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A comparative study of linear measurement of the brain and three-dimensional measurement of brain volume using CT scans

K. Hamano, N. Iwasaki, T. Takeya, H. Takita

Department of Pediatrics, University of Tsukuba, 1-1-1 Tennodai, Tsukuba-shi, Ibaraki-ken 305, Japan

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Abstract. Parameters of linear measurement were compared with actual brain volume to assess the significance of linear measurements as indices of atrophy in 31 neurologically normal children and 22 neurologically abnormal children. Brain volume was established by means of an image-analyzing system using contiguous CT scans. The parameters or indices estimated were: (1) the maximum transverse width of both hemispheres, (2) the maximum longitudinal length of both hemispheres, (3) the maximum frontal subarachnoid space, (4) the maximum width of the interhemsipheric fissure, (5) the maximum width of the Sylvian fissure, (6) Evans' ratio, (7) the maximum width of the third ventricle, (8) the cella media index, (9) the maximum width of the fourth ventricle. In neurologically normal children, the maximum transverse width of both hemispheres, the maximum longitudinal length of both hemispheres, the maximum width of the interhemispheric fissure and the maximum width of the Sylvian fissure correlated significantly with the combined volume (CV) of both hemispheres and basal ganglia. In particular, the maximum transverse width of both hemispheres and the maximum longitudinal length of both hemispheres had a high correlation. In neurologically abnormal children the maximum transverse width of both hemispheres and the maximum width of the interhemispheric fissure were significantly correlated with the CV of both hemispheres and basal ganglia.

The severity of cerebral atrophy has been estimated using several parameters of linear measurement obtained by CT scans and MRI. The changes with age of the longitudinal and transverse diameters of the brain, the size of the cerebral ventricles, the width of the subarachnoid space and the width of the Sylvian fissure in CT scans have been studied previously [1]. Some authors have also carried out linear measurement of the brain in cases of epilepsy [2] and have found this measurement useful as an atrophy index. However, the significance of linear measurements as an atrophy index of the brain has not been examined. We have already reported a method for accurately measuring brain volume in children using contiguous CT scan slices [3]. In this study, in order to examine the extent to which various linear measurements reflect brain volume and have significance as indices of atrophy, we compared linear measurements with brain volume at different ages in neurologically normal and abnormal children.

Correspondence to: K. Hamano

Materials and methods

The measurements were carried out on two groups of children. Group 1 comprised 31 neurologically normal children without mental retardation, consisting of patients with headache, simple head trauma and sporadic convulsions whose CT scans were diagnosed as normal by radiologists. There were 17 boys and 14 girls, ranging in age from 5 months to 12 years. Group 2 comprised 22 neurologically abnormal children, including 4 cases of cerebral palsy, 10 cases of mental retardation and 8 cases of cerebral palsy with mental retardation. There were 13 boys and 9 girls, whose ages ranged from 5 months to 14 years. Each group was divided into three subgroups (A, B and C) according to age (Table 1). The A subgroups of both groups comprised 11 and 8 children, respectively, ranging in age from 5 months to 2 years 11 months; B subgroups, 9 and 6 children ranging from 3 years 6 months to 6 years 7 months, and C subgroups 11 and 8 children ranging from 7 years 6 months to 14 years 0 months.

CT scans (Hitachi CT-600 scanner) were carried out parallel with the orbitomeatal line using a scan time of 6 s at 120 kV, 300 mA, and a slice thickness of 10 mm so that the entire brain volume was included in the slices.

Table 1. Number of cases in each of the groups and subgroups

Subgroup (ages, in years)	Group 1 (normal)	Group 2 (abnormal)	Total
A (0–2)	11	8	19
B (3–6)	9	6	15
C (over 6)	11	8	19
Total	31	22	53

Table 2. Group 1: correlation coefficient *(r)* and *P* value for each parameter or index of linear measurement and combined volumes of both cerebral hemispheres and basal ganglia in subgroups of group 1 (normal group)

Subgroup	No. of cases	Parameter or index								
		Evans	Cella	V3	V4	SS	IF	SY	LL	TW
A	11	−0.12	−0.25	−0.41	0.34	−0.50	−0.42	−0.59	0.94***	0.37
B	9	0.62	−0.09	0.67*	−0.53	0.24	0.36	0.31	0.84**	0.68*
C	11	−0.36	−0.01	0.19	0.62*	0.13	−0.50	0.37	0.29	0.72*
Total	31	−0.07	0.01	−0.06	0.05	−0.30	−0.39*	−0.44*	0.81***	0.79***

The maximum width of the fourth ventricle was compared with the combined volume of the cerebellum, midbrain, pons and medulla only
Evans, Evans' ratio; Cella, cella media index; V3, the maximum width of the third ventricle; V4, the maximum width of the fourth ventricle; SS, the maximum frontal subarachnoid space; IF, the maximum width of the interhemispheric fissure; SY, the maximum width of the Sylvian fissure; LL, the maximum longitudinal length of both hemispheres; TW, the maximum transverse width of both hemispheres
* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

Table 3. Group 2: correlation coefficient *(r)* and *P* value for each parameter or index of linear measurement and combined volumes of both cerebral hemispheres and basal ganglia in the subgroups of group 2 (abnormal group)

Subgroup	No. of cases	Parameter or index								
		Evans	Cella	V3	V4	SS	IF	SY	LL	TW
A	8	−0.61	−0.01	0.57	0.76*	−0.03	−0.43	−0.43	−0.32	0.60
B	6	0.05	0.10	−0.27	−0.21	−0.88*	−0.39	−0.01	0.36	0.37
C	8	−0.53	−0.18	−0.24	0.05	0.24	−0.87**	0.74*	0.87**	0.87
Total	22	−0.19	−0.16	0.09	0.05	−0.33	−0.55*	−0.36	0.36	0.68**

The maximum width of the fourth ventricle was compared with the combined volume of the cerebellum, midbrain, pons and medulla only.
Abbreviations as in Table 2
* $p < 0.05$; ** $p < 0.01$

The volume measurement of the brain was carried out according to our method, by which the mean percentage error of the calculated volume was 2.91 % compared with the real volume measured by the water displacement method already reported [3]. In each individual scan in image-analyzing system (Olympus CIA) was used to calculate the cross-sectional area by tracing the object contours of two parts of the brain: (1) basal ganglia and cerebral hemispheres of both sides; and (2) cerebellum, midbrain, pons and medulla. The volume of each part of the brain was obtained by multiplying the total area of each part by the slice thickness (10 mm).

The linear measurements were carried out on the sections showing the anterior horn most distinctly and taken directly from the film with the image-analyzing system. The following parameters were measured (Fig. 1): (1) Evans' ratio (the maximum distance between the two anterior horns/the maximum distance between the two internal laminae at the same level), (2) the cella media index (the maximum distance between the lateral ventricles at the level of the cella media/the maximum distance between the two internal laminae at the same level), (3) the maximum width of the third ventricle (V3), (4) the maximum width of the fourth ventricle (V4), (5) the maximum frontal subarachnoid space (SS), (6) the maximum width of the interhemispheric fissure (IF), (7) the maximum width of the Sylvian fissure (SY), (8) the maximum longitudinal length of both hemispheres (LL), (9) the maximum transverse width of both hemispheres (TW).

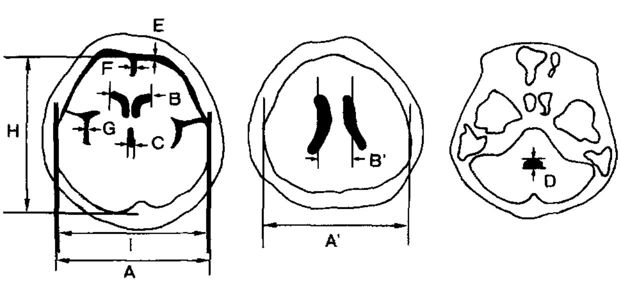

Fig. 1. The method of determining the parameters of linear measurement used in this study. *B/A,* Evans' ratio (the maximum distance between the two anterior horns/the maximum distance between the two internal laminae at the same level); *B'/A',* the cella media index (the maximum distance between the lateral ventricles at the level of the cella media/the maximum distance between the two internal laminae at the same level); *C,* the maximum width of the third ventricle; *D,* the maximum width of the fourth ventricle; *E,* the maximum frontal subarachnoid space; *F,* the maximum width of the interhemispheric fissure; *G,* the maximum width of the Sylvian fissure; *H,* the maximum longitudinal length of both hemispheres; *I,* the maximum transverse width of both hemispheres

The correlation between the combined volume (CV) of both cerebral hemispheres and basal ganglia and the values of the various linear measurements (except the maximum width of the fourth ventricle) was statistically analyzed within each group, using Student's *t*-test. The correlation between the CV of the cerebellum, midbrain, pons and medulla, and the maximum width of the fourth ventricle, was also analyzed in the same manner. Statistical significance was taken as $p < 0.05$.

Results

Tables 2 and 3 present correlation coefficients *(r)* and *p* values for each parameter of linear measurement and the CV of both cerebral hemispheres and basal ganglia or the CV of the cerebellum, midbrain, pons and medualla in groups 1 and 2.

In subgroup A of group 1 (Table 2), the maximum longitudinal length of both hemispheres was correlated closely ($P < 0.001$) with the CV of both hemispheres and basal ganglia. Other parameters showed no correlation. In subgroup B, the maximum width of the third ventricle, the maximum transverse width of both hemispheres and the maximum longitudinal length of both hemispheres were correlated with the CV of both hemispheres and basal ganglia. The maximum longitudinal length of both hemispheres showed a comparatively high correlation ($p < 0.01$). In subgroup C, the maximum width of the fourth ventricle and the maximum transverse width of both hemispheres were correlated with the CV of cerebellum, midbrain, pons and medulla respectively. Taking all the cases in group 1, the maximum width of the interhemispheric fissure, the maximum width of the Sylvian fissure, the maximum transverse width of both hemispheres and the maximum longitudinal length of both hemispheres were correlated significantly with the CV of both hemispheres and basal ganglia. The maximum transverse width and the maximum longitudinal length of both hemispheres had high correlations ($p < 0.001$). However, there was no correlation between either Evans' ratio, the maximum width of the third ventricle or the cella media index, and the CV of both hemispheres and basal ganglia; nor was there a correlation between the maximum width of the fourth ventricle and the CV of the cerebellum, midbrain, pons and medulla.

In subgroup A of group 2 (Table 3) the maximum width of the fourth ventricle was correlated significantly with the CV of cerebellum, midbrain, pons and medulla. The other parameters had no correlation. In subgroup B, the maximum width of the frontal subarachnoid space alone was correlated with the CV of cerebellum, midbrain, pons and medulla. In subgroup C, the maximum width of the interhemispheric fissure, the maximum width of the Sylvian fissure, the maximum transverse width of both hemispheres and the maximum longitudinal length of both hemispheres were correlated significantly with the CV of both hemispheres and basal ganglia. Taking all cases, the maximum width of the interhemispheric fissure and the maximum transverse width of both hemispheres were correlated significantly ($p < 0.01$) with the CV of both hemispheres and basal ganglia. The maximum width of the Sylvian fissure and the maximum longitudinal length of both hemispheres did not show a significant correlation, unlike the findings in group 1.

Discussion

The objective estimation of brain volume is very important for the accurate diagnosis of brain swelling or atrophy. To date, various methods of quantification including linear measurement [1, 4–8], planimetric or area methods [9, 10], computerized methods [11–13] and direct calculation of brain volume using sequential CT scans [3] have been reported. However, with the exception of linear measurement, these methods are not easily applied and are not of practical use since they are laborious and time-consuming and require equipment such as image-analyzing systems. On the other hand, linear measurements can be made very easily, and have practical use if their values accurately reflect brain volume or ventricular volume or the volume of the subarachnoid space.

Many parameters for linear measurement have been proposed [5, 6, 9]. Haug [6] used the maximum transverse inner diameter of the skull, the maximum width of the cellae mediae, the maximum distance between the tips of the frontal horns, the maximum width of the third ventricles and the maximum width of the interhemispheric fissure. Meese et al. [8] measured 21 parameters. The parameters used varied between studies and their individual significance has not been established. Gooskens et al. [13] simultaneously calculated both Evans' ratio and the maximum width of the subarachnoid space using linear measurement, and brain volume using the computerized method. However, they did not compare the values obtained by linear measurement with brain volume.

In our study we chose nine frequently used parameters of linear measurement and compared them with the brain volume of the normal and abnormal cases grouped according to age. As indicated in Table 2, the results of the normal cases (group 1) showed that there is no parameter which has a constant correlation with the CV of both hemispheres and basal ganglia or the CV of the cerebellum, midbrain, pons and medulla for all of the age groups (subgroups A, B, C). However, the maximum longitudinal length of both hemispheres and the maximum transverse width of both hemispheres presented very good correlations with the CV of both hemispheres and basal ganglia. The former correlation is significant in the age ranges 0–2 years (subgroup A) and 3–5 years (subgroup B). The latter correlation is significant in the age groups 3–5 years (subgroup B) and over 6 years (subgroup C). Taking all the cases of this group, only four parameters (IF, SY, LL, TW) showed a significant correlation. These findings indicate that of the nine parameters, the maximum longitudinal length of both hemispheres and the maximum transverse width of both hemispheres are the most useful in determining the presence of atrophy or swelling of the brain, and that the direction of brain development in Japanese children shifts from the longitudinal to the transverse direction between the ages of 3 and 5 years.

The results for group 2 (Table 3) show that no parameters correlate consistently with brain volume in the neurologically abnormal cases. In all the cases of this group the maximum width of the interhemispheric fissure and the maximum transverse width of both hemispheres are correlated significantly with the CV of both hemispheres and basal ganglia. These findings indicate that group 2 includes heterogeneous cases and that there is no adequate or reliable parameter of linear measurement for use in estimating brain volume in the neurologically abnormal cases.

The parameters of the ventricular system in our study, including Evans' ratio, the maximum width of the third ventricle, the cella media index and the maximum width of the fourth ventricle, showed no correlation with brain volume at all in either group. This result suggests that an abnormality in these parameters does not indicate changes in brain volume; neither does enlargement of the ventricular system always indicate brain atrophy, although these parameters have not been compared with the volume of the ventricular system.

Our study suggests that the parameters of linear measurement do not indicate actual brain volume but the volume of local areas of the brain, and that the measurement of brain volume itself is necessary for the exact estimation of brain atrophy or swelling, especially in neurologically abnormal cases.

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