DEVELOPMENT AND VALIDATION OF A NOVEL CRANIOFACIAL MACHINE LEARNING MODEL FOR THE VIRTUAL RECONSTRUCTION OF BILATERAL MAXILLARY DEFECTS

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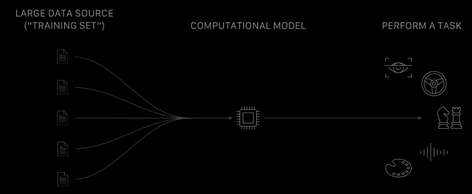
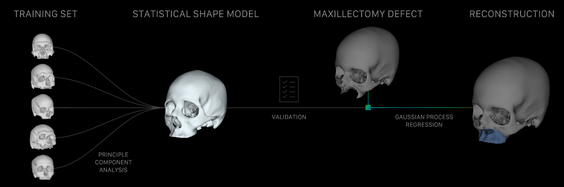
BACKGROUND

Surgical reconstruction is the current standard of care for maxillary defects resulting from trauma, congenital disease, or surgery. However, creating a virtual surgery plan (VSP) for reconstruction of bilateral maxillary defects is challenging because there is loss of a premorbid contralateral reference. The goal of this study was to simplify the pre-operative planning of fibula free flap reconstructions via a machine learning model that can virtually recreate missing anatomy in an automated and patient-specific manner.

A typical machine learning workflow:



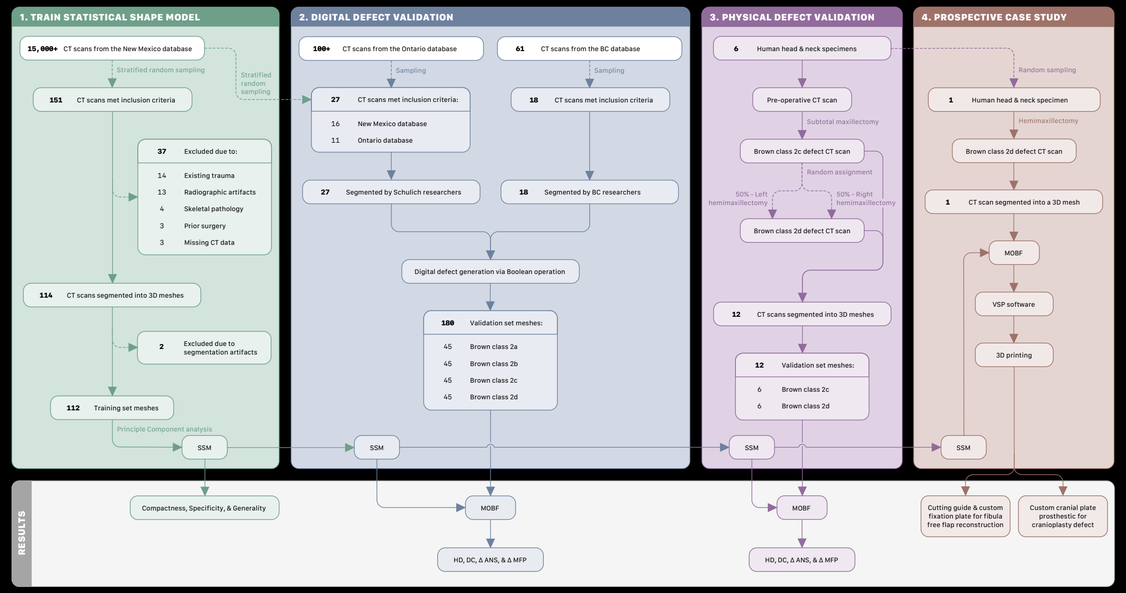
Our machine learning workflow for defect reconstruction:



OBJECTIVES

1. Train a statistical shape model (SSM) on a dataset of 112 segmented 3D meshes of the craniofacial complex
2. Validate the SSM's reconstruction accuracy for unseen meshes with various digitally generated maxillectomy defects
3. Validate the SSM's reconstruction accuracy for unseen meshes with various surgically generated physical maxillectomy defects
4. Apply this novel SSM-guided maxillary reconstruction VSP workflow in a prospective case study involving fibula free flap reconstruction and custom prothesis design

MATERIALS & METHODS

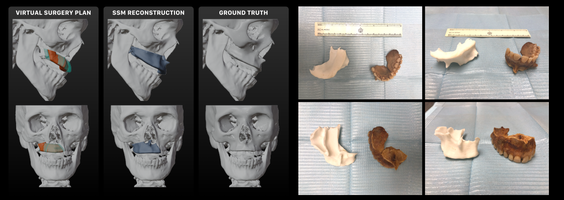


RESULTS

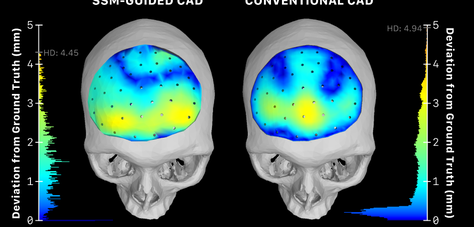
Outcome #1: Our SSM successfully captured the training set variance and was neither over- or under-fit to the population (compactness = 7.28×10^{5} mm^2, specificity = 1.18 mm, and generality = 8.12×10^{-6} mm)

Outcome #2: Our SSM reconstructed digitally and surgically generated defects with promising accuracy (mean 95th percentile Hausdorff distance = 5.47±2.39 mm, mean volumetric Dice coefficient = 49±14 %)

Outcome #3: SSM-guided pre-operative planning resulted in a more accurate VSP compared to standard methods (red = standard VSP, cyan = SSM-guided VSP)



Outcome #4: SSM-guided computer-aided design (CAD) of cranioplasty prostheses showed equal or slightly improved accuracy compared to conventional methods, while demonstrating substantial time savings (-22 minutes)



DISCUSSION

- Volumetric Dice coefficient likely underestimates reconstruction accuracy due to radiographic burnout in ground truth segmentations
- 95th percentile Hausdorff distance may have overestimated deviation from the ground truth due to high variation in nasal turbinate anatomy
- Deviation error in midfacial projection approximates the clinical relevancy threshold (< 2 mm)
- In conclusion, our machine learning model is expected to ultimately improve outcomes and reduce complications in patients with maxillary defects
- This SSM will aid future research in computational anatomy by providing an existing source of segmented meshes that are representative of natural maxillofacial variation

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