

Intramedullary Lengthening Nails in Adults: Review of Uses, Techniques, and Complications

Daniel Degenova¹, D.O.; Scott Hyland¹, D.O.; John Schrock¹, D.O.; Anthony Melaragno¹, D.O.; Benjamin C. Taylor¹, M.D.

¹ Department of Orthopaedic Surgery, Grant Medical Center, Columbus, Ohio, USA.

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Correspondence to: Benjamin Taylor, MD, 285 E State St, Columbus, OH 43215, USA.
Email: drbentaylor@gmail.com

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ABSTRACT

Distraction osteogenesis is a reliable method for lengthening, deformity correction, and treatment of non-unions, malunions, and bone defects. Fully implantable motorized intramedullary nails provide several advantages over the classically used external fixators, including improved patient comfort, reduced treatment time, and reduction in complications. The purpose of this article is to review the uses, techniques, and complications of motorized intramedullary nails in adults.

Key words: Intramedullary lengthening nail; Bone transport; Limb lengthening; Bone defect

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INTRODUCTION

Distraction osteogenesis is a common and successfully used treatment option for limb lengthening, deformity correction, and treatment of nonunions, malunions, and bone defects^[1,2]. Ilizarov introduced his method in 1950 to treat these bone defects using a circular external fixator^[3]. These original fixators are composed of stainless-steel circular frames that are connected to bone using either stainless steel wires under tension or rigid Schanz pins and are fixed to each other with threaded rods^[4]. Accurate planning and surgeon experience is paramount for the original Ilizarov method, with postoperative changes often needed for deformity correction^[4]. More recently, the Taylor Spatial Frame (Smith & Nephew) was introduced consisting of six obliquely placed adjustable struts connected to the proximal and distal rings^[5]. This allows multiaxial correction in six directions without the need to adjust the rings.⁵ Similarly, to ringed external fixators, is the use of uniplanar external fixation. This avoids the bulky ring external fixator and decreases the amount of pin sites; however, it has much less mechanical control^[6]. Overall, there are multiple complications associated with external fixator use with the most frequent being pin site infection found in up to 53% of patients^[7]. Other disadvantages include lengthy time spent in frames, risk of refracture after frame removal, skin pain, soft tissue tethering, and joint stiffness^[8]. Additionally, patients with circular external fixators have higher depression and anxiety scores^[9].

Due to the aforementioned complications of external fixators, the use of an implantable intramedullary lengthening nail was first described by Bliskunov in 1983 as a treatment option for limb-lengthening^[10]. This implant consisted of a telescopic nail that had a universal joint that connected to the outer table of the iliac wing^[11]. The Bliskunov nail lengthened by an internal ratchet system, powered by internally and externally rotating the hip^[11]. Shortly after, the Albizzia Nail (DePuy, Villerubanne, France) was introduced and also contained a ratcheting mechanism^[11]. This mechanism elongated the

nail by 0.07 mm per 20 degrees of limb rotation^[12]. Three time daily, the limb would be rotated 5 times to achieve 1 mm of lengthening. Sixty to 100 mm of lengthening could be obtained^[12].

Along the same lines as the Albizzia Nail, the Intramedullary Skeletal Kinetic Distractor (OrthoFix, Lewisville, TX) was introduced for femoral and tibial lengthening related to infection, trauma, polio, and burn^[13]. This mechanically unidirectional telescopic distracting intramedullary implant has proximal and distal parts, which are internally connected with a threaded rod consisting of two one-way clutches. Lengthening is activated by rotations of only 3-9 degrees with approximately 160 3-degree rotations results in 1 mm of distraction^[14]. The amount of distraction can be measured using a handheld monitor and the maximal distraction length of the nail is 80 mm^[14]. Patients are able to be weight bearing as tolerated with the nail using crutches^[13].

Due to the previously complications of external fixators and current intramedullary lengthening nails Baumgart et al. developed the first mechanical, motor-driven intramedullary lengthening nail known as the Fitbone (OrthoFix, Lewisville, TX) device for limb lengthening and bone transport^[15]. This system is used to treat bone defects from 3 to 12 cm in length in patients leg length discrepancies or bone loss^[15]. This implant consists of an electric motor powered by electricity transmitted via an induction coil placed in the subcutaneous tissue. Using an external transmitter placed over the coil, high-frequency electric energy passes through the skin to the motor. The motor delivers the torque that results in axial unidirectional movement^[14]. Of the original twelve patients, eleven were treated with limb lengthening and one was treated with bone transport after tumor resection; each had correction of the bone loss, without axial deformity or infection^[15]. The Fitbone Telescopic Active Actuator and the Fitbone Sliding Active Actuator are modifications to allow variable diameters with tibial implantation and bone transport, respectively^[16].

The latest intramedullary lengthening implant is the Precice nail (NuVasive Inc, San Diego, CA). This device is a telescopic internal lengthening nail with a generic rare earth magnet connected to a gear box and screw shaft assembly to allow lengthening of the nail^[17]. An external remote controller device contains 2 rotating magnets that when placed over the magnet within the nail, cause the internal nail magnet to rotate translating the thinner nail element telescoping out of the thicker surrounding nail^[17]. The nail can be both distracted and retracted by altering the settings on the external remote controller. This nail has been shown to be very accurate being within 1 mm of the desired length^[18]. Options of nailing include antegrade femoral piriformis or trochanteric entry, femoral retrograde and tibial implants. This implant has also been used for humeral lengthening and nonunion compression^[19,20]. The second generation of the nail is at least 2 times stronger in bending fatigue strength and has 3 times stronger coupling between the gears and lead screw^[14]. Full weight bearing is allowed after regenerate consolidation has occurred in 3 of 4 cortices^[14]. The purpose of this article is to review the uses, techniques, and complications of motorized intramedullary nails in adults.

INDICATIONS

Intramedullary lengthening nails have been utilized in the past three decades as an alternative to external fixation distraction systems. Intramedullary utilization has led to lower complication rates and higher patient comfort and satisfaction^[16,21]. Indications for surgical limb lengthening have been discussed with some controversy over

the years. Classic teaching suggests three different categories for limb length discrepancy which are less than 2 cm, which may be treated with observation and shoe lifts. The next category is patients with a 2-4 cm limb length discrepancy, which may benefit from limb lengthening and > 4 cm, where treatment may be beneficial to avoid future complications such as pelvic or lumbar abnormalities^[22]. When considering limb lengthening, consideration must be given to the patient's height, heel size, tolerability of the shoe lift, family opinion, and psychological aspects. In addition, having a clear understanding as to the etiology of the LLD is important for consideration for lengthening procedure^[23].

Congenital malformations such as tibial and fibular hemimelia, short femur syndrome and dwarfism secondary to achondroplasia may warrant consideration for leg lengthening^[22]. Oncologic conditions such as bone tumors or malignancies that comprise the skeletal integrity of the limb^[23]. Prior trauma secondary to gunshot wounds and motor vehicle accidents resulting in significant bone loss due to comminution or devitalization as well as nonunions, malunions, and osteomyelitis may also result in a defect that warrants bony segmental transport^[6].

TECHNIQUES

Each intramedullary device has its own unique technique and insertion strategy; however, some principles are universal across all devices. In order to implant internal lengthening rods in long bones, significant deformity, narrow intramedullary canal diameters, and obliterated medullary canals should not be present^[23,24]. Active infection should be avoided.

In general, lengthening with intramedullary nails requires weeks of planning prior to the procedure to prepare for any difficulties that may be encountered and ordering the correct implants. Due to the lengthening mechanism in each of the nail, they are all non-cannulated and straight. Insertion of nails in the humerus and tibia is typically not an issue in these bones, as they are often straight in the coronal and sagittal planes. The femur has an anterior sagittal bow, which must be factored in when placing one of the devices. Care must be taken not to ream out the anterior cortex of the femur. Blocking screws, half-pins or drill-bits can be used to create an optimal path^[25]. An osteotomy at the planned site is performed prior to reaming and nail insertion if it is indicated. Literature suggests over-reaming magnetic nails by 2 mm and motorized nails by at least 1 mm which allows for a more line to line fit^[15,26]. The nails are often inserted by hand, and rough impaction or excessive bending is avoided so that the internal gears are not damaged rendering the nail ineffective^[26]. Locking of the nail is performed in a standard fashion with a combination of jigs, if applicable, and free-hand. The lengthening mechanism is often trialed intro-operatively to make sure that it is intact.

Towards the end of the first week post operatively, lengthening begins approximately 1 mm/day, but typically not greater than 1.5 mm daily^[24]. Starting at 0.66 or 0.75 mm per day should be the maximum rate until radiographs demonstrate the formation of healthy regenerate bone^[18]. Femur lengthening typically begins 4 to 6 days postoperatively and tibial lengthening 7 to 10 days following index procedure^[24]. This may be performed in as little as 0.25 mm increments over three to four times a day^[27]. Regular radiographic checks every 2 weeks is recommended to assess for adequate bone regenerate. Speed of lengthening may be adjusted given the appearance on radiographs, as well as other patient risk factors for non-healing such as smoking, diabetes, vasculopathy, or concern for infection^[24].

If bone transport method is used, an osteotomy is required to create the segment for transport. Following bone segment docking, another surgery is performed to apply autologous bone graft and compression at the docking site. Bone graft options are at the choice of the surgeon, however, iliac crest, femoral reamings, or bone marrow aspirate are all adequate options to apply at the docking site to further stimulate healing^[28].

Weight bearing during the lengthening phase has been up for debate, but recommendations suggest 15 to 20 kg weight bearing to the operative extremity following a day of rest post operatively^[28]. Some studies have suggested early weight bearing may be a risk factor in leading to loss of achieved length and others have suggested holding off from full weight bearing until observing 3 consolidated cortices of the regenerate is appreciated^[29,30]. Nail removal is typically undergone at 12 to 24 months following index procedure per manufacturer suggestion^[31,32]. Removal of these nails is routine and magnetic resonance imaging (MRI) is discouraged while the nail is in place. There are minimal restrictions following this ambulatory procedure^[33].

In certain cases, the defect is greater than lengthening capacity of the nail. If this occurs, exchange nailing or “resetting” may be necessary to continue lengthening. This can be accomplished by removing the locking screws from the bone, winding back the nail and reinserting the locking bolts in a new position allowing it to continue lengthening once activated via magnetism or motorization^[34].

A technique that is increasing in popularity is plate-assisted bone segment transport (PABST) with motorized lengthening nails and locking plates for the treatment of traumatic or malignant bone defects in the diaphysis of long bones in the acute setting in an effort to eliminate the need for prolonged external fixation and to reduce treatment time^[28]. The plate allows stabilization of concomitant fractures, maintains limb length, and facilitates docking site fixation, while the intramedullary nail provides controlled distraction osteogenesis with minimal impact on surrounding soft tissues for the filling of bone defects^[28].

In this technique, a rigid locking plate is placed to span the defect using combinations of unicortical and bicortical fixation and is typically located on the lateral side of both the femur and tibia, although medial placement has been described^[28]. Plate placement is preferably located in the metaphyseal region, which is optimal for secure positioning, with screws trajectory planned to be posterior to projected path of motorized nail. The authors recommend using an external fixator to apply the locking plate for greater accuracy^[28,34]. Following spanning of the osseous defect, an osteotomy at the planned site is performed prior to reaming and nail insertion. The nail is then inserted in standard fashion and transport can begin.

In other words, the nail can be predistracted prior to insertion and then used to pull the fragment to fill the defect. If the defect is greater than lengthening capacity of the nail, exchange nailing or “resetting” may be necessary to continue lengthening. This can be accomplished by temporarily fixating the segment and compressing the nail, then relocking it in a new position allowing it to continue lengthening once activated via magnetism or motorization.

COMPLICATIONS

The relatively small number of cases and series make it difficult for standardized assessment and reporting with intramedullary limb lengthening. Success and complication rates seem to be primarily secondary to surgeon experience as well as length of distraction^[6].

Pain

Pain is the most common complaint with limb lengthening, which is theoretically decreased using intramedullary nails when compared to using other external constructs. Pain is thought to be caused by stretching of the periosteum with subsequent muscular spasm and bone inflammation^[36].

Pain is also a limiting factor in the use of the Bliskunov nail. This is due to this device needing to be rotated 20-30 degrees for lengthening, the mechanism can cease to be effective if the regenerate new bone becomes too stiff to allow this counter-rotation leading to a return trip to the operating room for osteotomy through the regenerate^[11]. Guichet et al. reported that all patients had pain during lengthening and 39% needed lengthening under general anesthesia due to the painful nature of this process^[12].

Nerve palsy

Nerve palsies have also been observed, most commonly the deep peroneal nerve. This may be due to rapid femoral lengthening causing neuropraxia. This complication may also be seen with excessive tibial lengthening and subsequent compartment syndrome. Discontinuation or pause in lengthening is usually treatment of choice to lead to neuropraxia improvement. Fasciotomy of the lower extremity may be warranted if there is concern for compartment syndrome^[37].

Device breakage

Failure of intramedullary devices can be a cause of concern since they are weaker than single-block nails used in the trauma setting. Construct malfunction or defects, surgeon error which may be due to forceful manipulation, improper assembly, or improper over-reaming techniques are several ways to contribute to implant failure. Patient-driven factors may also contribute to failure. Biological inhibition secondary to nonunion or weight bearing during lengthening with subsequent blockage. It is vital that the implant failure be recognized during follow ups so revision may be discussed to avoid harmful sequelae in treatment.

Breakage, blockage, and runaways are complications specific to intramedullary nailing devices. Breakages can commonly occur at stress risers where lengthening is taking place. Motor malfunction and blockage can result in early consolidation. Runaway nails, or nails that unintentionally lengthen more than desired (1.5 mm/day), can result in insufficient bone regenerate having damaging ramifications^[6,37].

Distraction issues

Issues with distraction have been largely contributed due to malfunction of the ratcheting mechanism of these lengthening nails. Distraction rates > 1.5 mm/day as mentioned above increase the risk for poor bone regenerate. One of the unique complications of the Albizzia Nail implant is the concept of the runaway nail in which the nail lengthens by greater than 1.5 mm per day due to the patients' daily activities^[38]. This occurred more often when the length of the distal femoral segment is less than 80 mm in length^[38].

In addition, a complication unique to magnetic nail is based on patient habitus. Driving mechanisms are not expected to function properly in individuals with a body mass index > 35. The wide soft tissue interval may interfere with external remote controller function of the PRECICE magnetically motorized nail^[27].

Poor regenerate

As mentioned, poor regenerate is a result of multiple risk factors. Runaway nails, patients older than 30 years of age, smoking, LLD

gain greater than 4 cm, and osteotomy at the same level of previous surgery or trauma all increase the risk for poor regenerate. Ryu et al also found particularly when studying tibial lengthening, the potential consequences of lengthening over nail technique compared to lengthening and then nailing. Their findings suggest potential decreased regenerate callus due to the concomitant tibial reaming and nailing, which may be due to the violation of the endosteal blood supply disruption^[38]. However, others argue that lengthening over the nail technique enables bone reamings to enter the distraction site serving as a scaffold for the regenerative process. It also provides a larger canal to facilitate bone sliding over the nail^[38,39].

Infection

Infection risk is substantially lower in intramedullary nail bone segment transport and reports show a 0% incidence compared to rates of 28-45% for superficial and 23% deep infection with revision in constructs using pins or wires. Rate of 3-12% has been appreciated in external fixation combined with solid intramedullary nailing. Previous history of open fracture should be carefully considered and avoidance of external fixator pins from contacting the nail have both been considered risk factors for infectious etiology^[6,16].

Joint stiffness

Knee arthrofibrosis and muscular contracture can occur if joint range of motion is not incorporated in recovery following surgery. Joint motion lubricates the articular cartilage, decreases pain, and prevents adhesions which is vitally important in regaining range of motion and functionality of the lower extremity^[41]. Literature reflects on the importance of incorporating motion into the recovery protocol instead, and cycling has shown to allow for more flexion/extension cycles than formal physiotherapy^[41,42]. Stretching also stimulates production of actin and myosin filaments^[43]. Regaining of motion is found to be better with nails and have optimal values during distraction-consolidation, regardless of nail type, with quicker return to functional capacity.

Iatrogenic deformity

Patients that undergo lengthening may also experience changes in mechanical axis of the extremity regardless of the presence of angular deformity. Example of this would be an increase in valgus angulation of the femur with retrograde femoral nailing. This is why it is of vital importance to account for potential change in geometric axis when using straight nails for limb lengthening, otherwise, iatrogenic deformity will be highly probable^[21].

Systematic review by Frost et al sought to quantify complications of intramedullary motorized nailing devices as they have become more popular in recent years over external fixation devices. Their results revealed a single complication for every three segments lengthened in the lower extremity. Of 34% of complications in treated segments, 15% experienced a significant deviation in treatment plan, 5% failed to attain lengthening goal, and 3% experienced new pathology or permanent sequela. Limitations with these numbers may be unreliable, as there is no formal standardized method of reporting complications in these patients in place^[44].

Complication rates with these lengthening procedures are of significant concern, and providers must consider the impact of these factors on patient outcomes. There has been a shift in use of intramedullary nailing systems for bone transport with proponents' primary reason being decreased infection rates and number of operations. Axelrod et al. demonstrated in their systematic analysis that comparing external fixation, combined internal and external

fixation, and mechanical lengthening nail showed similar outcomes in mean limb lengthening, infections, and need for reoperation^[45]. However, multiple studies report a decrease in complication rates compared to external constructs for limb lengthening (Nasto et al 2020)^[16]. Increased literature is needed to further quantify differences in methods of bone transport as well as the complication profile of these systems. As advances are made, the technology of these nails should continue to improve and optimize performance as well as limit complications^[45].

DISCUSSION

The evolution of limb lengthening techniques has been a technology of significant advances over the past several years. With external fixation constructs previously having been the gold standard, the popularization of intramedullary lengthening has increased in attraction to providers given the increase in patient satisfaction and decrease in complication rates. The progression in intramedullary nail technology has also been significant with the first-generation nails consisting of mechanical lengthening mechanism, subsequently graduating to the development of motorized nails, and ultimately with magnetized nails being utilized to achieve limb lengthening in osseous defects^[46]. Inspiration for magnetized lengthening nails originally derived from the use of scoliotic correctional growing rods used in the pediatric population^[47]. There have been over 250 cases utilizing the PRECISE nail since its introduction in 2011 with positive results demonstrating decreased complications and improved patient satisfaction in comparison to external fixation constructs and previous intramedullary implants. Lee et al demonstrated a significant decrease in complications in PRECISE nail groups (17.6%) compared to ISKD systems (74.3%) and other studies demonstrate lower non-device related complications^[48].

Second generation of PRECISE nails were developed due to weak distraction in the presence of dense regenerate as well as cases of failure of the first-generation construct at the transition of the modular portion of the nail^[17]. Improvements with the newer generation PRECISE 2 nail demonstrated greater mechanical strength as well as decreased surface degradation. The weak distraction force and implant fractures seen in PRECISE 1 nails had also improved in PRECISE 2 nails. However, deficiencies in the newer generation were found to be related to rotation coupled mechanism which led to additional surgery^[48].

CONCLUSIONS

Literature has demonstrated the use of intramedullary nails for limb deformity, extremity defects seen in trauma population, as well as nonunion and malunions. Given the successful use of these nails, the previous use of circular frames or external fixators in limb lengthening will anticipatorily continue to decrease in use^[46]. Important factors for future improvement in nail constructs regardless of mechanism of lengthening (i.e. mechanical, motorized, magnetic) is to limit the presence of distraction control and stability related complications. Future studies will be important in assessing the mechanical stability and strength of intramedullary lengthening nails, however, this technology implements a newer standard of care for patients with limb lengthening needs.

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