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Biomechanical comparison of straight DCP and helical plates for fixation of transverse and oblique bone fractures

BUNYAMIN AKSAKAL[1]*, MURAT GURGER[2], YAKUP SAY[3], ERHAN YILMAZ[1]

[1] Department of Metallurgy and Materials Engineering Yildiz Technical University, Istanbul, Turkey.
[2] Department of Orthopedics, Faculty of Medicine, Firat University, Elazig, Turkey.
[3] Department Metallurgy and Materials Engineering, Faculty of Technology, Firat University, Elazig, Turkey.

Purpose: Biomechanical comparison of straight DCP and helical plates for fixation of transversal and oblique tibial bone fractures were analyzed and compared to each other by axial compression, bending and torsion tests.

Method: An *in vitro* osteosynthesis of transverse (TF) and oblique bone fracture (OF) fixations have been analysed on fresh sheep tibias by using the DCP and helical compression plates (HP).

Results: Statistically significant differences were found for both DCP and helical plate fixations under axial compression, bending and torsional loads. The strength of fixation systems was in favor of DC plating with exception of the TF-HP fixation group under compression loads and torsional moments. The transvers fracture (TF) stability was found to be higher than that found in oblique fracture (OF) fixed by helical plates (HP). However, under torsional testing, compared to conventional plating, the helical plate fixations provided a higher torsional resistance and strength. The maximum stiffness at axial compression loading and maximum torsional strength was achieved in torsional testing for the TF-HP fixations.

Conclusion: From in vitro biomechanical analysis, fracture type and plate fixation system groups showed different responses under different loadings. Consequently, current biomechanical analyses may encourage the usage of helical HP fixations in near future during clinical practice for transverse bone fractures.

Key words: *straight DC plate, helical plate, biomechanics, fixation, bone fractures*

1. Introduction

Transverse and oblique fractures are the common fractures that occur during sportive activities and accidents. The latest advances in orthopedic surgery led to development of many techniques in fixation of such bone fractures. Internal fixation devices are in use for more than a century, but still there is a need to develop further bone fixation designs that would speed up the healing without causing any adverse effect on bone physiology [1]. The first significant compression plates were designed by Bagby and Wood [2], [3], however, such designs provided limited fixations. The Dynamic Compression Plates, DCP, providing self axial compression were used for treatment of reductive bone fractures [4], [5]. Cylindrical bone composites have been used via in vitro biomechanical tests and finite element analysis to show the effect of DCP fixations in diaphysial fractures [6] It was reported that, although possessing higher powers, the locking plates are often used in elderly patients with osteoporetic bone [7].

Helical plate osteosynthesis in internal fracture fixation is one of the latest proposals in treating fractures [8]. Some complications in fixation of oblique bone fractures by standard conventional compression plates was reported to be prevented by using helical plates that was the first idea published about helical plates [9]. Since the oblique fractures caused by tor-

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* Corresponding author: Bunyamin Aksakal, Department of Metallurgy and Materials Engineering Yildiz Technical University, 2334 Istanbul, Turkey. Tel: +90 212 383 4662, e-mail: baksakal@yildiz.edu.tr

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sional loading can be fixed by providing advanced holding capacity, the design of helical plates is proposed for better stable fixation [10], [1]. The helical plates were used [12] instead of conventional ones for humerus fractures at proximal. Such plates were placed on the lateral tubercle of the proximal and due to distal humerus and shaft directed the anterior deltoid muscle insertion was therefore preserved. There are also some studies in which the fracture was controlled through different fixation methods [13]–[17]. It was suggested that helical plate fixation might be better in terms of increasing healing of the fracture under various loadings [13]. Why helical plating? No doubt that this question may be asked by many orthopaedists and surgeons, because the ideal fixation treatment of bone fractures has not still been agreed [8] and consequently, straight DCP plating sometimes results in serious traumas and loosening effect and recovery problems after surgery [9], [11], [12]. Furthermore, using helical plating would benefit from better blood flow beneath the plate.

As can be seen from literature review, some research was conducted on alternative compression plates for internal fixation of bone fractures, however, none work was considered in a comparison with DCP and helical plate fixations applied to fix the oblique and transverse fractures. Before clinical applications, further analytical, *in vitro* and *in vivo* research is needed in order to make sure that reliable fixation and stable fixation was found between fractured bone and plate.

In this study, biomechanical comparison of the straight DCP and helical plates for transverse and oblique fracture fixations in combination of four fracture–plating systems was undertaken throughout an *in vitro* study.

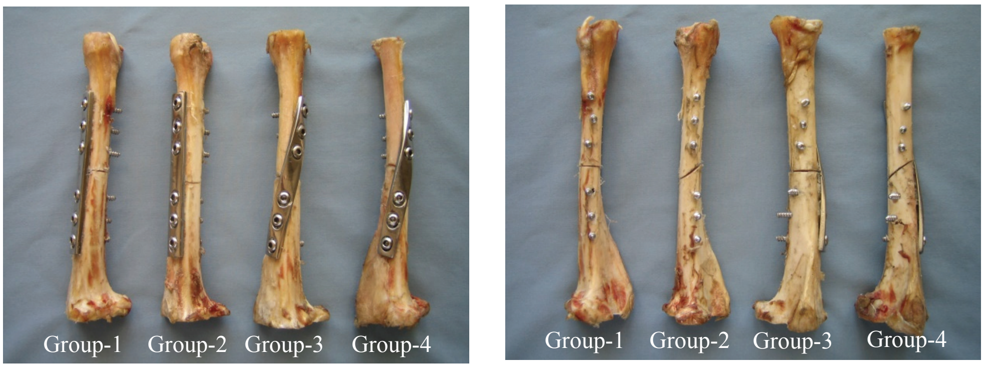
2. Materials and methods

2.1. Samples and fixation groups

The bone fracture–plate groups are classified into four groups each comprising oblique and transverse fractures with DCP and helical plate fixations (Table 1). Fresh cadaveric sheep tibias were supplied and used in these fixation groups by ELET Ltd. Elazig, Turkey. Eighty four sheep tibias were divided into four groups (Group 1 to 4) in a combination of fracture plate fixations. Tibias in the first group having transverse fracture (TF) were fixed by conventional compression plates (DCP). Tibias in Group 3 having 45° oblique fractures (OF) were fixed by conventional compression plates (DCP). Tibias in the second group having transverse fracture (TF) were fixed by helical plates (HP). Finally, tibias in the fourth group having the

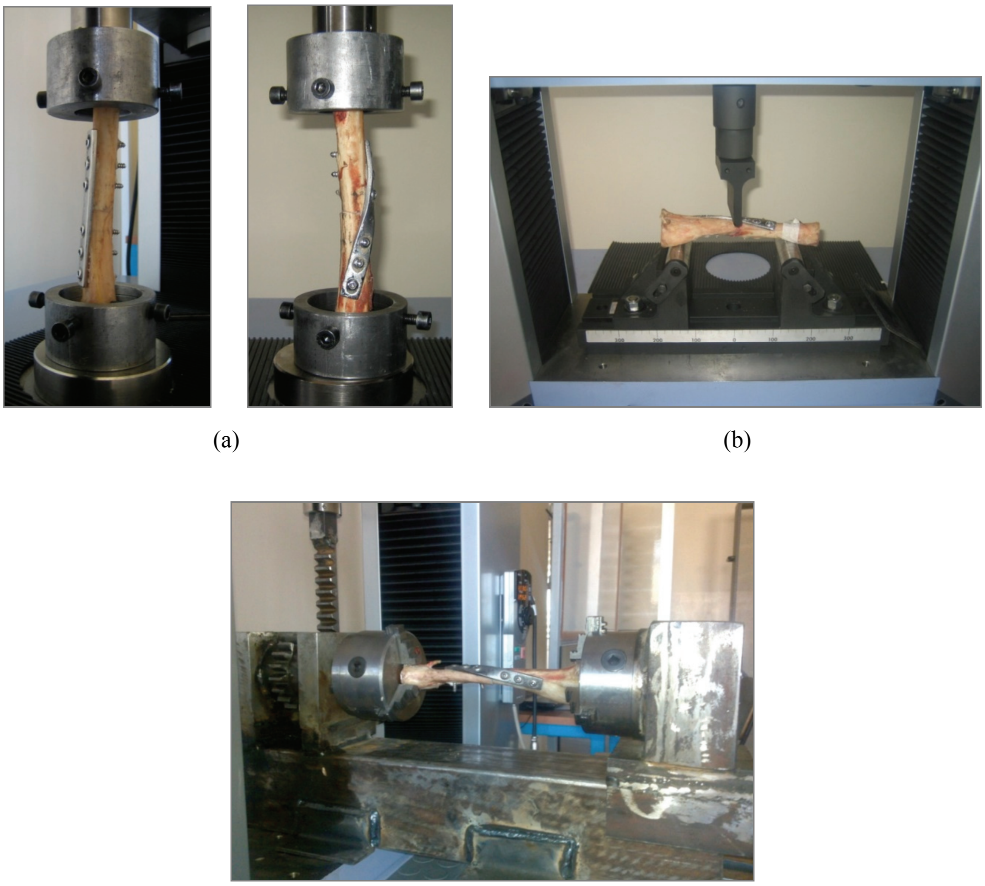
Table 1. Sample and fracture–fixation groups used during biomechanical tests

Sample Groups	Fracture-Fixation
Group I	TF-DCP (Transvers Fracture – Dynamic Compression Plate)
Group II	TF-HP (Transvers Fracture – Helical Plate)
Group III	OF-DCP (Oblique Fracture – Dynamic Compression Plate)
Group IV	OF-HP (Oblique Fracture – Helical Plate)



(a) (b)

Fig. 1. Conventional and helical plate fixation groups on oblique and trasverse fractures: (a) first view, (b) second view



(a)

(b)

(c)

Fig. 2. Illustration of experimental set up for: (a) compression, (b) 3P-bending, and (c) torsion tests

oblique fracture (OF) were fixed by helical plates (HP). Figure 1 shows such combination groups of fixations and Fig. 2a–c shows the test rigs. The fracture gap was kept about 1.5 mm on average. Each group had 7 specimen ($n = 7$) and these broken bone samples were fixed by two platings. The fixations were subjected to axial compression, bending and torsion tests.

2.2. Plates and screws

DC plates and cortical screws used during this work were made of stainless steel (ASTM F138). The dimensions of all plates were 110 mm in length, 13 mm in width, 4 mm in thickness, and having 6 screw holes. Because of laboratory constraints, the helical plates were twisted manually by 90° using an angular indicator located on a lathe chuck to lie on the lateral distal tibia during the current experiments. The dimensions of screw holes were 5×9 mm and the distance between each hole was 6 mm from the ends. The compression plates were applied after the bones were transected and were fixed onto tibias by using cortical screws (3.5 mm) with 120 Nm torque.

2.3. Bones

The number of 84 fresh sheep tibias in one year old (average) were provided having the bone mineral density (BMD) of (1.260 ± 0.035 g/cm^2) and diaphyses diameter of 17.14±1.49 mm. Bone mineral density (BMD) measurements were made by dual energy X-ray densitometry. The analysis was performed by placing the bones saparetely in the scan group by a dual energy X-ray densitometry device Discovery Wi (S/N 84440). The tibias were cut off from both ends to have 200 mm in lengths, then were sawn off from the middle to obtain oblique (45°) and transverse fractures by an automatic sawing machine. The average wall thickness was measured as 5mm from 28 sawn tibias.

2.4. Biomechanical tests

Biomechanical tests (compression, three-point bending and torsion) were executed by using a Universal test machine (SHIMADZU Autograph) with the help of 50 kN load cell. In order to overcome sliding of tibias from the upper and lower press platens, the extra cylindrical housings were manufactured and assembled on the test machine (Fig. 2a–c). Each tibial bone-plate fixation assembly was loaded by a universal testing machine under controlled loading. The compression and bending experiments were undertaken the samples for each configuration at a rate of 5 mm/min. Bending test rig dimensions had 130 mm distance between two beds and 5 mm punch radius. Torsion head consisted of a U-chuck and was fastened by a gear-rack section of the chuck allowing a circular motion. An external torsional moment was applied on the fixed specimens with a loading rate of 0.017 rd/sec.

2.5. Statistical analysis

The statistical analysis of data collected from the axial compression, bending and torsion tests have been executed using the SPSS (SPSS for Windows 13.0 SPSS Inc. 2004) and non parametric tests ($n = 7$) of Kruscal–Wallis test were applied to all groups. The Standard deviations of all groups were executed and given in Table 2. The groups showing statisticallysignificant difference ($p < 0.05$) were compared to each other by the Mann–Whitney U test.

Table 2. Mechanical property results during Compression, 3PB and Torsion Tests of fixations

Group	Compression			
	Elastic Moduls (MPa)	Tensile Strength (MPa)	Fracture Strength (MPa)	Strain, ε
1	399.9	5.09	4.04	0.006
2	91.2	2.88	2.84	0.005
3	277.21	6.05	4.81	0.003
4	104.71	5.07	4.19	0.012
Group	3P Bending			
	Elastic Modules (MPa)	Tensile Strength (MPa)	Fracture Strength (MPa)	Strain, ε
1	237.89	7.9	6.08	0.018
2	335.15	5.48	5.24	0.022
3	194.29	1.09	1.07	0.020
4	101.03	3.41	2.88	0.031
Group	Torsion			
	Elastic Modules (MPa)	Torsion (N.m)	Torsion Angle (Radyan)	Shear Stress (MPa)
1	4.27	0.57	0.19	7.78
2	8.72	0.54	0.28	7.28
3	2.48	0.56	0.21	6.96
4	9.86	0.37	0.052	8.34

3. Results

In order to show the advantages and disadvantages of possible alternative usage of helical plates over the conventional plates, a series of in vitro biomechanical tests were executed. Three loadings (compression, bending and torsion) applied on different cobmination of fracture–fixation systems showed various resistance and response to those loading systems. Figure 2a shows the axial compression test rig and loading for the straight DCP (on the left) and a helical plate fixation (on the right). Bending and torsion loadings are shown in Figs. 2b and 2c, respectively. From these tests, the stress-strains, torsional and bending moments were obtained and compared to each other. Through axial compression tests, stress strain curves were plotted and shown in Fig. 3 for all fracture–fixation groups. Figure 4 shows the recorded elastic modulus, fracture strength and strains of transverse and oblique fractures using both DCP and helical plates. Standard deviations of those results were calculated and shown in Table 2. Similar plots were provided for bending tests, as Fig. 5 shows the variation of

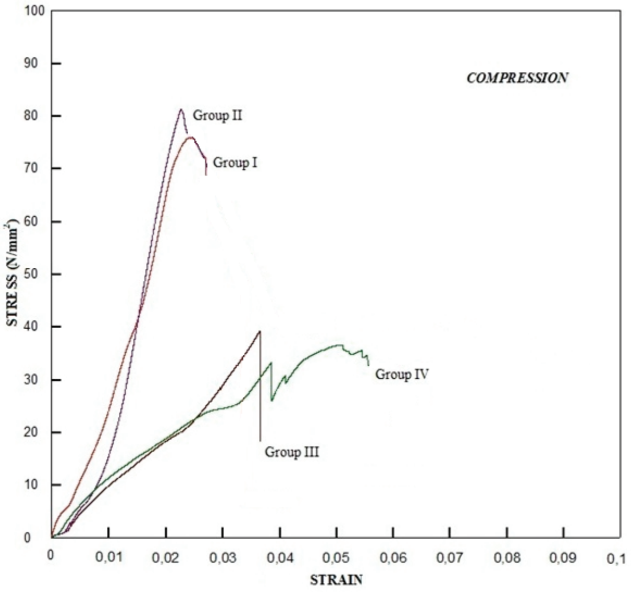


Fig. 3. Variation of average stress with strain for all fixation groups: (a) compression, (b) bending, and (c)torsion tests

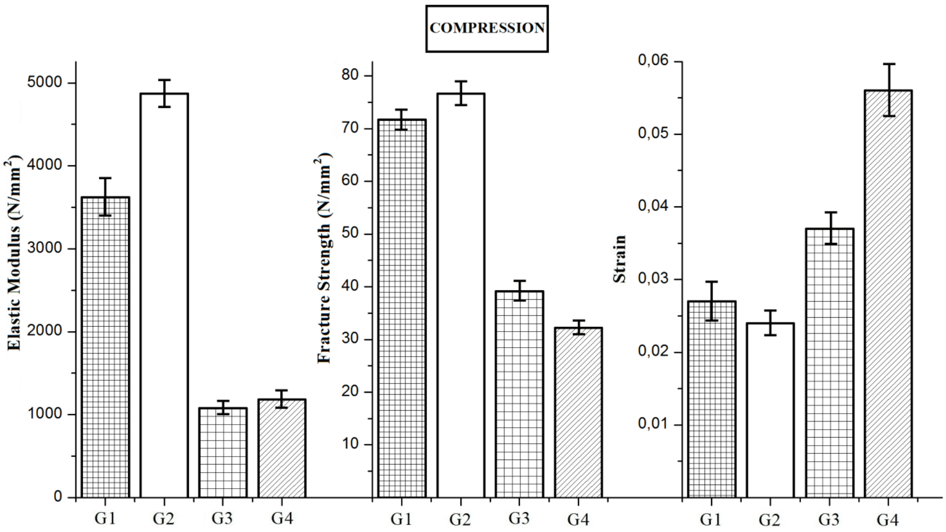


Fig. 4. Variation of average elastic modulus, fracture strength and strain values obtained from axial compression tests

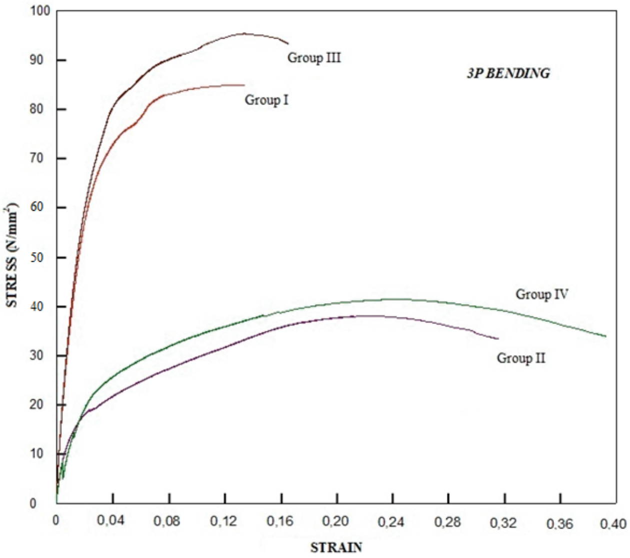


Fig. 5. Variation of average elastic modulus, bending moment and strain values obtained from 3PB tests

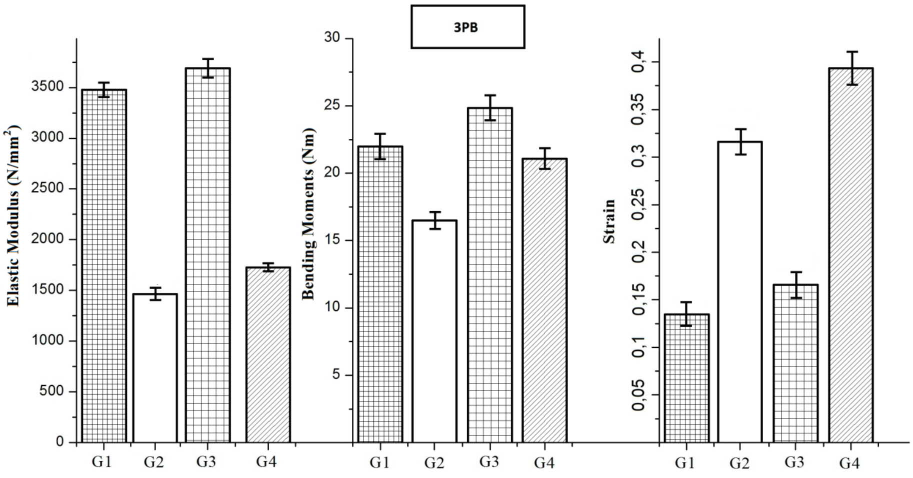


Fig. 6. Variation of average elastic modulus, bending moment and strain values obtained from 3PB tests

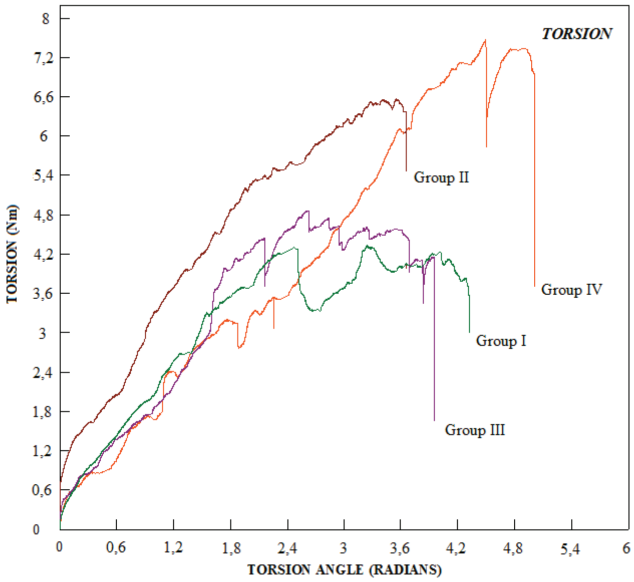


Fig. 7. Variation of average elastic modulus, bending moment and strain values obtained from 3PB tests

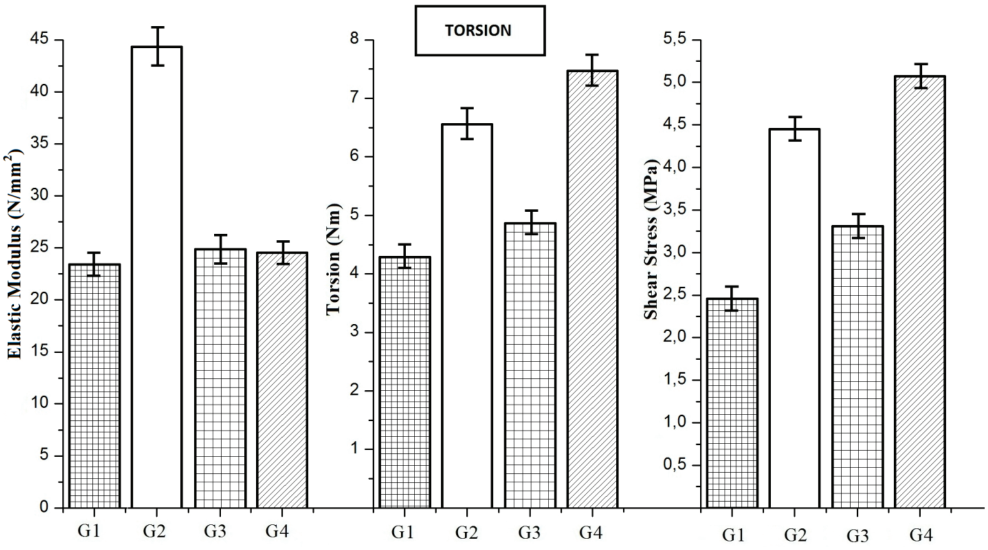


Fig. 8. Variation of average elastic modulus, torsion and shear stress values obtained from torsion tests

stresses with strains for all fixation groups. In addition, stiffness, bending moments and strains were compared with those of fixation groups. Torsional moment with torsion angle are presented in Fig. 7 during torsion tests. Throughout torsion tests of DCP and helical fixations of tibial bones, elastic modulus, torsional moment and shear strains are shown in Fig. 8 as columns. From these in vitro biomechanical tests the advantages and disadvantages of fixation in the four groups under various loadings have been demonstrated in comparison with DCP and helical plates.

4. Discussion

4.1. Axial compression

By comparison of the axial compression groups, in both plates, a statistically significant difference was found ($p < 0.05$) between DCP and helical plate (between G1 and 2, and between Gr3 and 4) fixation of transverse fracture. If the transverse bone fracture (G1) and oblique fracture (G3) implemented for DCP and HP fixation are compared, the difference obtained was not statistically significant. Also, if the HP with transverse fracture (G2) and helical plating with oblique fracture (G4) are compared, also no statistically significant difference was observed ($p > 0.05$).

The fracture–fixation systems in Group I(G1) and II(G2) both show higher potential to resist against axial compression forces than the fixations of Group III(G3) and IV(G4) (Fig. 3). These results suggest that in terms of stress and strains, there is not much difference between DCP or helical fixation of transverse and oblique fractures. But, higher stresses have been determined for transverse fractures compared to oblique fractures. The elastic modulus is a measure of stiffness of the system and as seen in Fig. 4, elastic modulus of helical plate fixation (G2) is higher than DCP plate fixation (G1) for transverse bone fractures and fracture strength of helical plate (G4) is a bit higher than the DCP plates (G3).

Lower biomechanical strength for the helical plates was found, however, the results were determined to be statistically insignificant as the helical and conventional plate fixations are implemented in both fracture group (TF and OF) types under axial compression loads. Consequently, it was found out that the fixation applied to transverse fractures (TF) exhibited more strength than the fixation implemented in the oblique fractures (OF). This is due to the fact that the direction of compressive loading implemented in transverse fracture was vertical to the fracture line and the cross sectional area affected by vertical strength was wide, and therefore cortical bones showed highest strength against compressive strength as similar comments given in [18] and [19].

Figure 5 shows the plotted stress–strain curves for those fracture fixation groups under 3P-bending tests with respect to strains. Compared to axial compression tests, here, G1 and G3 show different behaviour, e.g., the stresses in G2 decrease while the stresses of G1 increase. G1 and G3 show higher stresses than G2 and G4, which means TF-DCP and OF-DCP fixations resist better to bending loads than TF-HP(G2) and OF-HP (G4) fixations. Figure 6 also supports the results of changes in resistance of DCP and helical plate fixations in 3PB tests. Significant difference in elastic modulus and bending moments occurred and so strains increased as a result of these changes. These results indicate that helical plate fixations, especially for transverse bone fractures, have low resistance and stiffness against bending loadings. It can be seen from Fig. 6 that such values increase for the oblique fracture groups (G3 and G4). The neutral axis of the plate–bone system takes place very close to the plate outface of the bone during fixation by using HP fixation when exposed to bending loads. This causes a stress shield in the segments of the bones and causes the weakening in the segments [10], [11]. Therefore, for such loading the DCP provides higher stiffness and bending moments than those of the helical plate fixations.

From these results, especially Groups 1 and 3 show higher values of elastic modulus or stiffness, bending moment and strains compared to other groups. This means that straight DCP fixation of transverse fracture fixation groups of G1 and G3 can resist better to bending loads than other groups and has advantageous over other groups for such loadings. A statistically significant difference ($p < 0.05$) was found between the DC and helical plate fixations that were implemented in both transverse and oblique fracture types. However, when transverse (G1) and oblique fractures with straight DCP fixation (G3), and transverse and oblique fractures with helical plate fixation (G2 and G4) were compared, the difference obtained was not statistically significant ($p > 0.05$). Consequently, in 3P-bending tests and helical plate fixations exhibited lower biomechanical stiffness and strengths compared to counterpart DCP plate fixations.

Torsional moments mostly cause oblique or combined fractures and are vital to treat in orthopedic surgery. In order to show the behaviour of transverse and oblique fracture fixations by using straight DC and helical plates, torsional moments were applied onto those fixed bone specimens. The variation of torsional moment with torsion angle was plotted for all groups of fracture–fixation groups and shown in Fig. 8. The average torsional moment for G1 appeared to be 4.29 Nm and 6.56 Nm for G2. It decreased to 4.86 Nm for group (G3) and the maximum torsional moment was found to be 7.47 Nm, for the 4th group (G4). Such results suggest that both transverse and oblique fractures–helical plate fixation system resist better to torsional loading. Especially the trasversely fractured specimens which were fixed by helical plates (G2) provide high rigidity modulus. Hence, it can be concluded that the TF-HP (G2) possess the maximum stiffness and torsional moment and hence suggest better fixations compared to straight DC plate. High plastic deformation was observed at high torsional angles for the HP groups and the shear strength were found to be as twice as high in biomechanical strength in HP fixation groups compared to DCP groups (G1 and G3). In torsion tests, when the groups are compared to each other, the differences between the groups were statistically significant ($p < 0.05$) in terms of shear stress, strain and torsional moment. A significant difference ($p < 0.05$) was found between the straight DC plate and helical plate fixations that were performed for both fracture types (oblique and transverse) when torsional angle was compared among the groups. The difference between the groups was statistically significant ($p < 0.05$) when groups in torsional tests were compared with each other, consequently, it was found that the oblique fracture groups had much higher biomechanical strength against applied torsional loads and moments than the fixations with straight DC plate. Also, it was found that the groups with helical plate fixations had higher rigidity, torsional moments and shear stress than the groups with the straight DC plate fixations under torsional loadings.

5. Conclusions

Considering all of the biomechanical test results, it appears that the helical plates differ with respect to their abilities to resist axial compressive loading for transverse types of fracture. In three point-bending tests, the straight plates provided superior stiffness and strength for both fracture types, while in torsion, the helical plates were stronger but not more stiff for both transverse and oblique fracture types.

Despite the Helical Plates (HP) are not commercially available yet, however, our biomechanical results suggest that HP fixation provides better torsional strength than DCP-straight plates. Current experimental biomechanical analysis demonstrated the advantages and disadvantages of helical-plate fixations over the DC plate fixations for oblique (OF) and transverse bone fractures (TF). The maximum torsional strength was achieved for the TF-HP fixations. It was also shown that the fracture type–fixation system behaves in different ways under different loadings. For example, our current biomechanical analyses suggest that the helical fixations have advantages over transverse fractures under especially torsional loadings. Considering better blood flow assumption and some biomechanical advantages disadvantages of helical plating, however, further in vitro and in vivo studies must be conducted before clinical applications.

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