Measurement of Orbital Volume by Computed Tomography: Especially on the Growth of the Orbit

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Purpose: Using reconstructed x-ray computed tomography (CT) images of serial coronal sections, we measured the orbital volume and studied its changes with age.

Methods: The subjects consisted of 109 patients (74 male, 35 female) who had undergone x-ray CT. After the reproducibility of orbital volume measurements and laterality in individuals were confirmed, the relation between the orbital volume and age, sex, weight, and interlateral orbital rim distance were examined.

Results: The difference between two measurements in the same patient stood at 0.4% for measured volume, which showed good reproducibility of this measurement. The laterality in individuals stood at 0.06 cm^3; the difference was very small and no significant difference was found. Moreover, the orbital volume did not show any imbalance between the right and left eyes in any stage of growth. Both the height and the interlateral orbital rim distance had a strong correlation with the orbital volume.

Conclusion: Referring to the relation between age and orbital volume, a strong correlation with an almost identical approximate equation was obtained for both sexes until the age of 12. Presumably, the rapid growth of the orbit comes to an end by 15 years of age in boys and by 11 years in girls. This means that more than 95% of the growth of the adult orbit has already been completed by the first half of the teens. The mean orbital volume in adult Japanese is 23.6 ± 2.0 cm^3 in men and 20.9 ± 1.3 cm^3 in women. **Jpn J Ophthalmol 2001;45:600–606** © 2001 Japanese Ophthalmological Society

Key Words: Computed tomography, growth, Japanese, measurement, orbital volume.

Introduction

Not only changes in the limited volume of tissue in the orbit, but also changes in the shape and size of the orbit, cause exophthalmos and enophthalmos.[1–3] Oono[4] studied the orbital volume of Japanese by actual anatomical measurement and reported it to be 26.0 cm^3 and 25.9 cm^3 for the right and left eyes in men and 23.1 cm^3 and 23.2 cm^3 in women. A figure between 25 cm^3 and 30 cm^3 is widely accepted. As is generally known, the orbital volume varies with race and sex.[5]

Attempts at measuring the orbital volume by x-ray computed tomography (CT) have been made for a long time, but results of these studies have yet to be utilized clinically.[1,6,7] There has as yet been no report on the growth of orbital volume. Actual in vivo measurement, radiographs, and x-ray CT have been used merely as a method of one-dimensional measurement. So a great deal was expected of clinically applicable methods to measure the orbital volume and studies of basic data.[8–11]

Using reconstructed x-ray CT images of serial coronal sections, we measured the orbital volume and studied its changes with aging. The results made it clear that a more reliable measurement of orbital volume can be made by this method. Additionally, we studied the relation between the orbital volume and age by comparing parameters that can easily be

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obtained in the clinical practice of ophthalmology. This article is a report of our findings.

Materials and Methods

Subjects

The subjects were represented by 129 radiographs from 109 patients (74 male, 35 female) who had undergone x-ray CT for the orbit mainly because of injury and whose orbit was normal on one side. There are few cases of injury in infants and not enough cases are available. So cases not likely to affect the growth of the orbit on the normal side, such as a case of retinoblastoma involving one eye, were added to the subjects. CT was performed twice at intervals of about 2 weeks after surgery on a blowout fracture of the orbit in 20 of the 109 patients. The ages of the 109 patients ranged from 0.2 to 66.8 years, averaging 22.9 years.

Measurement of Orbital Volume

We used the X-Vigor general purpose Helical Volume x-ray CT scanner (Toshiba, Tokyo) under the following conditions: bed movement 1.0 mm/one revolution of x-ray tube, for 60 seconds.[12] From the CT image reconstruction on a CT console, the image angle was adjusted to Reid's base line, and a serial coronal section, a 2-mm slice, was reconstructed. From this image, a bony orbit was traced on a personal computer (Power Macintosh), using NIH Image (National Institutes of Health, Bethesda, MD, USA), an image-measuring software. The measurement area of the orbit in this study ranged from the lacrimal fossa to the optic canal (Figure 1). However, the part anterior to the lacrimal fossa, the lateral orbital rim and the part of the superior orbital fissure and inferior orbital fissure, the regions lacking a boundary formed by bone, were traced with a straight line (Figure 2). The sectional area of the orbit was measured in each slice. After addition, the orbital volume was calculated.

Reproducibility of Orbital Volume Measurement and Laterality

The orbital volume on the normal side before surgery was compared with that after surgery in order to study the reproducibility of measurements in 20 patients (fracture group: 14 male, 6 female; age range, 18 to 64 years; mean age = 33 years) in whom CT had been performed twice, before and after surgery for unilateral blowout fracture of the orbit. Additionally, in 26 patients (normal group: 17 male, 9 female; age range, 0.6 to 66 years; mean age = 25.1 years) who had no injury in the orbital bone, comparison was made of the orbital volume on both sides to study the laterality in normal individuals.

Relation Between Orbital Volume and Other Factors

A total of 109 normal orbits were studied. The relation of the orbital volume with obesity using the body mass index (BMI) was also studied in 18 male patients aged 20 to 40 of the 109 patients in this study. BMI refers to the value calculated by the body weight kg/(height m)^2. According to the criteria for obesity of the Japanese Society Concerning Obesity, BMI = 22 is defined as standard and ± 10% as normal at 20 and older for both sexes. In studying the relation between the orbital volume and age, the number of coronal sections (referred to as the number of slices) used in the measurement of the volume was also added as a parameter. This is a parameter that represents the depth of the orbit.

Results

Reproducibility of Orbital Volume and Laterality

Table 1 represents the results of measurements of the orbital volume on the normal side before and after surgery in the fracture group, and the orbital volume on both sides in the normal group. The difference between the two measurements in the fracture group stood at 0.09 ± 0.69 (mean value ± SD) cm^3 and no significant difference was found, which showed the reproducibility of this measurement to be good. The laterality in the normal group stood at 0.06 ± 0.56 (mean value ± SD) cm^3; the difference was very small and no significant difference was found.

The relation between laterality and age showed no fixed trend. Orbital volume showed no imbalance between the right and left eyes in any stage of growth (Figure 3).

Relation Between Orbital Volume and Other Factors

Figure 4 represents the relation between height and orbital volume, and Figure 5 illustrates the relation between the interlateral orbital rim distance and orbital volume. Both parameters had a strong correlation with the orbital volume. With respect to the relation between obesity and orbital volume, the pa-

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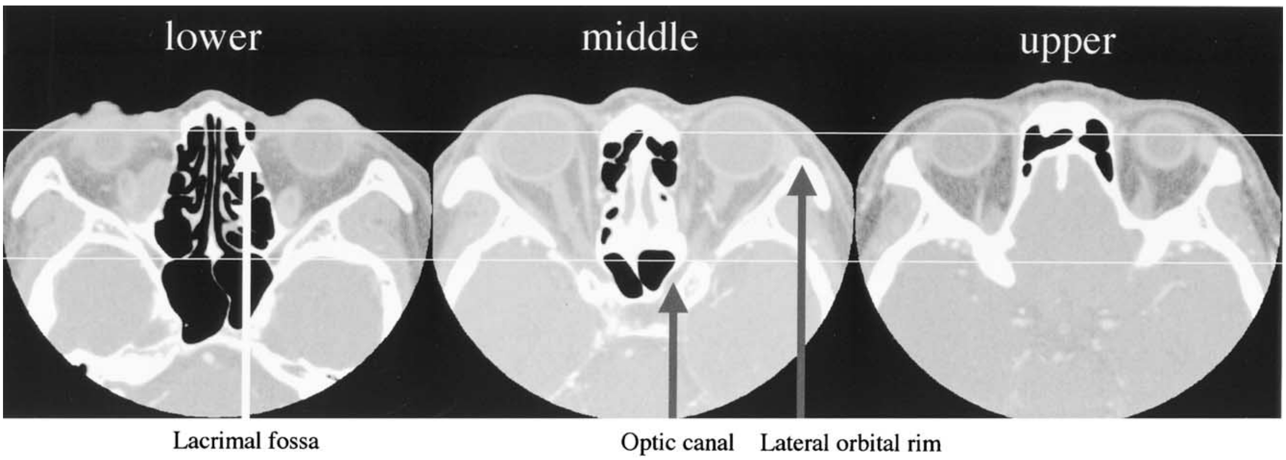

Figure 1. Tracing area. Normal side of operated group (20 cases) was used for study of reproducibility of measurement; both sides of normal group (26 cases) were used for study of laterality. After adjusting axial image to Reid's base line, 2-mm thick coronal sections were reconstructed between two lines indicated by arrows.

tients were divided into one group with the BMI value exceeding 24.2 and another group falling short of that level; 18 male patients aged 20 to 40 were studied. As the result, no significant difference was found between obesity and orbital volume (Table 2).

The relation between age and orbital volume was studied by age group (Figure 6). Orbital volume increased significantly up to the 12–18-year-old group in boys and up to the 6–12-year-old group in girls. Differences between the sexes became evident after the 12–18-year-old group. The orbital volume increased rapidly up to the 6–12-year-old age group with no differences between the sexes. So the patients were divided into a group of patients aged under 12 and a group over 12 to determine the correlation between age and orbital volume. The growth was almost the same for both sexes, there being a close correlation (Figure 7). The coefficient of corre-

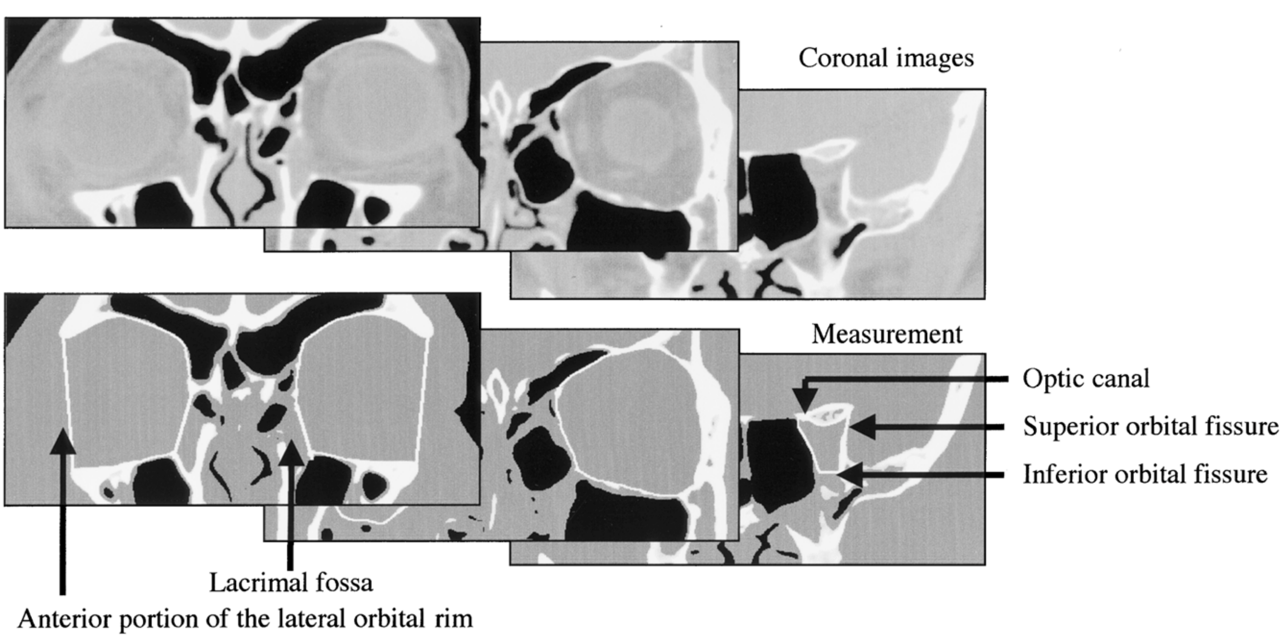

Figure 2. Tracing technique on personal computer using NIH Image. Portions lacking bony boundary are traced with straight line. Orbital volume was calculated from sum of each traced area.

Table 1. Measurement of Orbital Volume and Laterality*

	No. of Cases	Mean	SD	Min.	Max.	Paired *t*-Test
Pre-op measurement (cm^3)	20	23.84	0.52	19.6	27.3	
Post-op measurement (cm^3)	20	23.75	0.54	19.6	27.5	
Pre- minus Post-	20	0.09	0.69			$P = .56$
Right side (cm^3)	26	21.13	3.96	12.1	26.8	
Left side (cm^3)	26	21.07	4.03	12.0	27.9	
R minus L	26	0.06	0.56			$P = .58$

*Normal side of operated group (20 cases) was used for study reproducibility of measurement; both sides of normal group (26 cases) were used for study of laterality.

lation between orbital volume and age, and between height and interlateral orbital rim distance was high in the patients aged under 12 at 0.99 and 0.90, respectively. In estimating the orbital volume in this age group, relatively reliable values can be obtained whichever parameter is used, age, height, or interlateral orbital rim distance. A significant correlation, weak as it is, was found after age 12 as well, showing that the orbital volume increases gradually with age. From the intersection point of the approximate equation for those under 12 and that for those over 12, the rapid growth of orbital volume is presumed to stop at age 14.9 in boys and at age 10.9 in girls. The orbital volume then was 23.2 cm^3 and 20.1 cm^3, respectively.

In the 18–40-year-old group and in the over-40 group, where the growth is considered to have stopped in both men and women, the orbital volume increased further with age. To study this point, we compared the height, interlateral orbital rim distance and the number of slices between the two groups: the 18–40-year-old group and the over-40 group. The growth in height was significantly lower in the over-40 group for both men and women. The interlateral orbital rim distance and the number of slices increased significantly only in the men and showed no significant difference, albeit with a tendency to increase, in women (Table 3).

Discussion

Studies on the orbital volume using CT images have been reported since the mid-1980s, and the diagnostic and clinical usefulness of the data obtained has been recognized. However, most of the reports dealt with eyes with a blowout fracture of the orbit or thyroid ophthalmopathy,[13,14] and studies on the normal orbit are few.[6] With the measurement of orbital volume using sections of CT images, the extent of measurement anterior to the orbit differs from one section to another according to the kind of section used, horizontal, coronal, or sagittal, so comparing data measured using different sections is difficult. There have been many reports using only

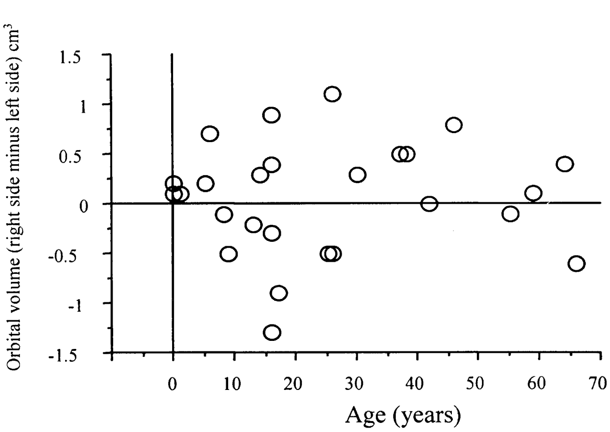

Figure 3. Relation between laterality and age. Right orbital volume minus left orbital volume is plotted for each case. Orbital volume showed no imbalance between right and left sides in any stage of growth.

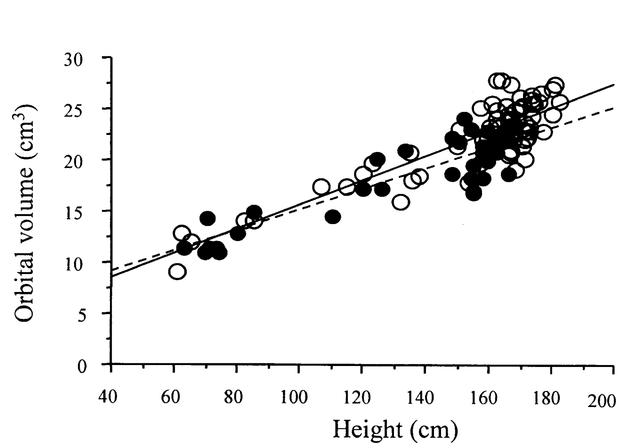

Figure 4. Relation between height and orbital volume. Male (○): $r = 0.86$ ($P < .0001$). Female (●): $r = 0.89$ ($P < .0001$).

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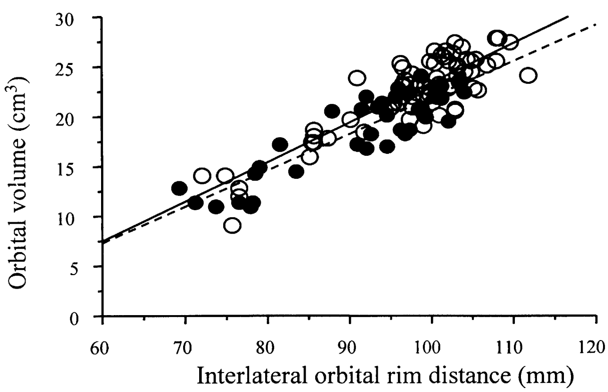

Figure 5. Relation between interlateral orbital rim distance and orbital volume. Male (○): $r = 0.87$ ($P < .0001$). Female (●): $r = 0.89$ ($P < .0001$).

horizontal sections to study the orbital volume,[1,6,7] but studies using the coronal section are few. In this study we measured the bony orbit from the lacrimal fossa to the optic canal using serial coronal sections. The thickness of the coronal sections used was 2 mm; the difference in orbital volume between using a 1-mm and a 2-mm thick section was about 0.2 cm^3 in a previous study.

Tracing the computer image is likely to cause an error. The error is shown to be 7–8% by Forbes et al[6] and 1.6% by McGurk et al.[15] In this study, we compared the orbital volume measured from data obtained by CT examination of the same orbit twice and found the error to be 0.09 ± 0.69 (mean ± SD) cm^3. This means that the reproducibility of measurement has an 0.4% variation against the value found, but no significant difference in the orbital volume was noted between the first and second measurements (paired *t*-test, $P = .56$). The accuracy of measurement was not investigated, because the error is considered to be very small and it was difficult to measure the same orbital area as the traced area in this study.

With respect to the laterality of the orbital volume in individuals, Forbes et al[6] stated that it was very small, and McGurk et al[15] reported it to be 0.65 cm^3. The actual anatomical measurement of the orbital volume in Japanese by Oono showed the laterality to be 0.1 cm^3. In the present study by CT, the laterality was 0.06 ± 0.56 (mean value ± SD) cm^3, there being no significant difference (paired *t*, $P = .58$), and this laterality did not correlate with age. The accuracy of measurement was not studied this time, but presumably it is at a level that would not cause a problem.

The methods of studying growth can roughly be divided into one method that deals with absolute growth based on age and another that deals with relative growth based on the growth of a part of the body. In the case of the study based on age, it involves factors such as differences between the sexes and individual difference, which precludes a one-dimensional study. In recent years, more importance has been attached to biological age or relative growth as a more appropriate method to assess growth.

Our study on the growth of orbital volume showed a strong correlation between the parameters easily obtainable in a daily clinical situation such as height and interlateral orbital rim distance, the coefficient of correlation being 0.86 to 0.89. However, the results of the present study showed some measured values different from the estimated values. To examine the reason, obesity in adult men aged 20 to 40 years was studied on the basis of the BMI value. An increase in orbital volume due to obesity was not found.

Referring to the relation between age and orbital volume, the orbital volume grew significantly in the 12–18-year-old group in boys and grew rapidly in the 6–12-year-old group in girls. Differences between the sexes became evident after the 12–18-year-old group. Figure 7 illustrates a strong correlation between age and orbital volume with an almost identical approximate equation obtained for both sexes aged under 12. Presumably, the rapid growth of the orbit comes to an end by 14.9 years of age in boys and 10.9 years in girls, although the calculation is based on estimated values. The orbital volume was

Table 2. Obesity and Orbital Volume

BMI*	No. of Cases	Orbital Volume (cm^3) Mean	SD	Unpaired *t*-Test
Overweight—obese (24.5 > BMI)	7	24.33	2.15	
Slim—standard (BMI ≤ 24.5)	11	23.65	1.96	$P = .50$

*BMI: body mass index.

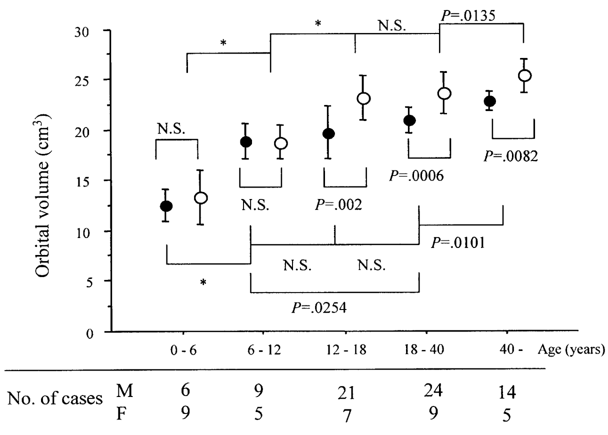

Figure 6. Relation between age and orbital volume studied by age group. Male (○). Female (●). Unpaired *t*-test. Error bar: ± 1 SD **P* < .0001.

then 23.2 cm^3 and 20.1 cm^3, respectively. The mean orbital volume in the 18–40-year-old group where growth has all but stopped in both sexes is 23.6 ± 2.0 cm^3 in men and 20.9 ± 1.3 cm^3 in women. This means that more than 95% of orbital growth in adults had already been completed in the first half of the teens.

To probe into the cause of the orbital volume having expanded significantly even after 40 years of age, we studied height, interlateral orbital rim distance, and the number of slices. Height decreased significantly after age 40 in both sexes and its relation to the orbital volume is rather paradoxical. The interlateral orbital rim distance and the number of slices were significantly increased only in men. Characteristically, height was low, the interlateral rim distance was wide, and the depth of the orbit was deep in men

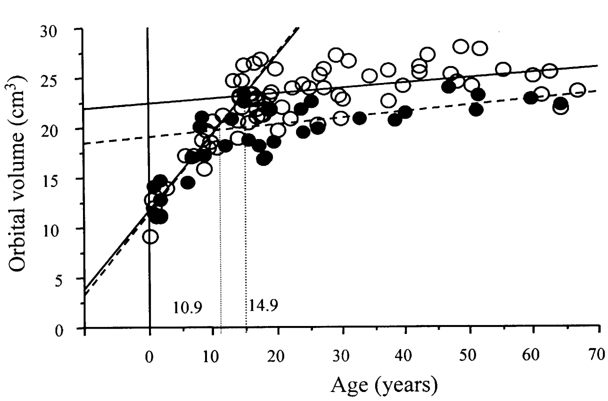

Figure 7. Correlation between age and orbital volume. Male (○): 0–12 years: $r = 0.92$ ($P < .0001$). Over 12 years: $r = 0.50$ ($P = .0205$). Female (●): 0–12 years: $r = 0.92$ ($P < .0001$). Over 12 years: $r = 0.36$ ($P = .0053$).

older than 40 years. It is not likely that orbital growth continued. The differences in skeleton according to the difference in generation might result from these characteristics. However, this is still a matter of conjecture.

Data from the Ministry of Health and Welfare, Japan, indicate that evident differences in height between the sexes manifest themselves from age 14. So it is reasonable that the orbital volume at age 12 or younger followed the same growth pattern for both sexes in our study. Using the intermedial canthal distance and the interpupillary distance as the indicators, Farkas et al[8] estimated the growth of the orbit. They have pointed out that the intermedial canthal distance attains full growth at age 8 in girls and at age 11 in boys, while the interpupillary distance reaches full growth at age 13 in girls and at age 15 in boys, and that the growth of the upper part of the face is faster than that of the lower part. Nakagawa et al[11] have reported that the interpupillary distance remains unchanged after age 18 in many cases. Yanagi[16] measured the orbital surface of the maxillary bone anatomically, reporting that its size remains almost constant after age 18 and that the upper part of the maxillary bone evidently matures faster than the lower part. The results of the present study also show that the increase in orbital volume is almost completed by age 18 or younger, and the time that the orbit matures is estimated at 14.9 years in boys and 10.9 years in girls, showing a tendency similar to that of the interpupillary distance and intermedial canthal distance.

What is generally known about the difference between generations includes the tendency to greater height, earlier maturity, and a change to shorter forehead and longer face. The orbital volume in the over-40 group in the present study requires further studies using a larger number of cases.

If a computer program for analyzing orbital volume is developed, orbital volume will be one of the useful parameters for understanding orbital disease.

Conclusions

1. Using x-ray CT images of 109 cases, 129 examinations, we measured the volume of the normal orbit and charted its growth.
2. Serial coronal sections in 2-mm thick slices ranging from the lacrimal fossa to the optic canal were used in the measurement of orbital volume.
3. The reproducibility of the measurements was good.

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Table 3. Height, Interlateral Orbital Rim Distance, and Number of Slices Between Two Groups

	Sex	18–40-Year-Old Group*	Over-40 Group*	Unpaired *t*-Test
Orbital volume (cm^3)	M	23.64 ± 2.02	25.32 ± 1.74	P = .0135
	F	20.89 ± 1.28	22.86 ± 0.88	P = .0101
Height (cm)	M	170.4 ± 6.0	164.3 ± 6.9	P = .0072
	F	159.0 ± 5.4	152.5 ± 4.3	P = .0402
Interlateral orbital rim distance (mm)	M	100.88 ± 3.60	103.89 ± 4.41	P = .0282
	F	96.61 ± 4.99	99.35 ± 2.29	NS
No. of slices	M	20.1 ± 1.0	21.0 ± 0.8	P = .0077
	F	19.7 ± 1.1	20.4 ± 0.9	NS

*Values are mean ± SD.
NS: not significant.

4. No laterality of the orbital volume was found.
5. Orbital volume strongly correlated with height and interlateral orbital rim distance, suggesting the possibility that orbital volume can be measured one-dimensionally. No differences between the sexes were found at age 12 or younger, and orbital volume strongly correlated with age as well.
6. Orbital volume was shown to grow rapidly until age 14.9 years in boys and until 10.9 years in girls. Orbital volume had then reached 95% of adult growth. The mean orbital volume between 18 and 40 years of age was 23.6 cm^3 in men and 20.9 cm^3 in women.
7. Orbital volume tended to increase in men and women aged 40 years or older. In comparing adults, differences between generations should also be considered.

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