Despite great advances in image-guided technologies, studying actual brain structures is still one of utmost importance. A detailed study of neuroanatomy through dissections in cadavers can provide the best orientation in that regard. The modern microneurosurgical approaches mainly require gyri and sulci orientation. With the contribution of surgical anatomical studies on the brain surface, several neurosurgical approaches can be easily performed today. Despite considerable knowledge of intracranial anatomy, little is known about eloquent brain parts and their bone relationships. Cranial-cerebral relationships, firstly described in the 19th century by Broca, were reevaluated in this study. Misinterpretation of the gyri and sulci pre- and intraoperatively may increase the complication rates. Identifying the gyri, especially when they are not neighboring the sulci or fissures, which are always persistent in the brain, may be very problematic. Therefore, in this study we especially aimed to highlight the methods to identify the gyri with the guidance of the craniometrical points and sutures.

**Methods**

Ten formalin-fixed adult skulls were obtained. Skulls with the signs of CNS trauma or disease were excluded. The scalp and cranial muscles were removed. The cranial sutures, lines, and craniometrical points were protected, and cranial fissure to cranial vault were evaluated.

**Results.** Three-fourths of the precentral gyrus and postcentral gyrus were in the superior parietal window. The inferior frontal gyrus extended to the inferior parietal window in 80%. The 3 important parts of this gyrus were located below the superior temporal line in all hemispheres. The orbital and triangular parts were in the inferior frontal window, and the opercular part was in the inferior parietal window. The superior temporal gyrus was usually located in the inferior parietal and temporal windows, whereas the supramarginal gyrus and angular gyrus were usually located in the superior and inferior parietal windows. The farthest anterior point of the Heschl gyrus was usually located in the inferior parietal window. The mean positions of arachnoid granulations were measured as 3.8 ± 0.39 cm anterior and 7.3 ± 0.51 cm posterior to the bregma.

**Conclusions.** Given that recognition of the gyral patterns underlying the craniotomies is not always easy, awareness of the coordinates and projections of certain gyri according to the craniometric points may considerably contribute to surgical interventions. (DOI: 10.3171/2008.10.JNS08159)

**Key Words**
- gyral anatomy
- neurosurgical approach
- sulcal anatomy
- surgical anatomy
- window anatomy
and all the remaining bone tissues were removed with the aid of a high-speed drill (Midas Rex Legend Gold Touch) (Fig. 1). The arachnoid granulations and branches of middle meningeal artery on the dura mater were observed (Fig. 2). Then, the dura mater was removed and the cortical structures were inspected. The procedure disclosed 8 windows in each hemisphere: superior frontal, inferior frontal, superior parietal, inferior parietal, sphenoidal, temporal, superior occipital, and inferior occipital windows (Fig. 1). The projections of the precentral gyrus, postcentral gyrus, inferior frontal gyrus, superior temporal gyrus, transverse temporal gyri, Heschl gyrus, genu and splenium of the corpus callosum, supramarginal gyrus, angular gyrus, calcaneum sulcus, and sylvian fissure on the windows were evaluated. Because these important cortical areas were located in 5 of the 8 windows when craniotomies were performed, these 5 windows (inferior frontal, superior parietal, inferior parietal, and temporal and superior occipital) were taken into consideration during evaluation. To perform a detailed investigation of the parts of the inferior frontal gyrus, the sulci that separated the parts were used. The locations of the arachnoid granulations through the sagittal sinus were observed. The morphometric measurements were done from the bone to the midgyral point. The measurements were obtained using a measuring tape (precision 0.1 mm), and a standard goniometer (precision 1°) was used for angular measurements. An analysis of the measurements (mean ± SD) was also performed.

Shrinkage of the cerebral hemispheres may occur at the time of fixation. Given that the reference points and the direction of measurements varied according to the gyrus examined, a constant linear correction factor was not used in this study. Thus, the sagittal distances of a gyrus located close to the middle of the cerebrum, such as precentral gyrus, will not be significantly affected by the shrinkage; however, the distances of the gyrus located far from the middle of the cerebrum, such as the orbital part of inferior frontal gyrus, may be affected more.

Results

Precentral Gyrus

The precentral gyrus was located 4.5 cm (right 4.34 ± 1.06 cm, left 4.66 ± 0.91 cm) behind the bregma on the midline (Fig. 3) and coursed laterally and frontally, creating a 59° (right 58.8 ± 5.49°, left 59.2 ± 4.37°) angle with the sagittal suture. Three-fourths of the precentral gyrus was in the superior parietal window. At the lower margin of the inferior parietal window, the gyrus reached...
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the sylvian fissure. The precentral gyrus extended to the temporal window in some hemispheres (30%). On the lateral surface, the gyrus was only 2.5 cm (right 2.46 ± 0.63 cm, left 2.54 ± 0.54 cm) behind the stephanion (Fig. 3). In most cases (80%), the precentral gyrus was a strip that had no connection with other gyri.

Postcentral Gyrus

The postcentral gyrus was located 6.5 cm (right 6.50 ± 0.68 cm, left 6.50 ± 0.65 cm) behind the bregma on the midline (Fig. 4) and coursed laterally and frontally constituting a 62° (right 61.9° ± 4.33, left 62.1 ± 4.38°) angle with the sagittal suture. Three-fourths of the postcentral gyrus was in the superior parietal window. At the lower margin of the inferior parietal window, the gyrus reached to the sylvian fissure. The postcentral gyrus extended to the temporal window in some hemispheres (10%). On the lateral surface, the gyrus was located 4.1 cm (right 4.07 ± 0.52 cm, left 4.13 ± 0.45 cm) behind the stephanion (Fig. 4). In most of the cases (90%), the postcentral gyrus was a strip that had no connection with other gyri.

Inferior Frontal Gyrus

The end of the inferior frontal gyrus was noted near the stephanion, 1.9 cm (right 1.97 ± 1.04 cm, left 0.89 ± 0.54 cm) posterior to the coronal suture (Fig. 5). Although the inferior frontal gyrus extended to the inferior parietal window in 80% of the cases, it extended to the superior parietal window in 20%. In the cases in which the inferior frontal gyrus extended to the superior parietal window, the end of the gyrus was located 0.7 cm (right 0.70 ± 0.14 cm, left 0.70 ± 0.18 cm) above the superior temporal line. In cases in which the inferior frontal gyrus extended to the inferior parietal window, the end of this gyrus was 1.8 cm (right 2.00 ± 0.75, left 1.70 ± 0.58 cm) below this line (Fig. 5). The sylvian fissure and its branches (anterior and ascending rami) were used to separate the inferior frontal gyrus into 3 parts: orbital, triangular, and opercular. The locations of these 3 important parts were below the superior temporal line in all the hemispheres. The orbital and triangular parts were in the inferior frontal window, and the opercular part was in the inferior parietal window (Fig. 5). The triangular part could be seen in the inferior parietal window (left 60%, right 50%) (Fig. 5), and the opercular part could be seen in inferior frontal window (left 30%, right 40%). The triangular part was located 1.9 cm (right 2.34 ± 1.42 cm, left 1.38 ± 0.63 cm) anterior to the coronal suture. The triangular part was located 1.4 cm (right 0.97 ± 0.54 cm, left 1.85 ± 0.79 cm) below the superior temporal line.

Superior Temporal Gyrus, Transverse Temporal Gyri, and Heschl Gyrus

In all hemispheres, the superior temporal gyrus was located in the inferior parietal and temporal windows, except in 1 hemisphere (5%), in which it was seen in the superior parietal window; the crossing point of this gyrus with the superior temporal line was located 7.9 cm behind the stephanion. The transverse temporal gyrus constitutes the posterior part of the upper surface of the temporal lobe, which is known as the temporal plane. The farthest anterior point of the temporal plane, which was also the anterior boundary of the Heschl gyrus, was usually located in the inferior parietal window. This point was placed on the same vertical line with the beginning point of the ascending ramus of the sylvian fissure and in 1 specimen, the point was located in the temporal window. The posterior-most boundary of the transverse temporal gyrus was in the area where the posterior ramus of the sylvian fissure curved upward. This point was located in the third quarter of the inferior parietal window in all cases.
anterior-most point of the temporal plane was found 2.8 cm (right 2.92 ± 0.80 cm, left 2.61 ± 0.80 cm) inferior to the superior temporal line. This point was located 0.8 cm (right 0.62 ± 0.15 cm, left 0.93 ± 0.39 cm) posterior to the coronal suture.

Supramarginal Gyrus

The point at which the sylvian fissure ended, which terminates in the middle of the supramarginal gyrus, was noted in order to evaluate the location of the gyrus. In all the hemispheres, this point was seen in the superior and inferior parietal windows. It was located 6.0 cm (right 6.03 ± 1.49 cm, left 6.04 ± 0.70 cm) in front of the lambdoid suture. The distance between this point and the sagittal suture was 6.7 cm (right 6.83 ± 1.28 cm, left 6.59 ± 1.32 cm) on the lateral surface of the hemisphere (Fig. 5). The crossing point of the sylvian fissure with the superior temporal line was located 6.4 cm (right 6.40 ± 0.83 cm, left 6.39 ± 0.88 cm) behind the stephanion in 12 hemispheres (right 4, left 8) (Fig. 5). In 80% of the cases, the supramarginal gyrus was seen under the parietal tuber.

Angular Gyrus

The end of the superior temporal sulcus, which terminates in the middle of the angular gyrus, was considered to evaluate the location of the gyrus. In all the hemispheres, this point was seen in the superior and inferior parietal windows. It was located 4.3 cm (right 4.39 ± 1.21 cm, left 4.16 ± 1.00 cm) in front of the lambdoid suture (Fig. 5). The distance between this point and the sagittal suture was 5.0 cm (right 5.01 ± 1.39 cm, left 5.00 ± 1.42 cm) on the lateral surface of the hemisphere (Fig. 5). The crossing point of superior temporal sulcus with superior temporal line was 8.4 cm (right 8.33 ± 0.55 cm, left 8.45 ± 0.54 cm) behind the stephanion. In 20% of the cases, the angular gyrus was located under the parietal tuber.

Calcarine Sulcus

The end of calcarine sulcus on superolateral surface was observed 4.4 cm (right 4.50 ± 1.02 cm, left 4.30 ± 1.13 cm) inferior and 1.7 cm (right 2.00 ± 0.80 cm, left 1.41 ± 0.64 cm) lateral to the lambda. The turning point of calcarine sulcus from the superolateral surface to the medial surface was different on the right and left hemispheres. The location of this point was 4.0 cm (right 4.00 ± 0.82 cm, left 3.90 ± 0.76 cm) inferior and 0.7 cm (right 1.01 ± 0.23 cm, left 0.40 ± 0.26 cm) lateral to the lambda.

Arachnoid Granulations

Arachnoid granulations were accumulated around (especially behind) the bregma (Fig. 2). The superficial veins of the hemispheres drained into these granulations. The area comprising these granulations was supplied by the branches of the middle meningeal artery (Fig. 2). In all the skulls, the positions of arachnoid granulations were measured as 3.9 ± 0.39 cm anterior and 7.3 ± 0.51 cm posterior to the bregma (Fig. 2). These structures were located 2.6 cm (right 2.40 ± 0.43 cm, left 2.77 ± 0.33 cm) laterally to the sagittal suture (Fig. 2).

Corpus Callosum

The distance between the nasion and genu of the corpus callosum was measured as 12.6 ± 0.44 cm, and the distance between the nasion and splenium of corpus callosum was 19.8 ± 0.82 cm.

Discussion

Proper craniotomy of a brain lesion and correct interpretation of the gyral structures under the craniotomy site is one of the most important steps in successful surgery.1,2,20,25 There are very few persistent sulci in the brain that are always present in every individual. Therefore, identification of gyral structures may not be easy. To identify these structures, the use of bone structures of the cranium may prove to be beneficial. To this end, in our study a window anatomy model was developed.

The linear correction factors of 0.88–0.94 can be determined at the usual fixation in ~4% formalin.14 However, the measurements refer to a relatively small number of cases. Given that the measurements were obtained after 10% formalin fixation, calculations of absolute linear measurements had to include ~0.9 as a shrinkage correction factor in the present study. Since the reference points and the direction of measurements varied according to the gyrus examined, a constant linear correction factor was not used in this study.

A reliable identification of functional cortical areas can be achieved through preoperative cortical mapping.10,21,26,29 In addition, the combination of the data obtained from neuronavigation systems and functional MR imaging evaluations may provide information on the functional cortical areas.12,15 The integration of sulcal and functional information of the brain and the importance of imaging were described by Jannin et al.6 In another study, Gong et al.4 described some cortical area findings obtained through diffusion weighted MR imaging techniques. The MR imaging techniques can also be used for superficial brain lesions in the precentral gyrus, as described by Hattingen et al.5 This study reformatted images for fast and easy determination of the locations of the precentral gyrus and perirolandic lesions. A similar study was reported by Krishnan et al.9 In that study, the authors described the functional MR imaging–integrated neuronavigation for correlation between the cranial lesion and motor cortex, which was one of the objectives of our study. Although we have used MR imaging assistance in surgical practice, the study itself focused on the detection of the important cortical areas by using craniometric points in the skull. This detailed anatomical information may prove useful in finding and interpreting the areas under the bone.

The positive contribution of advanced technology to surgical outcome is undeniable. However, it is also an undeniable fact that anatomical knowledge and 3D orientation are indispensable for successful surgical outcome. Another indication for the importance of anatomical knowledge is the fact that advanced technology is not always available and applicable.15,16
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the interhemispheric fissure, and the other end is in the sylvian fissure. These gyri project forward with an angle of 60°. Thus, their reflections on the midline are significantly different from those of the sylvian fissure. Consequently, a craniotomy closer to the midline will have a different motor and sensorial cortex orientation from that of a craniotomy closer to the sylvian fissure. The closer the precentral gyrus is to the sylvian fissure, the closer it is to the coronal suture, with the distance reducing to as much as 2.8 cm at the stephanion.

The sylvian fissure is a very important corridor for neurosurgical interventions. The anterior and ascending rami are of great importance in defining the inferior frontal gyri, and the posterior ramus is important in defining the supramarginal gyrus. If the rami of the sylvian fissures are not observed in the craniotomy area preoperatively, the definition of these gyri may be highly challenging. In that case, the presence of inferior frontal, precentral, and postcentral gyri in the area on the superior temporal line (in other words, in the inferior parietal window) should be kept in mind. No sulcal structures exist that will aid in defining the angular and supramarginal gyri. Particularly when the posterior ramus of the sylvian fissure is not observed in the craniotomy area, it is important to know that the area behind the external ear canal, where the inferior parietal and superior parietal windows merge, is where the supramarginal and angular gyri are located. A wide opening of the sylvian fissure is recommended for many neurosurgical interventions. It should be kept in mind that all of the important cortical areas such as the Broca, Wernicke, motor and sensory cortices, and Heschl gyrus neighbor the sylvian fissure, and in opening the sylvian fissure, trauma is likely to occur to the pial or vascular structures, which may lead to loss of functions related to these areas.

One point to consider in interventions to the midline lesions of the brain is the location of the arachnoid villi. These villi become denser right below the coronal suture and nearly 5 cm behind the coronal suture. Because these areas point to the venous drainage areas, the venous drainage of the cortical areas may be damaged during craniotomy and dura opening. The genu of the corpus callosum is located nearly in the middle of the nasion-bregma space. Most of the distal anterior cerebral artery aneurysms are found in the genu region. Thus, in planning an interhemispheric intervention, it is important that the posterior border of the craniotomy be 1 cm ahead of the coronal suture while clipping any aneurysm located in this area. This will help refrain from unnecessary hemorrhage and potential venous injuries.

The same should be observed in interventions to the Monro foramen (the interventricular foramen). The Monro foramen is always in front of the coronal suture and for pathological entities that are not behind the Monro foramen, the craniotomy should not exceed the coronal suture. The splenium of the corpus callosum is ~10 cm away from the bregma, and this area is located at the level of the interhemispheric origin of the postcentral gyrus. Keeping this in mind when handling the pathologies of this area may contribute in defining the postcentral gyrus.

The calcarine sulcus is located 4 cm below the lamb-

da, and because of its proximity to the confluence of sinuses, it can easily be recognized during surgery. However, it should be kept in mind that the confluence of sinuses in particular may deviate 2 cm from the midline to the right, and thus, the calcarine sulcus may deviate from the midline on the right.

Conclusions

Given that recognition of the gyral patterns underlying the craniotomies is not always easy, awareness of the coordinates and projections of certain gyri according to the craniometric points may considerably contribute to surgical intervention.

Disclaimer

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

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