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### Subtalar joint kinematics and arthroscopy: insight in the subtalar joint range of motion and aspects of subtalar joint arthroscopy

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CHAPTER 8

**General discussion and conclusions**

### The subtalar joint range of motion

The subtalar joint is an important joint in the hindfoot for the transfer of the body weight in human propulsion and the adaptation of the foot to the ground. Subtalar joint injuries such as a subtalar sprain can lead to a painful hindfoot or subtalar instability.<sup>1-6</sup> The clinical diagnosis of subtalar joint instability is difficult because there is no consensus on the diagnostic criteria for it.<sup>6-9</sup> One of the underlying reasons for having no consensus on the diagnostic criteria is the lack of a definition of the normal subtalar joint range of motion. This results from the difficulties with studying the subtalar joint as it has a complex joint geometry and the subtalar joint motion takes place in all three anatomic planes. Furthermore, the exact position of the bones is difficult to determine in-vivo as there are no clear anatomic landmarks of the talus or calcaneus available. As stated by Huson, the tarsal bones are considered to be in a closed kinematic chain.<sup>10</sup> The interdependency of motion of the tarsal bones makes assessment of isolated subtalar joint motion even more difficult. Accurate evaluation of in-vivo subtalar joint range of motion may aid the diagnosis of subtalar instability. In addition, it could be helpful for the evaluation of surgical interventions in the hindfoot and the design of a total subtalar joint prosthesis.

For the assessment of the range of motion in the subtalar joint in healthy individuals, a bone contour segmentation and matching technique was developed using computed tomography imaging (CT-BCM) for the precise registration of the position and orientation of the bones in the hindfoot. The CT-BCM technique was compared to roentgen stereophotogrammetric analysis (RSA). RSA is considered as the current gold standard for measurement of bone to bone motion in-vivo as it demonstrated high accuracy.<sup>11-13</sup> According to our measurements, the accuracy of CT-BCM to measure bone to bone motion is comparable to the accuracy of RSA. The advantage of the CT-BCM technique is that the image acquisition is more time efficient and no extra special equipment is needed to acquire the CT images. In contrast to the CT-BCM technique, the accuracy of the RSA technique is more variable as it is dependent on many technique related factors (type and quality of the calibration equipment, image quality, film flatness, number of tantalum bone markers).<sup>14,15</sup> Furthermore, the CT-BCM technique obviously does not have the risk of infection related to the placement of the bone markers or the risk of unintended intra-articular or otherwise faulty placement of bone markers. Although low dose CT settings are used, the disadvantage of CT-BCM is the radiation that is involved with image acquisition. Lowering the radiation dose for CT image acquisition is possible, however this could have a negative effect on the accuracy of the CT-BCM technique. Authors

have also used the non-invasive magnetic resonance imaging (MRI) to study bone to bone motion in the hindfoot.<sup>16-20</sup> However, for the semi-automatic bone segmentation and matching purposes the CT scan images are preferred over the MRI images as the CT is better able to depict the bony contours.

The range of motion of a joint is defined by the geometry of the articular surfaces, the ligaments, joint capsule, tendons and muscles that insert to the bones of the joint. For the assessment of the complete subtalar joint range of motion, the bones that constitute the joint have to be forced in extreme positions in different directions as far as allowed by the subtalar joint. An experimental device was designed in order to force the unconstrained foot in the extreme positions inside a CT-scanner. The eight extreme foot positions were defined in such a way that they describe the envelope of motion of the foot. The CT images of the foot in the extreme positions were used to reconstruct the geometry of the bones and to calculate the range of motion of the subtalar joint. To quantify the normal subtalar joint range of motion, the CT-BCM technique was used to study the subtalar joint range of motion in healthy volunteers. The helical axis parameters for the subtalar joint were consistent between the subjects in our series for extreme positions of the foot with a considerable eversion and inversion component. Furthermore, we found that the helical axis of the subtalar joint is running from postero-lateral-inferior to antero-medial-superior. This helical axis orientation is in agreement with the literature.<sup>10,21-27</sup> Contrary to other studies, we found a relatively little variation in the inclination angle in the group of healthy individuals, and moderate variation in the deviation angle of the mean helical axis for the extreme foot positions with an eversion and inversion component.<sup>25,28</sup> This could be the result from the talus-based coordinate system that was individually defined for every testing subject. The greatest relative motion between the calcaneus and the talus was found for the extreme eversion to the extreme inversion of the foot: a mean rotation about the helical axis of  $37.3 \pm 5.9^\circ$  and a mean translation along the helical axis of  $2.3 \pm 1.1$  mm. CT and MRI techniques have been used to quantify ankle joint motion between predefined input foot positions in-vivo.<sup>16,19,29</sup> Other authors studied the response of the ankle and subtalar joint in-vivo to an inversion or anterior drawer load using an MRI technique.<sup>30,31</sup> Outcomes of these studies are difficult to compare because of the variety of coordinate systems and joint motion definitions that were used in these studies. What minimum amount of subtalar motion should be required for a total subtalar joint prosthesis to function properly in the hindfoot of different groups of patients, is considered an interesting topic for future research.

An example of the application of in-vivo measurement of the hindfoot mobility after surgical intervention is the analysis of the effects of lateral column lengthening (LCL) in the treatment of adult acquired flatfoot deformity. The assessment of the postoperative talocrural and subtalar joint range of motion in-vivo could provide insight in the effects of the LCL procedures and this may help to guide clinical decision making in symptomatic flexible adult acquired flatfoot deformity. LCL has become an accepted procedure for the treatment of the symptomatic flexible adult acquired flatfoot deformity.<sup>32,33</sup> One of the LCL techniques is the calcaneocuboid distraction arthrodesis (CCDA) in which the mobility and the function of the calcaneocuboid joint is lost. The other LCL technique is the anterior calcaneal distraction osteotomy (ACDO) in which the calcaneocuboid joint is preserved. The latter procedure appears to be a more favourable option as it may have a lesser effect on the ranges of motion in the hindfoot. On the other hand, due to the calcaneal distraction in the ACDO procedure, the joint pressures may increase in the calcaneocuboid joint possibly leading to early degenerative changes.<sup>34,35</sup> Although comparative studies seem to favour the ACDO procedure over the CCDA procedure in terms of clinical outcome, the difference in subtalar joint and talocrural joint range of motion between the two procedures postoperatively was not previously described.<sup>36,37</sup> In our study, we found comparable results in the ACDO and CCDA patient groups (5 patients per group) after surgery for the talocrural and subtalar joint range of motion means. It must be emphasized that there was considerable variation in outcome between the patients within each group. Comparing the preoperative ranges of motions with the postoperative measurements in these patient groups was not possible as preoperative measurements were not available. Compared to the results from the 20 non-matched normal subjects that were reported earlier, the subtalar joint range of motion (extreme eversion to extreme inversion) was smaller following both LCL procedures. It should be kept in mind that the reduction of joint motion might not be of importance for a normal function of the ankle and foot of the individual subject that is going to be operated on. Lundgren et al. measured hindfoot, midfoot and forefoot joint motion in volunteers during walking on a flat surface using invasive bone markers and a 3D optoelectronic tracking system.<sup>38</sup> Lundgren measured less motion in the talocrural and subtalar joints in his healthy volunteers with normal walking than we did in our ACDO and CCDA patients since our postoperative measurements concerned the full range of motion. This finding illustrates that for normal walking the extremes of the full range of motion are not used. However, the extremes of the range of talocrural or subtalar joint motion might be required when walking on uneven surfaces or rough terrain with slopes.

Measuring the total range of subtalar joint motion (rotations about the helical axis for subtalar joint motion from extreme eversion to extreme inversion) in ten cadaveric specimens, DeLand et al. found an average of 30% loss of subtalar joint range of motion following isolated calcaneocuboid arthrodesis with a 10 mm lengthening fusion.<sup>39</sup> In our patients, the mean subtalar range of joint motion was 61% for the ACDO patients, and 65% for the CCDA patients of the mean range of subtalar joint motion as measured in the group of 20 normal subjects.<sup>40</sup> Although DeLand et al. used cadaveric specimens, the results from the present in-vivo study seem to support their results. Further prospective in-vivo studies should be conducted to assess the actual reduction of the talocrural and subtalar joint ranges of motion by measuring the range of motion before and after the specific surgical procedures. In addition, the CT-BCM technique can be used to study the differences in the ranges of ankle and subtalar joint motion in patients with hindfoot disease in comparison to their contralateral side. To reduce the radiation dose for the patient with uni- or bilateral CT image acquisition, a selection of the total number of extreme foot positions can be made, depending on the specific research question. With the introduction of the CT-BCM technique, an accurate and time-efficient technique has become available to study the bones in the hindfoot for the analysis of joint motion and the effects of surgical interventions on joint motion in detail.

#### **Subtalar joint arthrodesis and arthroscopy**

Subtalar joint arthrodesis (SA) is the treatment of choice for severe symptomatic osteoarthritis of the subtalar joint unresponsive to conservative treatment.<sup>41-43</sup> The most frequent indications for SA include primary or posttraumatic osteoarthritis, congenital tarsal coalitions or joint inflammation. The reports on the open SA techniques are generally favourable with a high union rate.<sup>41,42,44</sup> However, authors have reported complications such as hardware protrusion, lateral impingement, sural nerve injury, postoperative hindfoot malalignment, or infection.<sup>41,42,44,45</sup> To improve the outcome of SA, an analysis of the current operative techniques for SA as described in the literature helps to identify possible pitfalls. Knowledge of such surgical pitfalls and providing possible solutions for these problems will improve the SA techniques. This has the potential of yielding better patient outcome after SA.

The aspects of the different subtalar arthrodesis procedures were analysed in a literature review on papers that presented subtalar arthrodesis techniques. A meta analysis, including statistical analyses by data pooling was not possible, since the published series were invariably retrospective reviews of small heterogeneous groups of hindfoot pathologies. An

additional restriction was that only recently operative techniques and evaluation protocols have been described in sufficient detail to allow clear interpretation and evaluation. In summary, the following pitfalls were identified after reviewing the literature: complications related to the use of large incisions in open subtalar arthrodesis procedures, insufficient cartilage removal, improper bone graft selection and fixation techniques that could all possibly lead to a non-union of the arthrodesis. Other pitfalls included patient morbidity caused by bone graft harvesting, late hardware removal, postoperative varus or valgus hindfoot malalignment, and difficulties with the postoperative assessment of the state of bony fusion of the subtalar arthrodesis. The following solutions were suggested to overcome these potential pitfalls with the remark that some are still under development. If sufficiently trained and when applicable to the case of the patient, use of an arthroscopic approach to the subtalar joint is advised. If possible it is suggested to use local bone grafts (for example calcaneus) or allografts. Fixation of the subtalar arthrodesis should preferably be done by using two screws to prevent rotational micromotion that could lead to non-union of the arthrodesis. Furthermore, CT imaging of the subtalar joint arthrodesis is recommended for a detailed view of the state of the bony fusion. Further efforts should be taken to perform long-term follow-up studies to assess the effects of the many proposed adjustments of the subtalar arthrodesis.

An interesting alternative technique to the open approach to the subtalar joint is arthroscopic subtalar management as it has been credited with advantages for the patient.<sup>46,47</sup> Anatomic portals and arthroscopic anatomy of the posterior subtalar joint in cadaveric specimens were first described by Parisien and Vangness in 1985.<sup>48</sup> One year later, Parisien published the first clinical report on subtalar arthroscopy, which evaluated three cases with good results.<sup>49</sup> An overview of the aspects of the surgical technique for subtalar joint arthroscopy was provided based on a literature review and the experience of the authors with the 2-portal posterior approach.<sup>50</sup> Subtalar joint arthroscopy was applied as a diagnostic and therapeutic instrument for various indications. Therapeutic indications include intra-articular subtalar joint pathology such as chondromalacia or loose bodies, and extra-articular pathology such as the os trigonum. It was concluded that the technique of subtalar joint arthroscopy has slowly evolved as an alternative to open subtalar surgery. However, arthroscopic subtalar surgery is technically difficult and should be performed only by arthroscopists experienced in advanced techniques. There is a need for prospective clinical studies to provide more data on the complications of subtalar arthroscopy for the different indications.

More recently, the indication for subtalar arthroscopy has expanded to include the arthroscopic subtalar arthrodesis for end stage osteoarthritis with good to excellent clinical results.<sup>47,51-55</sup> Several different approaches and portal locations have been described for arthroscopic subtalar arthrodesis.<sup>50,56-58</sup> A symptomatic talocalcaneal coalition not responding to conservative treatment, is another indication for a subtalar joint arthrodesis. Arthroscopic subtalar arthrodesis in patients with a talocalcaneal coalition presents a technical challenge as the subtalar joint space is limited and the workspace in the hindfoot is reduced. The subtalar joint space is necessary for the introduction of small-size instruments (for example currettes) to be able to remove all of the articular cartilage from the joint. When insufficient cartilage is removed from the articular surfaces, there is the risk of a non-union of the arthrodesis. Given the fact that standard arthroscopic techniques for subtalar arthrodesis do not provide means to open up the joint, such techniques are difficult to use in patients with limited subtalar joint space. An arthroscopic posterior hindfoot approach with an extra sinus tarsi portal for arthroscopically assisted hindfoot arthrodesis was used in patients with a talocalcaneal coalition. The prone position of the posterior hindfoot approach allows for control of hindfoot alignment during surgery. Furthermore, the introduction of talocalcaneal lag screws is convenient with the patient in the prone position. Besides the standard posterolateral and posteromedial portals, an accessory portal at the level of the sinus tarsi is created to introduce a large diameter blunt trocar to open up the subtalar joint and to provide more workspace for an arthroscopic subtalar joint arthrodesis. An advantage of the 3-portal approach is that ring currettes can be introduced through the accessory sinus tarsi portal to remove the articular cartilage of the anterior part of the posterior talocalcaneal joint. In all 3 patients in our study it was possible to carry out a successful arthroscopic subtalar arthrodesis using the 3-portal technique with the patient in the prone position. Recently, Albert reported the results of posterior arthroscopic subtalar arthrodesis in 2 patients with a tarsal synostosis.<sup>59</sup> They used the 2-portal posterior hindfoot approach as described by Van Dijk.<sup>50</sup> He confirmed rapid bony fusion in his patients with an average time of fusion of 7 weeks. However, in both patients the complication of postoperative lateral submalleolar impingement occurred related to a postoperative hindfoot valgus malalignment. One of these patients eventually required a surgical resection of the calcaneal external edge. They also reported difficulties to reach the most anteromedial aspect of the posterior facet of the subtalar joint. The sinus tarsi portal as described in our study, makes it possible to reach the anterior aspect of the posterior facet of the subtalar joint and the cartilage can be removed completely. Albert criticised the use of a sinus tarsi portal as it would endanger the vascular supply to the talus, thereby increasing the

risk of a non-union of the subtalar arthrodesis.<sup>59</sup> Non-unions were not encountered in our small series of subtalar arthrodesis in three patients. The posterior arthroscopic subtalar joint arthrodesis seems to offer a minimal invasive procedure with rapid bony fusion and fast recovery to address subtalar joint pathology. Long-term randomised clinical trials should be conducted to compare the outcome of the open and the arthroscopic subtalar arthrodesis technique using the 3-portal posterior approach.

### Conclusions

- 1) The computed tomography based bone contour registration and segmentation method (CT-BCM) is an accurate technique for analysis of relative bone to bone motion in-vivo. The CT-BCM technique is equally as accurate as the current gold standard for bone to bone motion measurement, the roentgen stereophotogrammetric analysis (RSA).
- 2) The maximum range of motion of the talocrural and subtalar joint can be measured in-vivo using the CT-BCM technique.
- 3) The maximum range of subtalar joint motion measures a mean rotation about the helical axis of  $37.3 \pm 5.9^\circ$  and a mean translation along the helical axis of  $2.3 \pm 1.1$  mm for hindfoot motion from extreme eversion to extreme inversion as measured in a group of young healthy subjects.
- 4) The orientation and direction of the helical axes for hindfoot motion from extreme eversion to extreme inversion, or with a considerable eversion or inversion component, is consistently running from postero-lateral-inferior to antero-medial-superior.
- 5) There is substantial variance in terms of the postoperative ranges of motion of the talocrural and subtalar joint in patients surgically treated with a calcaneocuboid distraction arthrodesis (CCDA) or an anterior open wedge calcaneal osteotomy (ACDO) procedure for flexible adult flatfoot deformity.
- 6) The postoperative subtalar joint range of motion (from extreme eversion to extreme inversion) is smaller following two lateral column lengthening procedures (CCDA or ACDO) in flexible adult acquired flatfoot deformity as compared to a non-matched group of young healthy subjects.
- 7) Literature reviews are useful for identification of surgical pitfalls and provide possible solutions for the subtalar joint arthrodesis techniques.
- 8) The indications of subtalar joint arthroscopy have expanded and the technique of subtalar joint arthroscopy has slowly evolved as an alternative to open subtalar surgery for specific indications. However, arthroscopic subtalar surgery is technically challenging and should be performed by experienced arthroscopists.
- 9) A posterior arthroscopically assisted subtalar joint arthrodesis can successfully be performed in patients with a talocalcaneal coalition using the posterolateral and posteromedial portals in combination with an accessory sinus tarsi portal. Introduction of the blunt trocar through an accessory sinus tarsi portal can sufficiently open up the subtalar joint.

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## CHAPTER 9

**Summary**