



# Patient-Specific Three-Dimensional Model for a Safe Surgical Pathway in Sacral Chondrosarcoma

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## Abstract

Sacral tumors are amongst the most challenging procedures to treat because of the complex anatomy. This study determined whether patient-specific models change preoperative planning decisions made in preparation for en bloc resection of complex sacral mass surgical procedures. Imaging showed a big encapsulated mass at the S2–3 level involving the neural foramina and obscuring the nerve roots. High-resolution images were acquired and utilized to generate a patient-specific 3D tumor model. The visual and tactile inspection of 3D models allowed the best anatomical understanding, with faster and clearer comprehension of the surgical anatomy. The 3D sacral model was for observation of previously unapparent anatomical details; with this new technology, surgeon can observe their planned surgical intervention, explore the patient-specific anatomy and extension of the tumor, and sharpen their procedure choices. Moreover, multiple planes showed how far the angles on the plane would extend for osteotomy of the sacrum. Another result was identifying correct guides and safe venture landmarks. The study helped to establish safe osteotomy line wherever the nerve roots were retained and enabled osteotomy by preserving bilaterally the S1 and S2 nerve roots for wide excision of wide excision of primary sacral tumor to get adequate bowel and bladder functions. Finally, it helped to determine whether or not the remaining bone in the sacrum is sufficient for spinopelvic stability and needed fixation. It was decided spinopelvic fixation was not necessary for this case. Surgical intervention of sacral tumors varies depending on the tumor, its size, extension, and location. Surgery can have profound risks including unnecessary nerve root resection spinopelvic instability and suboptimal oncological resection. 3D models help to transfer complex anatomical information to clinicians and provide guidance in the preoperative planning stage, for intraoperative navigation and for surgical training purposes.

**Keywords** Sacral nerves · 3D printing model · Surgical planning · Sacral osteotomy · Chondrosarcoma

## Introduction

Although chondrosarcoma is a rare disease, it affects life quality of the patient [1, 2]. Patients with sacral chondrosarcoma typically complain of low-back pain, radicular pain, weakness, bowel or bladder dysfunction, and paresthesia. Imaging features of

various spinal tumors are often present similar characteristics [3]. Once the diagnosis has been determined, surgical therapy may be undertaken, but surgical treatment for sacral tumors can be quite challenging, with complications of neural compression, spinopelvic instability, and suboptimal oncological resection [4, 5]. For wide resection of primary malignant sacral tumors, partial or total sacrectomy is a highly demanding surgical procedure, consisting of a partial or total resection of the sacrum [6–8].

Partial sacrectomy is associated with compromising important motor, bladder, bowel, sensitivity, and sexual dysfunction [9–12]. Unfortunately, it is correlated with loss of important functions mentioned above depending on the resection level and nerve roots sacrificed. Due to the complex anatomy, the presence of proximal neurovascular bundles, and high risk of infection, it is only performed in selected cases where sacrectomy can influence patients' prognosis [13, 14]. Removing more than 50% of the S1–2 vertebra/sacral ala

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can result in lumbopelvic instability [15, 16]. Reconstruction of the spine-pelvic connection and spinopelvic fixation are needed [17].

Consequently, resections of sacral cavity-localized tumors are required of patient-specific complex anatomical and pathological features. Diagnostic imaging plays a major role in the diagnosis and characterization of sacral lesions, with imaging appearance and radiological reporting outcomes being utilized to direct patient-specific treatment planning [18, 19]. However, confidence in the comprehension of anatomical, pathological, and structural complexities which surgeons require to conduct osteotomies with tumor resections may not always be supported by 2D imaging alone [18, 19].

Currently, 3D printed models are being used as clinical tools in enhancing the viewer's cognitive comprehension of anatomy and pathology in areas such as medical education, surgical training, surgical planning, and operative simulation [20–25]. The newest developments in intraoperative stereotactic navigation have added to the accuracy and preciseness for addressing tumor surgery [26–30].

We hypothesize that 3D models with guidance have also been described in surgical planning for wide resection of sacral spinal tumors. They have been used to aid in localization of mass in the sacrum and pelvis, visualize operative margins (sacral neurovascular and pelvic structures), and plan osteotomies in order to optimize surgical intervention. The operative approach to sacral chordomas is tailored to lesion size and relationship to the sacrum, sacroiliac joints, and sacral nerve roots. Combined anterior-posterior approaches may be required in some circumstances. A fundamental aspect of surgical planning in osteotomies is the identification of sacral roots to preserve healthy bone tissue while en block resecting the tumor and, by the way, preserve the nerves of sacrum as much as possible to get normal or sufficient bowel and bladder function after the surgery. This creates significant cognitive load, especially for trainees, as it relies on image interpretation, anatomical and surgical knowledge, experience, and spatial sense.

The purpose of this study was to determine if creation of preoperative 3D patient-specific life-size models will assist resident-level trainees in making appropriate operative plans for osteotomies with sacral chondrosarcoma en block resection surgery. Correct interpretation of a patient's anatomy and changes occurring secondary to a disease process are crucial in the preoperative process to ensure optimal surgical treatment.

## Materials and Methods

The study included patient of middle aged with sacral tumors who underwent surgery at our university hospital. The patient had expanding masses in different dimensions in the presacral

region. Typical case was a 37-year-old female with abdominal pain (7 years) and incontinence (4 years). She commonly complained of hip pain and abdominal pain seeking medical help for incontinence. Selected case that would require significantly different preoperative plans based on key features identifiable in the preoperative CT imaging. In the MR imaging, a mass of  $7 \times 4.5$  cm and  $2.5 \times 2$  cm dimension was detected in the presacral region of the patient who applied to Ege University, Faculty of Medicine (Figs. 1a, b).

On examination, there was tenderness around the right posterior superior iliac spine, iliac crest, and sacroiliac joint. Her gait and station were within normal limits and she had 5/5 strength in iliopsoas, quadriceps, anterior tibial, extensor hallucis longus, and gastrocnemius muscles. With biopsy, chondrosarcoma was diagnosed, and the patient subsequently underwent a planned partial osteotomy and wide resection of the tumor under image guidance, with the surgery performed by a team of orthopedic spine surgeon (AMO) and orthopedic oncologist (DS). Ethics approval for this study was obtained from our university's Human Research Ethics Committee. Due to the retrospective collection of identified CT image data, ethics approval from the clinical center and patient consent was waived.

A questionnaire was applied to 10 orthopedic residents to evaluate the 3D model's perception. An Objective Structured Assessment of Technical Skills (OSATS) scale was used in the questionnaire to provide information about the competence and sensitivity of the anatomical model as a specialty training tool.

Pearson correlation coefficients and kappa statistics were used to assess the rating for OSATS questions. SPSS (18.0) program was used for statistical analysis, and the threshold value for statistical significance was calculated as 0.05.

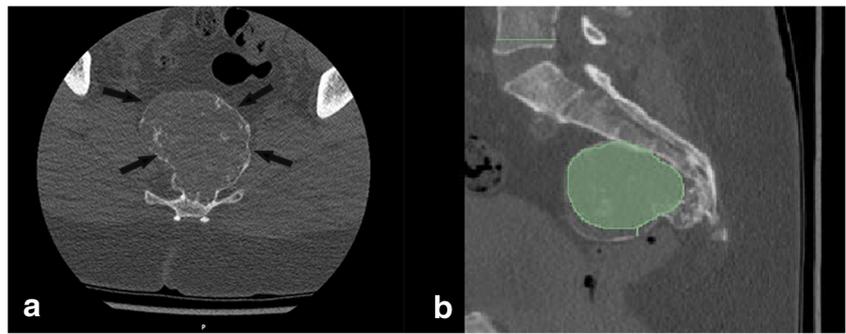
## Results

3D model was created with four steps CT data acquisition, image segmentation, image data editing, and 3D printing.

### Patient-Specific 3D Modeling

Data for 3D personalized models can be obtained from CT, MRI, and ultrasound using the Data Imaging and Communications in Medicine (DICOM) software. The data images are processed using segmentation and mesh generation tools and converted to a standard tessellation language (STL) file for printing. 3D printing technologies include stereolithography, selective laser sintering, inkjet, and fused-deposition modeling. The differences between the values obtained by the three modalities were submitted to standard statistical analysis (Wilcoxon two-tail paired test). CT images with the prediagnosis of chondrosarcoma were used for the

**Fig. 1** Preoperative CT images of patient with chondrosarcoma of the presacral region encapsulated mass (marked green). **a** Axial. **b** Sagittal view



projection of sacrum and the tumor area by using 3D slicer software. Image postprocessing time was approximately 7 h per sacrum with chondrosarcoma model.

### Printing of Image Postprocessing

Proposed tumor model and the sacrum in relation to the topographic neighbors were printed with Mass Portal (Figs. 2a, b). Each model took approximately 10 h to print. There was a high degree of correlation between CAD model dimensions and measurements made on the 3D tumor model. Tumor diameter measurements made on the 2D image sets were in good agreement with the measurements made on the corresponding 3D printed models.

The measurements were verified with patient specific models of CT measurements (Figs. 2a, b). The results of this study were not able to confirm whether the size of the printed model had an impact upon the viewer's ability to identify or

distinguish the details of tumor anatomy and their relationships. With the help of life-size individual 3D model, the borders of the osteotomy, the number of vertebra to conduct laminectomy, and sacral nerve roots to be cleared with were observed S3–5 laminectomies (Figs. 2a, b). Total tumor resections were planned to perform under 3D patient-specific model guidance without complications.

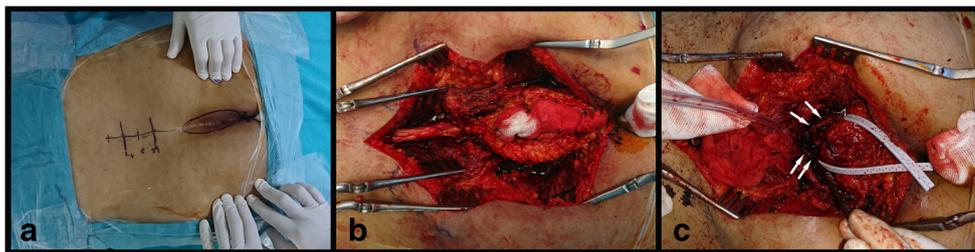
### Patient Positioning

After general anesthesia case was placed prone or side lying on a spinal operating table. Dorsal lumbosacral spine was sterilely prepared, and care was taken to drape the entire sacral spine as widely as possible. For skin surface anatomical landmarks were selected (posterior superior iliac spine, iliac crest, and midline spinous processes) and provided orientation during entire procedure (Fig. 3a).

**Fig. 2** **a, b** Preoperative planning of osteotomy orientation point and demarcation line using patient-specific model



**Fig. 3** **a, b** Application of partial osteotomy and tumor resection to orientation points. **c** Navigated instruments allow confirmation of adequate laminectomy prior to real osteotomy. White arrow: saved of S2 roots



## Incision

Midline skin incisions were planned. A straight vertical incision was made (starting from L4 vertebra spinous process to down to the coccyx 2 cm cranially to the anus with excision ex biopsy tracks, about 10–12 cm length). The sacrum and the extent of the tumor were checked using the scope. With electrocautery, dissection through fascia and muscles was performed down to the bones. During dissection around the tumor, 2–3 cm of gluteal muscles was preserved to provide an adequate tumor-free margin. At the upper end of the incision, dissection was done to identify the spinous processes and lamina of L3 to L5. Both posterior superior iliac spines and posterior inferior iliac spines were identified, and dissection was performed to expose the posterior part of both iliac crests, both iliac wings and ala of the sacrum. Once the bony sacrum was exposed, depending on the type of resection (intraregional, wide resection, and partial osteotomies) the margins of the desired resection were marked for tumor removal (Figs. 3a–c).

## Navigated Reference Frame for Sacral Surgery

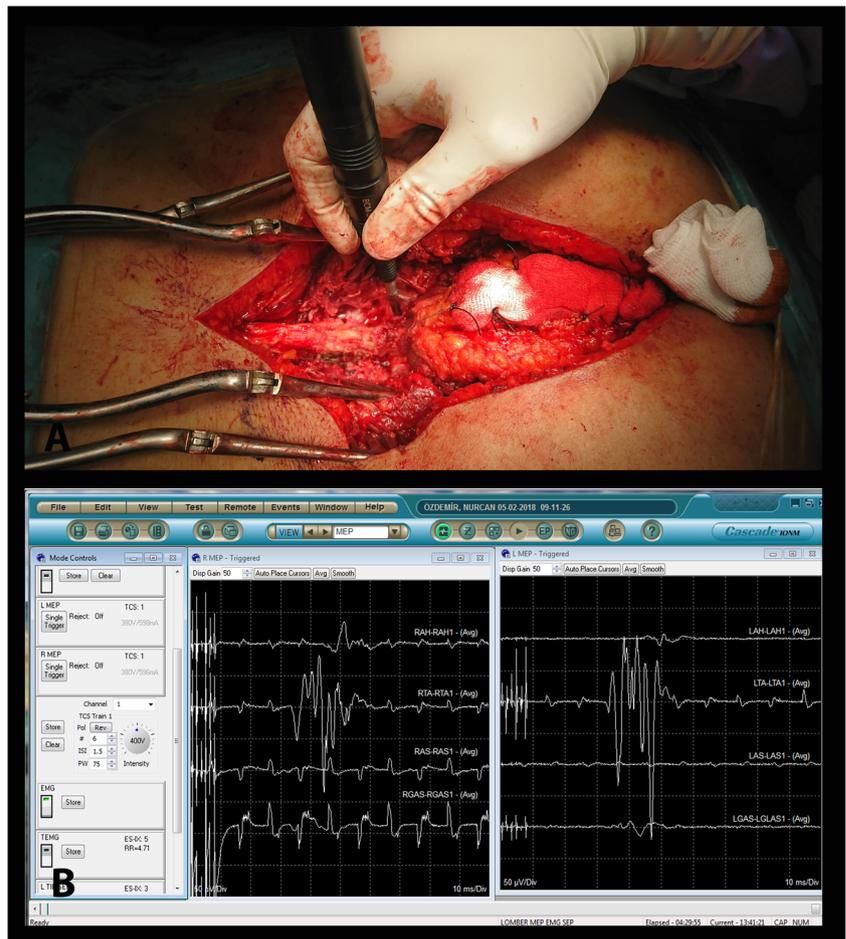
The ideal reference frame location always depends on the operative goals of the surgeon and the anatomy of the patient. For sacral surgery, the options for a personalized 3D model enable a successful navigation. Laminectomy was performed starting at S1–2, depending on the upper limit of the tumor. S1 and S2 nerve roots were identified and dissected down to the tumor mass. S2 root exposed bilaterally during the surgery (Fig. 3c). We tried to preserve as many nerve roots as possible. The nerve roots (distal to S2 roots bilaterally) that passed into the tumor mass have to be cut. Then, the margin of resection was re-evaluated carefully by the use of 3D print. The thecal sac had been cut inferiorly to the S2 vertebrae with laminectomy of the sacrum posteriorly (Fig. 4a). Therefore, the thecal sac was ligated at the S2–S3 level; with an osteotomy, the normal vertebral body or the disc above the tumor (S3 superior border) was cut in the postero-anterior direction. All the gluteal muscles above the sacral plexus were cut with electrocautery. Then, exploration of sacral plexus on both sides was carried out. The sacrospinal and sacrotuberal ligaments on both sides were directly identified and cut. At this stage, the cut sacrum with the tumor was easily mobilized

to facilitate blunt and sharp dissection between the tumor mass and the visceral organs. After the sacrum and the tumor were removed, all bleeding points were stopped. The tumor mass was examined for the free margin, and all findings were recorded. The level of the ligation of thecal sac and also the S2 nerve roots were checked by neuromonitoring (Fig. 4b). During the surgery the border of sacrum osteotomy and tumor was checked regularly with 3D print and also with scope to prevent more cranial osteotomy than S3 superior border and minimize the nerve damage (S2 and S1) (Figs. 4a, b). Tumor mass was removed safely without damaging the S1 and S2 nerves (Figs. 3c and 4a, b). S2 roots were saved with partial osteotomy distal to S3 superior border (Figs. 3c and 4a, b). Sacrum level on the sacroiliac joint was preserved as the mass did not involve the sacroiliac joint. This led the surgeon remain 50% of the sacrum (S1 and S2) and still had enough stability of the axial skeleton so that spinopelvic fixation instrumentation was not applied. As implantation carries a high risk of infection, postoperative complications were prevented this way. The skin and the rest of the soft tissue were repaired. Bulky pressure dressing was done to close the dead space and to minimize blood loss.

## Postoperative Period

On the third day after the operation, the surgical wound was examined and pressure dressing was re-applied. Any wound complications were identified and recorded. Neurological signs were re-evaluated. Plain radiograph after the operation was carried out to determine the osteotomy site. All stitches were removed at the end of the second week after the operation. Physical examination including neurological examination of the lower limbs and perianal area, per rectal examination and plain radiograph of chest, sacrum, and lower lumbar spine were carried out at each follow-up. During the first years after the operation, the patient was followed-up every 3 months. At last control (postoperative 9 months), there was no problem at surgical site and bladder and bowel control normal. The pathology report on the specimen describes a bone marrow lesion within the left S3–4 segment of the sacrum involving the neural foramina and obscuring the nerve roots, consistent with a chondrosarcoma. No operative complications were reported in cases. Postoperative images were obtained and can be seen in Fig. 5. The patients were not

**Fig. 4 a, b** Postoperative control of the area of laminectomy to minimize a possible damage of nerves (S1–S2) on sacral osteotomy



attributed to probable pelvic instability. The patient was not a candidate for pelvic reconstruction given.

**Surgical Outcomes**

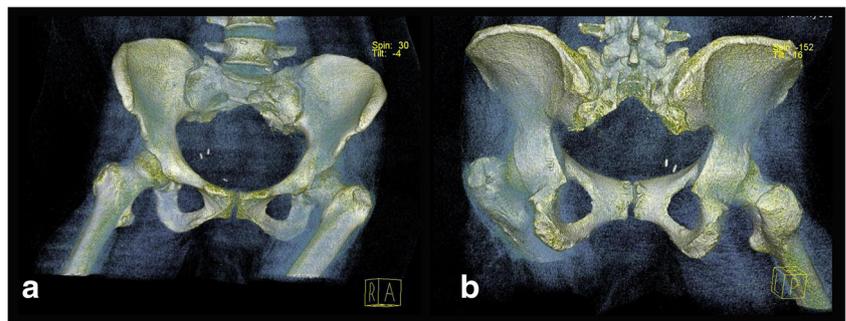
Surgical team head (DS) evaluated surgical assets of personalized 3D models, postoperatively:

Surgical team has planned the course of the surgery collaboratively together with spine surgeons and orthopedic oncologists. They considered 3D models to be useful in assisting interprofessional collaboration. One participant commented

on the model’s ability to allow for a better appreciation of the tumor’s anatomical orientation in space within the pelvis. Both surgeons believed that the 3D personalized model allowed for a better perception of information related to structural depth and spatial relationships when compared to the corresponding 3D reconstructed image provided.

It is useful for crowded surgical branch physicians to decide together; to act together, in which sequence of operations; to start; to continue; and to terminate the interference algorithm. In addition, each branch was useful in terms of evaluating the complications and solutions that might occur in

**Fig. 5 a, b** Postoperative CT imaging of the case



planning their own surgeries. It was also helpful to know how to resolve the closure of remaining defects after the mass removal of the team.

The records of case were reviewed with regard to symptoms, location and diameter of the tumor, tumor grade, extent of invasion, evidence of distant metastases, surgery, methods of reconstruction, time and site of recurrence, mortality, and subsequent follow-up. All details concerning the extent of surgical resection was carefully documented.

### Intraoperative Benefits

Both surgeons believed that 3D life-size model would be useful in the process of identifying a safe surgical pathway, in addition to intraoperative navigation and orientation. It was also suggested that the life-size model might be a useful supplementary tool for surgical team when learning how to interpret multi-planar medical images. It is also enabled to designate safe osteotomy corridor while preserving the nerve root and determining right sacral vertebra level. 3D life-like models also revealed the course of the coroner and sagittal plane angles that can extend within bone osteotomy border. This provided right and safe guidance and anatomical landmarks for the intervention.

3D life-size models also assisted in the decision making of the fixation of the remainder bone in the sacrum, following partial osteotomy. It was concluded that the case did not require fixation or implantation.

Neither surgeon was able to confirm that the 3D models could reduce operating times, by replacing the need for intraoperative visualization aids although they both believed in the potential for the models to reduce the chance of intraoperative complications in complex sacral tumors.

### Discussion

Sacral resection is a procedure with the potential to influence quality of life drastically [1, 3, 6, 11, 16, 19]. In sarcoma surgery, removal of tumor mass without extensive excision is essential. It is difficult to predict the association between specific nerve roots and residual function due to several factors. These factors include presurgical neurological status (disease may have damaged the roots prior to the surgery), the presence of variable anastomoses above the roots, onset of postoperative complications, collateral damage (for example, cutting the pelvic floor muscles could sever pudendal nerves with consequent loss of function, even if the roots are spared), personal motivation during rehabilitation, and time to follow-up [2, 4, 6, 13, 18, 31].

Prior to the surgery, the surgeon needs to know the change in the anatomical structure caused by the tumor. Use of visualization techniques such as transparency and overlays allows

viewers not only to see the operative field, but also the origin and course of nerve roots and their spatial relationships [18–20]. Although point-to-point measurements were not different, 3D personalized models increased the understanding of shape, scale, and anatomy [20–25]. It enabled understanding significantly faster than other media. In difficult surgical cases with complex anatomy and a need for efficient multidisciplinary coordination, 3D life-size models should be considered for surgical planning [26–30].

Involvement of the reporting surgeons in 3D personalized model production should also be considered to ensure accuracy of segmentation and identification of appropriate critical structures required for surgical planning. This may facilitate the acquisition of a patient-specific 3D model that is pathologically, anatomically, and structurally correct.

Chondrosarcoma are slow-growing tumors, and their clinical course is typically long. Bone destruction with characteristics of punctate calcifications and chondral matrix mineralization are the predominant findings [1, 5]. Clinical course of the disease is long similar to the ones reported in this case study. In patients with chondrosarcoma, CT and MRI often reveal a destructive lesion of bone with an associated soft-tissue mass with high water content in non-mineralized areas [18]. This study has similar radiological findings (Figs. 1, 2, 3, 4, and 5).

Based on the survey outcomes and participant feedback, it is evident that the real clinical value of the 3D sacral models lies in applications beyond diagnostic reporting where individuals are likely to gain a more in-depth and holistic understanding of anatomy and pathology through 3D representations of 2D images. Physical 3D modeling has been identified to support efficient and effective perception of positional and structural information through the direct visualization of anatomy and pathology (Figs. 2, 3, and 4). The mainstay of our research findings is the nuances in treating these sacral tumors with CT image-guided navigation to achieve optimal oncological resection, to reduce neurological complications, and to minimize recurrence. Malignant tumors are nearly always eccentric, and in order to achieve clear margins, excising the involved sacral nerves with the tumor partial osteotomy is most often blocked [31].

In this study, we created an anatomically accurate, patient-specific 3D model with sacral chondrosarcoma from MRI data and evaluated their impact in presurgical planning. A strong correlation was noted between the actual measurement on the CAD model and the measurements on 3D models. The 3D models allow easy visualization of the location and size of the tumor as well as the relationship of the tumor to key anatomical structures such as the sacral nerves roots. Furthermore, they allow surgeons to touch the sacral tumor and sacral roots, thereby enhancing their understanding of the anatomy and facilitating surgical planning (Fig. 3). Our results indicate that even experienced orthopedics may potentially benefit from

these models for planning of complex surgeries. Specifically, preoperative 3D sacral mass models could potentially promote laminectomy-osteotomy sparing surgery and preservation of healthy tissue, as surgeons gain a better understanding of the size and location of a tumor in relation to normal osseous tissue and sacral roots (Fig. 3). In our case, laminectomy and partial osteotomy were performed at S3–S5 (Figs. 3, 4, and 5). Without the use of 3D modeling, S2 nerve roots would not have been protected and the patient would have suffered from poor sphincter control in intestine and bladder. With the help of 3D modeling, preserving the nerve roots at S2 level in this intervention avoided restraints and provided a lifetime comfort to the patient in work and social life.

Since the concordance with what was actually performed improved with the 3D model, it is possible that 3D models may facilitate better anticipation of patient-specific anatomy and better planning for a complex surgery, potentially allowing for less changes to be made in the operating room, therefore reducing duration of induced complications related to complex tumor anatomy.

3D personalized life-size models with chondrosarcoma help clinicians understand disease processes and the patient's anatomy better (Figs. 2a, b). Models with life-like tactile and visual characteristics offer multisensory inputs that can enrich and aid in spatial cognition and learning. This is especially true in the context of a complex tumor involved with highly variable anatomy. It is an innovative navigational tool allowing a convenient surgery to the surgeon while preserving the life quality of the patient.

This study presents our first clinical experience within a series of patients whom we have applied 3D models and computer navigation-assisted surgery for musculoskeletal tumors. The tool provided tremendous advantages in selected cases of complex anatomy or special reconstruction. It improved planning of a resection and enabled an intraoperative visualization of the tumor and its surrounding anatomy. It also guided orientation of instruments including reconstruction devices and implants.

## Conclusion

3D imaging and modeling with navigation-assisted surgery represent a safe and helpful tool for resection of chondrosarcoma of the sacrum and may influence surgical treatment plans in selected cases to enable more limited resections. The application of medical imaging and 3D printers has been successful in providing solutions to many complex medical problems during the surgery. As technology advances, its applications continue to grow in the future. Further biomechanical tests are proposed for the evaluation of sacrum osteotomy level in future studies.

## Compliance with Ethical Standards

**Conflict of Interest** The authors declare that they have no conflict of interest.

**Ethical Approval** All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

**Informed Consent** Informed consent was obtained from all individual participants included in the study.

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