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Comparison of the biomechanics of plates with modified surface texture in an in vitro chicken model

Yüzey şekli değiştirilmiş plakların in vitro tavuk modeli ile biyomekanik karşılaştırılması

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Abstract

Aim: Plate and screw combinations have long been in frequent use in the surgical treatment of bone fractures. Developments in the essentials of surgical fracture treatment in the last few years are mainly due to a better understanding of different responses to varying mechanical conditions and advances in the science of materials used for treatment. This study aimed to assess the stability of plates whose surface texture had been modified without affecting their structural characteristics.

Materials and Methods: The plates used in the study were prepared as standard four-hole plates according to three different surface designs; sanded, grooved or smooth. The plates were designed for the particular characteristics of chicken bones; they were applied following transverse osteotomy of the femur. Their stability was biomechanically tested in vitro. The bones subjected to osteotomy and fixated by plates were tested for axial compression loading, three-point bending and torsion.

Results: Mean resistance force for grooved surfaced plates was superior to sanded and smooth surfaced plates for all test types. The plates with grooved surface were the most resistant, followed in the order by the sanded and the smooth (control) plates ($p<0.05$).

Conclusion: The study showed that the plates with surface modifications were at least as stable as the control group plates. We found most stable plate as grooved surfaced plate. The possible effects in the living organism are yet unknown.

Keywords: Biomechanics, plates, stability, osteosynthesis.

Öz

Amaç: *Kemik kırıklarının cerrahi tedavisinde uzun zamandır plak ve vida kombinasyonları sıklıkla kullanılmaktadır. Son yıllarda kırıkların cerrahi tedavisinin temel prensiplerinde bir takım değişiklikler meydana gelmiştir. Bu değişim kırık iyileşmesinin farklı mekanik koşullar altında farklılıklar göstermesinin anlaşılması ve kırık tedavisinde kullanılan malzeme bilgisinin gelişmesiyle olmuştur. Bu çalışmada yapısal özelliği değiştirilmeden yüzey şekli değiştirilen plakların stabilitesi değerlendirilmesi amaçlandı.*

Gereç ve Yöntem: *Çalışmada karşılaştırılan plaklar, üç farklı dizaynda (pürüzlü, oluklu ve pürüzsüz) ve standart olarak 4 delikli plak şeklinde tasarlandı. Tavuk kemiğinin özelliklerine göre hazırlanan plaklar, tavuk femurlarına yapılan transvers osteotomi sonrası fikse edildi. Plakların stabiliteleri in vitro koşullarda biyomekanik olarak test edildi. Plaklarla tespit edilmiş osteotomize kemiklere aksiyel yüklenme (kompresyon), üç nokta bükme (bending) ve burma (torsiyon) testleri uygulandı.*

Bulgular: *Yapılan in vitro biyomekanik testler sonucunda plakların stabiliteleri arasında istatistiksel olarak anlamlı fark saptandı ($p<0.05$). Oluklu yüzeye sahip plakların en dirençli olduğu görüldü.*

Sonuç: *Bu çalışma, yüzey şekli değiştirilmiş plak gruplarının özellikle aksiyel yüklenme altında en az kontrol grubu kadar stabil olduğunu gösterdi. Ancak kullanılan plağın canlı organizma içinde nasıl sonuçlar vereceği henüz bilinmemektedir.*

Anahtar Sözcükler: *Biyomekanik, plak, stabilite, osteosentez.*

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Introduction

Plate and screw combinations have been in frequent use for about a hundred years to treat fractures in orthopedic surgery. Better understanding of the factors affecting fracture healing; in particular, has helped aiming at an earlier and more functional healing process. The development of science and technology has resulted in new plate materials and designs.

Today, main problems in plate-screw fixation are the loosening and/or fracture that are formed due to the load on the plate and screw (1,2). Even though early problems related with plate-screw such as metal corrosion and resistance failures have now been corrected, it cannot be stated that more recent designs have solved all problems. The need for further studies is felt in order to both accelerate bone healing and develop a plate that will be free of adverse effects on bone physiology (3). The efforts to reduce the contact surface in order to optimize physiologic healing environment resulted in the development of limited contact dynamic compression plate (LC-DCP), the point-contact fixation (PC-Fix) and minimum-contact plate (MCP) (4). Although plate types and designs have been changed, there is limited data about the surface type of plates.

In this experimental study, we aimed to evaluate biomechanical stability of the different surface plates in an in vitro chicken bone model. We hypothesized that experimental plates with different surface types should reduce bone-plate contact area. Besides, they were intended to be at least equivalent to their traditional counterparts as to their biological properties, stability and physical resistance.

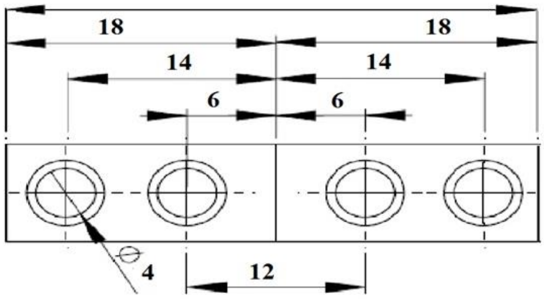
Materials and Methods

The present in vitro experimental biomechanical study was performed in collaboration with Ondokuz Mayıs University Department of Orthopedics and Traumatology and Atatürk University Mechanical Engineering Division Biomechanics Research Laboratory.

The experimental plates in this study were four-hole plates with made of stainless steel 316 L (ASTM #F55-82). This material was selected for its high resistance to corrosion and stress, and its ease of tooling.

Control group plates were not subjected to any additional operations. Other study groups' plates were two different designs of surface texture. Experimental plates worked by either sanding of the surface or opening 0.2 mm deep criss-cross grooves, respectively, for each group (Figure-1a/e and Figure-2). All plates were designed to the dimensions of chicken bones.

In this study, fresh chicken femurs were used. All femurs were used indifferently of left or right laterality, without undergoing any chemical process, after having been dissected without trauma from soft tissues. They were kept at +4°C until the experiment for up to 18 hours.



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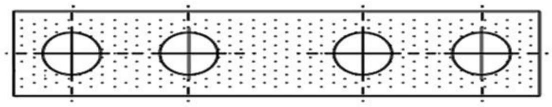

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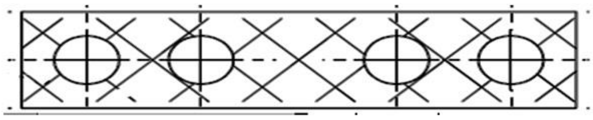

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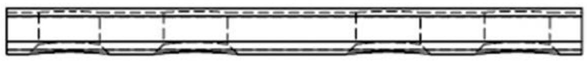

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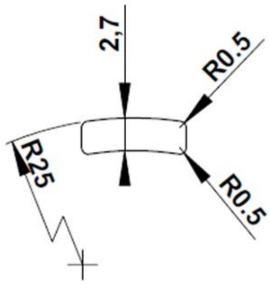

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Figure-1. a. Design of the plates used in the study (dimensions, millimeter). **b.** Design of the plates used in the study (sanded surface). **c.** Design of the plates used in the study (grooved surface). **d.** Design of the plates used in the study (profile). **e.** Design of the plates used in the study (elevation).

All bones were subjected to a transverse osteotomy by a motorized saw at mid-diaphysis, leaving a two millimeter (mm) defect in the fracture line. The plates were fixated to the bone using four 14x2 mm self-taping cortical screws. Screw holes 1.5 mm in diameter had been drilled for these screws, which were tightened by applying a standard torque of 1.5 Nm.

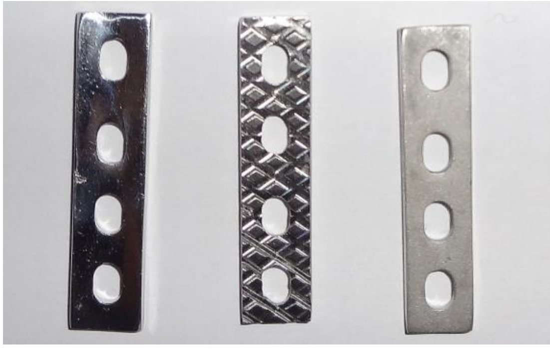

Figure-2. Appearance of the plates used in the study.

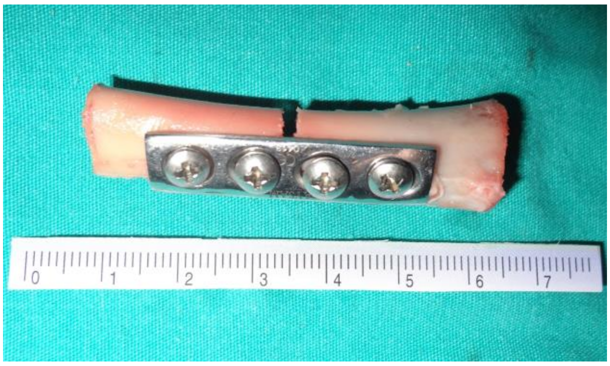

Figure-3. Bones prepared for axial loading tests.

Figure-4. A bone being tested for axial compression.

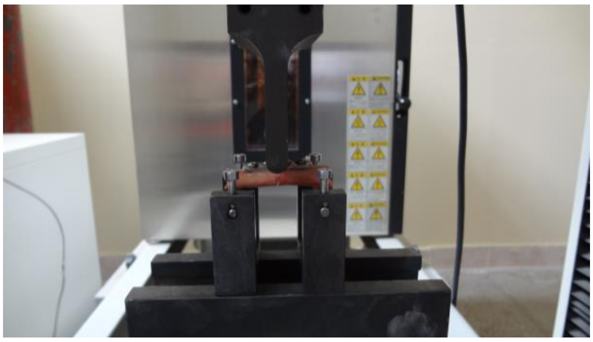

Figure-5. A bone being tested for three-point bending.

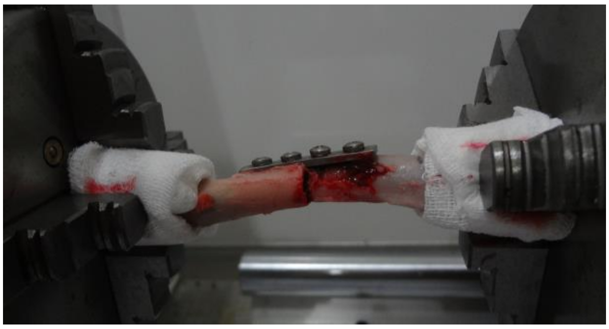

Figure-6. A bone being tested for torsion.

Figure-7. Bones prepared for torsion tests.

For the axial compression test, all bones were cut at the same length (60 mm), perpendicularly to the diaphysis in order to be placed upright on the test platform in standardized fashion. The distance between the plate edge and the osteotomy line was kept equal on both sides of the line (Figure-3, Figure-4).

The Shimadzu AG-IS 100 (Tokyo, Japan) device was used for the axial compression (Figure-4) and the three-point bending tests (Figure-5), while the rotation test was performed on a JINAN/NDW-200 (China) device (Figure-6).

A different bone was used for each loading test. The test groups consisted of ten experiments each. Three different groups of plates were fixated on a total of 90 chicken bones, of which 30 were subjected to axial compression testing, 30 to a three-point bending test and the last 30 to a torsion test.

The press device was calibrated before loading for each experiment for the axial compression and torsion tests. Compression was applied in a progressively increasing fashion, setting the press velocity to 1 mm/minute. Forces at the point of maximum resistance of the integral bone and its subsequent deformation were recorded.

For the torsion test, non-osteotomized contralateral bones were fixated to clasps at both ends with equal force and the loading force was equal for all experiments (Figure-6 and Figure-7). Rotation was applied in a progressively increasing fashion, setting the press velocity to 1 mm/minute. The amount of displacement achieved under loading was noted and the rotation calculated from it.

Statistical Evaluation

Results were stated as mean±standard deviation (SD). Statistical treatment of the loading test data was performed using the SPSS software package (SPSS 15.0 for Windows, SPSS Inc., 2006). A univariate model was built from general linear tests to evaluate the data from the axial compression, three-point bending and torsion tests. Results with a p value of <0.05 were accepted as significant.

Results

Different load displacement curves were obtained out of each group of plate design in each of the axial compression, three-point bending and torsion tests (Figures-8-10).

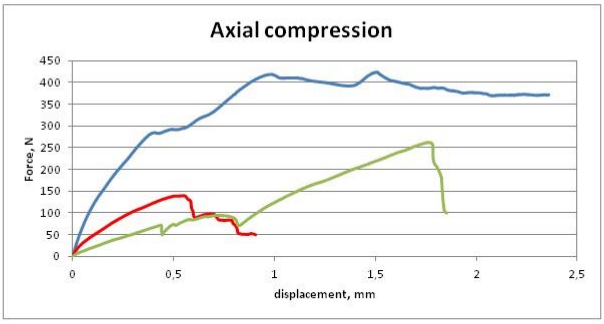

Figure-8. Load displacement curves for axial compression tests (blue: grooved surface, green: sanded surface, red: smooth surface)

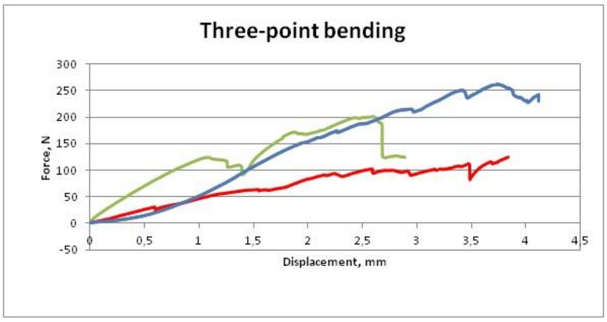

Figure-9. Load displacement curves for three-point bending tests (blue: grooved surface, green: sanded surface, red: smooth surface)

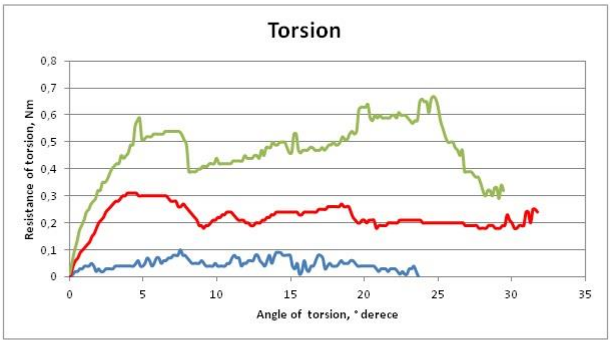

Figure-10. Load torsion angle curves for torsion tests (blue: grooved surface, green: sanded surface, red: smooth surface)

Mean resistance force for grooved, sanded and smooth surfaced plates under axial compression, three-point bending and torsion test was shown in Table-1. Mean resistance force for grooved surfaced plates was superior to sanded and smooth surfaced plates for all tests.

Table-1. Mean Resistance Force for Plates Under Different Biomechanical Tests (n=10).

	Axial compression (Newton)	Three-point bending (Newton)	Torsion (degree)
Grooved surface	328.1±54.5	227.9±138.2	19±3.6
Sanded surface	224.3±61.2	124.1±23	45.5±76
Smooth surface	147.9±6.5	107±13.7	56.5±37

Analysis of variance indicates that the differences both among the plate types and different tests with regard to the maximum withstood force are statistically significant, with a p value of 5%. A statistically significant correlation between different surface textures and types of test was also identified.

The plates with grooved surface were the most resistant, followed in the order by the sanded and smooth (control) plates (p<0.05, Table-2).

Table-2. Forces Achieving Deformation in the Plate and Bone Distributed by Type of Surface.

	Force* (Newton)
Grooved surface	189.33
Sanded surface	131.3
Smooth surface	103.8

*p<0.05

Discussion

The essential physical properties of the bone are resistance and rigidity. When the parts of a bone that was rigid before fracture become independently mobile, transmission of force through that bone, considered its essential function, becomes inexistent (5). Fracture treatment aims at ensuring stability with a minimum of damage to the vessels and tissues of the injured area and the best possible anatomic restoration (6). Various internal fixation methods and their different combinations are used for this purpose; plate and screw combinations being the most frequently encountered (5,7,8).

Fracture treatment using plates started in 1895, when Lane presented a metal plate for use in internal fixation. Being resistant and formable, metals are the main materials used for this purpose (6). The plates used in our study had been made from stainless steel with verified biocompatibility (316 L, ASTM No: F55–82) (6,9,10).

The resistance of plates depends directly from the raw material used, their shape and especially their thickness (6,9). All plates used in this study had the same raw material, geometric shape and dimensions.

Biomechanical tests are generally used to compare implants and fixation methods. Biomechanics testing aims to predict load changes in the body and predict the behavior of different systems. Cadaver bones from humans or animals or materials that imitate the mechanical properties of bone may be used to this end. Synthetic, homogeneous materials are being proposed as optimal; being entirely standardized (11-13). Studies performed with chicken bones have also been published (14). Our study strove to obtain a maximum of standardized conditions with animal cadaver bones. Cadaveric bones from chicken were selected as being the easiest and cheapest to obtain. In the absence of access and procurement difficulties, separate bone could be used for each single test; bones were allowed to be deformed.

Knowledge on the biologic aspects of fracture treatment has been increasing, especially in the last 20 years (6). Osteoporosis has been observed in bones fixated by rigid metal instruments; this is mainly traced back to two causes (15-17). One is the fact that rigid fixation materials keep the bone from the physiologic loads necessary for its self-regeneration; the other is reconducible to the effect on the periosteum, an extremely important tissue in blood perfusion, as a result of the wide surgical exposure during the placement of plates and the pressure exerted by the latter (3,15,18).

Reducing the contact area between the plate and the bone may minimize vascular damage in the fracture area, preventing or reducing osteoporosis and accelerating bone healing (16,17). Various authors attempted to avoid physiologic adverse effects by designing plates as resistant as the traditional ones but minimizing the plate-bone contact surface.

A Swiss group developed LC-DCP to increase stability while minimizing effects such as the decrease in perfusion and development of cortical osteoporosis following plate and screw implantation. This application managed to decrease the bone-plate contact area by about 50% (19).

Gunst et al. (20) established that blood perfusion was improved by the use of plates with reduced surface, using disulphine blue injections to evaluate cortical blood flow in sheep. The investigators of dynamic compression plate (DCP) and LC-DCP published histomorphometric data based on experiments with plates assuring full contact to the bone on one side; they found more necrosis on the side with full contact (3). Several clinical studies have indicated that healing times were similar to each other when using DCP and LC-DCP (3).

Abel et al. compared the MCP with the earlier established internal fixation plates DCP and LC-DCP using four-point bending and torsion tests. MCP was designed to reduce bone-plate contact area by 15% (21). A significant property of the new design was its minimization of damage to cortical blood flow by keeping the contact area away from the fracture area. Mechanically speaking, the MCP plate possesses sufficient rigidity and resistance for clinical applications; it is at least as stiff and strong as an already widely-used plate (21). The last mentioned study represents a precursor for ours. Plates with their contact area reduced by altering the surface texture were compared in in vitro tests to smooth-surfaced controls after fixation to chicken femurs in our study; plates with altered surfaces were found to be more stable. We found most stable plate as grooved surfaced plate.

Limitation of our study was that the effect of the experimental plates on bone physiology could not be evaluated, as the study had not been performed in an in vivo model.

Even though there is no universally recognized set of parameters for the fixation stiffness and strength that will ideally provide a successful healing, the reliability of fixation represents a priority. Therefore, a new fixation device that exhibits stiffness and strength comparable to those of the conventional models may be accepted as a reliable fixation. The plates newly designed with an altered surface texture to keep stability, especially axial and torsion stability, were found to be more stable than the control plates under the experimental force conditions of the study. The possible behavior in the living organism of the new grooved or sanded plates being unknown, appropriate in vivo controlled studies in the animal are needed.

Conflict of interest

The authors declare that there is no conflict of interest.

Funding sources

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