Evaluation of morphological changes influenced by medializing calcaneal osteotomy on flatfoot: Surgical simulation using finite element analysis

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INTRODUCTION: Adult-acquired flatfoot deformity is a condition in which the foot is deformed due to various causes, resulting in pain and limited range of motion of the ankle joint, which reduces activities of daily living. This causes a reduction in the medial longitudinal arch, forefoot abduction deformity, and hindfoot valgus deformity, affecting the foot in three dimensions [1]. Medial displacement calcaneal osteotomy (MDCO), an osteotomy technique performed to correct the deformity, involves cutting the calcaneus, moving the distal bone fragment medially, and fixing them with screws. Moving the Achilles tendon medially along the calcaneus alleviates the effects of the triceps surae that contribute to the valgus deformity of the hindfoot and changes the axis of rotation of the subtalar joint [2]. Although the standard recommendation for MDCO is to use an osteotomy site posterior to the superior peroneal branch, an osteotomy angle of 45°, and a bone displacement of 10 mm [3], the international consensus is 7–15 mm, depending on the degree of deformity [2], and which is largely at the surgeon's discretion. Prior surgical simulation can help surgeons select the appropriate technique for the patient's deformity. We performed MDCO on a flatfoot model created using the finite element method, and reported the effects of bone displacement on plantar pressure. In this study, the MDCO was performed on eight flatfoot models to investigate the effects of bone displacement on correction of the flatfoot deformity and plantar pressure.

METHODS: Eight patients with flat feet in Bluman classification stages 2A1 to 3B were included. After MDCO was performed on the flatfoot models created according to our protocol with medial displacements of 4, 8, and 12 mm and load simulation (Fig. 1), the M1M5 angle, anterior-posterior talar-1st metatarsal angle (APTM), talonavicular coverage angle (TNC), lateral talo-1st metatarsal angle (LTM), calcaneal pitch (CP), talocalcaneal angle (TC), and cuneiform to 5th metatarsal height (C5MH) were measured. In accordance with previous studies [4], the plantar pressure was divided into eight regions, as shown in Fig. 2, and the stress generated in each region was measured. The Wilcoxon signed-rank sum test was used to test the ratio of each parameter and the stress in each area preoperatively: medial calcaneal translation of 4 mm (MDCO4), medial calcaneal translation of 8 mm (MDCO8), and medial calcaneal translation of 12 mm (MDCO12).

RESULTS: The M1M5 angle, APTM, TNC, LTM, and CP were not significantly different preoperatively and postoperatively, regardless of the amount of displacement. C5MH showed significant differences between the preoperative values and MDCO4, 8, 12 ($p<0.0176$). Plantar pressure showed a significant increase in stress on the lateral side of the metatarsal, medial side of the forefoot, and medial side of the midfoot, whereas the stress on the medial side of the metatarsal decreased with increasing bone movement ($p<0.0176$). The stress in the medial and medial forefeet decreased and the stress in the lateral midfoot significantly increased ($p<0.0176$).

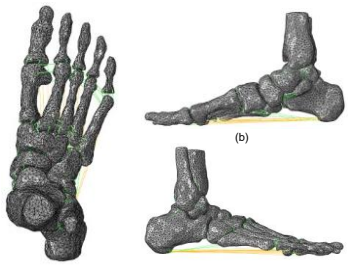

Figure 1. Constructed finite element flatfoot model: (a) top view, (b) medial view, and (c) lateral view. The green lines represent the ligament and the orange lines represent the plantar fascia

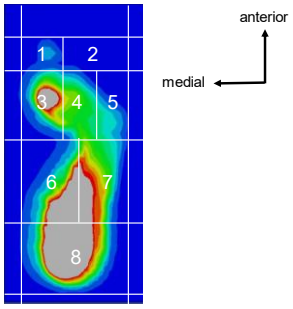

Figure 2. Division of the plantar contact area (1-8)

DISCUSSION: On the AP weight-bearing images, there were no significant changes in any of the measured parameters pre- and postoperatively, and MDCO did not contribute to improvements in the transverse arch or abduction deformity. Significant changes in the C5MH were observed on lateral weight-bearing images at 4, 8, and 12 mm, indicating that MDCO influences the formation of the medial longitudinal arch. In severe cases of forefoot abduction deformity, MDCO alone does not improve the bony structures of the foot, and a lateral column lengthening procedure should be added. Additionally, the plantar pressure results showed a decrease in the proportion of the medial stress and an increase in the proportion of the lateral stress, reflecting an improvement in the medial longitudinal arch. In some cases, MDCO12 results in excessive formation of the medial longitudinal arch and difficulty stepping on the big toe (Fig. 3). In cases that deviate from the concept of "the triangle support of the foot" after MDCO, additional medial arch techniques such as Cotton or Lapidus procedure may be necessary. Surgical simulation is useful for evaluating the impact of surgery on the foot in advance and for considering the appropriate surgical technique for each patient.

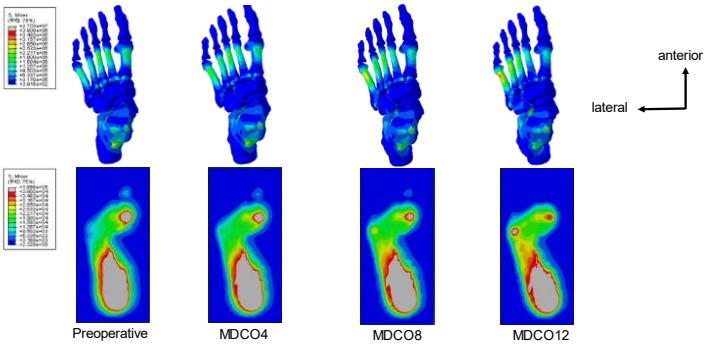

Figure 3. Stress distribution of the whole foot and the plantar pressure in a typical case is shown. The medial stress decreased and the lateral stress increased as the amount of bone motion increased. In MDCO 12, the patient was unable to step on the big toe.

SIGNIFICANCE: MDCO was effective for medial longitudinal arch formation in flatfoot deformity. MDCO was ineffective in improving the transverse arch and abduction deformity of the forefoot, and other techniques should be used in combination for severe cases. Simulation of surgery using the finite element method is useful to evaluate changes in the foot due to surgery in advance and to consider patient-specific surgical procedures.

REFERENCES: [1] DV Flores et al. (2019) *Radiographics.*, [2] C Schon L et al. (2020) *Foot Ankle Int.*, [3] Mann's surgery of the foot and ankle. 2013, [4] AJ Blackman et al. (2009) *J Orthop Res.*