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Anatomic Variation of the Optic Strut: Classification Schema, Radiologic Evaluation, and Surgical Relevance

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Abstract

Objective Anatomic variability of the optic strut in location, orientation, and dimensions is relevant in approaching ophthalmic artery aneurysms and tumors of the anterior cavernous sinus, medial sphenoid wing, and optic canal.
Methods In 84 dry human skulls, imaging studies were performed (64-slice computed tomography [CT] scanner, axial view, aligned with the zygomatic arch). Optic strut location related to the prechiasmatic sulcus was classified as presulcal, sulcal, postsulcal, and asymmetric. Morphometric analysis was performed.
Results The optic strut was presulcal in 11.9% specimens (posteromedial margin bilaterally anterior to limbus sphenoidale), sulcal in 44% (posteromedial part adjacent to the sulcus's anterior two thirds bilaterally), postsulcal in 29.8% (posteromedial margin posterior to the sulcus's anterior two thirds), and asymmetric (left/right) in 14.3%. Optic strut length, width, and thickness measured 6.54 ± 1.69 mm, 4.23 ± 0.69 mm, and 3.01 ± 0.79 mm, respectively. Optic canal diameter was 5.14 ± 0.47 mm anteriorly and 4.79 ± 0.64 mm posteriorly. Angulation was flat (>45 degrees) in 13% or acute (<45 degrees) in 87% specimens.
Conclusions Anatomical variations in the optic strut are significant in planning for anterior clinoidectomy and optic-canal decompression. Our optic strut classification considers these variations relative to the prechiasmatic sulcus on preoperative imaging.

Keywords
- optic strut
- optic canal
- anatomy
- morphometric analysis
- prechiasmatic sulcus

Introduction

Understanding the optic strut, anterior clinoid process, and adjacent anatomical structures is important for planning a neurosurgical approach to ophthalmic artery aneurysms and tumors involving the anterior cavernous sinus, medial sphenoid wing, and optic canal. Following Parkinson's first description of surgical approach to the cavernous sinus, many have contributed to understanding the microsurgical anatomy that is relevant to treatment of vascular and neoplastic lesions in this region.[1] Although much attention has been

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paid to the anatomical variation of the anterior clinoid process and its removal using intradural and extradural techniques, a paucity of data exists regarding the optic strut. The optic strut was first defined as the "sphenoid strut" by Jefferson in his 1936 radiographic study.[2] This pillar of bone connects the body of the sphenoid bone to the medial inferior portion of the posterior projection of the lesser wing of the sphenoid, that is, the medial inferior aspect of the anterior clinoid process.

In this computed tomography (CT) imaging-based study, we evaluate the anatomic variability (i.e., position and angulation) of the optic strut in 84 human skulls and propose a classification schema of optic strut position relative to the prechiasmatic sulcus. In addition to reporting the physical characteristics of the optic strut and canal, we discuss its relevance to surgical approaches and presurgical planning.

Materials and Methods

We evaluated the region of the optic canal, optic strut, prechiasmatic sulcus, and anterior clinoid process in 84 dry human skulls. The physical dimensions of the optic strut (i.e., length, width, thickness) and diameter of the optic canal were measured using calipers and variable ball gauges. Observing the location of the posteromedial margin of the optic strut relative to the prechiasmatic sulcus, our novel classification schema grouped the specimens into one of four types as presulcal, sulcal, postsulcal, or asymmetric (►Fig. 1). Angulation of the optic strut was also evaluated grossly as noted within the sagittal plane; specimens were classified as steep (acute angle) or flat (wide angle). Measurements were completed twice by one author (WDT); 15 specimens were rechecked by two authors (RGK, JTK) to ensure that the technique was accurate, reproducible, and without significant interobserver variability.

For each dry human skull specimen, CT scans were performed by a 64-detector scanner in a standardized axial plane, aligned with the zygomatic arch. Sections of 0.6-mm thickness were obtained helically using a 512 by 512 matrix and a 22-cm field of view, resulting in a voxel size of $0.43 \times 0.43 \times 0.6$ mm. Bone algorithm was used for reconstruction. We used OsiriX DICOM viewer software version 3.2.1 32-bit (Pixmeo, Geneva, Switzerland) to more accurately evaluate the optic strut angle—that is, with real-time multiplanar reformations of the image dataset. This resulted in multiplanar 0.6 mm images, evaluable in any imaging plane. Assessment of the images for bony detail was performed using a window and level setting that best demonstrated the osseous anatomic details; this window width was approximately 5600 at a level of 1000. Images were first oriented in the sagittal plane so that the hard palate aligned horizontal. In the coronal plane slice in which the optic strut was widest, a baseline was drawn across the skull base. Next, a line perpendicular to the base was drawn. The angle was measured between an axial line through the center of the optic strut and the line in the vertical plane (►Fig. 2).

Evaluation of random image sets from CT angiogram, LANDMARX neuronavigation, and BRAINLAB neuronavigation studies were used to determine if anatomic details of the optic strut position and angulation were apparent.

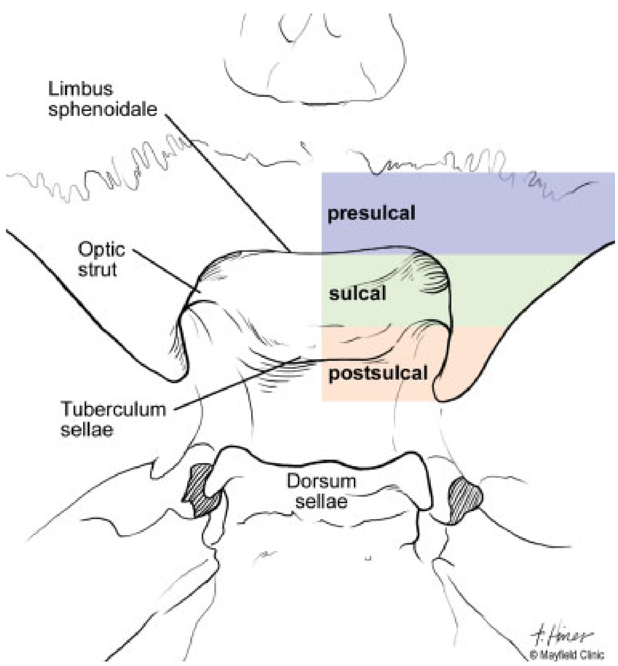

Fig. 1 Classification of the optic strut defined four types based on its location relative to the prechiasmatic sulcus in 84 dry human skulls. The optic strut was classified as *presulcal* if its superior medial limit was located anterior or adjacent to the limbus spenoidale; *sulcal* if adjacent to the anterior two thirds of the prechiasmatic sulcus; *postsulcal* if located posterior to the anterior two thirds of the prechiasmatic sulcus; or a*symmetric* when its location in a single specimen differed between the left and right sides. (Reprinted with permission from the Mayfield Clinic.)

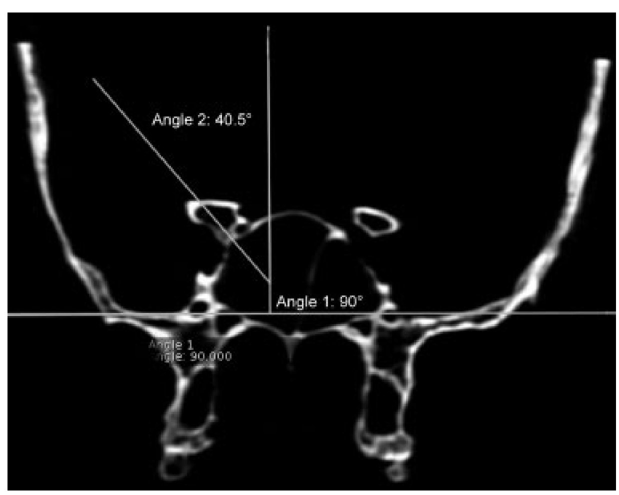

Fig. 2 Evaluation of optic strut angle. Using OsiriX DICOM viewer software version 3.2.1 32-bit (Pixmeo), images were first oriented in the sagittal plane by aligning the hard palate parallel to the plane of the floor. In the coronal plane slice in which the optic strut was widest, a baseline was drawn across the skull base. Next, a perpendicular line to the base was drawn before measuring the angle made between an axial line through the center of the optic strut and the line in the vertical plane. (Reprinted with permission from the Mayfield Clinic.)

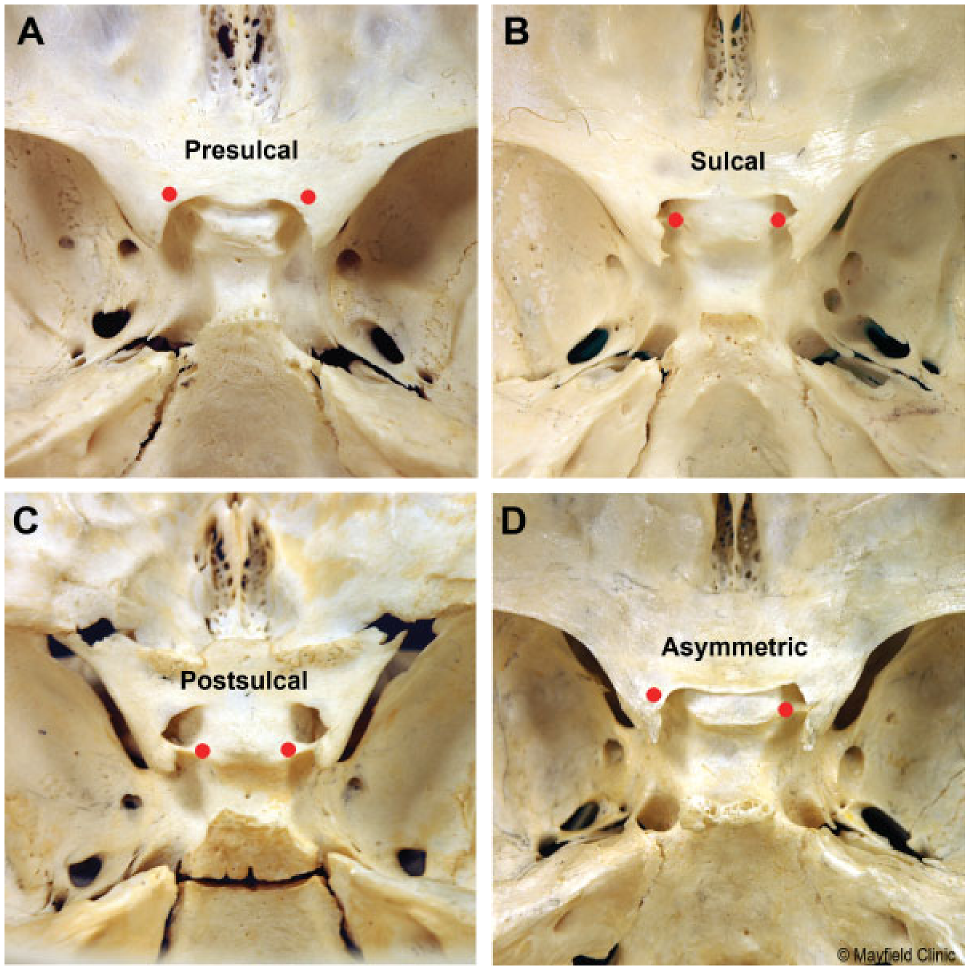

Fig. 3 Anterior-posterior position of the optic strut in 84 specimens. Relative to the prechiasmatic sulcus, the optic strut was presulcal (**A**) in 10 (11.9%) specimens, sulcal (**B**) in 37 (44%) specimens, postsulcal (**C**) in 25 (29.7%) specimens, and asymmetric (**D**; left/right sides) in 12 (14.3%) specimens. (Reprinted with permission from the Mayfield Clinic.)

Results

After using the varied locations to classify the optic strut relative to the prechiasmatic sulcus, we determined the incidence of each of the four types in the 84 dry skulls (►**Fig. 1**). The optic strut was considered presulcal in 11.9% of specimens when its posteromedial margin bilaterally was located anterior to the limbus sphenoidale, sulcal in 44% when it was adjacent to the anterior two thirds of the sulcus bilaterally, postsulcal in 29.8% when its posteromedial margin was posterior to the anterior two thirds of the prechiasmatic sulcus, and asymmetrical (left-right) with respect to its position in 14.3% of specimens (►**Fig. 3**). The incidence of a caroticoclinoid canal was 40% in the presulcal group, 13.5% in the sulcal group, 8% in the post-sulcal group, and 25% in the asymmetric specimens (►**Table 1**).

Table 1 Incidence of caroticoclinoid foramen relative to optic strut location

Classification	No. specimens	Incidence no. (%)
Presulcal	10	4 (40%), all bilateral
Sulcal	37	5 (13.5%), 3 of 5 bilateral
Postsulcal	25	2 (8%)
Asymmetric	12	3 (25%), 1 of 3 bilateral

The shape of the optic strut ranged from ovoid (like the wing of a plane) to round. Measurements of the length, width, and thickness of the optic strut were 6.54 ± 1.69, 4.23 ± 0.67, and 3.01 ± 0.79 mm, respectively. Subgroup evaluation of these parameters showed no statistically significant differences. The optic canal diameter was 5.14 ± 0.47 mm at its anterior aspect and 4.79 ± 0.64 mm at its posterior opening.

In each group, the mean angle of the optic strut in the coronal plane from the vertical ranged from 21.4 to 56.5 degrees (mean 38.93 ± 5.42 degrees) (►**Table 2**). We observed that an angle tended to widen as the optic strut was positioned more posteriorly. Strut angle was >45 degrees in 20% of postsulcal specimens.

Table 2 Optic strut angle measured in the coronal plane

Classification	Mean angle (degrees)	Range (degrees)
Overall	39.23 ± 5.97	
Presulcal	32.98 ± 5.53	21.39–41.22
Sulcal	39.71 ± 5.06	27.38–48.02
Postsulcal	41.54 ± 5.88	30.57–56.51
Asymmetric	38.57 ± 5.36	28.11–47.37

Discussion

In this study, we identified significant variability in both the anterior-posterior (AP) position of the optic strut and the angle of the strut relative to a standard vertical plane. Relative to the prechiasmatic sulcus, our classification of the optic strut AP location in 84 skulls revealed that the most common position was sulcal or adjacent to the prechiasmatic sulcus (44%), followed by postsulcal (29.7%) when located posteriorly, asymmetric (left/right sides in 14.3%), and presulcal (12%) when located anteriorly. With respect to the vertical plane, the optic strut angle varied widely, 21.39 to 56.51 degrees; this contrasts with the description of a relatively static angle of 53 degrees by Parkinson.[1] Interestingly, we also note a trend toward wider angles among more posteriorly located struts. We propose the utility of these two characteristics, optic strut position and angulation, during preoperative planning for cases that require access to the anterior cavernous sinus, internal carotid artery, ophthalmic artery, and optic canal.

Embryological Development of the Sphenoid Bone: Considerations for the Optic Strut

The variability of the bony anatomy of the skull base and its subsequent import to neurosurgeons navigating its corridors stems from its embryologic origins. The development of the sphenoid bone dictates the physical characteristics of the optic strut, anterior clinoid process, and optic canal. As reported by Lang, the complexity of the ossification process of the sphenoid bone contributes to normal anatomic variants.[3] Kodama defined 10 ossification centers of the sphenoid bone. Specifically relevant to our discussion is the fact that the basisphenoid portion includes two segments or ossification centers of the optic strut. First, an anteroinferior segment extends from the lesser wing of the sphenoid and second, a posterosuperior segment extends from the lesser wing to the presphenoid.[4] These two bony ridges grow toward each other, ultimately fusing (►**Fig. 4**).[4,5]

In the era preceding CT scan and digital subtraction angiography, a detailed evaluation of variation of the calvarium on x-rays often provided important information about the localization of pathology. In particular, the radiologic appearance of the optic canal and optic strut could suggest the presence of lesions, such as infraclinoid aneurysms, optic gliomas, or other orbital skull base lesions.[6–10] Even in the absence of pathology, the complexity of embryologic devel-

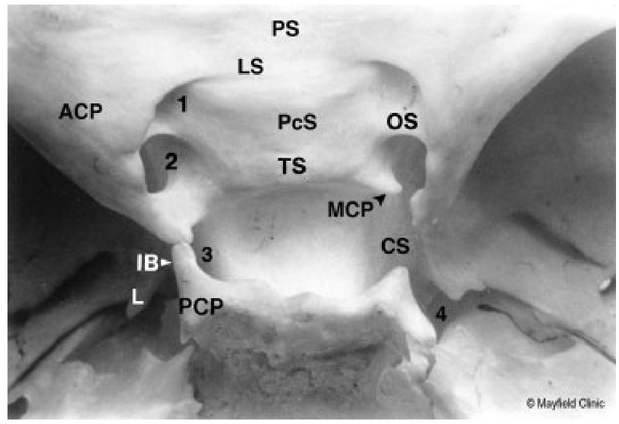

Fig. 4 Superior aspect of the sellar region. 1, optic canal; 2, caroticoclinoid foramen; 3, interclinoid foramen; 4, foramen lacerum; ACP, anterior clinoid process; CS, carotid sulcus; IB, interclinoid bridge; L, lingula; LS, limbus sphenoidale; MCP, middle clinoid process; OS, optic strut; PCP, posterior clinoid process; PcS, prechiasmatic sulcus; PS, planum (jugum) sphenoidale; TS, tuberculum sellae. (Reprinted with permission from the Mayfield Clinic.)

opment of the sphenoid bone can result in the many physical variations observed.[3,11,12]

Parkinson[13,14] and Dolenc[15,16] made notable contributions in describing safe surgical access to tumors and aneurysms in the region of the anterior cavernous sinus, superior orbital fissure, and optic canal. In providing the first detailed quantification of the optic strut, Parkinson described it as wing-shaped, with ranges in width from 2.5 to 4.0 mm and length from 4.0 to 8.0 mm.[14] In our series of 84 skulls, we similarly found width and length ranged 4.23 ± 0.67 mm and 6.54 ± 1.7 mm, respectively (data not shown).

In their extensive discourse on the anatomic variants important for a surgeon's approach to the cavernous sinus, Inoue et al highlighted the anterior clinoidectomy to "open up the clinoid space" to then gain access to the upper portion of the intracavernous segment of the internal carotid artery (ICA).[17] The authors noted that whether a caroticoclinoid foramen was present varied; this foramen was a variant of the medial sphenoid anatomy first described by Keyes.[18] Inoue et al additionally described the technical difficulty in removing the anterior clinoid process (ACP) in cases when a caroticoclinoid foramen or interclinoid bridge was present. However, they did not make any observation regarding variability of the optic strut.

Numerous surgical descriptions or variations of clinoidectomy have been proposed to facilitate surgical exposure in this region, specifically for isolating or exposing the ICA or ophthalmic artery aneurysms.[19–22] Although these studies detail the dural attachments and morphological variability of the clinoid process itself and optic canal, they did not consider the significance of the optic strut position related to surgical access of the anterior cavernous sinus or the degree of decompression of the optic canal.

Gonzalez et al first identified that the location of an ICA aneurysm relative to the optic strut provides a reliable method to determine whether an aneurysm lay within the subarachnoid space or in the extradural clinoid segment.[23] Confirming this relationship by both anatomic dissection and radiographic imaging, Beretta et al determined that the optic strut marks the dorsal limit of the distal dural ring and thereby may be used to identify intradural versus extradural lesions in preoperative decision making and treatment selections.[24] Despite the recognition of the anatomic relationship of the optic strut to common clinically important vascular lesions, no observations (before our study) elucidated the potential significance of anatomic variations in its location and angle.

We emphasize the importance of the optic strut's anatomic variability because of the increasing use of endoscopic approaches to lesions of the anterior skull base. Thus, this understanding becomes vital in three-dimensional anatomy, the impact of variants on the transnasal exocranial view, and limitations of certain approaches. In an elegant discourse on the endoscopic anatomy relevant to endoscopic endonasal cavernous sinus surgery based on cadaveric findings, Alfieri and Jho highlighted the consistency of the carotico-optic recess and the technique of bone removal to expose the "optic strut triangle."[25] Our data provide important considerations for this or other endoscopic approaches in light of the impact optic strut location (i.e., presulcal or anterior, postsulcal or posterior), particularly for extent of bone removal required or defining potential impediments in access to the surgical target. Further anatomic studies are required to clarify this. In addition, the location of the optic strut may now be a factor in decision making about which surgical approach might be used. For example, in the situation of optic nerve decompression in the setting of trauma or tumor compression, the position and/or angle of the optic strut may be significant for helping to determine which operative procedure—endoscopic transnasal, minimally invasive supraorbital, or pterional approach—would best suit the therapeutic objective.

Conclusions

Our anatomic study defined the variability in position and angulation of the optic strut, discovering significant variations in its AP location. Our broad classification of the optic strut position relative to the prechiasmatic sulcus in 84 skulls found that the strut was sulcal in 44% followed by presulcal in 12%, postsulcal in 30%, and asymmetric in 14% specimens. Of particular interest is that a caroticoclinoid canal is more common when the optic strut position is more anterior (40%) than posterior (8%). This first-time report of optic strut angle evaluated in the coronal plane noted great variability, ranging from 21.4 to 56.5 degrees from vertical. Surgeons approaching lesions involving the paraclinoid region, anterior cavernous sinus, and optic canal will benefit from appreciating these anatomic nuances. These nuances, which can be readily determined on preoperative imaging studies, may have important implications with respect to surgical planning, patient positioning, and intraoperative decision making.

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