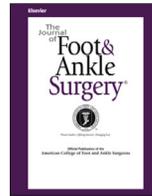




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Original Research

Biomechanical Comparison of Cannulated Screw Osteosynthesis With Tension-Band Wiring for Proximal Fractures of the Fifth Metatarsal (Jones Fracture)

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ABSTRACT

Jones fractures, which lie at the junction of the diaphysis to the metaphysis of the fifth metatarsal, are a well-described clinical issue. There are various surgical approaches, including the commonly performed cannulated screw osteosyntheses, and the less frequently used tension-band approach. The aim is to compare the biomechanical stability of these osteosyntheses. We performed an osteotomy on 16 fresh frozen fifth metatarsal bones from body donors representing a Jones fracture. The fractures were treated pairwise with screw osteosynthesis or tension-band wiring. This was followed by cyclic axial bending until osteosynthesis failure. Stability under axial bending force was higher in the screw osteosynthesis (mean: 70.0 ± 66.5 N) compared to the tension-band wiring (mean: 35.7 ± 23.3 N) group although not reaching statistical significance ($p = .116$). The study shows no statistically significant difference in biomechanical stability under axial loading between screw osteosynthesis and tension band wiring. Based on the data obtained, no differences can be observed from a biomechanical point of view. The study supports the established method of treating Jones fractures primarily with screw osteosynthesis. In addition, the data suggest that tension band wiring may be a good alternative osteosynthesis, for example, after failed casting treatment or failure of primary osteosynthesis.

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Metatarsal fractures are common in adults, consisting of 3.2% to 6.8% of all fractures (1). Of the metatarsal bones, the fifth is the most commonly affected with 56% to 68% of all metatarsal injuries (1,2). Jones fractures occur at the metaphyseal-diaphyseal junction at the base of the fifth metatarsal.

Poor blood supply as shown by Smith et al. (3) is a reason for prolonged healing time in nonoperative treatment of this fracture type leading to delayed union or non-union. Furthermore, activation of the peroneal tendons inserting proximally to the fracture site during gait contribute to dislocation of Jones fractures (4). Therefore, surgical treatment was recommended to avoid this complication and the associated more complicated course of treatment.

In a literature review by Dean et al., it was shown, that the acute Jones fractures, that are located approximately 1.5 cm distal to the proximal tuberosity (Dameron & Quill type II) are related to an

incidence of non-union of 20%, showing radiographic union mean times of 15.9 weeks under nonsurgical treatment (5). Surgical treatment showed decreased time for radiographic union of 7.1 weeks accompanied by a surgical complication rate of 22.6%, mostly screw related complications and rarely non-unions.

There is consensus that displaced type II fractures require operative treatment (6–9). But the management of non-displaced type II fractures is debatable. Many studies have shown a benefit of early fixation when compared to conservative cast therapy, resulting in earlier radiographic union, weightbearing, and return to normal activity, including sports (10,11).

There are several surgical procedures to treat type II fifth metatarsal fractures. The most used is that of cannulated screw osteosynthesis. Nevertheless, refracture following surgical treatment occurs by rates of 10% to 15% (5,7,12–14). As recently suggested, the use of headless compression screw may add a greater amount of stiffness than conventional, partially threaded screws (15). Plate osteosynthesis, that provides higher biomechanical stability compared to screw osteosynthesis is a viable proposition (16). A shorter time to fracture zone union was described for the plate in a clinical study (17). An alternative to this

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osteosynthesis, is tension-band wiring as suggested by Sarimo et al. (18). They treated delayed or non-union Jones fractures under cast therapy and described a postoperative radiographic union rate of around 12.8 weeks and a return to activity in about 14.7 weeks.

To the best of our knowledge there is no study evaluating the biomechanical stability of tension-band wiring in Jones fractures.

In our study we compare the biomechanical stability of tension-band wiring to that of cannulated screw osteosynthesis in fifth using a bending-stress cadaver bone model.

Materials and Methods

Specimens

Sixteen fresh frozen human fifth metatarsal (8 pairs) were isolated from body donors while obtaining the insertion of the peroneus brevis tendon. Bone mineral density (BMD) of all cadavers was determined in the associated calcanei (QDR 4500 Elite Densitometer.). The specimens were thawed at room temperature. The study was approved by the local ethics committee.

Fracture Model

Osteotomy was performed 1.5 cm distal to the styloid process in the metaphyseal zone involving the joint of the fourth/fifth metatarsal. The distance was measured with a ruler aligned with the shaft axis of the bone.

Osteosynthesis

Following the osteotomies, a screw osteosynthesis was performed on the right metatarsal bone and tension-band wiring on the left. The screw osteosynthesis was performed using a 4.5 mm cannulated titanium partial thread screw (Stryker GmbH & Co. KG) as suggested in the user manual. After measuring the possible screw length, the longest possible screw was used shown in Fig. 1A. The tension-band wiring was performed as described by Sarimo et al. using 1.25 mm K-wires and 1.0 mm cerclage wire shown in Fig. 1B. All osteosynthesis were performed by 2 experienced traumatological foot consultants. One clinically experienced surgeon performed screw osteosynthesis and the other performed tension band wiring to standardize the procedure.

Prior to embedding the osteotomy gap, all segments of K-wires and screws were capped with modeling clay to avoid contact with the embedment liquids (Fig. 2). Both ends of the specimen were embedded in liquid methymethacrylate (Technovit 3040) in a cylindrical form, matching the size of the mounting device of the test machine.

Test Design and Procedure

Biomechanical testing was performed using a universal material testing machine (TC-FR 1.0TH.D09, Zwick Z1.0). During the measurement the distal enclosing cylinder could slide freely in the longitudinal direction of the specimen axis using a 2-dimensional free-swinging table (Fig. 3).

The sufficiency of the osteosynthesis was plotted by using an ultrasound measurement system (ZEBRIS, CMS 70PV5, ZEBRIS Medical) applied to the specimen. One ultrasound sensor each was attached to the metatarsal base and the metatarsal diaphysis. The ultrasound measurement registers movement in a 3-dimensional space. Any movement of each attached button respectively to the sensing camera is registered every 33 ms. This

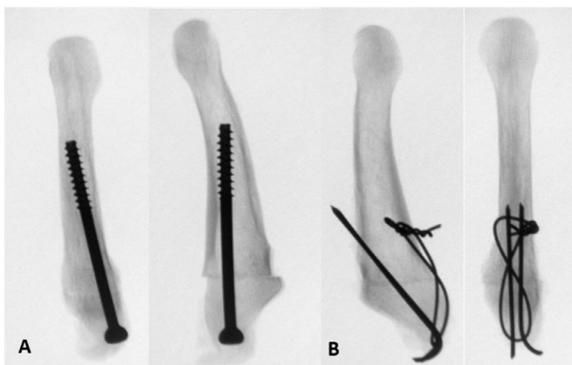


Fig. 1. Radiographic image of a fracture of the proximal junction of the metaphysis and diaphysis of the fifth metatarsal treated with A- cannulated screw osteosynthesis B- tension-band wiring.

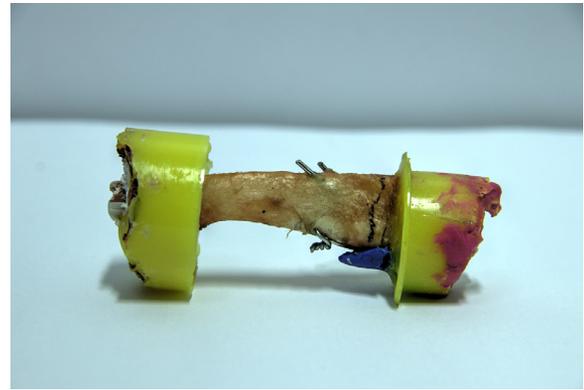


Fig. 2. Cadaver bone with tension-band wiring osteosynthesis capped with modelling clay, embedded distal and proximal.

results in a change in the coordinates system with a sensitivity of 0.1 mm. The distance of displacement is calculated afterwards. The protocol of axial loading force was determined by preliminary tests using a fifth metatarsal bone (SYNBONE). After 5 setting cycles, axial bending force was determined in 10 measuring cycles. Each specimen then underwent 10 cycles of a 10 N dorsally directed bending force at a rate of 1 mm/s and unloading to a tensile force of -5 N simulating unloading. After each cycle the force was increased by 10 N until osteosynthesis failure. As the definition of failed osteosynthesis is widely discussed and not conclusively defined, we assume a widening fracture gap larger than 2 mm as osteosynthesis failure. This threshold is commonly accepted describing foot and ankles fractures as displaced (7,19).

Shown is a prepared specimen with the added markers for ultrasound measurement (green and yellow). The proximal end of the fifth metatarsal bone undergoes 10 cycles per measurement of dorsal bending starting at 10 N and unloading of 5 N. The dorsally bending force is increased by 10 N per measurement until osteosynthesis failure.

Statistical Analysis

Statistical analysis was performed using the Wilcoxon test for comparison of median and rank sums of the two study groups. BMD values between groups were analyzed using the Wilcoxon test. The relation between BMD and osteosynthesis failure was analyzed by Spearman correlation coefficient. A $p \leq .05$ was considered statistically significant for all tests. The SPSS Statistics (version 21, IBM, Armonk) and graph pad PRISM (version 6, graph pad, San Diego) were used for all calculations.

Results

There were no significant differences in bone density between the two groups using the osteosyntheses cannulated screw osteosynthesis $154.9 \pm 45.3 \text{ g/cm}^2$ and tension-band wiring $156 \pm 43.3 \text{ g/cm}^2$ ($p = .779$).

There was no statistically significant correlation between the BMD and the axial bending force which led to osteosynthesis failure ($r = 0.566, p = .148$).

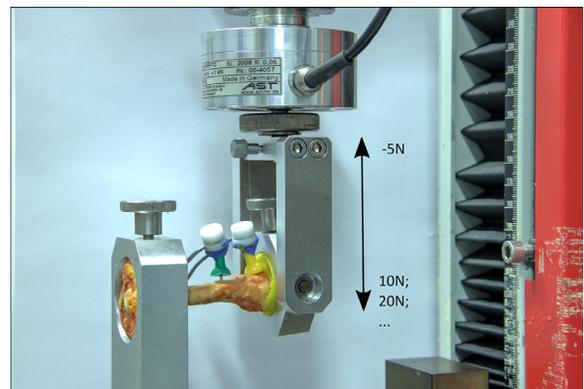


Fig. 3. Experimental set-up.

The group, that underwent cannulated screw osteosynthesis shows higher means (mean: 70.0 ± 66.5 N, minimum-maximum 10-170 N) at the point of osteosynthesis failure than the group that underwent tension-band wiring (mean: 35.0 ± 23.3 N, minimum-maximum 10-70 N) not reaching statistical significance ($p = .116$) (Fig. 4).

Discussion

In this study, we show that there is no difference in maximum failure load between the osteosynthesis with cannulated screws or tension-band wiring. Furthermore, no influence of bone density values could be seen.

For the test, the force was introduced via a dorsally directed vector, the existing rotational impulses through the tendon of the m. peroneus brevis were under-estimated (4,20). The value of rotational forces in Jones fractures has not been clearly proven, as the natural joint surfaces and surrounding soft tissue can only allow slight rotational movements. A possible higher stability against these rotational movements could not be considered with our test set-up. Improving rotational stability and compression of the fracture site may favor tension-band wiring. The displaced avulsion fracture is a more recognized site for tension-band wiring with respect to the slightly oblique fracture line (7). The strictly transverse fracture line is not ideal for tension-band wiring and requires an orthogonal entry for the K-wires.

To ensure the best possible stiffness of the screw osteosynthesis, conventional partially threaded screws were used. In biomechanical tests, these showed superiority to variable-pitch fully threaded headless compression screws (21). Screws of the same size were used for all cadavers with diameter 4.5 mm. A superiority of 5.5 mm could not be demonstrated in other studies (22,23). Due to the anatomical curvature of the fifth metatarsal correct screw length should be taken into consideration to avoid fracture gapping (24,25).

Twenty-five N load was estimated as physiologic load on the fifth metatarsal head during ambulation (26), this load could be provided in fractured bones treated with cannulated screws (mean: 70.0 ± 66.5 N) and almost with the tension band wiring (mean: 35.0 ± 23.3 N). Thus, a complete avoidance of weight bearing can be avoided and at least a partial weight bearing after surgical treatment can be considered.

Even though the outcomes with screw osteosynthesis have been satisfactory, there are 10% to 15% of the cases osteosynthesis failed and refractures occurred (5,27). In such cases revisional osteosynthesis may be indicated. Due to lack of alternatives, re-osteosynthesis is mostly performed using a larger screw (27). Tension-band wiring could be considered as an alternative. Taking into consideration that screw osteosynthesis is minimally invasive related to satisfactory clinical outcome as shown by early return to normal activity, there should be no change in the primary management of treating acute Jones fractures. This is supported by the experience of Sarimo et al., using tension-band wiring, that resulted in early weight bearing and an early return to activity after screw osteosynthesis (18).

The main clinical advantage of the tension-band wiring is more stability against torsional stability. The impact of the torsional impact on fifth metatarsal fracture has to be solidly proven with a further study.

We cannot make a statement about the maximum stability of the osteosyntheses in patients with surgically treated fifth metatarsal fractures because we did not test the specimens to failure. Additional cyclic testing would be useful. In addition, it is difficult to extrapolate the in vivo load to ex vivo fracture models. The biomechanical setup tries to adapt the in vivo forces as close as possible to the clinical setting. A recommendation on weight-bearing after osteosynthetic treatment of a fracture of the fifth metatarsal cannot be made on basis of biomechanical results alone. Further clinical studies are necessary to verify the statements made.

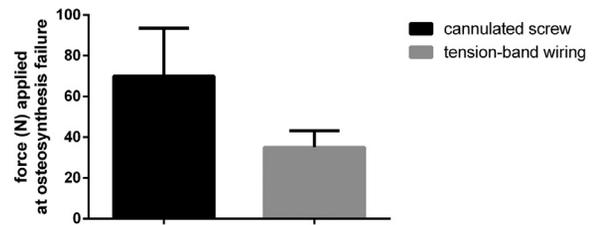


Fig. 4. Comparison between maximum forces before onset of osteosynthesis failure of the tension band wiring and screw osteosynthesis.

The study shows no statistically significant difference in biomechanical stability under axial loading between screw osteosynthesis and tension band wiring. Therefore, the data tend to support the use of the established method of treating Jones fractures with screw osteosynthesis. However, not from a biomechanical point of view, because in this respect the osteosynthesis methods are equivalent, but because of the minimally invasive surgical technique and the complications that can be minimized.

We believe that tension-band wiring is a viable proposition in stabilizing acute Jones fractures especially when rotational stability is considered or in cases of operative revisions. We, therefore, aim to challenge our hypothesis with a future study.

Statement of Consent

Informed consent was obtained during lifetime from all human subjects for experimentation involved in the study. Approval was granted by the Ethic Committee of the Friedrich-Schiller-University (University Hospital Jena, 2020-2016-Material).

Assessors

The first author (MU) and senior author (FK) were involved in planning the study, performing the experiments, data analysis and interpretation, writing the manuscript, and revising the manuscript. The coauthors were involved in planning the study (IG, JH, RL), performing the experiments (IG, JH), supervision (GH), and revising the manuscript (IG, JH, RL, GH).

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