# Motorized Intramedullary Lengthening Nails: Outcomes and Complications

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**Summary:** The outcomes of motorized intramedullary lengthening nails are overwhelmingly good with acceptable complication rates and high surgeon satisfaction. While patients report overwhelming approval to surgeons, universal orthopedic outcomes scores fail to capture the true benefits of these procedures. Many studies have been cited in table format in this report. Pearls from experienced surgeons are reviewed and include the benefits of antegrade nailing over retrograde, prophylactic soft tissue release, and blocking screw use. Pitfalls are explored to keep the reader vigilant for mechanical failure of the nail, delayed healing, and common tibial difficulties. Through compiling data, estimates of collective complication incidence are presented.

**Key Words:** Precice—Fitbone—magnetic lengthening nail—limb deformity—limb lengthening—Stryde.

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The outcomes of motorized intramedullary lengthening have been described in multiple studies with some utilizing patient-reported outcomes but most assessing the accuracy of the nail and its ability to accomplish the orthopedic goals safely. The first papers published on this topic were small, retrospective case series that reflected on the original versions of the Precice (NuVasive, San Diego, CA) and Fitbone (Wittenstein, Igersheim, Germany). Many of these manuscripts with larger patient cohorts have been included in this review. More recently, surgeons have built up a large volume of cases from which to study to answer more specific questions. These studies look at patient populations with more uniform demographics or compare different techniques or surgical methods in order to better understand how we can improve upon the status quo. The implants have been redesigned and improved making certain complications version specific. Efforts to identify model-specific flaws have been brilliantly classified by Lee et al[1] into device-related complications of internal lengthening nails. The Stryde nail (NuVasive, San Diego, CA), a stainless steel advancement of the Precice, allows far greater weight bearing and is recently available. There is no clinical Stryde data at this time for implant comparison.

Data are often best conveyed visually, and this review includes several tables for quick reference and comparison of studies (Tables 1–4). A final table has attempted to cull unique patient groups from each center (without counting any patient twice) in order to pool data and draw conclusions on the incidence of the complications that have been reported (Table 5).

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There are several pearls that have arisen out of the review of these articles which represent the combined experience of many surgeons:

## ANTEGRADE FEMORAL NAILING IS SUPERIOR TO RETROGRADE NAILING

Many surgeons would say this was intuitive since there is more muscle (blood supply) around a proximal femoral osteotomy site, the knee is not violated, blocking screws and not usually needed, the procedure is faster, and incisions are more hidden. However, data now support this assumption where the antegrade method was shown to yield a lower bone healing index (BHI)[3,4,8] and superior hip and knee motion.[3] Lengthening along the anatomic axis produces valgus as the knee glides medially, however the significance of this phenomenon has been contested. During antegrade lengthening, the femur tends to drift into varus often resulting in a net minimal deviation of the mechanical axis. In other words, the proximal varus that tends to occur with antegrade lengthening via nail bending often counteracts the lateral mechanical deviation witnessed with lengthening along the anatomic axis.[1,4] The use of a medial blocking screw can help counteract this varus bending. Trochanteric nail entry may produce more varus than piriformis entry. There are some cases of lengthening with 8.5 mm diameter nails where the lengthening site bent into enough varus to call it a malunion.[1,4] Suffice it to say that simply relying on preoperative radiographic planning may not result in the desired mechanical axis due to the numerous technical and biomechanical variables. Retrograde nailing is still superior for correcting distal femoral deformity and for obtaining a magnetic connection in obese patients.[3,8]

### Prophylactic Iliotibial Band (ITB) Release Avoids Knee Contractures

In studies where the ITB was routinely released[6] or where lengthening averaged 3 cm,[2,8] there were very few reports of joint contractures. Cases of congenital femoral deficiency are excluded from this generalization where ITB release does not ensure knee stability.[5] By contrast, surgeons that did not release the ITB prophylactically with average lengthening $>4$ cm were harassed by knee flexion contractures that required later release.[3] Recommendations are to release the ITB for femoral lengthening $>3$ cm,[3] but there is no downside to releasing it for all cases.[5]

### Use Blocking Screws

Blocking screws have become a vital part of the surgeon's ability to correct deformity with an intramedullary implant and to prevent new deformity during lengthening.[8,9,13,29] While most limb lengthening surgeons use blocking screws routinely, few have studied their effectiveness. Furmetz et al[9] looked at a nonrandomized cohort of femoral lengthening patients and saw slightly improved results with blocking screws. For larger deformity corrections and for corrections that were unacceptable with reaming alone, blocking screws were used. For small corrections they were not necessary. Authors concluded that these screws should be used for deformity corrections $>2$ degrees to improve control. One should also appreciate that the

**TABLE 1.** Lengthening Outcomes: Femur and Tibia

| Study (Implant) | N (Limbs) | BHI (d/cm) (Range/SD) | Deformity Correction (Degree) (Range) | Lengthening Accuracy-Precision | Years Follow Up (Range) and Outcome | Author Conclusion |
|---|---|---|---|---|---|---|
| Green et al[2] (Precice) | 31<br>F-23<br>T-8 | 44.5 (SD22.8) | NR | Length: 33.5 mm (29.4-37.6)<br>Accuracy: 96% achieved planned length | 29/31 limbs studied through consolidation.<br>17/31 two year follow-up.<br>Enneking Functional score improved 18%,<br>AAOS LLM & SF-36 no change | Patient-reported outcome scores were not sensitive to this patient population |
| Calder et al[3] (Precice) | 107<br>A-73<br>R-34 | A = 29 (15-80)<br>R = 36 (16-108) | Acute deformity correction in 12 patients.<br>Pre-Valgus 20<br>Pre-Varus 15 (6-20)<br>Pre-sagittal 27<br>Pre-torsion<br>28 (25-30).<br>Flexible reamers | Length: 46 mm (5-80); 105/107 limbs achieved planned length.<br>Lengthening induced deformity: MAD 5-10 mm: A-15/73, R-7/34;<br>MAD > 10 mm: A-10/73, R-9/34 | Time F/U NR.<br>Regained full joint motion: A-90%, R-88% | Accelerated weight bearing program may lower BHI. Antegrade nail created less deformity |
| Horn et al[4] (Precice/ Fitbone) | 50<br>P-34<br>Fit-16<br>R-23<br>A-21<br>T-6 | A = 34 (18-61)<br>R = 40 (24-76)<br>$P = 0.03$<br>T = 76 (49-122)<br>Age < 18 healed faster than age > 18: (BHI 27 vs. 43, $P = 0.005$) | Pre-Valgus Lat MAD 21 (4-50) mm;<br>Pre-Varus Med MAD 31 (14-58) mm<br>RPM.<br>R-Rigid reamers, A/T-Flexible reamers | Length: 40 mm (25-65)<br>Lengthening induced MAD = 3 mm (0-11) ($P = 0.9$) | 2.3 (1-6) | Lateral MAD from anatomic axis lengthening was counter-balanced by varus bending of the lengthened femur. Deformity correction then lengthening slowed BHI compared with lengthening alone |
| Szymczuk et al[5] (Precice) | 62<br>EF-32<br>P-30<br>(All F) | EF = 29.3 (SD, 12.7)<br>*P* = 34.8 (SD, 11.2) | NR | Length:<br>5.6 (SD, 1.7)-EF<br>4.8 (SD, 1.4)-P<br>All ITB release.<br>> 87% achieved planned length in both groups | 4.47 (SD, 2.7)-EF<br>1.86 (SD, 0.7)-P | Congenital Femoral Deficiency is challenging. Precice can correct length but knee subluxation may occur and impact lengthening goals |
| Fragomen et al[6] (LON vs. Precice) | 59 LON-20<br>P-39<br>(mixed A/R) | LON = 42.7 (24.4)<br>*P* = 30.5 (15.3) | Not recorded.<br>Flexible Reamers | Length: 40.4 mm (SD, 22.9)-LON, 38 mm (SD, 16.8)-P<br>Accuracy (mm): LON-3.6, P-0.3<br>Precision: LON-0.8, P-1.0 | 2.3 (1.1-3.1)<br>Knee ROM preserved | *P* more accurate and precise than LON, but yields similar BHI and regenerate quality |
| Richardson et al[7] (Cost LON vs. Precice) | 58 | NA | NA | NA | Cost: P-US$44,449; LON-US$50,255 ($P = 0.482$) | P fewer surgeries than LON (2.1 vs. 3.1). No significant cost difference |
| Iobst et al[8] (Precice) | 27<br>(All R) | 42 | Pre-Varus: Med MAD 24 (SD12.5)<br>Post Varus: MAD 6.9 (4.8)<br>Pre-Valgus: Lat MAD 23.7 (SD, 11)<br>Post Valgus: 5.4 (4.4).<br>All FAN.<br>All had blocking screws.<br>Mean correction 7 degrees.<br>Post MAD = 81% 8 mm<br>flexible reamers | Length: 30<br>Accuracy: 0.8 mm | 1.1 (0.6-2.4)<br>ASAMI: E-26, G-1 | FAN with blocking screws yields good results and accurate corrections |

| | | | | | | |
|---|---|---|---|---|---|---|
| Furmetz et al[9] (ISKD) (Orthofix, Lewisville, TX) | 31<br>B-15,<br>NB-16 | NR | Average deformity corrected: 2.4 (0.8-8.0) deg.<br>Blocking screws used in larger deformity corrections- not randomized.<br>Planning: end-point-first method, rigid reamers | Length: 36.8 mm (19.7-66.0) | F/U NR<br>Accuracy of deformity correction within 3.0 degrees in > 87% of cases | Use of dummy nails allowed for very close blocking screw placement ensuring proper alignment. Blocking screws make deformity correction > 2 degrees more accurate |
| Lee et al[1] (ISKD, P1, P2) | 115<br>F-88<br>T-27<br>ISKD-35<br>P1-34<br>P2-46 | NR | Lengthening induced deformity (deg.):<br>F, P1 = 1.1 deg. (0.7-4) valgus<br>T, P1 = 5.1 (3.2-8.8) valgus<br>F, P2 = 0 (± 3.5)<br>T, P2 = 2.8 valgus (2.1 varus-6.7 valgus) | Length:<br>P1-49 (± 8)<br>P2-51 (± 7)<br>Accuracy P1 = 1 mm (SD3)<br>Accuracy P2 = Femur 0 mm (± 2.5), Tibia 2 mm (± 2.5) | F/U =<br>P1-1.5 (± 0.33)mm<br>P2-1.25 (± 0.42)mm | Newer versions of the Precice address mechanical issues and were not tested |
| Wagner et al[10] (Precice-P1) | 32<br>F-24<br>T-8 | 36.4 (12.8-113)<br>F = 32.4 (13-113)<br>T = 48 (22-101) | NR | Length: 43 mm (15-65)<br>Accuracy 97%<br>Precision 92% | 1.6 (1-2)<br>Enneking score improved 3.8pts | Precice is comparable to other lengthening nails but an improvement over the ISKD |
| Hammouda et al[11] Post Trauma (Precice) | 17<br>All F<br>A-13<br>R-4 | 32 (16-51) | NR | Length:<br>38 (23-60)<br>Accuracy: 16/17 achieved planned length | 2.2 (1-3.7) | Acceptable results |
| Hammouda et al[12] Troch entry (ISKD, Precice) | 31<br>ISKD-18<br>P-13 | NR | NR<br>Flexible Reamers | Length:<br>54 (30-67) | 3.5 (1.4-9.0) | Acceptable results and no cases of femoral head necrosis |
| Accadbled et al[13] (Fitbone) | 26<br>F-15<br>T-11 | F = 73 ± 57<br>T = 83.5 ± 65 | Pre-Valgus 8.7 (4-15), Post-Valgus 3 (0-5);<br>Pre-Varus 13 (4-20), Post-Varus 2.1 (0-5)<br>Planning: RPM, rigid reamers | Length: 45 mm(20-80);<br>23/26 achieved planned length | 3.4 (2-5.3).<br>VAS during distraction 2.5 (0-4). ASAMI Function: E-21, G-1, Pr-1 | Good results |
| Karakoyun et al[14] (Precice) | 27<br>F-21<br>T-6<br>A-11<br>R-10 | 34 (27-52) | Angular correction 15.5deg (7-25)<br>Rigid reamers | Length: 48.2 (34-120) | 1.7 (0.4-3.6) | Acceptable results |
| Kirane et al[15] (Precice) | 25<br>F-17<br>T-8 | NR | Lengthening induced deformity:<br>F-MAD 1 Lat(2med-8 lat)<br>F-procurvatum 3deg (0-12)<br>T-MAD 5 Lat (0-8 Lat)<br>Flexible Reamers | Length: 35 (14-65)<br>Accuracy 96%<br>Precision 86% | 0.3 (0.06-0.6) | Expect coronal plane deformity and flexion to occur with lengthening. The tendency for the femur to bend into varus is counteracted by the lateral MAD from lengthening along the anatomic axis |
| Kreig et al[16] (Fitbone) | 32<br>F-21<br>T-11 | F = 35 (IQR, 27-44)<br>T = 48 (IQR, 34-63) | Pre-Varus Med MAD 13 (6-50)<br>Post-Varus MAD 4 (38 med-11 lat);<br>Pre-Valgus Lat MAD 13 (5-40)<br>Post-Valgus 0 (10 med-28 lat)<br>RPM | Length: 35.3 (20-80)<br>Accuracy:<br>30/32 within 5 mm of goal | 1.3 (1-2.3)<br>ASAMI: E-26, G-5, F-1 | The BHI was significantly lower for femur lengthening compared with tibial lengthening |

A indicates antegrade femur; ASAMI, ASAMI score;[17] B, blocking screws; BHI, Bone Healing Index; E, excellent; EF, external fixation; F, Femur; FAN, fixator assisted nailing; Fit, Fitbone; G, good; IQR, interquartile range; ITB, Iliotibial Band; Lat, Lateral; LON, Lengthening Over Nail; MAD, Mechanical Axis Deviation; Med, Medial; NB, No Blocking Screws; NR, Not reported; P, Precice; Pr, Poor; R, Retrograde femur; RPM, Reverse Planning Method;[18] T, Tibia; VAS, Visual Analogue Scale.



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**TABLE 2.** Lengthening Outcomes: Humerus

| Study (Implant) | N (Limbs) | BHI (d/cm) | Deformity Correction (deg.) (range) | Lengthening Accuracy-Precision | Years Follow Up (Range) and Outcome | Author Conclusion |
|---|---|---|---|---|---|---|
| Morrison et al[19] (Precice vs. EF) | 13 P-6, EF-7 | NR | Humeral deformity 5/13 (max, 50 deg.) | Length: 85 (EF), 66 (P) | > 0.5 | Nail stroke is limited and re-loading the nail can be done successfully. Lengthening rate was slower for Precice |
| Furmetz et al[20] (Precice and Fitbone) | 5 (3Fit-Antegrade, 2P-Retrograde) | 33.6 (25-45) | None | Length: 55 (40-65) | Anecdotal 100% satisfaction | More data are needed on internal humeral lengthening |
| Hammouda et al[21] | 6 | 36 (25-45) | Humeral deformity 3/6 (13 deg.) | Length: 51 mm (45-58) All achieved desired length | 1.8 (0.9-2.4) QuickDASH improved 22.7 patients | Acute distraction may be required at the osteotomy site to fit the nail-increase latency |

BHI indicates Bone Healing Index; EF, External Fixation; Fit, Fitbone; LON, lengthening over nail; NR, not reported; P, Precice.

mostly excellent outcomes presented in the literature are the result of proper blocking screw use even though not explicitly studied. The incidence of malunion after lengthening was 3% and many of these cases were due to lengthening induced deformity that could have been prevented with blocking screws.

## P1 Nails and P2.0 Crowns can Fracture

Although mostly of historical significance, Precice nails have faced adversity with regard to mechanical failure. The original Precice (P1) nail was modular, assembled on the back table, and had a weak spot at the welding seam. This was witnessed to fracture in some cases.[1,3,6,30,31] The engineers quickly replaced it with the P2.0 nail which did not fracture but instead had a weak crown at the junction of the large bore and the telescopic portion of the nail. The crown failed in torsion which led to variable mechanical performance including (1) continuing to function in lengthening, (2) not being able to lengthen but not shortening, and (3) shortening (running back) with loss of length. This was detailed meticulously by Lee et al[1] who noted that of 14 implanted nails that sustained crown fractures, only 2 of them required revision surgery. The true frequency of crown fracture was most likely higher than the reported 3% since the signs can be subtle and many times it did not lead to a clinical complication. Some reported complications may have been due to unrecognized crown fracture; for example "nail retraction" (running back) may have been the result of a broken crown. The P2.1 was introduced with a much stronger crown, now internalized, that failed at a vastly reduced incidence.

## Prevent Delayed Union and Nonunion

While uncommon, delayed union and nonunion are concerns (2% and 1% incidence, respectively) that can usually be prevented by surgical technique and careful observation. The percutaneous osteotomy with drill holes (vent holes), followed by reaming, followed by an osteotome has earned an outstanding track record for high-quality regenerate formation. The bone "swarf"[12] (reamings) deposited at the corticotomy site through the vent holes may have much to do with the rapid healing and low BHI seen in most series (antegrade femur average 33 d/cm) (Table 1). The vast majority of surgeon-authors used this method with great results. In contrast, osteotomy over an existing nail (which does not require reaming) with subsequent lengthening has produced slower healing with a higher BHI (average, 52 d/cm).[32] The optimal rate for lengthening is patient specific. Frequent follow-up radiographs are needed to modulate rate and rhythm to avoid poor regenerate. Once established, the management of these complications is similar among studies and includes: stopping lengthening, accordion oscillation of the regenerate, injection of

**TABLE 3.** Outcomes of Intramedullary Compression Nailing

| Study | N (Interfaces) | Compression | F/U (y) | Union Rate | Lengthening Sleeper Nail | Conclusion |
|---|---|---|---|---|---|---|
| Fragomen et al[22] (Precice) | 14 (Nonunion F9, T5) | Postop compression and recompression | 1.6 (0.5-2.8) | 13/14 | N = 1 Length = 50 mm | Recompression was applied until bending of locking bolts was seen |
| Vercio et al[23] (Precice compression of Allograft) | 15 (allograft-host sites) (F5, H3) | Intraop and recompression | 2 (1.2-3.5) | 12/15 | N = 2, Length = 55 mm | Half of the cases required recompression and united quickly thereafter |
| Watson et al[24] (Precice) | Technique Article | Intraop and recompression | NR | NR | NR | Apply recompression every 3 weeks until union |

F indicates femur; F/U, follow up; H, humerus; NR, not reported; T, tibia.

**TABLE 4.** Complications of Motorized Intramedullary Lengthening

| Study (n Limbs) | Complication (Incidence) | Lesson/Recommendation |
|---|---|---|
| Femoral and tibial lengthening | | |
| Green et al[2] | Nonunion (2)<br>Broken screw (1)<br>Dead nail (1)<br>Nail breakage during removal (1)<br>Deep infection (1) | Acceptable results |
| Calder et al[3] (107) | Joint contracture requiring releases (5)<br>Premature Consolidation (2)<br>Nonunion (3)<br>Locking bolt migration (10)<br>Dead nail (1)<br>Nail retraction (1)<br>Nail Breakage P1 upon removal (2)<br>Crown Failure P2 (1)<br>Proud R Nail with patellar symptoms (1) | Prophylactic ITB release for lengthening > 3 cm.<br>Age is inversely related to healing time.<br>Recommend antegrade method |
| Horn et al[4] | Stiffness-NR<br>Malunion: Lengthening induced procurvatum (F-1)(T-3) and varus (F-1)<br>Nonunion (1)<br>Locking bolt migration (3)<br>Dead Precice Nail (1)<br>Receiver failure (Fitbone) (1)<br>Late periprosthetic Fx proximal to Retrograde nail (2) | Trochanteric nails can introduce varus deformity if starting point is not at the tip.<br>Recommend antegrade method.<br>Adolescents heal faster than adults |
| Szymczuk et al[5] | All Congenital Femoral Deficiency<br>Contracture (9)<br>Subluxation (4)<br>Premature Consolidation (1)<br>Delayed Union (12)<br>Nail failure (2)<br>Nerve compression (2) | Manage delayed union by compressing the nail or removing locking screws.<br>Less adverse events with Precice.<br>Precice avoids transient loss of knee motion seen with EF |
| Haider and Wozasek[25] Complications (6/20) | Nonunion (Atrophic) (4)<br>Nail breakage (2) | Exchange nailing with a trauma nail and autograft of nonunion site for lengthening induced nonunion |
| Kanerva et al[26] | This was a study of mechanical testing of Internal lengthening nails with multi-axial loading and finite element analysis | Internal lengthening nails should be tested in a loading machine that can determine implant fatigue under COMBINED torque, bending, and compression which best simulates walking |
| Fragomen et al[6] (39) | Joint contracture (0)<br>Premature consolidation (2)<br>Malunion (1)<br>Delayed union (1)<br>Nail breakage P1 (1)<br>Residual LLD (1) | Prophylactic ITB release performed in all cases may have prevented knee stiffness. P had less complications than LON (18% vs. 45%) and saved a surgery |
| Iobst et al[8] | Knee stiffness (1)<br>Post tibial subluxation (fibular hemimelia) (1)<br>Premature consolidation (1)<br>Malunion: Procurvatum (1) | Use of > 1 Blocking screw, 6 mm Schantz pins, and 12.5 mm Nail were associated with higher accuracy |
| Foong et al[27] Retrieved Precice Implant Performance (11) | P2.1 had less wear than earlier designs<br>Anti-rotation device in P2.0 created the greatest wear.<br>No actuator pin Fx | P2.0 antirotation device demonstrated most wear and may explain the propensity for crown fractures |
| Pantagiotopoulou et al[28] Inspection of retrieved Precice implants (15) | P1- all had fractured actuator pins and internal corrosive debris.<br>P2, P2.1-had intact actuator pins, but titanium and biological debris was found internally without corrosion | Be cautious in re-using Precice nails as they may be at risk for corrosive implant failure particularly if they have been implanted for a prolonged time |
| Lee et al[1] | Distraction Control Complications:<br>ISKD-63%<br>P1-premature consolidation/inadequate force to distract regenerate (2)<br>P2-running back (retraction) (1),<br>Dead nail (1)<br>Stability Complication: P1-Bending no breakage (3), nail breakage (1)<br>P2- Bending-no breakage (8.5 mm nail) (7),<br>nail crown breakage (14)-2 were unstable<br>Delayed union P2 (2) | P1 suffered from nail breakage and failure to distract. P2 solved these issues but suffered from weak rotational stability. Rotational instability can be fixed with a monolateral external fixator. The 8.5 mm nail is weak in bending and affects coronal alignment |

**TABLE 4.** (*continued*)

| Study (n Limbs) | Complication (Incidence) | Lesson/Recommendation |
|---|---|---|
| Wagner et al[10] | Knee subluxation (1)<br>Fibula nonunion (1)<br>Tibia delayed union (1)<br>Femur delayed union (2)<br>Peroneal nerve entrapment (1)<br>VTE (1) | Acceptable results<br>For partial union: recommend BMAC, bone grafting, nail dynamization, exchange nailing |
| Hammouda et al[11] | Premature consolidation (2)<br>Nerve entrapment (1) | No implant-related complications |
| Hammouda et al[12] Troch entry (Precice) | Hip subluxation (1)<br>Premature consolidation (1)<br>Delayed union (2)<br>Dead nail (1)<br>No AVN<br>No Coxa Valga | Trochanteric entry is safe for patients as young as 7 year old |
| Accadbled et al[13] (Fitbone)(26) | Knee contracture (2)<br>Equinus Contracture (2)<br>CRPS (1)<br>Malfunction transmitter (1)<br>Skin necrosis (1)<br>Intracondylar fracture retrograde nailing (1)<br>Decompensation AV fistula leg requiring embolization (1) | Acceptable results |
| Karakoyun et al[14] | Stiffness-NR<br>Nail breakage (1) | Broken nails can be treated with exchange nailing using trauma nails.<br>Overlengthening can be resolved with reversing distraction and compressing the desired amount |
| Kirane et al[15] | Ankle contracture (2)<br>Toe clawing (1)<br>Premature Consolidation (1)<br>Delayed union (Tibia) (2)<br>Dead nail (1) | Acceptable results |
| Kreig et al[16] | Knee contracture (1)<br>Residual LLD > 7 mm (2)<br>Delayed union (2)<br>Locking bolt migration (4) with nail retraction (3)<br>Dead Nail (1)<br>VTE (1) | Acceptable results. New nail design prevents running back with loss of length |
| Humeral lengthening | | |
| Morrison et al[19] (Precice) | Elbow contracture (1)<br>Premature consolidation (1)<br>Loss of fixation and flexion of the osteotomy (1) | Acceptable complication incidence |
| Furmetz et al[20] | Loss of shoulder abduction (antegrade) (2)<br>Elbow contracture (retrograde) (1)<br>Proximal migration Humerus causing abandonment of lengthening (1)<br>Crown Fx P2.0 (1) | Both nails achieved goals and had some complications |
| Hammouda et al[21] | Shoulder stiffness (1) | Minimal complications |
| Compression Nailing | | |
| Fragomen et al[22] | Nonunion (1)<br>Compression induced deformity (2)<br>Deep infection (1) | Compression nailing may not be suited for proximal tibia metaphyseal nonunion |
| Vercio et al[23] | Knee stiffness (1)<br>Nonunion (2 site same patient)-radiation/chemo patient<br>Nonunion and Nail failure (1)<br>Backing out screw (1)<br>Allograft Fx (1) | Lower complication rate than seen with other implants |

AV indicates arteriovenous; AVN, avascular necrosis; BMAC, bone marrow aspirate concentrate; F, femur; Fx, fracture; ISKD, intramedullary skeletal kinetic distractor; ITB, iliotibial band; LLD, limb length discrepancy; NR, not reported; P1, original Precice nail; P2, second-generation Precice nail; P2.1, third-generation Precice nail; R, retrograde; T, tibia; VTE, venous thromboembolism.

bone marrow aspirate, open autologous bone grafting, and exchange nailing with a trauma nail. The phenomenon of partial bone union was raised by Wagner et al[10] whereby the regenerate unites strongly on one side but not on another. Although technically healed, the construct relies on an intramedullary implant to prevent fracture. Authors recommend grafting of the partial defect to reconstruct the bony cylinder allowing for eventual nail removal.

**TABLE 5.** Summary of Complications From Pooled Data

| All Long Bones (N = 551) | Incidence, n (%) |
|---|---|
| Joint contracture | 26 (5) |
| Joint subluxation | 8 (1) |
| Premature consolidation | 11 (2) |
| Malunion | 18 (3) |
| Nonunion | 6 (1) |
| Delayed union | 10 (2) |
| Locking bolt migration | 17 (3) |
| Locking bolt breakage | 1 (0.1) |
| Dead nail | 6 (1) |
| Nail retraction | 5 (1) |
| Nail breakage during consolidation (P1) | 5 (1) |
| Nail breakage upon removal (P1) | 2 (0.3) |
| Crown fracture (P2) | 15 (3) |
| Malfunction Transmitter (Fitbone) | 2 (3) |
| Nerve entrapment | 2 (0.3) |
| VTE | 2 (0.3) |
| Deep Infection | 1 (0.2) |

Dead nail indicates failure to distraction after implantation; Nail retraction, unwanted backing up of the nail with loss of length; P1, original Precice nail; P2, second-generation Precice nail; VTE, venous thromboembolism.

## The Tibia is Not the Femur

Outcomes for tibia lengthening using motorized intramedullary nails are commonly wrapped into mixed series of tibia and femur analyses (Table 1). Many studies have isolated the results of these 2 different long bones, but the quantity of tibial cases reported is low. Several issues unique to the tibia have borne out from these series. The tibia heals more slowly than the femur even using identical methods (average, BHI 57 vs. 33 d/cm, respectively). This means that the latency needs to increase and the distraction rate for the tibia needs to decrease. In the tibia, it is more difficult to prevent procurvatum deformity at the time of nail insertion and during lengthening.[4] A posterior blocking screw is recommended to mitigate this complication.[9,29,33] Valgus deformity during lengthening, the need for syndesmotic (fibular length stabilization) screws, and accurate start point are all challenges specific to the tibia. Compartment syndrome was not reported but remains a possible and potentially devastating complication. Peroneal nerve entrapment is rarely reported[10] but demands vigilance.

## Other

Locking bolt migration has been reported in many papers and was handled with reinsertion (or removal) of the bolt.[3,4,16] NuVasive now has fully threaded screws that can be used in lieu of the smooth bolts which may reduce this phenomenon. Dead nails are nails that fail to distract which typically refers to a freshly implanted Precice that fails the intraop distraction test and needs to be replaced. While the company tests every nail before shipping and the incidence of malfunction is low (1%), it is not zero. Therefore, every nail should be tested in vivo on the operating room table after insertion and before leaving the room. Some cases of the Fitbone nail had a malfunctioning transmitter that required replacement. The original version of the Fitbone had reports of running back which were prevented in the second iteration of the implant. In the upper extremity, retrograde humeral lengthening created elbow contractures and antegrade lengthening created shoulder stiffness. In antegrade nailing, it is recommended to avoid the bony insertion point of the rotator cuff but rather to split the cuff and enter the joint to create a start point for the nail.[24] The Precice nail was often too long for the humerus, an obstacle that was solved by creating a small gap at the osteotomy site[21] or cutting down either (or both) end of the nail.[19]

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