Multiplanar Osteotomies Guided by Navigation in Chondrosarcoma of the Knee

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Abstract

Surgical resection with adequate margins is the treatment of choice in chondrosarcoma. However, well-circumscribed lesions can be completely resected by performing multiplanar osteotomies guided by computer-assisted navigation. This type of resection had been recently described in select patients with sarcomas; however, these osteotomies are technically demanding to plan and perform intraoperatively. The use of navigation to assist in surgery is becoming more frequently described in orthopedic oncology.

The authors performed multiplanar osteotomy resections guided by navigation and reconstruction with intercalary allografts in 5 patients with chondrosarcoma around the knee. All the patients were women, with a mean age of 56 years. Four tumors were located in the distal femur and 1 in the proximal tibia. The 5 surgical anatomic specimens were 3-dimensionally reconstructed postoperatively and superimposed on a preoperative plan to check whether the resected specimen was consistent with the preoperative planned resection. At final follow-up, no patient experienced a local recurrence or metastasis. Four osteotomies each were performed in 3 patients, and 3 osteotomies each were performed in 2 patients, so 18 planes were evaluated. Mean difference in distance between preoperative vs final planes was 2.43 mm. Average functional score was 29 points. All patients resumed activities of daily living without restriction. This study’s results show that navigation with adequate preoperative planning allows surgeons to intraoperatively reproduce the planned resection with accuracy in complex multiplanar resections.

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Figure 1: Intraoperative photograph of two 3-mm Apex pins (Stryker Navigation, Freiburg, Germany) used in the distal femur in conjunction with the Stryker OrthoLock System (Stryker, Kalamazoo, Michigan) after the surgical approach is performed.

Figure 2: Intraoperative photograph of the tracker positioned in direct view of the navigation camera, such that they did not interfere with the surgical resection or operative field.
Chondrosarcoma is the second most common malignant primary bone tumor, surpassed only by osteosarcoma, and mainly affects the pelvis and the metaphyseal part of the long bones.\textsuperscript{1-6} Although high-grade chondrosarcomas are considered at risk of developing metastasis, the indication for treatment of chondrosarcoma is generally surgical resection only.\textsuperscript{1-9} Adjuvant radiotherapy and chemotherapy are reserved for patients with mesenchymal or dedifferentiated chondrosarcomas or those with insufficient surgical treatment.

For decades, treatment was limited to amputation of the limb with a poor prognosis. The development of new methods of diagnosis that more accurately define the limits of the tumor and the improvement of reconstructive surgical techniques have made limb salvage surgery possible for the majority of patients with chondrosarcoma. Multiplanar osteotomies using computer-assisted navigation have been recently described in select patients with sarcoma to preserve as much host tissue as possible without compromising the tumor margins.\textsuperscript{10} However, these osteotomies are technically demanding to plan and perform intraoperatively.

Navigation techniques to assist in surgery are improving and becoming more frequently described in orthopedic oncology.\textsuperscript{11-16} Intraoperative navigation allows a view of the tumor in the bone, which could aid in performing appropriate multiplanar osteotomies that provide the benefits of accurate bone resection.

The current authors describe a multiplanar technique for select patients with chondrosarcoma around the knee planned preoperatively with fused images and a CT-guided navigation system intraoperatively.

**MATERIALS AND METHODS**

The authors performed multiplanar osteotomy resections using CT-guided navigation and reconstruction with intercalary allografts in 5 patients with chondrosarcoma around the knee. All of the patients were women, with a mean age of 56 years (range, 42-71 years). Four tumors were located in the distal femur and 1 in the proximal tibia. No patients were lost to follow-up. Patients were informed of the advantages, disadvantages, and surgical alternatives to the resection technique. All diagnoses were made with needle biopsy preoperatively. All patients underwent diagnostic imaging with plain radiographs, CT, and magnetic resonance imaging (MRI) at the time of diagnosis.

After the preoperative imaging studies were performed, the CT scans and MRIs were fused. Image fusion is the process of combining relevant information from 2 or more images into a single image. The resulting image is the used for the preoperative planning.

Then, using MIMICS version 14.1 software (Materialise, Leuven, Belgium), the affected bone with the tumor was reconstructed, and the osteotomies were planned to resect the tumor. Once the tumor was resected, the bone defect was reconstructed with an allograft bone. The authors chose a similar bone allograft from the bone bank. To do so, CT scans of all the allograft bones in the bone bank were obtained, and 3-dimensional (3-D) models of the allograft bones were created using MIMICS. Based on this virtual model, the authors chose the best allograft by comparing the affected bone with the allograft bone. This process was performed during preoperative planning.

To make accurate cuts, the width of the saw was considered. The virtual surgical planning was imported into a CT-based navigation system (Stryker Navigation System II with OrthoMap version 1.0 software; Stryker Navigation, Freiburg, Germany) for resection planning (Figure 1). After the tumor was resected, a second navigation was performed in the allograft. In this way, the allograft was cut similarly to the bone defect, like a puzzle piece.

Intravenous antibiotics were administered immediately preoperatively. All patients were reconstructed with a hemi-
cylindrical intercalary allograft after tumor resection. A medial parapatellar approach was used in all cases. The navigation system was positioned opposite the surgeon, approximately 4 feet away from the patient. The camera was positioned over the patient’s knee and directed downward at 45°. After surgical exposure, two 3-mm Apex pins (Stryker Navigation) were placed on the distal femoral metaphysis or proximal tibial metaphysis at least 3 cm away from the programmed osteotomy lines in a secure area not affected by the tumor, as determined during the preoperative planning. A navigation tracker was fixed to the pins with the Stryker OrthoLock System (Stryker, Kalamazoo, Michigan) (Figures 2, 3). An image-to-patient registration to precisely match the operative anatomy and preoperative virtual CT images was performed by matching paired points and surface points. At least 3 landmark points (e.g., epicondyles and bone tuberosities) were identified in the affected bone based on the surgical exposure and visible anatomic points (Figure 4). Surface mapping of the bone was performed to reduce any mismatch between preoperative CT images and the patient’s anatomy (Figure 5).

After registration, the surgeon double-checked with the navigation pointer whether the surface of the patient’s bone in real time correlated with the virtual preoperative images. Then, using the navigation pointer, the osteotomies were marked on the surface of the bone. The directions of the bone cuts were determined with the pointer, and the osteotomies were performed with an oscillating saw (Figure 6).

Before frozen section examination, CT scanning of the bone resection was performed. The 5 surgical anatomic specimens were 3-dimensionally reconstructed postoperatively and superimposed on the preoperative plan. After frozen section, and once the margins were confirmed to be negative, the allograft bone was thawed in warm antibiotic saline solution. Allografts that most closely matched the host bone size and anatomy were selected from the bone bank. The defect was measured in all planes. Based on these measurements, the allograft bone was shaped to match the defect using an oscillating saw and secured in place using plates and screws (Figure 7).

Antibiotics were administered postoperatively for a minimum of 24 hours, or until the deep drains were removed. Patients were restricted from weight bearing for 3 to 6 months after reconstruction based on radiographic evidence of allograft healing. Follow-up occurred 2 and 6 weeks and 3 months postoperatively, then every 3 months until 2 years postoperatively,
and then every 6 months. All patients were followed for a minimum of 2 years. Plain radiographs and physical examination were performed at each follow-up. Chest CT was performed every 3 months until 2 years postoperatively and then every 6 months to evaluate for metastatic disease. Outcomes, including allograft healing, nonunion, tumor recurrence, fracture, hardware failure, infection, and pain, were recorded. Functional outcome was evaluated at final follow-up using the revised system established by the Musculoskeletal Tumor Society (MSTS) and adopted by the International Society of Limb Salvage (ISOLS). This score measures outcomes in 6 categories, including pain, function, use of walking aids, emotional acceptance, walking ability, and gait. Each parameter is scored 0 to 5 and combined for a possible total score of 30.

RESULTS

At final follow-up, no patient experienced a local recurrence or metastasis.

The resection margins were tumor free in all patients. No hardware failure occurred, and all allografts healed before 1-year follow-up.

The preoperative and the specimen 3-D models with virtual planes were transformed to a point cloud in a 3-D coordinate system. With this virtual model, different measures were performed to analyze the accuracy of the bone resection. Distances between planes were measured by applying a quantitative evaluation represented in a box plot. Three-dimensional colorimetric illustrations and histograms were used to analyze a qualitative evaluation (Figure 8). Four osteotomies each were performed in 3 patients, and 3 osteotomies each were performed in 2 patients, so a total of 18 planes were evaluated. Mean difference in distance between preoperative vs final planes was 2.43 ± 1.80 mm.

Average MSTS/ISOLS score at final follow-up was 29 points (range, 29-30 points). All patients were pain free or had only occasional pain that responded to anti-inflammatory medication. All patients resumed activities of daily living without restriction.

DISCUSSION

The primary objective in oncologic surgery is local tumor control. No adjuvant therapies exist for patients with chon-

Figure 5: Surface mapping of anatomic landmarks of bone. The navigation software calculated the registration errors, which indicated any mismatch between preoperative images and the patient’s anatomy.

Figure 6: Intraoperative photograph of the surgeon navigating the posterior osteotomy after registration. The resection level and the exact position of the osteotomies were controlled using operative instruments. This allowed real-time tracking of the spatial location of the tip of the instruments in relation to the patient’s anatomy on the virtual preoperative images.

Figure 7: Postoperative anteroposterior radiograph after healing of the intercalary hemicylindrical allograft. The allograft was stabilized with plate and screws.
drosarcomas, so the situation is more critical.\textsuperscript{3-5} Although in recent years curettage for low-grade chondrosarcomas has been reported, some studies report that recurrence after curettage could affect the final prognosis.\textsuperscript{1,7,8,18} The ability to perform the surgical procedure, surgical difficulty, durability of reconstructions, incidence of complications and morbidity, and survival prognosis for the patient are important to the surgeon when deciding the surgical resection.

The current study described multiplanar osteotomies for bone tumor resection guided by navigation based in 3-D preoperative planning, with functional results that are comparable with those obtained with curettage. Preservation of unaffected bone and soft tissue structures should reduce major complications, especially near articular surfaces, without affecting tumor margins.

In the 5 reported cases, the authors were able to maintain the articular surface and major ligament structures; this could explain the excellent functional scores in these patients.

Three-dimensional preoperative planning and navigation have been used in bone tumor resections in the past few years.\textsuperscript{11-16} These studies evaluated the accuracy of the method with histological studies of surgical margins, but none described the degree of error, in millimeters, that could exist with computer-assisted surgery.\textsuperscript{11-16} The accuracy of preoperative planning and navigation is unclear. In the 5 current patients, the authors were able to evaluate the accuracy of preoperative planning and the navigation system in tumor resection. The comparison between each osteotomy in 3-D preoperative planning and the plane created in the CT-scanned surgical specimen found the distances to be similar.

Accuracy in orthopedic surgery allows more predictable clinical results.\textsuperscript{19} Precision in cancer surgery is fundamental to removing a tumor with adequate margins. The navigation-assisted technique reported in this study allowed the authors to reproduce the preoperative planning more accurately. This was an important advantage because bone resection cuts are performed precisely.

**Conclusion**

This study’s results show that navigation with adequate preoperative planning allows surgeons to intraoperatively reproduce the planned resection with accuracy in complex multiplanar resections.

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