Use of a magnetic intramedullary nail for axial compression in endoprosthetic reconstruction of the humerus: a description of technique

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SUMMARY

Pathological fractures, both completed and impending, of the humeral diaphysis from primary or metastatic disease demand a reconstruction that restores stability while preserving shoulder function and alleviating pain. Conventional reconstructive approaches include the use of long-stemmed endoprosthetic devices, plate-and-screw fixation or intramedullary nailing, all of which can be limited in their success when residual bone is short or biologically weak. This case study details the management of a patient with metastatic leiomyosarcoma who presented with refracture through a previously cement-augmented lesion. Following resection, the diaphyseal defect was spanned using a custom humeral cage. A NuVasive PRECICE magnetically controlled intramedullary nail, pre-lengthened before insertion, was placed through the cage and shortened intraoperatively to achieve axial compression between the cage and bone segments. At the 6 month follow-up, the patient had excellent shoulder range of motion, apparent ingrowth into the cage, and he was able to resume activities of daily living with minimal pain.

BACKGROUND

The humeral diaphysis is a common site for primary and metastatic cancer, often causing pathological fractures that result in significant pain and reduced quality of life.[1 2] Despite being the third most common site for metastatic cancer, this location presents challenges to surgical management, as disruption of the deltoid and rotator cuff muscles, along with the proximity to the neurovascular bundle, may result in technically challenging and/or impractical resections.[2–6] For patients with significant functional impairments, intercalary resection with reconstruction using metal implants or cadaveric allograft is commonly used.[2] One frequently used metal implant in intercalary resections is the humeral cage, which consists of a cylindrical or mesh-like structure (ie, the gyroid) to be used as a scaffold to facilitate bone ingrowth to allow for structural stability in the humerus.[7 8]

In addition to providing a stable scaffold, achieving near-anatomic alignment of the proximal and distal humerus fragments with the metal cage is necessary for patients to have optimised function and pain levels postoperatively.[8–10] This is often achieved via axial compression, and standard practices include (a) preserving the necessary length of the proximal and distal segments to allow for the use of custom long-stem prostheses or (b) using endoprosthesis with built-in compressive mechanisms to assist in bone fixation.[9–12] However, there is limited evidence on the use of magnetic intramedullary nails (IMNs), such as the PRECICE nail (NuVasive Specialised Orthopaedics, San Diego, CA, USA), to achieve compression over a humeral cage in patients who have either failed other reconstructive options or do not have adequate bone length to achieve fixation using traditional approaches. The PRECICE nail is an interlocking, motorised nail that uses a magnetic telescoping rod to achieve slow bone lengthening and/or compression.[13] Applications of the PRECICE nail have been explored extensively in orthopaedic paediatrics and trauma.[14–17] For example, the primary use of the PRECICE nail was developed for limb lengthening surgeries in patients with congenital or acquired limb length discrepancies.[14 15 18] Additionally, the PRECICE nail has been used to successfully apply compression, prevent deformity and obtain union in non-union fractures of the femoral and tibial diaphysis.[17] However, evidence for their use in oncological reconstruction of the humerus remains limited.

CASE PRESENTATION

In this case, we describe the use of the PRECICE nail to achieve compression over a custom, flanged humeral cage (Restor3d, Durham, NC, USA) in a male patient who presented to our institution with concerns for re-fracture secondary to metastatic leiomyosarcoma to the humeral diaphysis, following prior treatment with cement augmentation at an outside institution (figure 1). He had an extensive oncological history and was first diagnosed with leiomyosarcoma of the right common iliac and right common femoral veins 17 years prior. Since then, he had undergone several oncologic surgeries, including multiple partial hepatectomies for metastatic liver lesions, and completed chemotherapy treatment with pazopanib.

2 years prior to presentation at our institution, MRI of the proximal humerus revealed osteoblastic lesions of the proximal humerus, concerning for metastatic disease. Initially, management of the lesion included resection with curettage and cementation and a stereotactic body radiation therapy dose of 35 Gy in five fractions. Approximately 1.5 years following the initial surgery, he then experienced worsening pain and increasingly limited

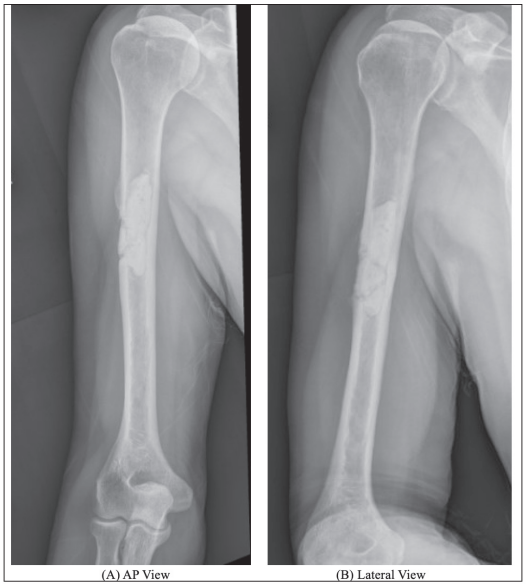

Figure 1 Two panels depicting the preoperative AP (A) and lateral (B) views of the R humerus at presentation to our institution. AP, anteroposterior

range of motion, prompting evaluation at the present institution. A nondisplaced fracture around the cement was noted on imaging. Management options discussed included conservative management, internal fixation with plating or intercalary resection of the affected segment.

The decision was made to proceed with intercalary resection, and a custom system was designed (Restor3d, Durham, NC, USA). This would consist of a cutting guide to facilitate resection, a jig to maintain length and alignment following segmental bone resection, and a custom, -printed cage-type endoprosthesis, which would accommodate the PRECICE nail spanning through its centre (figure 2A–C). The custom endoprosthesis was polished on the external surface in the regions of the spiral groove to eliminate contact between the radial nerve and a roughened implant surface. Although this system was designed as a custom solution for this patient, we believe that this type of approach could be generalised as a reconstructive technique for patients with intercalary segmental bone loss.

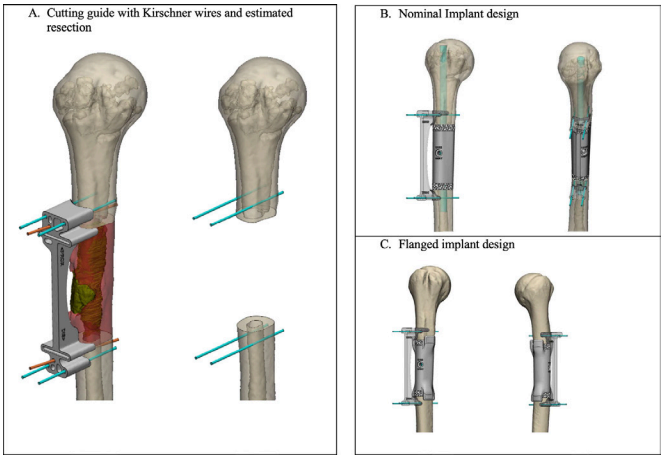

Figure 2 Preoperative computer-generated images of the cutting guide (A), the non-flanged (ie, nominal) implant (B), and the flanged implant (C), which was ultimately used.

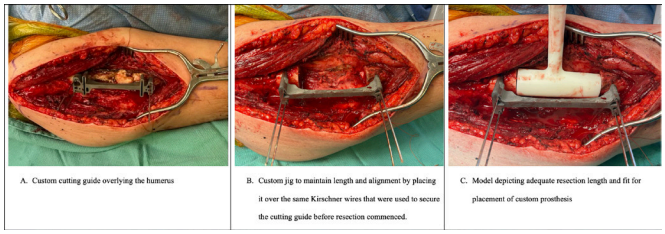

Figure 3 Intraoperative photograph showing the placement of the custom cutting jig over the affected segment of the humerus (A), following the intercalary resection (B), and with the model depicting adequate resection length (C).

TREATMENT

In the operating room, intercalary resection was planned and conducted in a standard fashion. Prior incision was extended longitudinally in an anterolateral approach with a proximal deltoid split. Proximally, the fascia over the biceps was incised, and dissection was continued along the lateral margin of the biceps. Distally, the interval between brachialis and brachioradialis was developed, and the radial nerve was identified and protected. Proximally, to perform appropriate resection, the central portion of the deltoid attachment was released and tagged for later repair. The brachialis was split, and the humerus and cement were exposed. The electrocautery and key elevator were used to carefully mobilise soft tissue off the humerus.

Next, the custom cutting guide was placed on the humerus (figure 3A) and pinned to the humerus with 4 1.6 mm-diameter Kirschner wires. Radiographs confirmed appropriate placement, and the humerus osteotomies were made. Following completion of both humerus osteotomies, the intercalary segment was removed and confirmed to fit appropriately in the model (figure 3B, C). The two options for implants included a cage with and without proximal and distal flanges. Both models contained a hollow segment matching the diameter of the PRECICE nail. The decision was made to proceed with the flanged model due to better intraoperative stability. The trial was removed, and the remaining humerus was reamed up to 10.5 mm for an 8.5 mm nail, in accordance with NuVasive guidelines. The flanged cage was placed into the segment (figure 4). Kirschner wires from prior guide placement confirmed appropriate rotation.

Figure 4 Intraoperative photograph showing the placement of the custom humeral cage with the cutting jig in place with four Kirschner wires.

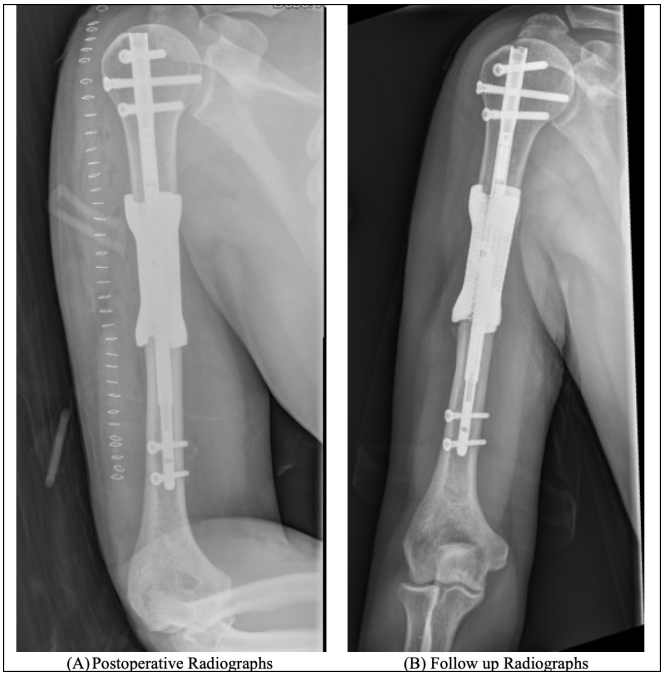

Figure 5 Postoperative radiographs from the immediate postoperative period (A) and the 6 month follow-up (B) visits showing a well-fitting humeral cage and the PRECICE intramedullary nail with adequate contact between the cage and the proximal and distal humeral fragments. JMR

The starting point of the humeral nail was obtained in a retrograde fashion by passing a guidewire through the custom implant and then through the proximal bone segment. This would ensure that a starting point would reflect the desired position for alignment of the implant within the intercalary gap. The guidewire was placed in the rotator interval and did not appear to violate the musculature. To allow for appropriate compression, the PRECICE nail was lengthened by 2 cm prior to insertion. The PRECICE nail was then implanted and secured with three proximal and two distal pegs: radiographs confirmed appropriate depth and placement of all hardware. The nail was then compressed with the magnet, placed in a sterile bag, until appropriate bone and implant contact was observed on radiographs. The compression process took approximately 15 min. The wound was closed in a standard fashion. The patient did well and was discharged home on postoperative day 1.

OUTCOME AND FOLLOW-UP

At his 6 month follow-up visit, the patient reported near-full range of motion and significant pain relief. He has been able to resume desired activities, including light sports. He was satisfied with his results and would continue to work with physical therapy. He has experienced improvement in arm function, now able to perform daily activities such as applying deodorant, shaving and brushing his teeth with his right hand. Active forward flexion was 160° and abduction was 170°. Radiographs obtained in the immediate postoperative period (figure 5A) and at 6 month follow-up (figure 5B) confirm adequate contact between the humeral segments and the 3D-printed cage.

DISCUSSION

This case describes the novel use of a magnetic IMN (ie, PRECICE nail) to achieve compression across a custom cage-type endoprosthesis following intercalary resection of diaphyseal humeral metastatic disease.

The magnetic, telescoping system offered by PRECICE nail makes it a valued option for surgical limb lengthening. However, the nail can also be expanded preoperatively to allow for subsequent compression. Although compression and/or lengthening for magnetic rods typically occurs postoperatively, in this case, the nail was lengthened prior to insertion, allowing for intraoperative compression across the proximal and distal sites of anticipated osseointegration. By delivering a controlled axial load in the operating room, we avoided extensive periosteal stripping and preserved the rotator-cuff insertion, factors that have repeatedly been linked to postoperative weakness after traditional endoprostheses.[19 20] Biomechanically, compression with the PRECICE nail increases friction at the bone–cage interface, resists shear and may stimulate bony ingrowth, paralleling results reported for femoral and tibial non-union treatment.[13 17] One critical factor in seeking ingrowth between the implant and the proximal and distal osseointegration sites is the proprietary geometry of the cage structure. The unit cell of the structural cage is a ‘gyroid’, a surface that is a repeating pattern in all three dimensions of space that has equivalent mechanical properties regardless of orientation. The gyroid structure has been demonstrated, for any given porosity, to have superior mechanical properties than truss or lattice structures in any loading orientation.[21]

To fully appreciate the advantages of this combined cage-and-nail system, it is important to consider the broader challenges of intercalary reconstruction. When performing an intercalary reconstruction of a long bone, the surgeon creates two sites, one proximal and one distal, where either osteosynthesis (eg, in the instance of a vascularised fibular graft) or osseointegration (eg, in the instance of a metal endoprosthesis) occurs. In addressing this, there are several limitations relevant to applying compression between both integration sites. One can use a cemented, segmental endoprosthesis with stems going into both the proximal and distal segments. This approach does not allow for ingrowth. While this same approach can, in theory, be taken with press fit stems, it is not typically done. If using a plate, our experience has been that dual compression plating to achieve compression at both osseointegration sites is typically inadequate to stabilise the entire construct. One can use a long bridge plate that spans the intercalary segment, but this comes at the expense of compression across the two osseointegration sites. Alternatively, one can use staple fixation to provide some compression at the two osseointegration sites and then span the entire construct with either a bridge plate or a statically locked nail. As demonstrated by this case, designing a cage-type implant that works with the PRECICE nail allows for centralised, evenly applied compression across the entire intercalary segment, which stabilises the implant and optimises the potential for osseointegration at both sites.

While the patient described in this report had leiomyosarcoma, this approach would be feasible for patients with metastatic disease or primary bone tumours of many other aetiologies with the common need for intercalary resection and reconstruction. However, the requirement for a larger final intramedullary canal diameter (ideally reamed to 10.5 mm) for the PRECICE nail, higher implant costs and potentially limited surgeon familiarity with this implant represent potential drawbacks that warrant further study.

In conclusion, controlled, intraoperative compression following intercalary resection was achieved with a PRECICE magnetic nail seated inside a custom humeral cage. The construct yielded rapid pain relief and return of near-full upper-extremity function before 6 months, despite prior failure of cement augmentation. This technique broadens the reconstructive options for patients whose bone stock or soft-tissue constraints are not amenable to traditional plating or long-stem endoprostheses. The positive early outcome from this single case should be prospectively examined in patients with longer radiographic follow-up to optimise nail-cage mechanics and refine intraoperative compression protocols.

Learning points

- This case describes the novel use of a PRECICE magnetic intramedullary nail to achieve compression over a custom, 3D-printed humeral cage in a patient with metastatic leiomyosarcoma.
- To achieve axial compression, the PRECICE nail was lengthened by 2 cm before insertion and then shortened intraoperatively using a magnet, a process that took about 15 min.
- The cage-and-nail system is designed to provide centralised, evenly applied compression to stabilise the implant and optimise the potential for osseointegration at both the proximal and distal sites.
- At his 6 month follow-up, the patient reported significant pain relief with near-full range of motion and had resumed desired activities, including light sports.

Contributors DAS: guarantor; direct patient care; conceptualisation; writing—original draft; writing—reviewing and editing. ADT, IP and WCE: direct patient care; conceptualisation; writing—original draft; writing—reviewing and editing. OB: direct patient care; conceptualisation; writing—reviewing and editing. NL: direct patient care; conceptualisation; writing—reviewing and editing; supervision. DL: conceptualisation; writing—reviewing and editing.

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