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The influence of contact surface shape on the mechanical properties of osteosynthetic plates

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Abstract. In order to reduce damage of the periosteum of the bone the contact surface on the osteosynthetic plates are usually grooved. Here, it was investigated how different kind of grooves influence bending stiffness and dynamic endurance of osteosynthetic plates. Four point bending tests were carried out according ISO 9585 also as three point dynamic bending tests. The results are presented and discussed.

1 Introduction

All clinical testing that has been done on biological materials so far points out that the conformational change of the contact surface on the osteosynthetic plates affects the integrity of the periosteum of the bone in the fractured area [1,2,3]. Osteosynthetic plates with smaller contact surface area have a smaller damaging effect on periosteum, which provides for the increased blood supply to the fractured area, faster fracture healing and reduces the need for patients' immobilization. This is reflected in the tendency in clinical practice to use osteosynthetic plates of the optimal size and contact surface configuration.

Thanks to the development of the new plate making technologies, primarily the microcast technology, the production of the complex geometry plates has been enabled, as well as that of the more complex contact surface area. When optimizing the size and the shape of contact surfaces, one must consider not only the clinical criteria, but also the mechanical criteria such as strength of plate and dynamic endurance.

This paper provides experimental results of the mechanical behaviour of the plates, with various types of contact surface shapes taken into account. The four point bending test was carried out according to the ISO 9585 [4] together with the dynamic bending test in which the load intensity and the number of cycles were adjusted to the exploitation conditions of the plates.

The presented results show that it is very important to take into account the dynamic loading in the osteosynthetic plate design.

2. Osteosynthetic plates

Osteosynthetic plate has several holes for bone screws positioned along its longitudinal axis and its function is to stabilize and join the ends of fractured bones (Figure 1). Usually it stays not less then six month in to organism causing damage of the periosteum of the bone [5]. The tendency is to

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reduce a contact surface which will increase fracture healing. But also osteosynthetic plate is loaded by static and dynamic load during exploitation and mechanical tests should be carried out in order to optimize the shape of the plate. Table 1 shows reduction of the contact zone related to the different kind of grooves.

Table 1. The size of contact zone for each type of plates

	size of contact zone
longitudinal grooves (LG)	19%
transversal grooves (TG)	35%
cross grooves (CG)	5%
inclined grooves (IG)	56%
no grooves (NG)	100%

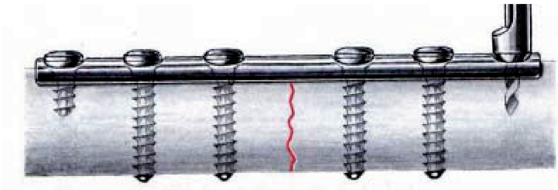


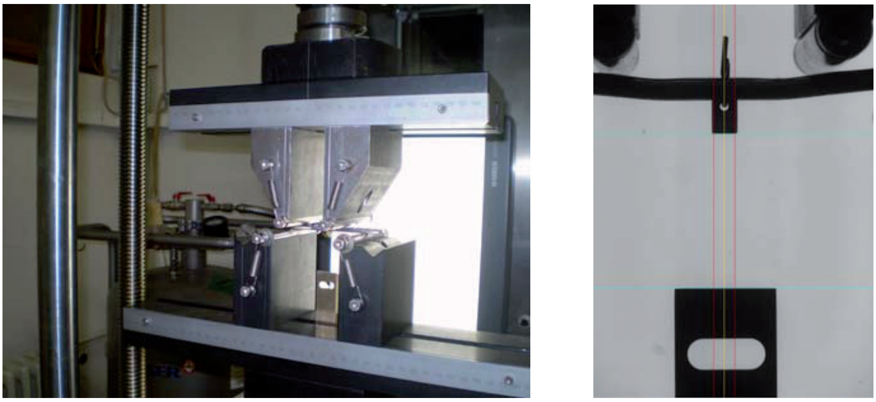
Fig. 1. Osteosynthetic plate fixed on the bone

2 Experimental procedures

Five different types of osteosynthetic plate are considered, with: longitudinal grooves (LG), transversal grooves (TG), cross grooves (CG), inclined grooves (IG) and no grooves (NG) on the aligning surface. Dimensions of the plates are 103x12x4 mm and material is medical steel (C2CrNiMo). Each type of test is repeated three times because of statistical reasons.

2.1 Static bending test

The four point bending test was performed according to the ISO 9585. The uniaxial testing machine '*Messphysik Beta 50-5*' was used for loading and the deflection measurement was carried out with '*Videoextensometer NG*' (Figure 1).



a) **b)**

Fig. 1. Four point bending test of osteosynthetic plate (a): h= 0,0165 m, k=0,042 m, and deflection measurement by videoextensometer (b).

Calculation of the equivalent bending stiffness was provided by the equation

$$E = \frac{\left(4h^2 + 12hk + k^2\right)Sh}{24}, \tag{1}$$

where h is the distance between inner and outer rollers, k is distance between inner rollers and S is the slope of the load-deflection curve

$$S = \frac{\Delta F}{\Delta f}. \tag{2}$$

Bending strength is calculated from the expression

$$\sigma_S = 0,5Ph, \tag{3}$$

where P is the proof load. Determination of the proof load is strictly defined by the norm. On the graph load-deflection straight line should be drown parallel to the linear part of the graph and offset by amount

$$q = 0,02\left(2h + k\right). \tag{4}$$

The intersection of this line with the curve is the proof point and this defined proof load P.

Mean values of the results for each kind of the plate are given in the Table 2. As expected, the greatest value of bending stiffness and bending strength has plate with no grooves. CG and IG plates have bending stiffness and bending strength higher then LG and TG plates.

Table 2. Results of the four point bending tests of osteosynthetic plates

	E_F [GPa]	S [N/mm]	σ_S [Nm]	E [Nm^2]
longitudinal grooves (LG)	128,53	930,02	10,54	7,14
transversal grooves (TG)	122,07	887,51	10,12	6,81
cross grooves (CG)	148,97	1081,96	11,81	8,31
inclined grooves (IG)	158,23	1143,18	12,41	8,78
no grooves (NG)	179,2	1303,8	15,03	10,01

Diagram load–deflection on the Figure 2 shows one (middle) curve per each type of plate.

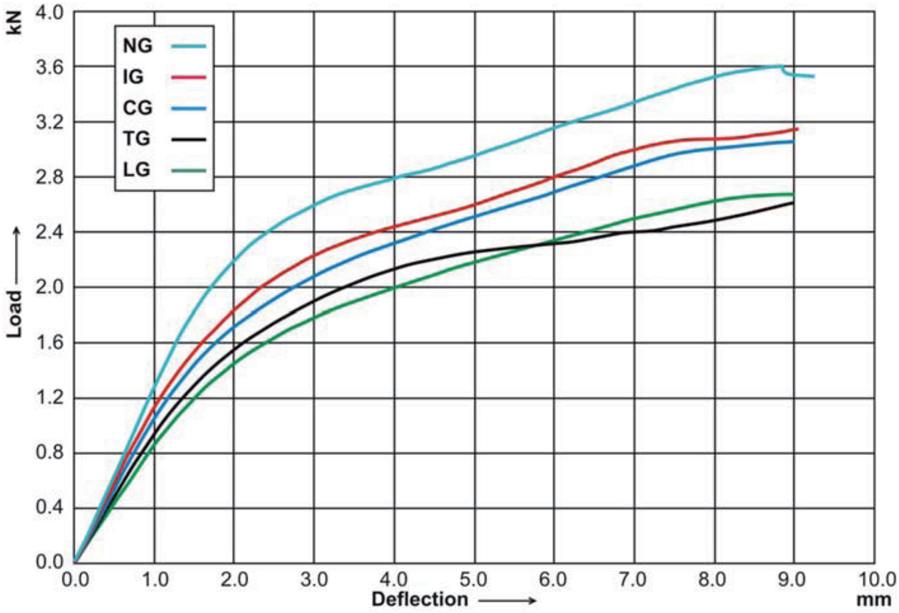
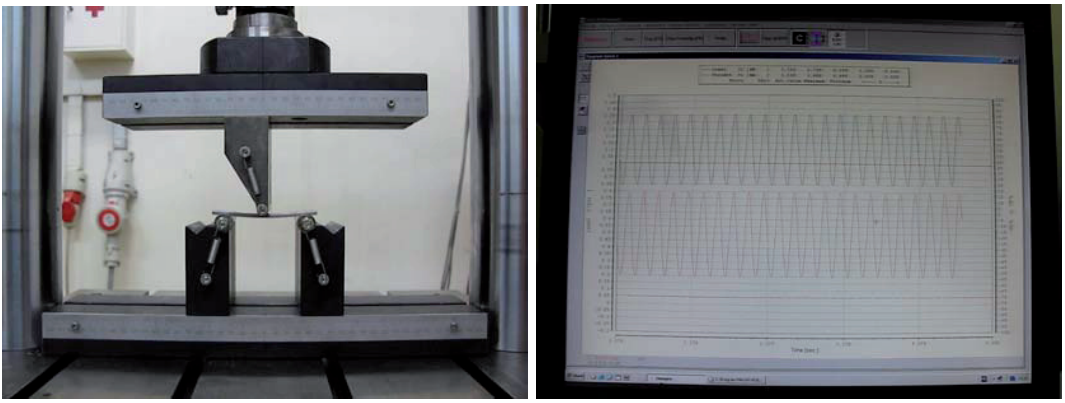


Fig. 2. Load-deflection diagram of four point bending tests

2.2 Dynamic bending test

During the dynamic bending test servo-hydraulic testing machine '*W+B LFV 50-HH*' was used with load control mode (Figure 3). The test was performed as a tri point bending test. Because there is no corresponding standard, the loading force is estimated to exploitation condition in the sinusoidal form between 200-800 N and frequency of the 5 Hz. Each test lasted until the specimen failure or 10^6 cycles. The stored data are number of cycle and maximum deflection of specimen in the each cycle. Distance between supported rollers was h_D= 0,075 m.

Mean values of the results for each kind of the plate are given in the Table 3.



a) b)

Fig. 3. Tree point dynamic bending test of osteosynthetic plate (a): h_D= 0,075 m, with sinusoidal load control (b): F=200-800 N, f= 5 Hz..

Table 3. Results of the tree point dynamic bending tests of osteosynthetic plates

	number of cycles before crack initiation
longitudinal grooves (LG)	45 979
transversal grooves (TG)	16 700
cross grooves (CG)	51 291
inclined grooves (IG)	53 676
no grooves (NG)	$>10^6$

Diagram max.deflection–number of cycles, on the Figure 2 shows one (middle) curve per each type of plate.

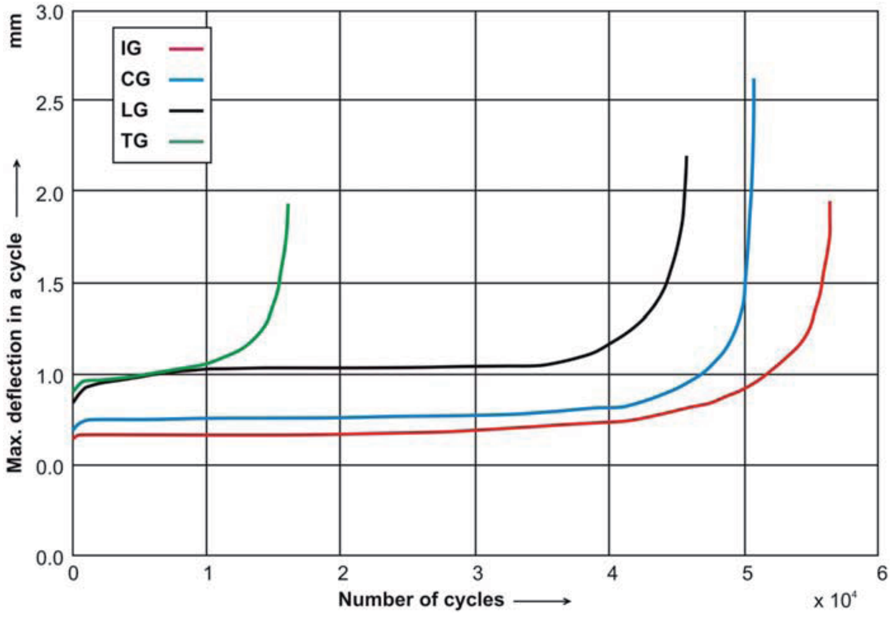


Fig. 2. Max. deflection – number of cycles of three point dynamic bending tests

In the first few cycles specimen are setting up and then follows stable period with constant amplitude of specimen deflection. After while crack initiates at the root of groove and amplitude of specimen deflection stars to rise up till crack propagate through the specimen thickness causing failure of the plate. Large difference of dynamic endurance between different types of the plates can be seen on the diagram. That means that mechanical tests must be involve in the optimizing process of the contact surface.

2 Conclusions

Osteosynthetic plates with smaller contact surface area have a smaller damaging effect on periosteum. This is reflected in the tendency in clinical practice to use osteosynthetic plates of the optimal size and contact surface configuration.

Four point bending tests show that osteosynthetic plate with no grooves has the highest bending stiffness and strength and also IG and CG osteosynthetic plates have higher bending strength then TG and LG plates.

Dynamic endurance tests show that the NG plate has no failure even after 10^6 cycles while plate with transversal grooves can not resist more then 20 000 cycles.

These results show that during the optimization of osteosynthetic plate it is not enough to make static bending test but also it is necessary to verify its dynamic endurance.

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