u_z(y)$
– the mandible model before BSSO

Distributions of the displacement component u_z, appropriate for the edge of the mandible segments *A* and *B*, scaled linearly for the maximum load $F = 450$ N are shown in figure 11. Distribution of the u_z in the analogous cross-section of the model M1 (mandible before BSSO) is presented in figure 12.

4. Discussion

The experiment described shows that the deformations of the mandible measured before and after bilateral sagittal split osteotomy (BSSO) differ significantly, which should be ascribed to the essential change of the characteristics of the mandible stiffness after cutting and inserting different implants. Taking 0.2 mm as the criterion determining the acceptable value of the relative mandible's fragments displacement (not causing damage in the process of new bone formation), it is clear (the table) that a primary stability of each of the three techniques of stabilisation is too low in the plain *xy* of fragments' fixation. In the direction *z* perpendicular to this plain, the smallest (and even) changes of the dimensions of the crack are appearing in the case of joining fragments by means of three bicortical screws (M4), the biggest one – in the case of four-hole miniplate (M2) fixation. In this last case, the "opening" of the crack is $\Delta u_z > 0.2$ mm. The analysis of the displacement vector components u_x and u_y showed a significant influence of the bending moment acting in *xy* plane and the analysis of u_z proved that miniplates are subjected to the torsion loading. Similar results were obtained in [12] for different fracture sites in the mandible.

Based on a detailed analysis of the mandible's segments interaction in M2–M4 models a thesis can be formulated that it is possible to increase the level of the mandible stabilisation by applying the "hybrid" technique, using four-hole or six-hole miniplates and appropriately placed bicortical screws. In the case of the fixation with the bicortical screws, the additional screw in the vicinity of the crack analysed should be examined or the applied scheme of the screws' location ought to be modified in such a way that one of them will be placed exactly in this area. Similar conclusions were given in [21].

Of course, the above proposals should be confronted with anatomical limitations (e.g. location of the blood vessels, nerves) and with the possibilities of applying the operating technique (internal access).

The results discussed above were obtained in conditions of mandible incisal loading caused by masseter and temporal muscles activity according to the scheme offered by ARMSTRONG [18]. Particularly in the case of comparative surveys, e.g., different osteosynthesis techniques, applying this scheme is highly justified because it takes into consideration the dominating role of these muscles in mandible loading. At the same time, the simplicity of these techniques is an advantage allowing a direct and true comparison of the findings obtained at other research centers.

In conclusion, the present experiment proved that the optical techniques applied (holographic interferometry and speckle photography) are effective tools for experimental evaluation of the primary stabilisation techniques. To obtain uniform conditions of the investigations, the models of the mandible subjected to the same scheme of the loading (for example, the Armstrong scheme) should be applied. It is suggested that the hybrid technique of the BSSO stabilization (miniplates with additional bicortical screws) can limit the relative displacements of segments.

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