Experimental and numerical approach to chosen types of mandibular fractures cured by means of miniplate osteosynthesis

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The paper presents experimental and numerical analyses of two cases of mandibular corpus fractures cured by means of miniplate implantation. In the laboratory tests, strain gauges and electronic speckle pattern interferometry methods were used, while in the numerical simulations finite element analyses were applied. The aim of such a combined approach was to verify a correctness of the numerical model applied with regard to the assumptions and simplifications which had been done when creating FEM for human mandible: healthy, broken and stabilized with miniplate implants.

Key words: strain gauges, ESPI, FEM, mandibular fractures

1. Introduction

Numerical modelling by means of finite element method (FEM) renders possible analysis and assessment of certain mechanical states in bone structures in order to estimate various problems appearing during medical treatment. However, numerical simulations, in general, need some simplifications with regard to real biological structures, in this case with regard to the anatomy of human stomatognathic system. The correctness of the assumptions and simplifications applied has to be verified experimentally. Two independent experimental methods were used: strain gauge method and electronic speckle pattern interferometry (ESPI)\(^1\). Two kinds of the most often cases of mandibular corpus fractures were considered: one-side and mutual fractures [1].

2. Aim of the paper

The aim of the experiments carried out was to describe the strain states in chosen areas of mandibular bones of healthy and broken mandibles and then to compare the results obtained with relevant analyses by means of FEM.

3. Material and methods

The strain gauge experiments were done using a mandibular model made of epoxy resin, a scale of 1:1, while in the electronic speckle pattern interferometry the experiments were carried out on anatomical preparation of human mandible taken post mortem,

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\(^1\) The experiments were carried out in cooperation with the Division of the Institute of Biomedical Engineering and Experimental Mechanics, Wrocław University of Technology.
two weeks after death. Both epoxy model and anatomical preparation were examined on similar experimental stands where occlusal loadings corresponding to physiological bite activity were transferred by mandibular

Fig. 1. Experimental stand for strain gauge tests

Fig. 2. Strain gauge arrangement on epoxy model of mandible

Fig. 3. Setup for investigating mandibular bone displacements:
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4. Discussion of the results

The comparison of the results of strain gauge experiments and FEM calculations for one-side corpus fracture is presented in table 1 and figure 7 for separate strain gauges and in table 2 and figure 8 for the rosettes for the principal strain values \( \varepsilon_1 \) and \( \varepsilon_2 \). Based on the set of data it can be concluded that in the case of strain gauge rosettes the results obtained are compatible with numerical calculations. An average error for rosette (2–3–4) was 23%, and for rosette (8–9–10), 13%. For separate gauges the values of an average error for healthy mandible and for broken one reach 20% and 25%, respectively.

For some separate strain gauges the differences are much bigger. Moreover, the asymmetry of mandibular work for left- and right-hand side ramus and condylar neck was noticed. We suppose that those differences appeared due to the imperfections of experimental stand, which enabled only in-plane pivot of temporal-mandibular joint and due to a lack of perfect fixation of ties representing mandibular muscles.

In the ESPI method, the percentage differences between strain values along the X-axis and Y-axis for the cases of healthy mandible and broken one (one-side fracture and mutual mandibular fractures) with regard to FEM simulations are shown in figure 9.

For healthy mandible the compatibility of both experimental and numerical results is almost perfect,
i.e., 7% and 8%, respectively, for $\varepsilon_x$ and $\varepsilon_y$ strain components. In the cases of broken mandible, the differences are relatively much higher, particularly for $\varepsilon_y$ strain component, reaching even 40%. For $\varepsilon_x$ strain component the differences approach respectively 18% and 16% for one-side and mutual fractures.

In our opinion, the divergences in FEM and ESPI results appear mainly due to the different ways of miniplate fixation in both experiments (numerical and speckle interferometry) and due to lack of modelling callus volume in laboratory experiment, while in the numerical simulations that element has been considered.
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Fig. 7. Differences in strain values in chosen areas of mandible calculated numerically and in strain gauge tests

Fig. 8. Differences in principal strain values for strain gauges and FEM calculations for rosettes

Fig. 9. Differences between ESPI results and strain values calculated in numerical simulations
5. Conclusions

1. The compatibility of the results of both experimental methods, i.e., ESPI and strain gauges, with the results of numerical calculations by means of FEM proves that the assumption taken into account when creating the numerical model was valid.

2. On the other hand, the divergence in the results obtained in each separate experimental and numerical experiments could be induced by:
   - Simplification in modelling temporal-mandibular joint in laboratory experimental tests (in-plate pivot of one degree of freedom) which results in overrigidity of mandible, particularly in the areas of mandibular ramus and condylar process. In numerical calculations, an elastic element representing joint disc was modelled which improved the mobility of mandible.
   - Simplified ways of modelling mandibular muscles in the areas of their attachments as well as the directions and values of their activities.
   - Methods of miniplate fixation with screws in both types of laboratory experiments, while in numerical simulations that junction was modelled on common nodes which eliminated mutual mobility of mandible and miniplate.
   - Possible errors in the way of assuming constrains in the area of anterior teeth in both laboratory experiments and numerical model.

References