


Use of a three-dimensional printed anatomical model for tumor management in a pediatric patient

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Abstract

The purpose of this study was to investigate the usage of an anatomical model to improve surgical planning of a complex schwannoma resection. As advancements in additive manufacturing continue to prosper, new applications of this valuable technology are being implemented in the medical field. One of the most recent applications has been in the development of patient-specific anatomical models for unique clinical education as well as for preoperative planning. In this case, a multidisciplinary team with expertise in research, three-dimensional printing, and medicine was formed to develop a three-dimensional printed model that could be used to help plan the reduction of a tumor from the cervical spine of a pediatric patient. Image segmentation and stereolithography creation were accomplished using Mimics and 3-matic, respectively. Models were developed on two different printer types to view different aspects of the region of interest. Reports from the operating surgeon indicated that the model was instrumental in the planning procedures of the operation and reducing operation time.

Keywords

Surgery, three-dimensional printing, surgical planning, anatomical model, tumor resection, plexiform schwannoma

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Introduction

Plexiform schwannoma is a rare form of tumor that typically grows in superficial soft tissues within the head and neck region. It accounts for 4.3% of all schwannomas with 23% of these cases being within the head and neck region. Furthermore, only 3% of these schwannomas effect a major network of nerves such as the brachial plexus.¹ The lack of documentation of this rare interaction as well as the possible complications involved with the tumor's entanglement in other local anatomy can make the treatment options difficult to plan. However, if gone untreated, the tumor can continue to grow to the point where it becomes debilitating or, rarely, life-threatening.² Surgical intervention has been incorporated in most treatment plans^{3,4} and has previously shown to be effective at restoring arm function when the tumor affects the brachial plexus.⁵

The rapid development of additive manufacturing has created a significant impact within the medical community. Specifically, three-dimensional (3D) printing has been used to develop low-cost prostheses,⁶ patient-specific surgical

tools,⁷ and accurate representations of patient-specific anatomy, otherwise known as anatomical models.⁸ As our understanding of various pathologies continues to increase, so do our options of providing effective treatment plans. The use of 3D printing allows for increased comprehension of pathological anatomy that can be useful for surgical planning. In addition, anatomical models can also be made to replicate tumor regions and their relationship to adjacent structures.⁹ In this case study, we report the use of 3D printing to develop

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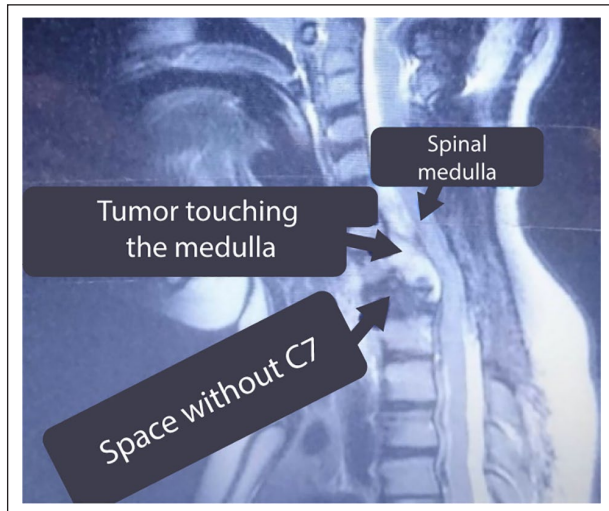


Figure 1. Sagittal CT slice of a 6-year-old patient showing the tumor compressing the medulla and cervical vertebrae damage.

accurate models of a pediatric patient's tumor within the spinal column to assist with the planning of a plexiform schwannoma resection. The researchers hypothesized that the use of a patient-specific anatomical model would improve the overall success of the surgery.

Case

Six-year-old patient

At the “Instituto De Neurocirugia” (Institute of Neurosurgery) located in Santiago, Chile, we assisted in providing treatment to a pediatric patient with plexiform schwannoma within the head and neck region. The tumor was growing rapidly and aggressively, causing the spine to compress from the fourth cervical vertebra to the first thoracic vertebra (Figure 1). The pressure caused by the tumor's growth against the spinal cord had resulted in the loss of mobility of the patient's right upper extremity as well as acute paraplegia. However, the tumor could not be removed entirely since it was interconnected with the right brachial plexus and complete removal would likely cause the patient to lose function in the affected upper limb. The patient had previously undergone seven operations to relieve pressure caused by the tumor's growth, to restore lower limb function caused by pressure to the spinal column, to implant titanium bars on the dorsal side of the vertebrae, and to repair damage done after the tumor engulfed the seventh cervical vertebral body.

Due to the tumor's large size, continual growth, and previous complications with the brachial plexus, the lead surgeon, a head and neck specialist from the Institute of Neurosurgery, requested an anatomical model of the cervical area to aid in planning the surgery. At the time, the patient's family and the Institute of Neurosurgery did not have the resources to access anatomical modeling services.

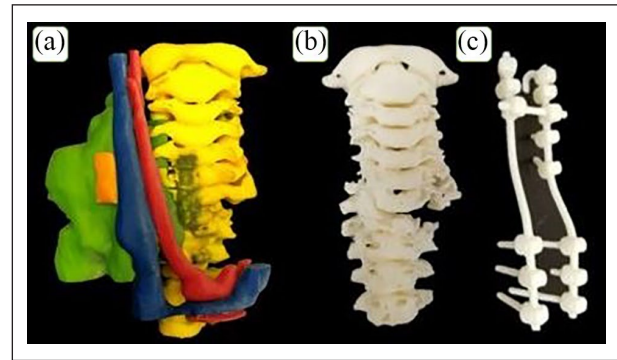


Figure 2. The 3D printed models of the patient's anatomy. (a) Multiple part version of the anatomical model. Components included are the spinal column (yellow), tumor mass (green), carotid artery (red), and jugular vein (blue). (b) Low-cost model excluding the tumor volume and local vasculature. (c) Replica of the previously implanted hardware.

After several meetings with the operating surgeons, a multi-disciplinary team from the Biomechanics Department at the University of Nebraska at Omaha, Children's Hospital and Medical Center of Omaha, and the University of Nebraska Medical Center (UNMC) was formed. Consent to develop the model and use for reporting was obtained by the patient's guardian. Our objective was to develop a low-cost 3D printed anatomical model for this pediatric patient to aid the surgeon in planning the tumor resection.

In order to develop the 3D representation of the region of interest, magnetic resonance imaging (MRI) and computed tomography (CT) imaging data were segmented into a stereolithography (STL) model using Mimics (Mimics, Materialise Interactive Medical Image Control System; Materialise, Leuven, Belgium). Once the regions of interest were segmented into individual structures, they were printed on two different printers: a multi-material printer (Connex3 Objet260; Stratasys, Inc., Eden Prairie, MN, USA) capable of producing complex models with multiple materials, and a low-cost desktop 3D printer (Ultimaker 2 Extended, Ultimaker B.V., Geldermalsen, The Netherlands). The multi-material model was used to represent the volume of the tumor, the spine, and local vasculature in different colors and cost roughly US\$300, while the low-cost model was used to recreate the cervical spine as well as the surgical hardware that was implanted previously and cost roughly US\$5 (Figure 2).

The surgical team used this model for pre-surgical planning with great success. The tumor bulk was successfully decreased, however could not be entirely removed at the time of the operation, to prevent permanent damage to the right brachial plexus. The surgeon attributed the success of the operation to the additional knowledge gained from observing the 3D printed model. Previous investigations that have used similar models have found reduced operating room times and fewer complications.¹⁰

Discussion

This case study presents the use of 3D printing to improve surgical planning of a complex plexiform schwannoma resection within the brachial plexus. The use of a 3D model allows for a more comprehensive understanding than viewing two-dimensional (2D) CT images and was necessary to comprehend the proximity of the tumor's growth to the brachial plexus. The surgeon reported a successful operation attributed to the additional information received after viewing the anatomical model.

Anatomical models have been previously used for tumor removal¹¹ and have been reported to change the course of some entire operations.⁹ In some cases, the use of an anatomical model may have prevented patient's death.¹² Although not necessary for all tumor resections, anatomical models can provide valuable insights while planning complex/anomalous surgical procedures. For this specific patient, the use of the 3D printed anatomical model was an essential part of the planning procedure due to the previous complications caused by the tumor's growth. While the surgeon's qualitative feedback was positive, one of the main limitations of this study was a lack of quantitative data to evaluate the model's utility. Similar models are likely to be useful in other complex procedures for a variety of different pathologies; however, exact quantification of this benefit requires further investigation. While more expensive model types can utilize multiple colors and materials, simple low-cost models still provided an improved level of understanding of the pathology compared to 2D images. The low-cost application is especially useful in developing countries with limited access to advanced medical equipment and advanced 3D printing techniques.

Conclusion

Our team was able to provide accurate 3D printed anatomical models for the vertebrae C1 to T4 where the tumor had expanded to aid in surgical planning (Figure 2). 3D printing of the anatomical region of interest allows for a more comprehensive understanding of complicated pathology interactions than using 2D CT images alone, as shown in this case. For this patient, two models of the spinal cord were produced. One model was produced using a high-end printer to represent various aspects, such as the tumor size and adjacent vasculature, in varying colors to make the delimitations clear. These multi-material prints are usually only accessible to developed countries due to their high fabrication costs. A second model with the tumor volume removed was produced using a low-cost printer to better visualize the C7 vertebral body damaged by the schwannoma and to measure the area of the hardware previously implanted. For this view of the spine by itself (a simple, single structure), low-cost printers are suitable. In this case, both models provided unique information about the tumor's impact on the adjacent anatomy to help the surgeon plan the procedure.

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Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Ethical approval

Ethical approval to report this case was obtained from the patient's legal guardian and The University of Nebraska Medical Center (IRB PROTOCOL # 258-18-EP).

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Informed consent

Written informed consent was obtained from the patient's legal guardians for their anonymized information to be published in this article.

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