Tibial Lengthening

Extraarticular Calcaneotibial Screw to Prevent Ankle Equinus

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Abstract Between 2003 and 2006, we used an extraarticular, cannulated, fully threaded posterior calcaneotibial screw to prevent equinus contracture in 10 patients (four male and six female patients, 14 limbs) undergoing tibial lengthening with the intramedullary skeletal kinetic distractor. Diagnoses were fibular hemimelia (two), mesomelic dwarfism (two), posteromedial bow (one), hemihypertrophy (one), poliomyelitis (one), achondroplasia (one), posttraumatic limb-length discrepancy (one), and hypochondroplasia (one). Average age was 24.5 years (range, 15–54 years). The screw (length, typically 125 mm; diameter, 7 mm) was inserted with the ankle in 10° dorsiflexion. Gastrocnemius soleus recession was performed in two patients to achieve 10° dorsiflexion. Average lengthening was 4.9 cm (range, 3–7 cm). Screws were removed

after a mean 3.3 months (range, 2–6 months). Preoperative ankle range of motion was regained within 6 months of screw removal. No neurovascular complications were encountered, and no patients experienced equinus contracture. We also conducted a cadaveric study in which one surgeon inserted screws in eight cadaveric legs under image intensifier control. The flexor hallucis longus muscle belly was the closest anatomic structure noted during dissection. The screw should be inserted obliquely from upper lateral edge of the calcaneus and aimed lateral in the tibia to avoid the flexor hallucis longus muscle.

Level of Evidence: Level IV, therapeutic study. See the Guidelines for Authors for a complete description of levels of evidence.

One author (DP) is a consultant for Smith & Nephew, Inc., (Memphis, TN).

Each author certifies that his or her institution has approved the human protocol for this investigation, that all investigations were conducted in conformity with ethical principles of research, and that informed consent for participation in the study was obtained.

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Introduction

Tibial lengthening using external fixation is a well-established method to equalize leg-length discrepancy [1, 2, 6, 7, 10, 19, 20, 22, 24, 25, 29, 30]. Equinus contracture of the ankle is a frequently encountered complication during tibial lengthening [2, 11, 21, 22, 25]. The options available for preventing this complication include physical therapy [27], bracing [16, 18], and/or spanning the ankle with the fixator [21].

During the past decade, internal lengthening devices were developed to reduce complication rates and to improve patient comfort [3, 5, 12–15, 23, 28]. Currently, three intramedullary lengthening devices are in clinical use: the intramedullary skeletal kinetic distractor (ISKD) (Orthofix Inc., McKinney, TX) [5, 14, 15, 28], the Albizzia nail (designed by Guichet and Grammont in France) [12, 13], and the Fitbone (Wittenstein Intens, Igersheim, Germany) [3, 23]. Of these three devices, the ISKD is the only device

approved by the FDA for use in the United States. Tibial lengthening with the ISKD has many advantages for the patient but presents some difficulties for the surgeon [5, 15, 28]. The device does not allow for precise control of the rate of distraction, and it is impossible to span the ankle to prevent equinus contracture. Because of this limitation, we developed a novel technique of inserting a temporary extraarticular ankle stabilization (EAAS) screw between the calcaneus and tibia to prevent equinus contracture.

We herein report the clinical results of using the EAAS screw to prevent equinus contracture during tibial lengthening with the ISKD. We also report the results of a cadaveric study in which we studied the anatomic structures at risk when the screw is inserted. The purposes of this article are to describe a new surgical technique, report our results and complications associated with the new technique, and describe the relevant pathoanatomy (cadaver study).

Materials and Methods

Clinical Study

Thirty-seven patients (49 tibiae) underwent tibial lengthening with the ISKD to treat limb-length discrepancy (LLD) or short stature between January 2003 and December 2006. Ten of the 37 patients underwent insertion of an extraarticular screw to prevent equinus. Of these 10 patients, two had fibular hemimelia, two had mesomelic dwarfism, and one each had congenital posteromedial bow, idiopathic hemihypertrophy, poliomyelitis, achondroplasia, posttraumatic LLD, and hypochondroplasia. The average

age was 24.5 years (range, 15–54 years). Minimum followup was 12 months (average, 28.2 months; range, 12–53 months). In our initial experience, we struggled to maintain the foot in dorsiflexion during the lengthening. We tried splints, casts, and physical therapy but found them unsuccessful in high-risk patients. High-risk patients are defined as patients with preexisting equinus requiring soft tissue release (as in tendo Achilles lengthening or Vulpis procedure) or unstable ankles (as in fibular hemimelia Paley type II or III [17]) and patients requiring extensive (greater than 3 cm) lengthening. In reaction to our observations, one of the senior clinical authors (DP) developed a novel technique, the EAAS screw, to securely stabilize the ankle during ISKD lengthening. This technique was introduced gradually during a 2-year period. As we became more experienced with the technique, we developed these indications: (1) lengthening more than 3 cm; (2) preexisting equinus; and/or (3) unstable ankle. The EAAS screw was used only in patients whom we thought at high risk for developing ankle equinus contracture and those who had an unstable ankle (Table 1). Ten of the 37 patients (four male and six female patients, 14 limbs) underwent insertion of an EAAS screw to prevent ankle equinus contracture. Clinical data were collected from a review of the patients' medical records. No patients were seen during followup specifically for this study. The clinical data collected included age, gender, diagnosis, preoperative LLD, amount of length achieved, indication for the insertion of the EAAS screw, date of surgery, duration of followup, details of surgery, pre- and postoperative ankle range of motion measured with a goniometer by the attending surgeons at pre- and postoperative visits, time to removal of EAAS screw, and complications.

Table 1. Patient data

Patient number	Diagnosis	Age (years)	Gender	Preoperative LLD (cm)	Length achieved (cm)	Followup (months)	Indication for EAAS screw
1	Fibular hemimelia	15	F	3	3	26	Unstable ankle; high risk for ankle contracture
2	Fibular hemimelia	17	F	6	5	53	Unstable ankle; high risk for ankle contracture
3	Idiopathic hemihypertrophy	17	M	6	5	12	High risk for ankle contracture
4	Congenital posteromedial bow	36	M	4.1	4.1	44	High risk for ankle contracture
5	Posttraumatic LLD (spastic hemiparesis)	18	F	6	5	18	Preexisting equinus contracture
6	Postpoliomyelitis LLD	54	F	4	3	25	Preexisting equinus contracture
7	Achondroplasia	16	M	n/a	7	25	High risk for ankle contracture
8	Hypochondroplasia	15	F	n/a	7	25	High risk for ankle contracture
9	Mesomelic dwarfism	28	F	n/a	5	17	High risk for ankle contracture
10	Mesomelic dwarfism	29	M	n/a	5	37	High risk for ankle contracture

EAAS = extraarticular ankle stabilization; LLD = limb-length discrepancy; n/a = not applicable.

Based on the radiographs, an independent observer (fellow) measured the preoperative LLD and length achieved. All relevant radiographs were available for all patients.

The patient was positioned supine on a radiolucent table. The tibial ISKD insertion was performed first, as per our routine surgical protocol [28]. Ankle range of motion was assessed to determine whether it was necessary to perform a soft tissue release to achieve 10° of ankle dorsiflexion. A gastrocnemius soleus recession was needed in two patients. The ankle was then held in 10° of dorsiflexion while a 2-mm guidewire was inserted from the posterior aspect of the calcaneal tuberosity to the lateral aspect of the distal tibia in an extraarticular position (through the posterior cortex of the distal tibia). The position of the guidewire was verified by using an image intensifier on the anteroposterior and lateral ankle views. The length of the screw to be used was measured by using a depth gauge. The guidewire was then overdrilled with a 5.2-mm cannulated drill. A 7-mm diameter fully threaded cannulated cancellous screw of the appropriate length (usually, 120–130 mm) was positioned from the calcaneus to the tibia (Fig. 1A–B). We do not recommend anterior tibial cortical penetration.

Fig. 1A–B (A) The patient had a malunited left tibial fracture with shortening and translational deformity. (B) Postoperative anteroposterior and lateral views show the ISKD in place before the start of lengthening. Note the position of the EAAS screw. A 4.5-mm diameter distal tibiofibular syndesmosis screw was also inserted to prevent disruption of the ankle mortise during lengthening.

Fig. 2A–B Intraoperative image intensifier (A) anteroposterior and (B) lateral views show the position of the EAAS screw in a cadaveric specimen. Note the screw starts on the back of the tuberosity of the calcaneus and is angled slightly on the anteroposterior view.

Patients with the EAAS screw followed the same standard postoperative protocol that all our patients with tibial ISKDs follow. The patients were allowed touchdown weight bearing during the distraction phase and partial weight bearing during the consolidation phase. For bilateral cases (eg, dwarfism), we achieve touchdown weight bearing by having the patients walk in the pool (hydrotherapy) with water up to the nipple level. The patients also can “stamp” their feet while seated. After the desired lengthening was achieved, the EAAS screw was removed.

Fig. 3A–B Cadaveric dissection shows (A) posterior and (B) lateral views of the EAAS screw and its relation to the sural nerve, posterior tibial nerve, flexor hallucis longus (FHL) muscle belly, and peroneal tendons.

However, if the patient could not achieve full knee extension, the screw removal was delayed to prevent ankle equinus from developing. In all cases, the EAAS screw was removed by 6 months to avoid an excessively lengthy period of ankle immobilization, even if residual knee flexion contracture was present.

We used paired *t* tests to identify differences between the pre- and postoperative ankle range of motion. The data met the assumptions of a parametric test. We used SPSS version 10 (SPSS Inc., Chicago, IL) for all analyses.

Cadaveric Study

A single surgeon (DP) inserted a fully threaded, cannulated cancellous screw (length, typically 125 mm; diameter, 7 mm) from the calcaneus to the distal tibia under image intensifier control (Fig. 2A–B) in eight human cadavers. The legs were then dissected to reveal the relation of the screw to the posterior tibial neurovascular bundle, peroneal tendons, sural nerve, Achilles tendon, flexor hallucis longus muscle, and ankle. The distance from the screw to each of these structures was measured in millimeters. Any injury to these structures was documented (Figs. 3A–B, 4A–E).

Results

Clinical Study

The average tibial lengthening was 4.9 cm (range, 3–7 cm). No patients developed an equinus contracture

during tibial lengthening. The EAAS screw was removed after lengthening was achieved (average, 3.3 months postoperatively; range, 2–6 months). Average preoperative ankle dorsiflexion was 10.36° ($\pm 6.50^\circ$; range, -5° to 20°) and plantar flexion was 38° ($\pm 5.04^\circ$; range, 30° to 40°). Average ankle dorsiflexion 6 months after removal of the screw was 10° ($\pm 5.88^\circ$; range, 0° to 15°) and plantar flexion was 37° ($\pm 4.13^\circ$; range, 30° to 40°). We observed no difference ($p = 0.752$ for dorsiflexion and $p = 0.136$ for plantar flexion) in pre- and postoperative ankle range of motion. No complications related to the use of the extra-articular calcaneotibial screw occurred. Our protocol required that the patient complete lengthening and attain full knee extension before the screw was removed. The screw was removed before this in three patients who exhibited knee flexion contracture because we felt that it was undesirable to leave the screw in longer than six months.

Cadaveric Study

The eight cadaveric legs were dissected to determine the distance from the EAAS screw to several anatomic structures. On average, the posterior tibial neurovascular bundle was 8 mm medial (range, 3–16 mm), the flexor hallucis longus tendon was 5 mm medial (range, 1–8 mm), the peroneal tendons were 20 mm lateral (range, 13–25 mm), the sural nerve was 18 mm lateral (range, 13–20 mm), the Achilles tendon was 7 mm posterior (range, 5–12 mm), and the ankle was 6 mm anterior (range, 3–10 mm) to the screw (Figs. 3A–B, 4A–E) (Table 2). The anatomic

Fig. 4A–E (A) The illustration shows a posterior view of the foot with the EAAS screw inserted. (B) A mediolateral view of the EAAS screw shows three cross-sectional levels of interest. (C) The cross-sectional view at level I shows the relationship of the screw to

structures at risk. (D) The cross-sectional view at level II shows the close relationship of the EAAS screw to the flexor hallucis longus muscle belly. FHL = flexor hallucis longus muscle. (E) The cross-sectional view at level III is shown.

structure most at risk was the flexor hallucis longus muscle belly. The screw grazed the lateral fibers of the flexor hallucis longus muscle belly in four of eight cadaveric legs. In the remaining four legs, the flexor hallucis longus

muscle was adjacent to the screw. The flexor hallucis longus tendon was never penetrated. All other structures of the legs were either untouched or were a safe distance from the screw.

Table 2. Distance of various structures from the extraarticular ankle stabilization screw

Structure	Distance in mm (range)
Posterior tibial neurovascular bundle	8 (3–16)
Flexor hallucis longus muscle belly	5 (1–8)
Peroneal tendons	20 (13–25)
Sural nerve	18 (13–20)
Achilles tendon	7 (5–12)
Ankle	6 (3–10)

Discussion

We describe a novel surgical technique to prevent equinus from occurring during tibial lengthening with an intra-medullary self-lengthening telescopic nail. We developed this technique after experiencing difficulties with equinus in some of our earlier cohorts of patients. Based on our clinical experience, we have been satisfied with this technique and our results support its success. However, we also were compelled to conduct an anatomic investigation of potential structures at risk by using a cadaver model.

Our clinical study had several limitations. First, the number of patients was relatively small (14 limbs in 10 patients) and might not have been large enough to reveal a small percentage of complications that might be associated with this method. Second, our measurements of ankle range of motion were purely clinical and might be subject to error [26]. Third, it is unknown how applicable this technique would be to the general orthopaedic community. Our center specializes in limb lengthening, and we have developed considerable expertise and experience in all aspects of limb lengthening, including identifying risk factors preoperatively and addressing postoperative complications.

External fixation to lengthen the tibia is a well-established technique [1, 2, 6, 7, 10, 19, 20, 22, 24, 25, 29, 30]. Ankle equinus contracture during tibial lengthening is a frequently reported complication [9, 18, 21]. The reported incidence in the literature ranges from 1% to 7% [9]. Joint contracture during lengthening occurs because of the tension generated in the muscle during distraction osteogenesis [21]. This affects biarticular muscles most because they tend to have fibers of various lengths, as opposed to uniarticular muscles, which have fibers of fixed length [21]. In biarticular muscles, inadequate adaptation of the perimuscular connective tissue during distraction osteogenesis results in the muscles becoming relatively short compared with the bone, resulting in joint contractures [8]. During tibial lengthening, the gastrocnemius-soleus-Achilles tendon complex is at risk. Tibial lengthening beyond the tolerance of the muscle to stretch will place this complex

under increasing tension, pulling the heel into the equinus position. The tolerance of the muscle complex to stretch depends on many factors: the rate of lengthening, the diagnosis and associated diseases of the patient (ie, higher incidence of complications in congenital, neuromuscular, and skeletal dysplasia cases), amount of lengthening (ie, more than 20% of the bone segment length), unifocal or bifocal lengthening, status of the gastrocnemius-soleus-Achilles tendon complex (eg, previous surgery, scarring), and the technique of pin insertion [18].

A number of options are available for preventing and managing ankle equinus contracture during lengthening [18, 21]. The problem can be dealt with preoperatively, intraoperatively, and/or postoperatively. Before surgery, the physiotherapist can teach patients a gastrocnemius-soleus-Achilles tendon complex stretching program and show them what to expect with splinting. During the surgical procedure, great care should be taken to avoid tethering the gastrocnemius-soleus-Achilles tendon complex with pins. The use of an atlas is recommended. If pins are inserted through this complex, they must be inserted properly by positioning the muscle group at its maximal stretch, with the ankle in full dorsiflexion. In high-risk cases (eg, lengthening more than 20% of bone segment length, scarred gastrocnemius complex, associated diseases [eg, congenital conditions, neuromuscular conditions, skeletal dysplasia], unstable ankle, when the patient is too young to cooperate with physical therapy), either prophylactic pinning of the foot or spanning the ankle with an external fixator is recommended. The ankle usually is spanned during the lengthening phase, and the foot component of the external fixator is removed during the consolidation phase. If prophylactic pinning of the foot and spanning of the ankle are not performed, a number of options are available to prevent ankle equinus contracture postoperatively. These options include passive stretching, positioning, and static and dynamic splinting of joints. The goal is to keep the muscle at its maximum stretch for as long as possible. However, especially in high-risk cases, it is difficult to prevent and correct equinus contractures with stretching, positioning, and splinting alone, unless the ankle can be maintained in the corrected position for at least 6 hours per day and the patient is compliant [27]. For high-risk cases, it might become necessary for the foot to be included in an external fixator secondarily to hold the ankle in dorsiflexion. Dorsiflexion can be achieved very easily with an external fixator.

Tibial lengthening with the ISKD has been developed to reduce the complication rates associated with external fixation and to improve patient comfort [5, 14, 15, 28]. However, the ISKD does not allow for precise control of the rate of distraction during lengthening and it is impossible to span the ankle to prevent equinus contracture.

Campbell [4] first described a permanent extraarticular ankle fusion in 1923 to treat the flail ankle with equinus deformity. He used an onlay bone graft from the calcaneus to the tibia to achieve fusion and correct the equinus deformity. A temporary extraarticular ankle arthrodesis with a screw has not been previously described in the literature. The senior author (DP) first used this technique in 2003. Since then, we have selectively used a temporary EAAS screw to prevent ankle equinus contracture from developing during tibial lengthening with the ISKD in patients at high risk for developing ankle equinus contracture. The indications for stabilizing the ankle in our series included lengthening more than 5 cm, unstable ankle, congenital or neuromuscular condition, skeletal dysplasia, and preexisting ankle equinus contracture.

The extraarticular calcaneotibial screw has been successful in preventing equinus contracture from developing during tibial lengthening with the ISKD. The preoperative ankle range of motion was regained within 6 months after screw removal. In this series, no complications associated with the insertion of this screw occurred. Specifically, we did not observe any mechanical failures (fractures of the screws) or any fractures caused by the screws. Our protocol of limiting weight bearing probably prevents this. Another potential complication is inadvertent ankle/subtalar joint compression. This is unlikely to occur because we always use a fully threaded implant, thus avoiding compression. Since this study was closed, we have had a recent case, still under treatment, in which a serious complication was observed. That patient developed a deep posterior compartment syndrome and tarsal tunnel syndrome from hemorrhage that seemed to result from the EAAS screw. It is unclear which vessel was damaged. The posterior tibialis artery was intact as assessed by Doppler ultrasonography, but a large hematoma was discovered at the time of surgical decompression.

The cadaveric study showed the potential anatomic structures at risk during insertion of the EAAS screw. The flexor hallucis longus muscle belly is most at risk, but unnamed branches of the posterior tibial artery and vein could also be at risk. The screw should be inserted in a slightly oblique fashion from the upper edge of the calcaneus, slightly lateral to the center, and should be aimed slightly lateral in the tibia to avoid injury to the flexor hallucis longus muscle.

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