IMPLEMENTATION OF THE NEWLY DESIGNED AND EXPERIMENTALLY VALIDATED LOCKING SYSTEM FOR TREATMENT OF FAVORABLE AND UNFAVORABLE MANDIBULAR FRACTURES

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1. Introduction

Biomechanical stability of osteosynthesis is of particular importance in fracture treatment. Commonly used devices such as locking plates provide a strong compression force between the bolt and screw which ensures a sufficient treatment. This paper introduces both the design process of FEA simulations with experimental validation of a newly designed locking plate system for long bone fractures and its further implementation in the treatment of mandibular fractures.

2. Materials and methods

First, simulations using FEM of the new (Fig. 1. a, b) and conventional (Fig. 1. c, d) locking system were conducted, examining their biomechanical stability. Afterwards, the two assemblies were produced and tested under cyclic loading (bending test) following an axial loading (push-out) test (Fig. 2), respectively.

The next step was implementing the new assembly in a bony environment on a fractured mandible. A commonly used device for treating angular mandible fractures [1] was selected as control sample. The images of the mandible were obtained from a healthy 83-year-old patient and further reconstructed using Mimics software (Materialise NV, Belgium). The assemblies were made in SolidWorks software (Solid Works, Dassault Systèmes, Massachusetts, USA) and imported in Abaqus software (version 6.14-5, Dassault Systèmes, France). Materials in simulations were set to be homogeneous and isotropic. Simulation parameters and load cases are presented in Table 1.

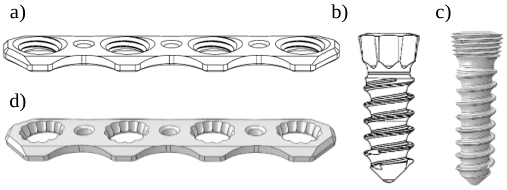

Fig. 1. Test sample (US11083507B2): a) plate; b) screw; control sample (WO2015/020789A1): c) screw; d) plate

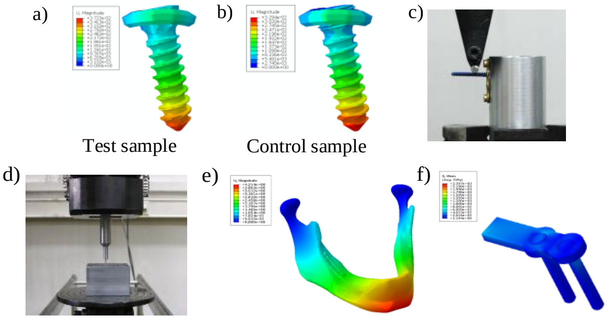

Fig. 2. Finite element simulations of: a) test sample and b) control sample; c) bending test; d) push-out test; e) displacement distribution of the conventional locking system; f) stress distribution of the new locking system

Table 1. Material parameters in Abaqus simulations

Material		***E* [GPa]**	***ν* [-]**	**Boundary**
Plate: Titanium (ISO 5832-2)		98.66	0.3	Tie
Screws: Titanium (ISO 5832-3)		101.5		
Cortical bone [1]		13.7		***ν*** on fracture site: 0.4 [3]
Spongy bone [1]		0.793		
Load case [N] [3]		Molar region		Incisal region
	S3	500		200
	S2	600		300
	S1	700		400

3. Results

Although the results obtained from the FEA simulations and experiments provide a fair amount of detailed information about both locking systems, only the crucial results are presented below.

Table 2. FEA results of the new and conventional locking system for long bones

	Load [N]	**u [mm]**	**σ [MPa]**
Control	3 (Bending)	0.0331	603.8
	15 (Axial)	0.0243	344.9
Tested	3 (Bending)	0.0385	387.5
	15 (Axial)	0.0273	333.0

Table 3. Average failure load in [N] of the new and control locking system under static axial loading

Control sample	747.14
Test sample	571.18

Table 4. Average stiffness c in [N/mm] of the new and control locking system under cyclic loading

Screw angle in plate [°]	**0**	**10**	**15**	**20**
Control sample	239.57	211.96	203.70	198.45
Test sample	244.56	217.40	211.48	239.82

Table 5. FEA results of the new and conventional locking system implemented on a fractured mandible

	Control	Tested	Control	Tested
Load case	**u [mm]**		**σ [MPa]**	
	Favorable mandible fracture			
S3	2.608	2.993	1413	2008
S2	3.415	3.959	1888	2682
S1	4.224	4.927	2354	3347
	Unfavorable mandible fracture			
S3	2.540	2.882	2682	1457
S2	3.298	3.736	3298	1881
S1	4.058	4.590	3905	2299

u [mm] … maximum displacement
σ [MPa] … maximum von Mises stress

4. Discussion

Table 2 shows 13% less displacement values of control locking system in regard to tested locking system. The same percentage can be seen in table 5 where the systems have been inserted into a fractured mandible. These values alone do not favor the new locking system, but the cyclic tests in table 4 displayed 17% greater stiffness values for the screw locked in the plate by 20°. This polyaxial feature of the new locking system serves as an advantage much needed in mandibular surgery where almost every screw is locked in the plate at an angle greater than 0°. We can also use these obtained stiffnesses to further reduce the plate thickness which is frequently produced under 1 mm in the maxillofacial surgery.

Moreover, static axial push-out tests carried out on 5 samples to determine the failure load of both systems which results are presented in table 3 show that the control locking system provides 24% greater values than the testing locking system. Be that as it may, considering the fact that bite forces never exceed 430 N on molar region and 210 N on incisal [4], the control system which endured almost 750 N on average turns out to be an oversized assembly. The new locking system withstands 572 N on average which is biomechanically sufficient.

In addition, the head of the new screw (Fig. 1. b) is designed in a way that makes the choice of the thread in a locking plate negligible because the thread on the plate is carved into the surfaces of the screw. The only condition is that the material of the plate has higher hardness than the screw material.

5. Conclusions

The new locking system showed equally higher displacement values for both long bone assembly (table 2) and mandible assembly (table 5) in comparison with the control locking system. In contrast, conducted experiments displayed greater stiffness values in favor of the new locking system. Further experiments are needed to confirm the same trend occurring in the new locking system implemented in a fractured mandible. Nevertheless, the new locking screw assembly with the presented biomechanical properties can be successfully used in treating of mandibular angle fractures.

References

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