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

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Figure 4 C shows the rotation components for ankel and subtalar joint range of motion from extreme combined eversion-plantarflexion to extreme combined inversion-dorsiflexion and figure 4 D from extreme combined eversion-dorsiflexion to extreme combined inversion-plantarflexion.

CHAPTER 5

Overview of subtalar arthrodesis techniques – options, pitfalls and solutions

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ABSTRACT

Background Subtalar arthrodesis (SA) is the preferred treatment for painful isolated subtalar joint disease. Although results are generally favourable, analysis of current operative techniques will help optimizing this treatment. The aim was to give an overview of SA-techniques and their pitfalls. Possible solutions were identified.

Materials and methods A literature search was performed for papers that presented SA operative techniques. The general technique was divided into phases: surgical approach, cartilage removal, bone graft selection, hindfoot deformity correction and fixation.

Results The published series were invariably retrospective reviews of small heterogenous groups of different hindfoot pathologies. The weighted outcome rate for SA was 85% (68–100%) performed in 766 feet and for SA requiring correction of malalignment 65% (36–96%) in 1001 feet. Non-union (weighted percentage 12%), malalignment (18%), and screw removal (17%) were the prevailing late complications.

Pitfalls The following pitfalls were identified: 1) early complications related to the incisions made in open approaches, 2) insufficient cartilage removal, improper bone graft selection and fixation techniques, all possibly leading to non-union, 3) morbidity caused by bone graft harvesting and secondary screw removal, 4) under- or overcorrection of the hindfoot possibly due to improper intraoperative verification of hindfoot alignment and 5) inadequate assessment of bony fusion.

Solutions The review provides solutions to possibly overcome some pitfalls: 1) if applicable use an arthroscopic approach in combination with distraction devices, 2) if possible use local bone graft or allografts, 3) use two screws for fixation to prevent rotational micromotion, and 4) improve assessment of operative outcome by application of detailed measurement protocols and validated outcome criteria.

Conclusion The literature review provides practical suggestions to optimize subtalar joint arthrodesis techniques.

INTRODUCTION

The subtalar joint is a complex joint, which plays a major role in inversion and eversion of the foot. The joint articulates between the talus superiorly and the calcaneus inferiorly (Fig. 1). Subtalar arthrodesis is an accepted surgical procedure for isolated subtalar disease unresponsive to conservative treatment. Indications include hindfoot disorders caused by posttraumatic, degenerative or rheumatoid arthritis, neurovascular disorders, talocalcanealcoalitions, and hindfoot deformities. The primary goals of a subtalar arthrodesis are pain relief, and restoration of hindfoot alignment, which should ultimately lead to increased mobility (Fig. 2). Pain relief is achieved by bony fusion which will prevent shear forces in the joint, and restoration of malalignment will diminish intra-articular peak forces. Although the subtalar arthrodesis technique can be considered a routine procedure in orthopaedic practice, it has been frequently indicated as technically demanding. Additionally, many authors have reported on significant postoperative problems such as non-union and malunion of the arthrodesis. The purpose of this study is to give an overview of existing subtalar arthrodesis techniques, indicate the pitfalls, and extract solutions.

METHODS

A literature search was performed in PubMed and Web of Science (up to May 2009), and a hand search using cross-references. Search terms were combined in various sets: subtalar joint, talocalcaneal joint, arthrodesis, technique, arthroscopy, fusion, hindfoot deformity, arthritis and biomechanics. All languages other than English, German, and Dutch were excluded. Selection was based on an abstract search where papers were included that presented a new subtalar arthrodesis technique, modifications of existing techniques, cross-references that occurred frequently, reviews, and studies with large population groups (more than 40 patients). This gave a database of ninety-one relevant papers of which sixty describe clinical results, and sixty-seven the operative technique (partly) in detail. Generally, the surgical procedure consists of removing the cartilage layers and subchondral bone from the joint. Subsequently, the bleeding bone surfaces of the talus and the calcaneus are realigned if required and fixated. Eventually, the surfaces will fuse thereby invalidating the subtalar joint. Following this general protocol, a structured analysis was performed by dividing the subtalar arthrodesis procedure into five separate phases (Fig. 2: grey area). For each phase, the various options as described in literature are summarized, followed by their pitfalls and potential solutions as presented in literature.
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Statistical analyses were not possible as little objective evidence was available. Therefore, to support the identification of pitfalls and limitations, a weighted success rate and a complication rate were calculated. Studies reporting results of less than 10 patients with a short follow up were excluded to minimize bias (10 papers). The patient populations with hindfoot deformity requiring anatomic restoration were clustered into one group.8,12,16-21,29-36 The papers with other indications were clustered in a second group.8,11,13,15,22-25,27,28,37-64 To summarize the clinical outcome of these 50 studies, a weighted success rate was calculated for each group. This consisted of the summation of a weight factor multiplied by the percentage of good and excellent clinical results that were explicitly described in a study. The weight factor of each concerning study was defined as the number of operated subtalar joints of that study divided by the total number of operated subtalar joints of all other studies describing the clinical outcome in a similar fashion. This way the studies presenting results of larger patient populations have a higher share in the weighted rate than papers reporting on smaller patient groups. A similar calculation was performed for the weighted complication rate. The complication rates for wound infection, damage to neurovascular structures and delayed wound healing were not split into separate groups. All references that were used to calculate a weighted clinical outcome or complication rate are indicated as well as the total number of feet that was used for the calculation.

RESULTS

Surgical approach

The surgical approach was divided into patient positioning and access (Fig. 3). For common open procedures, patients are placed in the lateral decubitus position lying on the unaffected side.13,22,24,27,28,33,45,48-50,63,64 or in supine position with an elevated hip.15,44,47,54,55,57,61,68,74 The subtalar joint is routinely (68% of the 63 papers) accessed with a lateral approach, where either an oblique incision is made over the sinus tarsi, an incision from the tip of the fibula to the base of the 4th metatarsal, or a longitudinal L-shape incision is made (Fig. 1).8-10,12,15,17,19-23,25-29,31-35,37,39,44,46,50,58,60,61,63,65,67-69 Kalamchi and Evans introduced a posterior approach using an incision on the lateral side parallel to the Achilles tendon while the patient is lying in prone position (Fig. 1).34 Other authors have adopted this position with11,13,62,70,72 or without combination of an arthroscopic technique.8,36,39,50,59,64,73 For the arthroscopic techniques, various combinations of access portals are suggested (Fig. 1).24,47,51,54,62,70,71

Compared to the size of the foot, relatively large incisions are used in the open techniques that carry the risk of wound infection (weighted rate 5% of 1089 feet, range 1–45%)8,12,13,15,21,23-26,28-31,35,39,40,42,48,50,58,59,74, neurovascular damage (weighted rate 10% of 426 feet, range 3–33%)8,22,27,39,40,45,50,57,59,61,64, and delayed wound healing (weighted rate 2.5% of 262 feet, range 1–5%)20,33,39,46,61,74. To prevent these early complications, an arthroscopic approach can be performed, as efforts are taken to develop safe access portals75,76, and clinical studies show absence of infections or neurovascular damage.24,47,52,53,62,71. However, contraindications for arthroscopy are gross malalignment of the hindfoot, and significant bone loss of the talus or calcaneus.24,47,52,53,54,77 Additionally, arthroscopic techniques are indicated as more demanding in terms of surgical skills.24,52,54 As most studies presenting arthroscopic approaches for subtalar arthrodesis reported results of less than 10 patients with a short follow up, they were excluded from calculation of weighted success or complication rates.

Cartilage removal

The creation of bleeding contact surfaces of the subtalar joint is a key step in obtaining solid fusion. All cartilage should be removed and a layer of around 2 mm of the subchondral bone, while maintaining congruent surfaces. Removal of all facets is performed with a chisel and an osteotome in the case of open techniques.8 Removal of the posterior facet is performed with a shaver, curettes and burrs in the case of arthroscopic techniques (Fig. 4).51,71

A pitfall of this operative step is insufficient removal of cartilage and subchondral bone. Hintermann et al. have measured the contact area in the subtalar joint with a single screw fixation (mean contact area 119–197 mm²).78 These values are on average only about 30% of the size of the entire posterior facet (582 ± 103 mm²).79 Insufficient tissue removal was probably the cause of non-unions as Gross80 and Fellmann and Zollinger80 argued for their clinical studies. Articular cartilage removal can be quite difficult and time consuming13 due to the limited exposure of the complex subtalar joint shape. To facilitate complete removal, extra workspace can be created by soft tissue removal8,12,17,20,21,24,26,41,42,50,51,53,61,68, lamina spreaders15,27,33,35,36,41,45,46,49,50,57,59,61,64,65,68,74, distraction devices13,22,27,54,55,64 or blunt trocars53,62,71. Nowadays, non-invasive distractors are available to increase the intraoperative joint space.81 Complete tissue removal is facilitated as well by the improved joint visualization when using an arthroscopic approach.52,54 Other solutions are the performance of initial distraction with the fixation screw82 and the development of a compliant shaver83.
Bone graft

Bone grafts can be applied in case of bone defects or in patients where correction of alignment is needed. Although insertion of bone grafts is not always required, they appear to enhance fusion. Three types of grafts have been used: cortical, cancellous, and combined corticocancellous grafts (Fig. 5). Cancellous bone grafts are mainly used to fill wedges thereby increasing bone-on-bone contact surface. Cortical grafts provide a strong and stiff strut which is suitable for correction of hindfoot deformity. A disadvantage could be a prolonged time till fusion and a slightly more likelihood of non-union when compared to the results with cancellous bone grafts. Therefore, corticocancellous bone grafts are a good alternative and are advocated by many authors. Autografts are harvested from the iliac crest or from the tibia or fibula. They require an additional surgery thereby potentially increasing patients’ morbidity. To reduce this, grafts can be harvested locally from the calcaneus, can be omitted when alignment is good, or allografts (bone bank) can be used. Notice that the results with allografts are not conclusive. Recent studies suggest that structural allografts are appropriate for reconstructive procedures. Lastly, new methods to enhance bone fusion are promising, such as external electrical stimulation or low-intensity ultrasound in patients with high risk of non-union, but further investigation is required to provide solid clinical evidence.

Hindfoot deformity correction

Manual realignment of the foot in an anatomic position during surgery has been described, as well as removal of excessive bone on either medial or lateral side at the subtalar joint level, and bone graft placement in an open wedge. A popular technique to perform hindfoot correction is the bone-block distraction technique to correct hindfoot valgus by placing a bone block on the lateral side of the subtalar joint. For functional outcome, precise correction is important. Several tools are applied to achieve this: uni- or bilateral assessment of hindfoot alignment on preoperative and postoperative lateral weightbearing radiographs of the ankle, and assessment of pre- and postoperative hindfoot alignment with goniometers. Alternatively, some authors have measured the resulting open wedge when the talus and the calcaneus are repositioned, and cut the bone graft to fit in the open wedge. Recently, fluoroscopy has been introduced for measurement of the amount of correction intraoperatively.

The clinical results for patients requiring correction of hindfoot deformity are generally less favourable (weighted rate 65% of 1001 feet, range 36–96%) than for other indications (weighted rate 85% of 766 feet, range 68–100%) . Limitations in obtaining satisfactory hindfoot alignment are frequently reported. This is supported by the relatively high complication rate of over- or undercorrection: weighted rate 24% of 883 feet for the studies with solely hindfoot deformities (range 2–51%) compared to a weighted rate of 5% of 421 feet for the studies with other indications (range 3–9%). These numbers are merely indicative, because the methods for determining hindfoot alignment after arthrodesis vary widely. Issues should be addressed in achieving a good correction: relation between per-, intra- and postoperative assessment and accurate assessment of correction (Fig. 6). Both radiographs and goniometric measurements are taken in a standing weightbearing state, which differs from the non-weightbearing patient position in the operating room. As a result, many surgeons have used the experienced eye to position the hindfoot in relation to the lower leg. The prone and supine positions are favoured, as especially, the lateral decubitus position impedes the usage of anatomical reference axes. Goniometric measurement should be avoided, because they lack accuracy and reliability. If pre- and postoperative radiographic measurements are performed, a precise measurement protocol should be described. Additionally, it is recommended to use specific views for radiographic hindfoot evaluation as they visualize the subtalar joint and the calcaneus more clearly. Means to judge correct alignment intraoperatively are limited. Measurement of the open wedge to match the size of a bone graft is a subsequent step where alignment already has been performed by visual inspection. New technical developments that have potential are 3D radiographic imaging, a device for measuring hindfoot alignment both in weightbearing standing position and in non-weightbearing prone position, and a ramp cage to provide stable correction, where the size of the ramp determines the amount of correction. The use of fluoroscopy is currently the best option for intraoperative verification.

Fixation

Initial compression of the bony surfaces is important to obtain solid fusion of the arthrodesis. Three approaches are described for fixation: the anterior approach with the screw inserted
from the talar neck in the calcaneus\textsuperscript{31,32,82,96}, the posterior approach with the screw inserted from the calcaneal tuberosity in the talus\textsuperscript{4,27,36,45,46,51,54,61-64,72}, and the plantar approach\textsuperscript{50,97} (Fig. 7). Generally, compression is achieved by means of one or two cannulated screw(s) that are positioned through the centre of the talar and calcaneal joint surfaces. An alternative is fixation with staples\textsuperscript{11,23,35,68} (Fig. 7). Different techniques are used to verify the correct position of the screw: cruciate ligament drill guides\textsuperscript{22,33,46,57,58,60,68}, fluoroscopy\textsuperscript{8,25,27,34,47,64,71}, guide wires\textsuperscript{44,55,65}, and a combination of fluoroscopy and guidewires\textsuperscript{13,15,24,32,36,41,45,47,50,53,54,60,61,66,70,74} (Fig. 7). With some arthroscopic techniques screw placement can be verified under direct arthroscopic view.\textsuperscript{71}

Problems that can occur are inadequate fixation leading to non-union: weighted rate 14% in 953 feet for the studies with solely hindfoot deformities (range 2–46%)\textsuperscript{12,17-21,26,30-34,36} vs. weighted rate 10% in 864 feet for the studies with other indications (range 2–30%)\textsuperscript{8,13,22,25,27,28,44,46,48,53,55,58-61,64,80}; and symptomatic hardware requiring screw removal: weighted rate of 14% in 168 feet for the studies with solely hindfoot deformities (range 10–32%)\textsuperscript{31,32,34,36} vs. weighted rate of 18% in 841 feet for the studies with other indications (range 1–64%)\textsuperscript{13,15,23,24,27,42,45,47,48,50,53,54,56,57,59-62,64,74}. Fixation with press-fit bone grafts only were reported to give significant rates of non-union and malalignment\textsuperscript{9,12,16-21,26,37,40,67} Additionally, fixation with one screw might not always be sufficient as rotational movement of the joint surfaces cannot be controlled. Therefore, the use of two screws is advocated (Fig. 7)\textsuperscript{8,22,27,45,98}. For specific patient groups such as people with severe rheumatoid arthritis, specific screw fixation techniques are proposed.\textsuperscript{99,100} Traditionally, assessment of consolidation has been performed with lateral weightbearing radiographs. Since that time, authors have expressed their doubts whether radiographic assessment of consolidation is reliable and accurate.\textsuperscript{8,12,20,28,44,84,101} Recently, it has been confirmed by Coughlin et al. that assessment of union cannot be determined accurately from standard radiographs.\textsuperscript{84} Assessment of bony union with CT-scans is significantly more reliable. Relative to the most appropriate means for assessing fusion are the criteria that define solid fusion. Only a few studies describe a more detailed evaluation protocol where solid fusion has been defined as osseous trabeculae crossing the arthrodesis site.\textsuperscript{8,36,47,48,87} Coughlin et al.\textsuperscript{84} and Davies et al.\textsuperscript{15} have proposed that fusion areas of more than 50% of the subtalar joint surfaces should be marked as solid union. Screw removal is independent of the approach used for screw insertion\textsuperscript{31}, and apparently cannot be prevented by verification of correct screw position. No solution for this problem is available at this stage. Ultimately, the fixation device should adapt to the changing environment and decrease its stiffness in time. Screws fabricated of bioabsorbable might be candidates to achieve this.\textsuperscript{102}

**General**

Besides the operative techniques, the condition of the patient and postoperative care also influence functional outcome (Fig. 2). Obesitas, diabetes, rheumatoid arthritis and severe neuromuscular problems have a known negative effect on the outcome\textsuperscript{8}, as well as the severity of the hindfoot deformity and the necessity to perform tendon transfers\textsuperscript{28,103}. Especially, smoking has a significant negative influence on achieving solid fusion.\textsuperscript{28,8,103} In general, a six weeks non-weightbearing cast, followed by a six weeks weightbearing cast is advocated (31 of 47 papers). In the past, early weightbearing (i.e. before six weeks) resulted in failures of the subtalar arthrodesis.\textsuperscript{18,31,37,39} Recently, full weightbearing as tolerated at any time following surgery has been reintroduced with minor complications and high rates of union.\textsuperscript{24,36,51,54,65,70}

**DISCUSSION**

With this literature overview, we identified the options, pitfalls, and available solutions for each of the five operative phases of the subtalar arthrodesis techniques. Comparing existing literature was difficult due to the wide variety of indications, and the demography of patient populations. A meta analysis, including statistical analyses by data pooling was not possible, since the published series were invariably retrospective reviews of small heterogenous groups of hindfoot pathologies.\textsuperscript{15} An additional restriction was that only recently, operative techniques and evaluation protocols have been described in sufficient detail that allow for unambiguous interpretation and evaluation.\textsuperscript{13,15,29,84} Notice that the calculated weighted outcomes in this study are merely indicative and no statistics can be performed.

Summarizing this overview, the following pitfalls were identified:
- Early complications related to large incisions,
- Insufficient cartilage removal, improper bone graft selection and fixation techniques, all possibly leading to non-union,
- Extra morbidity caused by bone graft harvesting and removal of painful screws,
- Under- or overcorrection of hindfoot malalignment
- Inadequate assessment of bony fusion.
Literature also provided solutions to overcome these pitfalls with the remark that some are still under development: if applicable use an arthroscopic approach in combination with new burrs and distraction devices, if possible use local bone graft or allografts, use two screws for fixation to prevent rotational micromotion, and improve assessment of operative outcome by application of appropriate diagnostics tools, detailed measurement protocols and validated outcome criteria. If doubt exists on solid bony fusion, a CT-scan is recommended and solid union is defined if more than 50% of the subtalar joint surfaces are fused. Further efforts can be taken to perform long-term follow-up studies to assess the effects of the many proposed adjustments to the subtalar arthrodesis operative techniques.

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FIGURES

Figure 1 Anatomy of the hindfoot focused on the subtalar joint. The three most frequently reported incisions are drawn for approaching the subtalar joint (obliquely over the sinus tarsi, tip fibula to fourth metatarsal and posterolateral approach) as well as the frequently reported arthroscopic portals.

Figure 2 Scheme indicating the primary functional outcomes of a subtalar arthrodesis: pain relief and increased mobility (1). This is achieved by bony fusion and if required restoration of hindfoot alignment. The categorization of operative phases is shown within the grey area (2). Factors that influence the surgical intervention complete the diagram (3).
Figure 3 Surgical approach: options, pitfalls and possible solutions. The numbers between square brackets indicate the number of papers describing this approach explicitly.

Figure 4 Cartilage removal: options, pitfalls and possible solutions. The numbers between square brackets indicate the number of papers describing this approach explicitly.
Figure 5 Bone graft: options, pitfalls and possible solutions. The numbers between square brackets indicate the number of papers describing this approach explicitly.

Figure 6 Correction hindfoot deformity: options, pitfalls and possible solutions. The numbers between square brackets indicate the number of papers describing this approach explicitly.
Figure 7 Fixation: options, pitfalls and possible solutions. The numbers between square brackets indicate the number of papers describing this approach explicitly.

CHAPTER 6

Arthroscopy of the posterior subtalar joint

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