Retrograde Femur Technique for Motorized Internal Limb Lengthening

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Summary: Deformities of the femur that combine deviations of axis and torsion with length discrepancies are seen quite often. Nevertheless, the surgical treatment can be demanding, especially if fully implantable lengthening nails are used for simultaneous lengthening and deformity correction. The technique of retrograde insertion of a lengthening nail into the femur offers a wider range for correction and allows the treatment of even complex deformities with a single-step procedure. The key to successful application of the technique is meticulous preoperative analysis and planning. The surgical procedure should follow a standardized protocol to avoid pitfalls. A complete overview of the technique of retrograde insertion of lengthening nails into the femur is given.

Key Words: lengthening rod—intramedullary lengthening nail—femur—retrograde nail—distraction osteogenesis—limb lengthening—deformity correction.

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INDICATIONS

Lengthening of the femur with motorized nails is often accomplished through an antegrade approach with higher-level osteotomies, which provide stability for both the proximal and distal fragments. Retrograde nailing provides the surgeon with more options for lengthening with simultaneous deformity correction by inclined positioning of the implant in the metaphyseal part of the distal femur.[1–3]

In this manner, realignment into the varus or valgus, in the anteversion or retroversion direction, and torsional corrections can be combined with lengthening in a very effective way. Even severe deformities can be treated in a one-step procedure. According to the level of osteotomy at the distal femur, lower osteotomies allow a larger extent of realignment. In contrast, higher osteotomies provide more stability to the distal fragment. Apart from extreme deformities, retrograde lengthening allows the surgeon to accommodate physiological valgus/varus, which may be worsened by lengthening using the antegrade approach (Fig. 1).

SURGICAL PLANNING

One has to keep in mind, that a surgical technique, which allows a high amount of deformity correction in a single step, is prone to technical mistakes. Therefore, meticulous clinical and radiologic preoperative planning of the whole procedure is inevitable, especially for fully implantable lengthening devices, compared with techniques with external fixation.

Starting with the clinical examination, range of motion (ROM) of hip joint, especially with regard to rotation in extension and 90-degrees hip flexion, has to be determined as torsion anomalies are quite common. Knee ROM and position of patella also need to be considered: limitation of knee extension and flexion can limit the retrograde approach to the femur, and deficits of range of joint motion can be corrected simultaneously.

RADIOLOGIC PLANNING

As in every procedure of deformity correction at the lower limb, a detailed analysis of a scaled long-standing radiograph (LSR) of both legs with compensated leg length discrepancies and centered patellae is crucial for preoperative planning. Alignment and joint angles of both legs should be analyzed.[4] In deformities of the distal femur combined with femoral shortening, osteotomy at the distal femur and retrograde nailing with a lengthening nail is the surgical technique of choice.

The clinical examination gives clear evidence on torsional deformities: if abnormal rotational ROM of the hip joint or

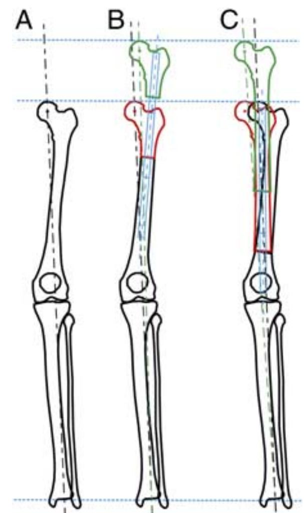

FIGURE 1. End-Point-First planning of lengthening of the femur. The green outlines of the fragments show their position at the endpoint of treatment, the red outlines the position at the end of the operation, before starting the lengthening. The example shows femoral shortening with a slight valgus deviation of the mechanical axis (A). Lengthening with antegrade (B) inserted lengthening nail leads to an increase of valgus deviation. As the inclined positioning of the nail in the proximal metaphysis of the femur is very limited, lengthening occurs along the anatomic axis of the femur, and therefore follows the natural valgus orientation of the femur. This effect can be neutralized by the use of the retrograde approach (C), which allows an inclination of the implant toward the varus direction in the distal metaphysis of the femur. The retrograde technique allows a wide range of simultaneous axis correction of the femur while lengthening.

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The authors declare that they have nothing to disclose.

For reprint requests, or additional information and guidance on the techniques described in the article, please contact Dr. med. Peter H. Thaller at peter.thaller@med.lmu.de or by mail at 3D-Surgery, Department of General, Trauma and Reconstructive Surgery, University Hospital, LMU Munich, Nußbaumstrasse 20, 80336, Munich, Germany. You may inquire whether the author(s) will agree to phone conferences and/or visits regarding these techniques.

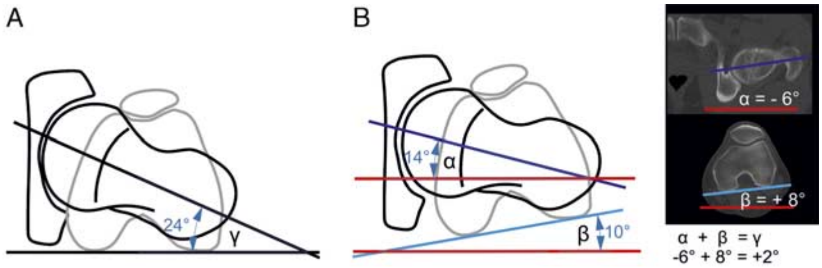

FIGURE 2. Torsion analysis of the femur by computed tomography (CT) scan is a fundamental technique for the assessment of torsional deformities. The result should always be combined with clinical findings of internal and external rotation of the hip joint in 90-degrees flexion and 0-degrees extension. Objective of the surgical treatment should be an individually assessed normalization of the rotational range of motion in the hip joint. A, Shows an overlay of the anatomic structures and the technique for assessment of the femoral torsion by CT scan. For calculating the true femoral anteversion, the apparent angles at the level of hip and knee joints are referenced to the virtual horizon (B). At analysis of the CT images of the hip joint, the amount of the angle of apparent femoral neck anteversion (α) is defined with a positive algebraic sign. If apparent retroversion is found, the angle is defined with a negative value. At the knee joint, the angle for apparent internal rotation (β) is defined as a positive value, vice versa, apparent external rotation at the knee is given negative values. After measurement of the angles, values are added and the sum is the value for true femoral neck anteversion.The given example of CT images show the calculation for a case of decreased femoral neck anteversion of +2 degrees.

conspicuous gait, such as inwardly pointing patellae, is seen, a low-dose computed tomography scan and analysis of the torsion of femur and tibia is recommended (Fig. 2). Usually, a restored physiological range of rotation in the hip joint implies a high functional benefit for the patient. The amount of torsion correction should always be determined by a combination of clinical and radiologic findings.

A full-length lateral view is also imperative to deformity planning and can also determine whether a retrograde technique is even feasible, as patients can sometimes have sagittal plane deformity preventing a retrograde starting point. In addition to limited access to the starting point, the internal shape of the dorsal femoral cortex also can set limitations to the size and positioning of the implant. The shaping of the medullary cavity by rigid reaming, therefore, may be required.[5] For every application of lengthening nails, we strongly recommend graphical preoperative planning, as, in this way, multiple crucial parameters such as the position of the osteotomy, the orientation of the implant in the metaphyseal and diaphyseal part of the femur, implant size and stroke, axis and joint ankles of the limb postoperatively and after lengthening can be determined in a comprehensive and easy way. Analysis can be performed with most PACS systems, although traditional calibrated and printed x-rays can be utilized if not available. For graphical planning, the LSR is best printed in real size on transparent paper or imported into graphic software and calibrated to have measurements in real size. A comprehensive, reliable, and cheap software to apply the End-Point-First (EPF) planning technique is Corel Draw.

The EPF planning method is performed in 4 steps:

(1) Defining the endpoint (EP) on the new Mechanical Axis (nMA)
Every EPF planning starts with drawing the nMA on the LSR. For femoral correction, the nMA is drawn from the center of the ankle joint through the center of the knee (or in the desired varus or valgus direction), high above the current position of the femoral head. The EP is now defined by marking the intended, new total length of the femur on the nMA.

(2) Drawing a second layer: intramedullary Nail-Shaft-Match (iNSM)
An outline of the femur is copied, and a real-sized outline of the chosen nail with its axis indicating its path further distally is matched into the shaft. The fit of the nail to the intramedullary femur is predefined, and the positioning is essential.

(3) Matching the iNSM and the planning layer
The center of the femoral head of the iNSM layer is adjusted to the planning's EP. By rotating the iNSM around the center of the femoral head, the nail's path is adjusted to its entry point in the femoral notch. The nail's path is copied to the planning layer.

(4) Defining the osteotomy and final draft for the surgery:
The ideal level of osteotomy in the distal femur is defined, drawn on the planning layer, and copied to the iNSM. The iNSM is repositioned to the EP, copied to the planning level, and driven down along the nail's axis until the osteotomy line of the iNSM meets the osteotomy line of the planning layer. The EPF planning is now finished. It shows the position of the

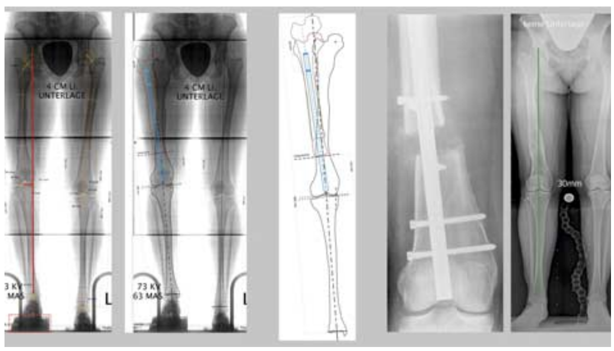

FIGURE 3. End-Point-First (EPF) planning for simultaneous lengthening and deformity correction of the femur by retrograde approach. The presented case was operated upon in 2010 with the use of an Orthofix ISKD nail. The primary posttraumatic varus deformity with a shortening of 4 cm of the right femur is shown on the left side. The next image shows the implementation of the EPF planning to the long-standing radiograph (LSR). The green outline at the EPF planning shows the position of the proximal femur at the end of treatment (= endpoint), whereas the red outline shows the position of fragments and implant at the end of the operation (= before start of lengthening). The anteroposterior view during the distraction period shows well the position of the implant in the distal femur, which is the same as planned preoperatively. The blocking screw in the medial metaphyseal part was used to adjust the inclination of the nail before distal interlocking according to the EPF planning. As an exception in this former ISKD nail case, the pair of sagittal and transverse blocking screws in the diaphyseal part add friction to the housing of this ratchet-driven nail, as those implants tended to lengthen too fast in case of lacking rotational stability. LSR for late follow-up, after removal of the implant restored leg length and centered mechanical axis of the right leg, which was predicted by the EPF planning (green outline).

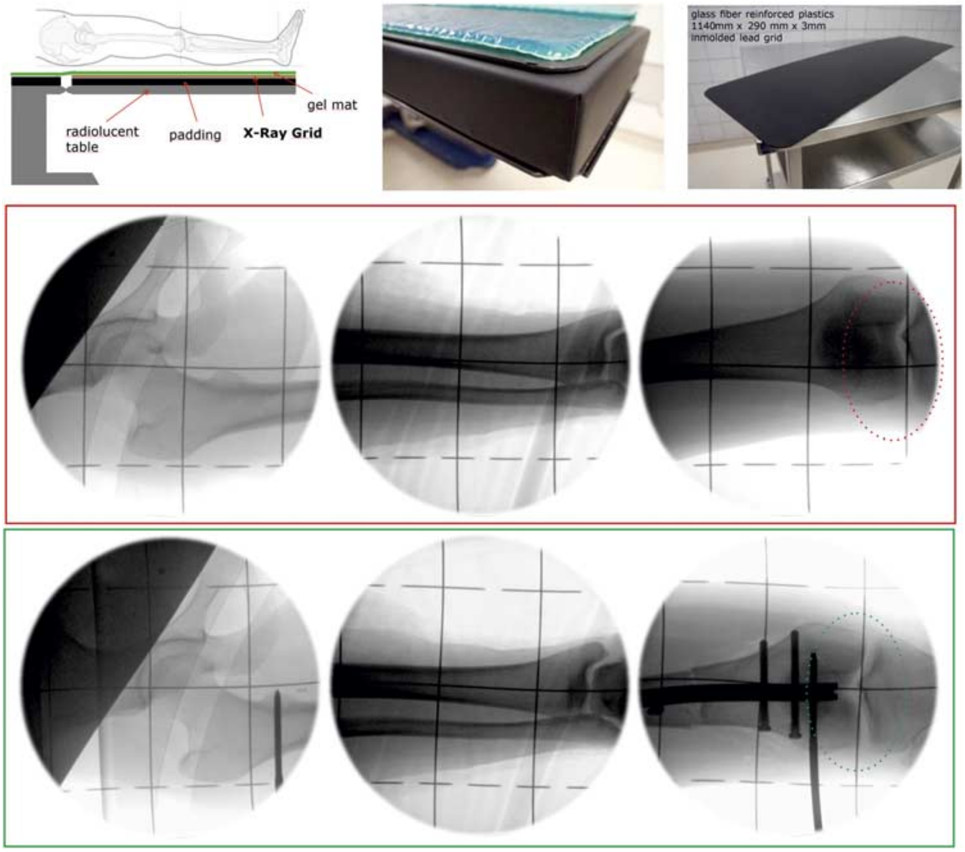

FIGURE 4. Intraoperative alignment control with the x-ray grid method. Intraoperative assessment of the mechanical axis is an important cornerstone for the precise implementation of preoperative End-Point-First (EPF) planning. The first image series shows the condition at the beginning of the operation; the solid line defines the mechanical axis of the leg, and slight valgus deviation is shown at the knee joint level. In the second series, the centered mechanical axis after insertion of the lengthening nail is shown. This finding matched the preoperative EPF planning.

osteotomy, the size and the planned orientation of the implant, the status after surgery, and the status after lengthening (Fig. 3).

SURGICAL TECHNIQUE

The print of the EPF planning or a digital version is taken to the operating room. Before starting surgery, the mechanical axis deviation of the limb is confirmed radiologically, for example, by the x-ray grid method with a c-arm and the x-ray grid (Fig. 4). If the mechanical axis is identical to the findings on the LSR, the EPF planning can be adopted without changes. In rare cases, a minor deviation between planning and intraoperative assessment of mechanical axis deviation is found, mostly because of the laxity of collateral ligaments of the knee. These findings should be implemented intraoperatively by minor change of osteotomy height and/or position of the nail to avoid overcorrection or undercorrection.

The next step is the insertion of Schanz pins in the distal and proximal part of the femur. Those pins are used for torsion control as, unlike at the lower leg, control of the torsion by clinical landmarks is not possible. When the pins are inserted laterally, meticulous radiologic control in the lateral view is essential. At the proximal femur, drilling of the hole for the Schanz pin can be demanding, because of the hard and slippery cortex. We prefer to center-punch the cortex by orthograde predrilling and correction of the drilling axis to horizontal orientation, once the tip of the drill has entered the bone. The proximal Schanz pin is placed at the level of the minor trochanter, in the dorsal cortex of the femur. At the distal femur, the Schanz Pin has to be inserted as posteriorly as possible, so as not to hinder the later pathway of the retrograde nail. The Blumensaat line must be respected to avoid damage to the knee joint or popliteal structures (Fig. 5). For those who are less experienced, a cannulated Schanz screw technique might be a safer option.

Thereafter, the retrograde approach to the knee joint is performed: we recommend an infrapatellar transverse skin incision of 1.5 to 2 cm and careful dissection of the structures anterior to the tendon. Once the longitudinal fibers of the patellar tendon are dissected, a closed scissor is inserted through the "curtain" of fibers, and the tendon is split longitudinally by opening the instrument. For opening the medullary cavity, we use the so-called Steel Sleeve instrument set,[6] to create a closed transarticular access to the medullary cavity. The thin-walled sleeve is guided by a trocar and K-wire, and it is impacted a few centimeters into the metaphyseal bone of the femur. Sticking deep in the bone, this impacted sleeve fully protects the soft tissues, the cartilage, and bone at the entry point from damage. No reaming debris will contaminate the knee joint. In addition, the sleeve safeguards precisely the desired pathway for the nail during reaming. Next, the level of the osteotomy is marked by radiolucent control on skin level with a radio-opaque skin staple according to the planning. After insertion of a guiding wire, the proximal fragment is reamed only until the planned osteotomy level is according to the EPF planning. In contrast to flexible reamers, the use of front-cutting rigid reamers, especially, allows eccentric removal of bone and thus a precise preparation of the medullary cavity for the insertion of straight lengthening nails. By

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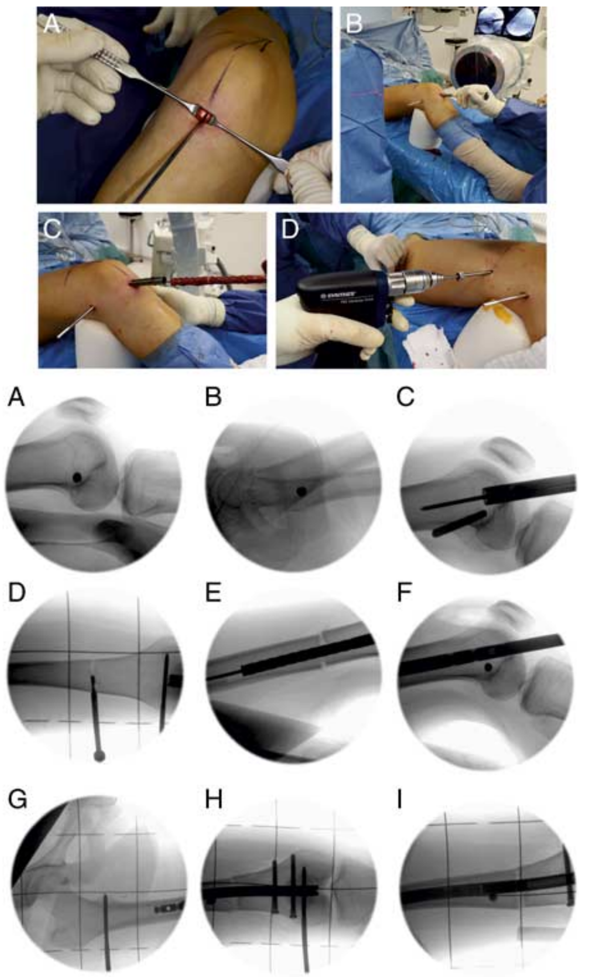

FIGURE 5. Photograph: Minimally invasive retrograde approach with blunt separation of the patellar tendon (A). B, Placement of a Steel Sleeve for protection of the intra-articular structures and the entry point. C, Rigid reaming of the metaphyseal part before osteotomy. D, Minimally invasive drill bit osteotomy. X-ray: Placement of distal Schanz screw for torsion control in side view, near Blumensaats line (A). B, Placement of proximal Schanz screw for torsion control in side view, at the level of trochanter minor. C, Retrograde impaction of a Steel Sleeve into the bone. D, Drill bit osteotomy under radiolucent control. E, Reaming of the dorsal diaphyseal cortex of the femur: note the rectangular step in the dorsal cortex that was created by the front cutting reamer. F, Retrograde insertion of the lengthening nail (PRECICE). G, Position of the implant proximally. H, Position of the implant distally, aiming at the medial cortex for simultaneous varisation. I, Varisation of the fragments at osteotomy; in this special case, a blocking screw for additional varisation and stabilization was placed laterally to the implant in the diaphyseal fragment.

using rigid reamers, the amount of overreaming is reduced to a minimum (mostly 0.5 mm only), which leads to more stable fixation of the implant. As the femur is curved to the anterior, the preparation of the internal posterior cortex deserves special consideration.[5]

If blocking screws are necessary, they may be inserted in the metaphyseal part of the femur before osteotomy. The later inserted screw should be adjacent to the nail to improve stability. Mostly, the preoperative planning already shows the position of the screw. The ideal case would be a 3-point fixation of the nail in the metaphyseal part by entry point, cortex at the level of osteotomy, and blocking screw[7] (Fig. 3).

Once the preparation of the distal femur is performed, as the next step, the drill bit osteotomy is performed. At the level of the osteotomy, a 4 mm sharp drill bit protected by a standard protection sleeve is inserted using a lateral stab incision. Multiple medial, medioanterior, and medioposterior drill holes are performed by entering over 1 or 2 lateral drill holes. If drilling is performed carefully at the far cortex, the periosteal injury is reduced to a minimum, and periosteal damage is only to be assumed at the drill hole at the lateral cortex. The final corticotomy is completed by a sharp 7 mm chisel. The completion of the corticotomy can be proven by gentle manipulation of the Schanz screws.

After mimicking the shape of the fragments according to the EPF planning, the rigid reamers are advanced stepwise proximally until the reamer has reached the later position of the nails tip according to the EPF planning. The lengthening nail is inserted, its height adjusted behind the entry point at the notch, and interlocked with the aiming device through 1 relocatable stab incision for the 2 screws before proximal interlocking; the adjustment of the torsion, indicated by the aforementioned Schanz screws, now has to be performed. Proximal interlocking is performed in the preferred techniques, and our personal recommendation is the use of a radiolucent gear drive. In contrast to intramedullary nails for fracture fixation, the locking holes of lengthening nails are not manufactured with an interference fit; hence, meticulous drilling is required. The Schanz screws can be removed earliest after the first proximal interlocking. Once the implant is inserted, the realignment according to the EPF planning is controlled and documented by the x-ray grid method. The final procedure in the operating room is the testing of the implant in situ by lengthening for a minor amount (usually 1 mm or less) to compare this by significant radiologic parameters (eg, the osteotomy gap or radiographic details of the nail). Nowadays, the mainly used magnetically driven nails are the first to offer the option of controlled backtracking by the same amount or a bit more to eventually enhance early bone formation.

POSTOPERATIVE ROUTINE

Patients are mobilized on the first day after the operation. For standard implants, we recommend partial weight-bearing with 20 kg and antithrombotic medication with low–molecular weight heparin. Oral analgetics according to the WHO scheme are administered, whereas non steroid antiphlogistic drugs (NSAID) are forbidden because of their inhibitory effect on bone formation. Calcium and Vitamin D are initially administered in high doses. Smoking is forbidden. Later generations of implants such as PRECICE Stryde have mechanical properties, which allow full weight-bearing for patients with regular body weight. Nevertheless, at thinner implants or cases with higher amounts of realignment, the stability of fixation of the implant in the metaphyseal part should not be overestimated. Patients are taught to use the controller of the implant autonomously already before the start of distraction on the fifth postoperative day. We divide the daily distraction rate of 1 mm in 3 portions of 0.33 mm.

Physiotherapy is of major importance and should be a daily routine for the patient. Transient limitations of knee extension because of the relative shortening of the dorsal muscles of the thigh are quite common. Even small deficits of ROM should be detected by the physician, and patients have to be encouraged to perform their exercise conscientiously. We recommend clinical control patient visits for check-up of ROM of the adjacent joints and radiologic control of the distraction

TABLE 1. Pitfalls and Tipps in Retrograde Lengthening of the Femur by Motorized i.m. Nails

Pitfalls	Tips
Iatrogenic maltorsion by missing or imprecise torsion control	Use stable 5 mm Schanz Screws proximal and distal and a sterile goniometer assessment
Preoperative and postoperative misjudgment of rotational range of motion in the hip joint	Intraoperative free range of motion of the hip joint also in 90 degrees flexion/no traction table (!)
Unintended changes in lateral plane, by malplacement of entry point	Check of entry point by precise lateral radiolucent view
Iatrogenic hyperextension due to tilting of distal fragment by straight lengthening nail	Use of an angulated nail (eg, troch entry or tibia nail) for retrograde femoral nailing and/or dorsally placed blocking screw in case of need
Ineffective, distant blocking screw or damage of the lengthening nail in case of to close drilling for blocking screw	Use of a temporarily inserted dummy nail for precise and tight placement of blocking screws
Propagating cracks to the osteotomy caused by blocking screw	Keep distance to the osteotomy, > 5 times of the screws diameter
Weakening of the proximal anterior cortex of the femur by interlocking from anterior, which might result in fracture and adhesion of muscles/fascia	Avoid proximal interlocking in the sagittal plane - meticulous interlocking from lateral is sufficient
(Sub)luxation of adjacent joints due to high forces during lengthening	Weekly or biweekly control of ROM If knee or hip ROM is compromized enhance physiotherapy, reduce lengthening speed or even consider temporary shortening
Lack of bone formation	Exclude adverse behavior of patient like smoking or excessive use of NSAIDs and also instability of the implant
Mechanical implant failure/long-term lack of stable consolidation	Immediate exchange of implant (if length achieved to solid nail)/timely debridement of poor regenerate and bonegrafting

i.m. indicates intramedullary; ROM, range of motion.

rate in weekly or biweekly intervals. After reaching the goal of distraction, the clinical controls are performed in 3 to 6-week intervals. Further callus formation and remodeling at the distal femur are regularly seen first in the posterior or medial regenerate. Patients are allowed full weight-bearing if 1 cortex is completed in the anteroposterior or lateral view.

Lengthening nails should be routinely removed in our opinion, as the complex mechanisms of those implants consist of several components, and therefore long-term adverse effects cannot be completely excluded. The removal of the nails is usually a simple procedure and not stressful for the patient as full weight-bearing can be allowed immediately after surgery.

TIPS FOR SUCCESS

In general, the retrograde implantation of lengthening nails into the femur is a safe technique, which offers great potential for simultaneous lengthening and deformity correction. However, like every powerful tool, this surgical technique also can entail severe consequences, if it is not fully mastered by the user. Tips and pitfalls are shown in Table 1.

REFERENCES

1. Strecker W, Kinzl L, Keppler P. Corrective osteotomies of the distal femur with retrograde intramedullary nail. *Unfallchirurg*. 2001;104: 973–983.
2. Thaller PH, Fürmetz J, Degen N, et al. Intraoperative customization of intramedullary nails - first results. *Injury*. 2019;50(suppl 3):11–16.
3. Kucukkaya M, Sokucu S, Thaller PH. Surgical techniques for lengthening and deformity correction of the femur with lengthening nails. *Tech Orthop*. 2015;30:183–188.
4. Paley D Principles of Deformity Correction, Corrected Ed. 2002. Corr. 3rd Printing 2005. Berlin: Springer-Verlag.
5. Kucukkaya M, Karakoyun Ö, Erol MF. The importance of reaming the posterior femoral cortex before inserting lengthening nails and calculation of the amount of reaming. *J Orthop Surg Res*. 2016;11. Doi:10.1186/s13018-016-0345-6.
6. Wolf F, Bösl S, Degen N, et al. Impacted Steel Sleeves for a minimally invasive approach in intramedullary nailing. *Injury*. 2019;50(suppl 3): 4–10.
7. Fürmetz J, Bösl S, Schilling J, et al. Blocking screws for alignment control in intramedullary limb lengthening. *Injury*. 2017;48:1597–1602.