Summary: Stature lengthening for short stature, often referred to as cosmetic stature lengthening, is controversial. Previous methods and devices have been fraught with high complications rates. The PRECICE intramedullary lengthening nail offers a superior alternative for these patients due to its minimal incision technique, remote controlled gradual distraction, the rate of which can be accurately modulated and the direction reversed, if necessary. The purpose of this study is to report the results of the PRECICE for short stature lengthening and to compare them to previously reported results with other methods. Another objective of this paper is to discuss the indications for treatment by exploring the motivation, selection, and outcome of such treatment. Fifty-one patients were lengthened for short stature with the PRECICE; 25 with the PRECICE 1 (P1) and 26 with the PRECICE 2 (P2). There were 7 bilateral tibial and 22 bilateral femoral lengthenings in the P1 and 4 bilateral tibial and 25 bilateral femoral lengthenings in the P2 groups. In total there were 58 P1 and 58 P2 bone segments lengthened. Lengthening was up to 6.5 cm for P1 and 8 cm for P2 with an average increase of 5.2 cm for P1 and 6.0 cm for P2. There were 7/58 (12.1%) implant failures for P1 and 1/58 (1.7%) for P2. The P1 failures were due to breakage of the nail through a weld in the nail in 4 cases and the breakage of the mechanism in 3 cases. The P2 failure may be related to too little overlap of the wider nail tube into the distal bone segment combined with potential stress fracture propagation due to small slots at the end of the larger tube of the nail. All nail breakages occurred in patients who did not comply with the weight-bearing restrictions. The new clutched mechanism and 1-piece outer tube construction in the P2, prevented fracture through the nail and mechanism failure in the P2 compared with the P1. Stress propagation by the small slots at the end of the P2 led to redesign with elimination of slots and release of the P2.1. There were 2 cases of suspected fat embolism despite venting and 1 deep vein thrombosis upon stopping anticoagulation, from which the patient recovered without further complication. There was 1 femur fracture through an anteroposterior femoral locking screw and 1 bilateral peroneal nerve stretch injury that fully recovered. All patients consolidated the distraction gap of the femurs and/or tibias without additional surgery. All returned to previous activities including sports. In comparison to previously published methods, the P2 had the lowest complication rate with the best overall reported results.

Key Words: stature lengthening—cosmetic lengthening—limb lengthening—stature dysphoria—PRECICE—implantable limb lengthening.

(Min Ortoph 2015;30: 167–182)
Patients all received an EOS (EOS Imaging, Paris, France) imaging study and full leg length anterior-posterior and lateral x-rays to ensure appropriate dimensions for nail insertion, quantitate body proportions (lower limbs to height and tibia to femur), preoperative leg length discrepancy, and alignment. A prerequisite for surgery was skeletal maturity of the lower limbs with closure of the lower limb physes. All patients had to stay in the vicinity until the end of the distraction phase, do daily physiotherapy at our center throughout the distraction phase, comply with weight-bearing restrictions until radiographic bone consolidation (distraction and consolidation phases), and come in for biweekly follow-up radiographs and examination by the surgical team during the distraction phase. The purpose of these visits is to monitor their muscle flexibility, nerve function, joint range of motion, and bone formation, as well as, to monitor that the amount of lengthening expected is confirmed by radiographic measurement. Although the ERC device has a digital read out of length, it only displays the presumed amount of lengthening. If a patient does not push the device down deep enough, they can get behind on the lengthening because the ERC magnet needs to be within 5.5 cm of the nail magnet to rotate it. It is not uncommon for patients to get behind on lengthening one side compared with the other. Typically, they are always on track on the right side if they are right-handed and vice versa. It seems they put less pressure on their thigh with the ERC device on the side opposite their dominant hand. Initially, the FDA required distraction with ERC to be done at the physician’s office. The FDA approved home use of the ERC as of October 2012 (Fig. 2). Before this date, the lengthening was performed daily by our orthopedic technologist. After October 2012, all patients were taught to perform the lengthening at home using the ERC device and the lengthening was performed by the patient or their personal care giver. All patients underwent preoperative physical and psychological evaluation by the surgeon. Psychologically, we evaluated motivation and objectives in an effort to evaluate how realistic patients’ goals were, compared with the achievable safe lengthening goal. A detailed mental health history was obtained, and the patient’s mood, thought form, suicidal risk, and reality conformance were assessed by the surgeon. Evaluation by a psychologist or psychiatrist was required when the surgeon believed that the mental health history was concerning or the patient reported major psychiatric disorder, extended previous use of psychiatric drugs, or any history of self-injury, suicidal ideation, or attempt. Only 1 patient in the study group was mandated to have a psychiatric evaluation before the lengthening.

The physical examination included documentation of preoperative gait, lower limb joint range of motion of the hips, knees, ankles, and subtalar joints, including prone hip and knee rotation profiles. Muscle length tests were performed to identify preoperatively tight soft tissues so as to plan for prophylactic soft tissue releases. For femur lengthening, these included measurement of the popliteal angle [flexion of the hip to 90 degrees with extension of the knee joint; (Fig. 3A); the angle measured between the vertical and the maximum knee extension position of the tibia] to assess hamstring muscle length, prone knee bend to assess the rectus femoris length by seeing if the prone knee bend was less than the supine knee bend before there was flexion of the pelvis (Ely test, Fig. 3B); and seeing if the knee would drop below horizontal in the lateral decubitus position with hyperextension of the hip and 90 degrees flexion of the knee (Ober test) to assess contracture of the iliotibial band (ITB) (Fig. 3C). For tibial lengthening, we measured the dorsiflexion of the ankle in maximum knee extension and compared it with the dorsiflexion with the knee flexed (Silfverskiold test) (Fig. 3D). If a muscle length test was positive, it indicated that the tight soft tissue would become contracted.

FIGURE 1. PRECICE 1 (P1) and PRECICE 2 (P2) tibial nails. The larger diameter part of the nail houses the mechanism. In the P1 there are welds at the upper and lower end of the mechanism (arrows). In the P2 there are no welds connecting the different parts of the larger diameter part of the nail.
even with small amounts of lengthening. This was an indication for soft tissue release or lengthening of that soft tissue at the time of the surgery. All patients who are planned for femoral lengthening >5 cm and who have a positive Ober sign and positive popliteal angle are recommended to have a distal release of the ITB and biceps tendon. A 3 cm midlateral incision in line with the intermuscular septum at the level of the superior pole of the patella is made. The ITB is cut transversely anterior to the incision. The intermuscular septum is cut transversely, avoiding the lateral geniculate vessels. The biceps tendon is identified and its aponeurosis cut transversely (muscle recession). In this study all patients with lengthening >6.5 cm had the ITB and biceps tendon lengthened. The ITB and biceps were not lengthened in patients planned for 4 cm or less of lengthening. In patients planned for 5 to 6.5 cm, they were lengthened only if the Ober and popliteal angles signs were positive. For lengthening >6.5 cm, the ITB was always cut irrespective of the results of the Ober test. The gastrosoleus recession, according to the author’s (D.P.) previously published method, is performed when the Silfverskiold test is positive, especially for tibial lengthening >5 cm. In this study no gastrosoleus recessions were performed.

Preoperative templating was done in all cases to determine nail diameter, length, and osteotomy level. The osteotomy level was planned to ensure that, at the end of desired lengthening, the wider portion of the nail remained engaged in the distal femur or tibia with approximately 3 cm of overlap. The senior author’s detailed description of femoral and tibial lengthening has been published previously. The surgery is done with the aid of fluoroscopy through a minimally invasive method with very small percutaneous incisions so as to leave minimal scarring (Fig. 4). Standard starting points for tibial and femoral antegrade (femoral: piriformis or trochanteric) nail insertion were used. (Retrograde femoral nailing is avoided due to greater knee complications, such as loss of knee flexion motion. It is also better to start the lengthening process without a knee hemarthrosis). The osteotomy was performed using a sharp osteotome after first predrilling the osteotomy site with 4.8 mm drill holes. A total of 3 entrance and 3 exit holes were made in the femur. In the femur, these drill holes were always made before reaming to act as venting holes, thereby reducing the risk of fat embolism, as well as to ensure that the reamings would extrude out the holes to “autograft” the osteotomy site. In the tibia, 1 anterior hole and 1 medial hole are drilled to avoid extrusion of reamings into the anterior or deep posterior compartments. Such extrusion can lead to compartment syndrome. Although percutaneous prophylactic fasciotomy of the anterior compartment can be performed to reduce the risk of compartment syndrome, it leaves the patients with bulging muscles anteriorly, which is unacceptable cosmetically. Therefore, it is best to avoid any extrusion into the compartments by not creating lateral or posterior cortical holes. Posterior and lateral cortical holes are drilled after the reaming in order to notch the tibia and make completion of the osteotomy easier. The canal is reamed 2 mm over the nail diameter for both femur and tibia. For the femur, the
noncannulated PRECICE nail is advanced up to the osteotomy site. An extension moment is applied while the bone is osteotomized with an osteotome from the lateral side. The nail is then advanced down the bone after the osteotomy is completed. In the tibia, the bone is osteotomized without the nail in place but after the reaming and drilling are completed. The nail is then inserted and advanced down the tibia. The location of the nail magnet is marked on the skin using fluoroscopy. The ERC is then placed stereotically on the area and activated for 7 minutes to lengthen 1 mm, which is confirmed on comparative images. For the tibia, a mid-diaphyseal fibular osteotomy is performed through a small postero-lateral incision, usually before the reaming of the tibia. The author’s (D.P.) fibular osteotomy technique is to make multiple drill holes with a 1.8 mm Ilizarov bayonet wire, followed by completion of the osteotomy using a small diameter osteotome (3 mm).

The fibula is also first fixed distally using a 4.5 mm screw between the fibula and tibia. The orientation of this screw, which is referred to as a “temporary arthrodesis screw of the tibiofibular joint” is proximal on the tibia and distal on the fibula. The author (D.P.) prefers the head of the screw to be on the fibular side. The proximal tibiofibular joint is also fixed with a screw. Whenever possible this is done using one of the proximal locking screws. This requires targeting the fibula at the time of insertion of the anteromedial to postero-lateral screw in the nail. As this screw is at a different level for the right or left legs, the nail has to be advanced more on the left side to match the trajectory of the screw hole with the head of the fibula. If the targeting misses the proximal fibula, a second 4.5 mm temporary arthrodesis screw should be inserted by first inserting a wire followed by a cannulated drill hole followed by the solid screw. The authors do not use a cannulated screw because it is too weak and may bend or break. The lengthening rate for the tibia is usually 0.75 mm/d and for femurs 1 mm/d (each broken into 0.25-mm intervals). The distraction starts on postoperative day 1 for patients under 30 years, and day 7 for those 30 years or older for femur lengthening and for all tibial lengthening. After surgery the patient is usually in the hospital for 3 to 4 nights. They are anticoagulated with XARELTO® (rivaroxaban) from the second or third day after surgery until they are fully ambulatory without crutches after completing the consolidation phase.

Coincidentally, there were equal numbers of limb segments (femur, tibia) lengthened in the P1 and P2 groups (P1—25 patients and 58 limb segments and P2—26 patients and 58 limb segments), which made for simplified statistical analysis (Table 1). In the P1 group, there were 6 nails for bilateral tibia lengthening (3 patients), 16 nails for 4 segment bilateral femur and tibia lengthening (4 patients), and 36 nails for bilateral femur lengthening (18 patients). In the P2 group, there were 2 nails for bilateral tibia lengthening (1 patient), 12 nails for 4 segments (3 patients), and 44 nails for bilateral femur lengthening (22 patients). Two femoral nails in each group (total of 4 nails) were inserted through trochanteric starting points and the remainder of the femoral nails by piriformis starting points. Overall our cohort consisted of 44 males and 6 females with a mean age of 27.8 years (range, 15 to 51 y). The mean preoperative height in patients was 164.7 cm (range, 150 to 180 cm) [64.8 inches (range, 59 to 70.9 inches)]. Patients were followed every 2 weeks during the distraction phase and once a month during the consolidation phase until anteroposterior and lateral radiographs demonstrated 3 of 4 cortices were solid. Radiographic alignment parameters were measured digitally as previously described, and done using PACS (Picture Archiving and Communications System) (OnePacs LLC, New York, NY).

The statistical analysis was carried out using the statistical software, SAS 9.2 (SAS Institute Inc., Cary, NC). All variables were analyzed as continuous, categorical, or ordinal, as deemed appropriate. Given the nature of data, a paired Student t test was used to analyze differences between matched data sets. Descriptive statistics were used when suitable. No power analysis was done prior, as this is a retrospective series. IRB approval for a retrospective study was obtained.

**RESULTS**

Overall goals of achieving length were excellent. Documented preoperative lengthening goals were 6.2 cm (range, 2.5 to 8.0 cm). Radiographically measured lengthening achieved was 5.6 cm (range, 1.7 to 8.0 cm). For the P1 group, the preoperative goal was 6.0 cm (range, 2.5 to 6.5 cm) and final length achieved was 5.2 cm (range, 1.7 to 6.5 cm) (Fig. 5). For the P2 group, the preoperative goal was 6.3 cm (range, 4.0 to 8.0 cm) and the final length achieved was 6.0 cm (range, 2.5 to 8.0 cm) (Fig. 6).

Rate of distraction was calculated as total length gained divided by total number of days of distraction. The overall rate of distraction for the entire group 0.83 mm/d (range, 0.48 to 1.1 mm/d); 0.82 mm/d for P1 and 0.85 mm/d for P2. For femurs alone 0.88 mm/d (range, 0.57 to 1.1 mm/d) and for tibias alone 0.63 mm/d (range, 0.46 to 0.91 mm/d).

**RADILOGICAL DATA**

The mechanical lateral proximal femoral angle (mL DFA), posterior distal demur angle (PDF A), posterior proximal tibial angle (PPTA), and medial proximal tibial angle (MPTA) were measured before and after lengthening. For femoral lengthening the mean mL DFA before and after are 87.3 degrees (±1.9 degrees) and 87.6 degrees (±1.9 degrees), respectively. This difference was not statistically significant (P = 0.06). For femurs the mean PDF A preoperative was 81.1 degrees (±1.3 degrees) and postoperative 81.0 degrees (±1.6 degrees). This was not statistically significantly different (P = 0.34). For tibial lengthening, the mean preoperative

![Image](http://www.techortho.com)

**TABLE 1. PRECICE Nail Type vs. Bone(s)**

<table>
<thead>
<tr>
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<th>PRECICE 1</th>
<th>PRECICE 2</th>
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</thead>
<tbody>
<tr>
<td>Femur</td>
<td>36</td>
<td>44</td>
</tr>
<tr>
<td>Tibia</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Femur + tibia</td>
<td>16</td>
<td>12</td>
</tr>
<tr>
<td>Total</td>
<td>58</td>
<td>58</td>
</tr>
</tbody>
</table>
MPTA was 86.5 degrees (± 1.7 degrees) and after lengthening was 90.0 degrees (± 3.2 degrees). The differences in the MPTA for tibial lengthening were statistically significant ($P < 0.01$).

Finally, the mean PPTA preoperative was 79.7 degrees (± 4.0 degrees) and 78.1 degrees (± 3.6 degrees) after treatment. This difference was not statistically significant ($P = 0.09$) (Table 2).

**COMPLICATIONS**

In the P1 group, there were 4 nail breakages in 3 patients (4/58; 7%), occurring in 3 femurs and 1 tibia (Fig. 5). All 4 nail breakages occurred in 3 patients who were admitted to not adhering to weight-bearing restrictions during the consolidation phase. These 3 patients were advised to remain at...
FIGURE 6. Preoperative anteroposterior and lateral full body EOS scans for assessment of body proportions, and alignment (A). PRECICE 2.12 mm diameter/245 mm length bilateral femoral lengthening showing progressive increase in femoral length during the distraction phase. The lengthening rate was 1 mm/d (B, C). The iliotibial band and biceps tendon were lengthened at the time of the surgery. Final limb length and alignment radiograph taken at the end of the distraction phase (80 d after surgery) (D). A total of 8 cm of lengthening was achieved. Anteroposterior and lateral radiographs of both femurs showing complete bone consolidation 2 months after completing the lengthening (E). The patient is seen standing beside a female friend and Dr Paley (Dr Paley’s height is 5 ft 11 inches) (F). The inset in this picture (upper left) shows this patient’s height measured at 6 ft 1 inch. He returned to sports activities 6 months after surgery. This case makes the point that it is not for us to judge who is to get this procedure based on their starting height. Stature dysphoria is independent of height. Some individuals such as this one live in a taller society or have much taller parents and siblings and are internally driven to have this done even though most people might not consider their starting height short. It is not for the surgeon to judge the patients motivation simply based on starting height.
TABLE 2. Joint Orientation Angles Before and After Lengthening

<table>
<thead>
<tr>
<th></th>
<th>Preoperative (SD)</th>
<th>Post (SD)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>mLDFA</td>
<td>87.3 (± 1.9)</td>
<td>87.6 (± 1.9)</td>
<td>0.06</td>
</tr>
<tr>
<td>PDFA</td>
<td>81.1 (± 1.3)</td>
<td>81.0 (± 1.6)</td>
<td>0.34</td>
</tr>
<tr>
<td>MPTA</td>
<td>86.5 (± 1.7)</td>
<td>90.0 (± 3.2)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>PFTA</td>
<td>79.7 (± 4.0)</td>
<td>78.1 (± 3.6)</td>
<td>0.09</td>
</tr>
</tbody>
</table>

mLDFA indicates mechanical lateral distal femoral angle; MPTA, medial proximal tibial angle; PDFA, posterior distal femoral angle; PFTA, posterior proximal tibial angle; SD, standard deviation.

50 lb (23 kg) weight-bearing with crutches or a walker until monthly radiographs demonstrated 3 intact cortices.9,17,19 None of these 3 had achieved cortical bridging. All 3 femurs went into procurvatum and varus deformity. All 3 femurs were treated by fixator-assisted nailing of the femurs. Under general anesthesia, the femur was straightened using 2 unicortical external fixators (anterior 2 pin monolateral and lateral 2 pin monolateral). The broken PRECICE was removed through the piriform fossa after the femur was straight. If some parts could not be extracted using long pituitary clamps, they were removed by inserting a retrograde Rush rod to push the distal end of the nail out the proximal end of the femur (Fig. 7). The length and alignment of the femur was maintained by the external fixator, whereas a standard femur locking nail (Trigen; Smith & Nephew, Memphis, TN) was inserted to stabilize the femur. After this nail was locked, the biplanar external fixators were removed, during the same operative procedure. The purpose of the external fixators was as instruments to correct the angular deformities and to maintain the alignment and length during the remaking. All 3 femurs healed without any loss of length and alignment. The fractures occurred during the consolidation phase, on day 175 after surgery in the first patient. The patient was walking unaided up the stairs. The second patient fractured his left femur PRECICE, while walking to the bathroom on postoperative day 96. He, too, was walking without crutches. After successfully treating the left femur, he broke the right femur on day 119. In all 3 instances, the nail broke through the weld of the nail that was either at the proximal or distal end of the mechanism. There was 1 fracture of a tubal P1 nail. This was identified at the time of elective nail removal surgery. The patient did not know that the nail had broken as the tibia healed uneventfully with a 5-degree procurvatum diaphyseal bend (Fig. 5). The distal end of the nail was extracted proximally by driving a Rush rod retrograde through the medial malleolus, pushing the distal segment proximally. There was 1 other femur fracture in the P1 group (Fig. 8). This fracture occurred through the anterior-posterior distal locking screw. The fracture occurred quite unexpectedly during a physical therapy straight leg raising hamstring stretch maneuver. The patient was again treated by fixator-assisted nailing. The nail in this case was intact.

There were 3 P1 femur nails that began distracting the bone and then failed to continue to lengthen (3/58; 5%). One of these patients presented as a premature consolidation. Two of these were treated with nail exchange and reosteotomy. In the third, the lengthening was stopped 1 cm short of the goal. This patient was planning to have a bilateral tibial lengthening performed at a later date, so the leg length difference was equalized during the second lengthening and height goals were achieved. Two tibias in 1 patient and 1 femur in another had delayed ossification and required with delayed weight-bearing and compression-distraction by the bidirectional nail mechanism (accordion maneuver; 0.5 mm distraction followed 4 h later by 0.5 mm compression, the cycle of which was repeated 2 to 3 times a day for a month or more). There was 1 deep vein thrombosis in a patient who stopped anticoagulation before full weight-bearing. Our protocol is to stop anticoagulation once a patient is approved to ambulate without device support. In the P1 group, there were no symptomatic fat embolisms, infections, or compartment syndromes (Table 3). In the P1 group, there was 1 patient who underwent bilateral femoral and tibial PRECICE nail lengthening simultaneously. He did not have any evidence of fat embolism, despite all 4 nails being inserted during the same surgery. The other 3 P1 patients that underwent bilateral femoral and tibial lengthening had each bilateral procedure performed at different times. None experienced fat embolism problems.

In the P2 group, there were 2 minor screw complications (2/58, 3%), both in tibial cases. One case had an inadvertent miss to the distal locking screws that was not seen until postoperative follow-up. Another case had a proximal tibiofibular locking screw back out and become prominent under the skin. In the first case, the 2 screws had sufficiently locked the nail that it lengthened without a problem. The tibia was redrilled and the locking screws inserted through the locking holes of the tibial nail at the surgery as the staged bilateral femoral lengthening surgery, which took place 3 weeks after the bilateral tibial lengthening surgery. In the back-out screw case, a threaded locking screw was used instead of the smooth peg-like PRECICE screws.

One P2 patient developed bilateral peroneal nerve partial paresis due to a stretch injury that occurred during the surgery. This patient had a very positive preoperative popliteal angle, which we elected to treat by hamstring muscle recessions. It is presumed that the straight leg raising maneuver to check the popliteal angle after the muscle recession, while the patient was still under general anesthesia, led to the stretch injury. This was treated by bilateral peroneal nerve decompression 3 days after surgery.20 Lengthening continued at a rate of 0.75 mm/d and the goal of lengthening was achieved. Both nerves gradually fully recovered both motor and sensory function despite lengthening.

In our P2 group, there was 1 nail breakage during late consolidation (Fig. 7). The nail silently bent into varus and produced a noticeable bump on the lateral side of the thigh. The patient continued to walk without pain and complained only about a thigh bump. This patient had disregarded the weight-bearing restrictions that were reinforced in writing to him each time he sent a follow-up radiograph during the consolidation phase. He too had stopped using crutches without being released to do so. He was treated by the fixator-assisted technique, but required an osteotomy of the already malunited (varus) femur. A single frontal plane, lateral external fixator was applied to correct the varus deformity. After removal of the proximal nail segment, a percutaneous osteotomy was performed through the apex of the bend. Once the femur was aligned by the fixator, the distal nail segment was pushed proximally through the piriform fossa by means of a retrograde Rush rod. The femur was then fixed with a locked intramedullary nail and the external fixator removed.

In the P2 group, there were no failures of the mechanism to distract and no premature consolidation. There were also no infections or compartment syndromes (Table 3). Two patients who underwent bilateral femoral P2 nail insertion were diagnosed with suspected fat embolism syndrome manifesting as low pulse oxymeter readings from the first postoperative day. This was associated with shortness of breath in 1 patient and mild mentation changes in both. The condition resolved after 1 day in 1 patient, but 4 days of additional hospitalization were
FIGURE 7. A, Preoperative anteroposterior full body EOS scans for assessment of body proportions and alignment. There is bilateral genu varum as measured by medial mechanical axis deviation (right side) and mechanical tibiofemoral angle (left side). This patient wanted to correct his genu varum and achieve 8 cm of lengthening. He underwent bilateral femoral PRECICE 2 lengthenings simultaneous with bilateral high tibial medial opening wedge osteotomies with locking plate fixation. Orthoroentgenogram and long lateral radiographs (B) show the 8 cm lengthening and the tibial osteotomies. Anteroposterior and lateral radiographs 2 months after the end of the 80-day distraction phase (C). The bone regeneration on the right is progressing well but there is not complete bony bridging yet. The patient was advised to continue weight-bearing restrictions using 2 crutches. Note that the wide part of the nail remains <1 cm engaged with the distal femur. There also appears to be a widening or failure of the crown of the nail as seen on the lateral view (arrow). As his leg felt solid he discarded the crutches and walked full weight-bearing. One month later he noticed a painless bump on the lateral aspect of the thigh. Radiographs reveal varus-procurvatum angulation and breakage of the nail (D, E). To extract the distal part of the nail, a frontal plate fixator was applied to straighten the femur. Once this was done, the proximal part of the nail was removed first and then the distal part was pushed out the piriformis fossa by a retrograde Rush rod (arrow, F). On this lateral radiograph, the external fixator body can be seen (*). The Rush rod tip is labeled with an arrow also showing the direction it is pushing. The femur was nailed with a nontelescopic locking nail (G). No length or alignment were lost.
required (usual hospitalization is 3 to 4 d) by the other patient whose right lung showed significant opacification on both chest x-ray and computerized tomography. There was no evidence in either patient of venous embolism on computerized tomography scan; neither was there evidence of aspiration or pneumonia in either case. The presumptive diagnosis of fat embolism was made after ruling out all other possible causes. Both patients had the medullary canal vented according to the multiple drill holes at the planned osteotomy level, as described above. Both recovered with only nasal prong oxygen treatments and neither required intensive care unit admission. As cited previously, none of the 4 patients who underwent bilateral femoral and tibial lengthenings experienced fat embolism problems.

In total there were 7 implant failure complications in the P1 group (7/58; 12.1%) and only 1 implant failure complication in the P2 group (1/58; 1.7%). This difference was statistically significant between the groups \((P = 0.02)\).

**DISCUSSION**

SSL is a controversial indication for limb lengthening. Limb lengthening for stature has been used successfully by numerous authors for the treatment of achondroplasia and hypochondroplasia1-5. Extensive limb lengthening (ELL) for dwarfism, is controversial but for different reasons. Patients with achondroplasia present with extreme short stature with associated lower limb deformities, short limb to trunk disproportion and rhizomelic disproportion of both upper and lower limbs. Their adult heights are usually between 3 ft 10 inches and 4 ft 4 inches. The goal of ELL for these patients is

<table>
<thead>
<tr>
<th>TABLE 3. Complications According to Nail Type</th>
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<tbody>
<tr>
<td><strong>PRECICE 1</strong></td>
</tr>
<tr>
<td>Nail breakage</td>
</tr>
<tr>
<td>Mechanism failure</td>
</tr>
<tr>
<td>Periprosthetic fracture</td>
</tr>
<tr>
<td>Premature consolidation</td>
</tr>
<tr>
<td>Locking screw backout</td>
</tr>
<tr>
<td>Compartment syndrome</td>
</tr>
<tr>
<td>Deep vein thrombosis</td>
</tr>
<tr>
<td>Nonunion</td>
</tr>
<tr>
<td>Delayed union</td>
</tr>
<tr>
<td>Joint subluxation</td>
</tr>
<tr>
<td>Hematoma</td>
</tr>
<tr>
<td>Partial peroneal nerve palsy (recovered)</td>
</tr>
<tr>
<td>Suspected fat embolism syndrome</td>
</tr>
<tr>
<td>Equinus contracture</td>
</tr>
<tr>
<td>Fascia lata/ITB contracture</td>
</tr>
</tbody>
</table>

ITB indicates iliotibial band.
to increase their heights to over 5 ft tall and ideally to the low normal range for their sex. ELL has been shown to greatly improve function and quality of life.\textsuperscript{1-5}

ELL for dwarfism cannot be compared with SSL of individuals starting at an adult height >5 ft and usually >5th percentile for their sex. Even the technical and strategic aspects of ELL for achondroplasia is not comparable because they are mostly done in childhood before skeletal maturity, whereas SSL is carried out after skeletal maturity. ELL is done repeatedly 3 or 4 times to achieve goals of 30 to 40 cm (12 to 16 inches), whereas SSL goals are usually 5 to 15 cm (2 to 6 inches). SSL goals can usually be achieved by a single bilateral femoral or tibial lengthening or at most, by bilateral femoral and bilateral tibial lengthening. ELL is done for functional reasons, whereas SSL is done for aesthetic and psychological reasons. ELL restores proportions to normal, whereas SSL usually takes normal proportions and alters them.

The senior author (D.P.) has been performing SSL since 1987. During this time, SSL was carried out by several methods: EFOL, LON, and ILN. Between 1988 and 2008, all SSL candidates were required to undergo a psychological evaluation by a single psychologist who is also one of the coauthors (W.W.). At the time, the authors sought to answer 3 questions relating to\textsuperscript{20} (1) Motivation: What motivates a person to seek SSL?; (2) Selection: Which patients are the best candidates to undergo SSL?; and (3) Outcome: Are patients who undergo SSL satisfied with the outcome?

Thirty patients (21 men, 9 women) were prospectively evaluated by D.P. and W.W. in an IRB-approved study before consideration for SSL using the intramedullary skeletal kinetic distractor (ISKD) ILN between 2000 and 2003.\textsuperscript{21} The average age was 29 years (range, 16 to 45 y). The average height was 162.3 cm (63.9 inches) for males and 152.9 cm (60.2 inches) for females. The average number of years of education of this group was 16 years and ranged between 10 and 22 years. On the basis of findings from this psychological evaluation, 17 of the 30 (57%) candidates were deemed to be psychologically fit to proceed for surgery. Of the approved 17, only 12 chose to proceed with surgery during the study period. Nine of these participated in a follow-up evaluation after lengthening. The data from this study was used to help answer questions about the motivation, selection, and outcome of SSL. Although this is a small cohort, it provides valuable insight regarding the psychology of patients who seek SSL.

The Motivation Question

Patients who presented for SSL seldom had a history of clear-cut systemic/endocrine disorder or psychosocial etiology, such as failure to thrive. In general, their short stature appeared to reflect genetic and constitutional endowments. In accepted patients, there was no patent psychiatric or psychological disorder; some surgical candidates had body dysmorphic disorder, which was considered a contraindication for SSL, but most accepted patients qualified at most for having an adjustment disorder. In general, patients were more likely to be professional or white collar workers and to have financial limitations on physical activity in the future. They should have realistic expectations about treatment outcomes, including any limitations on physical activity in the future. They should have the ability to collaborate over time with their surgeon and rehabilitative care staff. To the extent a prospective patient has a flexible and mature personality structure, good emotional regulation, self-awareness, and good interpersonal skills, he or she will have greater resources to contend with the challenges inherent in SSL. When a prospective patient presents for a radical and protracted elective procedure, it is essential to evaluate his or her fitness for such a treatment. It is important to gauge motivation and rule out psychiatric disorders (eg, body dysmorphic disorder). Coping skills and the ability to tolerate procedural stresses and pain must be determined, and there is a need to evaluate treatment response and outcome.

In the Paley and Windisch study, to assess fitness for lengthening surgery, prospective patients underwent a presurgical psychological evaluation by W.W., that included the Minnesota Multiphasic Personality Inventory-2 (MMPI-2), Millon Behavioral Health Inventory, and Rorschach Inkblot Test. These assessment tools were used to formulate a comprehensive evaluation of the patient’s perception of well-being, preoccupation with health issues, emotionality, coping styles explain the impact of short stature on self-concept and esteem. Such variables include prolonged caregiving responses,\textsuperscript{25} juvenile behavior,\textsuperscript{26} stigmatization,\textsuperscript{27} and self-consciousness.\textsuperscript{28}

There is substantial and growing literature regarding the life adjustment of short adults. Men tend to be more concerned with short stature than women; being a petite female is less stigmatizing and more culturally acceptable than being a short male.\textsuperscript{27,28} Consequently, more men present for consideration for stature lengthening. Short individuals who have been sensitized to height issues in childhood tend to be more troubled by their stature as adults.\textsuperscript{30} Those who seek stature lengthening almost always report a family concern with their height in childhood, evidenced by visits to multiple specialists and a sense of despair at the close of puberty. Stature exerts a genuine influence in several life areas, including dating relationships,\textsuperscript{31} mate selection,\textsuperscript{29,32} salary,\textsuperscript{33} occupational opportunity, and career success.\textsuperscript{34-37}

Paley and Windisch\textsuperscript{21} named this condition “stature dysphoria.” It is likely that persons suffering from stature dysphoria become aware of their short stature in childhood, often as a result of negative parental or peer appraisals. Over time, they come to attribute various adverse experiences with family, peers, school, and sports to their short stature. As adults, their continuing negative experiences in the social and occupational realms accentuate feelings of alienation and personal failure. Their selective attention, expectancies, and attributional biases convince themselves their short stature has irrevocably damaged their lives. As a consequence, they are prone to social anxiety, awkwardness, depression, low self-esteem, and interpersonal difficulties, often despite substantial success in various areas. In conclusion, patients seeking SSL are primarily motivated by a psychological preoccupation with their stature.

The Selection Question

Various factors play a significant role in a prospective patient’s ability to participate in and benefit from SSL. Persons seeking care should be sufficiently motivated to undergo the lengthening process with its attendant discomfort and inconvenience. They should possess sufficient information to give meaningful informed consent, including a solid understanding of treatment procedures, possible complications, and the need to participate in daily physical therapy. They should have realistic expectations about treatment outcomes, including any limitations on physical activity in the future. They should have the ability to collaborate over time with their surgeon and rehabilitative care staff. To the extent a prospective patient has a flexible and mature personality structure, good emotional regulation, self-awareness, and good interpersonal skills, he or she will have greater resources to contend with the challenges inherent in SSL. When a prospective patient presents for a radical and protracted elective procedure, it is essential to evaluate his or her fitness for such a treatment. It is important to gauge motivation and rule out psychiatric disorders (eg, body dysmorphic disorder). Coping skills and the ability to tolerate procedural stresses and pain must be determined, and there is a need to evaluate treatment response and outcome.

In the study of lengthening surgery, prospective patients underwent a presurgical psychological evaluation by W.W., that included the Minnesota Multiphasic Personality Inventory-2 (MMPI-2), Millon Behavioral Health Inventory, and Rorschach Inkblot Test. These assessment tools were used to formulate a comprehensive evaluation of the patient’s perception of well-being, preoccupation with health issues, emotionality, coping styles
and psychogenic attitudes, and his or her suitability for adapting to the rigor of the surgery and rehabilitation.

Patients accepted for SSL were more conventional in their response style on the MMPI-2 F Scale ($P = 0.005$), less likely to report symptoms of depression on the MMPI-2 D Scale ($P = 0.056$), less likely to report a history of antisocial behaviors on the MMPI-2 Pa Scale ($P = 0.077$), less likely to report symptoms of thought disturbance on the MMPI-2 Sc Scale ($P = 0.050$), less likely to report anxiety symptoms on the MMPI-2 ANX Scale ($P = 0.088$), and more likely to report supportive family relations on the MMPI-2 FAM Scale ($P = 0.033$).

On the Millon Behavioral Health Inventory, declined patients had a greater sense of future despair than accepted patients ($P = 0.058$). The 2 groups did not otherwise differ in personality attributes assessed by this measure. No detectible differences were observed in introversion-extroversion, inhibition, cooperation, sociability, confidence, forcefulness, respectfulness, sensitivity, tension, stress, pessimism, social anxiety, and vulnerability to emotional disruption under conditions of stress.

Rorschach findings for prospective patients indicated both accepted and declined patients tended to view the world in idiosyncratic and unconventional ways, impairing their adjustment, and felt a need to defend their self-image. Accepted patients were more emotionally reserved, whereas declined patients tended to feel overwhelmed. These individuals displayed excessive degrees of subjectively felt distress, and had a greater proneness to experience mixed emotional states and ambivalence.

Overall, these findings may appear to raise the question whether all persons seeking SSL should be referred for psychological evaluation and/or treatment. Assessing the suitability of a patient to undertake this procedure has merit. However, psychotherapy as an intervention to remedy insecurities related to stature often does not suffice. Although various forms of psychotherapy can help patients adjust to personal limitations and life circumstances, they cannot undo the ongoing stigmatization that often accompanies short stature. Indeed, many patients who seek SSL have already undergone substantial psychotherapy, only to find that environmental feedback and entrenched attitudes temper treatment outcomes, leaving them to experience ongoing distress and frustration. When an individual perceives his or her short stature to be debilitating, it can diminish the success and fulfillment experienced occupationally and interpersonally across the life span. A surgical solution, often offers the best hope for self-actualization and contentment.

The Outcome Question

Do postpsychological evaluations support the proposition that these patients become satisfied with their new body and perceive themselves differently? To date, there are no published studies on the effect of stature limb lengthening on psychological adjustment. In the Paley and Windisch study 9 patients (8 males, 1 female), completed a follow-up questionnaire an average of 4.8 years after their initial surgery date (see Box 1 below for sample questionnaire items). The mean height gain of these 9 subjects was 2.9 inches (preoperative height averaged 62.6 inches; postoperative height averaged 65.5 inches).

The data from Paley and Windisch indicate that patients are generally pleased with the stature they gain with SSL, despite the fact that their height gain was relatively modest, often leaving them at the lower percentiles on a height chart.

Two to 3 inches of additional height appears to have had a more profound impact on the patients’ psychosocial well-being than their relative approximation of the normative height range. Psychological factors may contribute to their satisfaction, even after they have increased their height by only 2 or 3 inches. Letting the issue go finally, irrespective of the amount of height gain may just be related to having finally done all that can be done. Several respondents indicated they felt no need to pursue further lengthening because they wished to focus their energies elsewhere and move forward in their lives. In this connection, Haley,38 coined the term “ordeal therapy” to describe a therapeutic intervention, which places the patient in a difficult or painful situation that tests character and provides the patient an opportunity to gain important insights that change attitudes and behaviors.

The outcome question is also dependent on both the physical outcome of the surgery (ie, whether the patient was able to return to previous activities of daily living and sports activity at the previous level of function) and whether it changed how they felt and saw themselves. Paley et al39 investigated a group of 11 patients treated by bilateral femoral lengthening with the ISKD between 2002 and 2006. All were males with average age 29 years (range, 15 to 53 y) with preoperative height of 163 cm (range, 156 to 170 cm) [64.2 inches (range, 61.4 to 66.9 inches)]. After lengthening the mean height was 169 cm (range, 155 to 178 cm) [66.5 inches (range, 61 to 70 inches)]. Four also had undergone bilateral tibial lengthening. There were 8 soft tissue contractures (range, 61 to 70 inches) (mean = 4.0), and less preoccupied by their height (mean = 4.0), but they still tended to feel uncomfortable telling others about their surgery (mean = 2.2) and by and large kept the matter to themselves. On a correlation analysis, their decrease in stature dysphoria was most highly correlated with a positive sense of treatment outcome (Pearson $r = 0.72, P = 0.03, R^2 (adj) = 44.4\%)$. At the same time, subjects reported having more pain than they had expected (mean = 2.0). Those with the most positive attitude reported the most negative surgical experience (Pearson $r = -0.74, P = 0.037, R^2 (adj) = 54.3\%)$. (It should be noted that all of these respondents had undergone lengthening with the ISKD method, which as discussed, has poor rate control and causes much more pain than the PRECICE method.)

**BOX 1. Two Questionnaire Items**

<table>
<thead>
<tr>
<th>I am satisfied with the outcome of my limb lengthening treatment</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strongly Disagree</td>
<td>Strongly Agree</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Somewhat Disagree</td>
<td>Somewhat Agree</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Neutral Disagree</td>
<td>Neutral Agree</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>I am now less preoccupied by my height</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Strongly Disagree</td>
<td>Strongly Agree</td>
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<tr>
<td>Somewhat Disagree</td>
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</tr>
<tr>
<td>Neutral Disagree</td>
<td>Neutral Agree</td>
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</tbody>
</table>

In this questionnaire, 4 subjects strongly agreed they were satisfied overall with the outcome of their limb lengthening, and 5 subjects somewhat agreed (mean rating = 4.4). There were no neutral or negative responses on this item. Moreover, subjects tended to report lengthening had addressed their problems (mean = 4.2) and that their future appeared bright (mean = 4.2). They reported they were less tense and dissatisfied after limb lengthening (mean = 4.0), and less preoccupied by their height (mean = 4.0), but they still tended to feel uncomfortable telling others about their surgery (mean = 2.2) and by and large kept the matter to themselves. On a correlation analysis, their decrease in stature dysphoria was most highly correlated with a positive sense of treatment outcome (Pearson $r = 0.72, P = 0.03, R^2 (adj) = 44.4\%)$. At the same time, subjects reported having more pain than they had expected (mean = 2.0). Those with the most positive attitude reported the most negative surgical experience (Pearson $r = -0.74, P = 0.037, R^2 (adj) = 54.3\%)$. (It should be noted that all of these respondents had undergone lengthening with the ISKD method, which as discussed, has poor rate control and causes much more pain than the PRECICE method.)
nerve symptoms, and 3 reosteotomies for premature consolidation. Three sequelae were observed: one was a minor complication where, despite a reosteotomy for premature consolidation, the remaining 1 cm could not be achieved. The other 2 sequelae involved nonunion. One case of nonunion healed after exchange nailing alone, and the other case healed after femoral allograft placement. Despite these complications, there was full restoration of function with return to preoperative activities and occupation. Enneking scores (evaluating pain, function, gait, walking distance and supports, and emotional acceptance) were normal preoperatively and showed no deterioration postoperatively.

In a second parallel study by the senior author, Paley et al46 studied 10 patients who underwent bilateral cosmetic tibial lengthening with the ISKD between 2001 and 2006. The preoperative height was 153 cm (range, 142 to 165 cm) [60.2 inches (range, 55.9 to 65 inches)]. The average amount of length obtained was 6.8 cm (range, 5 to 8 cm). The postoperative height was 160 cm (range, 150 to 170 cm) [63 inches (range, 59 to 66.9 inches)]. An average of 1 complication per limb was observed (range, 0 to 2 complications/limb). Nonunion occurred in 12 (60%) of 20 limbs. All nonunions were in patients who underwent >6 cm of lengthening. Nonunion was treated with exchange nailing (4 limbs), exchange nailing with allograft/autograft (5 limbs), and exchange nailing with autograft (3 limbs). Other complications included nerve injury in 1 limb that required nerve decompression, stress fracture in 1 limb after rod removal, and premature consolidation in 1 limb, which required shortening of the contralateral side. Despite the very high number of major complications in the ISKD tibial lengthening group, the preoperative and postoperative Enneking scores were not significantly different, indicating that aggressive treatment of complications can prevent permanent harmful sequelae of lengthening.

Intramedullary telescopic nails have tried to revolutionize how we accomplish distraction osteogenesis and circumvent the traditional complications seen with external fixation.41,42 Initial devices have made progress in the field and identified design weaknesses and new complications. Issues in the past include: intramedullary infections, distraction mechanism failure, nail breakage, unreliable rate control with too rapid distraction (so-called runaway nail), nonunions, and painful distraction mechanism.43,44,45 Previous mechanisms required rotation through the osteotomy, which can be painful and unpredictable and often require general anesthetic to accomplish distraction.43,45,46 In comparison, patient feedback regarding the ERC device and the PRECICE mechanism has been excellent, both for rate control and for evoking little or no pain. In contrast to our experience, Schiedel et al47 reported 43% (10/23) rate of required reprogramming of ERC for failure to achieve desired lengths according to the machine. This was not our experience and could be explained by inexperience and user error. Our patients are coached on how to use the device and have medical staff available daily if they require assistance.

The issue of rate control is important because it is a key principle to achieve distraction osteogenesis. Slow rates will predispose to premature consolidation requiring reosteotomy surgery. Distracting too fast can predispose to contractures, nerve injury, and joint subluxation. Rates over 1.5 mm/d have been shown to lead to poor regenerate formation, which may go on to nonunion.46,48 Our experience with the P2 has shown excellent reliability of the distraction mechanism. The P1, as was previously reported by one of the authors, had some failures to distract due to breakage of the mechanism.16 We experienced no cases that distracted more than the prescribed amount. We also had no cases of nonunion, unlike reports from other series.10,16,46,48 One previous study, looking particularly at reliability the PRECICE distraction mechanism, found P1 distraction accuracy to be 96%.49

Nail breakage is a previously reported complication with external fixation.8,12,13,16,43–46 This was also seen in our P1 cohort. These patients did not comply with the weight-bearing restrictions. All the P1 nails broke at the welds of the nail. Schiedel et al47 also reported breakage with the P1 nail. In comparison, in the same number of patients treated for the same indication, we saw only 1 nail breakage in the P2 nail with its 1-piece outer tube (no welds), despite allowing patients to bear 50% more weight than we did for P1 nails (75 vs. 50 lb for the 12.5 mm nail). The 1 breakage was again associated with a weight-bearing restriction noncompliant patient, who began walking without crutches prematurely. Two other contributing factors were identified that may have played a role. The length of the large diameter part of the nail remaining engaged in the distal cortical segment was 1 cm at the end of the distraction. This places a lot of stress on the telescopic junction of the nail. The authors recommend that there be at least 3 cm of overlap at the end of distraction to ensure that the stress distribution is not concentrated at this junction. Secondly, the end of the larger diameter of the nail is slotted at 4 places and mated and welded to a crown that has 4 ridges to provide antitortion stability to the telescopic nail. The fins between the slots are a site of fragmentation of the end of the nail tube. Breakages of the crown and fins have been identified in some cases including this patient (Fig. 9). To strengthen the nail and avoid crown failures, Ellipse Technologies released the P2.1 in December 2014, which has a modified keying feature without “thru-slots” or tack welds (Fig. 9).

Failure of the distraction mechanism has been reported with the P1 in 4% to 8% of cases,16,17 which is similar to the 3% we found in our series. This issue was addressed in the P2 redesign. In the P1, the problem lay with the connection between the gears and the drive shaft. There was no clutch mechanism. Therefore, if the nail met a high resistance, such as from a thick callus or large muscle mass, the powerful rotation of the magnet could fracture the connection to the drive shaft. In the P2, a clutch mechanism, in combination with a stronger junction to the drive shaft to prevent fracture and also increase the obtainable distraction force minimizes the risk of premature consolidation. We found no distraction failures in our P2 series.

Our P1 group had 3 patients with delayed union; 2 of these were tibial, which generally take longer to consolidate. In these patients we took advantage of the bidirectional nature of the nail and asked them to cyclic load the regenerate by alternating between elongating and shortening, 0.25 to 0.5 mm at a time at least 4 times a day. This “accordion” maneuver seemed to work well as these patients went on to heal without requiring bone grafting. Of importance, we had no patients with nonunion of the femur allowing tuba and no secondary procedures were required to achieve union. This is in marked contrast to the high nonunion rate experienced by the senior author in his 2 reports on femur and tibia stature lengthening with the ISKD.39,40,44

An important consideration with cosmetic limb lengthening is the long-term effect on the body and particularly the joints. Femoral lengthening along the anatomic axis versus the mechanical axis, theoretically leads to valgus deformity at the knee.47 With 94 femurs to analyze in our series, the mLDFA did not significantly change despite the theoretical expectation that it would. One explanation is that a very mild varus bowing of the titanium nail occurs in many cases of femoral
lengthening with the PRECICE. This mild varus may compensate for the tendency of the anatomic axis to go into valgus. This predicted valgus failed to be seen in another study as well.47

More surprising was the valgus deviation seen with tibial lengthening with the PRECICE. The 22 tibial cases demonstrated a significant change ($P < 0.01$) of the MPTA from 86.5 degrees ($\pm$ 1.7 degrees) preoperative to 90.0 degrees ($\pm$ 3.2 degrees) after lengthening. This may support the recent recommendation by Rozbruch and colleagues that blocking screws be used for tibial lengthening due to the wider canal at the level of the osteotomy site of the tibia.11,50–53

SSL by external fixation has been reported by several authors.6,7 Catagni et al6 (Lecco, Italy), reported on 54 patients undergoing the procedure using Ilizarov external fixators. At 6.25 years (range, 1 to 16 y) follow-up, the overall patient satisfaction was excellent (90.7%) or good (9.3%). They achieved an average 7 cm (range, 5 to 11 cm) of increased height for their patients. External fixation time was a mean of 9.5 months (range, 7 to 18 mo) with further casting 48% or bracing 51.85% into a brace after fixator removal. Other complications included: 35.2% equinus contracture requiring Achilles tendon lengthening, 48.2% pin site infection, 2 patients requiring bone grafting, and 3 patients with fracture collapse of the regenerate after frame removal. Overall 25 (46.3%) patients had to return to the operating room for further intervention. These cases were all tibial with double osteotomy sites, which may have increased complication rates.

Novikov et al7 (Kurgan, Russia) studied 131 patients undergoing cosmetic limb lengthening with the Ilizarov apparatus. They achieved a mean of 6.9 cm (range, 2 to 13 cm) of height gain with 5.75 years (range, 1 to 14 y) follow-up. All

FIGURE 9. Photographs of 2 nails removed from a patient who underwent bilateral femoral lengthening. There is a crown breakage on the right femur nail with propagation of cracks up from the nail slots (left side of figure) whereas the crown and slots remain intact on the nail from the left femur (right side of figure) (A). The PRECICE 2 (P2) nail antirotation mechanism uses 4 female “thru-slots” in the distal end of the proximal nail tube mating with the crown’s 4 male ridges, and secured with tacking welds after assembly (B). The new P2.1 antirotation feature is machined into the inner diameter of the distal end of the proximal nail tube without breaking through to the surface and without requiring welds (C). [Color figure online]
their patients were tibial monofocal or bifocal lengthening and 6 patients had additional femoral lengthening. The mean duration of the external fixator was 215 days (range, 71 to 390 d). Overall 48 patients (37%) experienced 59 complications during the treatment. These included significant infection in 8 patients (6.1%), equinus deformity in 12 patients (9.2%), and knee flexion deformity in 14 patients (10.7%). Four patients had significant regenerate deformity and 4 more had collapse after frame removal. Furthermore, 6 patients had peroneal nerve neuropathy, 6 more had delayed union, 1 had knee subluxation, 1 patient had a fracture, 1 patient needed reosteotomy, and fibula consolidation and another for the tibia. Patient outcome was excellent in 72 (55%), good in 52 (39.7%), satisfactory in 6 (4.6%), and poor in 1 (0.8%). In summary, this study also demonstrated a considerable complication rate with reoperation rate of 16.8%.

Kim et al.54 did a systematic review of 547 patients (1581 segments) for stature lengthening and identified phenotypically normal individuals as having higher complications and achieving less length that certain skeletal dysplasias (achondroplasia/hypochondroplasia).32 It is thought that certain skeletal dysplasias tolerate lengthening well because of inherent soft tissue laxity and high muscle length to bone ratio.1 It is an important consideration when comparing groups of stature patients, as each population will not behave the same. This review compiled 103 etiologically normal patients undergoing stature lengthening with external frames. The mean height gain was 6 cm (range, 3 to 8 cm) and rate of healing was reported per centimeter as 32 d/cm (range, 30 to 67 d/cm). The rates of pooled complications reported per segment were 1.06, which was higher than that found in other groups 0.68 (achondroplasia), 0.71 (Turner syndrome) and 1.08 (nondysplastic short stature). Patient outcome was statistically significant (P < 0.001). Hence these patients may be, in fact, more difficult to treat, which must be considered when looking at outcomes and comparing them between other studies with different or heterogeneous patient cohorts.

With a new implantable device that has reliable control, we have reduced the incidence of traditional complications associated with stature lengthening. SSL in our series yielded excellent results and low complications compared with the above studies. In light of the reported findings of Kim et al.54 regarding stature lengthening etiology, our series is homogeneous for short stature nondysplastic patients they concluded are more difficult to treat than other short stature etiologies. Despite this higher risk group, our rate of complications were lower than those reported by any other published series for SSL, as well as the senior author’s (D.P.) previous experience with the ISKD.39,40 especially in comparison to the P2 group. The P2 group had only 1 major complication (bilateral peroneal nerve stretch injury). The improvements in the P2 appear to have corrected the previous issues with the distraction mechanism and nail breakage. Please note that we are not downplaying the 2 cases of fat embolism but recognize that this can occur with any method that uses intramedullary reaming and nailing. Of note, both resolved quickly with supportive measures (oxygen and intravenous fluids).

It is important to emphasize problems that we did not experience and some technical tips that helped avoid complications in our 51 SSL patients treated by the PRECICE. These technical tips are essential to the success of this procedure.

(1) All of the patients achieved union. Reaming after first predrilling the osteotomy site ensures better bone formation due to extrusion of the reamings around the osteotomy site. As noted, it also decompresses the canal to help prevent fat embolism. This should be a routine for femoral lengthening, but avoided with tibial lengthenings due to the risk of compartment syndrome.

(2) There were no compartment syndromes from tibial lengthening. Only the anterior and medial cortices of the tibia were drilled to avoid extrusion of reamings into the deep posterior and anterior compartments, which can lead to compartment syndrome. We recently treated 1 such case from another center. The patient had a permanent foot drop and needed a tibialis posterior tendon transfer.

(3) The fibula in our study did not migrate in any patient due to proximal and distal fixation of this bone. A common error is due to the misconception that the fibula does not need to be fixed to the tibia proximally and distally. Lack of distal fixation leads the fibula to migrate proximally. Even incorrect fixation leads to the same problem. For example, fixation distally, with a transverse instead of an inclined screw, will resist the tendency toward proximal migration less than the distally inclined screw fixation we recommend.

(4) There were no contractures of the hip, knee, ankle, subtalar, foot, or toe joints. Physical therapy and bracing are important to prevent contractures. Lengthening for stature without these measures may lead to significant stiffness and contractures of joints.

(5) There were no infections in any of the PRECICE SSL patients. This is due to the fully implantable device, minimal invasive surgery, meticulous sterile technique, and the use of preoperative and perioperative antibiotics.

At our center we have seen patients from all over the world who arrive with disabling complications after failed SSL. These include equinus deformity due to Achilles tendon contracture (ballet feet); fascia lata contractures with hip flexion contracture and hyperlordosis (duckass); partial or complete failed regenerate bone formation, including fixators that cannot be removed due to failed healing; bent and broken hardware; malunions and nonunions of the tibia, fibula, and femur; proximal migration of the fibula; and many more. We must remind ourselves that these patients start functionally at 100%. The treatment goal is to end up with the same 100% functional level. Anything less than this is neither a good outcome nor a reasonable tradeoff for a few centimeters. Disability is too often an outcome of this surgery when performed by unqualified or inexperienced surgeons, which leaves patients with debilitating conditions and gives this surgery a bad reputation.

A few years ago the senior author (D.P.) saw 7 patients in the course of 2 years who were disabled by complications from bilateral tibial lengthening. All of these had been treated by a single surgeon. This resulted in 7 separate malpractice lawsuits and ultimately the loss of that surgeon’s medical license. Such cases give SSL and undeserved bad reputation.

Stature lengthening raises many questions: Should we agree to lengthen anyone for stature? Should we base this decision on a height threshold? Should we base this decision on psychological factors? Should we base this decision on ability to pay, as with other cosmetic surgeries?

Height threshold is arbitrary and judgmental (Fig. 6). Risk is not dependent on initial height; benefit is not necessarily greater for shorter individuals. Therefore the risk/benefit for shorter individuals is no different than for taller individuals. Stature dysphoria is a real entity. As documented, there is ample psychological evidence for this condition. However, motivation may be due to more benign reasons (eg, fashion models who want to have longer legs, individuals who desire access to jobs with minimal height requirements, etc.) Is it the surgeon’s job to judge the patient’s motivation as long as they...
are realistic about what can be achieved and aware of what the surgery and rehabilitation entails?

Cost is a major consideration. Insurance providers consider SSL to be a cosmetic procedure and therefore will not pay for it. The implants alone are very expensive. Added to the cost of hospitalization, operating and recovery room costs, anesthesia fees, surgeon fees, physical therapy, durable medical equipment (wheelchairs, walkers, crutches, comode), drugs (anticoagulant, analgesics, sleeping medications, muscle relaxants), office visits, x-rays, etc., the total cost is formidable and unaffordable to most. Ultimately cost is the limiting factor for most patients. Of concern, is that as this surgery is exempt from third party payers and because most surgeons and hospitals are paid up-front in cash, pricing is widely variable. Patients may acknowledge there are differences among providers related to skill and outcomes, but price can become an influential decision-driver.

At present one can find many stature lengthening centers advertised on the internet. How should the consumer decide among these? This is an unregulated business. The methods vary tremendously, as do the results. The cost of treatment in some foreign countries is an eighth to a tenth of the cost in the United States.

It is not our intention to condemn or advocate for any particular surgeon or center. However, we do feel that the results of the PRECICE method are ideal and better suited for this type of surgery than previous methods. For years the external fixator was the gold standard of limb lengthening. It offered the advantage of a minimally invasive surgery, with stable fixation, controlled rate and rhythm of distraction and even the ability to go reverse. It had the disadvantages of being in place for lengthy periods of time, mild tethering of muscles and skin, long unesthetic scars at the pin tracks, infections of the pin sites and no support for the bone after removal of the apparatus, putting the bone at risk for bending or breaking. The PRECICE ILN offers all of the advantages of the external fixator without the disadvantages. By not tethering the muscles or skin, it is less painful and motion limiting. There are fewer, smaller, and more aesthetic scars and no infections. For the first time we have a device and a method that are ideal for SSL.

Some surgeons believe the indications for stature lengthening are frivolous and unfounded. We hope to have dispelled this argument, as well as the negative association with “cosmetic surgery.” Unlike other cosmetic procedures, SSL places significant psychological and physical demands on patients and their families. The recovery is significantly more protracted and puts patients in wheelchairs, walker, or crutches for several months and requires months of rehabilitation. Patients frequently do not return to walking normally for 6 or more months. Such intensive rehabilitation is not required for other cosmetic procedures. This procedure is a significant disruption to patients’ lives (eg, personal, school, work, family, financial stress). Finally, most cosmetic procedures are less labor intensive to both the clinical team and the patient, do not require an inpatient surgery setting, frequent follow-up with x-rays, technical and clinical support for the hardware, and a constant vigilance for potential complications. As such we do not look at this as cosmetic surgery for purely aesthetic reasons. In the majority of patients it is being done because of a body image disorder that is beyond the patient’s control. Although at present “stature dysphoria” is not recognized as psychological disorder that is best treated by surgical reconstruction, the new evidence reported here supports this conclusion.

Orthopedic surgeons are not used to performing surgery for cosmetic reasons. On the basis of the senior author’s 28-year history of carrying out SSL, we would like to propose the following “ethical guidelines for SSL”: (1) the surgeon should consider patient safety and welfare first at all times—first do no harm (primum non nocere; Hippocratic oath in Latin); (2) the surgeon should make sure that patients are knowledgeable and really understand what they are undertaking including the nature of their condition, the way it is to be treated including the timelines for temporary disability, the risks of the procedure, and the prognosis; (3) the surgeon should not undertake this procedure unless he/she not only knows how to do the procedure but also how to prevent and treat complications in order to increase the likelihood of a successful outcome; and (4) provide the necessary infrastructure to support this treatment (eg, physical therapy, frequent follow-up, technical support).

REFERENCES


