A biomechanical study in cadavers of cast boots used in the early postoperative period after first metatarsophalangeal joint arthrodesis

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Objectives: To compare the effectiveness of 3 common models of walking boots (Walkabout, Samson Walker and Equalizer Premium Walker) to that of a fibreglass cast in protecting an arthrodesis of the first metatarsophalangeal (MTP) joint in the early postoperative period, we carried out a biomechanical study in cadavers in the bioengineering laboratory at Memorial University of Newfoundland. **Methods:** Two cadaver models of a first MTP joint arthrodesis were prepared by placing a strain gauge at the joint. This provided a measure of the bending moment across the fusion site. Walking was simulated by applying a force to the sole of the cadaver foot at multiple positions from heel to toe, representing the stages of gait from heel strike to toe off. **Results:** For both cadaver specimens, the Walkabout boot had the lowest mean moment. The Walkabout and Sampson Walker boots were better than the Equalizer Premium Walker boot and the fibreglass cast ($p < 0.05$), but the Walkabout boot was the best ($p < 0.05$). Also, for both specimens, the Walkabout boot had the smallest absolute maximum moment ($p < 0.05$). **Conclusion:** On a first MTP joint arthrodesis site, removable cast boots provide the same, if not more, reduction of force as a traditional cast.

Objectifs : Pour comparer l'efficacité de trois modèles courants de botte de marche (Walkabout, Samson Walker et Equalizer Premium Walker) à celles d'un plâtre de protection en fibre de verre pour une arthrodèse de la première articulation métatarsophalangienne (MTP) peu après l'intervention, nous avons procédé à une étude biomécanique sur des cadavres au laboratoire de génie biomédical de l'Université Memorial de Terre-Neuve-et-Labrador. **Méthodes :** On a préparé sur deux cadavres des modèles d'arthrodèse de la première articulation MTP en plaçant un tensiomètre au niveau de l'articulation, ce qui a permis de mesurer le moment de courbure au point de fusion. On a simulé la marche en appliquant une force à la plante du pied du cadavre à de multiples points, du talon aux orteils, qui représentaient les stades de la démarche, depuis l'attaque du talon jusqu'au soulèvement des orteils. **Résultats :** Pour les deux spécimens de cadavre, la botte Walkabout produisait le moment moyen le plus faible. Les bottes Walkabout et Sampson Walker étaient meilleures que la botte Equalizer Premium Walker et que le plâtre en fibre de verre ($p < 0,05$), mais la botte Walkabout était la meilleure ($p < 0,05$). Pour les deux spécimens, la Walkabout était aussi celle qui présentait le moment maximal absolu le plus faible ($p < 0,05$). **Conclusion :** Au site de l'arthrodèse de la première articulation MTP, les bottes rigides amovibles assurent une réduction de la force équivalente, sinon supérieure, à celle que garantit un plâtre traditionnel.

There are many conditions of the first metatarsophalangeal (MTP) joint that require surgical management. Two of the most common are hallux valgus and hallux rigidus. Arthrodesis is commonly reserved for more severe cases of these 2 problems. Historically these are the most common indications for first MTP arthrodesis, but many other indications exist, such as significant deformity of the first ray associated with an underlying neuromuscular disease (e.g., cerebral palsy, spastic paralysis or poliomyelitis) and the salvage of iatrogenic or postoperative complications of first-ray procedures (e.g., failed implant arthroplasty).[1]

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Numerous fixation techniques, including screw, wire and plate fixation, have been described and are currently in use.[1–6] Richardson and Donley[2] have outlined 4 common techniques, and the union rate seems to vary with the type of internal fixation used. In general, solid radiographic and clinical fusion is not seen before 6 weeks postoperatively.[1] In terms of postoperative care, recommendations vary from and often depend on the technique used. Some believe in almost immediate full weight bearing whereas others recommend nonweight bearing for a number of weeks postoperatively.[1–4] However, for the 4 techniques described by Richardson and Donley,[2] early weight bearing as tolerated is recommended. Also, in a randomized study of 61 cases of MTP arthrodesis, Lampe and associates[7] compared outcomes of patients allowed full weight bearing at either 2–4 days or 4 weeks postoperatively. They found no difference in radiographic union between the 2 groups on follow-up. Nonweight bearing is recommended when structural bone grafting is used for reconstruction of a failed silicone arthroplasty.[1,2]

When early weight bearing is instituted, either a postoperative walking boot or a walking cast is usually recommended for 6–12 weeks.[1–5] This serves to protect the arthrodesis site from excessive force until bony union has taken place, thus decreasing the possibility of fixation failure. Although a walking boot is most often recommended postoperatively, there is no clear indication of its effectiveness compared to a traditional plaster or fibreglass cast. The choice appears to be based on surgeon preference and experience. There are some general benefits of a walking boot over a cast, including easier wound care, convenience for the patient, and fewer return visits for wet or broken casts. The concerns with removable walking boots include compliance and proper application technique. There are several models of walking boots available, making the decision even more complex.

In this study we compared some of the more common models of postoperative walking boots available with respect to their ability to protect a first MTP joint arthrodesis in a cadaveric model during simulated weight bearing. The performance of a fibreglass walking cast was also tested for comparison.

Methods

To compare the load placed on the first MTP joint with the different boots, a device was designed to measure the magnitude of the moment force applied to this joint while walking. This was accomplished by placing a strain gauge at the joint, capable of producing a voltage output that is proportional to the bending moment (load) placed on the strain gauge itself. Walking was simulated by applying a force equivalent to average body weight to the sole of the cadaver foot. This weight was applied at multiple positions along the length of the foot from the heel to the toe, simulating the stages of gait from heel strike to toe off.

Two cadaver specimens were used, each consisting of a leg dissected at the level of the knee joint. Each specimen underwent the same preparation.

The first MTP joint was exposed, and resection of the distal end of the metatarsal head and the proximal aspect of the proximal phalanx was carried out. Approximately 7.5 mm of bone was removed from each side of the joint. This was to allow for the 15-m load cell (a 15 × 10 × 2-mm piece of 17-4 PM (ASTM code) stainless steel, to which the strain gauge is mounted) to be placed across the joint. The medullary canals of the phalanx and metatarsal were prepared to allow for insertion of the load cell. The load cell was then fixed in place with methylmethacrylate cement. The load cell was positioned across the resected joint such that the first toe was positioned in slight dorsiflexion (10°–15° in relation to the floor) and 15°–20° of valgus (Fig. 1). To anchor the leg to the test-frame proximally, a 10-mm diameter steel rod was cemented in the medullary canal of the tibia.

Three models of cast boots were used during the testing: (1) the Samson Walker boot (DeRoyal, Powell, Tenn.) (2) the Equalizer Premium

FIG. 1. Cadaver foot showing positioning of the load cell across the resected first metatarsophalangeal joint.

FIG. 2. A cast boot applied to the cadaver specimen and mounted in the test frame in readiness for the application of a force ranging from 0 to 70 kg over 7 seconds.

Walker boot (Ana-Tech, South Gate, Calif.) and (3) the Walkabout boot (Smith & Nephew, Memphis, Tenn.). These were chosen because they are among the most commonly used cast boots available. We used boots that were the size recommended by the manufacturer to fit the specimen. A fibreglass below-knee walking cast was also used for comparison. The boot or cast was placed on the cadaver leg, and the specimen was mounted into the test frame (Fig. 2). An Instron 8874 (Instron, Canton, Mass.) test frame was used which applied a 70-kg vertical force on the sole of the boot or cast. The force was applied at discrete locations along the sole of the foot by a 3-cm diameter bar. Thus for each boot or cast, there were 12 (foot 1) or 10 (foot 2) discrete sites where the force was applied, starting at a position 4 cm posterior to the medial malleolus and advancing distally in 2-cm intervals until the end of the sole was reached. This technique was designed to simulate the weight-bearing phase of gait from heel strike to toe off. The force was increased from 0 to 70 kg over a 7-second period, held for 5 seconds and released over 7 seconds. This allowed the reading from the strain gauge to stabilize and to negate any viscoelastic properties of the cadaver leg.

Both specimens were tested with each of the 3 cast boots and the fibreglass cast. The order of boot or cast used was randomized and was different for each specimen. The maximum resultant force across the MTP joint was measured by the strain gauge at each location of weight bearing along the sole of the cast or boot. Analysis of variance (ANOVA) was used to determine statistical significance ($p < 0.05$ was considered significant).

Results

To assess protection against fatigue-type failure (from repetitive small-magnitude forces) we compared forces at each location along the sole and the overall average moment. For each boot and the cast, the moment measured across the joint was determined at each of the weight bearing positions at 2-cm increments along the sole of the foot. The results are shown in Figs. 3 and 4. The means of these moments are listed in Table 1. For both feet, the Walkabout (Smith & Nephew) had the lowest mean moment. Foot 1 showed that the Walkabout and the Sampson Walker boots were both better than the Equalizer boot and the fibreglass cast ($p < 0.05$). Foot 2 showed that the Walkabout boot was better than all others ($p < 0.05$).

To measure the protection against sudden failure (from sudden high-magnitude load), we compared the maximum moment applied throughout the entire testing for all boots. The position of the applied load that created the maximum moment across

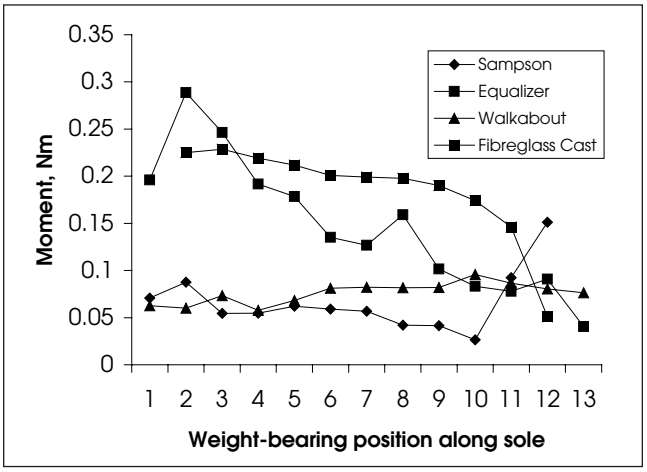

FIG. 3. Moment measurements (Nm) for each of the boots and the fibreglass cast at different positions (measurement 1 = heel, measurement 13 = toe), 2 cm apart, along the sole of the foot of cadaver foot 1.

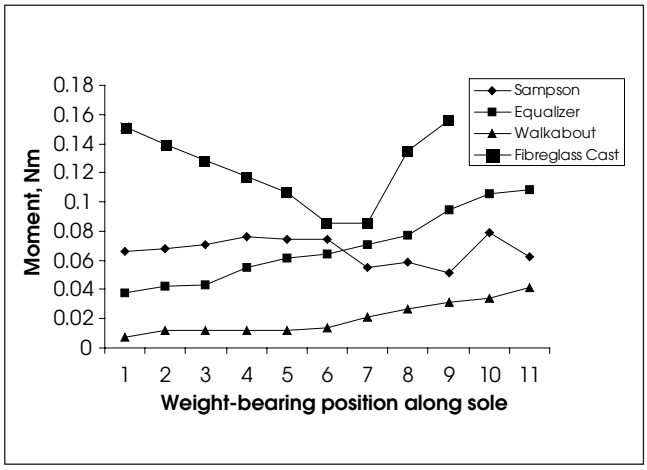

FIG. 4. Moment measurements (Nm) for each of the boots and the fibreglass cast at different positions (measurement 1 = heel, measurement 11 = toe), 2 cm apart, along the sole of the foot of cadaver foot 2.

Table 1

Mean Moment Measurements (Nm) for the Three Cast Boots and Fibreglass Cast in the Two Cadaver Feet

	Type of boot/cast			
Cadaver	Sampson	Equalizer	Walkabout	Fibreglass
Foot 1	0.0708	0.118	0.0694	0.112
Foot 2	0.0644	0.0727	0.0245	0.123

Table 2

Maximum Moment Measurements (Nm) for the Three Cast Boots and Fibreglass Cast at Any Position in the Two Cadaver Feet

	Type of boot/cast			
Cadaver	Sampson	Equalizer	Walkabout	Fibreglass
Foot 1	0.327	0.289	0.0957	0.229
Foot 2	0.0790	0.108	0.0416	0.156

the first MTP joint varied for each boot and the cast but usually was in the forefoot region. The absolute maximum moment measured at any position for each boot and the cast is listed in Table 2. Again, for both feet, the Walkabout had the smallest maximum moment ($p < 0.05$).

Discussion

Arthrodesis of the first MTP joint is a common procedure. Although there are no definitive studies, most would agree that internal fixation is not sufficiently strong to allow immediate, unprotected weight bearing. Thus, either restricted ambulation or external protection is recommended in the early postoperative period until the arthrodesis is solid.[1–4] Restricted weight bearing has several disadvantages. Activities of daily living would certainly be more difficult, and patients may delay their return to work. Muscle wasting and disuse osteopenia may result and further delay return to full activity. Alternatively, the use of external support (i.e., a cast) would protect the arthrodesis site and allow earlier weight bearing. A traditional plaster or fibreglass cast makes bathing difficult and does not allow examination of the wound without cast removal. A removable cast boot would seem to be a good option without the disadvantages of the traditional cast by providing easier wound care, being convenient for the patient, maintaining range of motion and requiring fewer return visits for wet or broken casts. We were concerned, however, that it would not provide the same level of protection to the arthrodesis site.

The fixation of a first MTP joint fusion can fail by 2 different mechanisms. A single force that exceeds the strength of the construct would result in sudden failure of the fixation, and repetitive forces of smaller magnitudes can result in failure through a fatigue-type process. Both of these mechanisms were addressed in our study. We showed that the removable cast boots we tested do at least provide the same reduction of force on a first MTP joint arthrodesis site as a traditional cast. Our data suggest that some boots even provide a better reduction in force. The Walkabout provided the largest reduction in applied moment across the joint when compared with the other boots.

The Walkabout boot has a number of notable features that may be attributable to its superior performance. First, the medial and lateral plastic splints are thicker and less flexible than in the other 2 boots. They were noted to flex less at the ankle during testing. Second, although each boot tested had 5 sets of Velcro straps to secure it in place, those on the Walkabout boot provided a more secure fit. As a result, there was less movement of the foot and ankle within the boot.

It is worth mentioning that the order of testing did not appear to affect the results. The Walkabout, which performed the best for both feet, was the first boot tested for one foot but was the third boot tested for the other.

In specimen 2, the moment applied to the fusion site jumped suddenly in the fibreglass cast test. The distal end of the cast failed and allowed excessive force to be applied to the test site. An alternative casting technique providing some reinforcement to the distal forefoot would have prevented this. This value was not used in the statistical analysis.

The soft tissues of cadaver feet do not have the same properties as living tissue, and this to some degree affected the readings; however, all variables, except the type of external support, were kept constant throughout the testing. The forces across the joint also were not physiologic. We did not attempt to apply a varus or valgus force to the construct. We felt our method of simulating the stance phase of gait was realistic given the ability to only apply a longitudinal force with our test frame. Also, the applied force that a first MTP joint fusion can tolerate before failing varies, depending on many factors, including bone quality and method of fixation. We cannot be sure that the protection provided by external support will be enough to prevent failure of fixation in all cases. The decision to allow early weight bearing will remain a clinical one.

Conclusions

If the surgeon plans to allow weight bearing in the early postoperative period after a first MTP joint arthrodesis, a removable cast boot will provide the same, if not more, reduction of force on the arthrodesis site than a traditional cast. Furthermore, there appears to be a significant difference in the protection offered by different styles of cast boots.

Competing interests: None declared.

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