#1630. 3D-Printed Anatomical Modeling for Surgical Planning, Real-time Operative Guidance, and Patient Education in Complex Primary Spine Tumors

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Disclosures

• The authors have no relevant financial disclosures
Background & Goals

- As 3D printing becomes more mainstream in clinical medicine, it is incumbent upon physicians to define its practical utility in various fields of specialized practice.

- In 2018, the Radiological Society of North America (RSNA) Special Interest Group on 3D Printing published guidelines on the clinical scenarios in which 3D printing may serve the greatest clinical utility, and suggested that complex bone and connective tissue neoplasms are appropriate use cases [1].

- In this study, we piloted 3D-printed, patient-specific anatomical modeling for both patient education and live operative guidance in consecutive complex primary spine tumor cases at a single institution.

Methods

- 9 patients referred to a single neurosurgical provider for large and/or complex primary spinal or sacral tumors were included over an 8-month period.

<table>
<thead>
<tr>
<th>Case #</th>
<th>Age &amp; Gender</th>
<th>Tumor</th>
<th>Spinal Levels</th>
<th>Tumor Volume (cm³)</th>
<th>Used in the OR?</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>70 M</td>
<td>Thoracic Chordoma</td>
<td>T10–T12</td>
<td>248.7</td>
<td>No*</td>
</tr>
<tr>
<td>2</td>
<td>68 M</td>
<td>Cervicothoracic Chordoma</td>
<td>C6–T5</td>
<td>250.0</td>
<td>Yes</td>
</tr>
<tr>
<td>3</td>
<td>82 M</td>
<td>Sacral Chordoma</td>
<td>S2–Coccyx</td>
<td>153.3</td>
<td>Yes</td>
</tr>
<tr>
<td>4</td>
<td>25 F</td>
<td>Sacral Osteosarcoma</td>
<td>S1–S3</td>
<td>98.9</td>
<td>Yes</td>
</tr>
<tr>
<td>5</td>
<td>48 F</td>
<td>Cervical Chordoma</td>
<td>C6–C7</td>
<td>3.3</td>
<td>No†</td>
</tr>
<tr>
<td>6</td>
<td>57 M</td>
<td>Atlantoaxial Schwannoma</td>
<td>C1–C2</td>
<td>13.8</td>
<td>Yes</td>
</tr>
<tr>
<td>7</td>
<td>63 M</td>
<td>Cervical Chondrosarcoma</td>
<td>C7</td>
<td>5.1</td>
<td>Yes</td>
</tr>
<tr>
<td>8</td>
<td>15 M</td>
<td>Sacral Ewing’s-like Sarcoma</td>
<td>S1–S3</td>
<td>204.5</td>
<td>Yes</td>
</tr>
<tr>
<td>9</td>
<td>28 F</td>
<td>Presacral Schwannoma</td>
<td>S1–S5</td>
<td>188.8</td>
<td>Yes</td>
</tr>
</tbody>
</table>

- All cases were printed pre-operatively, shown to the patient prior to surgery to explain the surgical plan, and also used intra-operatively as a live anatomic reference except in cases 1 (*), in which models were prepared post-operatively, and 5 (†), which was cancelled after the model was already printed.

- Patients were surveyed pre-operatively to assess understanding after seeing the model across various domains (i.e. location of lesion, surgical plan, rationale for surgery).
Methods

**Figure 1.** The process for virtually generating and 3D-printing a patient-specific spine tumor model from patient MR and CT imaging to final product, as illustrated by the case of a large left-sided pre-sacral schwannoma extending into the ipsilateral sciatic notch (case #9).

- (A) Single slice of a T2-weighted sequence acquired as part of an MR pelvis work-up with schwannoma (green) manually labelled on a single slice using 3D Slicer
- (B) Single slice of a CT pelvis with bone (yellow) and bowel (red) labels automatically segmented using Housfield Unit intensity thresholding
- (C) From MRI scan: 3D rendering of tumor mass (green), L5 and sacral nerve roots (off-white), and L4-L5 and L5-S1 intervertebral discs (blue) generated from manual two-dimensional boundary labels in 3D Slicer
- (D) From CT scan: 3D rendering of bony pelvic, sacral, and lower lumbar spinal anatomy (off-white), as well as bowel and rectum (red) generated from automatic two-dimensional boundary labels in 3D Slicer
- (E) MRI and CT 3D models combined using conserved anatomic reference (e.g. disc spaces, neural foramina) in Blender
- (F) Virtual print preview in Stratasys 3D-printing software
- (G & H) Final 3D-printed model of tumor and surrounding anatomy in anterior and posterior views
Results

**Figure 2.** 3D printed plastic models demonstrating patient-specific anatomy before (A–C) and following (C–E) en bloc resection of a large low thoracic right-sided chordoma (pink) with significant ventral and dorsal paraspinal extension and epidural spinal cord compression (case #1). Hardware placed intra-operatively is shown in blue in the post-operative model, and includes bilateral pedicle screws, bilateral double rods, and cross-connectors posteriorly as well as an expandable cage in the corpectomy defect anteriorly.
Figure 3. Plastic models generated for three primary tumors located at cervical levels which were all utilized intra-operatively to guide resection. Cases include (A–C, case #2) large right-sided cervicothoracic junction chordoma, (D & E, case #7) right-sided intralaminar chondrosarcoma with dorsal epidural extension and cord compression, (F & G, case #6) left-sided atlantoaxial schwannoma. Key anatomy is intentionally printed with intuitive structure-specific coloration on a multi-layer printer, in particular: vertebral, carotid, and subclavian arteries are pink, bone is white, spinal cord and nerve roots are yellow, esophagus is brown, trachea is light blue, intervertebral disks are dark blue, and tumor is green. A notable exception to this schema is the C6 & C7 vertebral bone in case #7, which was printed in clear plastic (arrows) so as to visualize the intra-osseous dorsally situated tumor through the laminar surface.
Figure 4. Plastic models generated for two malignant high sacral tumors with significant involvement of the unilateral sacroiliac joint (SIJ), including one osteosarcoma (A & B, case #4) and one Ewing’s-like sarcoma (D–F, case #8). In both cases, the model was designed pre-operatively to encompass L4–coccyx levels with nerve roots adjacent to the tumor visualized in yellow, as well as the entire unilateral SIJ and partial involved adjacent iliac bone. Tumor was printed in green, cauda equina and nerve roots in yellow, intervertebral discs in blue, and bone in white. Both procedures were three-stage surgeries involving an anterior retroperitoneal approach for midline sacral osteotomies (stage 1), posterior en bloc resection of the tumor with adjacent structures (stage 2), and SIJ reconstruction with cadaveric pelvis and femur struts (stage 3). In case #4, a second plastic model (C) was prepared to visualize the defect left after en bloc resection (stage 2) in preparation for SIJ reconstruction (stage 3). Like the other models in this series, the model was prepared to-scale, such that the precise dimensions of the defect could be carefully measured in order to cut appropriately sized struts from the cadaveric pelvis used for reconstruction. Temporary hardware placed in stage 3 is seen in blue in this model.
Figure 5. During five cases in which the 3D-printed model was used to guide an en bloc resection of a presumed malignant lesion, the successfully resected specimen was photographed side-by-side with the respective 3D printed tumor model for anatomic comparison. These cases comprise two chordomas (A & B), one Ewing’s-like sarcoma (C), one osteosarcoma (D), and one chondrosarcoma (E).
Conclusions

• After seeing the models, all patients reported that they “mostly” or “completely” understood all aspects of care which were assessed.

• Models were used as an anatomic reference in the operating room during seven of the nine cases, with highly positive feedback from the surgical teams in terms of technical utility and saved operative time.

• 3D printed models of pathologic anatomy are useful for operative guidance and patient education in spinal oncology, especially for complex osseous or connective tissue tumors requiring wide en bloc resection with negative margins and preservation of adjacent neurovascular structures.