Increased Accuracy, Confidence, and Efficiency in Anterior Ethmoidal Artery Identification with Segmented Image Guidance

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Abstract

Objective. To determine whether using image guidance technology with 3-dimensional image segmentation increases the endoscopic surgeon’s accuracy, efficiency, and confidence in identifying the anterior ethmoidal artery.

Methods. This is a cross-sectional study of attending physicians and residents at an academic medical center. Because identification of the anterior ethmoidal artery during image-guided surgery can be challenging, we studied the effect of anterior ethmoidal artery image segmentation (ie, partitioning and coloring) on surgeon test performance. A computerized test was administered to 16 surgeons who were asked to identify the anterior ethmoidal artery on multiplanar computed tomographic images and to answer multiple-choice questions. Half the questions showed segmented images of the anterior ethmoidal artery, and half showed images without segmentation. Efficiency and accuracy of identification and subjective surgeon confidence were determined for each question. Descriptive statistics were used to compare test performance for identification of the anterior ethmoidal artery on images with or without segmentation.

Results. Percentage of correct answers ($P < .001$), efficiency ($P < .001$), and confidence ($P < .001$) in identification of the anterior ethmoidal artery were significantly better with segmented computed tomographic images.

Discussion. We demonstrated that use of segmented images improves surgeons’ accuracy, confidence, and efficiency for identification of the anterior ethmoidal artery.

Implications for Practice. We describe how segmentation can allow surgeons to improve the surgical course by increasing their accuracy, confidence, and efficiency in identifying the anterior ethmoidal artery.

Keywords

anterior ethmoidal artery, image guidance, segmentation, surgical planning

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Image guidance technology has dramatically improved sinus surgery by providing real-time anatomic feedback, decreasing complications, and improving instrument precision.¹⁻⁸ However, the risk of injuring difficult-to-identify nearby structures is a concern of sinus surgeons. During the endoscopic sinus surgery portion of our training program for residents, we use preoperative image segmentation of the anterior ethmoidal artery (AEA). During preoperative planning for image-guided sinus surgery, rhinologic surgeons at our institution use image segmentation for key structures, including the AEA, in 3-dimensional computed tomography (CT) for intraoperative use. AEA image segmentation appeared to be useful at our institution. Consequently, we began investigating the potential benefits of AEA image segmentation and sought a method to quantify our subjective perception that it increased surgeon confidence and efficiency during sinus surgical procedures. We hypothesized that this technique improves surgeon confidence, accuracy, and efficiency. We tested this hypothesis by using a novel, experimental, simulated computer model to test surgeon performance.

Methods

CT Image Segmentation

After receiving approval from the Institutional Review Board (13-008579), we invited otolaryngology residents and attending physicians at Mayo Clinic (Rochester, Minnesota) to take our

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computerized test. The data are presented according to the SQUIRE 2.0 guidelines (Standards for Quality Improvement Reporting Excellence).

Multiplanar anonymized CT images, which had been obtained by a study author (J.F.P.) for use as sample cases for teaching purposes, were segmented (partitioned and then defined in color) with correlation between triplanar views (Figure 1). All patients had given permission for their images to be used for educational purposes. We selected sample images for the test from those previously identified sample cases. Neuroradiologists designed the initial CT protocol to use 0.4-mm-thick slices. Neuroradiologists performed conventional reading of the CT scans, but they did not perform pre-surgical segmentation. All segmentations were performed by an attending rhinologic surgeon (J.F.P.) who used the Brainlab platform (Brainlab AG, Munich, Germany) to integrate the segmentations into operative image guidance. The AEA was initially identified on coronal images. Simultaneous triplanar views were used to confirm the AEA on the axial image. The program’s drawing tools were used to manually color the AEA on 2 to 5 axial slices, depending on the superior-to-inferior angle of the AEA and any flaring at either end of the intrasinus portion of the AEA. The AEA was colored in red on the CT images. The colored AEA could then be identified on the coronal and sagittal images and followed on multiple coronal images along its oblique posterolateral-to-anteromedial course. For further quality assurance, a coauthor (J.R.W.) verified the segmentation of the AEA.

Test Design and Content

Participants were given a computerized multiple-choice test and asked to identify the AEA on CT images. Right and left orientations were marked identically on each image. Written instructions for the test were provided. Participants were informed that each multiple-choice question had only 1 correct answer. The instructions also stated that scoring was based on accuracy and speed; time spent rating confidence was not recorded. Participants served as their own controls because half the questions referred to segmented images and half referred to unsegmented images. Before participants began the test, they were given a sample question with the correct answer for each of the 2 types of images. Screenshots of sample questions (with unsegmented and segmented images of the AEA) are provided in Figure 1. The test included 20 images of the AEA (10 segmented and 10 unsegmented) with corresponding questions. For 10 of the questions, unique images were used for 5 segmented and 5 unsegmented examples. For the other 10 questions, 5 images were used twice, with the unsegmented image presented earlier in the test (1st, 3rd, 5th, 7th, and 9th) and the segmented version presented in random order (16th, 14th, 12th, 20th, and 18th). In total, 15 unique images were presented. After answering each timed question about the AEA, participants were given an untimed question and asked to rate their degree of confidence for each answer as 1 (not at all confident), 2 (not very confident), 3 (confident), or 4 (very confident).

Test Conditions

All participants took the test independently at their convenience. Questions were administered in the same order to every participant.

Statistical Analysis

The percentages of correct responses for questions about segmented images and questions about unsegmented images, the mean response time per question, and the mean subjective confidence rating per question were calculated for each participant. The response time, percentage of correct answers, and subjective confidence ratings were tabulated for each type of image with JMP software (SAS
Institute Inc, Cary, North Carolina). Because data were non-normally distributed, the Wilcoxon signed rank test was performed, and corresponding \( P \) values were calculated to compare differences in responses to segmented and unsegmented images while keeping the responses paired for each participant. Spearman \( P \) values were determined separately for responses to segmented and unsegmented images to assess correlations among confidence, response time, and percentage of correct answers.

**Results**

**Surgeon Characteristics**

Five otolaryngology attending physicians and 11 otolaryngology residents participated in this study. Year of residency ranged from postgraduate year 1 to 5.

**Accuracy**

The range of scores was higher for questions about segmented images (80%-100%) than for questions about unsegmented images (0%-60%). All participants had higher scores for segmented images than for unsegmented images \( (P < .001; \text{Figure 2}) \). The median difference between the 2 scores was 8 correct answers (range, 3-10).

**Efficiency**

For all participants (except 2 residents), the mean response time for questions about unsegmented images was greater than that for questions about segmented images (\textbf{Figure 3}). The median difference between response times for questions about segmented images and unsegmented images was \(-6.38\) seconds (range, \(-21\) to 1.7 seconds; ie, participants had faster response times for questions about segmented images). According to the Wilcoxon signed rank test, the difference in response times between questions about unsegmented and segmented images was significant \( (P < .001) \).

**Confidence**

All participants reported higher ratings (ie, more confidence) in their responses to questions about segmented images than in their responses to questions about unsegmented images (\textbf{Figure 4}); the mean difference was 1.65 on the 4-point scale \( (P < .001; \text{Wilcoxon signed rank test}) \).

**Discussion**

Image segmentation has been used in other surgical specialties as an aid in, for example, identifying cranial nerves, internal carotid arteries, and cavernous sinus in pituitary tumor resections; marking heart chambers to guide invasive cardiac procedures; navigating recurrent pituitary adenoma decompressions; excising abdominal tumors; and correcting arteriovenous malformations.

Studies were done on manual and automated segmentation of paranasal sinuses. Tingelhoff et al investigated variability in manual image segmentation for ethmoidal and maxillary sinuses, and Sinha et al used automatic segmentation to estimate natural anatomic variations. Pirner et al developed a database for automatic model-based image segmentation for paranasal sinuses, and Bui et al concluded that automated CT segmentation for airway and paranasal sinuses was highly accurate. To our knowledge, image segmentation of the AEA has not been previously described.
Furthermore, no metrics have been applied to assess the benefit of using AEA segmentation in image-guided surgery.

A major finding of this study is that image segmentation improves surgeon accuracy, confidence, and efficiency in identification of the AEA on CT images. With software, image segmentation can be performed quickly for small structures, such as the AEA, and having the surgeon do this provides quality assurance. Although the ever-increasing sophistication of automated segmentation will be helpful for images of larger structures, manual segmentation can be easily applied to images of smaller structures.

Overall, this study shows the importance of AEA image segmentation and how simple preoperative techniques can improve surgeon accuracy and confidence in identifying critical structures on CT images, with potential benefits during sinus surgery. Follow-up studies could apply metrics to the use of this technology during actual surgical procedures. Other areas of interest for further investigation include optimization of this technology (eg, with automation) and evaluation of metrics for image segmentation of other structures during image-guided operations in otorhinolaryngology and other specialties.

Implications for Practice

In this study, we describe how segmentation can be used to improve surgeon accuracy, confidence, and efficiency for identification of structures such as the AEA on sinus CT images. This technology may allow surgeons to improve the surgical course by allowing easier identification of key structures. Raising awareness of this practice and use of image segmentation of other structures may help facilitate safer and more efficient endoscopic sinus operations.

Author Contributions

Deeyar A. Itayem, analysis, interpretation of data, and constructing all graphs, drafting as well as revision, final approval, and accountable for work; C. Lane Anzalone, data analysis, drafting, final approval, and accountability for work; James R. White, design of the study and test, data acquisition, data analysis and interpretation, drafting, final approval, and accountable for accuracy; John F. Pallanch, conception and design of study and test, segmentations, data analysis and interpretation, draft revisions, final approval, and accountability for work; Erin K. O’Brien, analysis and interpretation of data, drafting and revision, final approval; accountable for accuracy.

Disclosures

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