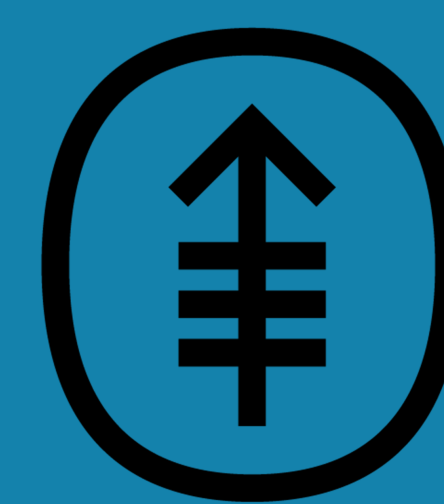




3D Printed Models as an Interdisciplinary Communication Tool for Precision Surgical Oncology in Sinonasal and Skull Base Tumors

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Introduction

- Craniofacial and skull base neoplasms are a very rare, heterogenous group that arise in an anatomically complex region.
- Majority of tumors involve the anterior cranial fossa.
- Treatment is an interdisciplinary approach involving otolaryngologists, ophthalmologists, neurosurgeons, plastic surgeons, radiologists, and radiation oncologists, medical oncologists, pathologists, and dentists.
- Virtual surgical planning (VSP) and three-dimensional models (3DM) have largely been employed in reconstruction of maxillofacial defects.
- 3DM can improve precision of oncologic resections with emphasis on clear margins and preserving critical structures and function.
 - Models provide a clearer understanding of the anatomic and pathologic relationships that benefits all phases of surgical care.
- We summarize our institutional experience in relation to VSP and 3DM in sinonasal and skull base surgical oncology. A case series is used to illustrate the utilization and benefits derived from VSP and 3DM in relation to ablation (pre-operative and intra-operative), communication, education, reconstruction, interdisciplinary teamwork.

Methods

- Patients at our institution undergo a thorough diagnostic assessment including discussion at a multi-disciplinary team meeting prior to initiation of treatment.
- This case series included 5 patients undergoing treatment from 2019 until 2021 where 3DM were utilized for craniofacial resections because they aided in ablation, communication, interdisciplinary planning, education, and/or reconstruction.
- 3DM are made using CT scan image data (0.5 mm slice cuts) that converted to a DICOM format and sent to DePuySynthes (Synthes® Maxillofacial 1302 Wrights Lane East, West Chester, PA), who digitally plan and design the surgical models and cutting guides.

Table of Representative Cases

Case	Age/ Sex	Diagnosis	TNM Staging	Treatment	Focus
1	61/F	Sinonasal SCC (p16+)	T4aN0	- Induction chemotherapy - Craniofacial resection - Adjuvant chemo and proton XRT	Ablation Orientation of pathology
2	72/F	Adenocarcinoma	T4aN0	- Endoscopic skull base resection - Adjuvant chemotherapy and proton therapy	Education
3	8/M	Embryonal rhabdomyosarcoma	T2N0	- Chemotherapy and proton therapy - Salvage surgery - Adjuvant chemo and proton XRT	Communication
4	84/F	Sinonasal SCC (p16-)	T4aN2b	- Orbit sparing maxillectomy - Adjuvant chemo, proton XRT	Reconstruction
5	54/F	spindle-cell rhabdomyosarcoma	T2bN0	- Chemotherapy and proton therapy - Salvage craniofacial resection - Adjuvant chemo and proton XRT	Interdisciplinary care

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Case 1



Figure 1: A) T1 weighted axial MRI pre-induction chemotherapy, B) T1 weighted axial MRI post-induction chemotherapy, C) 3D model showing the residual tumor and bony anatomy with hand drawn outline of planned ablation

- 61-year-old female with a T4aN0 p16+ sinonasal SCC arising from the right lacrimal duct that underwent neo-adjuvant chemotherapy prior to surgery
- Intra-operative ablation can be challenging in the sinonasal cavity and skull base due to the complex anatomy constrained by critical structures.
- Pathology can lead to anatomic distortions further complicating dissection in this area and the tumor ablation.
- The planned osteotomies are drawn onto the model clearly delineating the surgical approach and limits of the resection.
- 3DM was referenced intra-operatively to help ensure that the ablation was following the pre-surgical plan given the non-centripetal pattern of tumor response to neo-adjuvant chemotherapy meant the extent of the tumor became less apparent and the remaining tumor could not be used to guide ablation.
- The specimen and model were used to help orient the margins for histologic analysis.

Case 2

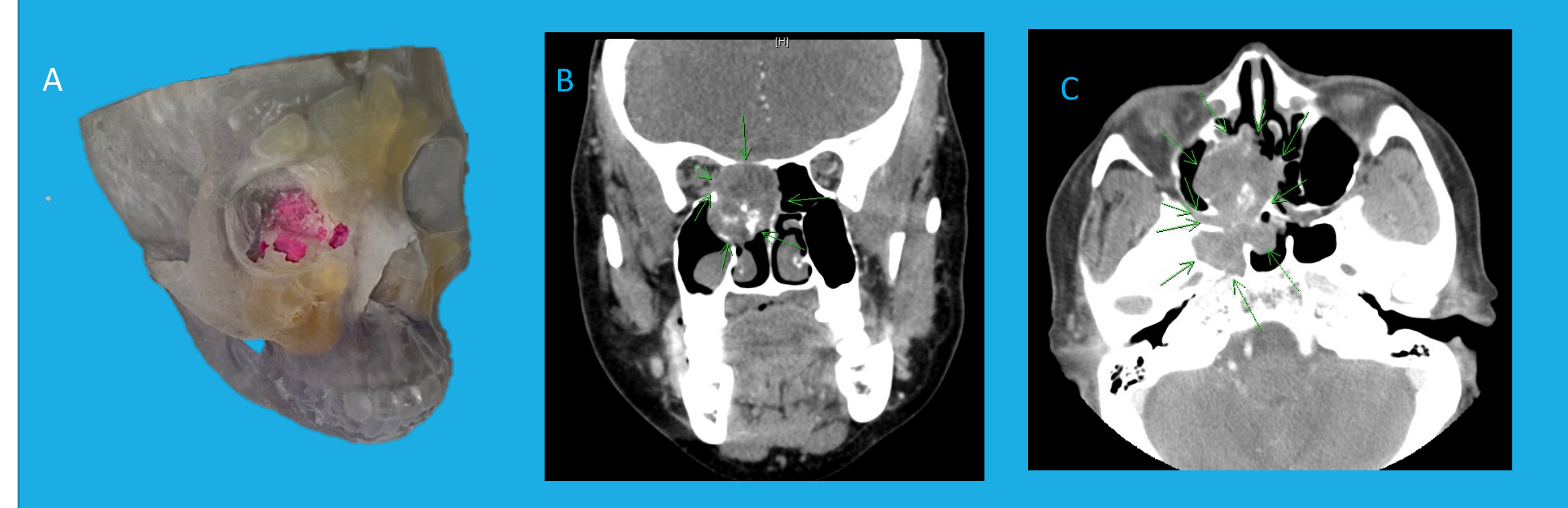


Figure 3: A) 3D model rendering of tumor and related bony and vascular structures B) CT Coronal slice showing the complexity of the tumor location C) CT axial image showing tumor relationship to the petroclival internal carotid artery

- Imaging showed ethmoid sinus mass with destruction of the medial maxillary wall with breach of the anterior cranial fossa and tumor abutting the right internal carotid artery.
- Trainees need to fully comprehend details of each case prior to surgery to avoid any complications and reduce surgery time and mortality.
- Training for beginners in the operating room is limited due to patient safety and efficiency especially for endoscopic transnasal cases where one surgeon operates.
- 3DM provide a tool since textbooks only provide 2D, static snapshots, of the real 3D anatomy and anatomic cadaver dissection cannot provide the actual pathology.

Case 3

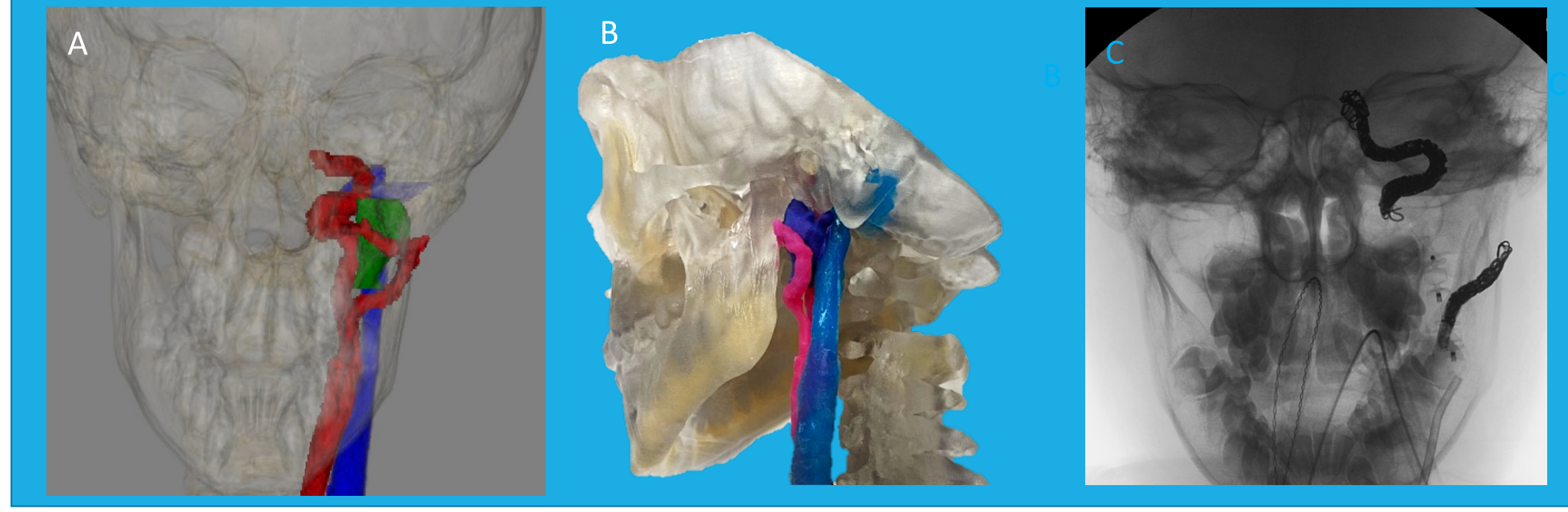


Figure 2: A) 3D radiologic rendering of tumor and related bony and vascular structures B) 3D model of tumor and related bony and vascular structures C) Image of pre-operative embolization of the left carotid system.

- 8-year-old male with a T2N0 embryonal rhabdomyosarcoma arising in his nasopharynx that underwent CRT but developed a left parapharyngeal recurrence.
- Figure 2A and 2B shows a 3DM displaying the proximity of the internal jugular vein, the internal and external carotid arteries to the tumor.
- Lip split and posterior mandibulectomy along with pre-surgical embolization of the internal carotid was decided
- 3DM was used to describe the surgical approach and the risks of the operation to the patient and family and improved communication and aided the informed consent process.
- There was a greater awareness of post-operative expectations which helped the patient and the family through the convalescent period.

Case 4

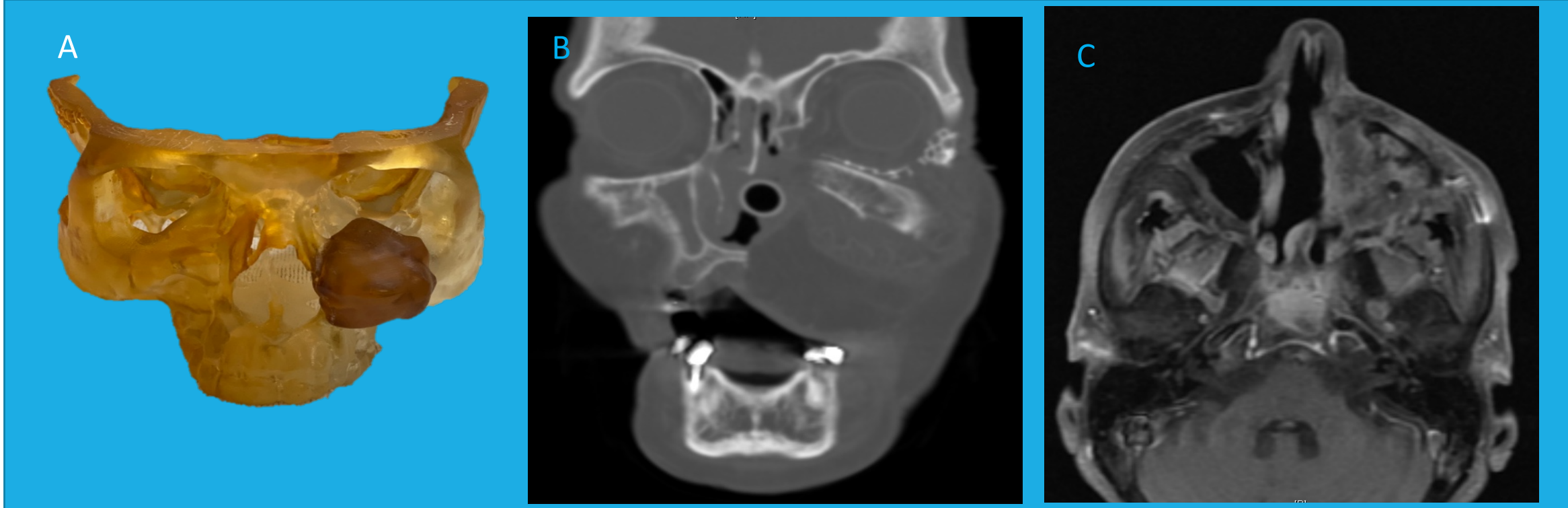


Figure 4: A) 3D model rendering of tumor B) CT Coronal slice the reconstruction with titanium mesh orbital floor, iliac crest bone, and soft tissue. C) T1 post-con MRI illustrating the symmetry of the reconstruction.

- 84-year-old female with sinonasal SCC of the maxilla that underwent a left hemimaxillectomy including palate, orbital floor, and nasal side wall with reconstruction that included iliac crest, titanium mesh, and vertical rectus abdominus myocutaneous free flap.
- Difficulty in craniofacial surgery is the reconstruction of the orbit and midface.
- Given the necessity of multiple teams required to treat the patient, teams need to be in sync with their planning.
 - Different neoplasms may be treated differently and the 3DM help the ablative team explain their necessary resection to the reconstructive team.
- 3DM used peri-operatively helps guide the ablative osteotomies to match the reconstruction to provide adequate repair of the defects created during the surgery.
- VSP makes guides to harvest bone from the donor site that will fit the defect.
- Reduced operating room time and anesthesia time
- Improves functional and cosmetic outcomes, which in turn improve patient outcomes.

Case 5

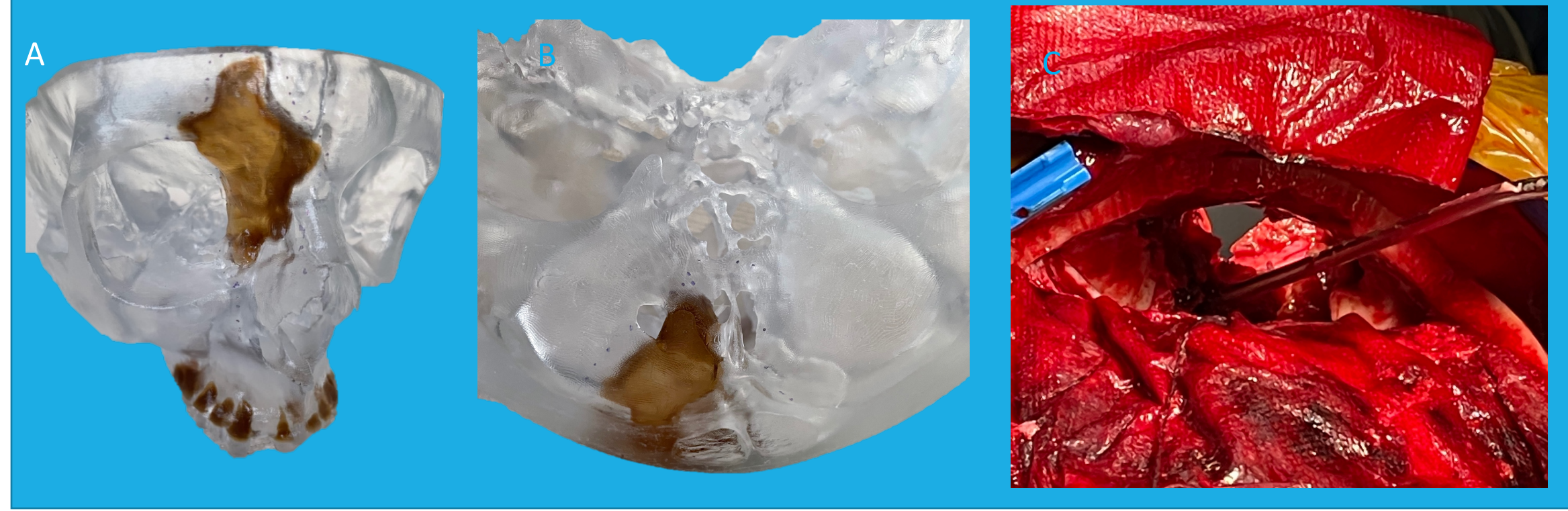


Figure 5: A) 3DM showing anterior view of the tumor B) 3DM with a cranial view. C) intra-operative view from the cranial side s/p resection of

- Combining CT, MRI, CT-angiography, and 3D-printed model, before surgery allows the multidisciplinary team to start from the relative positions of the skull base, nerves, blood vessels, and tumors, and observe the tumor base and the scope of invasion from multiple angles and close distances.
- Pre-operatively, the decision was made to proceed with an open craniofacial resection with skull base reconstruction using peri-cranial flap, calvarial bone graft, and free tissue transfer given the necessity of post-operative radiation treatment and to prevent CSF leak and brain herniation.
- The relevant bone markers were measured, and a large portion of the anterior table was resected based on the 3DM while protecting relevant nerve tissue and reducing vascular injury.
- Frequent referencing of the model intraoperatively was performed resulting in an en-bloc resection with tumor free surgical margins with a defect that was discussed prior to surgery and optimized to aid reconstruction.
- The defect and the specimen were then compared to the 3D models as an additional way to ensure completeness of ablation.
- Tumor specimen and the 3D models were then discussed with the pathologist to assist with orientation and pathologic assessment.

Discussion

- Sinonasal and skull base neoplasms are very challenging resections requiring multiple teams from various backgrounds and a strong grasp of the three-dimensional anatomy.
- 3DM provided an interdisciplinary communication tool to design the surgical approach.
- 3DM improves identification of important landmarks and vital structures and improves ablation and this may improve oncologic outcomes.
- 3DM that incorporate response to treatment over time help patients and physicians better understand the complex issues involved in surgical planning in an accessible manner
- 3DM are useful in trainee education.
 - 3DM has been used in lieu of cadavers for training in temporal bone dissection and with endoscopic training
- 3DM improve patients' ability to understand the complex treatments and help in the consent process for craniofacial resections which leads to improved patient satisfaction and outcomes.
- While 3DM has been used extensively in the reconstructive planning, it improves all aspects of craniofacial tumor resection from surgical planning, patient education and pathologic analysis.

