CASE REPORT

Dual Magnetically Expandable Intramedullary Nails for Treatment of a Large Bony Defect in a Patient with Sarcoma: A Case Report

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Abstract

Aim: To describe the surgical technique of performing an all-internal lengthening to address a large diaphyseal femur defect in the sarcoma patient.

Background: Various strategies exist to address large intercalary bone defects with various biomechanical and biological implications.

Case description: A 23-year-old female with high-grade osteosarcoma of her left femur underwent wide resection and an internal reconstruction of a 12.5-cm femoral defect using dual magnetic lengthening intramedullary nails resulting in restoration of leg lengths, and pre-resection function with minimal residual disability.

Conclusion: Preoperative chemotherapy, wide resection and post-operative chemotherapy for osteosarcoma are the current standard of care. Resection often leads to large bone defects requiring complex reconstruction. Following intercalary bone resection, biological reconstruction is a consideration. An all-inside technique was developed in an effort to minimise complications of long-term external fixation for distraction osteogenesis, or extensile secondary grafting procedures for induced membrane strategy.

Clinical significance: This previously unreported surgical technique allows for an all-internal lengthening of large diaphyseal bone defects. While specifically used in an oncologic post-resection setting, this technique is applicable to the broader limb reconstruction and lengthening practice and overcomes some inherent limitations to previously described techniques.

Keywords: Distraction osteogenesis, Limb lengthening.

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Background

Osteosarcoma is the most common primary malignancy of bone with a peak incidence in the second decade of life. Current standard of care consisting of preoperative chemotherapy, wide resection with limb preservation and post-operative chemotherapy has led to 5-year survival approaching 70%.[1,2] However, with that, comes the complexity of managing the often-large segmental osseous defect as a result of tumour resection. Historically, this has been accomplished with reconstruction using allograft, endoprosthesis, prosthetic–allograft composite or various vascularised autograft options. Intercalary resections resulting in large defects with preservation of adjacent articular ends are further amendable to biological reconstruction. For over 20 years, distraction osteogenesis using the patient's own bone to restore length has been performed in sarcoma patients.[3] This includes the use of stacked hexapod frames, monoplanar or circular frames in singularity, or assisted lengthening over intramedullary nails.[4–9]

Despite these techniques, management of large osseous defects remains a challenge as external fixation is wrought with high complication rates in sarcoma patients.[3] Additionally, few methods adequately address defects that are of size more than 10 cm. Furthermore, the large defects are much more challenging in the femur given decreased ability to apply ringed fixation, deformity induction from monorail external fixation, increased risk of contractures about the knee and deep pin infection secondary to the duration required to span large defects distracting at rates of 1 mm/day.[10–13]

Recently, the magnetic growing nails have offered promise, and new techniques have described the use of locking-plate assisted expandable intramedullary nails for osteogenesis in tibia and femur defects.[14–16] We describe the novel technique of using dual expandable intramedullary nails for an all-inside distraction osteogenesis in the setting of sarcoma resection for management of a large diaphyseal femur defect with completion of distraction within 10 months of index surgery.

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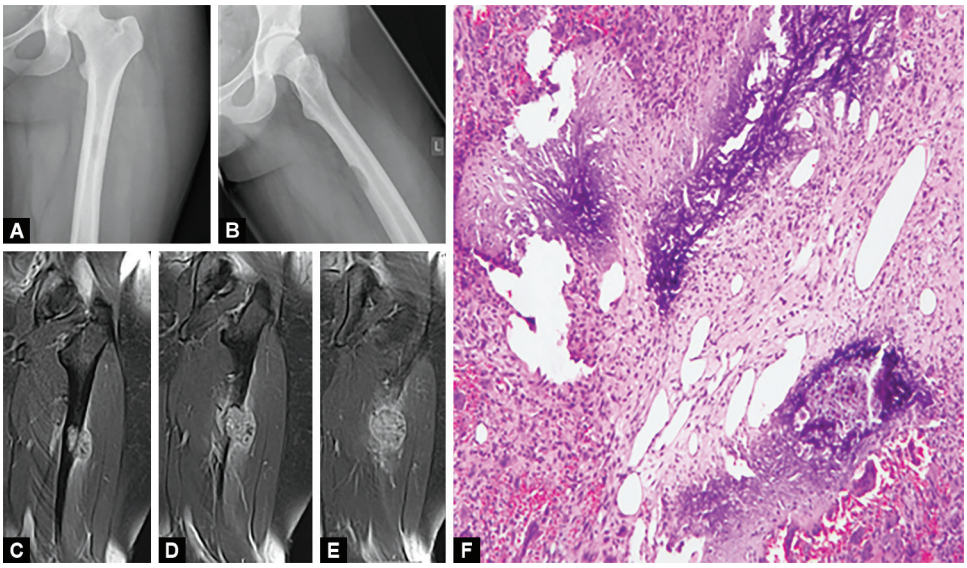


Figs 1A to F: Representative preoperative imaging. (A) Anteroposterior; (B) Lateral plain radiographs; (C and D) Sequential coronal; (E) Sagittal T1-fat saturated post contrast magnetic resonance imaging; (F) Histopathology of patient lesion obtained from open biopsy

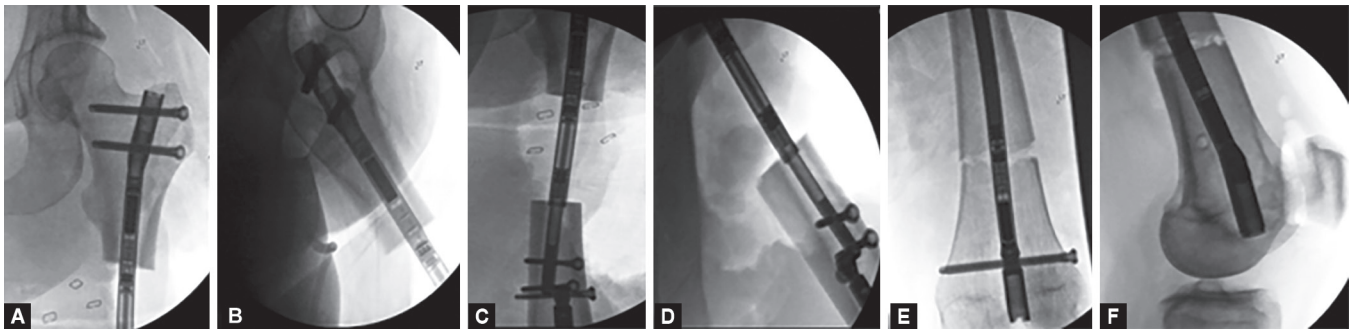
Prior to manuscript development, the patient was informed that data concerning the case would be submitted for publication and the patient agreed.

Case Description

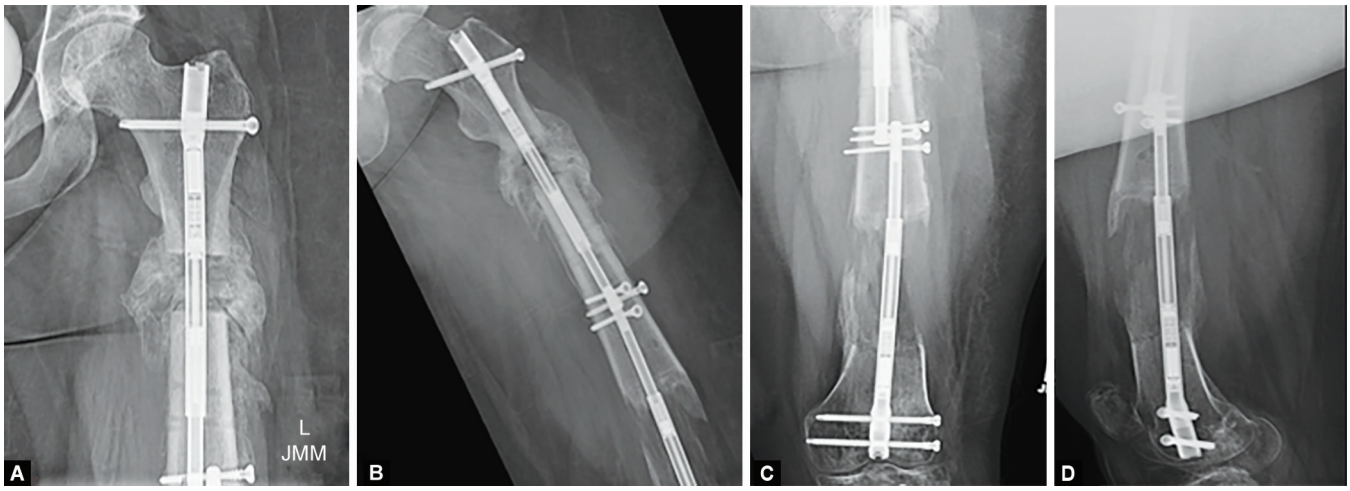
A 23-year-old, otherwise healthy female, initially presented with non-specific, atraumatic left thigh pain. Workup including plain radiographs and full femur magnetic resonance imaging (MRI) demonstrated a 4 cm × cm 4 × 2 cm juxtacortical lesion arising from the posterior aspect of the proximal femur concerning for malignancy without evidence of skip lesions (Figs 1A to E). Open biopsy was performed and confirmed the diagnosis of high-grade osteosarcoma (Fig. 1F). Staging studies were negative for metastatic disease, and 4 weeks following open biopsy, the patient began 12 weeks of AOST0331-MAP/EURAMOS-1 protocol chemotherapy as dictated by our institutional paediatric tumour board.[17] While not traditional, this 4-week period between biopsy and treatment initiation was needed to stabilise our patient's social situation, and provide appropriate genetic and psychological counselling with the goal to maximally optimise the patient prior to initiation of our protocol.

Three weeks following preoperative chemotherapy completion, resection and reconstruction was performed. Surgery began with placement of four parallel 5-mm Schanz pins from lateral to medial, two distally in the posterior femur and two proximally at the level of the lesser trochanter, to set rotation and pre-resection length for controlled establishment of post-resection alignment. With length and rotation accounted for, a standard lateral approach to the femur was performed. Prior to resection, parallel etches were made with a microsagittal saw on the lateral femur at the osteotomy sites for further rotational assessment during reconstruction. The tumour resection was then completed yielding negative intraoperative margins. In total, 12.5 cm of bone was resected. Reconstruction was then performed using two PRECICE intramedullary lengthening nails (NuVasive, San Diego, CA). First, the previously constructed external fixation frame was reattached to the Schanz pins in parallel orientation and with femoral etchings realigned to restore rotation of the limb. Due to the size of the osseous and soft tissue defects, the limb was then acutely shortened to 7 cm, using the frame, for a remaining 5.5-cm defect. The antegrade nail, 8.5 mm × 165 mm, was lengthened 5 cm on the back table and inserted through a standard greater trochanteric entry point. The nail was statically locked proximally and distally within the proximal aspect of the future transport segment. A second PRECISE nail, 8.5 mm × 165 mm, in its maximally shortened position was placed in retrograde fashion and statically locked distally and proximally allowing for slight overlap with the antegrade nail to enhance construct stability (which accounts for the use of comparatively smaller diameter nails). This allowed the antegrade nail to function as a shortening nail while the retrograde nail served as a lengthening nail (Fig. 2). Next, a transverse osteotomy was made using a 3.5-mm drill and stiletto osteotome in the distal meta-diaphysis creating a free distal intercalary segment for proximal transport. The external fixator was removed and all wounds were irrigated and closed in standard layered fashion. The patient was made non-weight bearing post-operatively with initiation of 1 mm/day of lengthening starting post-operative day 7. The surgical pathology revealed 60% necrosis and post-operative chemotherapy was resumed 3 weeks after resection and stopped 1 week prior to her second stage reconstruction.

Two months post-index surgery, both nails were removed, and the original retrograde nail, now maximally lengthened 5 cm, was repurposed and placed back into the patient in antegrade fashion (to now serve as a shortening nail), and a new 190 mm × 8.5 mm nail was placed in retrograde fashion (to function as the new lengthening nail) for planned 5 cm of an additional distraction (Fig. 3). Three weeks post-operatively, chemotherapy was resumed and the patient completed her remaining 12 weeks of post-operative chemotherapy for a total of 6 cycles, 25 weeks, of pre- and post-operative chemotherapy. Lengthening was completed 2 months following her second surgery resulting in nearly 10 cm of distal intercalary segment transport and 2 cm of proximal callous within the resection site (Fig. 4). Overall healing index (HI) was found to be 12.2 days/cm. No changes were made to the distraction protocol while on chemotherapy.



Figs 2A to F: Representative intraoperative fluoroscopic imaging at the time of index surgery



Figs 3A to D: Interval distraction of femur with distraction osteogenesis regenerates at 6 months status post-index procedure

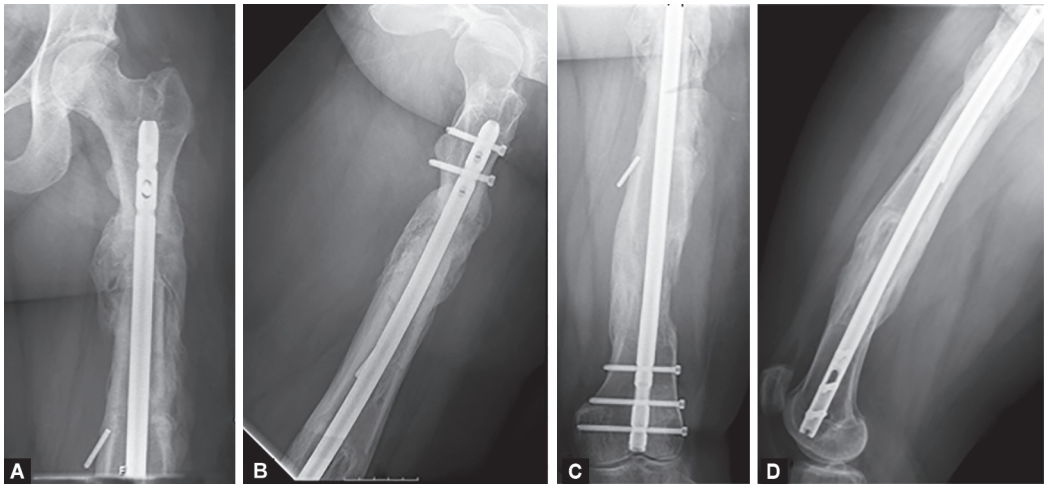
Fig. 4: Standing limb length film obtained 4 months post-index reconstruction demonstrating 9.5 cm of distal femoral regenerate and 2.5 cm of proximal resection callous with femoral lengths within 1 cm of total length

She remained foot flat weight-bearing for an additional 6 months to allow the regenerate to consolidate and mature. The second planned return to surgery was 10 months after the initial operation to replace her dual-nail construct with a standard retrograde intramedullary nail (380 mm × 12 mm) to promote stability and restore anatomic mechanical axis. The most recent follow-up, 18 months after index surgery, demonstrated stable reconstruction without evidence of recurrence. The patient resumed her normal activities and on exam, had 0–100 knee flexion with 5/5 strength and no reported pain. Overall Musculoskeletal Tumor Society (MSTS) functional score was found to be 93 with the patient reporting only a mild limp when running long distances. Imaging at that time demonstrated a stable appearing femur with abundant callus and maturing regenerate (Fig. 5). Overall lengthening was radiographically and clinically determined to be within 1 cm of the contralateral femur.

Discussion

Osteosarcoma is the most common primary malignancy of bone with current treatment strategies leading to limb preservation in the majority of patients. When the tumour is not juxta–articular, intercalary resection can often be performed maintaining the adjacent joint. Options for intercalary reconstruction include endoprosthesis, allograft, autograft or a combination of these constructs.[1] While intercalary endoprosthesis and other constructs for segmental defects have had some success, particularly in older patients or those with decreased life expectancy, their long-term durability is of less robust.[3,18–20] As a result, continued efforts to generate durable biological reconstruction methods, especially for younger patients, are important.

Despite advancements, the management of large segmental osseous defects with external frames continues to have high complication and low satisfaction rates in sarcoma patients.[21,22] While innovation has been successful primarily in the tibia with the application of expandable nails and multiplanar frames, the femur



Figs 5A to D: Representative post-operative imaging at 18-months follow-up. (A and C) Anteroposterior and (B and D) Lateral plain radiographs demonstrating maturing callous after completion of distraction

has had less success using multiplanar frames for large defects with studies primarily comparing frame to nail in much smaller defects.[23] As a result, solutions avoiding complications such as pin site and deep infections and addressing patient intolerance of external frames for long durations remains important.[24] To that effect, frame-assisted lengthening over nails has been shown to decrease duration of frame time, quicken bone healing, and protect against fracture through pin sites.[25] Still, the pairing of external frame with intramedullary device does confer a risk of deep infection communication *via* pin site infection.[11,26]

The all-inside lengthening method described here aims to address limitations and complications related to the use of either external fixators or endoprosthesis for reconstruction of large defects in young patients. Ideally, this technique is best served in the setting of larger defects which cannot be addressed by a single internal lengthening nail. Additionally, while used in this case for a purely diaphyseal defect, so as long as an adequate intercalary segment can be accommodated, and enough bone proximally and distally exists in which to statically lock the nails this technique could be a viable alternative to traditional reconstruction methods. This strategy also minimise soft tissue complications associated with external frames by circumventing the need for pin–tracts throughout the duration of lengthening.[27,28] Intramedullary distraction provides stable in-axis fixation across an established mechanical alignment, which is set at the time of surgery. This case demonstrates the application of this technique to a large osseous defect without reliance on subsequent open operations, as would be necessary with induced-membrane reconstructive procedures performed over intramedullary implants.[29] Additionally, as compared to other internal lengthenings/reconstructions, the use of a dual lengthening nail construct allows the surgeon to address very large defects by simultaneously shortening one nail while lengthening the other. This allows for regenerate growth both proximal and distal to the intercalary segment which would otherwise be beyond the abilities of single nail constructs. While three surgeries were needed in this case, the second and third surgeries were not extensile and done as minimally invasive as possible. In cases of smaller bone defects, this strategy could theoretically be performed with just two surgeries. Ultimately, the need for additional, albeit less invasive, surgery is inherent to this technique and should be considered prior to performing.

Limitations of this report are those inherent to single case reports. Moreover, given only this single-case example, detailed indications for this strategy have not yet been established. The future applications of this method will need to be followed and evaluated for the general applicability of the technique beyond the oncology patient. This technique is presented as an isolated case and claims of superiority over previously established techniques are beyond the scope of this report. Additionally, as this technique employs off-label use of internal lengthening nails (reuse of the previously implanted nail), the surgeon should critically assess the viability of this treatment technique on an individual patient level. Ideally, this treatment strategy should be compared to other means of addressing large bone voids such as intercalary allograft with or without vascularised autograft augmentation. Specifically, as it relates to performing an internal lengthening while on concurrent chemotherapy, we did not observe any issue in bony regenerate growth/remodelling nor is there any data to suggest otherwise. However, this is certainly at least a theoretical risk which should be fully considered and investigated. Other potential disadvantages of this technique are those inherent to the use of a magnetically expandable nail.[30] These include an increased risk of mechanical failure (nail bending and breakage) and other implant related issues such as adverse tissue reactions. The working length of short segment lengthening where the two nails overlap is biomechanically the weakest point in this construct. We chose to use relatively smaller nails for this technique so as to allow for a portion of nail overlap. We feel this overlap is critical so as to improve construct stability with the use of comparatively smaller diameter nails. Additionally, compared to other lengthening techniques, performing an all-inside lengthening requires a significantly higher upfront cost due to the high cost of magnetic lengthening nails. Notably though, overall cost is likely similar to other proposed techniques due to a lower complication profile and need for fewer overall operations to achieve a similar amount of lengthening.[31] In our case, three PRECICE nails were needed followed by a standard intramedullary nail. In smaller defects, this technique could be performed with just two PRECICE nails. Also, use of this technique requires a prolonged period of restricted

weight bearing. Techniques which allow osteogenesis over an external lengthening frame allow for earlier weight-bearing, and may be more appropriate for some patients.[32] Lastly, while small studies have evaluated the MRI compatibility of magnetic motor expandable nails, the safety of this technique is not fully understood. If MRI is required for disease surveillance throughout the duration of lengthening, more studies are needed to determine the effect of magnetic resonance on the implant magnetic motor.[33]

Conclusion

Preoperative chemotherapy, wide resection and post-operative chemotherapy for osteosarcoma is the current standard of care. Resection often leads to large bone defects requiring complex reconstruction. Following intercalary bone resection, biological reconstruction is a consideration. An all-inside technique was developed in an effort to minimise complications of long-term external fixation for distraction osteogenesis, or extensile secondary grafting procedures for induced membrane strategy.

Clinical Significance

This previously unreported surgical technique allows for an all-internal lengthening of large diaphyseal bone defects. While specifically used in an oncologic post-resection setting, this technique is applicable to the broader limb reconstruction and lengthening practice, and overcomes some inherent limitations to the previously described techniques.

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