Ankle arthrodesis using dowel bone graft and cancellous-bone screws

A mechanical study in cadavers

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Background There are numerous techniques for ankle arthrodesis.

Material and methods We studied the stability of an ankle arthrodesis with the use of two cross-screws combined with dowel graft technique in 14 fresh-frozen ankles from amputees. The arthrodesis was performed by a dowel graft technique, in the coronal plane in 7 specimens (group 1) and in the diagonal plane in the remaining 7 (group 2). Allocation into the two groups took place after normalization according to the bone mineral content of the specimens. All ankles were fixed with two 6.5-mm diameter cancellous-bone screws, with the ankle in neutral position. Tibiotalar motion was measured during 5 Nm torque loading in plantar flexion-dorsiflexion, abduction-adduction and eversion-inversion planes of the ankle joint. Two testing sequences were performed and the mean value of both tests in each direction was used for the analysis.

Results In all 3 planes, the torque applied caused more motion with the dowel graft in the coronal plane (group 1) than with the graft in the diagonal plane (group 2). The differences between the two groups were significant for abduction-adduction and eversion-inversion planes. Statistical analysis of differences between the first and second test showed significantly greater stiffness in group 2 than in group 1 in plantar flexion-dorsiflexion torque.

Interpretation The placement of a dowel graft in the diagonal plane in comparison to the coronal plane significantly increased the initial stability of an ankle arthrodesis.

Numerous arthrodesis techniques for the ankle have been described. These techniques can be divided into two main categories: those that use external fixation and those that use internal fixation. The surgical approaches and fusion techniques have tended to become simpler with time. One reason has been that in general, an ankle arthrodesis with internal fixation has fewer complications and is better tolerated than one using external fixation techniques (Ross and Matta 1985, Scranton 1985, Lynch et al. 1988, Maurer et al. 1991, Moeckel et al. 1991). In contrast to the internal fixation using plates, cross-screws can be inserted with minimal soft-tissue trauma, thereby preserving vascularity (Holt et al. 1991, Ross and Matta 1985, Scranton 1985). The cross-screw technique has gained popularity because of its simplicity (Chieppa et al. 1989, Cracchiolo 1990, Mann et al. 1991, Maurer et al. 1991, Morgan et al. 1985, Ogilvie-Harris et al. 1993, 1994). Baciu (1986) advised a dowel graft technique in which the graft was obtained in the coronal plane. This technique does not use hardware, and the dowel graft itself is used to stabilize the fusion. It has the advantage of being a simple and rapid method, with minimal soft-tissue dissection. Bone healing was achieved in 58/62 patients. Stranks et al. (1994) reported a modified dowel graft technique in which the graft was obtained in the sagittal plane at the midpoint of the joint. The fusion was stabilized by cross-screws. These authors reported union in 19/20 patients, with few complications.

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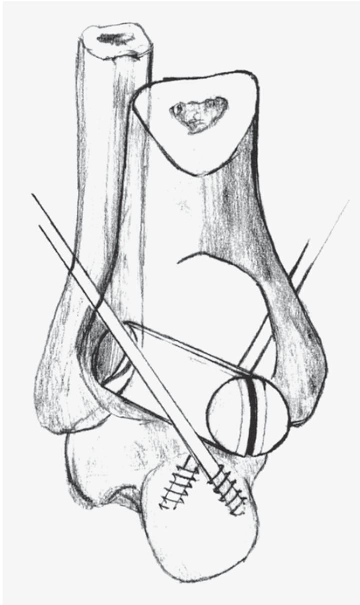

Figure 1. Diagram of the surgical technique in group 2, showing the dowel graft in the diagonal plane and rotated 90 degrees. The medial screw is placed posterior to the dowel graft and the lateral screw anterior to it.

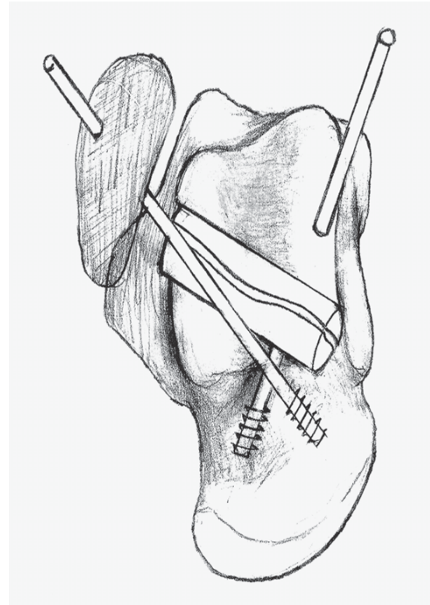

Figure 2. Diagram of the technique to show the position of the screws in the talar head.

To further improve the initial stability, we have developed a technique for arthrodesis in which two cross-screws are used, and a dowel graft is obtained in a diagonal plane from the anteromedial side of the joint towards the lateral malleolus. To our knowledge, the degree of stability of a fusion entailed by combined dowel graft and cross-screws has not been quantified, and how the direction of a dowel graft influences the stability of the fusion has not been investigated. In this study, we assessed any differences in the stability of a fusion after an ankle arthrodesis using dowel graft obtained in a diagonal plane or coronal plane.

Material and methods

We used 14 fresh-frozen ankle specimens from amputees. The specimens were stratified into two groups (1 and 2) according to their bone mineral content value (BMC) determined in the calcaneus by triple-energy X-ray absorptiometry (Swanpalmer et al. 1998 a, b). The radiation beam was directed transversally through the calcaneus. The results obtained were expressed in g/cm^2. To obtain standardized values, the bone mineral values measured were divided by the width of the heel bone at the measurement site. A relatively homogeneous region in the central part of this bone was measured (Szücs et al. 1992).

The specimens were stored in double plastic bags in a freezer at –20 °C and were thawed for 24 hours at room temperature before testing. An ankle arthrodesis was performed by using a dowel graft technique. The dowel was obtained in the coronal plane of 7 specimens in group 1 and in the diagonal plane of 7 specimens in group 2. In addition, all ankles were fixated with two 6.5-mm diameter cancellous bone screws, with the ankle in the neutral position (Figures 1 and 2). In all specimens, the tibia was sectioned at the mid-part of the shaft, and the diaphyseal part of the tibia was stripped of all soft tissue (Figure 3). The same orthopedic surgeon performed all the arthrodesis procedures with the help of an image intensifier. The mechanical tests were performed by one and the same engineer who was not aware of the operation method used.

Operative technique for group 1 (coronal graft)

A K-wire was introduced from the medial malleolus through the joint space of the ankle, to proceed through the lateral malleolus. A 4-cm vertical inci-

sion was then made over the medial malleolus. With the ankle joint in neutral position, a cannulated 16-mm diameter milling-cutter was threaded over the K-wire, passed through the medial malleolus and the joint, removing bone equally from the tibial and talar sides of the joint. The cylindrical bone graft was removed and it was then reintroduced in reverse, and rotated 90 degrees, so that the original surface of the joint was positioned in the vertical plane. With the foot held in neutral position, the ankle joint was fixed by inserting 2 short- threaded 6.5-mm diameter cancellous screws across the joint with their threaded parts anchored in the head of the talus (Figure 2). The first screw was placed through the fibula approximately 2 cm proximal to the joint, directed obliquely, and at a 45-degree angle to the axis of the fibula, into the proximal and medial part of the talar head. The second screw was placed in the same manner from the posterior cortex of the medial malleolus and directed to the inferior, medial part of the head of the talus (Figure 2).

Operative technique for group 2 (diagonal graft)

A vertical incision of 4 cm was made over the anteromedial side of the ankle. The capsule was opened and an 8-mm broad half-circle bone piece of the most anterior part of the medial malleolus was removed. A K-wire was introduced from the anteromedial corner of the upper surface of the talus through the joint space of the ankle, to proceed through the lateral malleolus (Figure 1). Thereafter, the same technique was used as for group 1 specimens.

The talus was then disarticulated from the foot and the calcaneus was stripped of soft tissue. The subtalar joint was fixed with 2 staples and one 6.5-mm diameter cancellous-bone screw. 3 K-wires were inserted into the calcaneus horizontally and transversally, protruding approximately 2 cm at both ends, to aid in rigidly fixing the calcaneus to a custom-made metal cup (Figure 3). The specimen was aligned to the cup so that the inferior surface of the calcaneus rested in the cup. A two-component plastic cement (Plastic Padding AB, Sweden) was poured into the cup, in order to embed and fix the calcaneus to it. To obtain additional fixation, 4 screws were driven through the cup into the cement. The cup was equipped with individual attachment points for the loading device. These points were placed centrally on each of the three sides of the cup, dorsally, laterally and plantarily. In this way, it was possible to generate a bending moment in the 3 centres of rotation during the 6 different motions of the ankle joint. A second metal cup, formed as a rectangular box with two open ends, was fixed to the tibia and fibula by plastic cement. The proximal metal cup was placed on a level surface and served as a frame of reference. It was secured in such a way that it allowed motion in one of the axes of rotation. The motion was created by applying a 5-Nm moment at one of the attachment points on the distal cup by means of a dead weight of 1 kg attached to the outer end of a 0.5-m long rod. This rod was always kept level in order to obtain a true moment. It was possible to evaluate two axes of rotation with the same reference set-up, while the third axis of rotation

Figure 3. A specimen after arthrodesis. The tibia is sectioned at the mid-part of the shaft, and the diaphyseal part of the tibia is stripped of all soft tissue. A metal cup with two open ends is fixed to the tibia and fibula by using plastic cement, and the calcaneus is fixed rigidly to a custom-made metal cup. This cup is equipped with individual attachment points for the loading device.

Table 1. The motion (in degrees) at the tibiotalar joint after applied torque in specimens with the dowel graft in the coronal plane (group 1), and with the graft in the diagonal plane (group 2)

	Group 1 (n = 7) Median (range)	Group 2 (n = 7) Median (range)	P–value
Plantar flexion-dorsiflexion	11 (5.5–17)	7.7 (3–12)	0.07
Abduction-adduction	11 (4–15)	4.5 (3.2–12)	0.04
Eversion-inversion	8 (4.5–14)	4.2 (3.5–7.5)	0.04

Table 2. Mean differences between the first and second tests, between the groups (degrees)

	Group 1 (n = 7) Median (range)	Group 2 (n = 7) Median (range)	P–value
Plantar flexion-dorsiflexion	2 (0–3)	0.5 (-2–1.5)	0.04
Abduction-adduction	1 (0–3)	0.5 (-1–1)	0.2
Eversion-inversion	1 (0–2)	1 (-1–2)	0.8

necessitated a 90-degree rotation of the proximal metal cup. The right-angled sides of the distal fixation cup were used for angle measurements with a goniometer (INOGON Sweden). Angle resolution was 0.2 degrees. To compare the stiffness of the specimens, each of them was subjected to 5 Nm of torque in the following order: plantar flexion, dorsiflexion, abduction, adduction, eversion, and inversion. Two testing sequences were performed and the mean value of the two tests in each direction was used for the analysis.

Statistics

We used ANOVA to assess differences in BMC and torque between the groups. Wilcoxon paired signed ranks test was applied to assess the differences between the first and second tests within the groups. Correlations were calculated with Spearman correlation coefficients. Significance was set at $p < 0.05$. We used the SPSS program (10.0).

Results

The mean BMC values for groups 1 and 2 were 0.013 g/cm^2 (SD 0.002) and 0.013 g/cm^2 (SD 0.006), respectively. In all 3 directions tested, the torque applied caused more motion with the dowel graft in the coronal plane (group 1) than with the graft in the diagonal plane (group 2). The magnitude of motion in abduction-adduction and eversion-inversion planes was significantly different between the two groups (Table 1). The statistical analysis showed greater differences in the results of the two tests obtained from plantar flexion-dorsiflexion torque, between the groups (Table 2). Specimens in group 1 showed significantly more motion in the second test during plantar flexion-dorsiflexion ($p < 0.05$) and eversion-inversion ($p < 0.05$). Within group 2, there were no significant differences between the motion obtained in the first and the second test in any plane. There was no significant correlation between the result of the tibiotalar motion in any direction and the BMC value.

Discussion

A biomechanical study performed by Thordarson et al. (1992) showed that an ankle arthrodesis using 2 cancellous-bone screws was more stable than the use of a Calandruccio triangular compression frame. It has been shown that a surgical technique inflicting minimal disturbances to the soft tissue and preserving bone vascularization shortens the

time to union and reduces complications (Myerson and Quill 1991, Ogilvie-Harris et al. 1993). Arthroscopically assisted arthrodesis (Myerson and Quill 1991, Ogilvie-Harris et al. 1993) and the dowel technique (Baciu 1986) are recommended if the patient has a plantigrade foot. Arthroscopically assisted arthrodesis using cross-screws has shown rapid union time and few complications (Myerson and Quill 1991, Ogilvie-Harris et al. 1993). However, this method is time-consuming and technically demanding. Baciu (1986) described a simple technique using only a dowel graft obtained in the coronal plane. The patients were allowed to increase weight-bearing progressively, in a walking cast. The technique resulted in a high union rate (15/62) despite the fact that the fusion was not rigid in any plane, especially in abduction-adduction and eversion-inversion planes. Our findings show that the rigidity of the fusion can be improved by placing the dowel graft in the diagonal plane. In addition, our approach has the advantage of providing better exposure and access to the joint surface for additional decortication. The dowel graft techniques also have the advantage that the decortication and arthrodesis are performed simultaneously as the graft is rotated 90 degrees, generally making autogenous bone graft unnecessary.

We found significantly greater differences between the first and second tests within group 1. This can be explained by the fusion method rather than the BMC value of the specimens, since the BMC value did not correlate with the results of the tibiotalar motion.

It is evident that an optimal ankle arthrodesis should have an internal rigidity that allows early active motions of the adjacent joints, e.g. in the forefoot, which is important for the final function (Ross et al. 1985). If the rigidity of a fixation is satisfactory, a removable below-the-knee brace for example should be good enough to secure the fixation during the union time (Ogilvie-Harris et al. 1993).

We believe that the rigidity obtained by diagonal dowel graft with additional two cross-screws is safe enough to permit early weight-bearing in a brace. We have attempted to assess and improve the rigidity of a surgical method which could be performed with minimal soft-tissue trauma. Whether or not the current approach will allow early weight bearing and mobilization of the adjacent joints remains to be evaluated in a randomized prospectively study.

The quality of the bone is the most important factor influencing the stability at the arthrodesis site and the stability of the fixation material (Thordarson et al. 1992). Thus, in all specimens the bone mineral density was determined using triple-energy X-ray absorptiometry. This measurement technique is associated with high precision and accuracy (Swanpalmer et al. 1998a), and allowed grouping of the specimens tested according to their bone properties. The fact that the bone mineral values obtained were true volumetric measures of the bone mineral in the heel reduced the effect of different bone sizes on the bone mineral values. That the bone mineral measurements took place in the same region of the heel bone also added to the comparability.

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No competing interests declared.

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