Cranial capacity measurement for modern Chinese adults based on 3D reconstruction

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ABSTRACT

الأهداف: تحديد متوسط سعة الجمجمة الحديثة للبالغين في الصين، وتقييم الفروق والاتجاهات بين الجنسين من أجل إنشاء قيم مرجعية طبيعية وتوفير الأساس النظري للعلاج الفردي في الممارسة السريرية.

المنهجية: أجرينا دراسة مقطعية في الفترة من يناير 2019م إلى يونيو 2020م. حصلنا على صور مقطعية رفيعة (0.9 مم) من 309 ذكور و 238 إناث من الصين، وتصنيفها في فئات 32-18، 47-33، الفئات العمرية 62-48 و77-63 و 92-78 عام. تم إجراء إعادة بناء ثلاثية الأبعاد باستخدام برامج محاكاة للحصول على قدرة الجمجمة للتحليل الإحصائي.

النتائج: كان متوسط سعة الجمجمة عند الرجال 1497.12±120.70 سم³ وللنساء 1326.24±95.72 سم³. كان متوسط سعة الجمجمة أكبر من قدرة النساء في جميع الفئات العمرية. بالإضافة إلى ذلك، أظهرت سعة الجمجمة عبر الفئات العمرية المختلفة اختلافات كبيرة بين الرجال والنساء.

الخلاصة: إن متوسط سعة الجمجمة للذكور الصينيين الحديثين أكبر من قدرة الإناث، ويظهر كلا الجنسين ميلاً إلى زيادة الحجم داخل الجمجمة خلال العقود القليلة الماضية. توفر النتائج التي توصلنا إليها بيانات مهمة لتحديد القيم المرجعية الطبيعية لقدرة الجمجمة لدى البالغين الصينيين الحديثين والأساس النظري للعلاج الفردي لبعض أمراض الجمجمة مع زيادة الضغط داخل الجمجمة.

Objectives: To determine the average modern adult cranial capacity in China, and assess the gender differences and trends in order to establish normal reference values and provide theoretical basis for individualized treatment in clinical practice.

Methods: We conducted a cross-sectional study between January 2019 to June 2020. Thin-slice (0.9 mm) CT scans of 309 males and 238 females from China were obtained, and classified into the 18-32, 33-47, 48-62, 63-77 and 78-92 years age groups. Three-dimensional reconstruction was performed using mimics software to obtain the cranial capacity for statistical analysis.

Results: The average cranial capacity of men was 1497.12±120.70 cm³ and that of women was 1326.24±95.72 cm³. The average cranial capacity of men was larger than that of women in all age groups. In addition, cranial capacity across the different age groups showed significant differences among both men and women.

Conclusion: The average cranial capacity of modern Chinese male is larger that of females, and both sexes show a tendency to an increase in the intracranial volume over the past few decades. Our findings provide important data for establishing normal reference values for cranial capacity of modern Chinese adults and theoretical basis for individualized treatment of certain cranial diseases with increased intracranial pressure.

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Cranial capacity, also known as total intracranial volume (TIV), includes the volume of the brain, cerebrospinal fluid and other structures within the cranial cavity.[1] Studies have shown cranial capacities varies according to geographical regions, race, gender and age.[2,3] While several reports have been published on the cranial capacities of different ethnic and racial groups such as South Africa, India, Korea and America, little is known regarding the cranial capacity of modern Chinese adults.[4,5]

Cranial capacity is a reliable parameter in pediatrics, forensic medicine, oral surgery and in the diagnosis of cranial cavity deformities.[6,7] However, its application

in cerebral hemorrhage and other diseases leading to intracranial hypertension has not been reported in the literature. Everyone have different Cranial capacity, even if the volume of intracranial hematoma is the same, intracranial hypertension will be different. Therefore, when the intracranial hematoma volume is used as an indication of cerebral hemorrhage surgery, the difference of individual cranial capacities should be considered at the same time. It is common knowledge that prior cranial capacity data is usually calculated through filling up the cranial cavity with sand, rapeseed or on the basis of the cranial diameters that are measured through CT images or head.[8,9] However, filling up the cranial cavity with sand, rapeseed and other fillers after autopsy is not an accurate method for obtaining the sample size, and also causes larger error due to the age of the samples. Furthermore, mathematical calculation of the cranial capacity on the basis of diameter also results in large errors, and the meridians and formulae for evaluating the cranial volume are not unified.[9,10] Therefore, there is at present no reliable reference for comparing cranial capacity between different populations. Three-dimensional reconstruction of cranial images and pixel filling is a novel approach for measuring cranial capacity.[11,12] The range of cranial capacity is drawn by the software, which then generates a volume map of the region of interest and measures the volume. It is not only accurate in measurement, but also beneficial to the measurement of cranial capacities with large living samples.[13]

Although the cranial capacity is of great significance, there is few report on the measurement of cranial capacity of modern Chinese adults in vivo with large samples of three-dimensional reconstruction technology. Therefore, this study can know the normal reference, sexual dimorphism, individual difference and changing trend of cranial capacity of Chinese modern adults which will provide a theoretical basis for individualized treatment of certain cranial diseases with increased intracranial pressure.

Methods. We conducted a cross-sectional study on the cranial capacity of Chinese adults of different ages and genders in Shaoxing City People's Hospital from January 2019 to December 2020. The cranial capacity is measured by reconstructing the 3D model using mimics software. Ethical approval was obtained from the Ethics Committee at the Shaoxing People's Hospital. Written consent was obtained from each individual as per the guidelines of Helsinki. We collect all head CTs carried out from January 2016 to June 2020 in Shaoxing People's Hospital and related Patient personal information. Inclusion criteria: 1.Between 18-92 years old; 2. Thin-slice (0.9 mm) head CT. Exclusion criteria: 1. The skull was incomplete; 2.craniofacial deformities; 3. Skull with osteoporosis; and 4. History of brain surgery. A total of 856 cases of skull thin-layer (0.9mm) CT cranial scans were gathered, of which 547 cases (309 males and 238 females) met the requirements. All CT data have been reviewed by radiologist Jiajun Zhou.

Grouping. The subjects were divided into the following age groups: 18–32 years (group A), 33–47 years (group B), 48–62 years (group C), 63–77 years (group D) and 78–92 years (group E). There were 71 cases (46 males and 25 females) in group A, 110 (64 males and 46 females) in group B, 136 (73 males and 63 females) in group C, 128 (70 males and 58 females) in group D and 102 (56 males and 46 females) in group E.

Operation process. First, we use Mimics software to open the thin-slice CT images. Then, the appropriate threshold size was selected for filling, and blank filling and extra-cranial portion erasure (**Figure 1**) were performed on each layer in the front, left and top views. Finally, the three-dimensional model was reconstructed (**Figure 2**) to calculate the cranial capacity.

Statistical analysis. Descriptive statics were used for quantitative variables, including means, confidence interval, standard deviations (SD), and minimum and maximum values. The cranial capacities of different age groups and sexes were analyzed for normal distribution test and homogeneity of variance. Different gender groups were compared by 2 independent sample t-test and analysis of variance (ANOVA) was used for different age groups. We use SPSS version 23.0 for windows

Table 1 - Normal value and difference of cranial capacity in different gender (cm³).

Sex	n	Mean±SD	CI	Max	Min
Male	309	1497.12±120.70	1483.61-1510.63	1875	1197
Female	238	1326.24±95.725	1314.02-1338.47	1657	1024
T		18.464			
P		1.8008E-59*			
*On behalf of 2 samples variance is not neat, using t' test					

Table 2 - Differences in cranial capacity between men and women in different groups (cm³).

Age /Sex	n	Mean±SD	CI	Max	Min	T	*P*-value
A							
Male	46	1500.13±117.67	1465.19-1502.45	1776	1251	4.899	0.000006*
Female	25	1354.32±123.64	1303.28-1405.36	1657	1151		
B							
Male	64	1541.48±123.09	1510.74-1572.23	1875	1279	12.146	7.0039E-22*
Female	46	1304.54±81.32	1280.39-1328.70	1479	1163		
C							
Male	73	1496.12±124.63	1467.04-1525.20	1791	1275	8.062	4.4915E-13*
Female	63	1349.02±86.99	1327.11-1370.93	1526	1151		
D							
Male	70	1488.13±111.36	1461.57-1514.68	1758	1197	9.283	6.0645E-16*
Female	58	1310.83±102.77	1283.80-1337.85	1515	1024		
E							
Male	56	1456.46±113.66	1426.03-1486.90	1780	1232	6.624	1.7779E-9*
Female	46	1320.93±87.77	1294.87-1347.00	1512	1161		

*on behalf of 2 samples variance is not neat, using t' test, CI (95% confidence interval), Max - Maximum of cranial capacity, Min - Minimum of cranial capacity

Table 3 - Differences in cranial capacity among different age groups (cm³).

Age	cranial capacity	
	Male	Female
A	1500.13±117.67	1354.32±123.64
B	1541.48±123.09	1304.54±81.32
C	1496.12±124.63	1349.02±86.99
D	1488.13±111.36	1310.83±102.77
E	1456.46±113.66	1320.93±87.77
F	4.006	2.493
P	0.003*	0.044*

* on behalf of 2 samples variance is not neat, using t' test

Table 4 - Comparison results between men and women in different age groups.

Age	A	B	C	D	E
Male					
A		0.718	1.000	1.000	0.648
B	0.718		0.260	0.096	0.001*
C	1.000	0.260		1.000	0.603
D	1.000	0.096	1.000		1.000
E	0.648	0.001*	0.603	1.000	
Female					
A		0.352	1.000	0.557	1.000
B	0.352		0.160	1.000	1.000
C	1.000	0.160		0.274	1.000
D	0.557	1.000	0.274		1.000
E	1.000	1.000	1.000	1.000	

* on behalf of 2 samples variance is not neat, using t' test

(SPSS Inc., Chicago, IL, USA) to deal with data. *P*-values<0.05 were considered statistically significant and Confidence intervals were set at 95%.

Results. This study studied the size of the cranial capacity of 547 Chinese adults. **Table 1** shows the difference between the means, confidence interval, standard deviation maximum value and minimum value of the cranial capacity of men and women, and there is a statistical difference (*p*<0.05) between the mean cranial capacity of men and women.

Table 2 shows the mean, confidence interval, standard deviation, maximum and minimum values of the cranial capacity of men and women in different age groups, and there are statistical difference (*p*<0.05) between the mean cranial capacities of men and women in all groups.

Table 3 and **Table 4** show the difference in cranial capacities between different age groups and results of pairwise comparisons of various age groups. The average cranial capacities among males of the different age groups showed significant differences, especially between those aged 32–47 and 78–92 years (*p*<0.05). In contrast, while the overall cranial capacity across the different age groups in females were significantly different, pairwise comparison did not show any marked differences.

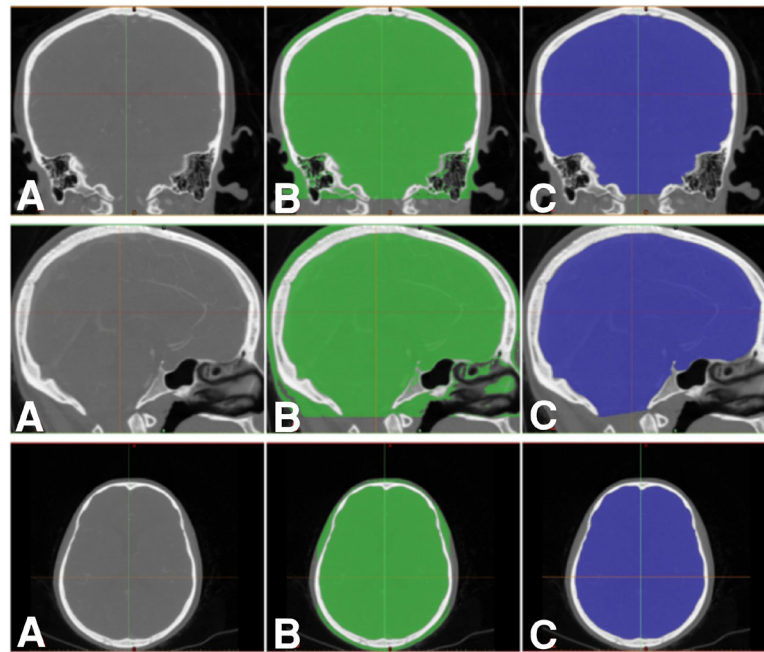**Figure 3** shows the cranial capacity and age distribution of 547 cases, and the cranial capacity

Figure 1 - Process of three-dimensional reconstruction for cranial capacity **A)** front, left and top views after importing data; **B)** front, left and top views after selecting an appropriate threshold; **C)** front, left and top views after erasing the extracranial portion.
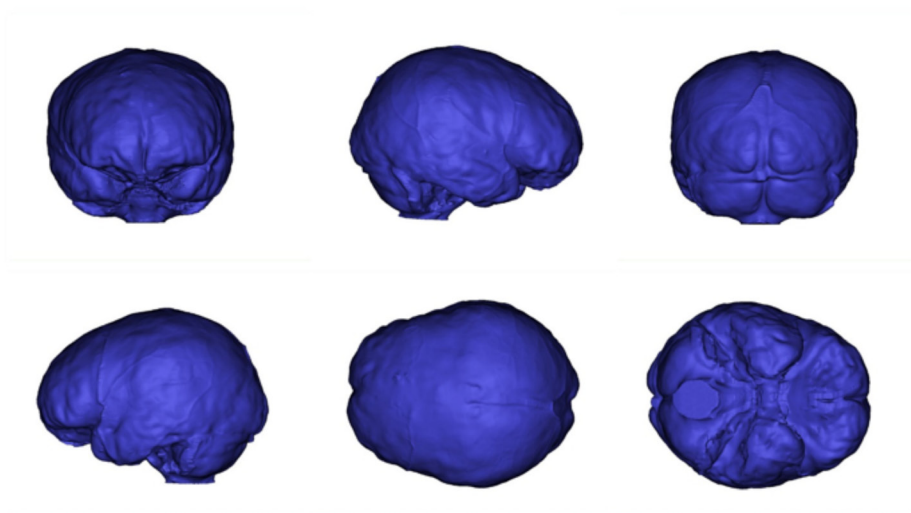

Figure 2 - Reconstructed 3d view.

tended to increase in both men and women over the past few decades.

Discussion. Unlike the volume of brain and cerebrospinal fluid, the cranial capacity does not change during aging or neurodegeneration in adulthood, and is therefore a useful parameter for various studies. There are few reports on measuring the cranial capacity of living modern Chinese adults by three-dimensional reconstruction of thin-layer CT scan images.

Some scholars have reported on the study of cranial capacity, but different research results vary. Kim et al[5] found that the mean cranial capacity of Korean males and females were 1594 cm^3 and 1425 cm^3, respectively. De Jong et al[4] showed that the cranial capacity of modern American men and women is 1619
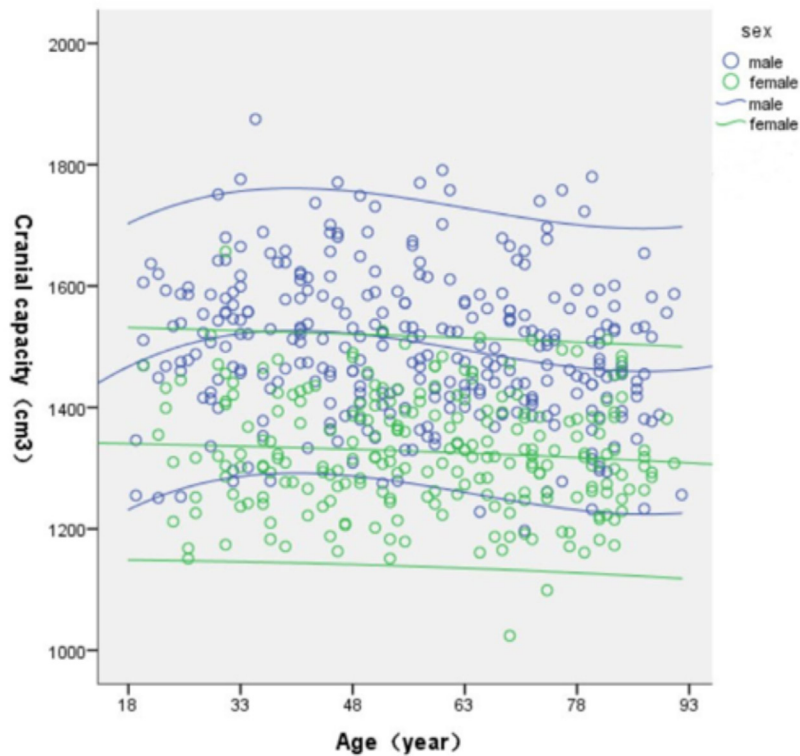
Figure 3 - Cranial capacity divided by age and sex. both sexes show a tendency to an increase in the intracranial volume over the past few decades.

cm^3 and 1422 cm^3. Eboh et al[1] demonstrate that the cranial capacity of modern Nigerian males and females is 1460 cm^3 and 1129 cm^3. In our cohort, the cranial capacity was 1497 cm^3 for males and 1326 cm^3 for females, which is more than that in Nigeria and smaller compared to that recorded in Korea and America. These differences may be caused by the geographical regions, descent, genetic profile, and even different sample sizes of the different studies.[14,15] This finding provide data for establishing the reference value of normal Chinese adult cranial capacity.

Previous studies have shown that the cranial capacity in men is larger than that in women.[4,5] In our study as well, the mean cranial capacity of male was about 13.0% larger than that of females. This is most likely due to the higher average height, weight, and cranial dimensions of men compared to women, which correlate to greater cranial capacity as well.[3,16] This difference is a highly relevant indicator in forensic science to determine the sex of a cadaver.[8,17]

As everyone knows that while the brain volumes increase and then gradually decrease after a certain age, the cranial capacity usually does not change after adulthood for individuals. However, the results of studies on the population born at different years are different; In a study of Korean adults, the cranial capacity of modern Koreans had increased by 90ml in the past 40 years.[5] A Euro-American study reported that the cranial capacity of Europeans and Americans is increasing and crania became relatively higher, narrower, and larger with longer cranial bases over the past 170 years. Both sexes changed, but female change was less pronounced than male change.[18] In our cohort, the cranial capacity of both men and women tended to increase over the past few decades. Furthermore, males in the age groups 32–47 and 78–92 years showed significant differences in their cranial capacity, whereas no significant difference was observed in the pairwise comparison of the various groups among females. Thus, slight increase trends of cranial capacity do exist in both men and women. This is a new finding in modern Chinese adults.

In the 1930s and 1940s, China was economically and medically backward due to the war of liberation, war with Japan and other reasons, which led to widespread malnutrition that most likely impaired normal development of the cranial cavity. The economic

development in later decades improved maternal and infant nutrition and medical care, which in turn decreased the incidence of neonatal mortality due to improper head and basin description and inadequate care.[5,18] This might explain the tendency to an increase in the intracranial volume over the past few decades and the significant difference in the cranial capacities of males aged 78–92 and 33–47 years. Furthermore, cranial capacity has grown over the course of human evolution,[19,20] although its effects would not manifest in just a few decades. However, the rapid socioeconomic and environmental changes witnessed in recent years may have accelerated the evolutionary changes.[21,22]

The average cranial capacity of men and women differed by 171 cm^3. In addition, the difference between the maximum and minimum cranial capacity of men was 678 cm^3, and that of women was 633 cm^3, which is highly relevant for the treatment of diseases involving an increase in intracranial pressure. The intracranial pressure begins increasing with a 5% reduction in the volume, and acute reduction of 8-10% can lead to severely raised intracranial pressure. Therefore, individual differences in cranial capacities would translate to different volume compensation in the acute phase. Therefore, patients with exceptionally large or small cranial capacity should be treated with caution. This is of great significance in the surgical selection of patients with hypertensive intracerebral hemorrhage. When using hematoma volume as a surgical indication for hypertensive cerebral hemorrhage, the difference in cranial capacity between individuals should be considered. For example, the ratio of hematoma volume to cranial capacity should be taken as surgery indications may be more reasonable. There is currently no literature report on this aspect, and further research is needed to elucidate the clinical relevance of intracranial capacity.

This study has following limitations that should be considered. The sample size of subjects younger than 32 and older than 78 years of age were small due to relatively fewer thin-slice CT scans for both age groups. In addition, the male to female ratios were also different in the younger and older demography, which may adversely influence the results. Finally, the CT data we selected came from patients treated by Shaoxing People's Hospital. The patient's own disease may have an impact on the cranial capacity.

Conclusion. In all groups, the average cranial capacity of modern Chinese male is larger that of females. Both sexes show a tendency to an increase in the intracranial volume over the past few decades, but the changes in men are more pronounced than in women. Our findings provide important data for establishing normal reference values for cranial capacity of modern Chinese adults and theoretical basis for individualized treatment of certain cranial diseases with increased intracranial pressure.

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Statistics

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