Okajimas Folia Anat. Jpn., 75(2-3): 155-162, August, 1998

Localization of the Central Sulcus and Adjacent Sulci in Human: A Study by MRI

By

Mine ERBİL*, Selda ÖNDEROĞLU, Nuran YENER**, Meserret CUMHUR*** and Ayşenur CİLA******

*Research Fellow in Department of Anatomy, Faculty of Medicine, Hacettepe University, Ankara, Turkey
**Associate Professor in Department of Anatomy, Faculty of Medicine, Hacettepe University, Ankara, Turkey
***Professor in Department of Anatomy, Faculty of Medicine, Hacettepe University, Ankara, Turkey
****Associate Professor in Department of Radiology, Faculty of Medicine, Hacettepe University, Ankara, Turkey

– Received for Publication, June 30, 1998 –

Key Words: Central sulcus, Precentral sulcus, Superior frontal sulcus, Postcentral sulcus, Marginal ramus, Variation, MRI

Summary: Variations in localization of the central sulcus and the sulci around the central sulcus namely the superior frontal sulcus, precentral sulcus, postcentral sulcus, marginal ramus of cingulate sulcus were studied in vertex sections retrospectively by magnetic resonance imaging (MRI) method in 3580 cases. Out of total number of cases, 1000 who did not show any macroscopic intracranial pathology were carefully selected for research. Additionally, 0–1 age group was excluded from the study because the sulci develop in first year of postnatal life, excluding the possibility of considering these as anatomical variations. Thus, the total number of cases is decreased to 990.

16 variations related to localization of the superior frontal sulcus, precentral sulcus, central sulcus, postcentral sulcus and the marginal ramus of the cingulate sulcus were identified. The asymmetries of the sulci, the most variable sulci and the distribution of the variations according to sex were statistically analysed.

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. The sulci are used for the localization of various pathologies deep to the cortex. Precise localization of these sulci can aid in localization of lesions and correlation with functional changes. With the advent of modern techniques, noninvazive visualization 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) do not. So that the anatomy of the major sulci is more important for the neurosurgeons[1–4,5,6–9,10,11,12,13,14,15–17]. Greitz (1991), developed an adjustable computerised atlas of 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. He showed two structures included in the data base which were not found in anatomic literature consulted. These two unnamed sulci, one on the orbital surface of the frontal lobe, lateral to gyrus rectus and one on its medial surface, anterior to and outlining the paracentral lobulus. These were consistently present in the anatomic specimens. These sulci were named as sulcus subfrontalis and sulcus paracentralis respectively[18].

During surgical approach to deep regions in the cortex the risk of damage to cerebral cortex is present. In certain cases surgeons can not localize the pathology although the radiologists have well marked the lesion by magnetic resonance imaging

For correspondance please address to: Mine Erbil, M.D., Ph.D., Hacettepe University, Faculty of Medicine, Department of Anatomy, 06100 Ankara, Turkey.

(MRI). Preoperatively, determining the localization of sulci is very important, as the surgeons work on very small regions[17,19,20,21]. It is generally stressed that the sulci must be localized by noninvazive methods like magnetic resonance imaging (MRI) to minimize the risk of damage[22,23].

Various investigations on localization of sulci done by different techniques were reported earlier[6–9,10,14,15]. The asymmetries of sulci were also studied in recent years and supposed that some of the neurologic diseases (Pick, dyslexia, autism and difficulty of learning) and the cerebral dominance may be related to these asymmetries[24,25–27]. However it is stated that further work is needed to establish the true validity and reliability of the localizations of sulci in a large series of cases[21]. The study presented here includes a large series of cases (990) and the most sensitive and noninvazive technique of the recent years, the MRI method.

Materials and Methods

Variations in localization of the central sulcus and the superior frontal sulcus, precentral sulcus, postcentral sulcus, marginal ramus of cingulate sulcus in human' right and left hemispheres were examined from the vertex sections retrospectively by MRI method (Cyro Scan T5, Philips the Netherlands) in 3580 cases. Out of total number of cases, 1000 who did not show any macroscopic intracranial pathology were carefully selected for research. The study group included cases between 1–86 ages. 0–1 age group was excluded from the study due to the fact that different localizations of sulci occur during their development in the first year of postnatal life, excluding the possibility of considering these as anatomical variations[28]. Thus the total number of cases is decreased to 990. Various localizations of the central sulcus, superior frontal sulcus, precentral sulcus, postcentral sulcus and the sulci around the paracentral lobule were determined.

The asymmetries of the sulci, the most variable sulci and the distribution of variations according to the sex, right, left and the bilateral hemispheres were evaluated and statistically analysed by chi-square test.

Results

16 variations related to the superior frontal sulcus, precentral sulcus, central sulcus and the postcentral sulcus were identified in vertex sections. When distribution of these variations was examined according to sex, different localizations in men and women were found to be statistically insignificant. The most variable localizations were in the superior frontal sulcus (38.2%) and the least were in the marginal ramus of cingulate sulcus (0.26%) in the study group. (Table 1)

There were 4 types of variations in localization of the superior frontal sulcus; they were the superior frontal sulcus which was small in the middle (22.9%) (Fig. 1, arrow), connecting with the precentral sulcus (67.4%) (Fig. 2, arrow), passing the precentral sulcus (21.8%) (Fig. 3, arrow) and connecting with the central sulcus (3.4%) (Fig. 4, arrow). (Table 2)

The frequency of variation in localization of the precentral sulcus was 27%. 5 variations related to the precentral sulcus were identified; laterally fork shaped (10.5%) (Fig. 5, arrow), medially fork shaped (57.8%) (Fig. 6, arrow), medially connecting with the central sulcus (0.1%) (Fig. 7, arrow), connecting with the midline (2.2%) (Fig. 8, arrow) and a small one (11.1%) (Fig. 9, arrow). Connection of the precentral sulcus with the central sulcus was found only in one case, bilateraly. (Table 3)

Different localizations of the central sulcus was determined in the study group (12%). There were two types of localization of central sulcus; connecting with the midline (34.6%) (Fig. 10, arrow) and the fork shaped central sulcus (1.8%) (Fig. 11, arrow). (Table 4)

The frequency of the variations in localization of the postcentral sulcus was 22.4%. They were connecting with the midline (20.6%) (Fig. 12, arrow), medially fork shaped (17.8%) (Fig. 13, arrow),

Table 1. Distribution of sulci according to right, left, bilateral localizations and to the sex (L: left, R: Right, BL: Bilateral)

CEREBRAL SULCI		FEMALE	MALE	TOTAL
SUPERIOR FRONTAL SULCUS	L	233	161	394
	R	238	157	395
	BL	197	159	356
PRECENTRAL SULCUS	L	169	147	316
	R	158	131	289
	BL	114	91	205
CENTRAL SULCUS	L	61	51	112
	R	24	25	49
	BL	97	103	200
POSTCENTRAL SULCUS	L	197	140	337
	R	97	94	191
	BL	87	58	145
MARGINAL RAMUS	L	4	2	6
	R	1	–	1
	BL	–	1	1
TOTAL		1677	1320	2997

Table 2. Distribution of superior frontal sulcus according to the left, right, bilateral localizations and to the sex (L: Left, R: Right, BL: Bilateral)

SUPERIOR FRONTAL SULCUS		FEMALE	MALE	TOTAL
SMALL	L	61	36	97
IN THE	R	54	47	101
MIDDLE	BL	19	10	29
CONNECTING WITH	L	105	86	191
PRECENTRAL	R	111	66	177
SULCUS	BL	163	137	300
PASSING THE	L	58	36	94
PRECENTRAL	R	56	39	95
SULCUS	BL	15	12	27
CONNECTING	L	9	3	12
WITH CENTRAL	R	17	5	22
SULCUS	BL	–	–	–
TOTAL		668	477	1145

Table 3. Distribution of precentral sulcus according to left, right, bilateral localizations and to the sex (L: Left, R: Right, BL: Bilateral)

PRECENTRAL SULCUS		FEMALE	MALE	TOTAL
LATERALLY	L	27	21	48
FORK	R	27	24	51
SHAPED	BL	5	–	5
MEDIALLY	L	109	95	204
FORK	R	100	84	184
SHAPED	BL	102	83	185
CONNECTING WITH	L	–	–	–
CENTRAL SULCUS	R	–	–	–
MEDIALLY	BL	–	1	1
CONNECTING	L	7	6	13
TO	R	3	4	7
MIDLINE	BL	1	1	2
	L	26	25	51
SMALL	R	28	19	47
	BL	6	6	12
TOTAL		441	369	810

ending at the anterior side of the marginal ramus (26.1%) (Fig. 14, arrow) and connecting with the marginal ramus (3.3%) (Fig. 15, arrow). (Table 5)

Marginal ramus was the least variable sulcus with respect to other examined sulci (0.26%). There was only one type of variation of that sulcus; the incidance of the fork shaped marginal ramus was 0.8%. (Table 6, Fig. 16, arrow)

The asymmetries between the hemispheres were observed and the frequency of these asymmetries are shown in table 7. Precentral sulcus was the most asymmetric one (39%) and central sulcus showed the minimum asymmetry with respect to other sulci examined (4.5%). (Fig. 17, 18, 19, 20, 21)

The paracentral sulcus and the marginal ramus which are the sulci located nearer to the paracentral lobule were also examined. There was no

Table 4. Distribution of the central sulcus according to the left, right, bilateral localizations and to the sex (L: Left, R: Right, BL: Bilateral)

CENTRAL SULCUS		FEMALE	MALE	TOTAL
CONNECTING	L	54	49	103
TO	R	18	23	41
MIDLINE	BL	97	102	199
FORK	L	7	2	9
SHAPED	R	6	2	8
	BL	–	1	1
TOTAL		182	179	361

Table 5. Distribution of the postcentral sulcus according to the left, right, bilateral localizations and to the sex (L: Left, R: Right, BL: Bilateral)

POSTCENTRAL SULCUS		FEMALE	MALE	TOTAL
CONNECTING	L	39	22	61
TO	R	32	43	75
MIDLINE	BL	38	30	68
MEDIALLY	L	58	46	104
FORK	R	23	18	41
SHAPED	BL	19	13	32
ENDING AT THE	L	93	64	157
ANTERIOR SIDE OF	R	30	29	59
MARGINAL RAMUS	BL	29	14	43
CONNECTING TO	L	7	8	15
MARGINAL	R	12	4	16
RAMUS	BL	1	1	2
TOTAL		381	292	673

Table 6. Distribution of marginal ramus according to the left, right, bilateral localizations and to the sex (L: Left, R: Right, BL: Bilateral)

MARGINAL RAMUS		FEMALE	MALE	TOTAL
FORK	L	4	2	6
SHAPED	R	1	–	1
	BL	–	1	1
TOTAL		5	3	8

Table 7. Distribution of asymmetries according to sex

ASYMMETRIES	FEMALE	MALE	TOTAL
SUPERIOR FRONTAL SULCUS	208	166	374
PRECENTRAL SULCUS	196	191	387
CENTRAL SULCUS	22	23	45
POSTCENTRAL SULCUS	182	150	332
MARGINAL RAMUS	177	131	308
TOTAL	785	661	1446

variation in the localization of those sulci.

Discussion

The importance of localization of the certain sulci in brain have led the investigators to examine the variations of sulci by different techniques.

Kido (1980), marked the superior frontal, precentral and central sulci of fixed brain specimens, then scanned by computed tomography and mentioned that the localization of the sulci is important to localize the masses observed in the brain[8].

Harkey, dissected the sulci of five cadaver brains, by using the operation microscope. The brains were then coronally sectioned to characterize the anatomical relationship between sulci and deep brain structures. Three primary sulci, which reliably provide an excellent operative approach to deep brain structures, were identified. These included the superior frontal sulcus, superior temporal sulcus and the intersection of the interparietal sulcus with the postcentral sulcus[19].

Sobel (1993), compared MRI anatomic and magnetoencephalographic (MEG) functional methods in determining the location of the central sulcus by using eleven healthy subjects and five patients with focal cerebral lesions. The central sulcus was located anatomically with MRI method using axial vertex and sigittal (midline and lateral) images. Of the three different sections, the axial yielded the most consistent results[14].

Naidich *et al.* (1995), reported that the sagittal sections of anatomic specimens and MR images well display the individual gyri and sulci around the low-middle convexity. They used 50 normal human hemispheres obtained postmortem and prepared by stripping surface vessels and pia-arachnoid to expose the contours of the gyri and the sulci. Each hemisphere was sagittaly sectioned. The use of the anatomic relationship for imaging diagnosis was documended in 100 sagittal MR images. They stated that the anatomical relationship described are more nearly constant anteriorly than posteriorly and these variations strongly influence the appearance of the lowmiddle convexity and the ability of the physician to accurately localize structures. The authors mentioned that superior frontal sulcus, precentral sulcus, central sulcus and the postcentral sulcus could have 1, 2, 3 or 4 segments and they classified these cases as right and left hemispheres. The authors also stated that superior frontal sulcus connects with the precentral sulcus in the ratio of 92% at right and 100% at the left hemisphere. In our investigation (990 cases) the superior frontal sulcus was connected with precentral sulcus in the ratio of 17.8% on the right side, 19.2% on the left hemisphere and 30.3% bilaterally. Discordance of these two results may be due to total number of cases and that the classification used in our study is as right, left and bilateral hemispheres. Naidich *et al.* used only the right and left hemispheres in their study. The authors also evaluated the asymmetries of the central sulcus and stated that the central sulcus showed little or no right-left asymmetry, continuous as a segment but they gave no quantification of results. We found that the central sulcus showed an asymmetry in the ratio of 4.5%. This value found for the right-left asymmetry is in accordance with the results of Naidich's study. Naidich also mentioned that these asymmetries were related to cerebral dominance[21].

Steinmetz *et al.* (1990), described the variability in location of functionally important perisylvian landmarks and the calcarine sulcus within the Talairach stereotaxic grid by using 20 healty volunteers (40 hemispheres). They identified no clear right-left asymmetry related to central sulcus and precentral sulcus but the postcentral sulcus was more variable and tended to be located farther posteriorly on the left than contralaterally. In the study presented here, there were 39% asymmetry of the precentral sulcus, 33.5% of postcentral sulcus[29].

Yaşargil (1994), recently reported that the lateral sulcus, collateral sulcus and parietooccipital sulcus had a 100% uninterrupted rate and the calcarine and central sulci were found to be uninterrupted in % 92 of his cases[23].

Kido *et al.* (1980), reported an article on use of the axial technique with CT and identified the posterior margin of the superior frontal sulcus and its relationship with the precentral sulcus and the central sulcus in 92 hemispheres of 50 patients. As a result they stated that when a sulcus was located an average of 4.6 cm. posterior to the superior portion of the coronal sutura, it would most likely to be the central sulcus and the anterior border of the precentral sulcus could be approximated by drawing a line 2 cm. anterior and parallel to the central sulcus[8].

Sobel *et al.* (1993), compared MRI anatomic and magnetoencephalographic (MEG) functional methods in locating the central sulcus by using 11 healthy subjects and 5 patients with focal cerebral lesions. They used axial vertex and sagittal (midline and lateral) sections. The axial method yielded the most consistent interrater results with complete agrement in 76% of sections. The intermethod discordance of the sagittal midline and lateral methods was 32% in control group and 33% in patients. As a result they stated that in the absence of an anatomic distortion, the central sulcus usually could be located on a single vertex axial, sagittal midline or lateral section through the Sylvian fissure using MRI anatomic methods[14].

Iwaswki *et al.*, compared identification of the central sulcus by the pattern of medullary branching of the cerebral white matter with identification by tracing the central sulcus from superior to inferior on axial CT sections of 104 healty subjects and 9 patients with space occupying lesions and cerebral angiograms. The authors described the medullary branching pattern as useful and implied a 100% identification rate but did not give a clear breakdown of his results and did not describe any interobserver comparisons[6].

Falk *et al.* (1991), identified a method for obtaining clear 3D magnetic resonance 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 8 normal adult volunteers. There were no significant difference in the lengths of the right and left central sulci. In an earlier study of endocranial casts from rhesus monkeys (Falk *et al.* 1990) they reported significant asymmetries in the location of both lateral and medial ends of the central sulcus. The findings for rhesus monkeys were consistent with the report by Kido *et al.* (1980)[3].

Approximately 60% of the brains were examined by Conningham, the upper end of the central sulcus was reaching over the dorsal margin to the medial surface of the hemisphere. In approximately 24%, it was just reaching the top margin of the hemisphere and in the remaining 19%, the central sulcus could not reach the top margin. In addition to supporting Cunningham's observation, Mickle also noted that the central sulcus may be positioned more forward or backward and may also variously connect to the other sulci in the frontal and parietal lobes[17].

In recent years, a variety of technologies have been used to image the brain functionally, because the cortical areas may not show adjustment with the theorical knowledge, like the investigation of Ojeman and Penfield[1,17,30].

The ultimate aim of the search for anatomical asymmetries is the better understanding of human higher cerebral functions. A strong tendency for hand preference is typically human and is probably related to the higher cerebral functions. The study of Le May (1977) showed that even the normal asymmetries of the brain affect the shape of the skull. Since the normal asymmetries of the brain were related to handedness, the shape of the skull also appears to be related to handedness. It can also be asked that whether the pattern of asymmetries can help to account for some childhood learning disorders such as autism and dyslexia. Also in the Pick's disease the lobes are affected resulting in asymmetric atrophy of the brain. Haslam *et al.* (1981), showed occipital asymmetries at the children who had dyslexia[24–26,31].

References

1) Bucholz RD. The central sulcus and surgical planning. AJNR 1993; **14**:926–927.
2) Ebeling U, Steinmetz H, Huang Y and Kahn T. Topography and identification of the inferior precentral sulcus in MR imaging. AJNR 1989; **10**:937–942.
3) Falk D, Hildebolt C, Cheverud J, Kohn LAP, Figiel G and Vannier M. Human cortical asymmetries determined with 3D MR technology. Journel of Neuroscience Methods 1991; **39**:185–191.
4) Fox PT, Mintun MA, Raichle ME, Miezin FM, Allman JM and Van Essen DC. Mapping human visual cortex with positron emission tomography. Nature 1986; **323**:806–809.
5) Gallen CC, Sobel DF, Waltz T, Aung M, Copeland B, Schwartz BJ, Hirschkoff EC and Bloom FE. Noninvasive presurgical neuromagnetic mapping of somatosensory cortex. Neurosurgery 1993; vol. 33, no. 2, 260–268.
6) Iwasaki S, Nakagawa H, Fukusumi A, Kichikawa K, Kitamura K, Otsuji H, Uchida H, Ohishi H, Yaguchi K, Sumie H and Kuru Y. Identification of pre and postcentral gyri on CT and MR images on the basis of the medullary pattern of cerebral white matter. Radiology 1991; **179**:207–213.
7) Katada K. MR imaging of brain surface structures: surface anatomy scanning (SAS). Neuroradiology 1990; **32**:439–448.
8) Kido DK, LeMay M, Levinson AW and Benson WE. Computed tomographic localization of the precentral gyrus. Radiology 1980; **135**:373–377.
9) King RB and Schell GR. Cortical localization and monitoring during cerebral operations. J. Neurosurg 1987; **67**:210–219.
10) LeMay M and Culebras A. Human brain – Morphologic differences in the hemispheres demonstrable by carotid arteriography. The New England Journal of Medicine 1972;

vol. 287, no. 4, 168–170.
11) Mueller WM, Yetkin FZ, Hammeke TA, Morris III GL, Swanson SJ, Reichert K, Cox R and Haughton VM. Functional magnetic resonance imaging mapping of the motor cortex in patients with cerebral tumors. Neurosurgery 1996; vol. 39, no. 3, 515–521.
12) Ojemann G, Ojemann J, Lettich E and Berger M. Cortical language localization in left, dominant hemisphere. J Neurosurg 1989; **71**:316–326.
13) Orrison WW, Davis LE, Sullivan GW, Mettler FA and Flynn ER. Anatomic localization of cerebral cortical function by magnetoencephalography combined with MR imaging and CT. AJNR 1990; **11**:713–716.
14) Sobel DF, Gallen CC, Schwartz BJ, Waltz TA, Copeland B, Yamada S, Hirschkoff EC and Bloom FE. Locating the central sulcus: Comparison of MR anatomic and magnetoencephalographic functional methods. AJNR 1993; **14**:915–925.
15) Suzuki A and Yasui N. Intraoperative localization of the central sulcus by cortical somatosensory evoked potentials in brain tumor. J. Neurosurg 1992; **76**:867–870.
16) Vanier M, Lecours AR, Ethier R, Habib M, Poncet M, Milette PC and Salamon G. Proportional localization system for anatomical interpretation of cerebral computed tomograms. Journal of computer assisted tomography 1985; **9**(4):715–724.
17) Whitaker HA and Selnes OA. Antomical variations in the cortex: Individual differences and the problem of the localization of language functions. Annals New York Academy of Sciences, pp: 844–854.
18) Greitz T, Bohm C, Holte S and Eriksson L. A computerized brain atlas: Construction, anatomical content, and some applications. Journal of Computer Assisted Tomography 1991; **15**(1):26–38.
19) Harkey HL, Al-Mefty O, Haines DE and Smith RR. The surgical anatomy of the cerebral sulci. Neurosurgery 1989; vol.24, no.5, 651–654.
20) Hu X, Tan KK, Levin DN, Galhotra S, Mullan JF, Hek-

Explanation of Figures

Plate I

Fig. 1. (arrow) Superior frontal sulcus which was small in the middle.

Fig. 2. (arrow) Superior frontal sulcus which was connecting with precentral sulcus.

Fig. 3. (arrow) Superior frontal sulcus which was passing precentral sulcus.

Fig. 4. (arrow) Superior frontal sulcus which was connecting with central sulcus.

Fig. 5. (arrow) Precentral sulcus which was laterally fork shaped.

Fig. 6. (arrow) Precentral sulcus which was medially fork shaped.

Fig. 7. (arrow) Precentral sulcus which was connecting with central sulcus medially.

Fig. 8. (arrow) Precentral sulcus which was connecting with the midline.

Fig. 9. (arrow) Precentral sulcus which was a small one.

Fig. 10. (arrow) Central sulcus which was connecting with the midline.

Fig. 11. (arrow) Fork shaped central sulcus.

Fig. 12. (arrow) Postcentral sulcus which was connecting with the midline.

Fig. 13. (arrow) Postcentral sulcus which was medially fork shaped.

Fig. 14. (arrow) Postcentral sulcus which was ending at the anterior side of the marginal ramus.

Fig. 15. (arrow) Postcentral sulcus which was connecting with the marginal ramus.

Fig. 16. (arrow) Fork shaped marginal ramus.

Fig. 17. (arrow) Asymmetry of the superior frontal sulcus.

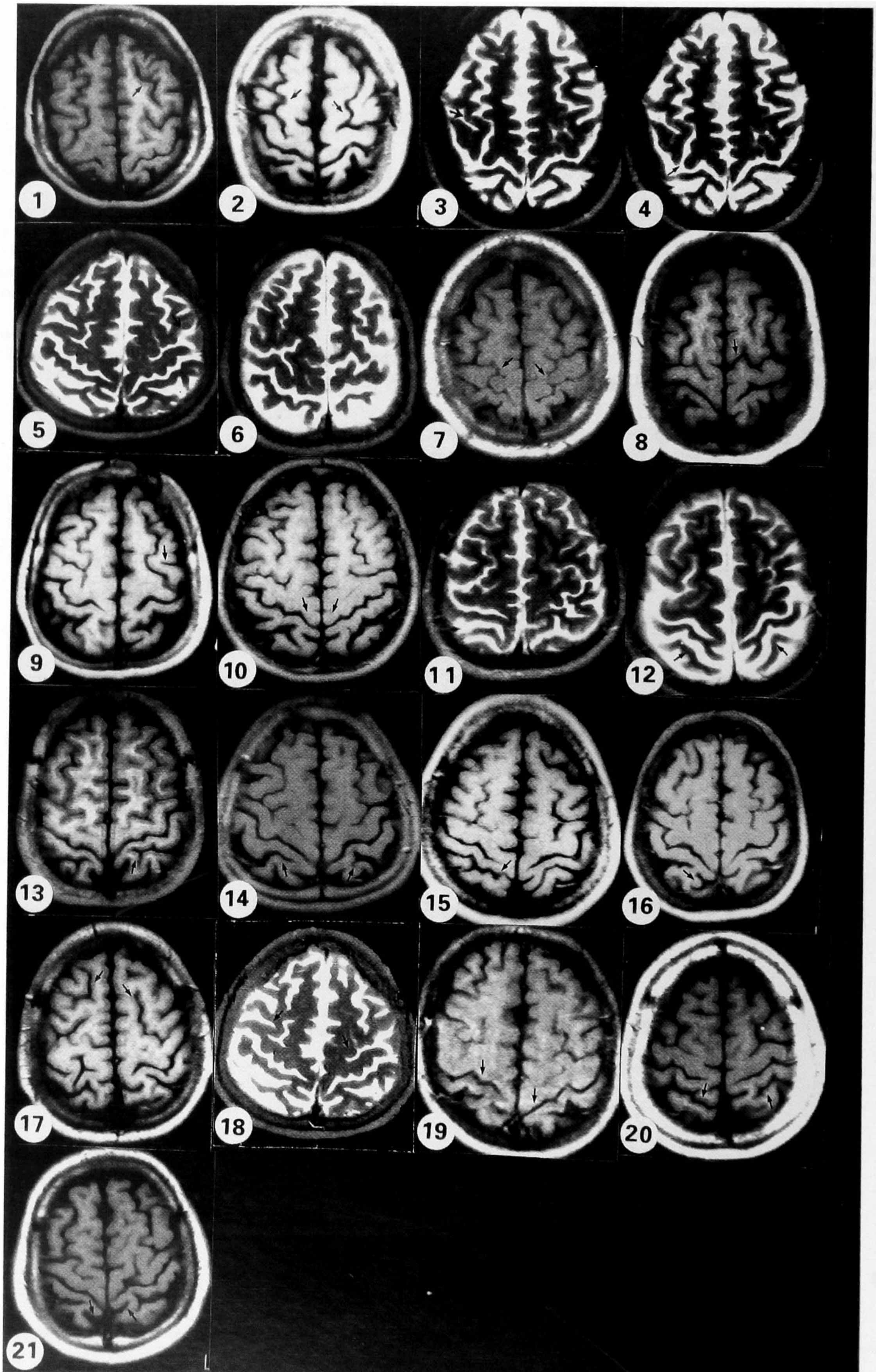
Fig. 18. (arrow) Asymmetry of the precentral sulcus.

Fig. 19. (arrow) Asymmetry of the central sulcus.

Fig. 20. (arrow) Asymmetry of the postcentral sulcus.

Fig. 21. (arrow) Asymmetry of the marginal ramus.

Plate I



matpanah J and Spire JP. Three dimensional magnetic resonance images of the brain: application to neurosurgical planning. J. Neurosurg 1990; **72**:433–440.
21) Naidich TP, Valavanis AG and Kubik S. Anatomic relationships along the lowmiddle convexity: Part I – Normal specimens and magnetic resonance imaging. Neurosurgery 1995; vol. 36, no. 3, 517–532.
22) Buchner H, Adams L, Knepper A, Rüger R, Laborne G, Gilsbach JM, Ludwig I, Reul J and Scherg M. Preoperative localization of the central sulcus by dipole source analysis of early somatosensory evoked potentials and three dimentional magnetic resonance imaging. J. Neurosurg 1994; **80**:849–856.
23) Yaşargil MG and Microneurosurgery. Georg Thieme Verlag Stuttgart, New York. Thieme Medical Publishers, Inc., New York 1994; vol. 4, pp. 19–24.
24) Galaburda AM, LeMay M, Kemper TL and Geschwind N. Right-left asymmetries in the brain. Science 1978; **199**:852–856.
25) Haslam RHA, Dalby JT, Johns RD and Rademaker AW. Cerebral asymmetry in developmental dyslexia. Arch. Neurol 1981; **38**:679–682.
26) Hier DB, Le May M and Rosenberger PB. Otizm and unfavorable left-right asymetries of the brain. Journal of Otizm and Developmental Disorders 1979; vol. 9, no. 2: 153–159.
27) Hier DB, Le May M and Rosenberger PB, Perlo VP. Developmental Dyslexia. Arch. Neurol 1978; **35**:90–92.
28) Richman DP, Steward M, Hutchinson W and Caviness V. S. Mechanical model of brain convolutional development. Science 1975; **189**:18–21.
29) Steinmetz H, Fürst G and Freund HJ. Variation of perisylvian and calcarine anatomic landmarks within stereotaxic proportional coordinates. AJNR 1990; **11**:1123–1130.
30) Berger MS, Cohen WA and Ojemann GA. Correlation of motor cortex brain mapping data with magnetic resonance imaging. J. Neurosurgery 1990; **72**:383–387.
31) Le May M. Asymmetries of the skull and handedness. Journal of the Neurological Science 1977; **32**:243–253.