3D Printing For Surgical Planning Of Canine Oral And Maxillofacial Surgeries

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Case Report

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Abstract

Background: Advanced diagnostic imaging is an essential part of preoperative planning in oral and maxillofacial surgery in veterinary patients. 3D printed model and surgical guide generated from diagnostic imaging can provide a deeper understanding of the complex maxillofacial anatomy and relevant spatial relationships. Additionally, patient-specific 3D printed models allow surgeons and trainees to better examine anatomical features through tactile and visual spatial feedback resulting in improved preoperative planning and enhanced trainee education.

Case presentation: Our case series consists of three 3D printed models segmented from computed tomography (CT) and cone beam CT (CBCT) and fabricated via desktop vat polymerization for preoperative planning and intraoperative guidance for resection of maxillary osteosarcoma, mandibular reconstruction after mandibulectomy, and gap arthroplasty for temporomandibular joint ankylosis in dogs.

Conclusions: We illustrate potential benefits and indications for 3D printing in veterinary oral and maxillofacial surgery. A 3D printed model facilitates the understanding of complex surgical anatomy and creates an opportunity to assess the spatial relationship of complex anatomical structures. The patient-specific 3D model facilitates individualized surgical planning allowing surgeons to tailor and augment the surgical plan by identifying challenging anatomy and simulating surgical steps in advance. This includes the planning of osteotomy lines and pre-contouring of titanium plates for reconstruction. The 3D printed model and surgical guide also serve as intraoperative reference and guidance. In addition to preoperative planning and intraoperative guidance, 3D printed models have the potential to improve veterinary resident and student training as well as pet owners' understanding and communication regarding the condition of their pets, treatment plan and intended outcomes.

Background

The field of veterinary oral and maxillofacial surgery is evolving thanks to innovation in surgical treatment options, increased willingness of pet owners to pursue advanced surgical care for their pets, and providers striving to match the standard of care established in human medicine [1]. Like its human counterpart, veterinary maxillofacial surgery involves complex and delicate craniofacial anatomy. Advanced diagnostic imaging, specifically computed tomography (CT) and cone beam computed tomography (CBCT), play an essential role in preoperative planning to evaluate the extent of disease in malignancy or injuries in trauma [2]. However, conventional CT and CBCT remain limited in portraying spatial relationships for complex anatomic details; even with 3-dimensional (3D) CT scan reconstruction these imaging modalities lack freedom of tactile manipulation. These shortcomings can be overcome by translating the imaging into a 3D printed model. With advances and increased accessibility of the 3D printing technology, there has been increased adoption of medical 3D printing including in veterinary medicine [3, 4]. Desktop vat polymerization is one of the leading technologies that has made 3D printing more accessible and affordable. The modality uses smaller printers and thus minimizes the space requirement while maintaining the high resolution needed for accurate fabrication of the complex and delicate maxillofacial anatomy. The 3D printed patient specific models allow surgeons, trainees, and pet owners to develop a better understanding of the anatomical features; this enhanced understanding further translates to improved preoperative planning and intraoperative guidance [5]. The application and benefits of 3D printing in oral maxillofacial surgery in humans have already been demonstrated [6] with increasing adoption in veterinary medicine [4, 7].

The present case series consist of canine skull models segmented from CT and CBCT. The files were downloaded as Digital Imaging and Communications (DICOM) files and imported into DICOM to PRINT® (D2P) (3D Systems, Inc. Rock Hill, SC) for segmentation to construct the 3D models. The files were then exported as Standard Tessellation Language (STL) files, imported into printer’s proprietary software PreForm v3.21.0 (Formlabs Inc. Somerville, MA), and 3D printed using Formlabs Form 3B desktop 3D printer (Formlabs Inc. Somerville, MA). The 3D printed models were used for preoperative planning and intraoperative guidance for resection of maxillary osteosarcoma, mandibular reconstruction after mandibulectomy, and gap arthroplasty for temporomandibular joint ankylosis in dogs.

Case Presentation

Case 1

Patient C.G. is a 9-year-old male English bulldog who presented with decreased oral intake and oral bleeding secondary to biopsy confirmed maxillary chondroblastic osteosarcoma. A preoperative contrast-enhanced CT (Toshiba Acquilion 64 CFX, Toshiba Medical Systems, Tustin, CA) was obtained with 1.0 mm slice thickness revealing localized osteolysis and early right nasal invasion without evidence of thoracic metastatic disease (Figure 1A). A 1:1 skull model with tumor was printed in white resin and tumor painted in red (Figure 1B). The 3D printed model was utilized for preoperative planning and sterilized to serve as intraoperative reference for a bilateral rostral maxillectomy. Visualization and tactile assessment of tumor extent in the 3D printed model led to the conclusion that curative intent surgery with 2 cm margins would carry a high risk of potential morbidity. Thus, it was elected to excise the tumor with conservative margins (0.5-1 cm) and treat with postoperative radiation therapy. Adjuvant radiation was performed (20 x 2.8 Gy) to a total dose of 56 Gy using 6 MV photons and an intensity-modulated radiation therapy (IMRT) plan with image-guided radiation therapy (IGRT). C.G. developed an oronasal fistula secondary to postoperative dehiscence and underwent subsequent repair following the completion of radiation therapy. At the time of this writing, the patient is doing well in remission and is approximately 8 months post-op.

Case 2

Patient P.P. is an 8-year-old male Boston terrier who presented with an oral plasma cell tumor of his rostral mandible. Despite the presence of extensive osteolysis, the dog was asymptomatic at presentation. Preoperative CBCT was obtained with 0.9 mm slice thickness (Xoran Vet Cat, Xoran Technologies, Ann

Arbor, MI) (Figure 2A). Subsequent chest radiograph demonstrated normal thorax without evidence of pulmonary metastasis. A 1:1 skull model was printed in white resin (Figure 2B). The 3D printed skull model was utilized for preoperative planning and subsequently sterilized to serve as an intraoperative reference for bilateral rostral mandibulectomy and pre-contouring of the titanium plate for subsequent mandibular reconstruction. Mandibular reconstruction with bone morphogenic protein (BMP) was performed 6 weeks following initial surgery to improve patient function and cosmesis. Patient is doing well post-operatively.

Case 3

Patient C.B. is a 6-month-old male silver Labrador retriever who presented with severely decreased range of motion secondary to recurrent temporomandibular joint ankylosis post gap arthroplasty. Joint ankylosis developed secondary to a dog bite that occurred at 8 weeks of age. Initial gap arthroplasty was performed 10 weeks after the trauma due to progressive decrease in range of motion with eventual inability to open mouth. Approximately 3 months following the initial surgery, the range of motion began to progressively decrease and it was suspected that there was new bone formation with subsequent ankylosis. CBCT was obtained with 0.9 mm slice thickness (Xoran Vet Cat, Xoran Technologies, Ann Arbor, MI) confirming TMJ ankylosis. Due to the increased complexity of the surgery, 3D models with surgical guides were printed. A 1:1 skull model was printed in white resin (Figure 3A-B) and a surgical guide was fabricated for the osteotomy of the temporal bone exostosis; the surgical guide was printed in surgical guide resin (Figure 3C). The 3D printed skull and surgical guide were sterilized to serve as intraoperative reference and guidance for the gap arthroplasty and osteotomies of the temporal and zygomatic bone exostosis (Figure 4A-B). The patient currently maintains a normal range of motion postoperatively.

Discussion

Our case series demonstrates potential benefits and indications for 3D printing in veterinary oral and maxillofacial surgery by improving the diagnosis and treatment of pathology through more accurate preoperative planning. Our 3D printed skull in Case 1 with maxillary osteosarcoma enhanced both the surgeon’s and pet owner’s understanding of the tumor extent leading to the augmentation of treatment plan from curative intent surgery with wide margin to conservative margin with postoperative radiation therapy in order to reduce the potential high risk of morbidity with wide margin. Traditional 2D images of CT or CBCT can be challenging for pet owners to interpret; allowing the owners to see and physically manipulate the 3D model of their pet facilitated comprehension of the surgical complexity, possible complications, and enriched the informed consent process resulting in proceeding with the conservative margin surgery followed by radiation therapy as in Case 1.

Patient-specific 3D printed models can also facilitate complex surgical planning with the ability to simulate the surgical steps in advance including planning of osteotomy lines and pre-contouring of titanium plates for reconstruction. The fabrication of custom-fitting surgical guides for osteotomies further translates the virtual preoperative plan to surgery by improving the precision and accuracy for optimal postoperative result [8]. These benefits have been shown to reduce surgical time and cost [9, 10]. Winer et al. reported saving at least 15 minutes of intraoperative time using 3D printed skulls for pre-contouring reconstruction plates in 19 veterinary patients [4]. The complication risk in canine oral surgery, specifically with mandibulectomy and maxillectomy, is increased by 36% for each additional hour of surgery [11]. Thus, minimizing surgical time with improved preoperative planning and intraoperative guidance from 3D printed models and surgical guides has the potential to improve patient outcomes.

In addition to preoperative planning and intraoperative guidance, 3D printed models may enhance veterinary trainee education. Preece et al. demonstrate that students who used 3D models performed better and had a better learning experience than those using digital models or textbooks suggesting that 3D models enhance understanding of anatomical structures and their relationships [12]. Patient specific 3D printed models further facilitate trainee's understanding of the complex surgical anatomy, potentially reducing the need for cadaveric specimens as well as morbidity and mortality for patients during their surgical experience on living patients [5]. Incorporation of 3D printing in training of surgeons is well documented including a program at the University of North Carolina at Chapel Hill that fabricates patient specific models to train surgical residents [13].

Most barriers and limitations of 3D printed models include the upfront cost of acquiring a 3D printer, materials, segmentation software, the expertise required for the fabrication process and quality assurance, and the time needed for printing and post-processing. However, 3D printing has become more accessible with desktop vat polymerization technology making it more affordable with a smaller footprint printer minimizing the space requirement while maintaining the high resolution needed for accurate fabrication of the complex delicate maxillofacial anatomy. The multitude of materials including biocompatible materials that can be sterilized for intraoperative patient contact use will likely facilitate further adoption of 3D printing in the clinical and surgical setting. Depending on the size and complexity of the canine skull, it took between 10 to 36 hours to complete the printing process for our case series and approximately 2 additional hours for post-processing. However, the 3D printing and post-processing time required did not negatively impact patient care in the cases highlighted in this series. For all three cases the printing and processing occurred during pre-surgical planning. As such, in general, we would not expect the time commitment required to complete the 3D printing process to affect patient care as the candidates selected for 3D printing are usually complex cases that require preoperative imaging acquisition followed by a stage procedure for thorough diagnosis and preoperative planning. Thus, the 3D printing process takes place concurrently with the preoperative surgical planning prior to the scheduled surgery. With advancement of 3D printing technologies, production time and cost will likely continue to decrease.

In conclusion, 3D printed models can improve preoperative planning and intraoperative guidance while enhancing veterinary training and pet owner communication. As 3D printing technology continues to advance, there will be increased adoption in veterinary medicine as it is already evidenced in human medicine with more hospitals offering medical 3D printing and recently approved Current Procedural Terminology (CPT) codes for reimbursement.

Abbreviations

3D – 3-dimensional

CT – Computed tomography

CBCT – Cone beam computed tomography

DICOM – Digital Imaging and Communications

STL – Standard Tessellation Language

IMRT – Intensity-modulated radiation therapy

IGRT - Image-guided radiation therapy

TMJ – Temporomandibular joint

BMP – Bone morphogenic protein

CPT – Current Procedural Terminology

Declarations

Consent for publication: Written informed consent was waived from the veterinary patients for publication of this case series and accompanying images.

Availability of data and materials: The datasets used in the current study are available from the corresponding author on reasonable request.

Competing interests: The authors report no financial conflicts of interest associated with this research.

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Author's contributions: Y.H. segmented, 3D printed the models, drafted the manuscript, and prepared all figures. B.L. and S.L.G. compiled patient data and performed the surgeries. All authors reviewed and edited the manuscript.

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Figures

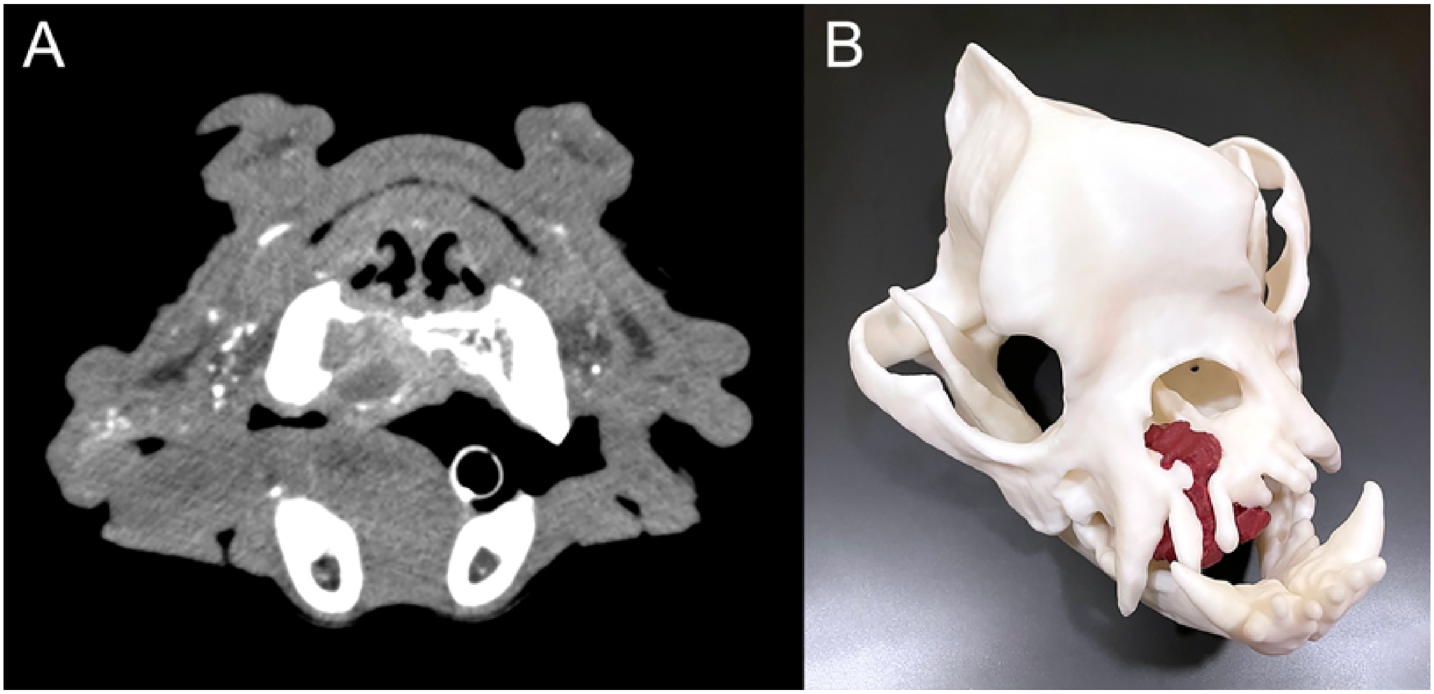

Figure 1

(A) Transverse section of preoperative contrast-enhanced CT demonstrating early right nasal invasion of the right maxillary osteosarcoma. (B) 3D printed canine skull in white resin with right maxillary chondroblastic osteosarcoma painted in red.

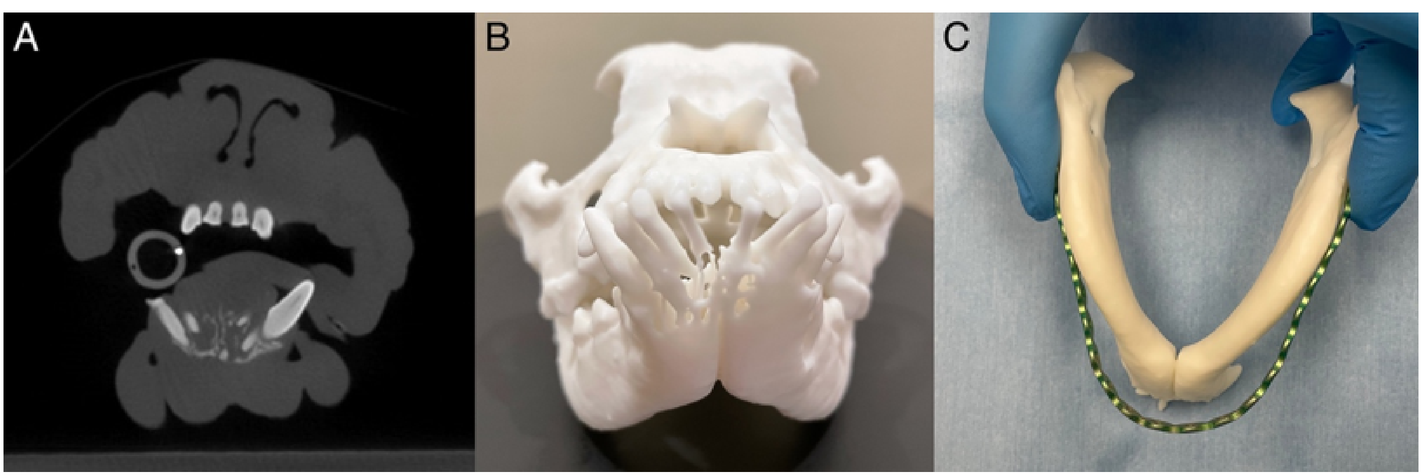

Figure 2

(A) Transverse section of preoperative CBCT demonstrating extensive osteolysis of rostral mandible secondary to oral plasma cell tumor. (B) 3D printed canine skull in white resin. (C) Pre-contouring of titanium plate for mandibular reconstruction using the 3D printed mandible.

Figure 3

(A) Frontal view of the 3D printed canine skull printed in white resin. (B) Lateral view of the 3D printed skull demonstrating the right temporomandibular joint ankylosis. (C) Cutting guide printed in surgical resin and seated on the temporal bone exostosis of the 3D printed cranium.

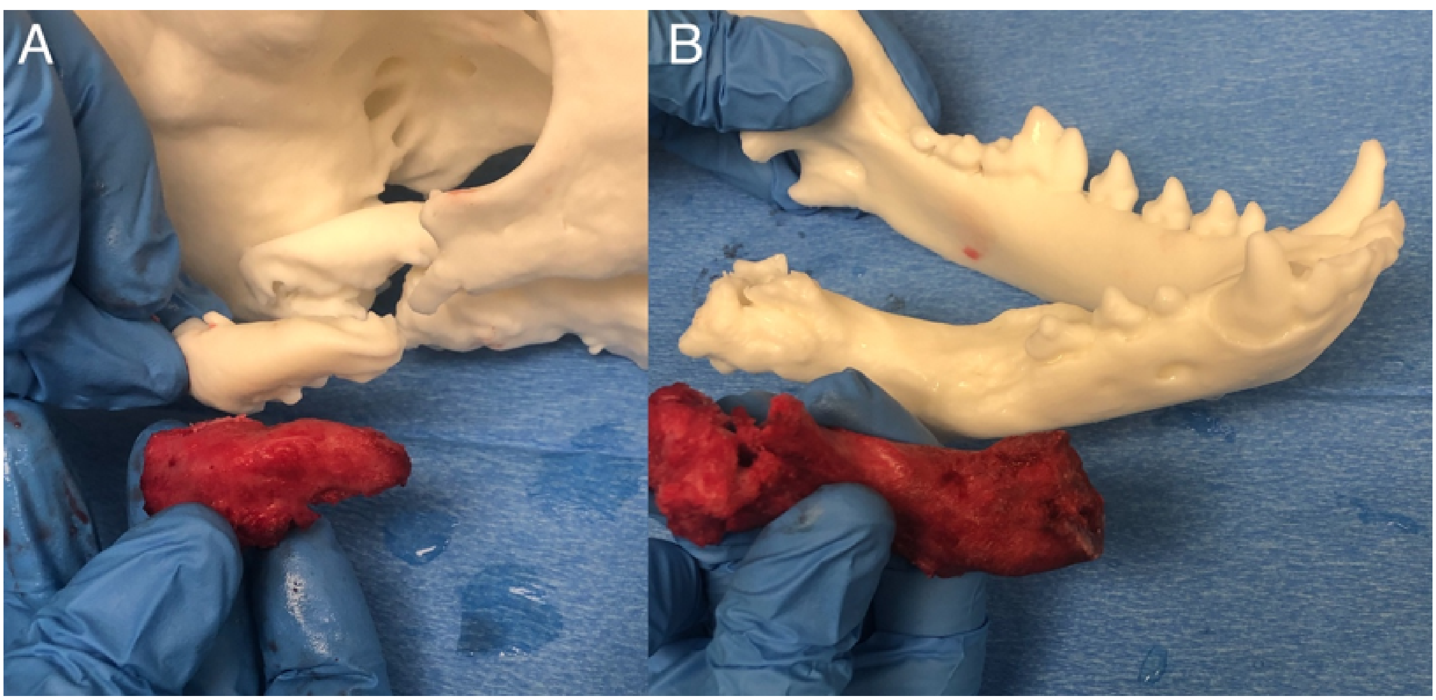

Figure 4

(A) Osteotomy of the zygomatic bone with reference to the 3D printed model. (B) Osteotomy of right caudal mandible with reference to the 3D printed mandible.