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Original article

Medial malleolus fractures: A biomechanical comparison of tension band wiring fixation methods

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ABSTRACT

Background: This study compared the biomechanical properties of three different fixation methods of tension band wirings, used in the treatment of medial malleolus fractures. The first method used an innovative "handmade bent pin" for cerclage fixation. The second method used a U-shaped K-wire to attach the cerclage to the medial tibial cortex. These two novel fixation techniques were compared with the traditional tension band wiring technique which is fixated to the bone by a screw.
Hypothesis: Novel fixation techniques of tension band wiring provide stable fixation.
Material and methods: In this study 27 artificial bone models, which medial malleolus fractures were simulated on, were used. Using an electromechanical test device, the force required to pull out each implant was assessed and compared.
Results: This study found that; while handmade bent pinning resulted averagely 840.25 N (range: 647–1066 ± 118.72) and U-shaped K-wire fixation was 381.71 N (range: 176–651 ± 150.2) pull out strength, traditional tension band wiring indicated 871.33 N (range: 549–1008 ± 137.74) pull out strength.
Discussion: Handmade bent pinning method provide similar results with traditional tension band wiring. Therefore, in suitable cases, it may be an acceptable alternative to traditional tension band wiring techniques when treating malleolar fractures. Although the outcomes of U-shaped K-wire fixation indicated lower than other two groups, the outcomes were comparable with the literature. So while performing tension band wiring, both handmade fixation systems may be used in certain cases. For Orthopaedic surgeons, it is better to know and think about these alternative handmade pinning systems created from simple K-wires during the surgery if needed.
Level of evidence: IV, Biomechanical trial.

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1. Introduction

Fractures of the medial malleolus are among the most commonly seen in orthopedic and trauma surgery. There are several accepted fixation methods for treating these types of fractures, including screws, tension band wiring with cerclage or suture materials, absorbable implants, and plate fixation [1–5]. The number of screws, screw thickness, and whether the counter cortex is passed, vary based on the method chosen and the fracture characteristics. Several methods involve the use of Kirschner (K) wires, in addition to a screw [2].

In tension band wiring, the cerclage is folded on itself before forming a figure-eight. This system is then fixed to the medial tibial metaphysis. The current literature describes two methods for fixing the tension band to the medial tibial cortex [2,3]. In the first method, a bone tunnel is opened at the metaphysis and the cerclage is passed through the tunnel. In the second method, the cerclage is attached to a screw that has been sunk into the medial tibial cortex [2,3]. Since we used synthetic bones, the first method could not be used. So in this study the second method, which a screw is used into, was considered for control group.

This study compares the biomechanical properties of three different fixation methods of tension band wirings, while fixing it to the medial tibial cortex. The first method used a U-shaped K-wire

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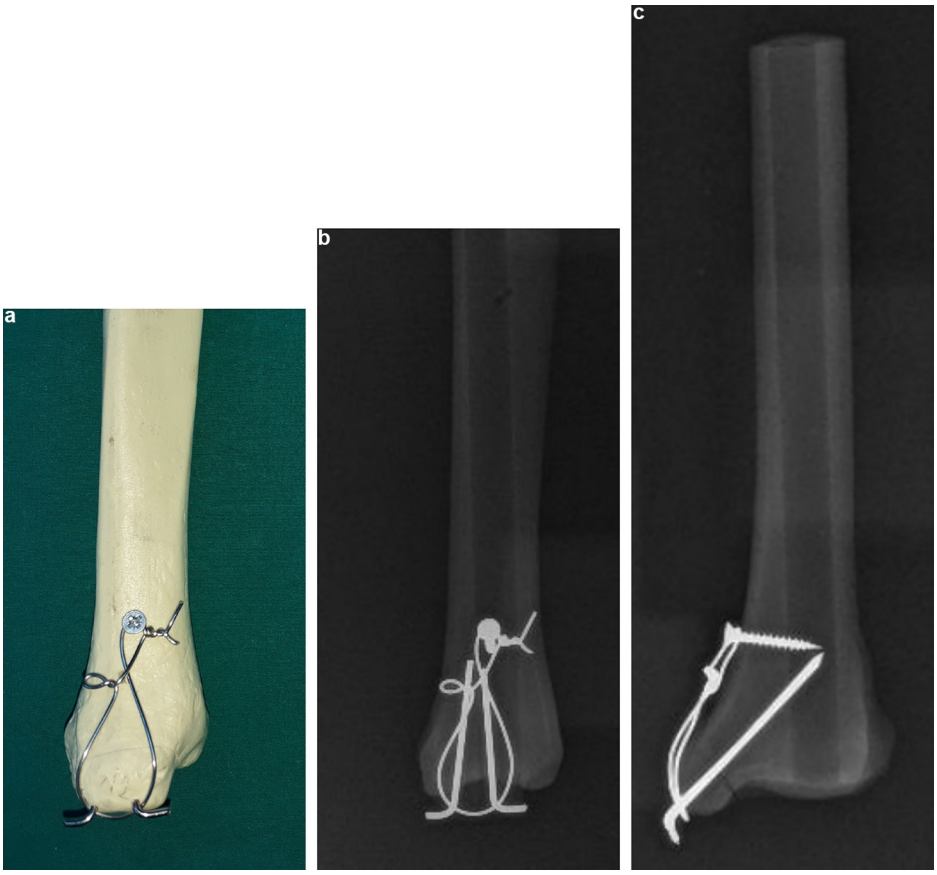


Fig. 1. Photograph of a traditional tension band wiring (Group A) test model (1a). Lateral radiograph (1b) and anteroposterior direct X-ray (1c) views of traditional tension band wiring.

to attach the cerclage to the medial tibial cortex (Group B). The second method used an innovative "handmade bent pin" for cerclage fixation (Group C). In this biomechanical trial our hypothesis was whether these two novel fixation techniques using 1.8 mm K-wire were reliable. To proof our hypothesis those two novel techniques were compared with the traditional tension band wiring technique which is fixated to the bone by a screw (Group A).

2. Methods

This study was performed on 27 artificial distal tibial bone models (Synbone®, Malans, Switzerland) with simulated malleolar fractures. All models were prepared by a single Orthopaedic surgeon. To simulate a medial malleolar fracture, an osteotomy was performed using a 3 mm thick surgical saw. The osteotomy line ran perpendicular to the medial malleolar axis and at 45 degrees to the longitudinal axis of the bone model. The line began at the plafond laterally, and terminated medially 15 mm proximal to the tip of the malleolus. The resulting fracture mimicked a 44-B2.2 type fracture under the Orthopedic Trauma Society (OTA) classification. To improve reduction during re-fixation, tunnels were created in the medial malleolus using K-wires. The K-wires were removed prior to performing the osteotomy. Finally, the bone models were numbered randomly and divided into three groups (A–C) using an online randomization program [6].

Group A underwent traditional tension band wiring (Fig. 1). In this group, the fracture line was fixed with two parallel, 4 cm long and one cortex K-wires. The distal ends of each wire were bent to 90 degrees and cut into a hook shape. Next, a screw was placed 2.5 cm proximal to the tibial plafond. Finally, an 18-gauge stainless steel cerclage wire was passed around the K-wire hooks and the screw to form a figure-eight. The cerclage was tensioned by pulling on twists on each side.

Group B underwent staple fixation using a novel method (Fig. 2). A 2 cm long, 1.8 mm thick K-wire was bent at 0.5 cm and 1.5 cm to form a U-shape. While the distal fixation steps were the same as with traditional tension band wiring, fixation to the tibial plafond was different; in this group, the cerclage was attached to the tibia metaphysis with the aid of the U-shaped K-wire instead of a screw.

Group C underwent fixation using a novel technique that employed handmade bent pins (Fig. 3). A single-piece implant was manually constructed using a 30 mm long, 1.8 mm thick K-wire. First, the K-wire was bent onto itself at the middle. Next, the two ends of the wire were bent at 135 degrees. Finally, the implant was set into the bone using a hammer.

Each implant then underwent tensile test with displacement controlled rate of 20 mm/min (0.3 mm/sec) using an electromechanical universal testing device (TCS, Test Control Systems, Ankara, Turkey) with a 20 kN ± 0.25 tension/compression load cell. To simulate impact failure in biomechanical tests, 0.01–10 mm/s can be chosen in regular strain rate at which bone is subjected. So in this study it has been chosen a displacement controlled rate of approximately 0.3 mm/sec as did Fowler et al. [3].

Bone models were placed upside-down in the test device. The distal aspects of the models were fixed to the lower plate of the device using a 3.0 mm K-wire inserted diagonally through the plate and the tibial diaphysis (Fig. 3b). To test implant pull out strength, a 2.5 mm wide tunnel was created in the malleolus fracture segment and a 2.0 mm steel wire was passed through the tunnel. The attachment point of the steel wire was asymmetrically positioned outside of the loading axis to simulate both pull and shear forces (Fig. 3b). The experiment was terminated when the implant system

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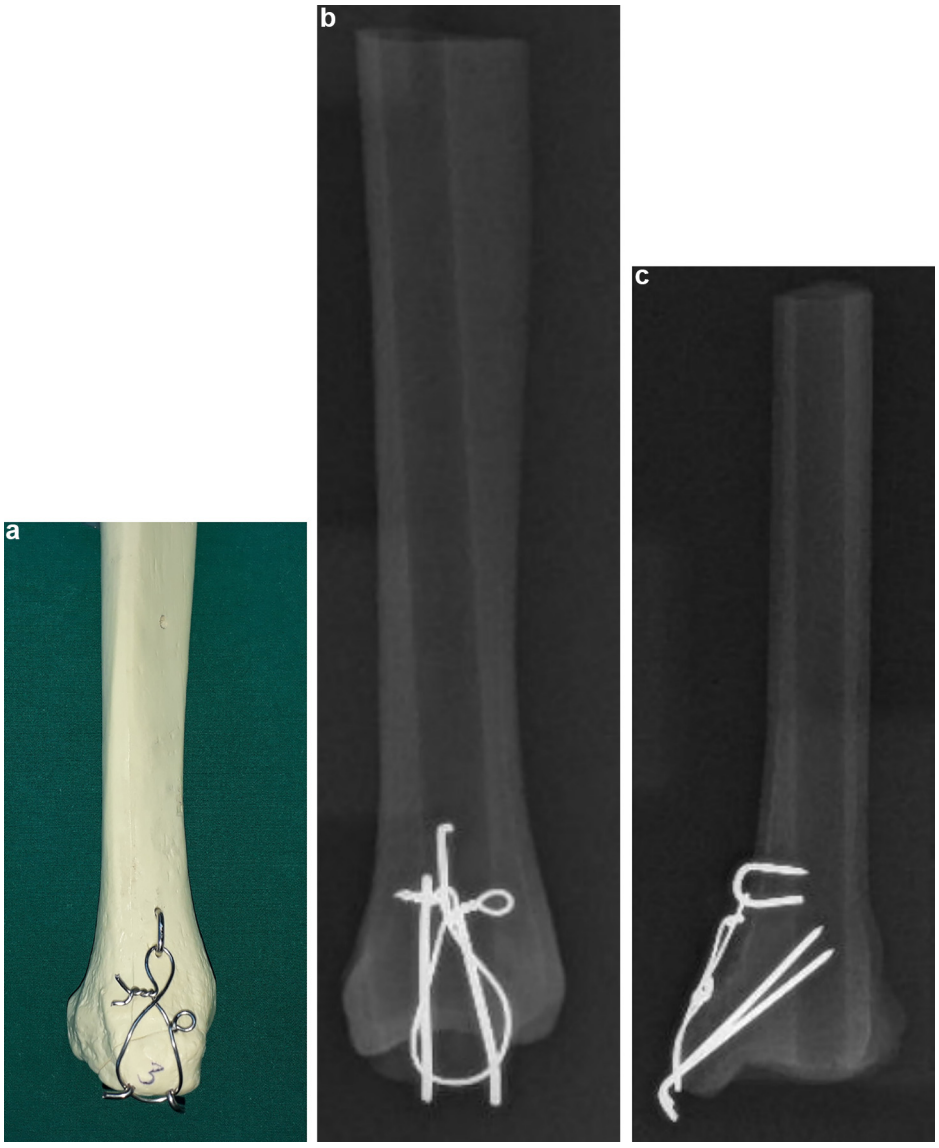


Fig. 2. Photograph of the U-shaped K-wire metaphyseal fixation method (Group B) test model (2a). Lateral radiograph (2b) and anteroposterior direct X-ray (2c) views of the U-shaped K-wire fixated tension band wiring.

(either bone model or hardware) failed, or when the bone model tensile strength was less than 30% of the maximum strength value.

Statistical analyses were performed using SPSS software (ver. 21.0; SPSS Inc., Chicago, IL, USA). In all analyses, $p < 0.05$ indicated statistical significance. The data were compared within and between groups. The Shapiro-Wilk test was used for assessing normality of distribution. While Groups B and C were normally distributed, Group A was not. The outcomes were compared between the different fixation methods using the Kruskal-Wallis test. The Dunn-Bonferroni post hoc analysis was applied following a significant Kruskal-Wallis test.

3. Results

This study was performed on a total of 24 bone models (Table 1). Since they were deformed during pretests; two bone models from the U-shape K-wire fixation group (Group B), and one from the handmade bent pinning group (Group C), were excluded. Handmade bent pinning (Group C) resulted in the highest-strength implants, while U-shaped fixation (Group B) resulted in the lowest-strength implants (Table 2). In general, failure in Groups A and C occurred due to screw extraction, while failure in Group B occurred due to U-shaped K-wire extraction (Table 3).

There was no significant difference in strength between Groups A and C ($p = 1.00$). Group B had significantly lower strength than the other groups ($p < 0.05$) (Table 2).

4. Discussion

In this study we found that handmade bent pins provide comparable results with traditional fixation method. While this outcome was compatible with our hypothesis, the outcomes of fixation with U-shaped K-wire were not as good as we were expecting. So this study indicate that handmade pinning, which can be easily created during the surgery would be used in certain cases.

Traditionally, tension band wiring has been the preferred fixation method for medial malleolar fractures with smaller fragments that are not suitable for screw fixation [2–4,7]. However, it is possible to use tension band wiring for any fracture of the medial malleolus [2,8]. The most common issue encountered during tension band wiring is difficulty passing the cerclage wire through the semicircular bone tunnel [8]. In these cases, cortical screw

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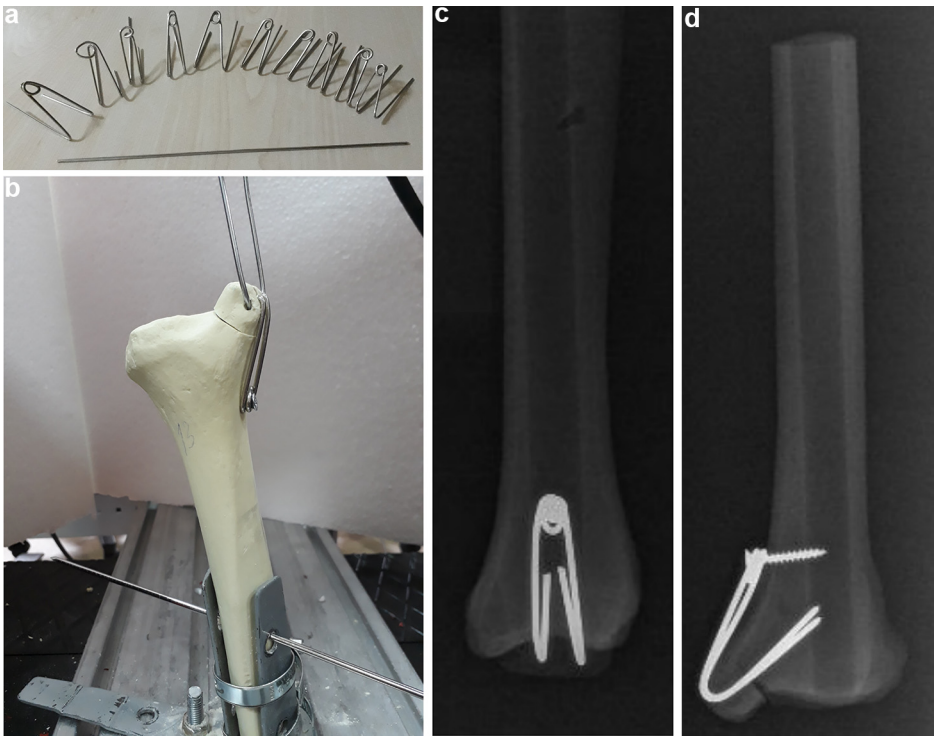


Fig. 3. Photograph of the handmade bent pins (Group C) before implantation (3a). Bone models were placed upside-down in the test machine (3b). Lateral radiograph (3c) and anteroposterior direct X-ray (3d) views of the handmade bent pinning.

Table 1
Descriptive features of the bone models.

	n	Mean	Minimum–Maximum	Std Dev
Group A: traditional tension band	9	871.33N	549–1008 N	137.74
Group B: U-shaped K-wire fixated tension band	7	381.71N	176–651 N	150.2
Group C: handmade bent pin	8	840.25N	647–1066 N	118.72

Table 2
Comparison of maximum strength of the fixation methods.

	p
Group A–B, (Traditional – U-shaped K-wire fixated tension band)	0.01
Group A–C, (Traditional tension band – Handmade bent pin)	1.00
Group B–C, (U-shaped K-wire fixated tension band – Handmade bent pin)	0.02

Dunn-Bonferroni post-hoc outcome after Kruskal-Wallis test.

Table 3
Failure characteristics in different designs.

	Group A (*n* = 9)	Group B (*n* = 7)	Group C (*n* = 8)
Fracture of the bone from the metaphysis	1 (11%)	–	2 (25%)
Pull out of the screw	5 (55%)	–	6 (75%)
Failure of the cerclage	3 (33%)	–	–
Pull out of the staple	–	7 (100%)	–

fixation may be required. While screw fixation results in adequate biomechanical performance, the hardware can commonly be felt underneath the skin, periodically necessitating implant removal. For this reason, new implants and designs are needed when traditional tension band wiring methods cannot be used. It is better for orthopaedic surgeons to know that they can easily create fixation system using a K-wire during the surgical procedure if needed. Because, in certain cases, handmade implants can be extremely useful during surgery. In the practice of orthopaedics, handmade implants are commonly used during arthroplasty [9,10], olecranon [5] and patella fractures [11], and also syndesmotic repair [12]. The handmade bent pinning fixation method presented herein is unique; this method, which is easy to prepare and apply, provides fixation that is as effective and stable as conventional tension band wiring methods (Table 2 and Table 3). A previous cadaveric study showed that the force required to distract the osteotomy line in a medial malleolus fixated by conventional tension band wiring was 194.64 N [7]. Precise measurement of the amount of fracture line displacement was not possible in this study. Therefore, the minimum force that the system was able to carry was reported. The experiment was terminated automatically at a value 30% lower than the maximum force value, or upon implant failure. During pulling, 25% of the Group B bone models fractured at the metaphyseal level while maintaining system stability (Fig. 2c).

The use of a U-shaped K-wire for fixation of the cerclage wire to the medial tibial metaphyses has not been previously described. There are several possible advantages to this method, including less skin irritation (leading to lower rates of removal), ease of application and access, and low cost. In this study, U-shaped K-wire fixation was weaker than traditional tension band wiring. A single bone model had a minimum strength value of only 176 N, while all others were above 309 N (range: 176-651; average: 381,71 N). These results seem promising when compared with similar cadaveric studies (194.64 N) [7]. Further investigations, including cadaveric studies and clinical trials, are required to evaluate the biomechanical efficiency of the staple system.

One of the limitations of this study is being an experimental study without invivo behaviours of the implants. Another limitation was that we were not able to test cortical tunnel fixating technique while fixating tension band to the tibial metaphysis.

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This study showed that handmade bent pin fixation results in implants of equivalent strength to those produced by traditional tension band wiring methods. Based on these results, handmade pinning may represent an effective alternative modality for treating medial malleolus fractures, particularly in resource-limited operating theatres. Further research, including randomized controlled trials, is required to fully assess the effectiveness of this novel fixation method.

Disclosure of interest

The authors declare that they have no competing interest.

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Contribution

All authors have approved the manuscript and final article. The contribution of the authors are listed below:

- E. Uygur: study design, drafting of manuscript, critical revision;
- O. Poyanli: interpretation of the results, drafting of manuscript, critical revision;
- İ. Mutlu: acquisition of data, analysis of data, critical revision;
- T. Çelik: acquisition of data, analysis of data, interpretation of the results;
- F. Akpinar: study conception, critical revision, interpretation of the results.

References

[1] Clyde J, Kosmopoulos V, Carpenter B. A biomechanical investigation of a knotless tension band in medial malleolar fracture models in composite sawbones. J Foot Ankle Surg 2013;52:192–4.
[2] Georgiadis GM, White DB. Modified tension band wiring of medial malleolar ankle fractures. Foot Ankle Int 1995;16:64–8.
[3] Fowler TT, Pugh KJ, Litsky AS, Taylor BC, French BG. Medial malleolar fractures: a biomechanical study of fixation techniques. Orthopedics 2011;34:349–55.
[4] Varenne Y, Curado J, Asloum Y, Salle de Chou E, Colin F, Gouin F. Analysis of risk factors of the postoperative complications of surgical treatment of ankle fractures in the elderly: a series of 477 patients. Orthop Traumatol Surg Res 2016;102:245–8.
[5] Nieto H, Baroan C. Limits of internal fixation in long-bone fracture. Orthop Traumatol Surg Res 2017;103:61–6.
[6] Urbaniak GC, Plouse S. Research randomizer (version 4.0). [Accessed on 23/01/2017. Available from: https://www.randomizer.org].
[7] Johnson BA, Fallat LM. Comparison of tension band wire and cancellous bone screw fixation for medial malleolar fracture. J Foot Ankle Surg 1997;36:284–9.
[8] Kanakis TE, Papadakis E, Orfanos A, Andreadakis A, Xylouris E. Figure eight tension band in the treatment of fractures and pseudarthroses of the medial malleolus. Injury 1990;21:393–7.
[9] Villanueva M, Ríos A, Pereiro J, Chana F, Fahandez-Saddi H. Hand-made articulating spacers for infected total knee arthroplasty: a technical note. Acta Orthop 2006;77:329–32.
[10] Chen AFPJ. Antibiotic-loaded bone cement and periprosthetic joint infection. J Long Term Eff Med Implant 2014;24:89–97.
[11] Cerciello S, Cote M, Lustig S, et al. Arthroscopically assisted fixation is a reliable option for patellar fractures: a literature review. Orthop Traumatol Surg Res 2017;103:1087–91.
[12] Kara AN, Esenyel CZ, Sener BT, Merih E. A different approach to the treatment of the lateral malleolar fractures with syndesmosis injury: the ANK nail. J Foot Ankle Surg 1999;38:394–402.

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