SIIM CMIMI22
Conference on Machine Intelligence in Medical Imaging
OCT 2-3 | VIRTUAL

Automated Segmentation of the Eustachian Tube for Applications in the Management of Eustachian Tube Dysfunction – A Deep Learning Framework

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Introduction
Eustachian tube (ET) dysfunction is a common condition within the Otolaryngology domain seen in both the pediatric and adult population. Current works on morphological analysis of the ET for diagnostic purposes rely on manual annotation of computed tomography (CT) imaging. However, manual segmentation is cumbersome and difficult to translate into the clinical domain. In this work, we present the preliminary results of the state-of-the-art deep learning approach for automated segmentation of the ET and its neighboring structures to streamline the process of studying the intricate anatomy of this structure and pave the path for correlating certain parts of the tube to patient-reported symptoms.

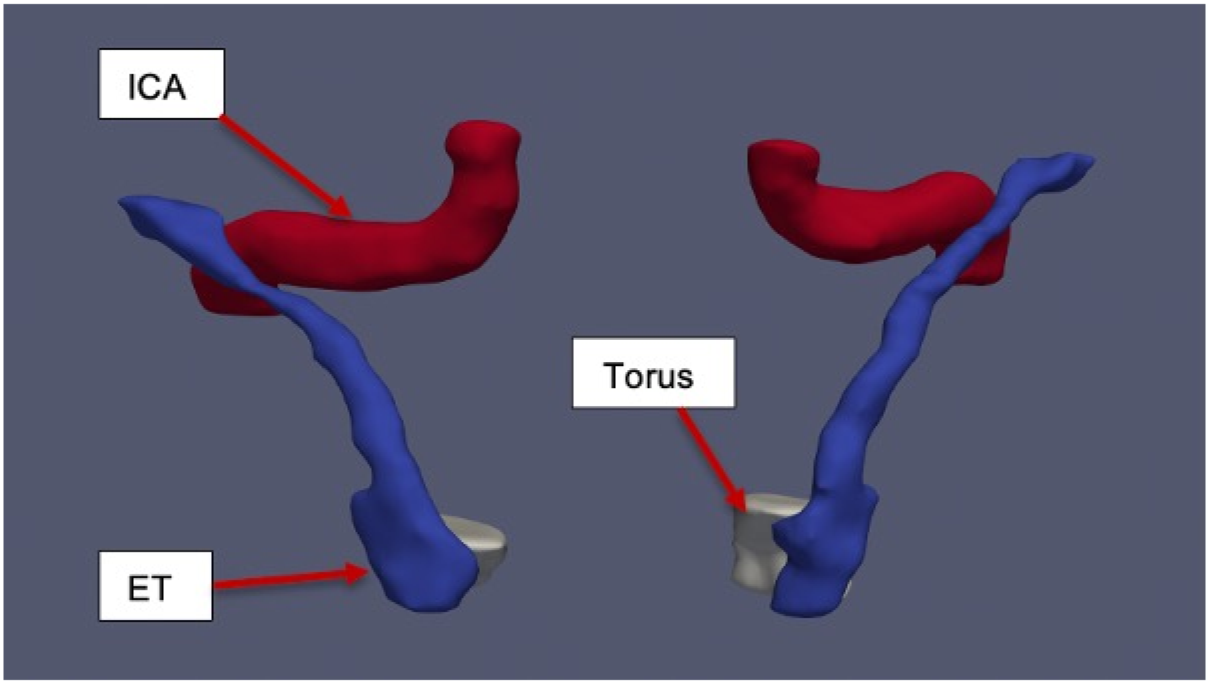
Hypothesis
ET and nearby critical structures can be automatically segmented on CT imaging using a deep learning approach.

Methods
This was a retrospective cohort study approved by the institutional review board. CT images from a tertiary referral Otolaryngology center for adult patients (> 18 years of age) were included. Manual annotation of the regions of interest were performed via an open-source software, 3D slicer. We included three segmentations: eustachian tube, internal carotid artery (ICA), and torus tubarius (TT) to optimize the networks' learning (Figure 1). nnUNet was thereafter used for training the segmentation network. The Dice Similarity Coefficient (DSC) and Average Hausdorff Distance (AHD) was calculated to quantify the performance of the DL framework on the test CT volumes.

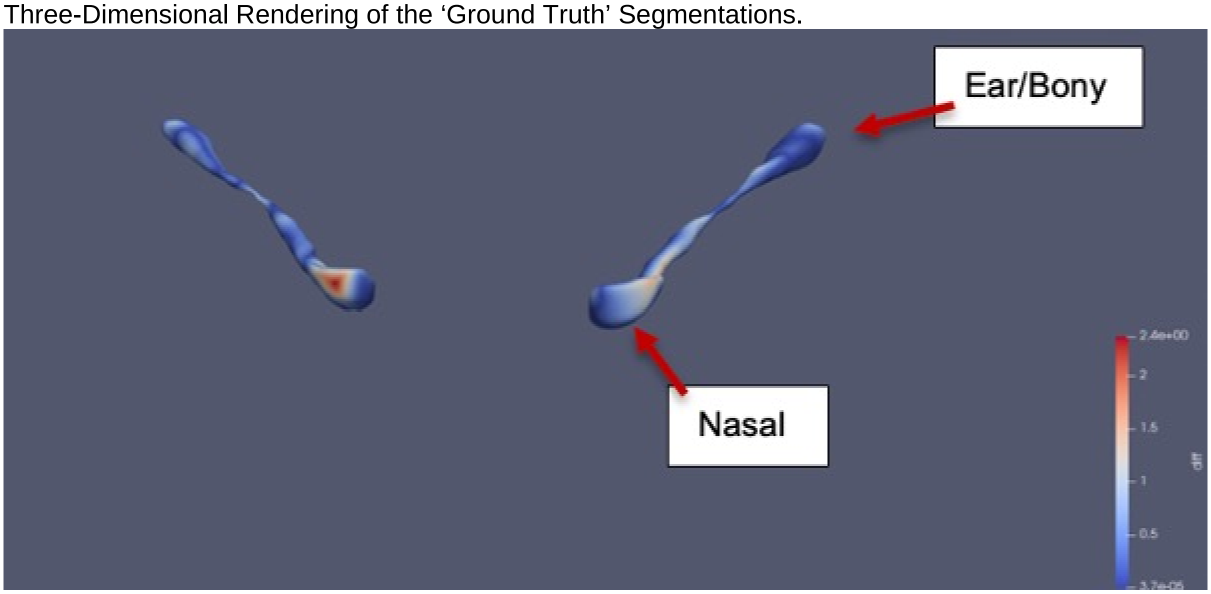
Results
22 CT scans were used for training the segmentation network. Predictions were assessed on 9 test CT volumes. The framework showed increased accuracy along the bony and pharyngeal openings of the ET whereas there was decreased accuracy along the mid-cartilaginous segment as assessed via a heat map (Figure 2). The DSC for the ET, ICA, and TT were 0.649, 0.891, and 0.735 respectively, whereas the AHD was 0.455, 0.205, and 0.402 for the three respective structures.

Conclusion
We have developed the first deep learning framework which performs automated segmentation of the eustachian tube and surrounding anatomical structures with promising results. Next steps will focus on improving the performance of the segmentation network in predicting the mid-segment of the ET.

Statement of Impact
This pipeline serves as a tool for studying large datasets within the clinical domain in an efficient manner. Given its automated nature, it shows promise in being integrated into the current clinical workflow for the diagnosis and treatment of patients with ETD.



Three-Dimensional Rendering of the ‘Ground Truth’ Segmentations.



Heat map in comparing errors between the ‘Ground Truth’ and ‘Predicted’ Segmentations for the Eustachian Tube.

Keywords
Eustachian tube; Deep learning; Image segmentation; Eustachian tube dysfunction; Surgical intervention; Computer-aided surgery