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The central sulcus. Perioperative identification and surgical implication

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Abstract

The central sulcus is an important anatomical landmark the location of most of the anatomical structures and cortical lesions are described by their relation to the central sulcus [9,19]. During direct observation of the cerebral cortex, it is not always easy to understand the cortical anatomy of the sulci and gyri due to the presence of arachnoid matter. Furthermore, there often is anatomical variation in this region [13]. Therefore, this paper presents the crucial methods for identifying the central sulcus's exact anatomical location as it is critical for the neurosurgical team and to discuss its surgical implications.

Pertinent anatomy

The central sulcus is located between the frontal and the parietal lobes of the brain, separating the primary motor cortex in the precentral gyrus anteriorly from the primary sensory cortex in the postcentral gyrus posteriorly [9,19]. Classically, the central sulcus is divided into three parts: an upper curvature with an anteriorly directed convexity, a lower curvature that is - although less well defined - also anteriorly directed, and in between, there's a middle curvature with a posteriorly directed convexity. The central sulcus is generally continuous, although an interruption is seen in approximately 1% of cases [10,19]. The approximate percentage of the depth of the superior peak of the central sulcus is 36% of the sulcal length, the inferior peak at 62% of the sulcal length, and the 'Pli de Passage Fronto-Pariétal Moyen' (PPFM), which is a surface landmark of the primary motor area of the hand was at 47% of sulcal length. The mean sulcal depth varies slightly between the two hemispheres being 16.6 ± 1.3 mm for the left central sulcus and 16.4 ± 1.2 mm for the right sulcus [3].

The inferior end of the central sulcus often doesn't reach the sylvian fissure, although there's usually a small bridge connecting the inferior

Keywords
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ends of the precentral and post-central gyri; however, in 19% of cases, there was an anastomosis with the sylvian fissure, in 17% with the anterior subcentral sulcus, and in 7% with the posterior subcentral sulcus. The superior end of the central sulcus, however, extends into the medial surface in the majority of cases, and in the few in which it doesn't reach the superior margin, it can end in a bifurcation. An anastomosis with the cingulate sulcus was only described by Benedikt. The inferior and superior ends have numerous variations in shape (straight shaped, T shaped, Y shaped) and direction, whether anteriorly or posteriorly. The central sulcus can connect with the precentral gyrus, postcentral gyrus, and small free sulcus over the precentral gyrus. The side branches of the central sulcus vary greatly in their location and number. But due to the variability and inconsistency, their clinical and anatomical significance is scarce [10].

Similar variations of the normal sulcal anatomy in the central lobe of the brain were reported by observing the sulcal patterns while studying the in vivo magnetic resonance imaging (MRI) data. The different criteria between the two studies included the straight-shaped inferior end and T-shaped inferior end of the central sulcus, along with the number of sulcal connections with small free sulcus in the left precentral gyrus. Yet, the most observed difference was related to the number of side branches and connections, with more depressions seen in the post-mortem description than in the MRI analysis, which can be attributed to the lower spatial resolution in MRI data [7,10].

Preoperative identification

Perioperative identification of the central sulcus can be done using craniometry which utilizes certain craniometric points as the landmarks from which measurements of the skull and facial structures to analyze specific osseous features in different populations. The application of the craniometric points established the footing of modern neurosurgery to tailor craniotomies in specific areas of attention [11,16].

The Tylor-Haughton method utilized different lines to localize the central sulcus using the Frankfurt plane (which is a line extending from the inferior margin of the orbit to the superior margin of the external auditory meatus), the distance between the two points, the nasion and the inion (Na-In) along the calvarium is divided in quarters (25%-50%-75%), the line from the middle of the orbit to the 75% mark of the (Na-In), which corresponds to the sylvian fissure from the orbit to posterior ear line (a perpendicular line from the mastoid directed upward). The central sulcus is situated 2cm posterior to the 50% mark between (Na-In) corresponding to the superior Rolandic point (SRP), to the connection of the sylvian fissure and condyle line (which is a perpendicular line extending from the mandibular condyle directing upward), corresponding to the inferior Rolandic point (IRP) [16].

According to Broca, the central sulcus is identified by an oblique line between two main points: the superior Rolandic point (SRP) and the inferior Rolandic point (IRP). The SRP can be located from the uppermost point of the second vertical line at its connection with the horizontal line intersecting the Bregma. The IRP is situated at the intersection of the horizontal line from the external angular process of the frontal bone to the lambda suture and the auriculo-bregmatic line [16].

Rothon's method of detecting the central sulcus includes three lines. The first one is the (Na-In) line. The second line represents the sylvian fissure which is an oblique line extending from the outer angular process of the frontal bone to the three-fourths point of the (Na-In) line. The third line is a tilted line extending between the midpoint of the zygomatic arch to the halfway point of the (Na-In) line. The intersection of this last line with the 50% mark on the Na-In line corresponds to the SRP. The IRP is defined at the meeting of the midpoint of the third line with the sylvian fissure [16].

Several methods based on imaging modalities such as computerized tomography (CT) or MRI have been suggested to help neurosurgeons and neuroradiologists in accurately localizing the central sulcus. On conventional CT and MRI, the central sulcus is defined indirectly in relation to cortical or commissural landmarks, which are often easily identified in the normal brain [19].

Radiological efforts to identify the central sulcus are imminent, including the localization of the central sulcus by detecting specific radiological signs. One of the most commonly suggested methods consists of localizing the precentral knob, which can be recognized on the axial plane by the form of the Greek letter inverted 'Omega', which is named the 'Omega sign' [13]. The contralateral Omega sign can be applied to clarify the topographic location of a lesion, giving a quick idea of the relationship between the pathology and the precentral and postcentral gyri preoperatively [2] (Figure 1A).

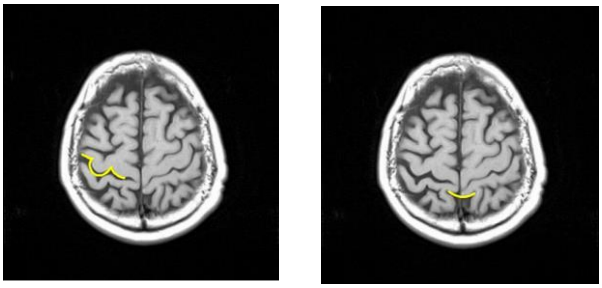

Figure 1. 1A: Brain MRI (Axial section) showing: Omega sign. **1B**: Brain MRI (Axial section) showing: Bracket sign.

While the Omega sign may be a useful anatomic landmark for the preoperative localization of the hand motor area, precise localization of the sign depends on the experience, anatomical distortion, and the need for multiple scanning planes [20].

Other less reliable signs from the axial aspect include the Bracket sign, the upper and the lower T signs, the lower L sign, the M sign, the bifid postcentral gyrus sign, the thin postcentral gyrus sign, the midline sulcus sign, and the 'white grey sign' [5,8,13,15,18]. The 'U sign' characterizes the subcentral gyrus, which is a U-shaped gyrus surrounding the most inferolateral extent of the central sulcus [8,18] (Figure 1B-E).

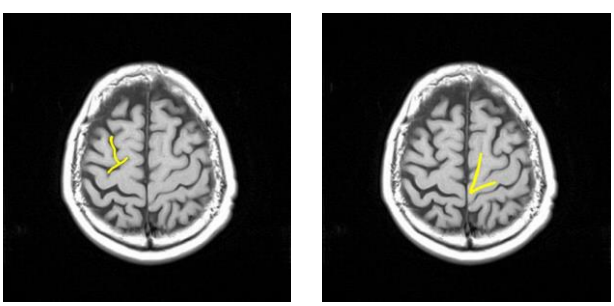

Figure 1. 1C: Brain MRI (Axial section) showing: Upper 'T' sign. **1D**: Brain MRI (Axial section) showing: 'L' sign.

These radiological signs are inconsistently helpful in identifying the central sulcus, and their reported presence ranged between 54.5% and 98.9% [18]. Notably, most of these signs are based on the superior aspect of the central sulcus. The 'invisible cortex sign', on the other hand, is seen as iso-intensity in the peri-rolandic cortices relative to the adjacent white matter on diffused weighted imaging (DWI) MRI. It can be of value in detecting the inferolateral part of the central sulcus on a single axial image without needing to rely on the more superior aspects of the sulcus [15].

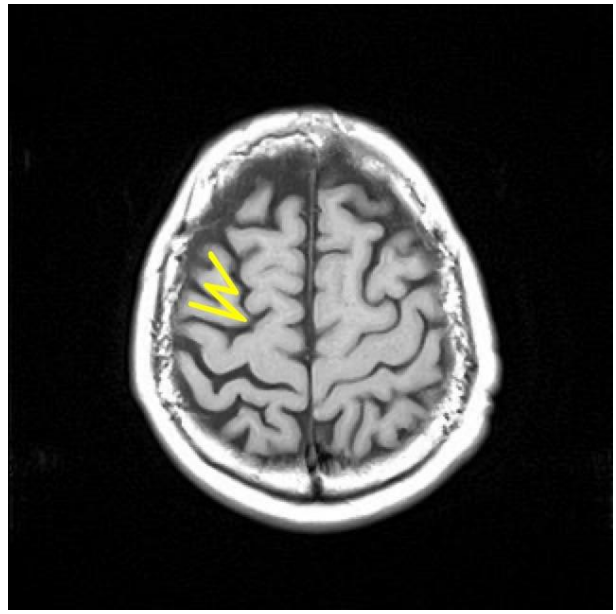

Figure 1. 1E: Brain MRI (Axial section) showing: 'M' sign.

The central sulcus can also be identified by localizing the central sulcal vein using functional MRI (fMRI) [19]. Complex finger movements can be studied to detect the function of the primary motor hand area also by using fMRI and positron emission tomography (PET) scan [20].

Interoperative identification

Intraoperative identification of deep-seated or very small cortical pathologies may be difficult because of the absence of visible anatomical landmarks. Technical development in computer-assisted surgery (CAS) has led to the introduction of frameless image-guided navigation systems for identifying small or deep-seated lesions and intraoperative anatomical guidance [6].

The brain is considered a geometric bulk that can be divided by three imaginary interconnecting spatial planes (horizontal, frontal, and sagittal) based on the Cartesian coordinate system. Any point within the brain can be localized by measuring its distance along these three intersecting planes. Neuro-navigation provides accurate surgical orientation by referencing this coordinate system of the brain with a parallel coordinate system of the threedimensional image data of the patient; therefore, these images become precise point-to-point maps of the corresponding site within the brain [4,14].

Certain intraoperative electrophysiological mapping techniques are combined with neuro-navigation to relate the functional regions to the site of the lesion and to the patient's distinct anatomy [6]. Neuro-navigation reduces the length of surgery, lowers the risk of wound infections, and shortens the time of hospital stay. In addition, it reduces the risk of neurological morbidity by allowing the neurosurgeon to assess the relationship between the lesion and the surgical approach to protect the neighboring critical brain structures [1].

SURGICAL IMPLICATIONS

The operative neurosurgical approaches that expose the central sulcus are classified according to the specific segment of the central sulcus exposed.

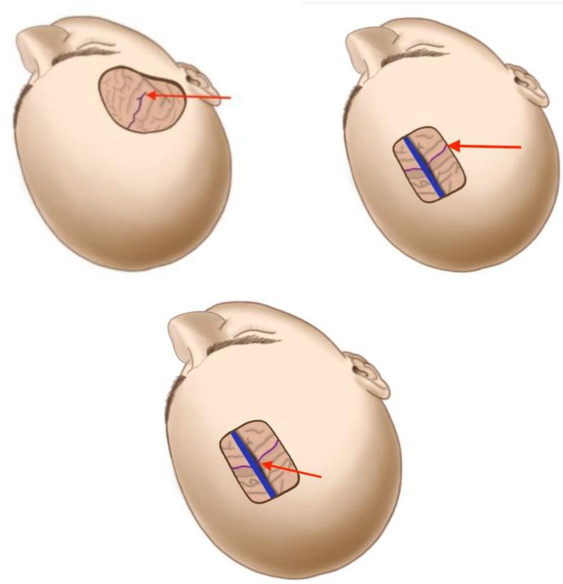

Figure 2. 2A: The surgical approaches that are exposing the central sulcus: Typical pterional approach showing the inferior end of the central sulcus (red arrow). **2B**: The surgical approaches that are exposing the central sulcus: The para sagittal approach shows the superior end of the central sulcus (red arrow). **2C**: The surgical approaches that are exposing the central sulcus: The paramedian approach shows the middle and the medial segment of the central sulcus (red arrow).

The approaches that expose the inferior end of the central sulcus include the typical Pterional approach, which can also reveal the subcentral gyrus and the cortical area surrounding the sylvian fissure [12]. The approaches that expose the superior end of the central sulcus include the parasagittal approach (with or without transcallosal approach) around the midline of the cranial vault for lesions along the midline and the interhemispheric fissure, therefore, it can reveal the upper part of the central sulcus [1]. The approaches that expose the middle segment of the central sulcus include the paramedian retro-coronal approach for eloquent and peri-eloquent cortical lesions (Table 1) (Figure 2).

Table 1. Neurosurgical approaches revealing the central sulcus according to the segment exposed.

Exposed segment of the central sulcus	Surgical approach	Description of the approach
Inferior end of the central sulcus	Typical Pterional approach	Pterional craniotomies expose the Sylvian fissure with the inferior part of the middle frontal gyrus, inferior frontal gyrus, superior temporal gyrus, and the middle temporal gyrus. This approach is indicated for vascular pathologies arising from the circle of Willis, lesions located in or around the cavernous sinus, the sella turcia, and the parasellar and subfrontal regions (12).
The superior end of the central sulcus	Parasagittal approach with or without transcallosal approach	The parasagittal approach is indicated in craniotomies to reach the midline of the cranial vault, which require safe exposure of the superior sagittal sinus or its boundaries. Used mainly in common lesions of the midline of the cranial vault, including parasagittal and Falcine meningiomas, along with lateral and third ventricle lesions, which often directly involve the superior sagittal sinus (1).
The middle segment of the central sulcus	Paramedian retro-coronal approach	It is the parasagittal approach when the targeted lesions are cortical or subcortical. Particularly when the lesions are around the central sulcus, i.e., lesions deep or within the precentral and postcentral gyrus. These pathologies can

		be approached by parasagittal or paramedian craniotomy located behind the coronal suture. This approach will expose the middle segment of the central sulcus and does not include the lateral end or the medial end segments of the sulcus.

Limitations

There are multiple shortcomings in almost all the methods for central sulcus identification, including the numerous anatomical variations and inaccuracy of the imaging modalities, the invasiveness, time consuming, as well as unavailability of fMRI or neuro-navigation [10,18,20].

Considering the risk and the eloquence of the area and the lack of the exact operative knowledge for most neurosurgeons in the pericentral area. Recognition of all the variations and revision of all the identification methods aid the neurosurgeons in identifying the central sulcus will be of critical value for the success of the surgery and improving the patients' outcome.

Based on the above, although the advancement of imaging techniques to has a huge value in localizing the central sulcus, however, central sulcus identification still forms a surgical challenge for most neurosurgeons. Utilizing preoperative craniometry, preoperative imaging identification methods, intraoperative neuro-navigation, intraoperative neurophysiological electrophysiological monitoring, and cortical stimulation as a collaborative effort will definitely increase the safety of the surgery in any approach targeting the pericentral areas.

Conclusion

Although the central sulcus is a very important anatomical landmark, variability in its parts and anatomy can make it difficult to readily identify it. Integrating the preoperative and intraoperative techniques described can minimize the complications of false identification in surgery, and further understanding of the variability in the anatomy and its surgical implication helps increase the safety of surgery.

Abbreviations

CAS: Computed assisted surgery,
CT: Computed tomography,
DWI: Diffuse weighted imaging,
fMRI: Functional magnetic resonance imaging,
IN: Inion,
IRP: Inferior Rolandic point,
MRI: Magnetic resonance imaging,
Na: Nasion,
PET: Positron emission tomography,
PPFM: Pli de Passage Fronto-Pariétal Moyen,
SRP: Superior Rolandic point.

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