Custom Knee Device for Knee Contractures After Internal Femoral Lengthening

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abstract

The development of knee flexion contractures is among the most common problems and complications associated with lengthening the femur with an internal device or external fixator. Conservative treatment strategies include physical therapy, serial casting, and low-load prolonged stretching with commercially available splinting systems. The authors developed an individually molded, low-cost custom knee device with polyester synthetic conformable casting material to treat knee flexion contractures. The goal of this study was to evaluate the results of treatment with a custom knee device and specialized physical therapy in patients who had knee flexion contracture during femoral lengthening with an intramedullary lengthening femoral nail. This retrospective study included 23 patients (27 limbs) who underwent femoral lengthening with an internal device for the treatment of limb length discrepancy. All patients had a knee flexion contracture ranging from 10° to 90° during the lengthening process and were treated with a custom knee device and specialized physical therapy. The average flexion contracture before treatment was 36°. The mean amount of lengthening was 5.4 cm. After an average of 3.8 weeks of use of the custom knee device, only 2 of 27 limbs (7.5%) had not achieved complete resolution of the flexion contracture. The average final extension was 1.4°. Only 7 of 27 limbs (26%) required additional soft tissue release. The custom knee device is an inexpensive and effective method for treating knee flexion contracture after lengthening with an internal device. [Orthopedics. 2015; 38(7):e567-e572.]

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Loss of knee range of motion is a common problem after femoral lengthening, regardless of the lengthening technique used.\textsuperscript{1,6} Multiple modifications of lengthening techniques have been made to reduce this complication.

Limb-lengthening with the Intramedullary Skeletal Kinetic Distractor (ISKD) (Orthofix, Inc., Lewisville, Texas) avoids the use of external fixators.\textsuperscript{7} This technique eliminates the need to transfix muscles with pins and wires, which reduces associated pain and thus allows easier rehabilitation. Knee extension contracture, which is a limited ability to flex the knee and is associated with external fixation,\textsuperscript{8} potentially can be reduced when transfixion of the thigh muscles is avoided. However, use of the ISKD potentially can lead to a knee flexion contracture, which is inability to fully extend the knee. Unlike traditional lengthening techniques with external fixation, the ability to extend the apparatus across the knee joint to stabilize and position the joint is lost.\textsuperscript{4} A disadvantage of the ISKD is inability to control the rate of lengthening.\textsuperscript{6} Kubiak et al\textsuperscript{9} reported uncontrolled femoral lengthening in 9\% of their patients. In a more recent study, Simpson et al\textsuperscript{10} reported uncontrolled femoral lengthening in 21\% of their patients. A knee flexion contracture may develop with uncontrolled femoral lengthening because the hamstring may not have had the opportunity to lengthen in tandem with the femur.

Why is knee extension so important?

Severe knee flexion contracture in patients after limb lengthening can result in knee subluxation,\textsuperscript{1} which can lead to a host of other problems. In patients with congenital limb deficiency, knee flexion contracture causes rotatory subluxation of the knee and internal dislocation of the patella. Further, the adverse effect of knee flexion contracture on physical function has been well explored. Knee flexion contracture of 15° or greater has been shown to lead to mechanical overload in both the affected and the nonaffected limb.\textsuperscript{11} This contracture also increases the quadriceps force required to stabilize the knee in weight bearing. A corresponding increase in tibiofemoral and patellofemoral joint surface stress and muscle fatigue results in pain and discomfort.\textsuperscript{12} In terms of gait, knee flexion contracture can affect walking velocity and step length\textsuperscript{13} and alters trunk kinematics.\textsuperscript{14} Knee flexion contracture also can result in a shortened limb, which defeats the purpose of limb-lengthening surgery.

Although the effect of knee extension on outcome and function is well known, few studies have reported on complications related to loss of joint motion. The available studies had either small\textsuperscript{15} or mixed\textsuperscript{16,17} sample sizes and reported mixed results. To the authors’ knowledge, only limited studies have discussed conservative management of knee flexion contracture after femoral lengthening with an internal device.\textsuperscript{18} A better understanding of the development and management of knee flexion contracture in patients after femoral lengthening with an internal device is important to improve patient care. This study had 3 goals: (1) to determine the incidence of knee flexion contracture in patients after femoral lengthening with the ISKD; (2) to report on the management of knee flexion contracture with a customized knee device in these patients; and (3) to determine factors that predict the development of knee flexion contractures in these patients.

**Materials and Methods**

The authors conducted a retrospective cohort evaluation of patients treated with ISKD femoral lengthening at their institution between 2002 and 2007. During this time, 100 patients (121 limbs) underwent surgery performed by 3 experienced limb-lengthening surgeons (S.C.S, D.P., J.E.H.). The patients also underwent mid-diaphyseal osteotomy. A detailed description of the surgical technique was previously reported.\textsuperscript{6} All patients underwent surgical iliobibial band release at the level of the superior pole of the patella.

From this cohort, patients with persistent knee flexion contracture (knee flexion contracture group) after isolated femoral limb lengthening, despite treatment, were identified. Knee flexion contracture was defined as a passive knee extension deficit of 10° or more. Therefore, the final sample of the knee flexion contracture group included 23 patients (27 limbs) undergoing femoral lengthening with the ISKD. The institutional review board approved the study procedures.

**Physical Therapy and Knee Flexion Contracture Intervention**

All patients were mobilized on postoperative day 1 and were allowed 50 lb (22.6 kg) of weight bearing. They were gradually advanced to full weight bearing after 2 of 4 cortices were completely healed. Patients had daily physical therapy sessions 5 times a week in the outpatient setting. Physical therapy interventions included posterior anterior joint mobilization to improve knee extension; stretching of the hamstrings, tensor fascia lata, and iliobibial band; and neuromuscular electrical stimulation of the quadriceps. A custom knee device was applied to the limb when a knee flexion contracture of at least 10° was noted.

All of the custom knee device splints (Figure 1) were designed and customized with a standardized technique. Polyester-based casting tape (Dynacast PII BSN Medical, Charlotte, North Carolina) was used. This lightweight material conforms well and is rigid enough to transmit optimal force. The fabrication protocol for custom knee devices was previously described.\textsuperscript{19} Briefly, after casting of the thigh and the shank of the index leg, polycentric knee hinges were bent around the knee in alignment with the axis to conform to the patient’s anatomy. The hinges were...
placed into greater flexion than the available extension range to increase extension moment at the knee joint. Once the hinges were incorporated into the cast, 2 proximal and 2 distal hooks were applied. These hooks were used as fulcrums to anchor a TheraBand (The Hygenic Corporation, Akron, Ohio) for application of tension. The level of TheraBand used was dependent on patient need and gradually increased over time.

Each brace took approximately 60 to 90 minutes to construct, at a total cost of $215 to $255. All custom knee devices used in this study were fabricated by 1 of the authors (A.B.).

The following custom knee device protocol was advised:

1. Wear the custom knee device at maximally tolerated tension 6 to 8 hours daily. Apply the TheraBand in a figure-of-8 configuration, crossing the distal femur to provide knee extension moment.
2. Prop the heel on a pillow to use gravity and promote knee extension when sitting or lying down for an extended time.
3. Use the custom knee device for an additional 2 to 3 weeks for 1 hour, twice a day, even after full extension is achieved, to maintain the correction obtained.

Patient demographics, the etiology of limb shortening, and lengthening parameters were obtained. Outcome measures included passive knee range of motion, which was measured with a standard goniometer with the patient in the supine position with 10° to 15° of hip flexion.

Statistical Analysis
Analysis was performed with SPSS version 18.0 (SPSS Inc, Chicago, Illinois), to detect differences between measurements. \( P < .05 \) was considered significant.

RESULTS
In total, 27 of 121 limbs (22.3%) had knee flexion contracture after femoral shortening with the ISKD. This group included 23 patients, 14 male and 9 female, with an average age of 25 years (range, 11-58 years). Three patients had bilateral knee flexion contractures. Sixteen patients had femoral lengthening secondary to congenital shortening, 4 patients (8 limbs) because of short stature, 2 patients for posttraumatic shortening, and 1 patient as a result of shortening after childhood poliomyelitis.

The mean amount of lengthening in the study patients was 5.4 cm (range, 3.3-7.5 cm). Brace treatment was started an average of 3.9 weeks (range, 1-7 weeks) after limb lengthening surgery. Mean flexion knee contracture before brace application was 36° (range, 10°-90°). Overall, after an average of 7.9 weeks (range, 5-11 weeks) of custom knee device application, only 2 of 27 knees (7%) did not achieve full resolution of knee flexion contracture (Figure 2). Resolution was defined as having flexion contracture of 5° or less. One patient had a residual 15° of knee flexion contracture (initially 20°) after 10 weeks of use of the custom knee device. This patient had concurrent knee subluxation related to the limb lengthening surgery and required a course of BOTOX A (Allergan, Inc, Parsippany, New Jersey) injections to relax the muscle around the knee. The second patient had residual knee flexion contracture of 10° (initially 55°) and required surgical nerve release for peroneal nerve symptoms. Average final extension was 1.35° (range, 0°-15°).

This study also found a relationship between the amount of limb lengthening and knee flexion contracture. Patients with 5 to 8 cm of lengthening had an average flexion contracture of 43° compared with 30° in patients with 4.9 cm or less of lengthening (\( P = .055 \)) (Figure 3). In 7 of 27 limbs (27%), soft tissue release was also required to address the knee flexion contracture. However, surgery was avoided in 20 of 27 limbs (73%).

Other complications related to the limb lengthening procedure included 13 peroneal nerve problems, and 5 of these required nerve release. Fourteen patients (14 limbs) had knee subluxation. Considering the study population, subluxation is more common in patients with congenital femoral deficiency as a result of absence of cruciate ligaments.

No complications related to use of the custom knee device were noted.

DISCUSSION
Knee flexion contracture is common after femoral lengthening, regardless of the lengthening technique used. In the current study, knee flexion contracture occurred in 27 of 121 limbs (22.3%). Many modifications in lengthening techniques have been made to reduce this complication. The authors developed and tested a new custom knee device to resolve this complication. This study reported a tech-
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A technique for the management of knee flexion contracture in these patients that included a custom knee device and specialized physical therapy. In this study, 25 of 27 patients (93%) achieved full resolution of knee flexion contracture after an average of 7.9 weeks of treatment.

Knee flexion contracture occurred in 27 of 121 patients (22.3%) after ISKD lengthening was performed at the study institution. A number of factors are associated with knee flexion contracture. One disadvantage of the ISKD, which is no longer marketed in the United States, is inability to control the rate of lengthening in some patients. Kenawey et al. emphasized that the distraction rate should be less than 1.5 mm/d to avoid this complication. It was difficult to estimate the distraction rate for the patients in the current study; the guideline is 1 mm/d.

Magnitude of lengthening is also an associated factor for knee flexion contracture. In the current study, patients with 5 to 8 cm of lengthening had an average of 43° of flexion contracture compared with 30° of knee flexion contracture in patients with lengthening of 4.9 cm or less. Venkatesh et al. treated 20 patients with achondroplasia with external fixation and divided the patients into 2 groups according to whether lengthening was less than or more than 50% of the initial bone length. They found that lengthening of more than 50% of the initial bone length was associated with joint stiffness and decreased range of motion.

In a study of 35 patients after femoral lengthening, Barker et al. found that loss of knee extension occurred in children younger than 18 years. In addition, loss of more than 40° of extension during the lengthening phase may be associated with posterior knee subluxation, at which point lengthening should be halted.

Few studies have reported conservative management of knee flexion contracture after femoral lengthening. Shabtai et al. treated 18 patients (21 segments) with congenital limb shortening with the PRECICE intramedullary nail (Ellipse Technologies, Inc, Irvine, California). This nail is controllable and also reversible. All patients were treated with a custom knee device postoperatively to prevent knee flexion contracture. Only 1 of 18 patients (5.5%) in this study required surgical release after knee flexion contracture. Al-Oraibi showed the efficacy of serial casting for the treatment of knee flexion contracture in children with spina bifida. The numerous advantages of a custom knee device compared with serial casting include less wearing time, lighter weight, and the ability to perform hydrotherapy in combination with physical therapy. In addition, knee motion to maintain full range of motion after lengthening is very important.

To avoid contracture, the muscle should be under tension for as many hours

Figure 2: A 16-year-old girl with congenital short femur after 5.5 cm of femoral lengthening with an Intramedullary Skeletal Kinetic Distractor (Orthofix, Inc, Lewisville, Texas). Photograph showing treatment before use of the custom knee device with 40° knee flexion contracture (A). Photograph obtained 2 weeks after physical therapy and use of a brace (B). Photograph obtained 3 months postoperatively showing full knee extension (C).

Figure 3: Effect of amount of lengthening on loss of knee extension.
as possible. Stretching exercises do not lead to prevention of contracture unless they can be maintained for at least 6 hours daily.4

The high success rate with the custom knee device is not surprising. This custom-molded, hinged device delivers a sustained stretch over time. The custom knee device is removable, easy to apply, and inexpensive. The approximate material cost of fabricating a typical custom knee device includes the cost of polycrystalline hinges ($65) and 4 to 6 rolls of casting tape ($14 to $33), for a total material cost of $79 to $98.

In addition, making a custom knee device is billed as Current Procedural Terminology code 09575 (fabrication of long leg splint). The average charge is $135. Therefore, the total cost of a custom knee device is $223.

In comparison, traditional off-the-shelf dynamic splints involve a monthly rental rate. The cost billed to the patient’s insurance for these devices varies from $816 to $2040. McGrath et al21 treated 47 patients with mean knee flexion contracture of 22° after total knee replacement. Of these 47 patients, 40 (85%) achieved full extension after a mean treatment time of 9 weeks.

Other advantages of the custom knee device include custom fit, a lever arm, and variable resistance. In addition, the device can be fitted and applied in the clinic the day it is needed. In contrast, off-the-shelf dynamic splints require measurements, insurance approval, and a separate fitting appointment. As a result, fitting of the device may be delayed by 2 to 3 weeks. The only limitation that the authors observed with a custom knee device was that patients sometimes needed assistance in applying the brace.

Most previous publications on knee stiffness addressed surgical treatment. Quadricepsplasty, anterior distal hemi-epiphysiosis with a tension band plate, and arthroscopic or open surgical capsular release are surgical methods to treat decreased knee range of motion after limb lengthening for various etiologies.22-26

Limitations
A limitation of this study is that it was a retrospective noncomparative study. No control group was used, and therefore the natural pattern of resolution is unknown.

Conclusion
The study findings suggested that use of a custom knee device in conjunction with specialized physical therapy is an inexpensive, noninvasive treatment and is effective for patients after femoral lengthening. However, the clinical benefit and cost-effectiveness of this approach await verification with randomized studies.

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