STABILITY OF ANKLE ARHTRODESIS WITH INTERNAL FIXATION.
A PRELIMINARY FINITE ELEMENT STUDY.

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Introduction

Ankle arthrodesis or fusion is a popular choice of treatment for painful and disabling ankle disease. Many ankle fusion techniques have been described, varying in their surgical approach, articular surface preparation and type of fixation. Numerous clinical results have been published regarding the different fusion methods applied on a variety of patient populations. These clinical results are difficult to compare and there is little agreement on which method achieves the best result. However, compression internal fixation seems to offer one of the best outcomes, with high union rates, shorter fusion times and fewer complications (Abidi NA et al., 2000; Cheng YM et al., 2000; Thermann H et al., 1999).

The factors affecting the mechanical behaviour of ankle arthrodesis are not clearly understood. Initial stability has been suggested to play an important role on the final success of arthrodesis. Several biomechanical studies have compared the rigidity of the constructs resulting from different methods of ankle arthrodesis, reporting the gross relative motions between the two bones involved, tibia and talus (Friedman RL et al., 1994; Thordarson DB et al., 1992; Miller RA et al., 2000; Thordarson DB et al., 1990). However, none of them referred to the relative micromotions that took place at the fusion site. These micromotions may be related to the success of fusion, with excessive motion leading to non-union, as happens in joint replacement between the porous-surfaced implant and the surrounding bone. Numerous finite element (FE) analyses have studied the mechanical conditions affecting implant fixation, although, to the authors’ knowledge, no FE analysis has been performed to study the stability of ankle arthrodesis. In this preliminary study, we modelled the case of ankle arthrodesis performed with flat cut resections of the tibia and the talus and internally fixed with two crossed screws. We compared the stability of the fusion construct subjected to torsion and posterior-anterior (PA) shear force, when the screws crossed the joint at different levels.

Methods

An intact healthy male ankle was CT scanned in neutral position. The geometries of the talus and tibia were extracted from the CT images (the fibula was ignored for the purpose of this study). The distal end of the tibia and the talar dome were resected with parallel cuts. Two stainless steel screws were crossed through the joint from both sides of the tibia into the body of the talus, at an angle of 30 degrees with the longitudinal axis of the tibia. Three models were built, crossing the screws 5 mm above the joint line, at the level of this line and 5 mm below it (Table 1). The models were meshed with first order tetrahedral elements. The element edge length was 1.5 mm for all the contact surfaces and 2.5 mm for the rest of the model.

<table>
<thead>
<tr>
<th>Model name</th>
<th>Screw length (mm)</th>
<th>Crossing level (mm)</th>
<th>Number of elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Above</td>
<td>65</td>
<td>+5</td>
<td>67343</td>
</tr>
<tr>
<td>On</td>
<td>65</td>
<td>0</td>
<td>66392</td>
</tr>
<tr>
<td>Below</td>
<td>60</td>
<td>-5</td>
<td>63104</td>
</tr>
</tbody>
</table>

Table 1. Length and location of the screws in the respective models, and total number of finite elements.
A modified version of the free software Bonemat (Laboratorio di Tecnologia Medica, Istituti Ortopedici Rizzoli, Bologna-Italy) was used to convert the bone density value obtained from the CT scans into Young’s modulus for every element. The Young’s modulus of the screws was assumed to be 200GPa. The Poisson’s ratio for the bones and screws was assumed to be 0.3. The screws were rigidly attached to the tibia at the proximal end, to simulate the effect of the screw head, and glued to the talus at the distal end, to simulate the thread. The distal talus was fully constrained. Two load cases similar to the ones reported in the biomechanical studies were considered to compare the stability of the constructs. An external torque of 10 Nm was applied to the tibia in the first load case and a posterior-anterior shear force of 500 N in the second case. The contact surfaces were considered with two different values of friction, representing two extremes cases. In the first instance, the contact was assumed to be frictionless. In the second instance, the friction coefficient for the cancellous bone-to-bone interface was assumed to be 0.7 and 0.4 for the tibial cancellous bone-stainless steel screw interface (Shirazi-Adl A et al., 1993). All the models were solved in Marc K7.3.2. Relative displacements between the pairs of contact nodes (one belonging to the tibia and the other to the talus) were calculated to compare the micromotions predicted at the fusion site.

**Results & Discussion**

The relative displacements of the nodal pairs at the contact interface were interpolated to be displayed as contour bands on the resected surface of the talus (Figure 1). All the constructs clearly presented higher micromotions due to torsion than to the shear force, in agreement with Thordarson et al. results (Thordarson DB et al., 1990). In the torsion test, the model with the screws crossed beneath the joint line showed the lowest peak micromotions (approx 49 μm). The largest peak micromotions took place with the screws crossed at the level of the joint line (approx 65 μm). Crossing the screws above the joint line produced marginally lower peak micromotions (approx 63 μm) than crossing them at the joint line. When friction was...
considered, an overall decrease in the micromotions was observed, ranging from 11 to 21%. As for the P-A shear test, all the constructs showed the largest micromotions in the medial and posterior-medial margins (peak value approx 28 µm for the models with the screws crossing on and below the joint line). The model with the screws crossing above the joint line had the smallest micromotions. The decrease in micromotions observed when considering friction was higher than in the torsion test, ranging from 39 to 100%.

This study has shown that FEA is able to assess the performance of arthrodesis techniques. The results predicted better stability at the fusion site when the two screws cross below the joint line. This model showed the lowest micromotions due to torsion, though it was not always the most stable when subjected to the P-A shear force. However, the magnitude of the micromotions due to the shear force was lower than due to torsion. In addition, as the casts commonly used after this type of arthrodesis do not completely constrain torsional motion, maximising torsional strength is desirable (Friedman RL et al., 1994). Further research will analyse the effect on stability of the angle between the screws and the longitudinal axis of the tibia, as well as the effect of different articular surface preparation. Most of the clinical results of tibiotalar arthrodesis suggest that compression across the joint plays a main role in the final outcome along with the initial stability. Future work is also required to consider this compressive action of the screws across the joint.

References


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