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CASE REPORT

Femoral Bone Transport With a Combined Method Using a PRECICE Nail and Cable Lengthening Technique

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Summary: This report presents a case of an open distal femur fracture with a 13-cm segmental bone defect, treated with a unique and previously undescribed use of an internal lengthening nail in conjunction with a cable bone transport. The patient was treated with a staged reconstruction using a combination of a distal femoral locking plate and internal magnetic lengthening nail. In addition, an internal cable was applied to allow for lengthening beyond the 8 cm provided by the nail. The patient also underwent exchange to a standard titanium trauma nail upon completion of bone transport that allowed for immediate weight-bearing and correction of varus malangulation. The patient has successful bony bridging of all fracture sites and is walking without thigh pain at 13-month follow-up after the start of reconstruction. This case demonstrates a number of important novel concepts in achieving bone transport with internal fixation.

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INTRODUCTION

Treatment of segmental bone loss in the femur can be very challenging. Generally, the 2 approaches used to address the bone defect are bone grafting and distraction osteogenesis. Modern bone grafting methods are more successful in the femur than in the tibia.[1] However, the requirement for bone donor sites and invasive techniques to extract the bone can be limiting. In addition, deep infection with graft loss and hardware contamination require additional surgery and can create a truly limb-threatening situation.

Distraction osteogenesis with external fixation is a powerful tool for creating large quantities of biologically normal new bone with no morbidity of bone harvest and a low risk of deep infection.[2–4] However, distraction osteogenesis with external fixation has proven challenging in the femur.[5,6] The large soft tissue envelope causes pin site problems that can be severe, and achieving mechanical stability can be difficult due to the long distance between external fixator and pin–bone interface causing a tendency toward varus deformity as transport progresses. Notably, transport with external fixation over a nail has improved the ability to counteract the forces acting on the femur and seems to offer superior results.[7] Nonetheless, pin site problems persist, and risk of deep infection of the nail from the external fixation components is a serious concern.[5,8] It is possible to overcome these challenges and achieve success, even in very difficult cases, but it is burdensome for both patient and provider.

Internal magnetic lengthening intramedullary nails (IMLNs) were first introduced in an effort to perform distraction osteogenesis for limb lengthening. These devices take advantage of the power of distraction osteogenesis while eliminating complications associated with external fixation pins and wires. IMLNs have evolved from earlier internal ratcheting mechanisms such as the Albizzia/Guichet (DePuy, Villerbuane, France) and Intramedullary Skeletal

Kinetic Distractor (Orthofix, McKinney, TX) devices, to more precisely controlled magnetic nails such as the Fitbone (Wittenstein intense GmbH, Ingersheim, Germany) and PRECICE (NuVasive Inc, San Diego, CA) nails.[8,9] These devices have proven to be revolutionary for patients who require limb lengthening by allowing for distraction osteogenesis without the need for external pins and wires.

IMLNs are designed in principle to lengthen a bone or compress a fracture site. They do not feature a mobile segment in the middle to allow for bone transport with maintenance of overall bone length and stability. Despite this obstacle, bone transport has been attempted using IMLNs. There are currently only 2 published single case reports documenting bone transport with an IMLN. The first was in 1997 by Baumgart of a 12-cm transport for knee fusion in a patient with Ewing sarcoma.[9,10] This report did not provide details of the author's surgical technique but reported that successful healing was achieved. The second was a report introducing a tube system that can be used with any IMLN to perform bone transport.[10] This report detailed the steps of the procedure, but reported screw loosening that had to be revised, and did not show or report on successful final healing of the bone after docking. An additional downside of this method is that it uses custom components that are not generally available.

Another method for internal transport that has been proposed, but not published to date, is stabilizing the bone using a locking plate and screws while using the IMLN to push or pull the bone segment for transport until the bone ends meet for docking. This method does not require custom or off-label components and provides flexibility in achieving stable fixation. However, it does have the downside of being very invasive with a large amount of hardware.

Another obstacle to performing bone transport with an IMLN is the limit of the stroke length. The maximum distance that an IMLN can lengthen from its initial shortened position is referred to as the stroke length of the nail. Currently available IMLNs shorter than 245 mm have a stroke length of 50 mm, whereas nails of 245 mm and greater in total length have a stroke length of 80 mm. No currently available devices offer greater than 80 mm of stroke length. Eighty millimeters is sufficient to address many bone defects, but it is insufficient for larger defects that may benefit the most from transport.

Currently, the limitation in stroke length obligates an additional surgery to allow adequate transport length for larger bone defects. In this report, we detail a new option for additional lengthening beyond stroke length provided by the nail. Before this report, 2 approaches were available to gain further lengthening. The first is to remove the IMLN and replace it with an IMLN that is fully compressed. Replacement with a new IMLN is the easiest and most time-efficient option but is extremely expensive. Alternatively, although the use is off label, the IMLN that was removed can be compressed to its original length on the back table and reimplanted with new locking bolts. It is important to understand that IMLNs move slowly when driven by the external magnetic controller (actuator). It takes 560 minutes to compress an IMLN 80 mm with the actuator. Fortunately, there is now a fast distractor/compressor that can fully compress the nail 80 mm on the back table in approximately 12 minutes. Compressing the nail can therefore be done in a reasonable period but still requires an invasive procedure for nail extraction and replacement.

The second approach, as reported by Krettek and El Naga,[10] is an additional operation for removal of transport segment locking bolts, with temporary stabilization of the transport segment, followed by a return to the operating room at the end of the day to place new locking bolts in the transport segment with the nail in a fully compressed position. In this scenario, the patient sits for the duration of the day (560 min/9.3 h) with the actuator on their leg, after having the locking bolts removed, to compress the nail to its original starting position before having new screws placed in a second operating room session later that day. Although this method eliminates the invasiveness and cost of swapping nails, 2 operations are required and adequate length of the transport segment must be present.

Here, we report on a successful case of bone transport in the femur using a PRECICE nail in combination with a variable angle distal femoral locking plate for bone stabilization. Furthermore, we report the use of an internal cable loop to facilitate additional lengthening, up to the distance of the stroke length of the nail (8 cm), without need for nail exchange or acute backup. Accordingly, this method allows for up to 16 cm of bone transport with only a simple procedure at the middle of the transport to connect the internal loop. The patient in this report also received a staged exchange nailing with removal of the PRECICE nail and placement of a standard titanium trauma nail after completion of the transport. This report therefore introduces several novel concepts in the treatment of bone defects.

PATIENT INFORMATION

The patient is a 54-year-old man who sustained an open femur fracture in a motorcycle crash. He presented with an 8 × 5-cm wound in the anterior thigh with missing bone, and exposed bone fragments stripped of soft tissue from a highly comminuted and contaminated distal femur fracture (Fig. 1). There was also a highly comminuted open tibia fracture and second to fourth metatarsal fractures in the ipsilateral foot. He has significant medical risk factors, including a history of lung adenocarcinoma in long-term remission after chemo and radiation 9 years prior, diabetes mellitus reasonably controlled with metformin, hypertension, and coronary artery disease s/p stenting 1 year ago.

After adequate resuscitation, he was taken to the operating room for debridement of the open fractures, spanning external fixation, and placement of antibiotic cement beads (Figs. 2A, B). He returned to the operating room for staged debridement, reconstruction of the comminuted articular segment with lag screws, and exchange of beads for a methylmethacrylate spacer impregnated with antibiotics several days later (Figs. 2C, D). After another interval of several days, he was taken for definitive treatment of his tibia fracture with an intramedullary nail together with revision of the knee spanning external fixator, pinning of his foot, and staged debridement of the femur with exchange of the spacer. We then prepared for skeletal reconstruction of the femur the following week as described below.

SURGICAL TECHNIQUE FOR STAGED RECONSTRUCTION

Procedure 1

Femur reconstruction began with removal of the spanning external fixator and cement spacer. The proximal bone segment was prepared by removing bony spikes from the end using a micro-100 saw and constant iced saline irrigation to prevent burning of the bone until there was circumferentially intact bone and a healthy bleeding surface. PRECICE nail application began with a 12.5 ×

FIGURE 1. A–C, Anteroposterior and lateral radiographs taken on the day of injury showing extensive bone loss and distal comminution. D and E, Sagittal and axial computed tomographic images demonstrating extensive articular involvement of the distal femur.

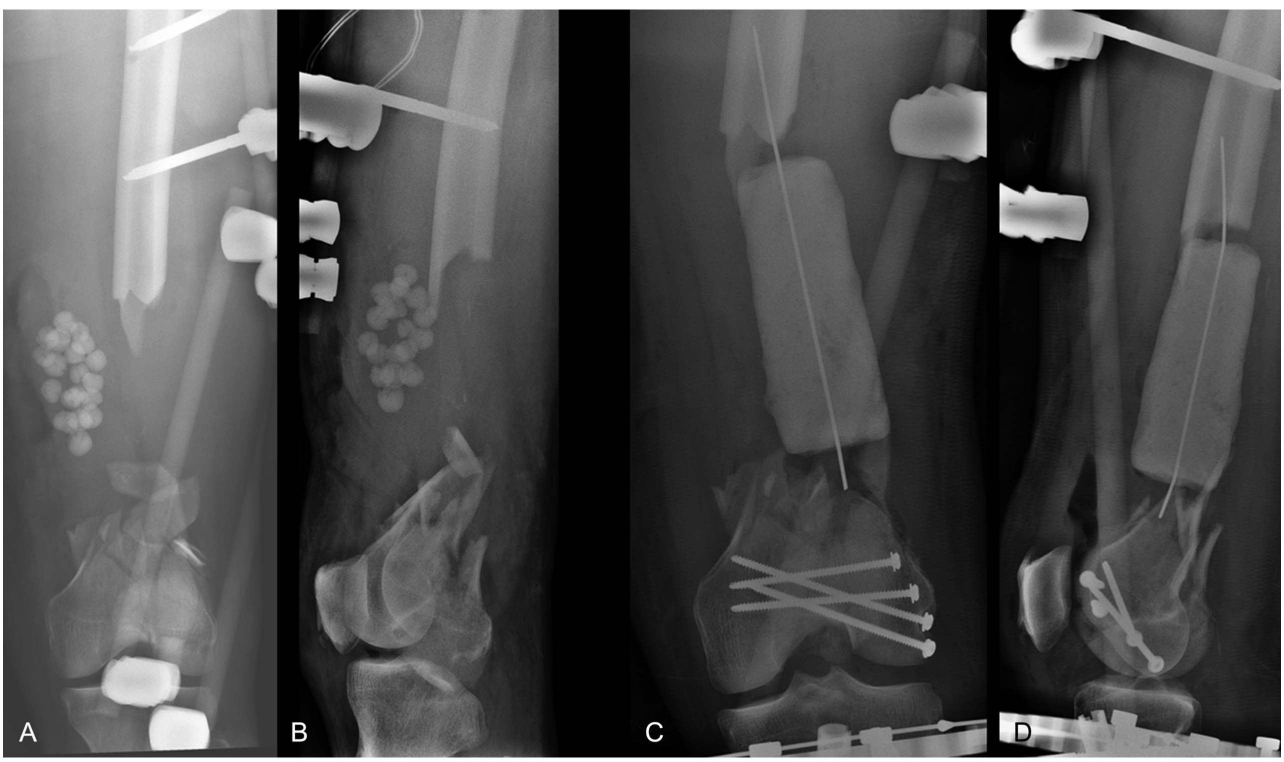

FIGURE 2. A and B, Anteroposterior and lateral radiographs taken on the day of injury after initial debridement, placement of a spanning external fixator, and placement of antibiotic impregnated methylmethacrylate beads. C and D, Anteroposterior and lateral radiographs after staged debridement, placement of an antibiotic-impregnated methylmethacrylate cement spacer, and lag screw fixation of the distal articular fracture.

245-mm device, which was chosen because it is the shortest IMLN that allows for an 8-cm stroke length. The larger diameter nail was chosen to allow for a more sure communication with the actuator through the thick soft tissue envelope of the upper thigh. Given the long distance of the osteotomy from the proximal metaphysis, either trochanteric or piriformis nails would have been effective, but we chose a trochanteric nail for ease of placement in the supine position. If the osteotomy is in the proximal metaphysis, a piriformis nail is preferred to optimize control of alignment with the cortical rim fit at the piriformis fossa, which is reliably in line with the intramedullary canal.

The nail was placed in standard fashion with canal reaming to 14.5 mm and advanced only as much as necessary to allow for 2 proximal locking screws with the nail left proud at the insertion site to provide space distally. The site of the osteotomy was then marked at the location of the most proximal of the distal locking holes (Figs. 3A, B and 4A). The osteotomy is performed at this location to allow for later access to the most proximal of the distal locking holes to pass the cable. The location of the osteotomy is critical to allow for placement of the cable through the locking hole at the next stage as demonstrated in Figures 4B, 5A, B. The nail was temporarily backed-up proximally and multiple drill holes were performed at the site that had been marked for the osteotomy. The osteotomy was not completed at this time and the nail was temporarily advanced back into position for plating.

A variable angle distal femoral locking plate was then fixed to the distal articular segment. Variable angle locking was chosen so that the proximal screws could be placed around PRECICE nail. Appropriate length was determined using the contralateral femur as a template and the plate was fixed to the proximal segment with 4 variable-angle locking screws, all placed posterior to the nail.

Next, a cable was placed into the transport segment. The cable was placed in the mid-equator of the canal of the bone segment distal to the end of the nail using the technique previously described for use with balanced cable transport (Fig. 4A).[11] The cable loop placed in the bone was not connected in any way to the nail at this time. The ends of the cable were then brought distally to the distal articular block. The cable ends were passed on opposite sides (anterior and posterior) to the most proximal locking screw in the distal fixation block of the femoral locking plate. This made the locking screw a fulcrum to guide transport during the next stage of reconstruction. The cable ends were then brought proximal and left floating freely adjacent to the transport segment to provide easy access from a lateral approach for the next stage of reconstruction.

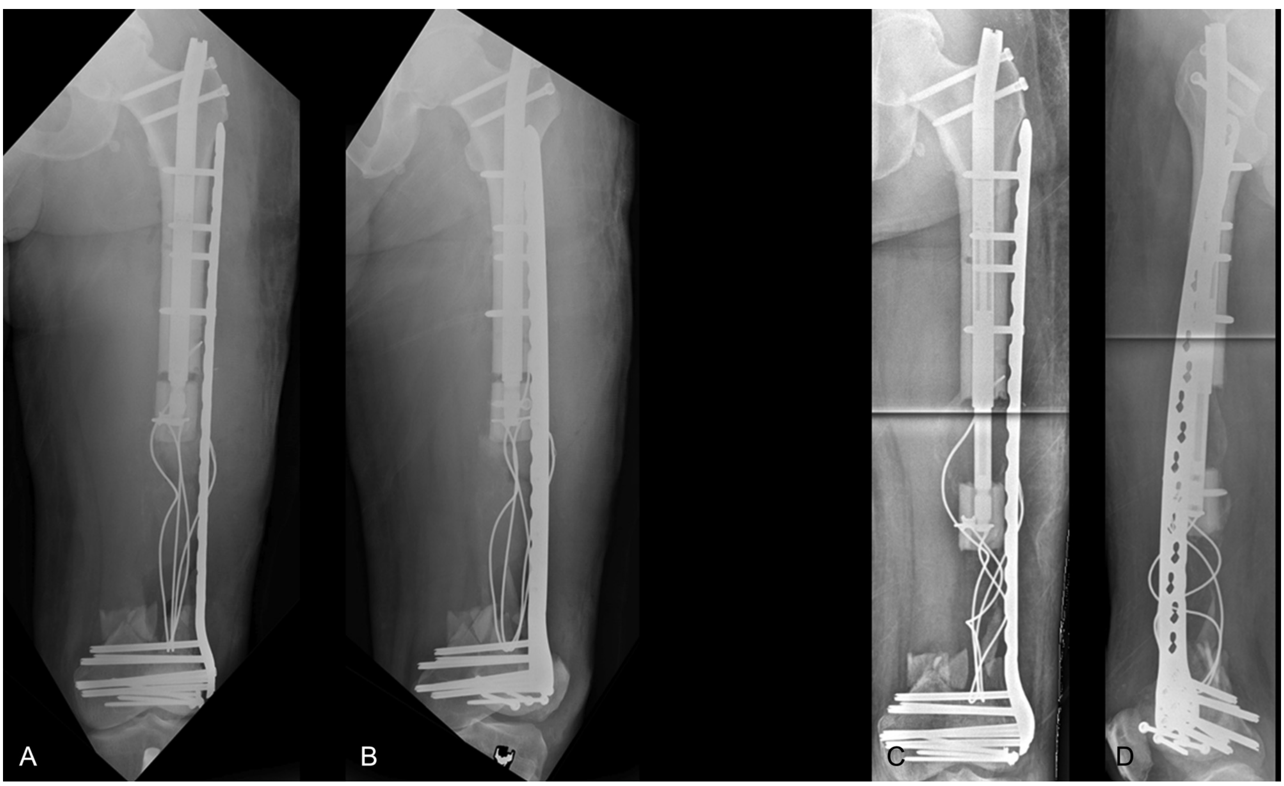

FIGURE 3. A and B, Anteroposterior and lateral radiographs after bone reconstruction procedure 1, with a variable angle distal femoral locking plate providing internal fixation to stabilize the fracture. A PRECICE magnetic internal lengthening nail is present proximally with 2 proximal locking screws and 1 locking screw distally in the transport segment. There is a cable attached to the transport segment that is looped in opposite directions around the most proximal locking screw in the distal fixation block and the ends are left free in the soft tissues adjacent to where they will later be passed through the nail. The osteotomy is evident in the femoral shaft at the level of the most proximal locking screw in the telescoping nail. Note that the nail is prominent proximally and the transport segment is short because this is the shortest PRECICE nail available with an 8-cm stroke length. C and D, Anteroposterior and lateral radiographs during transport showing a ring of regenerate bone and advancement of the nail. Note that at this time the cable has no function and are there only for later use.

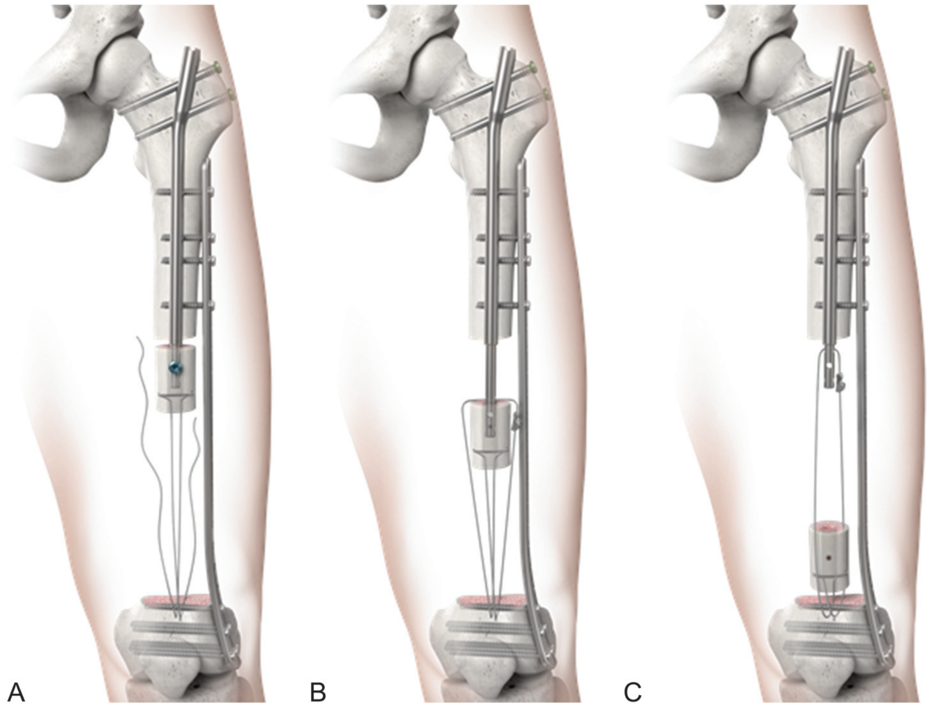

FIGURE 4. A, Graphical representation of the image (3A) showing the placement of the PRECICE nail and cables at the end of the first operation before distraction osteogenesis. Note that the cable placement in the bone does not incorporate the nail, and the ends of the cable are left free. B, Graphical representation of image (4A) illustrating completion of the cable loop through the locking hole of the PRECICE nail. This step is performed when maximal distraction of the nail is reached. C, Graphical representation of image (4C) illustrating the continued distraction of the bone segment as it is pulled distally by the cable loop toward the fulcrum screw by the compressing PRECICE nail.

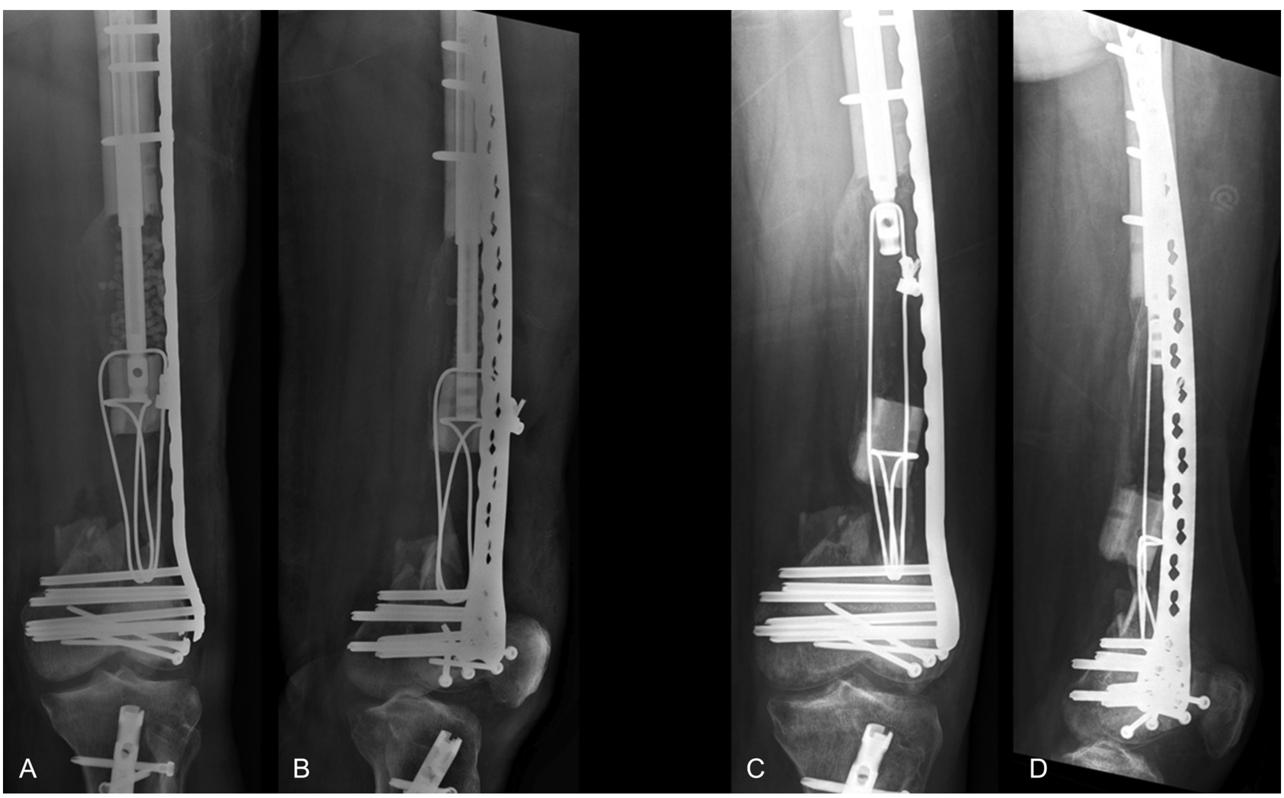

FIGURE 5. A and B, Anteroposterior and lateral radiographs taken postoperatively from bone reconstruction operation 2. The cable has been passed through the most proximal locking hole in the nail and the loop is complete. The area of the central canal was found to have a benign culture negative cyst surrounded by a ring of regenerate bone. This area was supplemented with Stimulan resorbable calcium sulfate beads impregnated with tobramycin and vancomycin as a precautionary measure in case the cultures had come back positive. C and D, Anteroposterior and lateral radiographs at the completion of transport. Note that the nail has now fully retracted and the distal bone fragment has advanced into position where it is now impinging upon a fragment that is healed to the distal articular block. It is also notable that there is a mild varus bend over the large working length of the plate.

The nail was retracted above the osteotomy site, and the osteotomy was completed with an Ilizarov osteotome. The PRECICE nail was advanced back into position, proximal locking screws were placed through the jig, and a single distal locking screw was placed using perfect circles technique in the transport segment. The nail was tested and found to be functioning properly. The patient began lengthening on postoperative day 7 at 1 mm/d and progressed at that rate throughout the transport process (Figs. 3C, D).

Procedure 2

The patient returned to the operating room 2.5 months after IMLN placement. Radiographs taken several days prior revealed that the IMLN was almost fully distracted with a regenerate column of 75 and 63 mm of space between the distal end of the transport segment and the optimal docking site. We began the procedure by reopening a portion of the lateral incision to provide access to the transport segment. We then placed a unicortical locking screw through the plate and into the bone transport segment to hold it in position while modifications were performed. This step is important because there is a major risk of regenerate rebound in which the transport segment shortens if left free without fixation. We then removed the distal locking screw from the PRECICE nail. The nail was compressed by 2 mm to provide better access to the proximal locking screw hole and to assure that the nail was working in the reverse direction. We next proceeded to find the medial end of the cable to pass it through the locking hole. The cable ends were left adjacent to the transport segment during the prior operation to allow for easy access from a limited lateral approach to both the cable ends and the locking hole in the IMLN.

During this dissection, we were surprised to discover that the central area of the transport zone was essentially a cyst filled with benign appearing fluid. The cyst was surrounded by periosteal regenerate bone and no medullary regenerate was present, consistent with the bone observed on radiographs. We have never previously opened the zone of distraction osteogenesis when using an IMLN, so we were not sure of the significance of this finding. We were concerned that the cyst could be a sign of infection despite its benign appearance. Given these concerns, we decided to send cultures and place calcium sulfate beads with vancomycin and tobramycin into the area of the central cyst. Our rationale was that the beads would help to treat infection, if present, and if no infection, they could potentially augment bony healing. Ultimately, multiple cultures taken from the site were all negative for evidence of infection; the patient never exhibited signs of infection, and the beads were resorbed without obvious signs of ossification in the area of the cyst. We then passed the medial side of the cable through the proximal locking hole. The cable was pulled as tight as possible by hand without a tensioner to avoid acute distraction of the transport segment, and the cable was locked into the loop (Figs. 4B and 5A, B). The patient began to use the actuator to compress the nail and pull the cable toward the fulcrum on the first postoperative day at 1 mm/d.

We felt that given the remaining defect was much smaller, less than 63 mm, than the 80 mm of compression available from the nail, docking with some reserve for docking site compression was possible. In retrospect, it took close to a week for the transport segment to start moving after initiating nail compression. This time lag indicates that hand tightening left excess slack in the cable that had to be taken up before distraction. Theoretically, this still left enough distance to complete the transport, but for future cases, a tensioner carefully applied with low tension may be preferred. This must be done with great care because over-tensioning can cause a catastrophic acute distraction of the transport segment. Therefore, tensioning must be performed with fluoroscopic monitoring to assure that tensioning ceases with any sign of transport segment.

Procedure 3

Transport progressed smoothly after the initial slack was removed until the transport segment came into contact with a spike of bone from the distal articular block. Once the transport segment met the bone spike, it slowed and stopped moving. The optimal docking site was still about 13 mm away from the transport segment, but the segment was now in direct apposition to distal spikes of bone (Figs. 4C and 5C, D). We decided that this was sufficient transport and that it would be best to finish by supplementing the docking site with bone graft and exchanging the PRECICE nail for a trauma nail. Unfortunately, the patient was then lost to follow-up for over 3 months due to urgent personal business. When he returned, regenerate consolidation had progressed but the docking site was unchanged, so we proceeded as previously planned.

A lateral distal femur approach exposed the docking site. The cables were removed, and all scar tissues were debrided between the transport segment and articular block. We next removed the PRECICE nail and replaced it with a trochanteric antegrade nail. The new nail was advanced across the docking site, and the thigh was manually manipulated to eliminate the varus angulation that had developed across the span of the plate during the transport. Manipulation of the thigh allowed the nail to pass to the center of the distal articular block, and an anatomic alignment was achieved. We had planned to remove screws as necessary from the distal end of the plate, but only a single screw removal was required. We placed locking screws into the distal end of the nail and harvested bone graft from the contralateral femur using a reamer irrigator aspirator. The autograft bone was placed at the docking site in a 60/20/20 mixture with mashed up cancellous cubes and calcium sulfate beads with antibiotics (Figs. 6A–D).

Postoperatively, the patient was allowed to fully weightbear. He was able to weightbear without pain in his femur within 2 months after the final operation. Radiographs taken 13 months after the initial operation show substantial regenerate calcification and incorporation of the distal bone graft (Figs. 7A–D). The authors consider this to be an implant-dependent union in which there is bridging bone across all segments, and the patient is clinically well, but the strength of the bone would not be adequate for weightbearing without the presence of the internal fixation. We anticipate additional consolidation time of at least 6 months before full healing is achieved.

DISCUSSION

This case presents the treatment of a comminuted distal femur fracture with a very large (13 cm) bone defect. The patient underwent a novel 3-stage reconstruction of his femur with bone transport using an IMLN together with a distal femoral locking plate and a cable loop. This combination was able to produce a transport greater than the maximum stroke length of the IMLN without the need of exchange to a new nail, removal of the transport nail, or a 2-procedure pit stop to acutely back up the nail. The patient had a number of comorbidities that put him at high risk for

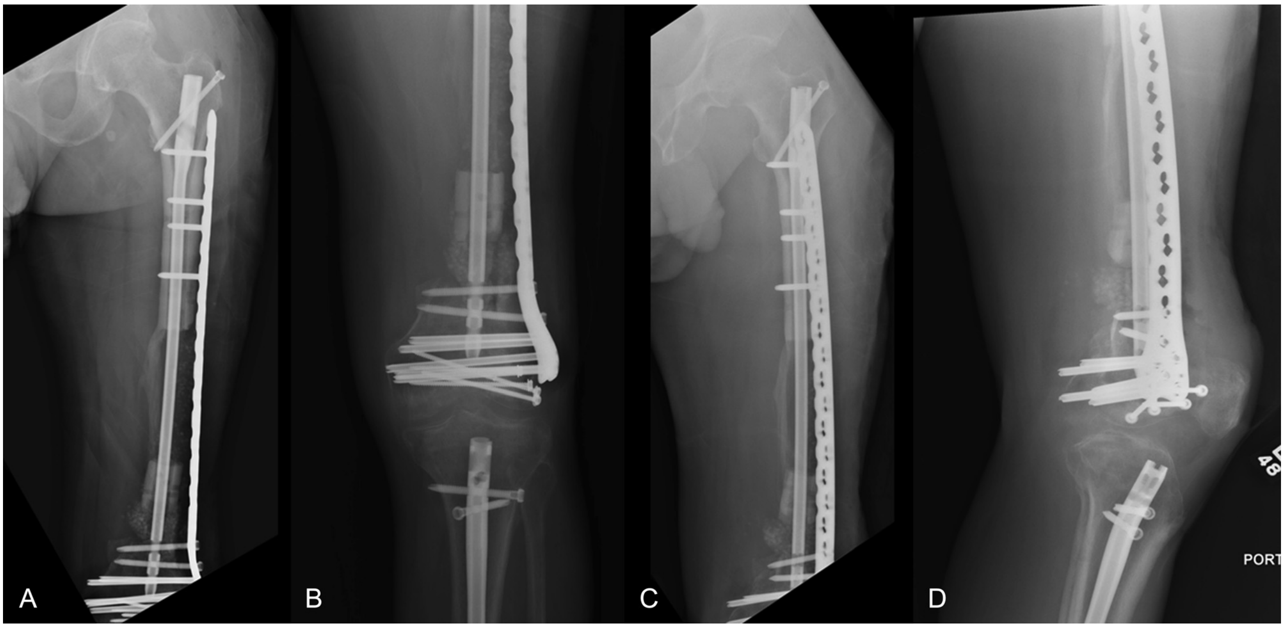

FIGURE 6. A–D, Anteroposterior and lateral radiographs of the femur after removal of the PRECICE nail, placement of an antegrade titanium trauma nail, and bone grafting of the docking site. Note that the alignment was easily adjusted by manual manipulation performed during placement of the intramedullary nail. After placement of the nail and distal locking screws, the alignment is anatomic and the fixation is stable for immediate weight-bearing.

infection and poor healing, including diabetes mellitus and a history of lung cancer with chemotherapy. Despite these concerns, the overall reconstruction was very successful.

We encountered some obstacles during the reconstruction such as the excess slack in the cable that caused a delay in transport after closing the cable loop. We also noted a change to varus near the end of the transport that, similar to what is observed with external fixation, had to be corrected as part of the final procedure. This is important to note because fixation with the lateral locking plate alone after completion of transport would have clearly led to

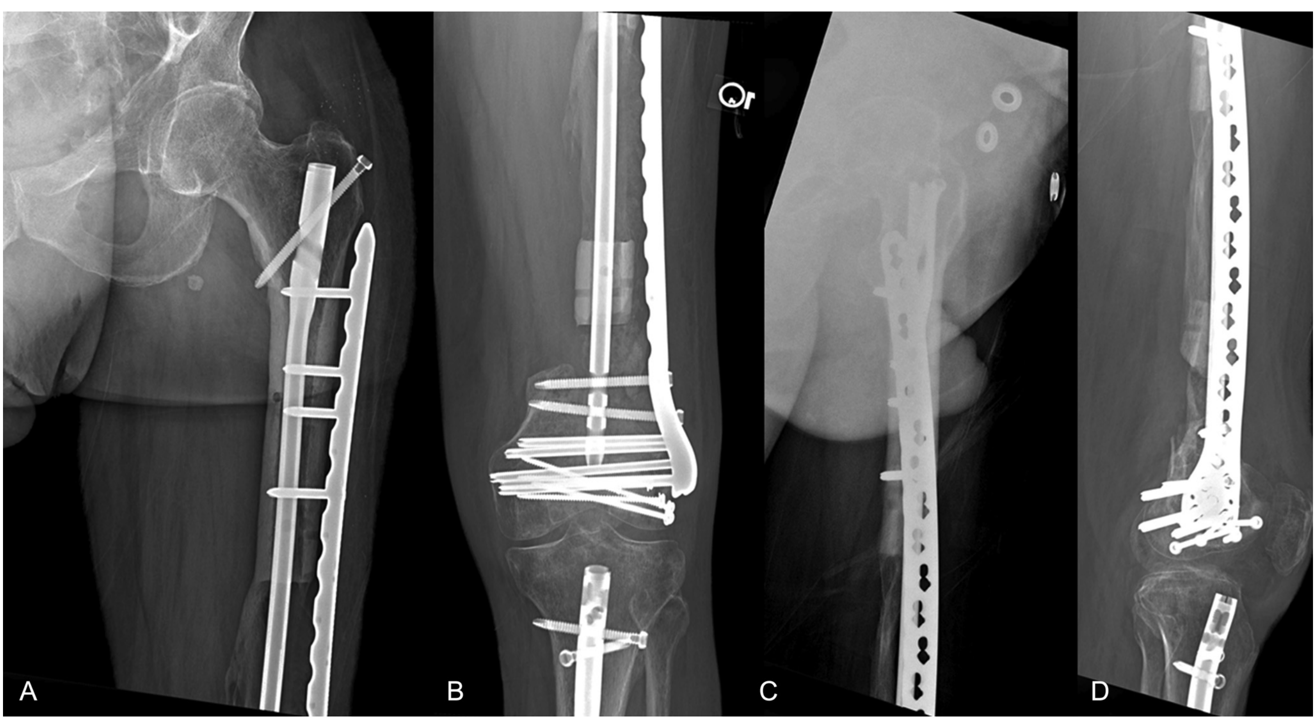

FIGURE 7. A–D, Anteroposterior and lateral radiographs at 13 months of follow-up showing consolidation of the regenerate and incorporation of the distal bone graft.

malalignment. Also, it is notable that the transport segment was 13 mm short of the ideal docking site at the end of transport. Judging by the amount of space necessary to complete the transport from the time of cable loop application, the transport should easily have made it to the ideal docking site. However, some distraction distance was lost as noted above due to initial slack in the cable loop. In addition, the transport segment was hung up on a bone fragment from the distal bone end. It is not clear whether the bone spike was a mechanical block to further transport or whether the increased distraction force required to push against the spike led some of the forces to be transferred to bending of the plate instead of pull on the bone segment. Either way, the nail reached full compression with the transport segment impinging on the bony spike. This led to the need for more bone grafting of the docking site than otherwise would have been necessary. However, none of these issues prevented a successful final outcome.

This is an exciting case that demonstrates many new concepts and findings related to the use of bone transport with IMLN and for massive defects in the femur in particular. This is the first report of a bone transport used to treat a femoral defect performed with an IMLN. Another new concept that has been applied by others, but not previously published, is the use of locking plate fixation to support length and alignment of the bone while the nail drives the transport. This is also the first report where an IMLN was used in combination with a fully internal cable loop to pull the bone segment; and also the first to demonstrate the successful use of a locking screw from a fixation plate as a fulcrum for cable transport.

In addition, this is the first report, to our knowledge, to advocate a planned exchange of the IMLN for a trauma nail at completion of transport. This is significant because it allows for early mobilization and weight-bearing as well as potentially stimulating regenerate consolidation. It also provides the crucial ability to address malalignment that can develop during transport and protects the distal femoral plate from breaking after having spent a long time supporting the long segmental bone defect. Furthermore, we observed an unexpected improvement in sagittal alignment with recreation of the femoral bow, which had been and is typically flattened by the straight IMLN. Notably, the replacement with a trauma nail also eliminates the need for an additional later surgery to remove the IMLN as is recommended by the manufacturer. For the above reasons, we strongly advocate this approach, especially for femoral bone transport.

All these concepts are useful in developing effective strategies to potentially treat amenable bone defects with distraction osteogenesis using purely internal fixation. We anticipate further technological innovations, such as internal bone transport magnetic nails, will be available soon. Such innovations will provide a powerful new tool, and application of many of the concepts introduced here will likely remain important to achieve success with these new technologies.

CONCLUSIONS

This case demonstrates that treatment of large bone defects in the femur with distraction osteogenesis using internal fixation alone is now possible. This case also reports a simple method for large bone defects to allow for lengthening beyond that provided by the stroke length of the nail. Regenerate formation with the IMLN, at least in the case, seems to be strictly periosteal in nature. Several obstacles were encountered, especially the development of varus malalignment during transport despite the presence of the locking plate. We strongly advocate planning for staged removal of the IMLN and placement of a trauma nail at the end of transport to facilitate immediate weight-bearing and optimization of alignment.

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