Six Walls of the Cavernous Sinus Identified by Sectioned Images and Three-Dimensional Models: Anatomic Report

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■ BACKGROUND: **For the diagnosis and surgical treatment of diseases around the cavernous sinus (CS), radiologists should achieve complete mastery of the sectional anatomy of the CS, and neurosurgeons need to understand the stereoscopic orientation of the CS and circumjacent structures. However, despite the complicated structure of the CS, the current educational resources for its sectional and stereoscopic anatomy are insufficient. Another problem is that the definition of CS walls varies for each researcher. The purpose of this study is to redefine the walls of the CS and to provide related educational materials.**

■ METHODS: **Previous studies on the shape of the CS were analyzed. Sectioned images of a cadaver were prepared at 0.1-mm intervals to be made into three-dimensional (3D) models of the CS and neighboring structures.**

■ RESULTS: **Based on other studies, the shape of the CS was redefined as a hexahedron, consisting of 6 walls, and was illustrated as a schematic figure. Scientific exactitude of the hexahedron was proven through matching the points with the actual structures on the sectioned images and 3D models that were made in this study.**

■ CONCLUSIONS: **The combination of the hexahedron theory, the sectioned images, and the 3D models in this study will enhance the efficiency of studying CS anatomy. The educational resources of this study can be obtained free of charge by medical students, radiologists, and neurosurgeons requiring knowledge of CS anatomy.**

INTRODUCTION

The cavernous sinus (CS) is frequently affected by tumors from the adjoining pituitary gland. CS meningiomas or the extension of nasopharyngeal tumor also can occur. In addition, the CS is occasionally affected by infection or thrombophlebitis from its connected veins. These pathologic conditions often involve cranial nerves and the internal carotid artery (ICA), which are germane to the CS (2, 3, 17, 18). Computed tomography (CT) and magnetic resonance imaging (MRI) scans have been used in diagnosis of these diseases of the CS. After diagnosis, these diseases can be treated with minimally invasive direct surgery (1, 5, 8, 20-22) or radiosurgery (6, 19).

For accurate and rapid interpretation of CT or MRI scans of the CS, radiologists should achieve a complete mastery of the sectional anatomy of the CS. For a surgical approach to the CS, neurosurgeons need to have perfect understanding of the stereoscopic orientation of the CS and the neighboring structures. However, the CS anatomy is difficult to understand for several reasons. First, the definition of walls of the CS is different for each researcher (**Table 1**) (1, 5, 7, 22). Second, the relationship between the CS and neighboring structures is highly complicated (9, 16). Last, educational materials on the sectional and stereoscopic anatomy of the CS are insufficient.

Key words
- Cavernous sinus
- Cross-sectional anatomy
- Dura mater
- Microsurgery
- Three-dimensional imaging
- Visible Human Project

Abbreviations and Acronyms
CS: Cavernous sinus
CT: Computed tomography
ICA: Internal carotid artery
MRI: Magnetic resonance imaging
PDF: Portable document format
3D: Three-dimensional

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Table 1. Definition of the Walls of the Cavernous Sinus in Several Studies

Study	Number of Walls	Meninges of Walls
Umansky et al., 1994 (20)		Medial wall—mostly periosteal
Marinkovic et al., 2001 (7)	5 (lateral, medial, posterior, superior, inferior)	Medial wall—dural and partially periosteal
		Inferior wall—periosteal
Yasuda et al., 2005 (22)	5 (lateral, medial, posterior, anterior, superior)	
Isolan et al., 2007 (5)	5 (lateral, medial, posterior, anterior, superior)	
Campero et al., 2010 (1)	4 (lateral, medial, posterior, superior)	Medial wall—dural
		Lateral wall—meningeal, periosteal
Present study, 2015	6 (lateral, medial, posterior, anterior, superior, inferior)	Medial wall—meningeal
		Inferior wall—periosteal

Considering ambiguous definitions of CS walls, it is essential to redefine walls of the CS and to arrange them into a schematic figure. In addition, educational resources that include the new definition of CS walls are important. To accomplish these tasks, we redefined the walls of the CS using sectioned images and three-dimensional (3D) models.

MATERIALS AND METHODS

For analyzing the shape of the CS, related articles published since 1976 were searched in the U.S. National Library of Medicine and National Institutes of Health (http://www.ncbi.nlm.nih.gov/pubmed/) (1, 2, 4, 5, 7, 17, 20, 22). After the analysis (Table 1), the inferred shape of the CS was drawn into a schematic figure employing Adobe Illustrator (Adobe Systems, Inc., San Jose, California, USA) (Figure 1).

In previous studies (12, 13), we prepared sectioned images of the head as follows. The cadaver head was embedded in a gelatin solution and frozen to yield the ideal state for cryosectioning. The head was sectioned using a cryomicrotome and photographed using a Canon EOS 5D digital camera (Canon, Inc., Tokyo, Japan) with a Canon 50-mm microlens to make high-quality horizontal sectioned images (intervals, 0.1 mm; pixel size, 0.1 mm × 0.1 mm; color depth, 48-bit color). We created coronal and sagittal images by reconstituting the prepared horizontal sectioned images using software we developed.

The CS and its related structures were selected for the segmentation process (Table 2). The segmentation method by Adobe Photoshop (Adobe Systems, Inc.) was developed in our previous study (11), and the methods were used in this study as follows. Among the horizontal sectioned images at 0.1-mm intervals, the images at 0.5-mm intervals were selected. On the selected images, boundaries of the selected structures were outlined using the magnetic lasso tool semiautomatically or lasso tool manually. The inner area of the outlined structure was filled with specific colors using the paint bucket tool to make segmented images.

Employing Mimics version 10.01 (Materialise, Leuven, Belgium), the color-filled structures in the segmented images were stacked and reconstructed by surface modeling to build the 3D models. The models were saved as stereolithography files and placed in a portable document format (PDF) file using 3D Reviewer, the accompanying software of Acrobat 9.0 Pro Extended (Adobe Systems, Inc.) (10, 14, 15).

RESULTS

Sectioned Images and 3D Models of CS

In horizontal, coronal, and sagittal sectioned images at 0.1-mm intervals, the walls of the CS and nearby structures were identified in detail (Figure 2). Based on the horizontal sectioned images, the segmented images including 58 structures (Table 2) were produced. By surface reconstruction of the segmented images, 3D models of the CS and neighboring structures were produced and inputted to a PDF file (261 MB). In the PDF file, the 3D models could be handled and sectioned freely even by laypeople (Figure 3).

CS as a Hexahedron

The shape of the CS was inferred by analysis of published articles and observation of our sectioned images and 3D models. The shape of the CS was a hexahedron consisting of 6 walls and 8 points (Figures 1–3). The lateral wall was larger than all other walls. The superior wall was horizontal; the anterior and posterior walls were coronal; the lateral and medial walls were sagittal; the inferior wall was oblique (Figures 1 and 2).

Lateral Wall of CS

The 4 points of the lateral wall were in contact with the structures as follows: lateral anterosuperior point, anterior clinoid process; lateral anteroinferior point, inferomedial end of superior orbital fissure; lateral posterosuperior point, apex of the petrous part; lateral posteroinferior point, lateral end of the foramen lacerum (Figures 1 and 3B). The ophthalmic veins connected with the anterior border of the lateral wall; the oculomotor and trochlear nerves ran along the superior portion of the lateral wall (Figure 1B). The trigeminal ganglion, located at the posteroinferior portion of the lateral wall, split into the ophthalmic, maxillary, and mandibular nerves (Figures 1B, 2E, 2F, and 3C). The structures were situated on the exterior of the lateral wall (Figure 3D).