

The experimental model for biomechanical research of midface

Nenad DRVAR, Stjepan JECIĆ, Predrag KNEŽEVIĆ*, Vedran UGLEŠIĆ*

*University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture
Ivana Lučića 5, 10000 Zagreb, CROATIA*

** University Hospital "Dubrava", Maxillofacial Department
Avenija Gojka Šuška 6, 10000 Zagreb, CROATIA*

Introduction

The facial skeleton is made up of thin segments of bone encased and supported by a more rigid framework of "buitresses". The buttress system absorbs and transmits forces applied to the facial skeleton. Masticatory forces are transmitted to the skull base primarily through the vertical buitresses, which are joined and additionally supported by the horizontal buitresses. When external forces are applied, these components prevent disruption of the facial skeleton until a critical level is reached. Fractures of the facial skeleton distort the patient's appearance, and may compromise the function of the masticatory system, ocular system and nasal airway. The classic fracture patterns were described by LeFort in 1901. The technique for midface surgery has evolved directly from orthopedic surgery utilizing direct fixation with plates and screws. It means direct exposure, exact anatomical reconstruction of the buitresses and fixation of the fragments. Buttress reconstruction will prevent late midfacial collapse or elongation and secondary deformity.

Problem statement

The forces exerted on the cranium and midface are complex, three-dimensional and difficult to evaluate. They produce various strains on fixation plates, in every direction, with a predominance of bending and torsion stresses as opposed to compression forces. The first source of strain is the result of the masticatory forces. This strain is certainly less important and easier to neutralize on the midface than on the mandible. Except for the mandible where biomechanical forces are well documented, biomechanical research of midface has not been performed to confirm the techniques which we are using today. Present surgical techniques are using minimally one, but very often more screw pairs per each fixation plate [1,2]. Such techniques have been clinically proved to be strong enough to withstand all forces and to ensure bone healing without interfragmentary compression. Hereby we tried to determine if plates with only one screw pair can be used for fixation in a same way as plates with two screw pairs already are.

Experiment

From geometrical similarity viewpoint there are no two skulls in the world that could be considered alike (and one can't conduct experiments on live patients, for obvious reasons) so it would be difficult to create the relevant numerical model for the examination of midface biomechanics. From the material similarity viewpoint, bone is a composite material whose local material properties vary depending on the local position on the skull, as well as with the age of the human patient, making realistic numerical model even more complex.

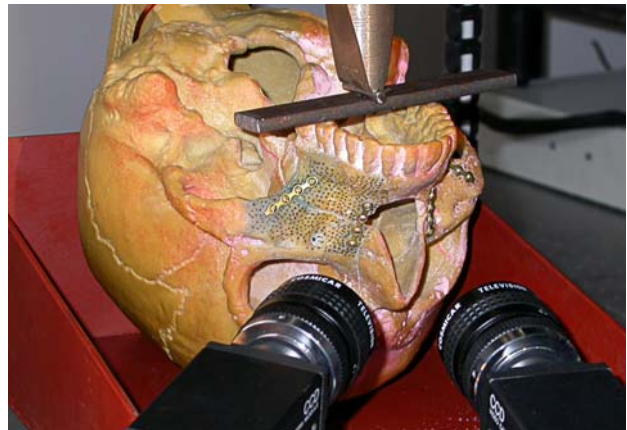


Figure 1.

We found that even cadaver skulls are not adequate because of rapid loosing of proteins and water. Thus, we choose to simplify the material model by using a Synbone plastic model of the actual human skull made of Baydur 60 whose mechanical properties from the surgical point of view sufficiently resemble the actual bone (softer foamy structure on the inside and hard surface).

Most of the loading forces of the midface are the result of the mastication, which can be considered dynamical process with random load distributions depending on: food hardness and its granulation, eating habits and health of the tooth. Instead of numerical modeling of the mastication process of damaged and normal facial skeleton, experimental approach is suggested. We tried to produce the adequate experimental model which could imitate the transmission of the forces through midface (as it actually happens in the natural human skull). Chosen method enables us to mimic the typical midface fracture

and to apply various lengths of connecting plates. Such experiment, according to the results, enables optimal surgical treatment of midface fractures.

Chosen plastic model of a human skull is fixed in the loading device (Figure 1.) and loaded in the following conditions: symmetrically loaded on the last pair of tooth without a crack that will serve as a reference, and cracked low horizontal maxillary fracture with disruption of the tooth-bearing section (classified as Le Fort I fracture) skull fixed with four plates attached with two and four screws, respectively (Figure 2). Successive compression loading tests were conducted on a screw driven tensile/compression testing machine Messphysik BETA 50/5 with constant loading speed of 1 mm/min (loading can be considered static). Muscles required for mastication control distribution of mastication forces that cease at the skull base. Such a complex force distribution model had to be simplified so a special 4 point support was used to prevent model movement during the loading process. To monitor the local surface deformation in the areas near the titanium fixation plates the object grating method based GOM Aramis system is used.

Results

Object grating method [3] enabled us full field analysis of the surface strain distribution near the crack, but it provides strain data only in the optically visible area near the fixation plates (how close we can get depends on the facet size). This method can't measure the effects straight beneath the fixation plates. For the purposes of this paper we will observe local deformations near the pterygomaxillary buttress plate. To illustrate local strain distribution, Figure 3. presents a V. Mises strain distribution across the cross section A-B (Figure 2.) for a symmetrical loading condition (Figure 1.) with extreme static load of ~300N per teeth. Results for other plate pairs and asymmetrical loading conditions will be presented elsewhere.

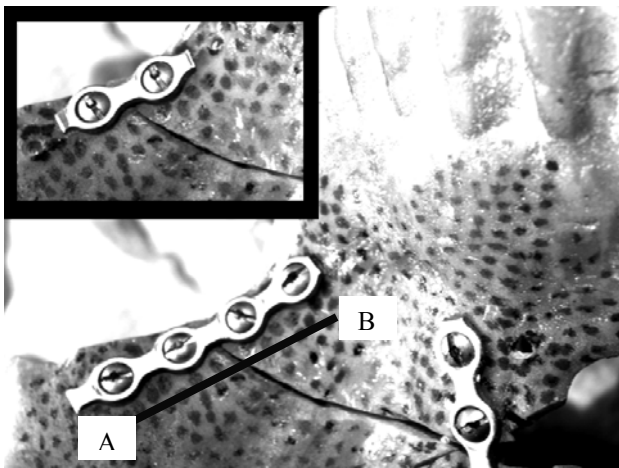


Figure 2.

According to Figure 3, strain distribution for non-fractured model (curve *a*) shows that bone has its regular function and that force trajectories are uniformly distributed along the cross section. For a fractured model, curve *c* represents measured distribution near the single screw pair fixation plate. For a given loading condition relative to non-fractured model V. Mises strain is large in the location of a crack (i.e. center of a plate) and rapidly

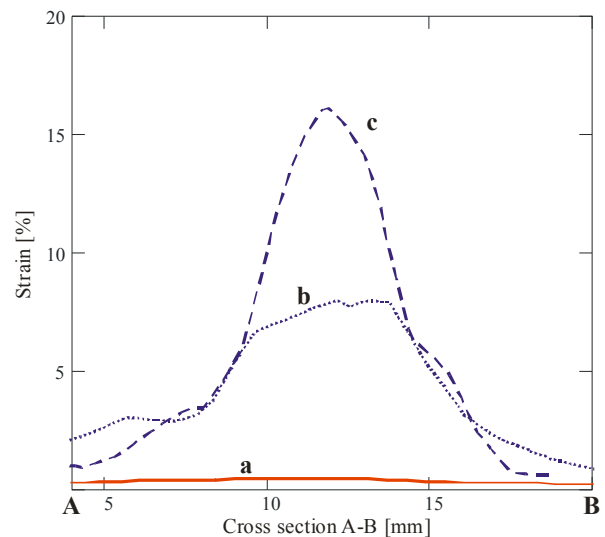


Figure 3.

vanishes towards both ends of a plate. Providing that plates with two screw pairs have more uniform strain distribution than plates with one screw pair, one would expect curve *b* to have wider distribution than actually measured. Instead, the effect of using longer two screw fixation plates is that strain peak is nearly twice lower than for a single screw pair fixation plate, while strain distribution towards the plate ends is similar to curve *c*.

Conclusion

Results of the preliminary experiment of the force and strain trajectories on the non-fractured skull proved that from geometrical viewpoint our model confirms with hypotheses set by medical literature. Based on that assumption, the experimental results conducted on our simplified model of fractured skull confirm with the clinical experience with one screw pair fixation plates. It is determined that outer screw pair has little effect on local strain distribution near the plate ends, but it substantially lowers contact forces along the crack. It is reasonable to expect that mastication forces used in this biomechanical research of midface will not be achieved by human patients until injured bone completely regenerates, thus the actual strain peaks near cross section A-B as measured in Figure 3 will be substantially lower. By taking into account dynamical process of mastication and possibility of screw loosening because of bone fatigue, usage of longer two screw pair fixation plates is advisable in situations when bone is injured in such a way that remaining fragments cannot sufficiently transmit forces along the crack. Based on the presented results it is clear that object grating method can be successfully used in biomechanical model research which motivates us to conduct further investigations through dynamical experiments on the actual cadaver skulls.

References

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