Original article

Patient-specific instruments for surgical resection of painful tarsal coalition in adolescents

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ABSTRACT

Introduction: Congenital tarsal coalition resection in adolescents may be hindered by the complex three-dimensional anatomy of the talocalcaneal joint. Perioperative fluoroscopy is not greatly contributive, especially for talocalcaneal coalition.

Hypothesis: 3D planning and patient-specific instruments facilitate the procedure.

Materials and methods: A made-to-measure surgical guide (patient-specific instrument) was used in 9 consecutive patients for tarsal coalition resection (7 talocalcaneal and 2 calcaneonavicular coalitions). The guide was created by 3D modeling from the CT scan of the foot. Placed on the bone surface, it oriented the saw blade to resect the bone bridge at the appropriate depth. A fascia lata allograft was interposed. Complete resection and absence of recurrence were checked on postoperative CT in talocalcaneal and on radiography in calcaneonavicular coalitions.

Results: Resection was complete in all cases, with no recurrence at last follow-up.

Discussion: This technique makes tarsal coalition resection easier and more reliable and may be recommended to improve precision.

Level of evidence: Level IV, prospective study of a new surgical technique.

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1. Introduction

Tarsal coalition or congenital tarsal synostosis is characterized by an abnormal bone, cartilage or fibrous junction between 2 or more hind- and/or midfoot bones. It is frequent, with an incidence of about 1% of the general population [1,2]. Talocalcaneal and calcaneonavicular coalitions are the most frequent forms [3]. There is probably male predominance [4], and some studies have reported a hereditary factor [5,6]. Tarsal coalition is bilateral in 50% of cases [7].

It is a frequent cause of foot and ankle pain, with onset during the second decade of life or sometimes in adulthood. It impairs subtalar motion (inversion and eversion) and may induce iterative ankle sprain, flatfoot and tarsal tunnel syndrome [1,6].

Diagnosis is founded on X-ray for calcaneonavicular coalition (AP, oblique and lateral views), and CT for talocalcaneal coalition. Several indirect signs have been described [8]. In talocalcaneal coalition, possible signs are the “talar beak” (broadened anterosuperior part of the talar neck) and the “C sign” (continuous cortical contour from medial talus to sustentaculum tali). In calcaneonavicular coalition, the “anteater nose” sign corresponds to a lengthened and broadened anterior calcaneal process.

The present study reports an original tarsal coalition resection technique using a patient-specific instrument (PSI) and assesses its contribution to surgery.

2. Material and methods

2.1. Series

Nine consecutive patients presenting with talar coalition underwent PSI-assisted surgical resection after failure of conservative
treatment: i.e., pain persisting after at least 6 months’ use of insoles and abstention from sport. Table 1 presents clinical data. There were 7 talocalcaneal and 2 calcaneonavicular coalitions. Two were cases of recurrence after primary resection (1 talocalcaneal and 1 calcaneonavicular). Weight-bearing ankle radiographs showed no significant valgus. Hindfoot range of motion was assessed clinically, with the patient prone, knee in flexion. The examiner stabilized the ankle with one hand and induced calcaneal inversion-eversion with the other. All patients were assessed preoperatively on AOFAS score [9] (Table 1).

**Table 1**

Clinical data and results for the nine patients.

<table>
<thead>
<tr>
<th>Cases</th>
<th>Sex</th>
<th>Ages at surgery (years)</th>
<th>Sides</th>
<th>Types</th>
<th>Preoperative symptoms</th>
<th>Preoperative AOFAS score</th>
<th>Follow-up (months)</th>
<th>Postoperative imaging</th>
<th>Postoperative imaging at last follow-up</th>
<th>Postoperative AOFAS score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>F</td>
<td>16</td>
<td>L</td>
<td>TC</td>
<td>Pain in walking, ankle sprain</td>
<td>68</td>
<td>14</td>
<td>Complete resection</td>
<td>No recurrence</td>
<td>87</td>
</tr>
<tr>
<td>Case 2</td>
<td>M</td>
<td>12</td>
<td>L</td>
<td>TC</td>
<td>Pain in walking</td>
<td>68</td>
<td>16</td>
<td>Complete resection</td>
<td>No recurrence</td>
<td>97</td>
</tr>
<tr>
<td>Case 3</td>
<td>M</td>
<td>11</td>
<td>R</td>
<td>TC</td>
<td>Pain in sport</td>
<td>81</td>
<td>23</td>
<td>Complete resection</td>
<td>No recurrence</td>
<td>87</td>
</tr>
<tr>
<td>Case 4</td>
<td>M</td>
<td>13</td>
<td>R</td>
<td>TC</td>
<td>Pain in walking</td>
<td>68</td>
<td>12</td>
<td>Complete resection</td>
<td>No recurrence</td>
<td>97</td>
</tr>
<tr>
<td>Case 5</td>
<td>F</td>
<td>11</td>
<td>L</td>
<td>CN</td>
<td>Pain in walking</td>
<td>48</td>
<td>14</td>
<td>Complete resection</td>
<td>No recurrence</td>
<td>87</td>
</tr>
<tr>
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<td>F</td>
<td>12</td>
<td>R</td>
<td>TC</td>
<td>Pain in walking</td>
<td>68</td>
<td>16</td>
<td>Complete resection</td>
<td>No recurrence</td>
<td>97</td>
</tr>
<tr>
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<td>M</td>
<td>16</td>
<td>L</td>
<td>TC</td>
<td>Pain in walking, ankle sprain</td>
<td>68</td>
<td>15</td>
<td>Complete resection</td>
<td>No recurrence</td>
<td>87</td>
</tr>
<tr>
<td>Case 8</td>
<td>M</td>
<td>16</td>
<td>L</td>
<td>TC</td>
<td>Pain in walking</td>
<td>68</td>
<td>14</td>
<td>Complete resection</td>
<td>No recurrence</td>
<td>97</td>
</tr>
<tr>
<td>Case 9</td>
<td>F</td>
<td>21</td>
<td>L</td>
<td>CN</td>
<td>Recurrence of pain in walking after primary resection</td>
<td>79</td>
<td>37</td>
<td>Complete resection</td>
<td>No recurrence</td>
<td>94</td>
</tr>
</tbody>
</table>

F: female; M: male; R: right; L: left; TC: talocalcaneal; CN: calcaneonavicular.

**Fig. 1**. Eleven-year-old boy. A. Preoperative CT scan of the right foot (coronal slices) showing the talocalcaneal coalition. B. 3D-preoperative reconstruction. C. Plaster model obtained by rapid prototyping. D and E. Acrylic-PfMA patient-specific instrument molded on the plaster foot model. F. Peroperative image: medial approach centered on the sustentaculum tali, and guide positioning on bone surface. G. Peroperative image: resection of the coalition by introducing the saw blade in the guide. H. Peroperative image: interposition of fascia lata allograft after resection of the coalition. I. Postoperative CT scan showing a complete resection.
2.2. Preoperative planning and PSI

Systematic preoperative CT of the coalition was performed on a Philips ICT 256 Scanner, with 0.9 mm slices every 0.3 mm. 3D reconstruction used Mimics software (Materialise, Leuven, Belgium).

For the first patients, a plaster model of the foot was produced by rapid prototyping from the CT scan (Figs. 1 and 2). An acrylic and polymethyl-methacrylate PSI was then molded from the plaster model.

In later patients, the model was created by 3D modeling rather than prototyping; the PSI was created virtually, then prototyped, comprising one reusable standardized titanium component and a second patient-specific polyamide component (Fig. 3). Planning, design and production costs for the made-to-measure PSI were around €800.

2.3. Surgical technique

The patient was positioned in dorsal decubitus, with a pneumatic tourniquet to the thigh. In talocalcaneal coalition, the approach was medial, with an incision over the sustentaculum tali. The posterior tibial and flexor hallucis longus tendons were...
reclined respectively forward and backward to expose the bone bridge (Fig. 1). In calcaneonavicular coalition, the incision was anterolateral, forwards of the sinus tarsi; the extensor digitorum brevis muscle was reclined distally, exposing the coalition (Fig. 2). The PSI (sterilized on the eve of surgery) was positioned on the bone surface, having been designed so as to give a perfect fit in a single possible position. It was fixed using two K-wires to ensure stability, and could then guide the direction of the saw blade. It was further designed to ensure correct resection depth, the blade being introduced fully into the PSI so as to reach but not damage the healthy subtalar joint.

To reduce recurrence risk, a frozen fascia lata allograft, provided by our center’s tissue bank, was thawed in physiological saline, plus rifampicin to reduce infection risk, then folded several times before positioning, to obtain a “concertina” effect under talocalcaneal movement. At end of surgery, the capsular and tendinous planes were carefully closed.

2.4. Postoperative care

Walking was systematically resumed as soon as pain allowed. Physical therapy for mid- and hindfoot mobilization was initiated at 1 week. Sport was authorized at 6 months. Systematic postoperative imaging assessed complete resection and non-recurrence, on CT for talocalcaneal [Fig. 1] and plain X-ray for calcaneonavicular coalition [Fig. 2]. Systematic clinical assessment was performed by postoperative AOFAS score [9] (Table 1).

3. Results

Mean follow-up was 17.9 months, with a minimum of 12 months. Table 1 shows results in the 9 patients. There were no postoperative complications, and notably no allograft infection. The planned correction was systematically achieved, with no recurrence on CT at last follow-up. Five of the 9 patients had excellent results, with AOFAS score >90, and 4 satisfactory results (AOFAS >80).

All patients reported alleviation of presenting symptoms and all returned to sport. Improved hindfoot mobility was found systematically on clinical examination.

4. Discussion

Surgery is indicated only in symptomatic tarsal coalition resistant to conservative management. One attitude is triple arthrodesis (talocalcaneal, talonavicular and calcaneocuboid) [7,10,11], but long-term follow-up has found onset of secondary tibiotalar osteoarthritis in 58% to 77% of cases [12–14]. An alternative of choice consists in resecting the synostosis, providing good results in terms of pain alleviation and prevention of osteoarthritis [15–18], although not in all reports. It is not always straightforward during actual surgery to determine precise location and orient the saw blade for bone bridge resection, and it is also difficult to stop before involving the healthy talocalcaneal joint. Fluoroscopy is often poorly contributive. Arthroscopic resection has also been reported [19,20], but involves a long learning curve [21], longer operating time [18], risk of posterior tibial pedicle neurovascular lesion [22] and difficulty in positioning material [23].

We therefore suggest the present original technique of resection guided by a patient-specific instrument created by 3D CT-based modeling of the coalition. The guide is made-to-measure and perfectly fits the synostosis, enabling excellent resection precision: the PSI determines resection angle and depth. The technique thus enhances surgical precision, avoiding deviation and over-resection. Producing such PSIs does not increase indications for resection, but increases procedural precision. Interposition material is still required, to avoid recurrence. Other materials than fascia lata have been reported, such as muscle or fat; we prefer fascia lata, for its mechanical resistance, and the possibility it offers of concertina folding and cutting to measure.

The present coalition resection technique is reserved to feet that are well-aligned or only slightly in valgus; more severe valgus requires other techniques, such as triple arthrodesis or coalition resection associated to lengthening of the great apophysis of the calcaneus [24].

The technique has other advantages: shorter surgery time and a smaller surgical approach. Drawbacks include the time needed to produce the PSI (about 1 week), its extra cost and the necessity of CT scanning. The technique has evolved, as seen in the 2 types of guide used during the present study. The “molded” acrylic/PMMA model had the drawback of bulkingness. The more recent “bi-material” designs are smaller; the titanium component is standardized and reusable, while the polyamide component is made-to-measure by rapid prototyping; there is metal-metal contact between the guide and the K-wires and saw blade, avoiding soft tissue contamination by polyamide debris.

In conclusion, tarsal coalition resection using patient-specific instrumentation gave good results, with systematic alleviation of presenting symptoms and increased range of hindfoot motion. Resection was systematically complete, with no recurrence. This original technique makes tarsal coalition resection easier and more reliable, and may be recommended as a useful aid to improve precision in this type of resection.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.
References
