Experimental model in cadavera of arthroscopic resection of calcaneonavicular coalition and its first in-vivo application: preliminary communication

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Open surgical resection of calcaneonavicular coalition is indicated after the failure of conservative treatment. Our objectives are to develop the arthroscopic surgical technique and to check the feasibility of the arthroscopic resection of the calcaneonavicular coalition. We designed and performed endoscopic resection of the calcaneonavicular ligament and part of the anterior process of calcaneus as a simulation of the coalition resection on four cadaver specimens. After this procedure, we successfully performed the first resection in a 12-year-old girl, without any soft tissue interposition. American Orthopaedic Foot and Ankle Society Hindfoot Scale was 55 before surgery, 98 after 10 weeks, and 100 after 2 years without recurrence. ***J Pediatr Orthop B*** **00:000–000**

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Introduction

Calcaneonavicular coalition (CNC) is a fibrous, cartilaginous, or bony connection between the calcaneus and the tarsal navicular bone, which results from a congenital failure of differentiation and segmentation of primitive mesenchyme. Its prevalence ranges from 1 to 7% [1–3], although only 25% become symptomatic [4]. The clinical presentation includes pain and a history of repeated ankle sprains.

The conservative nonoperative treatment resolves symptoms in approximately 30% of patients [5]. In the remainder, surgical resection of CNC is indicated and good results are expected [6,7]. Soft tissue interposition techniques have decreased the radiologic recurrence rate [8–13].

As of now, minimally invasive techniques (i.e. endoscopy–arthroscopy) are available for resection of either soft tissue or bone. Their use in hindfoot surgery is evolving, and as shown in other procedures, the arthroscopic technique is an advantage in terms of safety [14,15], scar tenderness [14], infection rates [14,16–18], cost effectiveness [14,19], pain [14,19], faster return to activities, and cosmetic results [14,17,20].

We have developed an experimental model of simulation for the arthroscopic resection of CNC with four fresh frozen cadaver specimens. After carrying out this surgical simulation, we performed the procedure in a 12-year-old girl. We present an anatomical study of the viability of the endoscopic resection of CNC in a cadaver and report the first in-vivo surgical intervention with a follow-up of 2 years.

Cadaver study

Materials and methods

We have designed an experimental model based on the visualization and resection of the calcaneonavicular ligament (CNL), and of the anterior process of calcaneus to create a 7–10 mm-wide gap between the calcaneus and the navicular bone.

Four fresh frozen specimen feet were used. We have tested the surgical technique in four feet using different portals in each. In this manner, we have designed our ideal technique by deciding what was the optimal location for arthroscopic portals (the most useful and safest). After performing the resection, dissection of specimens was carried out. Soft tissue and neurovascular structures were checked for damage and the amount of bone resection was measured and noted. We also measured the distance from the portals to surrounding neurovascular structures (Table 1). The details of the surgical technique for each specimen are described below.

Specimen 1

We tried to reach the CNL from a point immediately anterior to the sinus tarsi, and placed the visualization

Table 1 Summary of cadaver anatomical study and dissection

	Visualization portal		Working portal				
Specimen number	Location	Distance to sural nerve (mm)	Location	Distance to deep peroneus nerve (mm)	Nerve damage by portals	Extensor brevis resection	Visualization
1	Between calcaneus cuboid joint and sinus tarsi	20	Lateral border peroneus tertius	–	No	15 mm wide	Good
2	Sinus tarsi	0	Lateral border peroneus tertius	6	Complete rupture sural nerve		Bad. Difficult orientation
3	Antero lateral corner of calcaneus	11.04	Medial border of extensor tendons	11	No	Ample resection, affecting motor nerve	Good
4	0.5 cm more anterior than specimen 3	6.9	Medial border of extensor tendons	6.4	No	Limited	Good

and working portals posterior to the calcaneocuboid and talonavicular joints, respectively [21]. The working portal was placed at the lateral border of the peroneus tertius tendon. The anatomic dissection did not show a lesion of neurovascular or tendinous structures.

Specimen 2

We chose a location for the visualization portal more posteriorly and reached the CNC in a 45° direction from the sinus tarsi anteriorly to the talocalcaneal ligaments. The working portal was placed at the lateral border of the peroneus tertius tendon in line with the calcaneo-cuboid joint. This approach had worse visualization and we experienced orientation difficulties. It was difficult to observe the lateral side of the navicular bone because it was hidden behind the talus head from this perspective. Once we started to resect the bone, it was necessary to establish a third portal to complete the procedure. During dissection, we noted that the visualization portal was not safe because it caused a complete rupture of the sural nerve.

Specimen 3

The visualization portal was placed at the anterolateral corner of the calcaneus. The working portal was placed at the medial border of the extensor tendons, 2 cm medial to the visualization portal (Fig. 1). After soft tissue clearance (i.e. extensor brevis muscle), good visualization of the CNL was achieved. The ligament and bone resection was then completed.

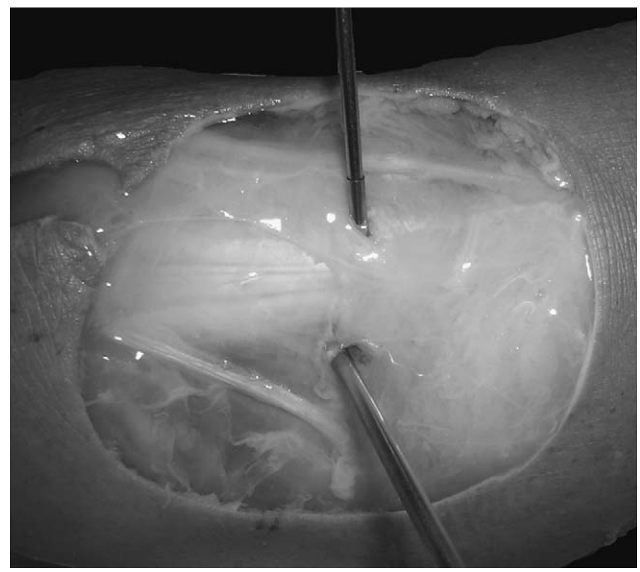
Specimen 4

In this specimen, we placed portals similar to those in specimen 3, but placed them 0.5 cm more anteriorly. We concentrated on minimizing the extensor brevis muscle resection. We felt comfortable with the portals and completed the procedure without visualization or orientation difficulties. We were able to perform the surgery in a living person.

Results

It is possible to arthroscopically visualize and resect the CNL and anterior process of the calcaneus (Fig. 2).

Fig. 1



Specimen 3, left foot after skin dissection, showing the visualization and working portals. Note the relationship between portals and extensor tendons, extensor brevis muscle, sural nerve, and cutaneus branche of superficial peroneus nerve.

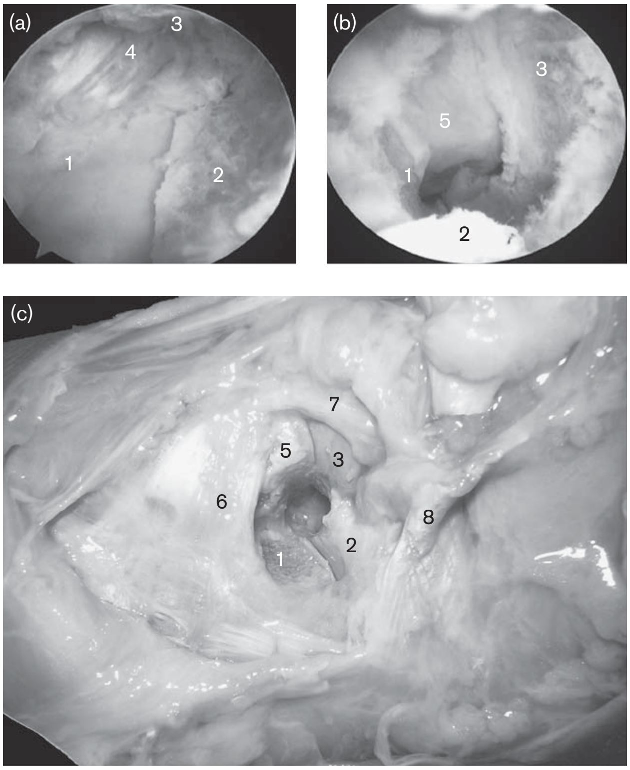
After practicing on four cadaver feet, we recommend (i) placing the visualization portal anteriorly to the calcaneocuboid joint and parallel to the dorsal surface of the cuboid, which improves the safety of the sural nerve and the visualization of the CNL, (ii) placing the working portal in line with the visualization portal at either the medial border of the extensor tendons or between the first and second extensor tendons and direct it perpendicularly to the visualization portal. We recommend staying close to the bone and limiting soft tissue resection (especially extensor brevis muscle) to the tissues close to the CNL.

In-vivo procedure

Patient and methods

A 12-year-old girl with unilateral CNC. The patient's symptoms appeared 1 year before surgery. Her symptoms were pain in the lateral side of the foot when walking,

Fig. 2



(a) Arthroscopic visualization of calcaneonavicular ligament; (1) calcaneus, (2) cuboid, (3) navicular, (4) calcaneonavicular ligament. (b) Arthroscopic visualization after resecting ligament and bone; (5) talus head. (c) Picture showing deep dissection of specimen 4. Note the bone and soft tissue resection; (1) calcaneus, (2) cuboid, (3) navicular, (5) talus head, (6) talocalcaneal ligament, (7) dorsal talonavicular ligament, (8) extensor retinaculum divided and retracted distally.

and inability to run and walk on uneven surfaces. The pain also prevented the patient from skating. Physical examination found a painful and decreased range of pronation and supination. Flexion extension was normal and was free of symptoms, and the ankle was stable. The American Orthopaedic Foot and Ankle Society (AOFAS) Ankle-Hindfoot Scale [22] before surgery was 55.

Radiographs (Fig. 3a) showed a narrowed calcaneonavicular gap and a widening and flattening of the anterior process of the calcaneus, with rough, irregular, and poorly defined cortices of the calcaneus and the navicular bone (type 3 CNC according to Lysack and Fenton [2]), which is interpreted as syndesmosis.

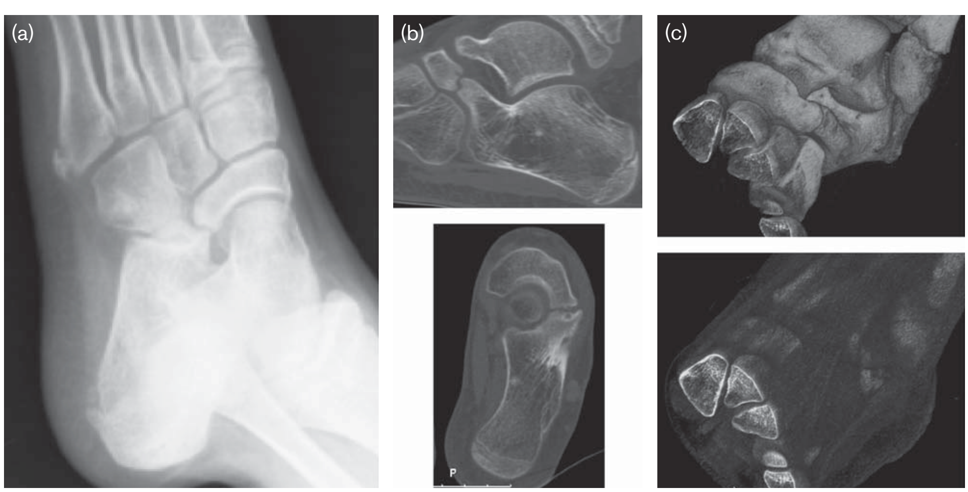
A computed tomography (CT) scan (Fig. 3b) confirmed syndesmosis and showed small subchondral degenerative cysts in the anterior process of the calcaneus and the navicular bone. Three-dimensional reconstruction with soft tissue representation was also made for planification of surgery (Fig. 3c).

Informed consent was given by the parents before surgery. The ethics committee approved the carrying out of the surgery arthroscopically.

Surgery was performed under general anesthesia. A tourniquet was applied tightly. The first step was identifying bony and soft tissue landmarks. The calcaneonavicular bar was palpable (Fig. 4a).

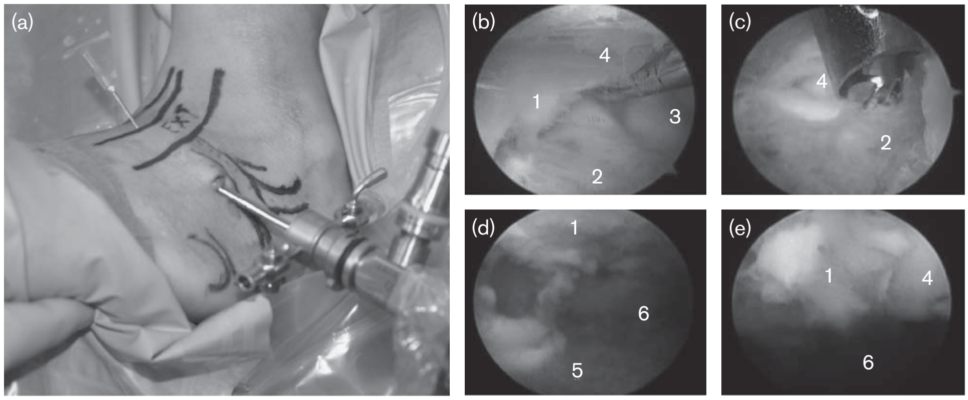
We localized the visualization portal with a needle, and placed it 3–4 mm anteriorly to the calcaneocuboid joint

Fig. 3



Preoperative imaging of the in-vivo case. (a) Radiographs of the 12-year-old girl. Narrowed calcaneonavicular gap and widening and flattening of the anterior process of calcaneus, with rough, irregular and poorly defined cortices of calcaneus and navicular what is interpreted as a syndesmosis (type 3 calcaneonavicular coalition according to Lysack and Fenton [2]). (b) Computed tomography exam confirmed syndesmosis and showed small subchondral degenerative cysts in the anterior process of calcaneus and navicular. (c) Three-dimension reconstruction with soft tissues representation was used for planification of surgery.

Fig. 4



Intraoperative pictures. (a) Drawing of skin landmarks. Note the portals and the calcaneonavicular bar, which was palpable. (b) Arthroscopic visualization of calcaneonavicular coalition (CNC); (1) Navicular, (2) CNC coalition, (3) talus head, (4) dorsal talonavicular ligament being retracted by arthroscopic probe. (c) Arthroscopic resection of CNC. (d) Resection completed; (5) cuboid, (6) space created by CNC resection. (e) Resection completed.

(Fig. 4a). We started with a 2.7 mm lens and after setting this in place switched to a regular 4 mm lens for better inflow. We were not able to place a working portal in the planned position during cadaver practice because of the dimensions of the calcaneonavicular bar, and were forced to move it anteriorly and laterally. We used a soft tissue arthroscopic shaver to clear soft tissue enough to have good visualization of the dorsal calcaneocuboid joint and the lateral side of the scaphoid and talonavicular joints (Fig. 4b). We also used a radiofrequency device to control bleeding and for soft tissue resection. Bone resection was started from the dorsal to the plantar side and was performed by a 3.5 mm arthroscopic burr (Fig. 4c). As the procedure progressed, the fibrous syndesmosis became visible and the burr was not able to resect it; therefore, we used the soft tissue resector and a radio frequency device.

After resection was completed, we checked the dimensions of the gap with an arthroscopic probe and subtalar motion (Fig. 4d and e). We noted an iatrogenic resection of the subchondral calcaneal bone 4 mm deep under the anterior subtalar joint. At the end of the procedure, we closed the incisions with monofilament regular skin sutures and infiltrated the portals and the space created by the resection with ropivacaine (7.5%). The patient wore an ankle splint for 10 days and then began weight bearing.

Results

The patient was discharged the day after surgery and took ibuprofen only on the first night at home. She began weight bearing on the 10th postoperative day and recovered the full range of motion in the 6th week. She reported no pain during this period. In the 10th week, the patient began dance, sports, and running activities without any limitation. The AOFAS Ankle-Hindfoot Scale [22] was 98. In the 12th and 25th month after surgery the AOFAS Ankle-Hindfoot Scale [22] was 100. Radiographs 1 year after surgery showed no recurrence. A CT scan shows complete and adequate resection of the CNC (Fig. 5).

Discussion

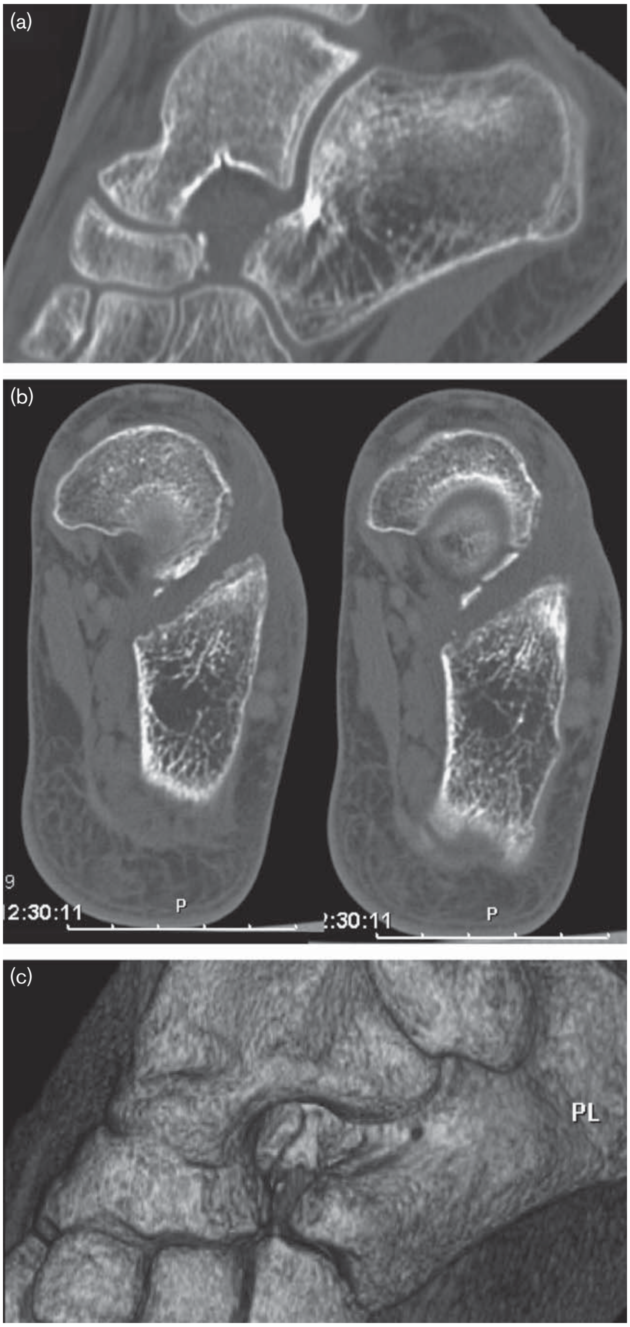
The surgical treatment of symptomatic CNC is indicated for patients with recurrent and disabling symptoms after the failure of conservative treatment, and is eventually performed in most cases [23]. Resection of CNCs was first reported by Badgley [24] in 1927. Interposition of the extensor digitorum brevis was added to the resection procedure, and was reported by Bentzon [25] in 1930. Autologous fat has also been used for the same purpose [26].

The reported results of surgical resection of CNCs without soft tissue interposition in children have been good-to-excellent in several studies with as many as 20 years follow-up [6,7,12,13].

Mitchell and Gibson [6] reported the results of 41 CNC resections without soft tissue interposition for the treatment of painful spasmodic flat foot. Satisfactory results were obtained in 31 feet (75.6%), after a mean follow-up of 6 years. There was a recurrence of the bar, to a large extent, in one-third of patients and to a lesser extent in another third. They identified the long-standing deformity and adaptative changes in tarsal joints as predictors of unsatisfactory results. Satisfactory results were correlated with good subtalar motion.

The long-term results after excision of calcaneonavicular bars without any soft tissue interposition were reported by Inglis *et al.* [7]. Eleven of 16 (68%) feet were

Fig. 5



Computed tomography results after surgery. (a) Coronal views. (b) Sagital views. (c) Three-dimensional reconstruction.

symptom-free after 20 years. In three cases, failure was treated by triple arthrodesis. The radiologic recurrence rate was 25%.

These results can be compared with those of the CNC bar excision and extensor brevis muscle interposition. Gonzalez and Kumar [9] reported 77% good and excellent results and partial reformation of the bar in 22% feet. In this series, three cases of 75 required triple arthrodesis. Moyes *et al.* [10] compared the results of bony CNC resection with extensor brevis interposition (10 cases) with resection without an attempt to fill the gap (seven cases). Three of these seven patients had radiologic recurrence whereas none of the 10 patients with muscle interposition had radiologic recurrence. This study from 1994 was retrospective and not randomized.

Some of the complications of surgery are related to the surgical approach and wounds. Neuroma has been said to be responsible for 50% of the bad results in the series on CNC resection by O'Neil and Micheli [15]. A minimally invasive approach may contribute to a decrease in the complication rate.

Arthroscopy for the hindfoot has shown advantages in terms of time consumed, safety, pain relief, cost, faster return to activities, and cosmesis. These advantages have been confirmed in two procedures: calcaneoplasty for Haglund's deformity [14,17,18] and subtalar arthrodesis [19,20].

Arthroscopic resection of the calcaneal process for the treatment of Haglund's disease has been compared with the open procedure in a randomized and prospective study of 33 calcaneoplasties by Leitze *et al.* [14]. The AOFAS scores were not significantly different and the time to recovery was the same in the two groups, but the endoscopic procedures were performed faster than the open procedures (44 compared with 56 min) and were associated with fewer complications: altered sensation was 10% compared with 18% for the open procedure, scar tenderness 7% arthroscopic, compared with an 18% open, and infection rate of arthroscopic surgery was 3% compared with 12% in open cases. Van Dijk *et al.* [17] performed 21 endoscopic calcaneoplasties for Haglund's disease and found no infections. In Ortmann's study of 32 endoscopic calacaneoplasties, there were no wound complications or postoperative infections [18].

In Scranton's study, hospital stay of patients treated with arthroscopic subtalar arthrodesis was 1.7 days shorter than the stay of patients treated with open subtalar arthrodesis [19].

We have conducted an experimental cadaver study and found that it is both possible and safe to reach the calcaneonavicular region and perform either soft tissue or bone resection.

After this cadaver experience, we performed a minimally invasive resection of a symptomatic calcaneonavicular syndesmosis in a 12-year-old girl. The application of the simulative experimental model to the actual CNC had two difficulties. The location of the working portal designed in the cadaver study was not useful because of the size of the bar, and we were forced to move the portal more anteriorly and horizontally. The amount of bone to be resected was obviously significantly larger than in the cadaver, and this increased the surgery duration. We have decided to make a second cadaver safety study using the same working portal that we used in this first in-vivo case. This study is currently running, and thus our work is in progress both in the experimental and the clinical setting.

The radiologic and functional results of this first in-vivo case were excellent. We have not made any soft tissue interposition between the calcaneus and the navicular bone. This may be considered a limitation of the procedure and according to previous studies there could be a concern about recurrence [9,10,13].

The studies by Mitchell and Gibson [6]and Inglis *et al.* [7] show satisfactory results in 70% of patients without soft tissue interposition [8]. With regard to these studies, it seems that not every case of CNC requires muscle interposition. In this patient with incomplete ossification, we thought that repetitive impingement between the calcaneus and the navicular bone during gait and eversion was responsible for the pain, as shown by the degenerative subchondral cysts detected in the CT scan (Fig. 2b). This idea has been recently advanced by Lui, [27] who also recommends arthroscopic resection of CNC.

The extensor brevis interposition requires 3 weeks to heal and between 6 and 10 weeks immobilization [26,28]. Tachdjian [26] recommended keeping the foot in a plastic splint and waiting for weight bearing until the full range of motion is achieved, usually between the 8th and 10th week. The arthroscopic technique allows earlier motion, which also can help to prevent reformation of the bar [27]. In our case, weight bearing and motion began on the 10th postoperative day, the full range of motion was achieved by the 6th week, there was no pain during this period, and by the 10th week the patient was involved in sports and dance. After 1 year there was no radiologic evidence of recurrence, and the AOFAS score was 100 points and remained 100 points after 2 years.

The question to address is the reproducibility of the technique with regard to both the patients and the surgical team. With regard to patient selection, at the moment, we can offer a subjective opinion based on our experience. We are confident that the painful synchondrosis, with a decreased but not absent range of motion, can benefit from this procedure. We do not yet have an opinion about larger completely ossified bars. With regard to the surgical team, it has experienced a prolonged training period in knee, shoulder and ankle arthroscopy. We would not recommend this technique for surgeons who are not familiar with hindfoot arthroscopic techniques.

Another definite point of discussion is the necessity of filling the gap after arthroscopic resection. It is generally accepted to include soft tissue interposition as part of the treatment of CNC [8–13]. Either fat or fascia lata autografts can be successfully placed arthroscopically after resection. Advanced arthroscopic suture-passing instruments make this theoretically possible. Even extensor brevis interposition is possible by arthroscopic means. However, this is a future line of research that we have not yet begun in the cadaver laboratory. It is our opinion that patient selection and preoperative planning should clearly anticipate soft tissue (i.e. extensor brevis muscle) interposition and, for patients considered for interposition, we recommend open surgery. In case of the necessity to fill the gap during the arthroscopic procedure, we would suggest converting the procedure to an open one and completing the filling of the gap by means of open surgery. We feel that versatility is a definite advantage of the open method that has not yet been shown in relation to the arthroscopic method.

Conclusion

Although this is a work in progress, arthroscopic resection of CNC is possible and safe, and provides satisfactory pain relief and subtalar motion restoration for patients with synchondrosis and decreased range of motion in which impingement can be a source of pain. It is, however, technically highly demanding, and a large series of patients are needed before we recommend this technique as a standard. Patients considered for soft tissue interposition should be scheduled for open surgery.

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The authors state that there are no conflicts of interest.

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