Review

CENTRAL CEREBRAL SULCUS: ANATOMY, IMAGING METHODS AND CLINICAL SIGNIFICANCE

K. Mine Erbil, M.D., Ph.D. / M. Mustafa Aldur, M.D., Ph.D.
Deniz Demiryürek, M.D., Ph.D. / Alp Bayramoğlu, M.D., Ph.D.

Department of Anatomy, Faculty of Medicine, Hacettepe University, Ankara, Turkey.

The cerebral hemispheres are subdivided into a number of lobes by sulci and fissures. The most striking sulci on the convex surface of the brain are the lateral sulcus and the central sulcus. The central sulcus (of Rolando) is a deep and usually continuous furrow running downward and slightly forward from the middle of the superior border of the hemisphere to the lateral sulcus without quite reaching the latter. The sulcus shows two kneelike bends and usually incises the superior border to reach the medial surface. The vertical precentral sulcus runs parallel to the central sulcus and it is sometimes broken up into superior and inferior segments. The postcentral sulcus is also usually broken up into superior and inferior segments and runs parallel to the central sulcus (1).

Cerebral convolutions appear in man in the fifth fetal month and continue their development upto the first postnatal year. The first convolutions to appear, the primary ones (such as the central and calcarine fissures) and secondary ones (such as the parieto-occipital sulcus) are relatively constant in their location, configuration and relationship to cortical architectonic fields. The central, precentral and postcentral sulci appear, each in two parts, upper and lower, which usually coalesce shortly afterwards although they may remain discontinuous (2-4).

The brain is an unusual organ in that many of its most important functional centers are located on its surface. It has been mapped and divided into a number of distinctive areas that differ from each other. Important functional centers of the body, like motion, sensation, hearing, visualizing and speaking are located on certain gyri of the cortex. These centers are in close relation with the sulci of the brain. Neurosurgeons who are preparing to resect a lesion would like to have a noninvasive means of assessing its location relative to these critical areas (5).

It is very important to know the surface anatomy of the brain for several reasons. First, although the boundaries of macroanatomic areas do not necessarily correspond exactly with functional areas, high-quality brain images can aid in planning surgical procedures and, particularly, in establishing optimal surgical approaches so that functional disruptions are minimized. Second, it has been suggested that abnormal variations in sizes and shapes of parts of the brain are associated with a number of functional impairments, such as dyslexia, Down syndrome, dementia of depression, human immunodeficiency virus related dementia, mania, schizophrenia and Huntington's disease. The sulci are used for the localization of various pathologies deep to the cortex. Precise

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Correspondance to: K. Mine Erbil, M.D. - Department of Anatomy, Faculty of Medicine, Hacettepe University, 06100, Ankara, Turkey
e.mail address: merbil@hacettepe.edu.tr

localization of these sulci can aid in localisation of lesions and correlation with functional changes: With the advent of modern techniques, non-invasive visulization and identification of cortical structures have become possible. Anatomic imaging, such as computed tomography (CT) and magnetic resonance imaging (MRI) have greatly enhanced the ability of a neurosurgeon to detect and safely resect intracranial lesions. It is generally accepted that the minor sulci and gyri show large variations from one brain to another but that the major fissures (central, lateral sulci) do not. So that the anatomy and the localisation of the major sulci are important for the neurosurgeons in localising the tumours (6-25).

Localising the central sulcus and consequently the postcentral and precentral sulci is one of the problems encountered by radiologists who try to determine the three-dimensional location of brain lesions. When the brain is held in both hands and rotated it is easy to follow the central sulcus starting from the small paramedian notch of the paracentral lobule. However, finding this sulcus on sagittal anatomical sections is much more difficult and in many cases it can only be identified on each section after reconstruction of the brain. In certain cases surgeons cannot localise the pathology even though the radiologists have well marked the lesion by MRI.

The numerous morphological variations of the central sulcus have been described in Retzius' classical treatise of anatomy published in 1896. They are also noticeable when the two hemispheres of the same brain are compared (26).

Several anatomic and radiological examinations of identifying the sulci have been developed and many variations according to these sulci have been found. Cunningham in 1892 mentioned that in approximately 60 percent of the brains the upper end of the central sulcus reached over the dorsal margin to the medial surface of the hemisphere. In 24 percent of the cases it just reached the top margin of the hemisphere and in the remaining 19 percent the sulcus fell short of the top margin. In approximately 19 percent of the brains in this same series the central sulcus showed a shallow connection with the lateral sulcus. In addition to supporting Cunningham's observations Mickle also noted that the central sulcus may be positioned more forward or backward and may also variously connect to other sulci in the frontal and parietal lobes (27). During our examinations different localisations of the central sulcus was determined in our study groups (12%). As Mickle mentioned the central sulcus was connecting with the precentral sulcus (0.1%) and with the superior frontal sulcus (3.4%) in some of our cases. Connection of the precentral sulcus with the central sulcus was found only in one case bilaterally.

In the last century Bischoff and Retzius published meticulous investigations on the typical course, the variation and embryonic morphogenesis of human cerebral sulci. They concluded that sulci which appear early in embryological development become the less variable and deepest sulci in the adult. Sulci which become obvious after the 8^{th} month of gestation show considerable variations both in their branching pattern and position. The sulci appearing first are called principle sulci. The lateral sulcus, the central sulcus and its parallels and in addition the superior temporal sulcus belong to this category (28).

LeMay et al. mentioned that functional differences of the cerebral hemispheres are great, thus, arteriography offers a method of studying anatomic hemispheric differences (29). Kido et al. marked the superior frontal, precentral and central sulci of fixed brain specimens and then scanned the brains by computed tomography. A constant relationship between the posterior ends of the superior frontal and precentral sulci facilitated accurate identification of the anterior border of the precentral gyrus. They stated that precise localisation of this gyrus can aid in localisation of lesions and correlation with functional changes (30). The frequency of the connection of the posterior ends of the superior frontal sulcus and the precentral sulcus was found as 67.4% in our series.

In Berger's report brain maps derived intraoperatively from patients undergoing tumour resection were correlated retrospetively with MR images, with respect to the precise localisation of the motor cortex, in an attempt to identify useful preoperative MR imaging landmarks that correspond to functional brain regions. The central sulcus and the precentral gyrus were accurately identified in all cases by localising the pair of central sulci seen on high vertex axial images, even though parasagittal and far-lateral sagittal planes were less likely to localise the central sulcus (31). We also used the vertex sections during localising the sulci of the cases as this method was the most effective and the easiest one.

Iwasaki et al. illustrated a new method for identifying the pre- and postcentral gyri on CT and MR images of the brain, on the basis of the pattern of the medullary branches of the cerebral white matter. They stated that the most commonly used method to identify the gyri depends on recognition of the central sulcus by surface arrangement of the sulci. Since MR imaging depicts the medullary branches more clearly than does CT, this new method should facilitate identification of the gyri with either modility (32).

Falk et al. described a method for obtaining clear 3D MR images of the cortical surface of the brain in living human subjects. By combining volume composite and depth encoded images they obtained surface coordinate data that resulted in highly repeatable measurements of sulcal lengths and cortical surface areas in normal adult volunteers. The study indicated that the lateral end of the central sulcus was in a more rostral position on the left side in humans. But there were no siginificant differences in the lengths of the right and left central sulci. In Kido's report it was mentioned that the medial end of the central sulcus was located more rostrally on the right side in human brains, however, they did not report on the lateral end of the central sulcus (33).

In Naidich's review, he stated that MR imaging displays all the gross anatomy of the brain. He classified the major anatomic features of the low-mid convexity. He mentioned that multiple studies in patients and in anatomical material have shown that there are reproducible asymmetries in the surface features of the two hemispheres which appear to be related to the side of cerebral functional dominance. There has been a revival of interest in cerebral asymmetries during the past few years since Geschwind and Levitsky, in 1968 and these asymmetries have been studied for a long time by many authors (34-37).

Vannier et al. tested the repeatability and accuracy of brain surface cortical sulcal lengths measurements obtained with 3D reconstructions of volumetric, gradient-echo MR images. The central sulcus was measured from its beginning (near the superior medial border of the hemisphere) to its end (which is separated from the lateral sulcus by the arched gyrus). At the end he mentioned that an expanded study was required to confirm his results (17).

Greitz, developed an adjustable computerised atlas of the human brain surface which can be adapted to fit individual anatomy. It is primarily intended for positron emission tomography (PET) but may also be used for single photon emission computerised tomography, transmission computerised tomography, magnetic resonance imaging and neuroimaging-based procedures, such as stereotactic surgery and radiotherapy (38).

Sobel et al. purposed to compare MR anatomic and magnetoencephalographic (MEG) functional methods in locating central sulcus and as a conclusion they mentioned that MR anatomic techniques can usually identify the central sulcus, but in the presence of anatomic distortion, the MEG functional method adds significant information (39).

Gallen et al. studied the validity of magnetic source imaging (MSI). Localisations were confirmed intraoperatively by direct cortical recording of somatosensory evoked potentials and/or direct motor stimulation. Complete agreement was found between MSI and intraoperative mapping in locating the central sulcus (40).

According to Yasargil's report, surgically relevant descriptions of the sulcal anatomy and its associated vascularity have until recently been lacking. He mentioned that according to Ono's classification, central sulcus was found to be uninterrupted in 92% of the cases and the postcentral sulcus was found to be uninterrupted in 46% of the cases. The precentral sulcus was an interrupted sulcus in 100% of the cases (41).

Buchner et al. stated that surgery of lesions within or close to the central area of the brain always carries the risk of iatrogenic motor or sensory deficits. In these cases it is impossible to determine from images if a tumour is located in the pre- or postcentral gyrus, particularly if the central sulcus is displaced. Thus the authors used a combination of dipole source analysis of scalp recorded SSEP (somatosensory evoked potentials) with 3D MR imaging as a tool for preoperative localisation of the central sulcus (42).

Naidich et al. studied 50 normal human hemispheres prepared by stripping surface vessels and pia-arachnoid to expose the contours of the gyri and sulci. The use of the anatomic relationships for imaging diagnosis was documented in sagittal MR images of the full width of the brain obtained from 50 male and 50 female patients. Analysis of the anatomic sections and sagittal MR images revealed a typical configuration of sulci that appears to represent the common pattern or archetype. They found that the precentral sulcus separated the precentral gyrus from the superior, middle and inferior frontal gyri anterior to it, except where the middle frontal gyrus fuses with the anterior surface of the precentral gyrus. The central sulcus coursed posteriorly and superiorly to define the posterior surface of the precentral gyrus and the anterior surface of the postcentral gyrus. The central sulcus did not unite with the lateral sulcus. Instead in most cases the lower end of the CS was closed and sealed away from the lateral sulcus by the fusion of the lower ends of the precentral gyrus and postcentral gyrus under the central sulcus. The postcentral sulcus may appear as one long continuous sulcus, as two discontinuous segments designated the superior postcentral sulcus and the inferior postcentral sulcus, or as multiple small segments. According to Naidich further work is required to establish the true validity and reliability of localisation of the sulci (43).

According to Sandor's report major sulci like central sulcus are critical landmarks since they define the boundaries of lobes and serve as rough indicators of functional areas of the cerebral cortex. In normal brains these sulci have the following features: 1- they occur in approximately the same location and orientation on different subjects; 2- they run long distances across the brain surface without being interrupted by secondary cortical folds; 3- they are the deepest features on the cortex. Although they can have quite complex shapes these sulci are among the most constant features on the brain surface (44).

In 1998 Yoshiura et al. localised the characteristic signal intensity and compared it with the location of the anatomically determined sensorimotor cortex in normal and diseased brains. The sensorimotor cortex was located by identifying the central sulcus. As a result the perirolandic low signal intensity seen on MR images is located exactly in the anatomic sensorimotor cortex in normal brains whereas a mismatch can occur in abnormal brains (45).

Preoperatively localisation of the sulci is very important. During surgical approach to deep regions in the cortex the surgeons work on very small areas so the risk of damage to cerebral cortex is highly present. Several anatomic methods have been identified for localisation of the central sulcus since 1800s but according to all the authors studying this field further investiations are required.

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