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Biomechanical comparison of the wedge supported plates at PTO

A. Yardimeden [a,*], M.H. Kelestemur [b], I. Esenkaya [c]

[a] Department of Mechanical Engineering, Dicle University, 21280 Diyarbakir, Turkey
[b] Department of Metallurgical and Materials, University of Firat, Faculty of Engineering, Eng., Elazig 23119, Turkey
[c] Department of Orthopaedics and Traumatology, Inonu University, School of Medicine, Malatya-Turkey
* Corresponding author: E-mail address: ayardim@dicle.edu.tr

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ABSTRACT

Purpose: Proximal tibial osteotomy (PTO) is a widely used surgical procedure for the treatment in medial compartment osteoarthritis of the knee with mal-alignment, particularly in young and active patients. Several types of plates are developed recently at the medial opening wedge osteotomy technique. The main aim of this study is to make stress analysis and compare the stability of a commonly used anatomic “T” plate and 3 different wedge supported plates and their combinations which are designed by one of the author of this article.

Design/methodology/approach: In this biomechanical study, calf tibial models were used in order to compare the stability of the plates under axial compression loading. 2 and 4 holes rectangular shape wedge supported plates, 4 holes reversed “L” shape wedge supported plates or combination of these and 6 holes anatomic “T” plates were used for the models. The compression behaviour of the model was tested by using a universal mechanical testing machine. And, a numerical method, ANSYS finite element code, was used for the stress analysis of the plates.

Findings: The specimen fixed with the combination of 4 holes reversed “L” shapes and 2 holes rectangular shape plates and 6 holes anatomic “T” plates showed significantly better stability than those of others. The numerical and experimental results were well agreed.

Practical implications: When Ti alloy plate is compared with stainless steel plate it is observed that the stress values do not change under applied loads and it does not show an advantage in term of stress. However, literature indicates that it has higher fatigue life and better electro-chemical properties.

Originality/value: Biomechanical comparison of the wedge supported plates at proximal tibial osteotomy.

Keywords: Numerical techniques; Bone plate; Proximal tibial osteotomy; ANSYS

METHODOLOGY OF RESEARCH AND ANALYSIS AND MODELLING

1. Introduction

Proximal tibial osteotomy (PTO) is a widely accepted and an extensively used surgical procedure for the treatment in medial compartment osteoarthritis of the knee with mal-alignment, particularly in young and active patients [1].

Proximal tibial osteotomy (PTO) was proven to be an effective treatment method for medial compartment osteoarthritis of the knee for young and more active elderly patients. Although unicompartmental and total knee arthroplasty cannot offer the high functional level of desired activity in young patients, PTO can offer high activity levels for the patients [3-5] Various techniques with stable osteosynthesis have been described in the literature [1, 3, 5–17]. Therefore, a stable fixation at the time of osseous consolidation of the PTO is a prerequisite for a satisfactory result. However, biomechanical experimental studies comparing the fixation techniques of PTO remain insufficient [4, 8, 14-18].

Various techniques having stable osteosynthesis are preferred recently in the literature. In his studies Esenkaya İ. carried out and evaluated a series [1, 7] of surgical techniques for PTO and he has developed couple of plates to alternate with the existed ones from the view point of stability, optimal shape and geometry etc.

Although clinical study is the ultimate investigative tool, it is often difficult to identify and, isolate important parameters because of confounding variables. Cadaver study is limited by the problems created from performing several comparative experiments on the same specimen. Mathematical modeling is a technique that overcomes many of these problems [19].

The main aim of this study is to make stress analysis and compare the stability of a commonly used anatomic "T" plate and 3 different wedge supported plates and their combinations which are designed by one of the author of this article.

2. Material and method

A standardized osteotomy was performed with a band saw (blade thickness 2 mm in tooth) starting at the medial cortex 4 cm below the medial border of tibial articular surface run through to a point that 1 cm below the lateral tibial articular surface and 1 cm medial to the lateral tibial cortex. Triangular shape of bone mass having 4 mm thickness vertically was taken out after the osteotomy due to blade thickness of band saw bilaterally. An approximately 15^o osteotomy angle that was suitable for the medial opening wedge osteotomy was distracted to 10 mm by using the angle scale distractor which was developed and reported in detail elsewhere (Esenkaya, 2006) [20], then osteotomy was fixed by four types of combination of 10 mm wedge height supported plates (TR-2002 02021Y-Hipokrat/ Turkey) (Esenkaya, 2006) [7] and six holes anatomic "T" plates without wedge (Hipokrat / Turkey). All plates and screws were made of stainless steel (316L/1.4441) and their drawn pictures are show in figures 1-4. Some experimental results done with usage of these plates have been introduced already in the literature [2]. A numerical method, ANSYS finite element code, was used for the stress analysis of the plates.

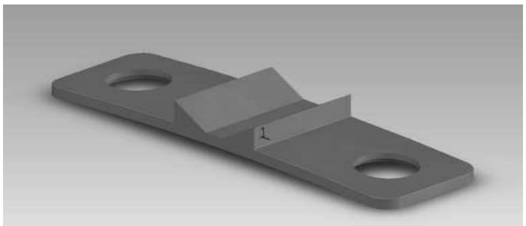

Fig. 1. Rectangular plate with two holes

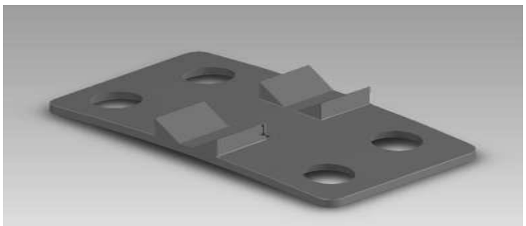

Fig. 2. Rectangular plate with four holes

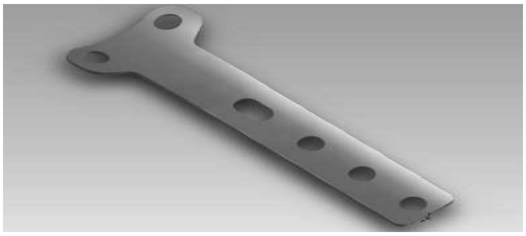

Fig. 3. T support plate with 6 holes

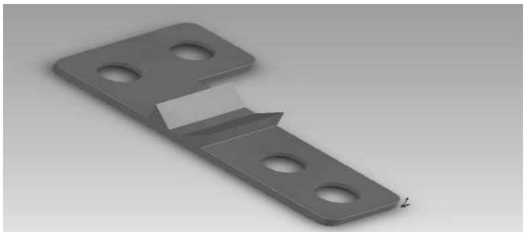

Fig. 4. L shaped plate with 4 holes

3. Numerical analysis of plates

The plate models have been created in ANSYS code and loads of 3000N, 5000N and 7000N have been applies on their surface. Stress analysis have been carried out by applying Von Mises Yielding Criteria. 3D, 10 Node tetrahedral solid model is used for the finite element model of both the plates and bone materials since plates are mounted into the bones. Plates are assumed linear, elastic, isotropic and homogenous materials. Plate materials are "316L/1.4441 stainless steel" and "Ti-6Al4V/IMI 318 Ti alloys" (Table 1). Auto mesh is applied to the plates after modeling of them. Optimal dimensions of the elements are found 0.8 and accordingly analyzed. Element properties of the plates analyzed in ANSYS shown in Table 2. After determining the loads and boundary conditions on the model, the solutions have carried out.

Table 1.
Material properties of plates

Material	Modulus of elasticity (MPa)	Poisson rate
Stainless Steel (316L/1.4441)	200.000	0.3
Titanium (Ti-6Al4V/IMI 318)	100.000	0.3

Table 2.
Element Properties of the Plates analyzed in ANSYS

Plate	Element no	Node number	Element size	Element type
1	21964	35257	0.8	SOLID92
2	39233	62830	0.8	SOLID92
3	58828	94273	0.8	SOLID92
4	28119	45427	0.8	SOLID92

4. Results and Discussion

Bone plates are often used to support fractured bones. The bone plates are affixed using screws on to the bone over the fracture so that load is transferred via this bone plate while the bone is healing after which the plate is removed from the body. The bone plate should be biocompatible but should also have the appropriate mechanical properties.

Clinical research by Hastings [21] has shown that this is not desirable, as bone does not strain. Scwyzer and Tonino [22,23] have established that callus formation, ossification and bone union are hampered by the lack of strain in bone. This result in not only the fractured part but also the whole bone structure becomes osteoporotic. Bone plate should be just strong enough to promote the healing of fracture yet not so stiff as to hinder the bone union. Therefore, new types of bone plates are required which will have stiffness close to that of bone, yet biocompatible. Bone plates made of composites are possible candidates as they can be manufactured to stiffness similar to that of bone; they have high strength (or stiffness) to weight ratio, and non-corrosive. Further, the resulting composite behavior can be tailored to nearly any requirement by choosing suitable matrix and reinforcement materials. Zimmerman [24] has also shown that composite design possesses good static and fatigue resistance as against laminated or random design [25].

It is observed that stress intensifies at the hole edges and between the wedges of the plate according to Von Mises yielding creteria in the stress analysis of first sample which is rectangular plate with two holes. Additionally, stress and its intensity increase proportionally with increasing the load (Fig. 5).
Stresses intensify at the same region at the samples with 4 holes rectangular plate and L shaped plate with 4 holes. Stress and its intensity increase proportionally with increasing the load in these plates too (Fig. 6 and 8).

Stress intensifies at the lowest hole and edges of the upper holes in the stress analysis of the plate with 6 holes and stress increase with increasing the load in the plate (Fig. 7).
When Ti alloy plate is compared with stainless steel plate it is observed that the stress values do not change under applied loads and it does not show an advantage in term of stress [26]. However, literature indicates that it has higher fatigue life and better electro-chemical properties [27].

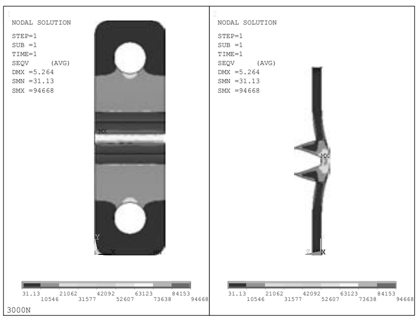

Fig. 5. Stress distribution of rectangular plate with two holes, Von mises criteria is applied (3000N)

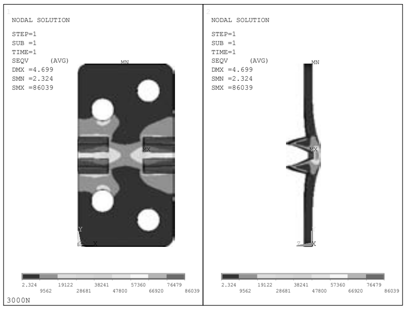

Fig. 6. Stress distribution of rectangular plate with four holes, Von mises criteria is applied (3000N)

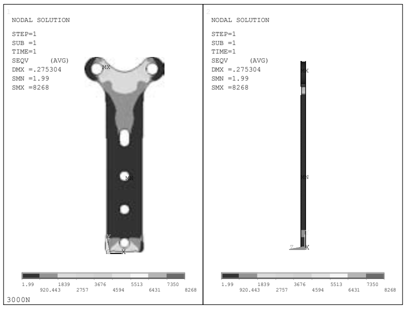

Fig. 7. Stress distribution on the plate with six holes and without wedges, Von mises criteria is applied (3000N)

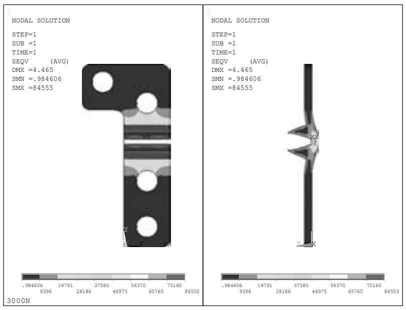

Fig. 8. Stress distribution of the L shaped plate with four holes, Von mises criteria is applied (3000N)

It is determined that the most stabile plate among the plates which are investigated is the plate with 6 holes. Rectangular plates with 2 holes and 4 holes are failed under lower axial compression loading when compared with the other two plates. A knee carries 3.9 times of a body weight during the regular walking condition, therefore it is obvious that all plates are stable for this criteria. The numerical and experimental results were well agreed. [2].

Consequently, the plates, designed by Esenkaya, are stable in term of loading condition and the average force values at these points is higher than the loading force on a knee during the normal paced walking or running conditions.

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