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Biomechanical comparison of conventional versus modified technique in distal chevron osteotomies of the first metatarsal: A cadaver study

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ABSTRACT

Background: Distal chevron osteotomy can be performed using a conventional or a modified technique. The aim of this biomechanical study was to compare the stability of the two techniques.
Methods: Eighteen first metatarsals from nine pairs of fresh frozen human cadaver feet were used. A distal chevron osteotomy was performed using the conventional technique in group 1 (n = 9) and using the modified technique in group 2 (n = 9). The head of the first metatarsals was loaded in two different configurations (cantilever and physiological), using a materials testing machine.
Results: In the cantilever configuration, the relative stiffness of the osteosynthesis in comparison with intact bone was 60% (±21%) in group 1 and 65% (±25%) in group 2 ($p = 0.61$). In the physiological configuration, it was 47% (±29%) in group 1 and 47% (±21%) in group 2 ($p = 0.98$). The failure strength in the cantilever configuration was 235 N (±128 N) in group 1 and 210 N (±107 N) in group 2 ($p = 0.47$).
Conclusions: The conventional and the modified technique for distal chevron osteotomy in the treatment of hallux valgus show a comparable biomechanical loading capacity in this cadaver study.

1. Introduction

Hallux valgus is a common foot deformity. Many different osteotomies of the first metatarsal can be used for surgical correction of hallux valgus [1–5]. In 1979, Johnson et al. published the results for 18 patients after surgical correction of hallux valgus using a chevron osteotomy [6]. A “V” displacement osteotomy of the metatarsal head for hallux valgus and metatarsus primus varus was introduced by Austin and Leventen in 1981 [7]. Donnelly et al. modified the shape of the chevron osteotomy in 1994, resulting in a long plantar arm and a short dorsal arm [8]. To date, chevron osteotomy with minor modifications has been one of the most frequently used and widely accepted operations for treating hallux valgus.

Several biomechanical studies investigating the initial stability of distal chevron osteotomy have been published. Trost et al. compared a screw with two Kirschner wires for fixation of distal chevron osteotomies using the conventional technique in human cadavers [9]. Dalton et al. performed a distal chevron osteotomy with a short plantar arm and a long dorsal arm and compared plantar and dorsal orientation of a screw or a Kirschner wire, different sizes of Kirschner wires, and a tension-band effect in polyurethane foam models and human cadavers [10]. Vienne et al. studied the stability of modified chevron osteotomy, scarf osteotomy and reversed “L” osteotomy in sawbones [5].

To the best of our knowledge, no biomechanical studies have been published investigating different shapes of distal chevron osteotomy. Particularly with regard to modified chevron osteotomy with a long plantar arm and a short dorsal arm, introduced by Donnelly et al. in 1994, a biomechanical study assessing the stability in comparison to the conventional technique is still lacking [8].

The aim of the present biomechanical study was to determine whether there are any differences in stability between the conventional technique and a modified technique for distal

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chevron osteotomy. The primary aim was to measure the failure load, and a secondary aim was to compare the stiffness of the two techniques.

2. Materials and methods

The study was conducted with the approval of the local ethics committee (ref. no. 16-211). Nine matched pairs of fresh frozen human cadaver feet were used for the study (Table 1). Four of the donors were male and five were female. The donors' mean age was 80 (range 66–95 years). The bone mineral density in each specimen was measured in the posterior third of the calcaneus using dual X-ray absorptiometry (DEXA; Lunar iDXA, GE Healthcare, Chicago, USA) [9,11,12]. Radiographs of the specimens in dorsoplantar and lateral projections were taken in order to exclude any osseous pathology.

All soft tissues were removed. The specimens were wrapped in saline-soaked compresses and stored at −20 °C between the experiments. The first metatarsals used in the study had an average length of 6.5 cm (range 5.8–7.3 cm). For the experiments, the specimens were thawed at room temperature for 12 h.

The base of each first metatarsal was embedded perpendicularly in cold curing resin to a depth of 2 cm (Technovit® 4004, Heraeus Kulzer GmbH, Wehrheim, Germany) to achieve stable fixation in the materials testing machine [9].

Each specimen was tested in two loading configurations, in accordance with the method described by Favre et al. [2]: cantilever (Fig. 1) and physiological (Fig. 2). The cantilever configuration represents the most frequently used and well-established experimental set-up for biomechanical investigation of osteotomies of the first metatarsal [1–5,9,13–18]. The physiological configuration was introduced by Favre et al. to respect muscular contraction during walking [2].

Load was applied to the head of each first metatarsal with a materials testing machine (Z010, Zwick Roell, Ulm, Germany) at a displacement rate of 2 mm/min [2]. The preload was 5 N. The maximum load applied to intact bones was 150 N in the cantilever configuration and 550 N in the physiological configuration [2]. Load displacement curves were recorded, and the stiffness of the intact first metatarsals was calculated.

After testing of the intact first metatarsals, distal chevron osteotomies were carried out by the first author. The apex of the osteotomy was located at the center of the metatarsal head, 10 mm proximal to the metatarsophalangeal joint line. The angle of the distal chevron osteotomy was 70°. The osteotomy was carried out with a 0.6-mm saw blade. One first metatarsal from each pair was assigned to group 1 (n = 9): conventional technique with the dorsal and plantar arm equal in length (Fig. 3). The other first metatarsal from each pair was assigned to group 2 (n = 9): modified technique with a long plantar arm and a short dorsal arm (Fig. 4), introduced by Donnelly et al. in 1994 [8]. In both groups, the distal fragment

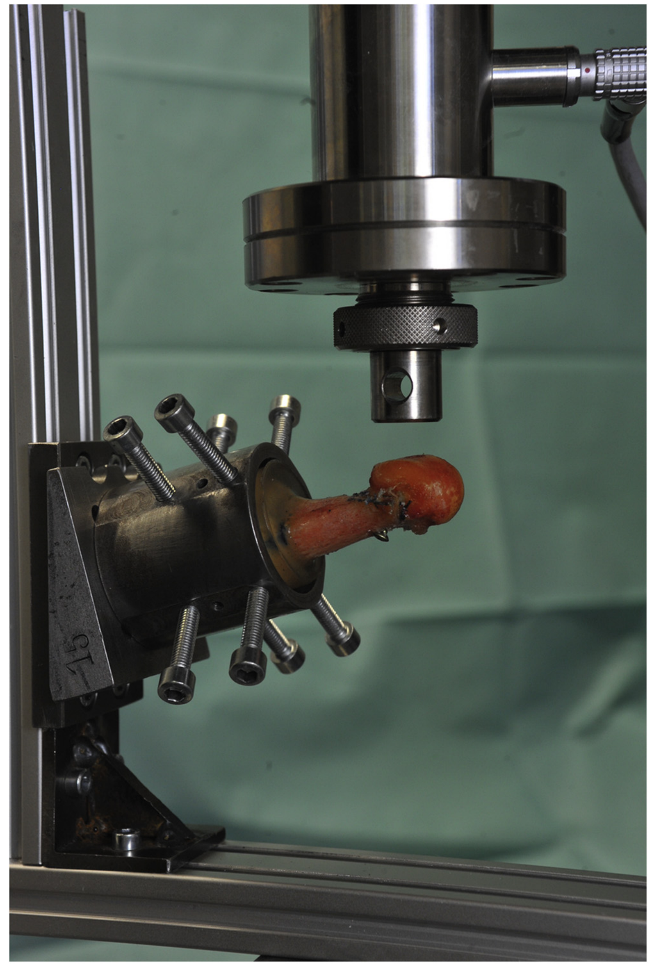

Fig. 1. The experimental set-up for cantilever testing.

was moved 5 mm laterally and fixed with a 2.7-mm cortical screw (self-tapping, 24–28 mm long, titanium; DePuy Synthes, Zuchwil, Switzerland) using a lag screw technique. The screw hole was positioned from dorsomedial to plantolateral, at an angle of 10–15°. After insertion of the screw radiographs were taken in dorsoplantar and lateral projections to verify correct implant positioning (Fig. 5).

All of the first metatarsals were retested in both loading configurations after distal chevron osteotomy. The maximum load applied in the physiological configuration was reduced to 300 N to avoid damage to the distal chevron osteotomy [9]. In the cantilever configuration, the first metatarsals were loaded to failure. Failure was defined as displacement of 10 mm, or when a decrease in load to 75% of the maximum load was recorded [19]. Failure strength

Table 1
Study population.

Specimen	Age (years)	Sex	Technique of distal chevron osteotomy	
			Right first metatarsal	Left first metatarsal
1	87	Female	Conventional	Modified
2	81	Male	Conventional	Modified
3	76	Male	Conventional	Modified
4	84	Female	Conventional	Modified
5	70	Male	Modified	Conventional
6	80	Female	Modified	Conventional
7	95	Female	Modified	Conventional
8	66	Female	Modified	Conventional
9	82	Male	Modified	Conventional

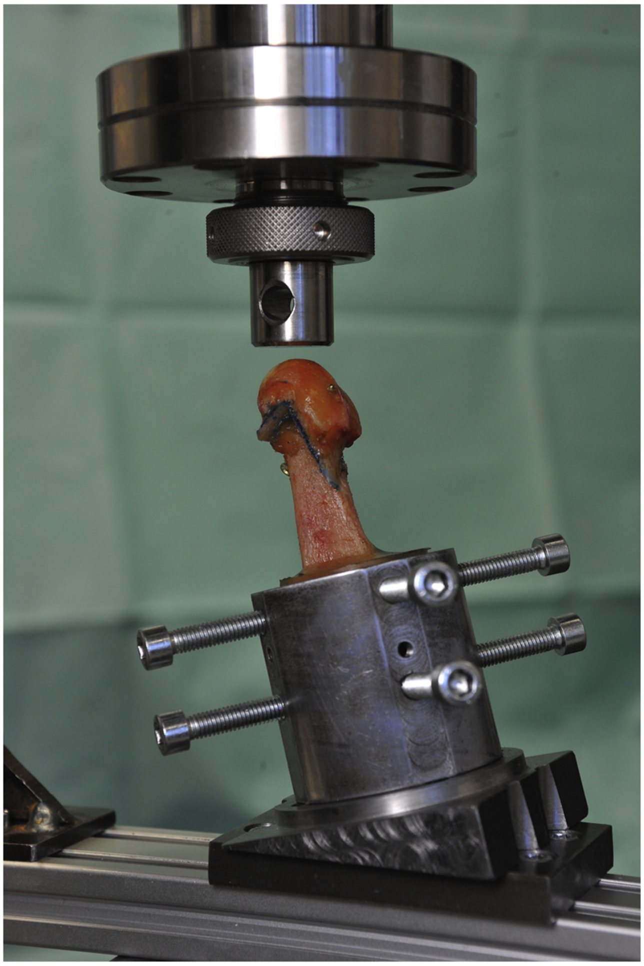

Fig. 2. The experimental set-up for physiological testing.

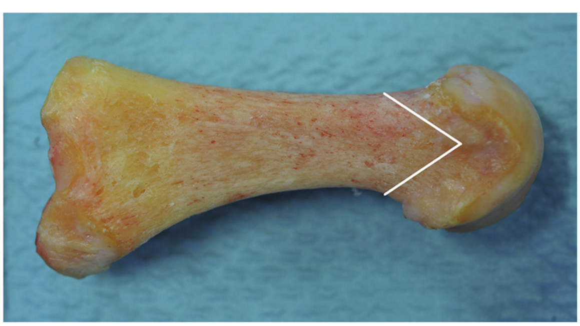

Fig. 3. Design of a distal chevron osteotomy using the conventional technique.

was defined as the maximum load reached during testing [2,5]. The mode of failure was noted.

Force displacement curves were analyzed in Microsoft Excel 2007 (Microsoft Corporation, Redmond, Washington, USA). A linear curve was fitted to the first linear part of the force displacement curve. The slope of the linear curve was taken as stiffness. The ratio of the stiffness of the osteotomized bone to the stiffness of the intact bone was calculated using the method described by Favre et al. [2].

Statistical analysis was carried out using IBM SPSS Statistics for Windows, version 22.0 (IBM Corporation, Armonk, New York, USA). The Shapiro–Wilk test was used to check the normal distribution of data. The results from the two groups were compared using a paired Student's *t*-test. Correlations between bone mineral density and failure strength were evaluated using Pearson correlation. Statistical significance was set at the 5% level ($p \leq 0.05$).

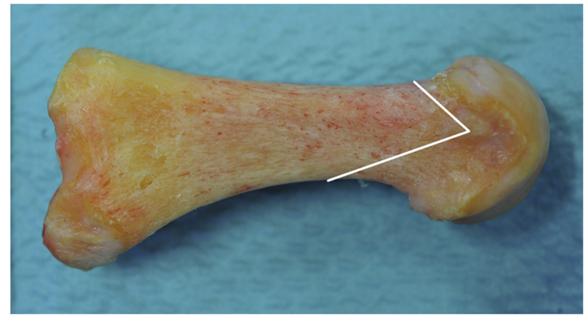

Fig. 4. Design of a distal chevron osteotomy using the modified technique.

3. Results

The results of bone mineral density and mechanical testing are shown in Table 2. The mean bone mineral density was 0.63 g/cm^2 (±0.16 g/cm^2) in group 1 (conventional technique) and 0.62 g/cm^2 (±0.18 g/cm^2) in group 2 (modified technique) ($p = 0.75$; [−0.04; 0.05]). In the physiological configuration, the mean stiffness ratio was 47.0% (±28.6%) in group 1 (conventional technique) and 46.7% (±20.6%) in group 2 (modified technique) ($p = 0.98$; [−27.8; 28.5]). In the cantilever configuration, the mean stiffness ratio was 60.1% (±21.5%) in group 1 (conventional technique) and 64.9% (±24.5%) in group 2 (modified technique) ($p = 0.61$; [−25.3; 15.7]). When the osteotomized bones were loaded to failure in the cantilever configuration, a mean failure strength of 234.7 N (±127.8 N) was measured in group 1 (conventional technique) and a mean failure strength of 210.4 N (±106.5 N) in group 2 (modified technique) ($p = 0.47$; [−49.6; 98.2]).

Fig. 6 shows the correlation between bone mineral density and failure strength. The Pearson correlation coefficient was 0.88 in group 1 (conventional technique) ($p < 0.01$) and 0.62 in group 2 (modified technique) ($p = 0.08$).

The failure mode of the first metatarsals with distal chevron osteotomies is shown in Fig. 7 for group 1 (conventional technique) and in Fig. 8 for group 2 (modified technique). All of the specimens in both groups failed as a result of distal lateral segment rotation.

4. Discussion

This experimental study compared the biomechanical properties of first metatarsals that underwent distal chevron osteotomy using a conventional or modified technique. Stiffness ratios were calculated for the physiological and cantilever configuration. The ratios were similar when distal chevron osteotomy was performed using the conventional or the modified technique. However, in both groups the stiffness ratio was lower in the physiological configuration than in the cantilever configuration.

Trost et al. compared a screw with two Kirschner wires for fixation of distal chevron osteotomy in conventional technique in human cadavers. They found similar stiffness ratios in physiological and cantilever configuration when using a screw for fixation [9]. In their biomechanical study, Favre et al. noted comparable stiffness ratios when investigating first metatarsals after distal chevron osteotomy fixed with a screw, but they reported a higher stiffness ratio in the physiological configuration than in the cantilever configuration [2]. The reason for this discrepancy between the findings of Favre et al. and the present study with

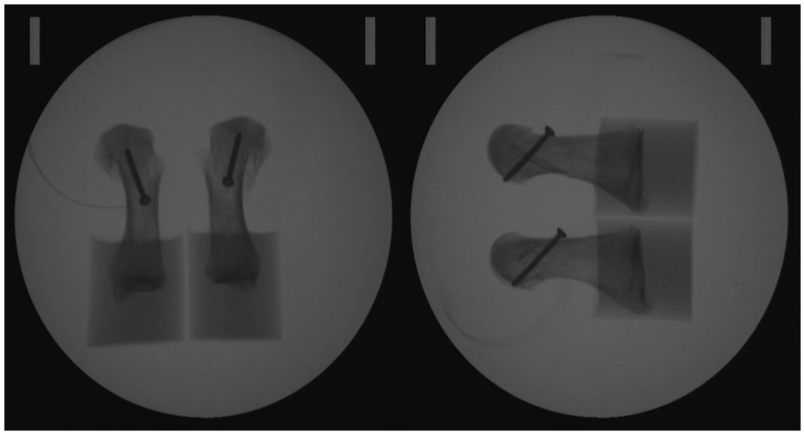

Fig. 5. Radiographs in dorsoplantar and lateral projection after distal chevron osteotomy using either the conventional technique (left first metatarsal) or the modified technique (right first metatarsal).

Table 2
Results relative to bone mineral density and mechanical testing (N = 9 per group)

	Group 1 (conventional technique)	Group 2 (modified technique)	*p* [95% confidence interval]
N	9	9	
Bone mineral density (g/cm^2)	0.63 ± 0.16	0.62 ± 0.18	0.75 [−0.04; 0.05]
Stiffness ratio (physiological) (%)	47.0 ± 28.6	46.7 ± 20.6	0.98 [−27.8; 28.5]
Stiffness ratio (cantilever) (%)	60.1 ± 21.5	64.9 ± 24.5	0.61 [−25.3; 15.7]
Failure strength (N)	234.7 ± 127.8	210.4 ± 106.5	0.47 [−49.6; 98.2]

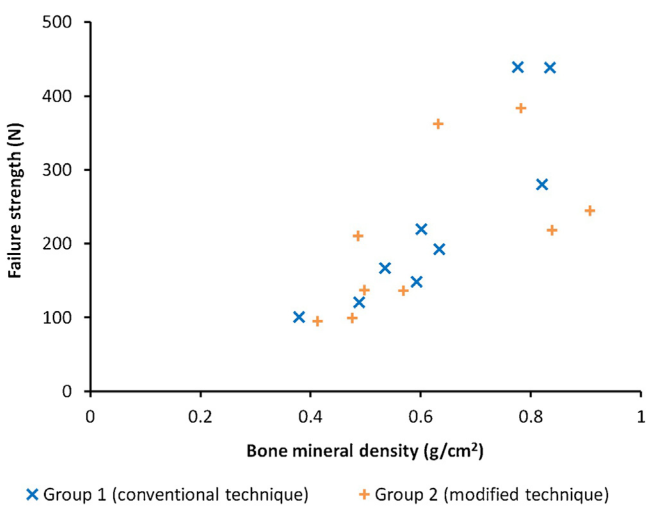

Fig. 6. The correlation between bone mineral density and failure strength. Group 1 (conventional technique): Pearson correlation coefficient 0.88; $p < 0.01$. Group 2 (modified technique): Pearson correlation coefficient 0.62; $p = 0.08$.

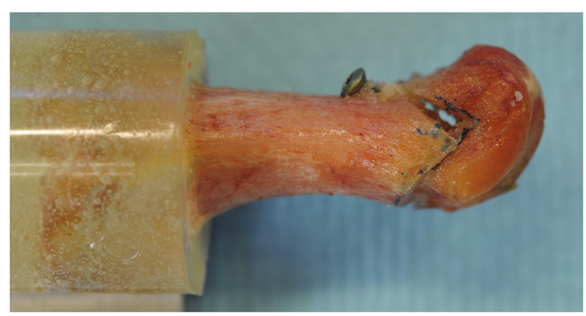

Fig. 7. Failure mode of a distal chevron osteotomy using the conventional technique. All of the specimens failed as a result of distal lateral segment rotation.

regard to the stiffness ratios is not clear, but it might be due to intrinsic differences in the materials used [2].

Failure strength is an important parameter in biomechanical studies investigating the stability of different types of osteotomy. In the present study, the average failure strength was 234.7 N in first metatarsals that underwent distal chevron osteotomy with the conventional technique. In the other group, a modified technique for distal chevron osteotomy was used, and an average failure strength of 210.4 N was measured. This result suggests that there is no difference in stability between the two techniques for distal chevron osteotomy. It appears to be the case that modification of distal chevron osteotomy resulting in a longer plantar arm does not increase the stability of the osteosynthesis. However, it is important to bear in mind that both types of distal chevron osteotomy in the present study showed a failure strength and therefore stability that were comparable to those reported in other biomechanical studies. Trost et al. found a similar failure strength of 187.2 N for first metatarsals after distal chevron osteotomy using the conventional technique fixed with a screw [9]. Favre el al. investigated distal chevron osteotomy using a conventional technique fixed with a screw and reversed-L osteotomy fixed with two screws in human cadavers [2]. The shape of the reversed-L osteotomy used by Favre et al. is similar to the modified chevron osteotomy used in the present study [2]. Favre et al. reported a failure strength of approximately 150 N for distal chevron osteotomy and a failure strength of approximately 270 N for reversed-L osteotomy [2]. The higher failure strength of reversed-L osteotomy can be explained by the second screw used for fixation and the difference in the shape of the osteotomy. Vienne et al. observed a failure strength of 309.5 N for modified chevron osteotomy fixed with a screw in a saw-bone study [5]. This finding is difficult to compare with the results of the present study, as Vienne et al. used saw bones for the mechanical testing and in

Fig. 8. Failure mode of a distal chevron osteotomy using the modified technique. All of the specimens failed as a result of distal lateral segment rotation.

the present study human cadavers were used [5]. This may explain the higher failure strength observed by Vienne et al. for modified chevron osteotomy [5].

Failure strength is influenced by many parameters, with bone mineral density being an important one. The bone mineral density was therefore measured in every specimen used in the present study. The aim with specimen distribution was to achieve a similar mean bone mineral density in both groups, and this was accomplished in this study (Table 2). The correlation between bone mineral density and failure strength is shown in Fig. 6. There was evidence of a statistically significant positive association between bone mineral density and failure strength in both groups. In group 1 (conventional technique) it was significant, while in group 2 (modified technique) it was not significant. This shows that bone mineral density is an important factor influencing the failure strength and thus the stability of distal chevron osteotomy. The effect of bone mineral density on failure strength has been poorly investigated for osteotomies of the first metatarsal. Trost et al. noted a significant positive correlation between bone mineral density and failure strength in first metatarsals after distal chevron osteotomy using the conventional technique fixed with a screw [9]. In a biomechanical study investigating Ludloff osteotomy, Hofstaetter et al. reported a significant positive correlation between bone mineral density and osteotomy fixation stiffness [14].

The failure mode is an important aspect that needs to be addressed in a biomechanical study investigating the stability of a surgical technique. In the present study, all of the specimens in both groups failed as a result of distal lateral segment rotation. This is the common failure mode with distal chevron osteotomy, and it was also reported by Trost et al. and Favre et al. [2,9].

This study has several limitations. An important one is the relatively small number of specimens investigated. This is a problem with most biomechanical studies, as there are only limited numbers of fresh frozen cadaver specimens available.

This biomechanical study also investigated the primary stiffness of distal chevron osteotomy. The effects of bone healing cannot be determined in a biomechanical cadaver model. The findings of the study are therefore only applicable to the day of surgery.

5. Conclusions

In conclusion, no statistically significant differences in stability were observed between the conventional and the modified technique for distal chevron osteotomy. In surgical correction of hallux valgus, the conventional and the modified technique for distal chevron osteotomy showed a comparable biomechanical loading capacity in the present study.

Declarations of interest

None.

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