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Biomechanical Evaluation of Calcaneocuboid Distraction Arthrodesis: A Cadaver Study of Two Different Fixation Methods

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ABSTRACT

Calcaneocuboid distraction arthrodesis can be used to treat stage 2 posterior tibial tendon dysfunction. Nonunion, graft resorption, and implant failure have been reported after this procedure. This study compared two of the most commonly used methods for fixation of calcaneocuboid distraction arthrodesis. Twelve pairs of cadaver feet underwent simulated calcaneocuboid distraction arthrodesis. One specimen in each pair was fixed with two crossed 3.5 mm cortical lag screws. The contralateral specimen was fixed with a cervical H-plate. The calcaneus was fixed and a load was applied to the plantar aspect of the cuboid at a rate of 5mm/minute until joint separation of 3mm or fracture occurred. The average applied load to failure at 1.0 mm of joint separation was 30.5 +/- 11.6 N for the crossed screws and 77.7 +/- 36.4 N for the cervical H-plate (p = 0.001). The average stiffness at 1.0 mm of joint separation was 27.5 +/- 10.9 N/mm for the crossed screws and 43 +/- 21.2 N/mm for the cervical H-plate (p = 0.036). The higher stiffness and load to failure may account for the decreased nonunion rate noted anecdotally by some surgeons with H-plate fixation over crossed screw fixation for calcaneocuboid distraction arthrodesis.

INTRODUCTION

Lengthening the lateral column of the foot has been employed in the treatment of symptomatic stage 2 posterior tibial tendon dysfunction. Evans initially described placing a tibial cortical graft into an intracalcaneal osteotomy to correct calcaneo-valgus deformity in children.[7] Subsequently other authors have reported generally good results in the symptomatic adult and pediatric flatfoot with variations of this technique, often using a different graft source or adding additional bone and/or soft tissue procedures to it.[2,3,5,6,7,8,10,11,12,13]

Potential complications of the Evans procedure include the risk of damaging the anterior or middle facets of the calcaneus or developing subsequent calcaneocuboid arthritis.[4,12,14] To address these concerns a modification of this technique in which lateral column lengthening is performed through a calcaneocuboid distraction arthrodesis instead of an intracalcaneal osteotomy was described. Several authors have reported good short-term results in adult stage 2 posterior tibial tendon dysfunction with calcaneocuboid distraction arthrodesis.[1,15,16,17,18]

Various methods of internal fixation for calcaneocuboid distraction arthrodesis have been used, which include no fixation, k-wires, staples, single or multiple screws, and plates. The optimal method of fixation has yet to be determined. Complications including nonunion at the graft site, graft resorption, and implant breakage have been noted. Anderson and Davis, reported implant failure occurring only with pins and screws but not with staples or plates.[1] Toolan et. al. had a higher nonunion rate with the use of two crossed screws than with a cervical H-plate.[17] Malunion and nonunion are often associated with sub-optimal clinical results and may be related to a lack of adequate fixation at the fusion site. The purpose of this study was to try to determine the relative biomechanical strength of different methods of fixation for calcaneocuboid distraction arthrodesis. Motion through the calcaneocuboid fusion site after two different fixation methods was examined under load and the stiffness and applied load to failure measured.

MATERIALS AND METHODS

Twelve matched pairs of fixed cadaver feet amputated above the ankle along with a section of posterior iliac crest from the same cadavers were obtained from the department of Anatomy at the authors' institution. The age of the donors ranged from 53 to 83 years. The soft

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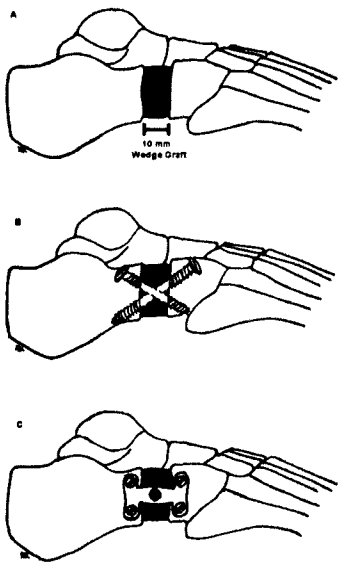

Fig. 1a, Placement of a 10mm tricortical iliac crest graft into the calcaneocuboid joint;
Fig. 1b, Fixation with two crossed 3.5 mm screws;
Fig. 1c, Fixation with a cervical H-plate.

tissues surrounding the calcaneocuboid joint were stripped and the articular cartilage removed. A 10 mm wide trapezoidal-shaped tricortical iliac crest graft harvested from the same cadaver was inserted into the calcaneocuboid joint. One specimen in each pair was fixed with a laterally placed 28 mm H-plate (Synthes: Paoli, PA) with two 3.5 mm cortical screws in the calcaneus and two 3.5 mm cortical screws in the cuboid. The contralateral specimen was fixed with two crossed 3.5 mm cortical screws placed using lag technique with the starting holes in the dorsolateral calcaneus and cuboid (Figure 1). Fixation was randomly assigned by alternating left and right for each pair.

A testing protocol similar to that described by Kann et. al. was used.[9] Each specimen was placed in a specially designed clamp so that the calcaneus was held firmly and the calcaneocuboid joint was allowed free motion (Figure 2). An extensometer was placed across the calcaneocuboid joint. The point of calcaneus load to the calcaneocuboid joint line was determined as the center of the cuboid and kept constant. The specimens were attached to the MTS test frame system. The orientation of the specimen placed the plantar surface facing the hydraulic ram to simulate weight- bearing. The load was applied by a hydraulic ram at a rate of 5 millimeters per minute (mm/min) until fracture of the construct or until indication of 3.0 millimeters of separation at the joint by the extensometer. Failure was defined as either fracture or separation of 1.0 mm, whichever occurred first. Stiffness and applied load to failure were determined at 1.0 mm. Our method does not truly measure stiffness, but, in fact, uses a clinically applied force to produce gapping or fracture failure, i.e. clinical failure. This standardized force was then used to calculate stiffness using the linear portion of the load-deformation curve for each specimen.

The data were collected using the MTS Testworks™ 759.90 software. Data were plotted as Load-Deformation curves for each pair of cadaver feet using Microsoft Excel™ 97 software. Statistical significance was determined with a paired two-tailed Student's t-test.

RESULTS

Data were analyzed for 12 pairs of cadaver feet. A typical load-deformation curve is shown for a representative pair of feet (Figure 3).

The range of applied load to failure at 1.0 mm was 16 to 54 newtons (N) with crossed screw fixation. The range of applied load to failure at 1.0 mm was 22 to 145 N with H-plate fixation. The average applied load to failure at 1.0 mm was 30.5 N and 77.7 N for calcaneocuboid lengthening with the crossed screws and the H-plate, respectively. (Table 1) A statistically significant ($p = 0.001$) difference was found between the two different methods of internal fixation with regard to applied load to failure at 1.0 mm.

The range of stiffness at 1.0 mm was 13 to 42 newtons per millimeter (N/mm) with crossed screw fixation. The range of stiffness at 1.0 mm was 15 to 86 N/mm

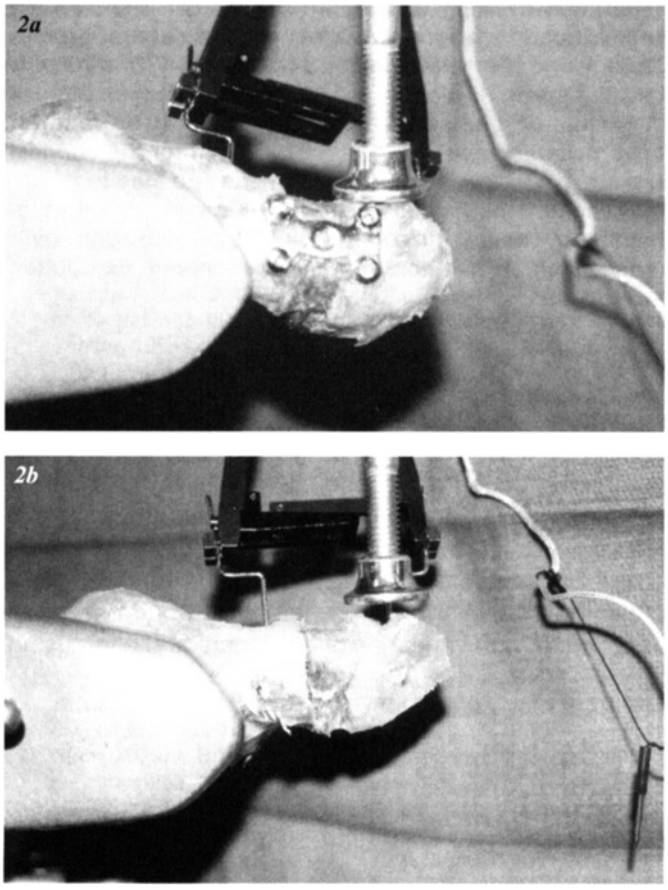

Fig. 2: a, Specimen setup with cervical H-plate; b, Specimen setup with crossed screws.

Table 1. Applied Load at 1mm (N/mm).

Pair No.	Crossed Screws	H-Plate
1	54	58
2	16	69
3	26	83
4	33	145
5	39	50
6	21	52
7	48	79
8	28	46
9	28	134
10	16	22
11	31	94
12	26	101
Average	30.5	77.7
Standard Deviation	11.6	36.4

p=0.001

Table 2. Stiffness at 1mm (N/mm).

Pair No.	Crossed Screws	H-Plate
1	49	26
2	13	42
3	25	60
4	22	27
5	38	34
6	17	25
7	42	53
8	28	32
9	25	72
10	16	15
11	31	86
12	24	44
Average	27.5	43.0
Standard Deviation	10.9	21.2

p=0.036

with H-plate fixation. The average stiffness at 1.0 mm was 27.5 N/mm and 43 N/mm for calcaneocuboid lengthening with the crossed screws and the H-plate, respectively. (Table 2) A statistically significant ($p = 0.036$) difference was found between the two different methods of internal fixation with regard to stiffness at 1.0 mm.

DISCUSSION

Overall good results have been reported using calcaneocuboid distraction arthrodesis for adult stage 2 posterior tibial tendon dysfunction. However, there has been a higher reported incidence of nonunion as compared to the Evans procedure. In the reported series of Evans procedures known to the authors the graft was usually secured in the osteotomy site with a single screw or k-wire, and occasionally no fixation was used. In these studies there was one delayed union and no nonunions reported.[2,3,5,6,7,8,10,11,12,13] After calcaneocuboid distraction arthrodesis, 12 nonunions in 88 cases have been reported[1,16,17,18]. In one study, nonunion and graft resorption were associated with implant failure which occurred only with pins and screws and not when staples or plates were used.[1] A 24% nonunion rate (8/34) with crossed screw fixation and a 0% nonunion rate (0/7) with cervical H-plate fixation was reported in another study.[17]

The higher nonunion rate with graft insertion at the calcaneocuboid joint as compared to within the anterior calcaneus may be in part due to slower healing of subchondral as compared to cancellous bone and decreased inherent stability secondary to motion available at the calcaneocuboid joint. Therefore, stronger, more rigid fixation may lead to a lower nonunion rate for calcaneocuboid distraction arthrodesis.

The process of model testing in this study was similar to that previously described by Kann et. al.[9] This study biomechanically evaluated, under load, two types of screw fixation for calcaneocuboid fusion in a proposed triple arthrodesis procedure. While the technique of loading the model is alike, our study differs in the types of fixation, the use of a bone graft for distraction, and the clinical application of its use.

The purpose of our study was to compare the most common methods of fixation for calcaneocuboid distraction arthrodesis. Our data clearly showed a significant difference in the strength of the H-plate compared to crossed screws for lateral calcaneocuboid distraction arthrodesis. Both the applied load to failure at 1.0 mm and stiffness at 1.0 mm were significantly greater

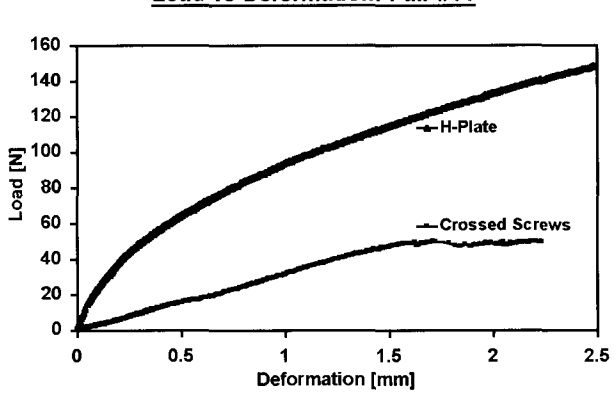

Fig. 3: Load vs. deformation curve for specimen pair number 11.

(p=0.001, 0.032 respectively) with H-plate fixation. These findings suggest that the cervical H-plate may lead to a lower rate of calcaneocuboid nonunion, graft resorption, or loss of graft position. Other factors may play a role in fusion rates including length of cast immobilization and weight-bearing restrictions, thermal damage at the fusion site related to use of a saw as compared to an osteotome, and patient factors such as age. Theoretical disadvantages of the cervical H-plate include increased cost and prominence which may require subsequent hardware removal.

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