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PHYLOGENETIC DEVELOPMENT OF BRAIN AND BRAIN SULCI IN PRIMATES

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INDEXING WORDS

primates; phylogenesis; cerebrum; frontal lobe; occipital lobe; calcarine sulcus; cingulate sulcus; cotton-thread

SYNOPSIS

The purpose of this study was to investigate the phylogenetic development of the cerebrum and cerebral sulcus in primates. The species selected were *Macacus*, *Hylobates*, *Pan* and *Homo sapiens*. These samples are classified as old world monkeys (Cercopithecidae), anthropoid apes (Pongidae), and Man (Hominidae). Although these four species divided up and went their separate ways from about the Oligocene era, the pattern of the cerebral sulci is similar. Of various cerebral sulci, the cingulate and calcarine sulci were selected, because they run on the medial surface of the cerebrum. The length of these sulci and fronto-occipital (FO) length were measured by a "cotton-thread" method. With the increase of size (FO-

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length) and weight of the brain, these sulci became longer, but there were no significant differences in the ratio of the calcarine sulcus to the FO-length among these four species. On the contrary, the ratio of the cingulate sulcus to the FO-length in Pan and Homo sapiens was significantly higher than in the other species, indicating that this ratio becomes higher with the phylogenetic development. The results of the present study suggest that the ratios of these sulci to the FO-length can be used as good indices to assess the degree of the phylogenetic development of the brain.

INTRODUCTION

There are several studies on phylogenesis of the brain in primates.[1-4] Many of them are comparative studies on the relationship between size and weight of the brain and the body weight.[1,5-7] While the recent studies have focused on the relationship between the neurogenesis and the behavior, brain size or number of neuron in various portions of the brain.[8-12] The cerebral sulci can be easily and precisely measured in the whole brains. It can be easily accepted that they become longer with increase in size and volume of the brain,and suggests that the development of the cerbral sulci might be closely related with the phylogenetic development of the brain. To date, however, there are no comparative studies dealing with the cerebral sulci from the phylogenetic view point. It might be of interest to compare the development of the fronto-parietal and occipital lobes for studing the phylogenetic development of the brain. We think that the development of these lobes should be assessed with some indices obtained from the medial surface of these structures. Thus in the present study, the length of the cingulate and calcarine sulci, as well as the ratios of these length to the fronto-occipital (FO) length were used as indices and statistically compared among the four species of primates such as human, chimpanzee, gibbon and crab-eating monkey.

SUBJECTS AND METHODS

The subjects studied were whole brains of various kinds of primates: 21 men (*Homo sapiens*) that belong to Hominidae; four chimpanzees (*Pan*) and five gibbons (*Hylobates*) which belong to Pongidae; and 11 crab-eating monkeys (*Macaca fascicularis*) that belong to Ceropithecidae. All were female adults. The average age of the men was 57.6 ± 6.4 years old (mean ± SD). These brains had been stored in 10% formalin for 2 to 10 years. The brains used had no deformity. These brains were cut at the mid-sagittal plane, and the length of the cingulate and calcarine sulci were determined by measuring the length of the cotton thread that had been placed in each sulcus. By this method, these sulci can be measured even in the whole brains which were not cut at the mid-sagittal plane. The cingulate sulcus commenced below the rostrum corporis callosi, and terminated at the point just before the sulcus parito-occipitaris. The clcarine sulcus commenced at the site where the splenium corporis callosi ended, and its terminus was at the end of the occipital lobe. At the same time, the length of the FO line was measured, and the ratio of the length of each sulcus to the FO length was used for comparison. Statistical analysis was done using the unpaired *t*-test and Statview software (Abacus Concepts Inc, Berkeley, CA, USA).

RESULTS

The mean of brain weight in each primates is shown in Table I and Fig. 1. The mean of the FO-length, cingulate and calcarine sulci, the ratio of two sulci to the FO length of each primates are shown in Table II. Figure 2 shows the means of FO lengths. Figure 3 shows the mean length of the cingulate sulcus in each primate. Figure 4 shows the mean length of calcarine sulcus in each primate. Figure 5 shows the ratio of the length of sulcus cinguli and that of sulcus calcarinus to the

FO-length in each primate. Figure 6 shows the brains of the four species of the primates studied.

The order of the length of the cingulate sulcus in both hemispheres was as follows: *Homo sapiens* > *Pan* > *Hylobates* > *Macacus* (Table II, Fig. 3). The differences among the species were statistically significant ($P < 0.0001$). As to the cingulate sulcus, the ratio was in the descending phylogenetic order from *Homo sapiens* to *Macacus*: *Homo sapiens* > *Pan* > *Hylobates* > *Macacus*. The differences were significant among the primates examined. No significant difference was found between the left and right hemispheres in each primate. In the left hemisphere, there was a significant difference between *Pan* and *Macacus* (*Pan* > *Macacus*, $P < 0.0046$), but there was no significant difference between *Pan* and *Hylobates*, or between *Hylobates* and *Macacus*. The results of the right hemisphere was the same as those of the left hemisphere. The comparison of the ratio of sulcus in the right hemisphere showed significant difference between *Pan* and *Hylobates* ($P < 0.01$), and between *Pan* and *Macacus* ($P < 0.001$). However, there was no significant difference between *Hylobates* and *Macacus*.

The order of the length of the calcarine sulcus in both hemispheres was as follows: *Homo sapiens* > *Pan* > *Hylobates* > *Macacus* (Table II, Fig. 4). In the calcarine sulcus, dispersion was seen in the left brain. When the ratio was compared between the *Homo sapiens* and other primates, there was a significant difference between *Homo sapiens* and *Macacus* (*Homo sapiens* > *Macacus*, $P < 0.006$), but there was no significant difference between *Homo sapiens* and *Pan*, or between *Homo sapiens* and *Hylobates*. The comparison among the other species in relation to *Homo sapiens* showed a significant difference with *Macacus*, but there was no difference between *Homo sapiens* and Pan, or between *Homo sapiens* and *Hylobates*. In both of the hemispheres, there was a significant difference between *Homo sapiens* and *Macacus* (*Homo sapiens* > *Macacus*, right $P < 0.003$, left $P < 0.002$), but no significant differences were found between *Homo sapiens* and *Pan* or *Homo*

Table I . Brain weights.

Species	*Macacus*	*Hylobates*	*Pan*	*Homo sapiens*
number	11	5	4	21
brain weight (g)	59.0 ± 1.9	87.5 ± 5.3*	336.6 ± 23.3*	1257 ± 26.9*

unpaired *t*-test. *, $P < 0.001$.

Table II . Sulcus and FO length and their ratios.

	Species	FO length (cm)	Cingulate sulcus (cm)	Calcarine sulcus (cm)	Cingulate sulcus/FO (ratio)	Calcarine sulcus/FO (ratio)
Right	*Homo sapiens*	15.6 ± 0.74	15.7 ± 1.47	7.8 ± 0.88	0.98 ± 0.11	0.50 ± 0.06
	Pan	10.0 ± 1.10‖	8.8 ± 0.98‖	5.4 ± 0.60·	0.88 ± 0.05	0.53 ± 0.01
	Hylobates	6.5 ± 0.33‖	4.6 ± 0.04‖	3.5 ± 0.68‖	0.71 ± 0.07‖	0.54 ± 0.78
	Macacus	5.7 ± 0.21‖	4.0 ± 0.37‖	3.3 ± 0.44‖	0.69 ± 0.06‖	0.58 ± 0.67‡
Left	*Homo sapiens*	15.7 ± 0.67	15.5 ± 1.94	7.6 ± 1.16	1.00 ± 0.10	0.48 ± 0.07
	Pan	9.7 ± 1.30‖	8.3 ± 0.15‖	5.9 ± 0.66*	0.83 ± 0.08†	0.52 ± 0.03
	Hylobates	6.4 ± 0.20‖	4.6 ± 0.49‖	2.9 ± 0.59‖	0.72 ± 0.06‖	0.47 ± 0.08
	Macacus	5.7 ± 0.25‖	3.8 ± 0.32‖	3.3 ± 0.35‖	0.67 ± 0.06‖	0.57 ± 0.08*

unpaired *t*-test. *, $P < 0.02$; †, $P < 0.01$; ‡, $P < 0.003$; ·, $P < 0.002$; ‖, $P < 0.0001$.

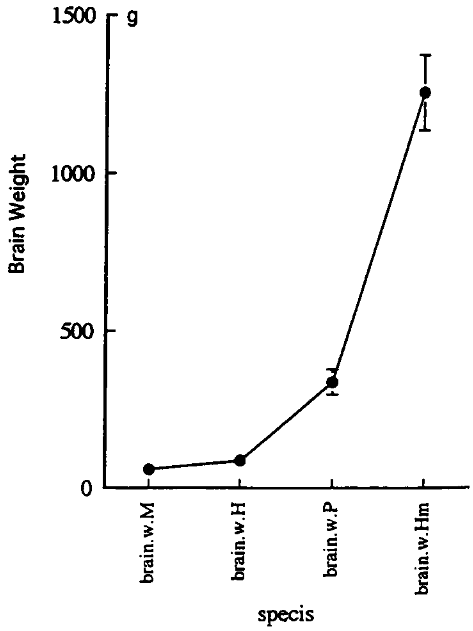

Fig. 1. Mean brain weights. Data are shown as mean ± SD.

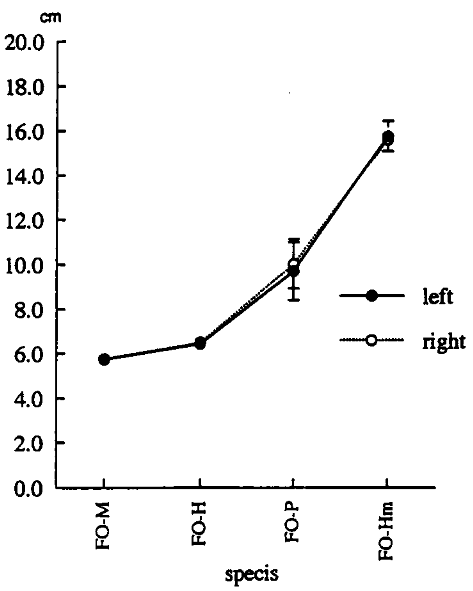

**Fig. 2. Mean lengths of the fronto-occipital (FO) line.
Open circle, left hemisphere; solid circle, right hemisphere.
Data are shown as mean ± SD.**

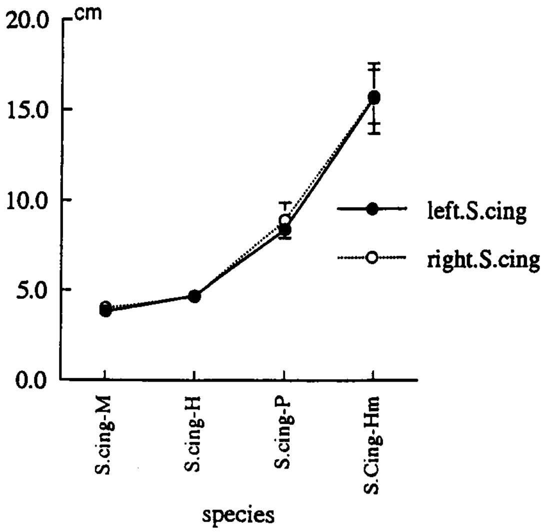

Fig. 3. Mean lengths of the sulcus cinguli.
Open circle, right sulcus cinguli; solid circle, left sulcus singuli.
Data represent mean ± SD.

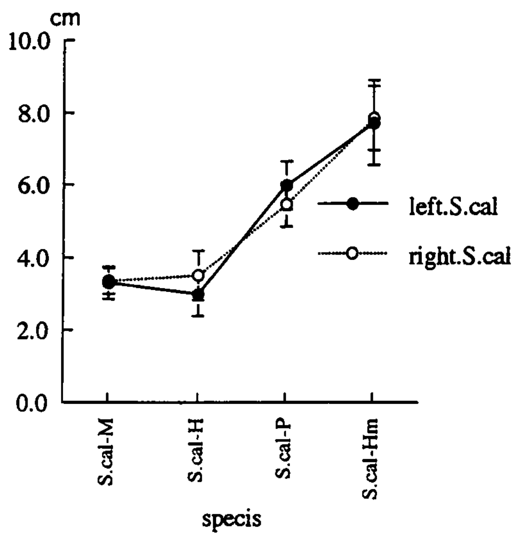

Fig. 4. Mean lengths of the sulcus calcarinus.
Open circle, left sulcus calcarinus; solid circle, right sulcus calcarinus.
Data are shown as mean ± SD.

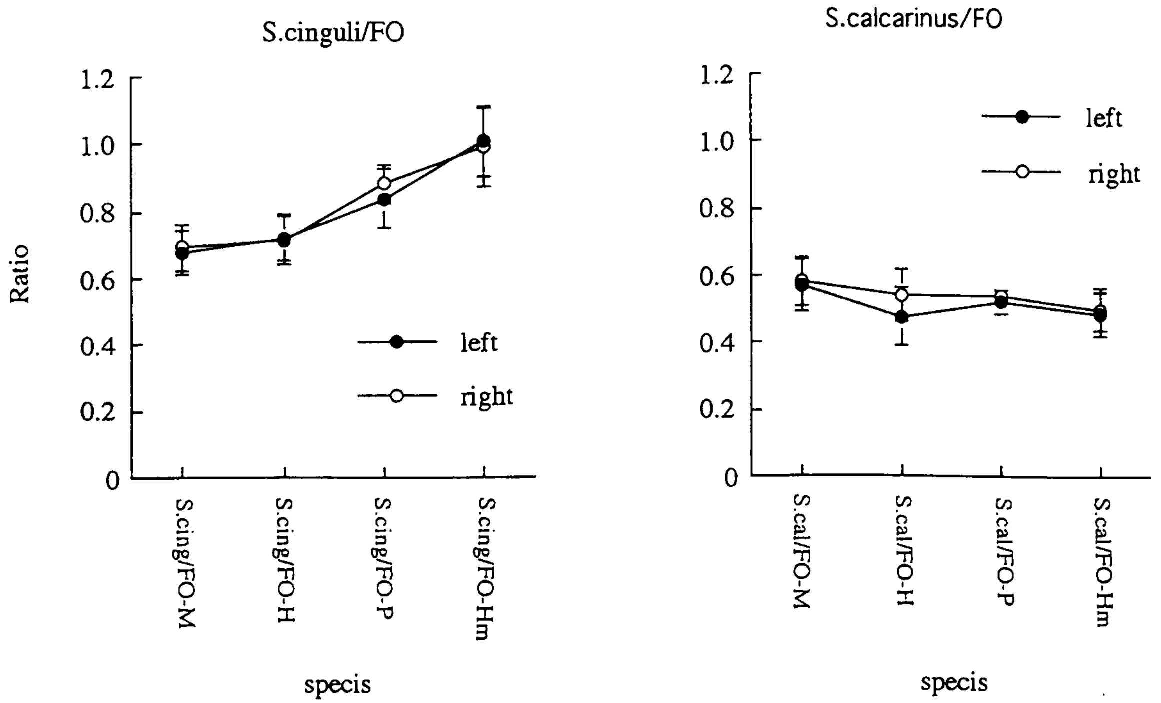

Fig. 5. Ratio of the length of the brain sulcus to the length of the fronto-occipital (FO) length. Open circle, left sulcus/FO; solid circle, right sulcus/FO. Data are shown as mean ± SD.

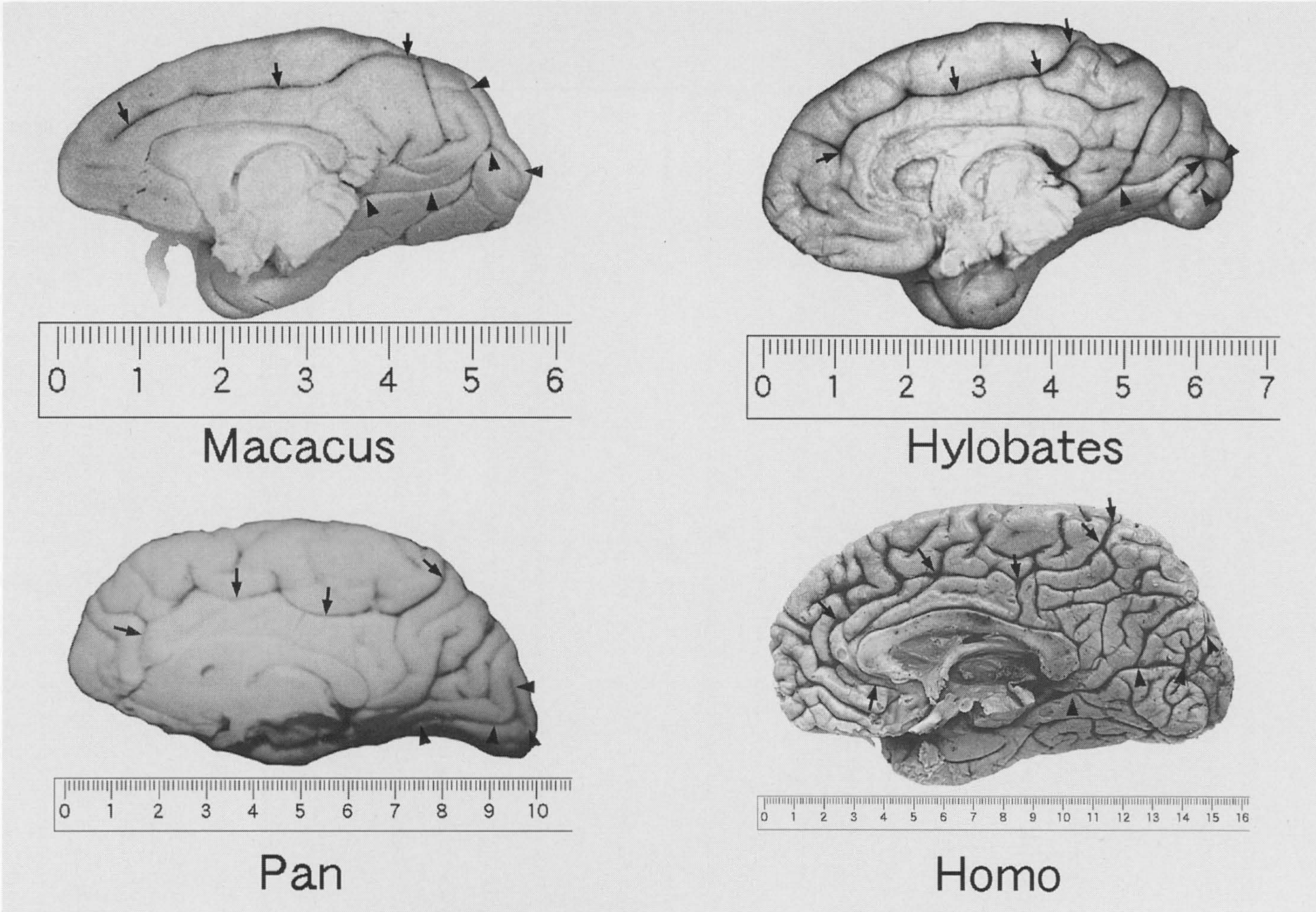

Fig. 6. The photomicrogrphs of brains of the four species studied.
Arrows indicate the cingulate sulcus and arrow heads indicate the calcarine sulcus.

sapiens and *Hylobates*. The mean levels of ratio tended to decrease as follows: *Homo sapiens* < *Pan* < *Hylobates* < *Macacus* (Table II, Fig. 5).

DISCUSSION

The brain used for this study had been stored in 10% formalin for more than 2 years. According to Tunemitu et al,[14] the volume and weight of the fixed brain with 10% formalin solution are relatively constant during the first 80 to 90 weeks. Although they increase in the next several days, thereafter gradually decrease to a stable level at 90th to 100th weeks from the start of fixation. Therefore, the brains we studied in the present study are thought to be relatively in stable condition. To measure the cerebral sulci , we developed a new method named "cotton-thread method". In this method , a cotton thread placed in each sulcus is cut at both ends and measured afterwards. This method was a very simple and convenient one, as the groove is not straight all the time, and it was also possible to measure the length on the medial surface of the uncut whole brain.

Although these four species divided up and went their separate ways from about the Oligocene era[13], the pattern of the cerebral sulci is very similar. The cingulate and calcarine sulci were selected as indices of the regional development of fronto-parietal and occipital lobe. The cingulate sulcus is running from the subcallosal area to the anterior parietal region on the medial surface of the hemisphere. This sulcus bifurcates at approximately the border between the frontal and parietal lobes, and the marginal part ascends toward the dorsal surface of the cerebrum. The other branch of the sulcus goes along the cingulate gyrus toward the isthmus of the gyrus taking in most of the brain as an interrupted, independent, subparital sulcus. The marginal part of the sulcus can be considered to represent the volume of the anterior two-thirds of the hemisphere. The mean of calcarine sulcus was considered to be an index that shows the volume of the posterior one-third, particularly of the occipital lobe. This sulcus is seen on the medial surface and is closely related to the primary visual cortex.

The FO line was taken up as the standardized length of the brain sulcus in each primate. The volume and weight of the brain were very different among the primates used in this study. The range was from about 60 g in the *Macacus* to over 1000 g in *Homo sapiens*. Therefore, to compare the developmental difference of the specific sulci, the length of each sulcus had to be standardized to compare it with that of the whole brain.

The ratio of the cingulate sulcus to the FO-length becomes larger with the phylogenetic development of the brain. On the contrary, there were no significant differences in that of the calcarine sulcus to the FO-length among the four primates. It appears that the anterior two-thirds of the brain including the frontal, anterior part of the parietal and limbic lobes develops with the phylogenetic development of the brain, while the posterior one-third including the posterior lobe and the posterior part of the pariental lobe does not, as far as primates are concerned. The results of the present study suggest that the ratios of the cingulate and calcarine sulci to the FO-length can be used as good indices to assess the degree of the phylogenetic development of the brain.

REFERENCES

1. Barbara, L. Finlay and Richard, B. Darlington.: Science 1995. 268. 1578/1584. Linked regularities in the development and evolution of mammalian brains.
2. Brand, S. and Rakic, P.: Neuroscience 1979.4.767/778. Genesis of the primate neostriatum: [^{3}H]-thymidine autoradiographic analysis of the time of neuron origin in the rhesus monkey.
3. Band,S. and Rakic,P.:Neuroscience 1980.5.2115/2138.Neurogenesis of the nucleus accumbens septi and neighboring septal nuclei in the rhesus monkey: A combined

[^{3}H]-thymidine and electron microscopic study.
4. Cooper, M. L. and Rakic, P.: J. Comp. Neurol. 1985. 242. 611/653. Neurogetic gradients in the superior and inferior colliculi of the rhesus monkey.
5. Holloway,R.L., Bauchot,R., and Andy, J. D.: The primate brain(Appeleton-Century-Crofts) 1970. 299/310. Neural parameters, hunting, and the evolution on the human brain.
6. Jerison, H. J.: Science 1961. 133. 1012/1014. Quantitative analysis of evolution of the brain in mammals.
7. Jerison, H. J.: The primate brain (Appeleton-Century-Crofts) 1970. 225/244. Gross brain indices and the analysis of fossil endocast.
8. Kordower, J. H. and Rakic, P.: J. Comp. Neurol. 1990. 291. 637/653. Neurogenesis of the magnocellular basal forebrain nuclei in the rhesus monkey.
9. Luskin, M. A. and Shatz, C. J.: J. Comp. Neurol. 1985. 242. 611/631. Neurogenesis of the cat's primary visual cortex.
10. Quiring, O. P.: Growth 1941. 5. 301/327. The scale of being according to the power formula.
11. Rakic, P.: J. Comp. Neurol. 1977. 176. 23/52. Genesis of the dorsal geniculate nucleus in the rhesus monkeyÅSite and time of proliferation, routes of migration and pattern of distribution of neurons.
12. Rakic, P.: Science 1974, 183. 425/427. Neurons in rhesus monkey visual cortex: Systematic relation between time of origin and eventual disposition.
13.Simon,E.L. : Scientific American .1964.211 (1) .50/62.The early relatives of man
14. Tunemitu, K., Somo, T., Yokoyama, N., and Kozima, K.: Ann Univ Kobe Sch Med. 1957. 7. 2650/2653. Volume of change of the brain in fixation fluid (in Japanese).