



## UvA-DARE (Digital Academic Repository)

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

Beimers, L.

**Publication date**  
2012

[Link to publication](#)

#### **Citation for published version (APA):**

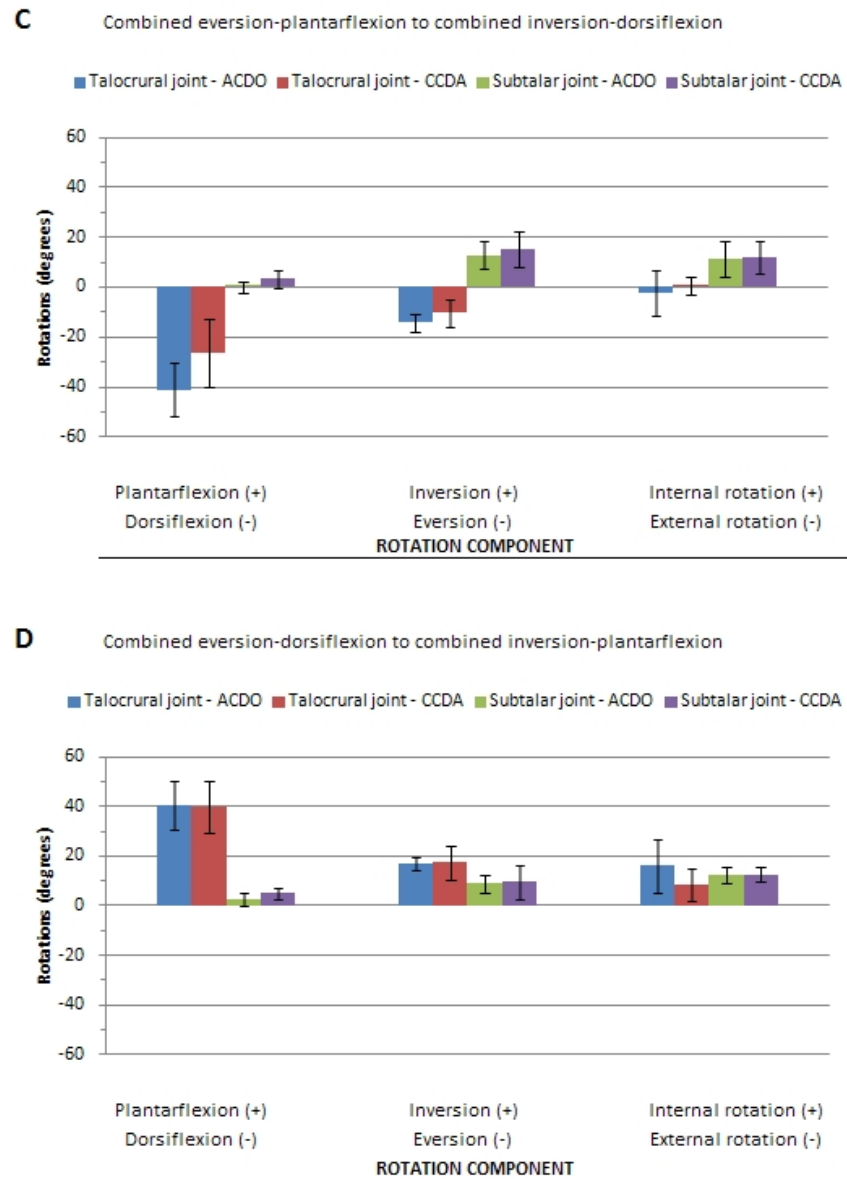
Beimers, L. (2012). *Subtalar joint kinematics and arthroscopy: insight in the subtalar joint range of motion and aspects of subtalar joint arthroscopy*. [Thesis, fully internal, Universiteit van Amsterdam].

#### **General rights**

It is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), other than for strictly personal, individual use, unless the work is under an open content license (like Creative Commons).

#### **Disclaimer/Complaints regulations**

If you believe that digital publication of certain material infringes any of your rights or (privacy) interests, please let the Library know, stating your reasons. In case of a legitimate complaint, the Library will make the material inaccessible and/or remove it from the website. Please Ask the Library: <https://uba.uva.nl/en/contact>, or a letter to: Library of the University of Amsterdam, Secretariat, P.O. Box 19185, 1000 GD Amsterdam, The Netherlands. You will be contacted as soon as possible.



**Figure 4 C** shows the rotation components for ankle 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.

## Overview of subtalar arthrodesis techniques – options, pitfalls and solutions

G.J.M. Tuijthof, L. Beimers, G.M.M.J. Kerkhoffs, J. Dankelman, C.N. van Dijk

*Foot and Ankle Surgery* 2010;16(3):107-116

This research was co-funded by the Minimally Invasive Surgery and Interventional Techniques program, Delft University of Technology, Delft, The Netherlands. The program had no involvement in the study design, the collection, analysis and interpretation of data; in the writing of the manuscript; and in the decision to submit the manuscript for publication.

## 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.<sup>1</sup> The joint articulates between the talus superiorly and the calcaneus inferiorly (Fig. 1).<sup>2-6</sup> 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, neuromuscular disorders, talocalcaneal coalitions, and hindfoot deformities.<sup>7-15</sup> 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.<sup>13,16-24</sup> Additionally, many authors have reported on significant postoperative problems such as non-union and malunion of the arthrodesis.<sup>8,20,25-29</sup> 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.

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.<sup>9,12,16-21,26,29-36</sup> The papers with other indications were clustered in a second group.<sup>8,11,13,15,22-25,27,28,37-64</sup> 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.<sup>13,22,24,27,28,33,45,48-50,63,64</sup> or in supine position with an elevated hip.<sup>35,44,47,54,55,57,61,65,66</sup> 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).<sup>8-10,12,15,17,19-23,25-29,31-35,37,39-44,46,50,55-58,60,61,63,65,67-69</sup> 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).<sup>38</sup> Other authors have adopted this position with<sup>51,53,62,70-72</sup> or without combination of an arthroscopic technique<sup>8,36,39,50,59,64,73</sup>. For the arthroscopic techniques, various combinations of access portals are suggested (Fig. 1).<sup>24,47,51-54,62,70,71</sup>

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%)<sup>8,13,15,21,23,26-28,31,35,39,40,42,48,50,58,59,74</sup>, neurovascular damage (weighted rate 10% of 426 feet, range 3–33%)<sup>8,22,27,39,40,45,50,57,59,61,64</sup>, and delayed wound healing (weighted rate 2.5% of 262 feet, range 1–5%)<sup>29,33,39,46,48,61,74</sup>. To prevent these early complications, an arthroscopic approach can be performed, as efforts are taken to develop safe access portals<sup>75,76</sup>, and clinical studies show absence of infections or neurovascular damage<sup>24,47,52,53,62,71</sup>. However, contraindications for arthroscopy are gross malalignment of the hindfoot, and significant bone loss of the talus or calcaneus.<sup>24,47,52,53,54,77</sup> Additionally, arthroscopic techniques are indicated as more demanding in terms of surgical skills.<sup>24,52,54</sup> 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.<sup>8</sup> Removal of the posterior facet is performed with a shaver, curettes and burrs in the case of arthroscopic techniques (Fig. 4).<sup>51,71</sup>

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 mm<sup>2</sup>).<sup>78</sup> These values are on average only about 30% of the size of the entire posterior facet (582 ± 103 mm<sup>2</sup>).<sup>79</sup> Insufficient tissue removal was probably the cause of non-unions as Gross<sup>18</sup> and Fellmann and Zollinger<sup>80</sup> argued for their clinical studies. Articular cartilage removal can be quite difficult and time consuming<sup>13</sup> due to the limited exposure of the complex subtalar joint shape. To facilitate complete removal, extra workspace can be created by soft tissue removal<sup>9,12,17,20,21,24,26,41,42,50,51,53,61,68</sup>, lamina spreaders<sup>15,27,33,35,36,41,45,46,49,50,57,59-61,64,65,68,74</sup>, distraction devices<sup>13,22,27,54,59,64</sup> or blunt trocars<sup>53,62,71</sup>. Nowadays, non-invasive distractors are available to increase the intraoperative joint space.<sup>81</sup> Complete tissue removal is facilitated as well by the improved joint visualization when using an arthroscopic approach.<sup>51,54</sup> Other solutions are the performance of initial distraction with the fixation screw<sup>82</sup> and the development of a compliant shaver<sup>83</sup>.

### 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<sup>33,47,48,74</sup>, they appear to enhance fusion<sup>28</sup>. 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.<sup>8,13,22,25,31,32,36,41,44,45,48,51,52,60,62,63,84</sup> Cortical grafts provide a strong and stiff strut which is suitable for correction of hindfoot deformity.<sup>13,16,18,22,27,42,43,47,48,50,55,58,59</sup> 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.<sup>13,16,22</sup> Therefore, corticocancellous bone grafts are a good alternative and are advocated by many authors.<sup>9,12,15,19-21,28,29,34-40,49,54,67,72</sup> Autografts are harvested from the iliac crest<sup>8,13,15,22,27,28,31,36,37,39-41,43-45,50,55,59,61</sup> or from the tibia or fibula<sup>8,9,12,16,18,20,21,29,30,36,54,61,63,74,84,85</sup> (Fig. 5). They require an additional surgery thereby potentially increasing patients' morbidity. To reduce this, grafts can be harvested locally from the calcaneus<sup>8,15,23,28,34,38,46,57,61</sup>, can be omitted when alignment is good<sup>77</sup> or allografts (bone bank) can be used<sup>8,12,17,26,36,48,53,59,64,69</sup>. Notice that the results with allografts are not conclusive.<sup>8,17,69</sup> Recent studies suggest that structural allografts are appropriate for reconstructive procedures.<sup>64,66,86</sup> 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.<sup>63,87</sup>

### Hindfoot deformity correction

Manual realignment of the foot in an anatomic position during surgery has been described<sup>16,18,21,25,28,31,33,46,48,55,58,65,68,72</sup>, as well as removal of excessive bone on either medial or lateral side at the subtalar joint level<sup>51,57,68</sup>, and bone graft placement in an open wedge<sup>13,15,32,34,35,37-41,44,60,61</sup> (Fig. 6). 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<sup>8,9,12,17,19,20,22,26-29,36,42,43,45,48-50,59,64,67,72</sup> (Fig. 6). For functional outcome, precise correction is important.<sup>80</sup> Several tools are applied to achieve this: uni- or bilateral assessment of hindfoot alignment on preoperative and postoperative lateral weightbearing radiographs of the ankle<sup>13,18-22,25-27,29,32-34,41,42-46,48,50,56,57,59,72</sup>, and assessment of pre- and postoperative hindfoot alignment with goniometers<sup>11,33,44,45,57,59</sup> (Fig. 6). 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.<sup>8,27,35,36,43,59,64</sup>

Recently, fluoroscopy has been introduced for measurement of the amount of correction intraoperatively.<sup>28,34,50,64</sup>

The clinical results for patients requiring correction of hindfoot deformity are generally less favourable (weighted rate 65% of 1001 feet, range 36–96%)<sup>9,12,16-21,26,30-33,35</sup> than for other indications (weighted rate 85% of 766 feet, range 68–100%)<sup>8,11,15,23,24,39,40,44,46-48,53-55,57,58,62,74,80</sup>. Limitations in obtaining satisfactory hindfoot alignment are frequently reported.<sup>18,23,25,26,30,39,57</sup> 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%)<sup>9,12,16-19,26,29-32,34,36</sup> compared to a weighted rate of 5% of 421 feet for the studies with other indications (range 3–9%)<sup>8,22,37,42,46,50,55,57,64</sup>. These numbers are merely indicative, because the methods for determining hindfoot alignment after arthrodesis vary widely.<sup>66</sup> Issues should be addressed in achieving a good correction: relation between pre-, 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<sup>72</sup>, as especially, the lateral decubitus position impedes the usage of anatomical reference axes<sup>88</sup>. Goniometric measurement should be avoided, because they lack accuracy and reliability.<sup>89,90</sup> 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.<sup>91-93</sup> 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<sup>73,94</sup>, a device for measuring hindfoot alignment both in weightbearing standing position and in non-weightbearing prone position<sup>95</sup>, and a ramp cage to provide stable correction, where the size of the ramp determines the amount of correction<sup>49</sup>. The use of fluoroscopy is currently the best option for intraoperative verification.<sup>28,34,36,50</sup>

### 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<sup>31,32,82,96</sup>, the posterior approach with the screw inserted from the calcaneal tuberosity in the talus<sup>8,27,36,45,46,51,54,61-64,71,72</sup>, and the plantar approach<sup>50,97</sup> (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<sup>11,23,35,68</sup> (Fig. 7). Different techniques are used to verify the correct position of the screw: cruciate ligament drill guides<sup>22,33,46,57,58,60,68</sup>, fluoroscopy<sup>8,25,27,34,47,64,71</sup>, guide wires<sup>44,55,65</sup>, and a combination of fluoroscopy and guidewires<sup>13,15,24,32,36,41,45,47,50,53,54,60,61,66,70,74</sup> (Fig. 7). With some arthroscopic techniques screw placement can be verified under direct arthroscopic view.<sup>71</sup>

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%)<sup>12,17-21,26,30-32,34-36</sup> vs. weighted rate 10% in 864 feet for the studies with other indications (range 2–30%)<sup>8,15,22,25,27,28,44,46,48,53,55,58-61,64,80</sup>, and symptomatic hardware requiring screw removal: weighted rate of 14% in 168 feet for the studies with solely hindfoot deformities (range 10–32%)<sup>31,32,34,36</sup> vs. weighted rate of 18% in 841 feet for the studies with other indications (range 1–64%)<sup>8,13,15,23,24,27,42,45,47,48,50,53,54,56,57,59-62,64,74</sup>. Fixation with press-fit bone grafts only were reported to give significant rates of non-union and malalignment.<sup>9,12,16-21,26,37,40,67</sup> 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).<sup>8,22,27,45,98</sup> For specific patient groups such as people with severe rheumatoid arthritis, specific screw fixation techniques are proposed.<sup>99,100</sup> 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.<sup>8,12,20,28,44,84,101</sup> Recently, it has been confirmed by Coughlin et al. that assessment of union cannot be determined accurately from standard radiographs.<sup>84</sup> Assessment of bony fusion 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.<sup>8,36,47,48,87</sup> Coughlin et al.<sup>84</sup> and Davies et al.<sup>15</sup> 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<sup>31</sup>, 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.<sup>102</sup>

### General

Besides the operative techniques, the condition of the patient and postoperative care also influence functional outcome (Fig. 2). Obesity, diabetes, rheumatoid arthritis and severe neuromuscular problems have a known negative effect on the outcome<sup>8</sup>, as well as the severity of the hindfoot deformity and the necessity to perform tendon transfers<sup>28,103</sup>. Especially, smoking has a significant negative influence on achieving solid fusion.<sup>28,8,103</sup> 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.<sup>18,31,37,39</sup> Recently, full weightbearing as tolerated at any time following surgery has been reintroduced with minor complications and high rates of union.<sup>24,48-51,54,65,70</sup>

### 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 heterogeneous groups of hindfoot pathologies.<sup>15</sup> 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.<sup>13,15,29,84</sup> 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.

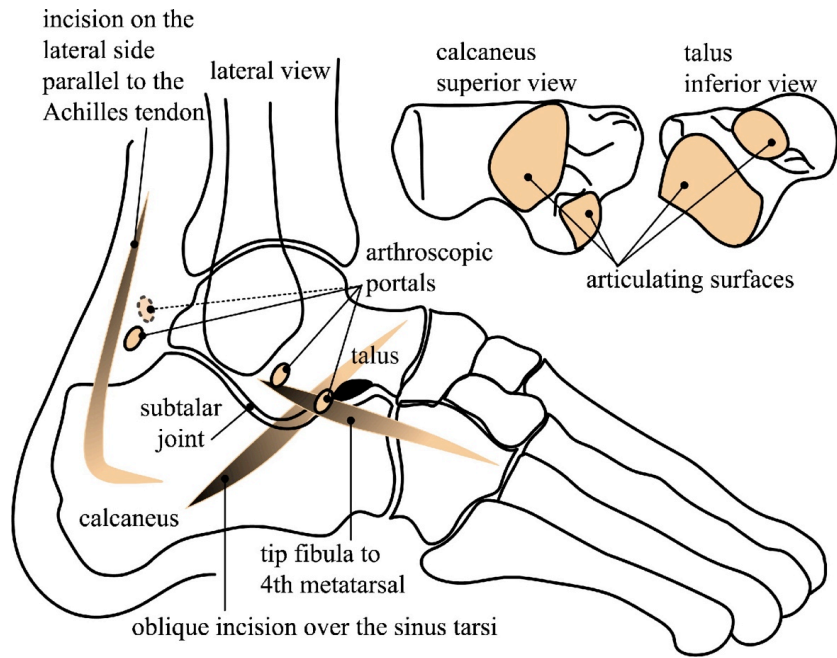
## REFERENCES

1. **Beimers L, Tuijthof GJ, Blankevoort L, Jonges R, Maas M, van Dijk CN.** In-vivo range of motion of the subtalar joint using computed tomography. *J Biomech.* 2008;41(7):1390–97.
2. **Inman VT.** The joints of the ankle, Williams & Wilkins Company, Baltimore. 1976.
3. **Perry J.** Anatomy and biomechanics of the hindfoot. *Clin Orthop.* 1983;177:9–15.
4. **Sarrafian SK.** Biomechanics of the subtalar joint complex. *Clin Orthop.* 1993;290:17–26.
5. **Rockar P.** The subtalar joint: anatomy and joint motion. *J Orthop Sports Phys Ther.* 1995;21(6):361–72.
6. **de Palma L, Santucci A, Ventura A, Marinelli M.** Anatomy and embryology of the talocalcaneal joint. *Foot Ankle Surg.* 2003;9:7–18.
7. **Donatto KC.** Arthritis and arthrodesis of the hindfoot. *Clin Orthop.* 1998;X:81–92.
8. **Easley ME, Trnka HJ, Schon LC, Nade S.** Isolated subtalar arthrodesis. *J Bone Joint Surg Am.* 2000;82:613–24.
9. **Grice DS.** An extra-articular arthrodesis of the subastragalar joint for correction of paralytic flat feet in children. *J Bone Joint Surg Am.* 1952;34:927–40.
10. **Laughlin TJ, Payette CR.** Triple arthrodesis and subtalar joint arthrodesis. *Clin Podiatr Med Surg.* 1999;16:527–55.
11. **Mann RA, Baumgarten M.** Subtalar fusion for isolated subtalar disorders. *Clin Orthop.* 1988;226:260–265.
12. **Pollock JH, Carrell B.** Subtalar extra-articular arthrodesis in the treatment of paralytic valgus deformities. *J Bone Joint Surg Am.* 1964;46:533–541.
13. **Buch BD, Myerson MS, Miller SD.** Primary subtalar arthrodesis for the treatment of comminuted calcaneal fractures. *Foot Ankle Int.* 1996;17:61–70.
14. **Bibbo C, Anderson RB, Davis WH.** Complications of midfoot and hindfoot arthrodesis. *Clin Orthop.* 2001:45–58.
15. **Davies MB, Rosenfeld PF, Stavrou P, Saxby TS.** A comprehensive review of subtalar arthrodesis. *Foot Ankle Int.* 2007;28:295–297.
16. **Seymour N, Evans DK.** A modification of the Grice subtalar arthrodesis. *J Bone Joint Surg Br.* 1968;50:372–375.
17. **Engstrom A, Erikson U, Hjelmstedt A.** The results of extra-articular subtalar arthrodesis according to the Green-Grice method in cerebral palsy. *Acta Orthop Scand.* 1974;45:945–951.
18. **Gross RH.** A clinical study of the Batchelor subtalar arthrodesis. *J Bone Joint Surg Am.* 1976;58:343–349.
19. **Ross PM, Lyne ED.** The Grice procedure: indications and evaluation of long-term results. *Clin Orthop.* 1980;153:194–200.
20. **McCall RE, Lillich JS, Harris JR, Johnston FA.** The Grice extra-articular subtalar arthrodesis: a clinical review. *J Pediatr Orthop.* 1985;5:442–445.
21. **Hsu LCS, Jaffray D, Leong JCY.** The Batchelor-Grice extra-articular subtalar arthrodesis. *J Bone Joint Surg Br.* 1986;68:125–127.
22. **Bednarz PA, Beals TC, Manoli A.** Subtalar distraction bone block fusion: an assessment of outcome. *Foot Ankle Int.* 1997;18:785–791.
23. **Huang PJ, Fu YC, Cheng YM, Lin SY.** Subtalar arthrodesis for late sequelae of calcaneal fractures: fusion in situ vs fusion with sliding corrective osteotomy. *Foot Ankle Int.* 1999;20:166–170.
24. **Tasto JP, Laimins PD.** Recent advances in ankle arthroscopic techniques, J.S. Parisien, Editor, Current techniques in arthroscopy, Thieme, New York (1998), pp. 181–194.
25. **Scranton PE.** Results of arthrodesis of the tarsus: talocalcaneal, midtarsal, and subtalar joints. *Foot Ankle.* 1991;12:156–164.

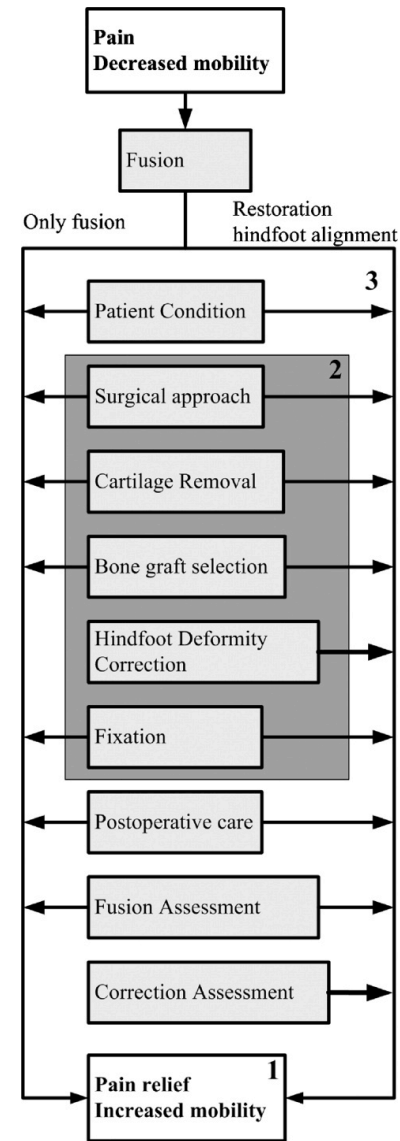
26. **Moreland JR, Westin GW.** Further experience with Grice subtalar arthrodesis. *Clin Orthop.* 1986;207:113–121.
27. **Carr JB, Hansen ST, Benirschke SK.** Subtalar distraction bone block fusion for late complications of os calcis fractures. *Foot Ankle Int.* 1988;9:81–86.
28. **Chahal J, Stephen DJ, Bulmer B, Daniels T, Kreder HJ.** Factors associated with outcome after subtalar arthrodesis. *J Orthop Trauma.* 2006;20:555–561.
29. **Bourelle S, Cottalorda J, Gautheron V, Chavrier Y.** Extra-articular subtalar arthrodesis. A long-term follow-up in patients with cerebral palsy. *J Bone Joint Surg Br.* 2004;86:737–742.
30. **Lahdenranta U, Pylkkanen P.** Subtalar extra-articular fusion in the treatment of valgus and varus deformities in children. A review of 162 operations in 136 patients. *Acta Orthop Scand.* 1972;43:438–460.
31. **Dennyson WG, Fulford GE.** Subtalar arthrodesis by cancellous grafts and metallic internal fixation. *J Bone Joint Surg Br.* 1976;58:507–510.
32. **Hadley N, Rahm M, Cain TE.** Dennyson-Fulford subtalar arthrodesis. *J Pediatr Orthop.* 1994;14:363–368.
33. **Kitaoka HB, Patzer GL.** Subtalar arthrodesis for posterior tibial tendon dysfunction and pes planus. *Clin Orthop.* 1997;345:187–194.
34. **Jeray KJ, Rentz J, Ferguson RL.** Local bone-graft technique for subtalar extraarticular arthrodesis in cerebral palsy. *J Pediatr Orthop.* 1998;18:75–80.
35. **Marti RK, de Heus JA, Roolker W, Poolman RW, Besselaar PP.** Subtalar arthrodesis with correction of deformity after fractures of the os calcis. *J Bone Joint Surg Br.* 1999;81:611–616.
36. **Pollard JD, Schuberth JM.** Posterior bone block distraction arthrodesis of the subtalar joint: a review of 22 cases. *J Foot Ankle Surg.* 2008;47:191–198.
37. **Thomas FB.** Arthrodesis of the subtalar joint. *J Bone Joint Surg Am.* 1967;49:93–97.
38. **Kalamchi A, Evans JG.** Posterior subtalar fusion. *J Bone Joint Surg Br.* 1977;59:287–289.
39. **Noble J, McQuillan WM.** Early posterior subtalar fusion in the treatment of fractures of the os calcis. *J Bone Joint Surg Br.* 1979;61:90–93.
40. **Johansson JE, Harrison J, Greenwood FA.** Subtalar arthrodesis for adult traumatic arthritis. *Foot Ankle.* 1982;2:294–298.
41. **Romash MM.** Reconstructive osteotomy of the calcaneus with subtalar arthrodesis for malunited calcaneal fractures. *Clin Orthop.* 1993;290:157–167.
42. **Amendola A, Lammens P.** Subtalar arthrodesis using interposition iliac crest bone graft after calcaneal fracture. *Foot Ankle Int.* 1996;17:608–614.
43. **Chan SC, Alexander J.** Subtalar arthrodesis with interposition tricortical iliac crest graft for late pain and deformity after calcaneus fracture. *Foot Ankle Int.* 1997;18:613–615.
44. **Fellmann J, Zollinger H.** Isolated talocalcaneal interposition fusion: a prospective follow-up study. *Foot Ankle Int.* 1997;18:616–621.
45. **Burton DC, Olney BW, Horton GA.** Late results of subtalar distraction fusion. *Foot Ankle Int.* 1998;19:197–202.
46. **Dahm DL, Kitaoka HB.** Subtalar arthrodesis with internal compression for post-traumatic arthritis. *J Bone Joint Surg Br.* 1998;80:134–138.
47. **Scranton PE.** Comparison of open isolated subtalar arthrodesis with autogenous bone graft versus outpatient arthroscopic subtalar arthrodesis using injectable bone morphogenetic protein-enhanced graft. *Foot Ankle Int.* 1999;20:162–165.
48. **Flemister AS, Infante AF, Sanders RW, Walling AK.** Subtalar arthrodesis for complications of intra-articular calcaneal fractures. *Foot Ankle Int.* 2000;21:392–399.
49. **Zion I, Shabat S, Marin L, London E, Matan Y, Howard CB, et al.** Subtalar distraction arthrodesis using a ramp cage. *Orthopedics.* 2003;26:1117–1119.
50. **Rammelt S, Grass R, Zawadski T, Biewener A, Zwipp H.** Foot function after subtalar distraction bone-block arthrodesis. A prospective study. *J Bone Joint Surg Br.* 2004;86:659–668.
51. **Carro LP, Golano P, Vega J.** Arthroscopic subtalar arthrodesis: the posterior approach in the prone position. *Arthroscopy.* 2007;23:445–454.
52. **Jerosch J.** Subtalar arthroscopy—indications and surgical technique. *Knee Surg Sport Tr Arch.* 1998;6:122–28.
53. **Amendola A, Lee KB, Saltzman CL, Suh JS.** Technique and early experience with posterior arthroscopic subtalar arthrodesis. *Foot Ankle Int.* 2007;28:298–302.
54. **Glanzmann MC, Sanhueza-Hernandez R.** Arthroscopic subtalar arthrodesis for symptomatic osteoarthritis of the hindfoot: a prospective study of 41 cases. *Foot Ankle Int.* 2007;28:2–7.
55. **Russotti GM, Cass JR, Johnson KA.** Isolated talocalcaneal arthrodesis. *J Bone Joint Surg Am.* 1988;70:1472–1478.
56. **Mangone PG, Fleming LL, Fleming SS, Hedrick MR, Seiler JG, Bailey E.** Treatment of acquired adult planovalgus deformities with subtalar fusion. *Clin Orthop.* 1997;341:106–112.
57. **Mann RA, Beaman DN, Horton GA.** Isolated subtalar arthrodesis. *Foot Ankle Int.* 1998;19:511–519.
58. **Sammarco GJ, Tablante EB.** Subtalar arthrodesis. *Clin Orthop.* 1998;349:73–80.
59. **Trnka HJ, Easley ME, Lam PW, Anderson CD, Schon LC, Myerson MS.** Subtalar distraction bone block arthrodesis. *J Bone Joint Surg Br.* 2001;83:849–854.
60. **Haskell A, Pfeiff C, Mann R.** Subtalar joint arthrodesis using a single lag screw. *Foot Ankle Int.* 2004;25:774–777.
61. **Catanzariti AR, Mendicino RW, Saltrick KR, Orsini RC, Dombek MF, Lamm BM.** Subtalar joint arthrodesis. *J Am Podiatr Med Assoc.* 2005;95:34–41.
62. **Lee KB, Saltzman CL, Suh JS, Wasserman L, Amendola A.** A posterior 3-portal arthroscopic approach for isolated subtalar arthrodesis. *Arthroscopy.* 2008;24:1306–1310.
63. **Coughlin MJ, Smith BW, Traugher P.** The evaluation of the healing rate of subtalar arthrodeses, part 2: the effect of low-intensity ultrasound stimulation. *Foot Ankle Int.* 2008;29:970–977.
64. **Garras DN, Santangelo JR, Wang DW, Easley ME.** Subtalar distraction arthrodesis using interpositional frozen structural allograft. *Foot Ankle Int.* 2008;29:561–567.
65. **Moss M, Radack J, Rockett MS.** Subtalar arthrodesis. *Clin Podiatr Med Surg.* 2004;21:179–201.
66. **Chou LB, Halligan BW.** Treatment of severe, painful pes planovalgus deformity with hindfoot arthrodesis and wedge-shaped tricortical allograft. *Foot Ankle Int.* 2007;28:569–574.
67. **Mallon WJ.** The Grice procedure, extra-articular arthrodesis. *Orthop Clin N Am.* 1989;20:649–654.
68. **Mann RA.** Arthrodesis of the foot and ankle, R.A. Mann, M.J. Coughlin, Editors, Surgery of the foot and ankle, Mosby, St. Louis (1993), pp. 673–713.
69. **Michelson JD, Curl LA.** Use of demineralized bone matrix in hindfoot arthrodesis. *Clin Orthop.* 325 (1996), pp. 203–208.
70. **Lundeen RO.** Arthroscopic fusion of the ankle and subtalar joint. *Clin Podiatr Med Surg.* 1994;11:395–406.
71. **Beimers L, de Leeuw PA, van Dijk CN.** A 3-portal approach for arthroscopic subtalar arthrodesis. *Knee Surg Sports Traumatol Arthrosc.* 2009;17(7):830–834.

72. **Deorio JK, Leaseburg JT, Shapiro SA.** Subtalar distraction arthrodesis through a posterior approach. *Foot Ankle Int.* 2008;29:1189–1194.
73. **Richter M, Zech S, Bay R.** 3D-imaging (ARCADIS) based computer assisted surgery (CAS) guided drilling for screw placement in subtalar fusion. *Foot Ankle Int.* 2009;30:163–6.
74. **Savva N, Saxby TS.** In situ arthrodesis with lateral-wall osteotomy for the sequelae of fracture of the os calcis. *J Bone Joint Surg Br.* 2007;89:919–924.
75. **Feiwell LA, Frey C.** Anatomic study of arthroscopic portal sites of the ankle. *Foot Ankle.* 1993;14:142–147.
76. **Schmeiser G, Kunze C, Militz M, Buhren V, Putz R.** Anatomic basis for a minimally invasive approach to the subtalar joint. *Arch Orthop Trauma Surg.* 2004;124(9):621–625.
77. **Tasto JP.** Arthroscopic subtalar arthrodesis. *Tech Foot Ankle Surg.* 2003;2:122–28.
78. **Hintermann B, Valderrabano V, Nigg B.** Influence of screw type on obtained contact area and contact force in a cadaveric subtalar arthrodesis model. *Foot Ankle Int.* 2002;23:986–991.
79. **Barbaix E, Van Roy P, Clarys JP.** Variations of anatomical elements contributing to subtalar joint stability: intrinsic risk factors for post-traumatic lateral instability of the ankle? *Ergonomics.* 2000;43:1718–1725.
80. **Fellmann J, Zollinger H.** Versteifungseingriffe am unteren Sprunggelenk - wechselnde Konzepte im Wandel der Zeit. *Z Orthop.* 1996;134:341–345.
81. **van Dijk CN, Verhagen RA, Tol HJ.** Technical note: resterilizable noninvasive ankle distraction device. *Arthroscopy.* 2001;17: E12.
82. **Blake SM, Loxdale PH.** The subtalar distraction screw. *Ann R Coll Surg Engl.* 2005;87:206.
83. **Tuijthof GJ, Herder JL, van Dijk CN, Pistecky PC.** A compliant instrument for arthroscopic joint fusion. Proceedings of ASME design engineering technical conferences and computers and information in engineering conference. Salt Lake City, Utah, USA (2004).
84. **Coughlin MJ, Grimes JS, Traugher PD, Jones CP.** Comparison of radiographs and CT scans in the prospective evaluation of the fusion of hindfoot arthrodesis. *Foot Ankle Int.* 2006;27:780–787.
85. **Lian G, Pfeffer GB, Frey C.** Hindfoot arthrodesis. Current practice in foot and ankle surgery, McGraw-Hill, San Francisco (1993), pp. 262–284.
86. **Myerson MS, Neufeld SK, Uribe J.** Fresh-frozen structural allografts in the foot and ankle. *J Bone Joint Surg Am.* 2005;87:113–120.
87. **Donley BG, Ward DM.** Implantable electrical stimulation in high-risk hindfoot fusions. *Foot Ankle Int.* 2002;23:13–18.
88. **Lewis G.** Biomechanics as a basis for management of intra-articular fractures of the calcaneus. *J Am Podiatr Med Assoc.* 1999;89:234–246.
89. **Buckley RE, Hunt DV.** Reliability of clinical measurement of subtalar joint movement. *Foot Ankle Int.* 1997;18:229–232.
90. **Elveru RA, Rothstein JM, Lam RL.** Goniometric reliability in a clinical setting. Subtalar and ankle joint measurements. *Phys Ther.* 1988;68:672–677.
91. **Cobey JC.** Posterior roentgenogram of the foot. *Clin Orthop.* 1976;118:202–207.
92. **Saltzman CL, El Khoury GY.** The hindfoot alignment view. *Foot Ankle Int.* 1995;16:572–76.
93. **Lamm BM, Mendicino RW, Catanzariti AR, Hillstrom HJ.** Static rearfoot alignment: a comparison of clinical and radiographic measures. *J Am Podiatr Med Assoc.* 2005;95:26–33.
94. **Easley M, Chuckpaiwong B, Cooperman N, Schuh R, Ogut T, Le IL, et al.** Computer-assisted surgery for subtalar arthrodesis. A study in cadavers. *J Bone Joint Surg Am.* 2008;90:1628–1636.
95. **Tuijthof GJ, Herder JL, Scholten PE, van Dijk CN, Pistecky PV.** Measuring alignment of the hindfoot. *J Biomech Eng.* 2004;126:357–362.
96. **Thomas PJ.** Placement of screws in subtalar arthrodesis: a simplified technique. *Foot Ankle Int.* 1998;19:416–417.
97. **Lehnert B, Gosch C, Sims GE.** A plantar approach for fixation of subtalar joint arthrodesis. *J Foot Ankle Surg.* 2004;43:67–69.
98. **Chuckpaiwong B, Easley ME, Glisson RR.** Screw placement in subtalar arthrodesis: a biomechanical study. *Foot Ankle Int.* 2009;30:133–141.
99. **Kuwada GT.** Modification of fixation technique for a subtalar joint and triple arthrodesis. *J Am Podiatr Med Assoc.* 1988;78:482–485.
100. **Burks JB, Comerford JS.** Synthes tubular external fixation system for isolated subtalar arthrodesis. *Clin Podiatr Med Surg.* 2003;20:181–194.
101. **Astrom M, Arvidson T.** Alignment and joint motion in the normal foot. *J Orthop Sports Phys Ther.* 1995;22:216–222.
102. **Michelson JD.** Ankle fractures resulting from rotational injuries. *J Am Acad Orthop Surg.* 2003;11:403–412.
103. **Ishikawa SN, Murphy GA, Richardson EG.** The effect of cigarette smoking on hindfoot fusions. *Foot Ankle Int.* 2002;23:996–998.

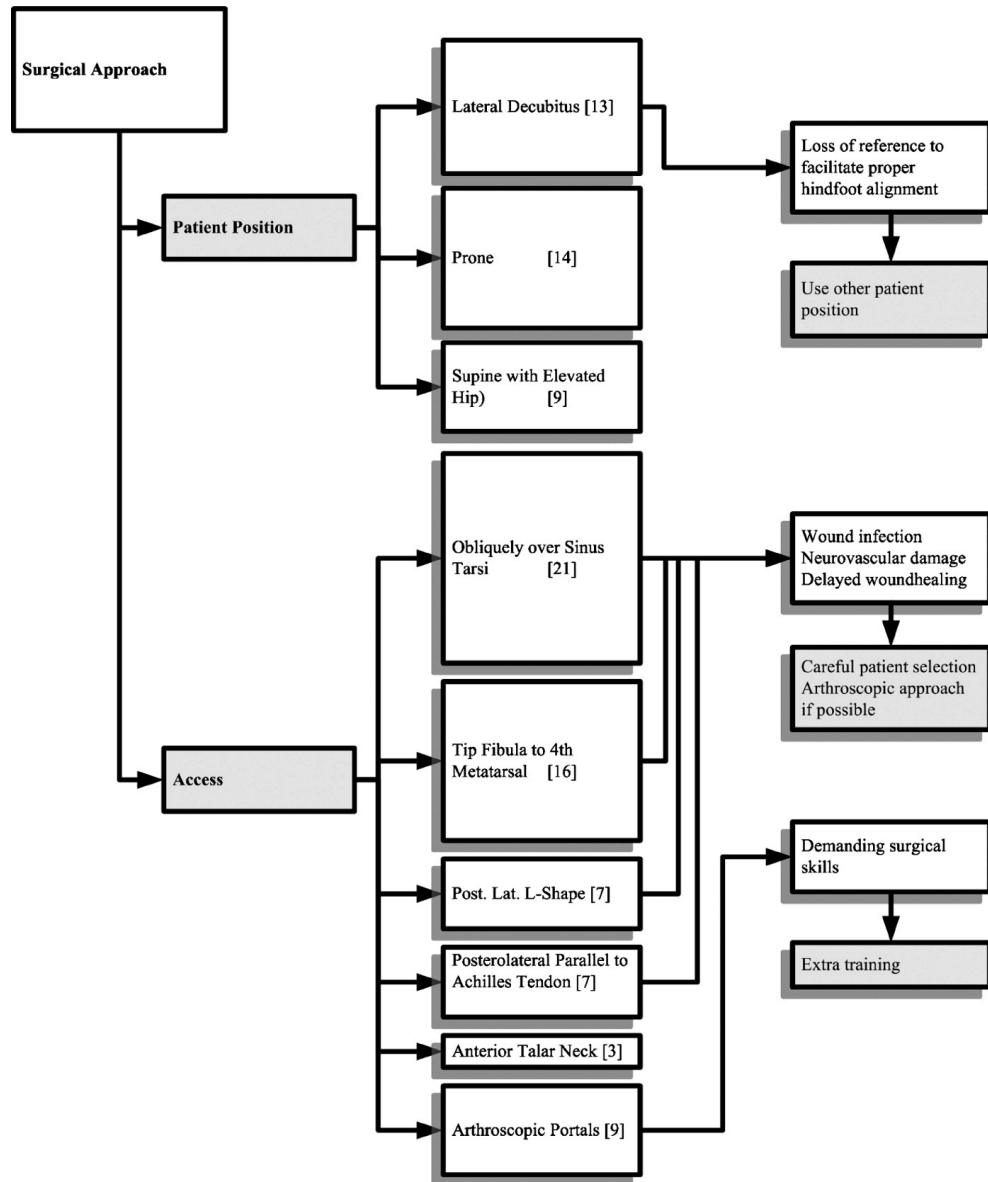
FIGURES



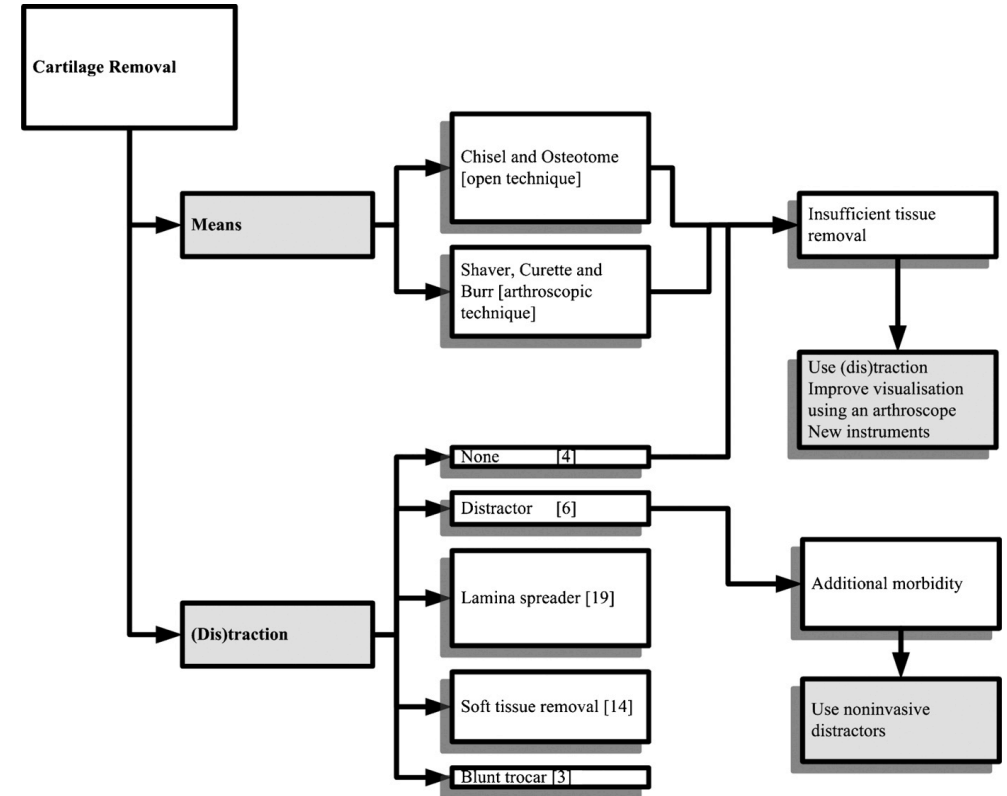
**Figure 1** Anatomy of the hindfoot focused on the subtalar joint. The three most frequently reported incisions are drawn for approaching the subtalar joint (obliquely over the sinus tarsi, tip fibula to fourth metatarsal and posterolateral approach) as well as the frequently reported arthroscopic portals.



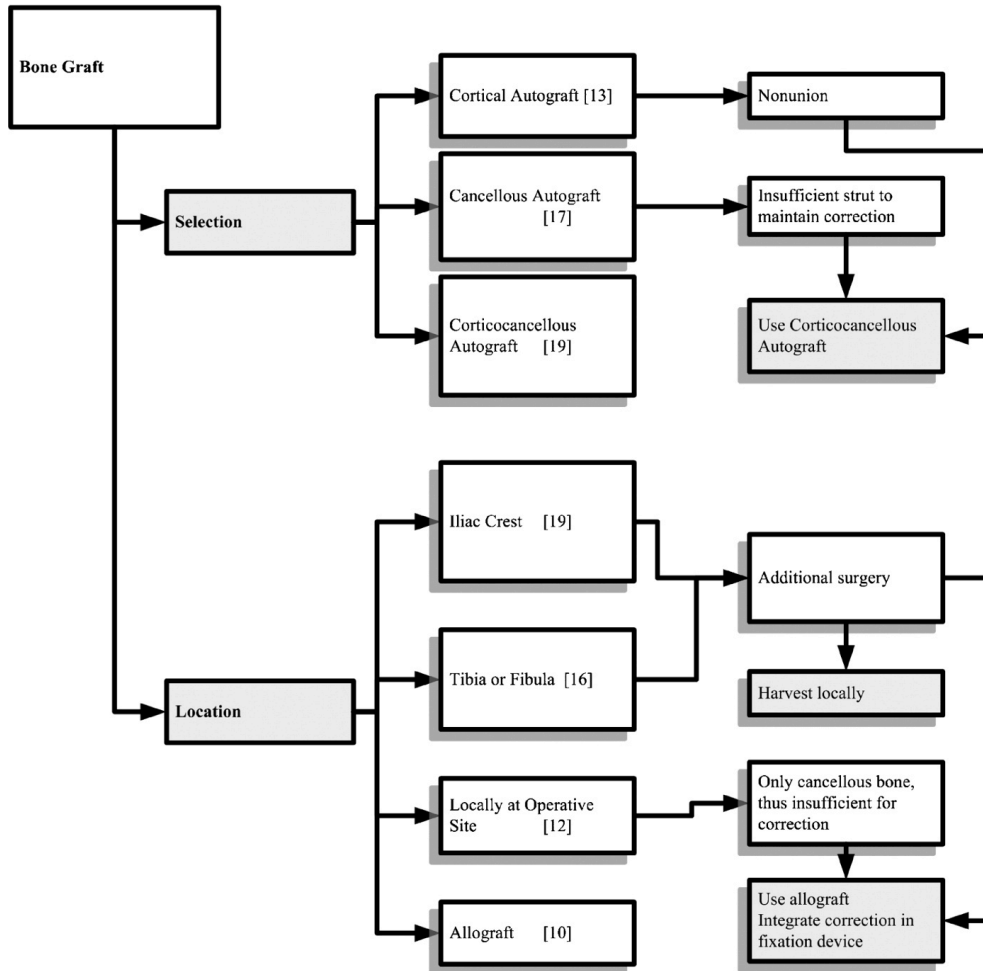
**Figure 2** Scheme indicating the primary functional outcomes of a subtalar arthrodesis: pain relief and increased mobility (1). This is achieved by bony fusion and if required restoration of hindfoot alignment. The categorization of operative phases is shown within the grey area (2). Factors that influence the surgical intervention complete the diagram (3).



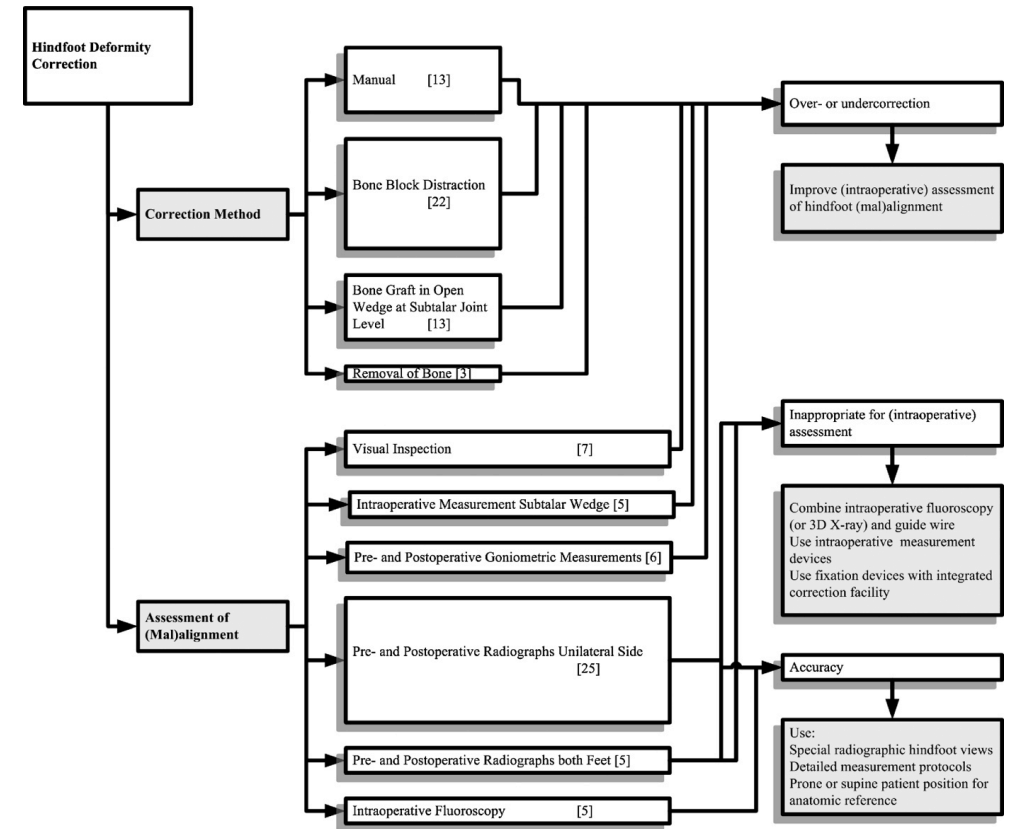
**Figure 3** Surgical approach: options, pitfalls and possible solutions. The numbers between square brackets indicate the number of papers describing this approach explicitly.



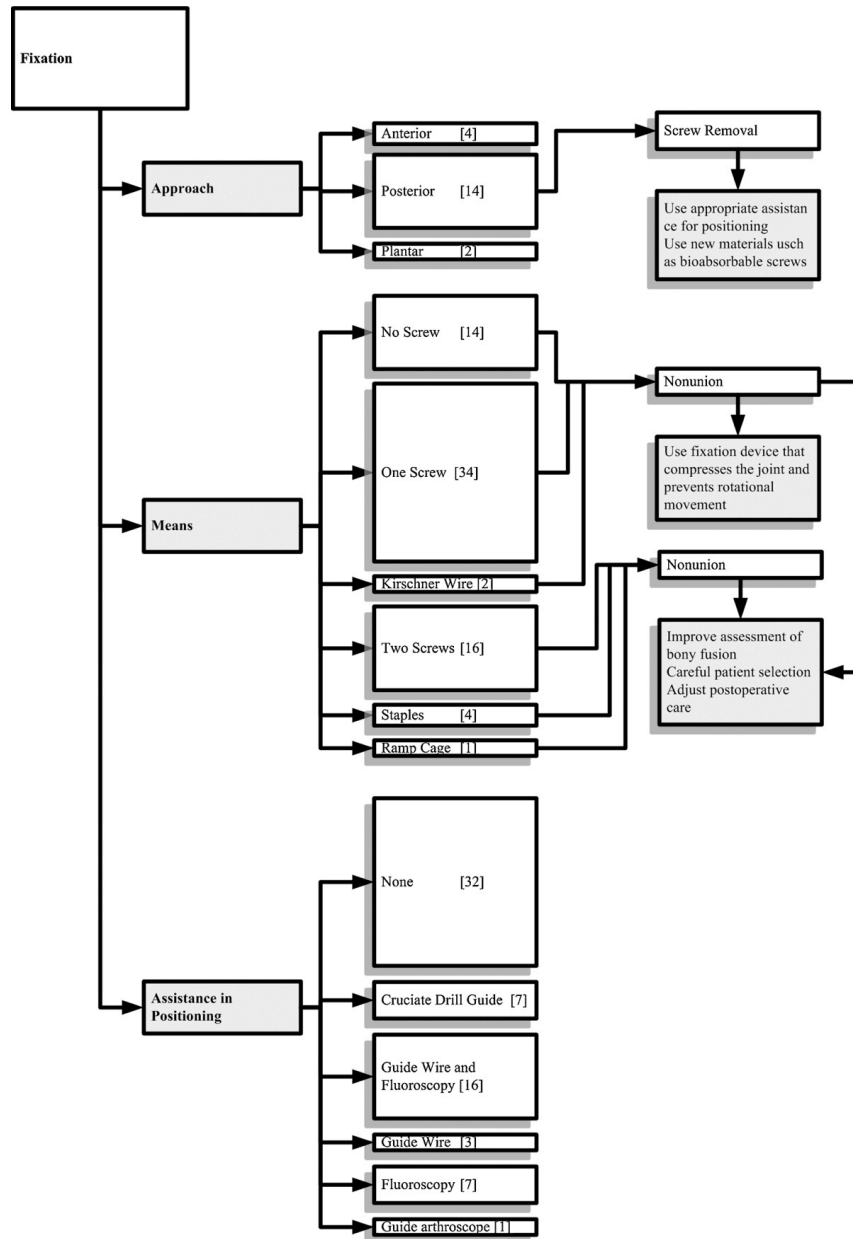
**Figure 4** Cartilage removal: options, pitfalls and possible solutions. The numbers between square brackets indicate the number of papers describing this approach explicitly.



**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.

## Arthroscopy of the posterior subtalar joint

L. Beimers, C. Frey, C.N. van Dijk

*Foot and Ankle Clinics* 2006;11(2):369-390