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ORIGINAL ARTICLE

Biomechanical Comparison of Headless Compression Screws, Kirschner Wires and Bioabsorbable Pins in Distal Oblique Metatarsal Osteotomy for Correction of Hallux Valgus

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Background: Distal osteotomy of the first metatarsal is a widely used method for the correction of mild-to-moderate hallux valgus deformities. The objective of this study was to compare the stability of headless compression screws, kirschner wires and absorbable pins in terms of stiffness and maximum load in distal oblique metatarsal osteotomy.

Methods: A total of 30 4th generation first metatarsal synthetic bone models were divided into three groups according to the fixation techniques. The stiffness of the first metatarsal was calculated as the slope of the linear curve that fit with the first linear part of the force displacement curve. The failure strength was recorded as the maximum load. The stiffness and

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maximum load values in the axillary and transverse configurations were compared between the three fixation groups.

Results: The stiffness was statistically higher in Group K and Group C compared to Group B in both axial and transverse loading. Similarly, the maximum load was significantly higher in both Group K and Group C compared to Group B in both loading conditions. No significant difference was found between Group K and Group C in stability. The higher failure strength was obtained with headless compression screws (113.34±35.88 N) in the axial loading. The lowest failure strength was found in the absorbable pins technique (16.17±7.72 N) in the transverse loading.

Conclusion: No significant difference was found between the Kirschner wires and headless compression screws techniques, although the highest strength was obtained with headless compression screws that are increasingly used in orthopedic practice.

Hallux valgus (HV), also known as a bunion, is a common deformity of the forefoot caused by several mechanisms such as trauma, shoes, arthritis and medial column instability and genetic factors (1). It usually presents with a laterally deviated proximal phalanx and medially deviated first metatarsal head, causing discomfort and pain (2). The common complications of HV include pain, recurrence, avascular necrosis, hallux varus, reduced range of motion, transfer metatarsalgia, and discomfort and decreased quality of life (3). The exact etiology of HV has not yet been fully understood. It is more common among women and those who wear tight shoes.

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HV deformity is a relatively common condition seen in approximately 23% of adults aged 18 to 65 years (4).

In the treatment of HV, usually non-surgical conservative treatments are trialed first. Non-surgical treatment options include medial bunion pads, shoe modification, stretching, ice therapy, orthoses and analgesics (5). Surgical treatment is indicated when conservative treatment attempts fail, because HV is a progressive disorder. Numerous different surgical procedures have been described for the treatment of HV depending on the source and extent of the deformity, although there is still no consensus on the most appropriate surgical method (6, 7). The main goal of a surgical treatment of HV should be alleviation of pain and stable restoration of the physiological metatarsophalangeal and intermetatarsal angle. Among these, distal osteotomy of the first metatarsal is a widely used method for the correction of mild-to-moderate HV deformities. This technique can be performed utilizing several forms such as Chevron, oblique and transverse osteotomies. The original distal oblique osteotomy is mainly based on an oblique osteotomy of the distal third of the first metatarsal with a combination of medial exostosis remodelling as described by Wilson in 1963. The line of osteotomy is on the medial side at the proximal end of the exostosis and extends laterally at 45°C (8). A number of modifications have been made to this technique up to today.

Many fixation techniques have been described for distal oblique dome osteotomy, including Kirschner wires, screws, plates, staples and absorbable pins. The choice of the fixation

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technique is usually based on the physical status of the patient, degree of HV and preference of the surgeon. Kirschner wire fixation is commonly preferred due to its simplicity and low cost (9). However, it has complications such as pin site infection and Kirschner wire migration. Headless compression screws have been increasingly used in orthopedics practice because of their advantages, including improved internal holding power, better maintaining compression and resisting bending stress with movement and headless design, which helps to avoid motion interference (10). These screws do not require routine removal after bone healing, but increased angular correction leads to a decrease in contact area in these screws. Bioabsorbable pins eliminate the potential risks such as pain in the surrounding skin and infection, and provide faster rehabilitation due to less postoperative pain (11). However, compression which is often desired across the osteotomy interface cannot be achieved by the use of absorbable pins.

Although there few biomechanical studies in the literature comparing several fixation techniques in distal Chevron osteotomies of the first metatarsal (6, 12), to the best of our knowledge, this is the first biomechanical study in the literature that compare the stability of various fixation techniques used in distal oblique metatarsal osteotomies. Therefore, in this biomechanical study, we aimed to compare the stability of headless compression screws, k-wires and absorbable pins in terms of stiffness and maximum load in distal oblique metatarsal osteotomy for correction of hallux valgus.

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Material and Methods

A total of 30 4th generation first metatarsal synthetic bone models made up of solid foam (Selbones Research Laboratory, Kayseri, Turkey) were used in the study. All sawbone models were subjected to distal metatarsal oblique osteotomy utilizing a microsagittal saw..The Sawbone models were divided into three groups according to the fixation technique used. Group K underwent fixation with two 1.6 mm Kirschner wires, Group C with one 3.5 mm headless compression screw, and Group B with two bioabsorbable pins. The fixation was performed by sliding the metatarsal head laterally and the metatarsal shaft medially. Anterior-posterior and lateral X-rays were obtained in all fixation models (Figure 1).

The fixation following distal oblique osteotomy was performed using 2 Kirschner wires in Group K. The Kirschner wires were positioned with an angle of 10-15° at dorsomedial-to-plantolateral direction. Group C osteotomies were fixed with a headless compression screw. The fusion site was compressed and fixed using a 3.5 mm headless compression screw. In Group B, two absorbable pins were used for fixing the osteotomy. The pins were 8 cm long with a diameter of 2.5 mm. The proximal end of the pin was mounted on a handle, while the last 5 mm was tapered with a rounded point distally.

Each specimen was tested under cantilever (transverse) and physiologic (axial) loading configurations in accordance with the method described by Favre et al. (6) (Figure 2). The cantilever configuration is one of the most commonly used and well-established bending

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techniques for experimental biomechanical studies in the field of orthopedics (12, 13, 14). The cantilever bending simulates the anatomic position of the first metatarsal while standing and measures the effect of reaction force from the ground. However, it cannot measure the force created by muscular contractions during walking. Therefore, Favre et al. developed the physiologic configuration, a second experimental set-up for experimental material testing of the first metatarsal. Based on the estimated amounts of ground reaction and muscular force acting at the first metatarsophalangeal joint, an angle of 13° to the axis of the first metatarsal is used in this figuration (6).

In the present study, the Sawbone was freeze-fixed from the base with acrylic material and placed horizontally on the test device. In the cantilever configuration, the first metatarsal was positioned at an angle of 15° between its axis and a horizontal line. A load was then applied in the plantar-to-dorsal direction on the head of the metatarsal with a material testing machine (Z010; Zwick Roell, Ulm, Germany). The preload was applied as 5 N with a displacement rate of 1 mm/min. In the physiologic configuration, the maximum load was applied as 300 N. The load displacement curves were recorded and analyzed in Microsoft® Excel 2007 (Microsoft Corp., Redmond, WA, USA).

A linear curve was matched with the first linear part of the force displacement curve. The stiffness of the first metatarsal was calculated as the slope of the linear curve. Failure was defined as 10mm-displacement or a load decreased to 75% of maximum load applied. The

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failure strength was recorded as the maximum load. The stiffness and maximum load values in the cantilever and physiologic configurations were compared between the three fixation groups.

Statistical Analysis

The statistical analysis of the obtained data was performed using SPSS version 22.0 Statistics for Windows, version 22.0 (Statistical Package for Social Sciences, IBM Corp., Armonk, NY, USA). Normality of the data was analyzed with the Saphiro-Wilk test. The variables were compared between two groups using a paired Student's t test. $p<0.05$ values were considered statistically significant.

Results

In the axial loading, there were statistically significant differences between the groups in terms of stiffness (p=0.027) and maximum load (p=0.008) horizontally. The stiffness was found as 26.07±8.18 N/mm in Group K and 14.15±3.62 N/mm in Group B. Accordingly, the stiffness was statistically higher in Group K compared to Group B (p=0.028). Similarly stiffness was statistically higher in Group C compared to Group B (26.75±5.94 vs 14.15±3.62) (p=0.016). The maximum load was significantly higher in Group K (102.8±30.74 N) and Group C (113.34±35.88 N) compared to Group B (26.8±9.46) (p=0.009, p=0.009; respectively). Figure 3 shows stiffness and maximum load values in the axial loading according to the groups.

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In the transverse loading, there were statistically significant differences between the groups in terms of stiffness (p=0.024) and maximum load (p=0.008) vertically. The stiffness was found as 6.93±2.49 N/mm in Group K and 2.7±1.66 N/mm in Group B. Accordingly, the stiffness was statistically higher in Group K compared to Group B (p=0.016). Similarly stiffness was statistically higher in Group C compared to Group B (6.28±2.41 vs 2.7±1.66) (p=0.028). The maximum load was significantly higher in Group K (74.6±21.60 N) and Group C (92.8±38.96 N) compared to Group B (16.17±7.72) (p=0.009, p=0.009; respectively). Figure 4 shows stiffness and maximum load values in the transverse loading according to the groups. The stiffness and maximum loads based on the loading mechanisms according to the groups are given in Table 1.

Discussion

The literature lacks biomechanical studies on distal oblique osteotomies for the correction of hallux valgus. There is only one biomechanical study and a few clinical studies comparing different fixation methods in distal Chevron osteotomies of the first metatarsal by Trost et al. (12). Distal oblique osteotomies have been investigated only in clinical studies and thus, this is the first biomechanical study in the literature comparing various three different fixation techniques in distal oblique metatarsal osteotomy for the correction of hallux valgus (HV). In the present study, we compared fixations with headless compression screws, Kirschner wires

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and bioabsorbable pins in terms of stiffness and maximum load in the axial and transverse loading conditions.

Stiffness and failure strength (maksimum load) are two important parameters in the assessment of the stability and performance of osteotomies. In our study, we investigated the stiffness of the first metatarsal with different fixation methods on a synthetic Sawbone model. The highest stiffness was obtained with compression screws in the axial loading and Kirschner wires in the transverse loading. However, there was no statistically significant difference between the two techniques. The stiffness was significantly higher in both compression screws and Kirschner wires compared to bioabsorbable pins in both cantilever and physiologic configurations. In their biomechanical cadaveric study, Trost et al. compared a single screw with two Kirschner wires in distal Chevron osteotomies of the first metatarsal. They used the ratio of the stiffness of the osteotomized bone to the stiffness of the intact bone and found similar rates between the two fixation methods in both cantilever and physiologic configurations (12). Similarly, in another biochemical study of distal Chevron osteotomies Favre et al. found similar rates of stiffness after distal Chevron osteotomy fixed with one screw (6). On the other hand, stiffness may differ between cantilever and physiologic configurations. In our study, the stiffness was higher in the cantilever loading as in the study by Favre et al. and in contrast to the study by Trost et al. The difference results between the studies might be caused by the intrinsic characteristics of the materials used.

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Failure strength is an important parameter in biomechanical studies in which the stability of different fixation modes is compared. In our study, the highest strength was found as 113.34±35.88 N with headless compression screws in the axial loading. In addition, the maximum load was statistically significantly higher both with Kirschner wires and headless compression screws compared to bioabsorbable pins in both axial and transverse loading conditions. On the other hand, no significant difference was found in failure strength between Kirschner wires and headless compression screws. Similar to our study, in the study by Trost et al., failure strength was found to be similar between screw fixation and Kirschner Wire (12). However, unlike our study, the failure strength was higher with Kirschner Wire fixation. We attributed this difference to the technical properties of the screws used. Favre et al. found a similar failure strength of approximately 150 N with 1 screw fixation in distal Chevron osteotomy (6). Dalton et al. compared stability of fixation with 1 Kirschner Wire and 2 Wires in a cadaver and foam model study and reported a higher failure strength with 2 Kirschner Wires in distal Chevron osteotomy of the first metatarsal (15). It seems that using a further wire increased the stability of the fixation. In our study we also used 2 Kirschner Wires, but it is difficult to compare the results because of the different designs of the study by Dalton et al. and our study.

Several studies have compared various fixation techniques in terms of stability. Jung et al. compared pin fixation and combined screw fixation in Chevron osteotomy and reported higher

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stability with the combination of K-wires plus screws compared to the pin fixation (16). In their biomechanical study, Peng et al. compared headless compression screw and AO cannulated lag screw in the fixation of Hoffa fractures and reported higher strength and stability with headless compression screw (17). In addition, it has been reported that headless compression screws are becoming more common in orthopedics practice (10, 18, 19).

Conclusion

The findings of our study indicate a higher stability with both Kirschner wires and headless compression screws compared to bioabsorbable pins as fixation techniques used in distal oblique osteotomy for the correction of the hallux valgus. Although no significant difference was found between the Kirschner wires and headless compression screws techniques, headless compression screws showed the highest failure strength. We think that headless compression screws that are increasingly used in orthopedic practice could be preferred for these osteotomies. However, given the lack of data in the literature, further biomechanical studies are needed to determine the most appropriate fixation method more precisely. In addition, studies comparing distal Chevron, oblique and transverse techniques with various fixation models could also provide a significant contribution to what is known today.

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Limitations

This study has several limitations. First, the number of bone models studied was relatively small. Second, the study was performed on synthetic bone models and thus, the results can not be generalized to in vivo situations. Finally, we could not directly compare our results since there was no similar study on distal oblique osteotomies. On the other hand, being the first biochemical study in the literature on this issue is a strength of the study.

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Conflict of Interest: None reported.

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Table 1. Stiffness and maximum load values of the groups based on the loading mechanisms

Loading mechanism	Group K (Two Kirchner wires)	Group C (Compression Screw)	Group B (Bioabsorbabl pins)	Group K vs Group C	Group K vs Group B	Group C vs Group B
Axial				**p**	**p**	**p**
Stiffness (N/mm)	26.07±8.18	26.75±5.94	14.15±3.62	0.917	**0.028**	**0.016**
Max Value (N)	102.8±30.74	113.34±35.88	26.8±9.46	0.463	**0.009**	**0.009**
Transverse				**p**	**p**	**p**
Stiffness (N/mm)	6.93±2.49	6.28±2.41	2.7±1.66	0.602	**0.016**	**0.028**
Max Value (N)	74.6±21.60	92.8±38.96	16.17±7.72	0.465	**0.009**	**0.009**

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Figure 1. Anterior-posterior and lateral X-rays of the fixation models

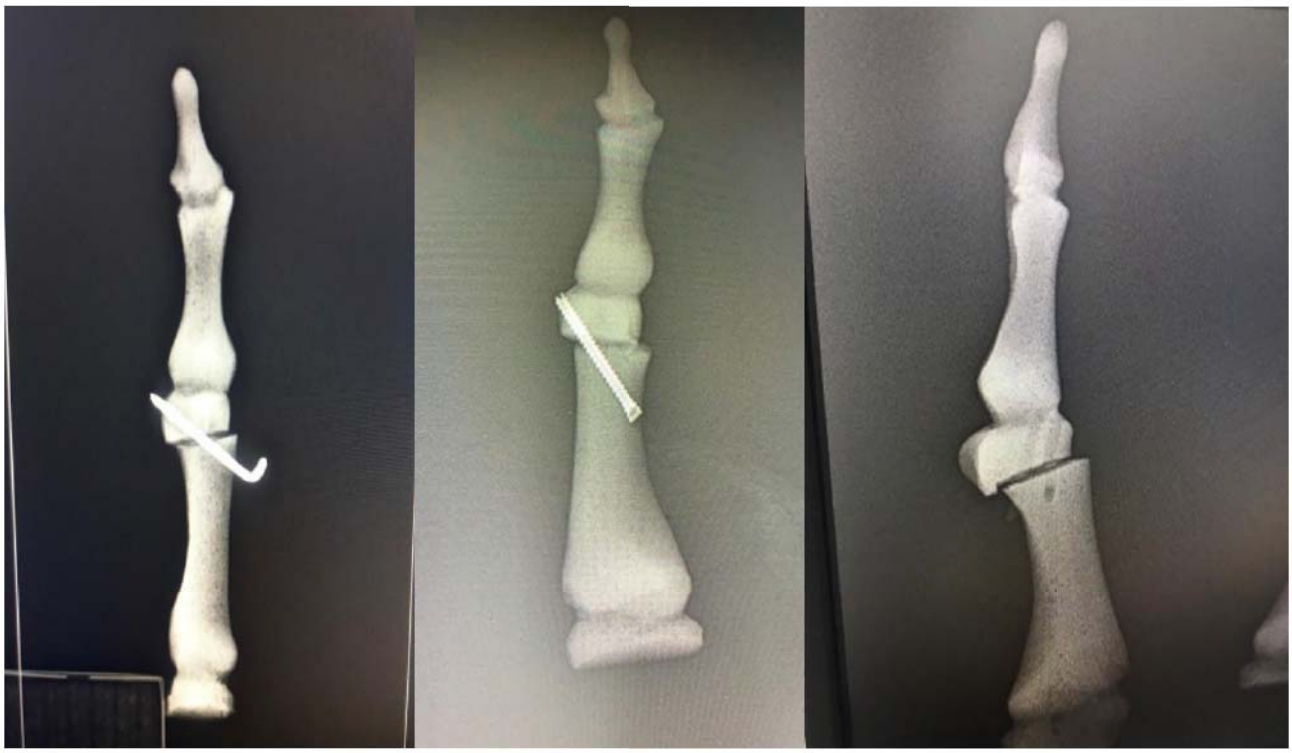

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Figure 2. Axial and transverse loading on a fixation model.



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Figure 3. Stiffness and maximum load values of the fixation methods in the axial loading

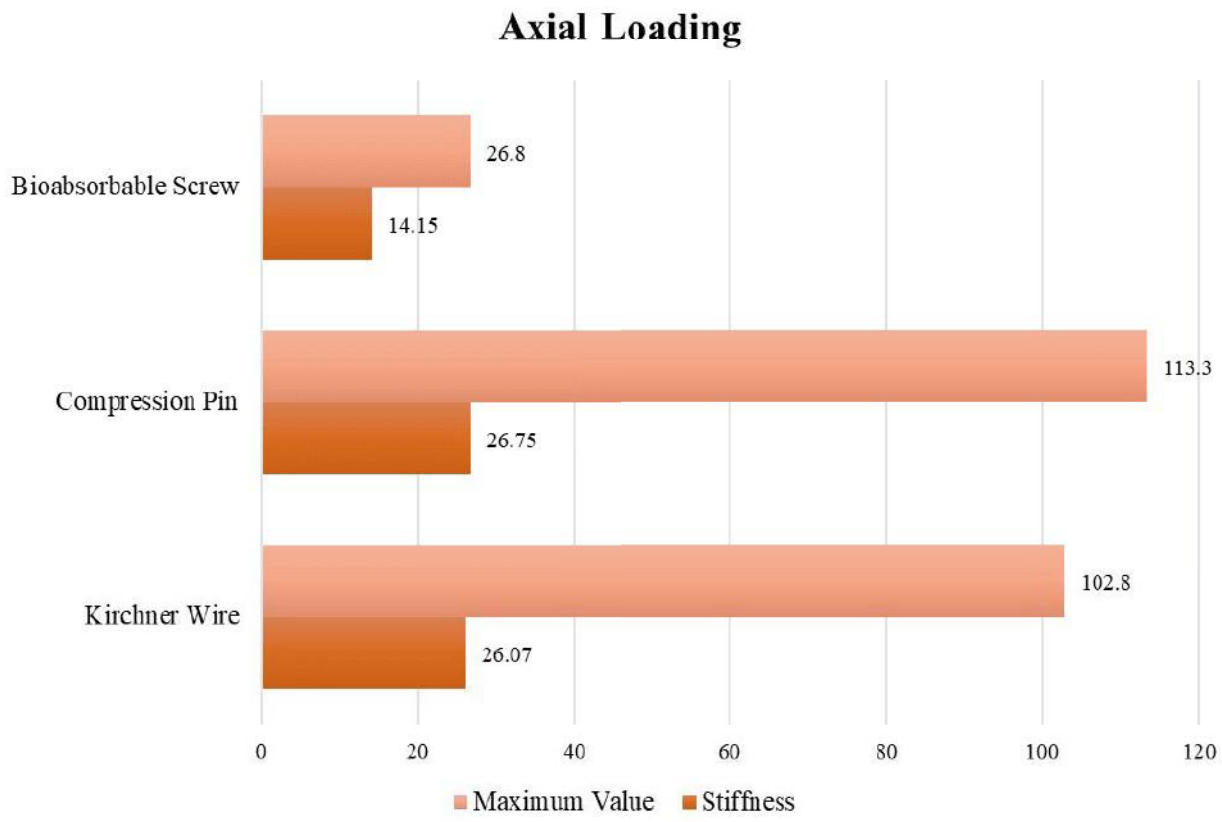

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Figure 4. Stiffness and maximum load values of the fixation methods in the transverse loading

