The optimal calcaneal osteotomy angle based on a simplified static force analysis

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SUMMARY
Based on a simplified static force analysis an optimal calcaneal osteotomy angle of 33 º was determined. With this angle the shear force in the osteotomy plane is minimal.

INTRODUCTION
Malalignment of the ankle can be corrected with a calcaneal osteotomy (CO). For this correction, surgeons recommend an osteotomy angle of 45º relative to the plantar foot sole **(Fig. 1)**. The optimal osteotomy is the angle in the sagittal plan for which the osteotomy does not displace under weight bearing conditions and may accommodate earlier weight bearing rehabilitation.

The purpose of this study was to determine the optimal osteotomy angle in the sagittal plane from a force analysis for the second half of stance during walking and to evaluate the relation between foot geometry and the optimal CO angle.

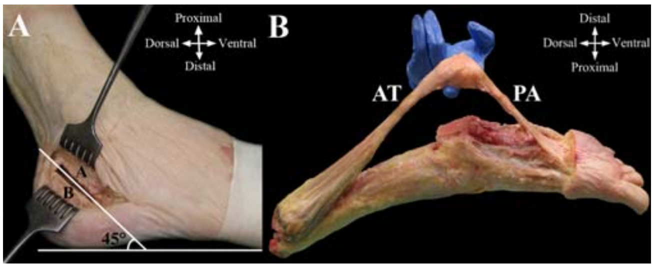

Figure 1A. *In this specimen a CO was performed whereby an osteotomy angle was used of approximately 45º relative to the foot sole. A: anterior calcaneal fragment; B: posterior calcaneal fragment.*
Figure 1B. *he PA an AT insert on the posterior calcaneal fragment. Both structures carry forces during gait and may cause shear forces on the posterior calcaneal fragment.*

METHODS
Free body diagrams (FBD) were made of the hindfoot and of the posterior calcaneal fragment for second half of the stance phase **(Fig. 2)**, where the force in the plantar apeunorosis (PA) and Achilles tendon (AT) are the highest. The force and moment equations were derived from the free body diagrams.

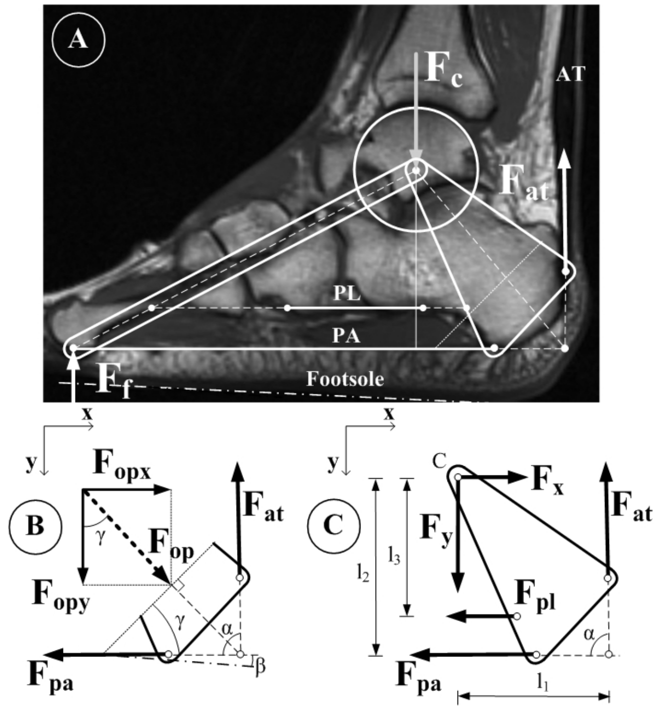

Figure 2A: *Sagittal T1-weighted MRI study of a foot that is modeled as a system of two trusses, at the apex connected by a hinge and stabilized by two wires representing the plantar aponeurosis (PA) and the long plantar ligament (PL). The ground reaction force at the forefoot (F_f) is balanced by the joint contact force (F_c) and the Achilles tendon (AT) force (F_{at}).*
Figure 2B: *The free body diagram of the posterior calcaneal fragment in a calcaneal osteotomy (CO). The forces acting on the posterior calcaneal fragment in the second half of the stance phase are the PA force (F_{pa}), the AT force (F_{at}), and the force in the osteotomy plane (F_{op}). If the force ratio (F_{pa}/F_{at}) and the directions of PA and AT are known, then the direction of the resultant force (F_{op}) can be calculated. If the CO is performed perpendicular to F_{op}, the shear force in the osteotomy plane is theoretically zero. Angle β is the angle between the footsole and PA.*
Figure 2C: *The free body diagram of the posterior truss of the foot model. From the moment balance of moments around the center of the distal talus (point C) the force ratio (F_{pa}/F_{at}) can be determined. An assumption needs to be made for the direction and magnitude of the force in the PL (F_{pl}) relative to F_{pa}. The force ratio (F_{pa}/F_{at}) is then depending on the direction of the PA, PL and AT and the moment arms l_1 of F_{at}, l_2 of F_{pa} and l_3 of F_{pl}. The ratio (l_2/l_1) is a relative measure for the height of the foot arch.*

Required information to calculate the optimal osteotomy angle:

- Force directions of the PA and AT (measured on 58 MRIs)
- Force ratios of the PA and AT
    - 7 individuals from literature (0.55 (SD 0.19))[1], during the last phase of stance where $F_{at} \geq 1.0$ body weight**.**

      AND
    - Determined on 58 MRIs from a free body diagram of the posterior truss of a foot model **(Fig. 2C)**.

RESULTS AND DISCUSSION

Based on the force directions and the 7 force ratios of the PA and AT, 7 CO angles were calculated on each MRI **(Fig. 3)**. A mean CO angle of 33º (SD 8º) relative to the plantar foot sole was determined in an average population.

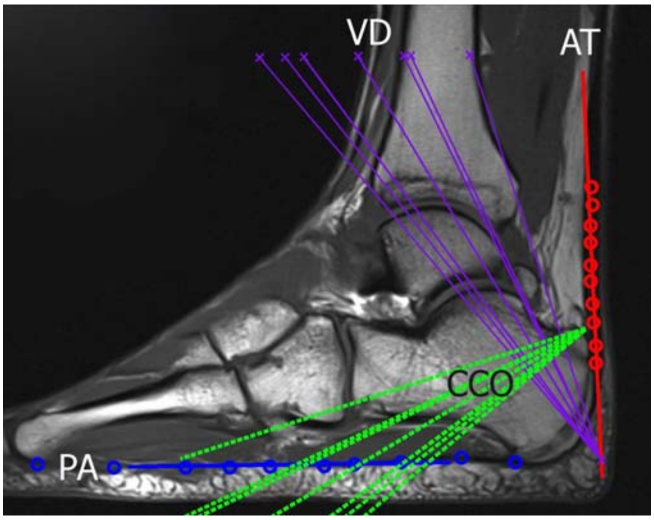

Figure 3. *Custom software routines written in Matlab (Mathworks, Natick, MA) were used to calculate the optimal CO angle on sagittal T1-weighted MR images (n=58) at the level of the fourth metatarsal bone. The PA and the AT were marked with 10 points to calculate the force direction. Based on the force direction of the PA, and AT, and the 7 different values for the force ratio (F_{pa}/F_{at}), 7 resultant force vector directions (VD) were calculated on each MRI. The optimal CO angle relative to the foot sole was determined by the line CCO that is perpendicular to VD.*

Based on the static force analysis of the hindfoot, a mean force ratio of 0.54 (SD 0.08) was determined between the PA and AT, and a mean osteotomy angle of 33.0 degrees (S.D. 4º) degrees) was calculated. Linear regression analysis revealed that CO angle and the geometric ratio between l_2 and l_1 were well correlated (r = 0.90) **(Fig. 4)**. In a pes planus foot geometry the CO angle was higher, while in a pes cavus foot geometry the CO angle was lower.

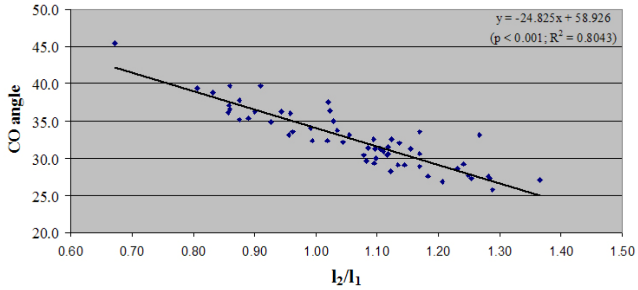

Figure 4: *A linear regression analysis revealed that the CO angle and the relative height of the foot arch (l_2/l_1) were well correlated (r = 0.90). In a pes cavus foot geometry the ratio l_2/l_1 was higher and the optimal CO angle was smaller. In a pes planus foot geometry the ratio l_2/l_1 was smaller and the optimal CO angle was higher.*

CONCLUSIONS

Although the range of the optimal osteotomy angle is relatively large, an osteotomy angle of 33 degrees relative to the plantar foot sole is recommended for a CO. The relatively large range of the optimal CO angle can be explained by variations of foot geometry.

REFERENCE

1. Erdemir A et al. Dynamic loading of the plantar aponeurosis in walking. JBJS AM 2004 Mar;86-A(3):546-552