Original Article

The cranial capacity of the Saudi population measured using 3D computed tomography scans

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ABSTRACT

الأهداف: قياس سعة الجمجمة لمجموعة من السعوديين البالغين.

المنهجية: كانت هذه دراسة شاملة مستعرضة استخدمت 488 فحصًا للتصوير بالأشعة المقطعية (CT) للرأس (275 منهم من الذكور) لقياس حجم الجمجمة. تم تحميل شرائح الاشعة المقطعية بسمك 0.625 مم باستخدام برنامج "3D-Slicer" المتاح مجانًا، الذي بنى بعد ذلك الصور وبنى وحدة ثلاثية الأبعاد.

النتائج: كانت السعة الجمجمية المتوسطة (±SD) للذكور هي 1481.6 (± 110) سم٣ (النطاق: 1241–1723 سم٣)، بينما كانت السعة الجمجمية للإناث هي 1375.4 (±104) سم٣ (النطاق: 1203–1678 سم٣). أظهرت هذه الدراسة أن الذكور لديهم متوسط سعة جمجمية أكبر بنسبة 7% من تلك للإناث في هذه الدراسة. كانت سعة الجمجمة المتوسطة للذكور بين أعمار 31 و 40 عامًا أكبر مقارنةً بالنسبة للذكور الذين تتراوح أعمارهم بين 61 و 80 عامًا (p<0.05).

الخلاصة: أظهرت هذه الدراسة أن السعة الجمجمية المتوسطة للذكور كانت أكبر من تلك للإناث. يمكن أن تساعد نتائج هذه الدراسة في تحديد السعة الجمجمية الطبيعية للبالغين في المملكة العربية السعودية. ينبغي القيام بمزيد من الأعمال للمساعدة في إنشاء بيانات مرجعية للسكان السعوديين.

Objectives: To measure the cranial capacity of members of the Saudi adult population across ages and genders.

Methods: This was a retrospective cross-sectional study that used 488 Computed Tomography (CT) scans of heads (of which 275 males) to measure cranial volume. The CT slices 0.625 mm thick were uploaded using the freely available software "3D-Slicer", which then reconstructed the images and built a 3D module.

Results: The mean (±SD) cranial capacity of the males was 1481.6 (±110) cm^3 (range: 1241–1723 cm3), whereas the cranial capacity of the females was 1375.4 (±104) cm^3 (range: 1203–1678 cm3). This study showed that the males had a mean cranial capacity that was 7% greater than that of the females in this study. The average cranial capacity of the males between the ages of 31 and 40 years was statistically significantly larger to that of the males aged 61–80 (p<0.05).

Conclusion: This study demonstrated that the average cranial capacity of the males was larger than that of the females. These study results can help to determine the normal cranial capacity of adults in Saudi Arabia. Further work should be carried out to aid in establishing reference data for the Saudi population.

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Cranial capacity, an indicator of the brain's volume, is usually used as an indicator that represents the brain's size.[1] Cranial capacity has gained importance in morphometric studies and in certain disciplines, including forensic science, pediatrics, human development, and oral surgery.[2] In addition, certain deformities within the cranial cavities can be diagnosed by using this brain volume indicator.

Many methods have been established for estimating cranial capacity. These include traditional methods that measure the height, length, and width of the external surface of the skull to compute the cranial capacity.[3,4] Other studies measured the cranial volume directly through studying dry skulls filled with small objects, such as seeds or sand grains, or water to measure the volume.[5]

However, the traditional methods have limitations, including the exclusion of the bone thickness when taking measurements from the external surfaces and

errors due to variations in the age of the sampled skulls filled with small objects. Additionally, few skulls are available to study within certain populations due to ethical principles, especially those that pertain to donating bodies for study and research in medical science.[6] Nevertheless, other methods such as regression formulas were largely acceptable as measurements of cranial volume until several studies revealed that bone thickness and other internal structures within the cranium could cause errors in the calculations.[7]

Intracranial volume was studied first using computed tomography (CT) scan slices as early as 1988. This technique's accuracy was validated by applying it to 10 dry skulls and comparing the resulting values to the actual intracranial volumes that were calculated by filling the skulls with water. Nowadays, with the development of CT imaging, the internal body structure has been well studied and measurements established.[8,9] Currently, semi-automated techniques to reconstruct CT scan images have facilitated measuring and comparing cranial volumes for different populations in different age groups. Additionally, the volumes are now easily measured and quantified using readily available 3D software.[10] These methods involve uploading images of CT head scans in DICOM format using 3D software, then selecting a region of interest, and then quantifying the brain volume.[9]

Studies have shown that several factors, including gender, age, and geographical region, can affect cranial volume.[11–14] Nevertheless, racial differences are one of the most controversial factors that may influence the cranial capacity. Studies have documented well these racial differences across different populations, including Americans,[15] Chinese,[12] and Indians.[16] However, studies on the Saudi population are few and little is known about the Saudis' cranial volume in contrast to what is known about other populations' cranial volumes. This study provides normative data on the cranial volume of the adult Saudi population across age and gender using 3D software.

Methods. To make sure this study has not been carried out in Saudi population, a review of the literature was carried out to demonstrated firstly the methods used to quantify the Cranial capacity. Studies include number of references that aided in writing the literature review. The reference list of those included studies were also browsed to include relevant studies. Other citation tracking tools were used, such as Scopus or Web of Science, to see how often a particular paper has been cited. Then, searching through academic databases such as PubMed and Google scholar, using specific words such as (Saudi, Saudi Arabians, Cranial Capacity) to determine whether a study has been carried out on Saudi Arabia. Searching the database mentioned above has revealed no similar study.

This is a retrospective cross-sectional study to determine the cranial volume of the adult Saudi population across age and gender. The study was carried out in a large teaching hospital (Najran University Hospital) in southern Saudi Arabia. The study was conducted by collecting CT head scans that had been produced between September 2020 and August 2022. To eliminate factors that might affect the measurements of the cranial volume, the inclusion criteria limited participants to adults aged between 18 and 80 who had no craniofacial deformities or head fractures. The patient's file was screened to exclude those with a history of brain surgery, severe osteoporosis, or any neurological defects. All of the retrieved CT scans were assessed by an experienced radiologist for their appropriateness. Before the start of the study, ethical approval was granted through the ethical committee at Najran University.

In total, 488 CT scans of heads (of which 275 were from males) met the inclusion criteria and were retrieved. The CT head scans were then divided based on the patients' ages into 5 age groups, as shown in **Table 2**. Then, thin-slice CT scan images were uploaded using freely available software 3D Slicer V.5.1 (Brigham and Women's Hospital, Harvard Medical School, Boston, MA, USA in DICOM format) after anonymizing the patient data. The open platform 3D Slicer offers a number of modules to reconstruct the images.[17] Within the software, a volumetric segmentation section called Segment Editor (SE) was used to construct the regions of interest. The threshold function within the software facilitated the selection of a range of intensities to include in the measurement (**Figure 1**). Thereafter, when the image was correctly imported, the window width was adjusted using the volume module option that then distinguished between the brain tissues (namely soft tissue and bone) and the outer area of each slice. Then the 3D was reconstructed to provide an interactive visualization of a 3D image from which the cranial volume was measured.

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Statistical analyses were undertaken using SPSS v.25. The results were displayed as descriptive data, including standard deviations (±SD), means, and upper and lower volumes. The cranial volume results obtained using the age and gender variables were compared across the four age-groups using t-tests. An interclass correlation (ICC) was performed to assess the intra-observer reliability. For all tests, the *p*-value was considered significant if it was <0.05.

The Committee of Scientific Research & Conferences in the Faculty of Medicine, Najran University has reviewed the study protocol and ethically approved the study application to be conducted which is a matched cross-sectional study to evaluate [The Cranial Capacity of the Saudi Population Measured Using 3D Computed Tomography Scans]. All participants understand the purpose of the research and agree to participate voluntary. The current study complies with the Declaration of Helsinki.

Table 1 - Mean difference between males and females carinal volume.

	N	mean (±SD)	Max-Min	*P*-value	95% CI
Males	275	1481.6 (±110)	1241-1723	0.000017	1364.8-1598.4
Females	213	1375.4 (±104)	1203-1678		1259.9-1490.9
Statistical difference between males and females (*p*-value<0.05)					

Table 2 - Mean intracranial volume for each age-group in males and females.

Gender	Age group	N	Mean (±SD)	Range	95% CI
Males	18-30	41	1481±118	1241-1698	1367.2-1594.8
Males	31-40	53	1506±116	1347-1723	1403.8-1608.2
Males	41-50	64	1489±109	1327-1685	1392.2-1585.8
Males	51-60	71	1476±113	1361-1692	1374.4-1577.6
Males	61-80	46	1456±107	1313-1609	1354.4-1557.6
Females	18-30	34	1374±97	1203-1552	1280.4-1467.6
Females	31-40	37	1406±114	1279-1617	1298.4-1513.6
Females	41-50	46	1369±112	1215-1678	1270.6-1467.4
Females	51-60	52	1372±102	1298-1621	1301.8-1442.2
Females	61-70	44	1356±118	1238-1593	1255.5-1461.5
			*p-value		

Results. The study population was drawn from a large teaching hospital in the southern region of Saudi Arabia (Najran). Only CT scans of Saudi citizens were included in the study; this was confirmed using the national identification information in the patient file. The whole head scan volume from the foramen magnum to the vertex was included in the CT scan. All of the scans had a slice thickness of 0.625 mm. Scans that had any artifacts were excluded from the analysis.

In total 488 CT scans of heads were included in the analysis. The mean (±SD) cranial capacity of the males was 1481.6 (±110) cm^3 (range: 1241–1723 cm^3), whereas the cranial capacity of the females was 1375.4 (±104) cm^3 (range: 1203–1678 cm^3). The difference between the mean cranial capacity of the males and that of the females was statistically significant (p<0.05; Table 2).

In the comparison based on age groups, the mean cranial capacity of males between 31 and 40 years of age was statistically significantly different to that of males between 61 and 80 (p<0.05). in females, there was no significant differences across the age groups in regards to the cranial volume.

The 3D slicer is semi-automated software that depends partially upon the user. However, to ensure the measurement was not biased by the user, a second reader blindly applied the same protocol on 40 CT head scans. A high correlation between the 2 users was observed, with the IC coefficients of 0.981 for male head scans, and 0.989 for female head scans.

Discussion. Cranial volume plays an important role in many fields, including the medical and forensic fields. Historically, autopsy research has provided the most accurate measurements for cranial volume.[18] However, variable post-mortem handling techniques and religious beliefs and cultures in certain populations

Table 3 - Studies reporting mean carinal capacity in different population.

Study	Males			Females			Region	Method
		SD	95% CI		SD	95% CI		
De Jong et al 2017	1619 cm^3	120	(1379, 1859)	1422 cm^3	110	(1202, 1642)	United States	MRI
Kim et al 2018	1594 cm^3	115	(1364, 1824)	1425 cm^3	105	(1215, 1635)	Koreans	MRI
Eboh et al 2016	1460 cm^3	N/A	N/A	1129 cm^3	N/A	N/A	Nigerian	External Measurement
Ilayperuma 2011	1421 cm^3	100	(1221, 1621)	1300 cm^3	95	(1110, 1490)	Sri Lankan	External Measurement
Acer et al 2007	1306 cm^3	N/A	N/A	1141 cm^3	N/A	N/A	Turkey	External Measurement
Hwang et al 1995	1470 cm^3	130	(1210, 1730)	1317 cm^3	120	(1077, 1557)	Koreans	Dry skulls filled with seeds

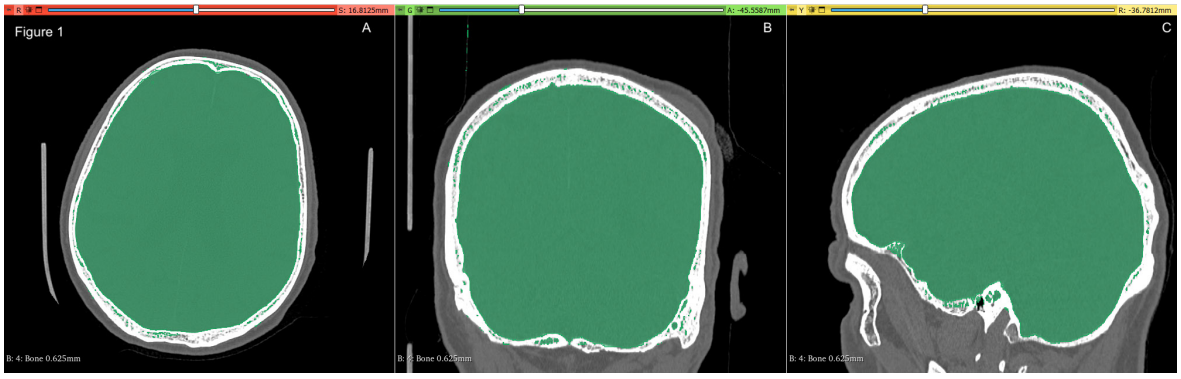

Figure 1 - Region of interest (ROI) is chosen in the 3D slicer and highlighted across different dimensions.

are issues in investigations based on autopsies.[6] Now, with the advances in medical imaging, such as the ability to reconstruct 3D modules, users are able to extract different measurements. In this study, the cranial capacity based on CT head scan images was calculated using a free online tool.

The results of this study reveal a difference in cranial capacity between males and females that has been also reported for other populations. In a study on contemporary Americans, A recent study showed that the mean cranial capacity was 1619 cm^3 in men, whereas in women it was 1422 cm^3.[19] Furthermore, the mean cranial capacity of Korean males was 1594 cm3 and that of Korean females was 1425 cm^3.[20] Additionally, studies from Africa have suggested that the mean African cranial capacity differs from that of Asians and Americans: the cranial capacity for African males was 1460 cm^3 and for females was 1129 cm^3.[20] The current study included mastoid air sinuses in calculation of cranial capacity. Additionally, the measurements of mastoid air sinuses have been shown to be affected by other factors such as age, sex and ethnicity.[21,22]

These differences among populations have been attributed to several factors, including genetic variation, geographical region, and race. Beals et al[23] studied more than 20,000 skulls from around the world to measure cranial capacity and found that the mean cranial volume of Africans was 1268 cm^3, of Europeans was 1362 cm^3, and of East Asians was 1415 cm^3.[23] Additionally, using external head measurements from a stratified random sample of 6325 United State army troops, a study showed that the mean head volume of Asian Americans was 1416 cm^3, of European Americans was 1380 cm^3, and of African Americans was 1359 cm^3.[24] In the population of Sri Lanka, the mean cranial capacity of males was measured as 1421 cm^3 and 1300 cm^3 of females.[25] **Table 3** presents the cranial capacity of different populations.

This study results are in line with the previous research, the cranial capacity of men has been demonstrated to be greater than that of women.[19,26,27] This study showed that the males had a mean cranial capacity that was 7% greater than that of the females in this study. This can be attributed to the differences in weight and height between men and women; cranial capacity tends to be larger among those who are taller and heavier. In forensics, this variation is a crucial clue for establishing the gender of a deceased body.[28] Although brain volume increases during childhood and then decreases as people age, cranial capacity hardly changes once a person reaches maturity. Studies on populations of varying ages have yielded conflicting findings: a study of East Asian adults found that the average cranial capacity had increased by 90 cm^3 over the previous 40 years.[26] Additionally, according to a study comparing Europeans and Americans, during the past century, the average cranial capacity of both populations has increased and so have their cerebral capacities.[29] Although both genders experienced increase, those in men were more significant than those in women.

In this study, an increase was observed in cranial capacity among certain age groups in males and females. In males particularly, a statistically significant difference in cranial capacity was observed between those in their 70s and those in their 30s, suggesting a slight upward trend in cranial capacity with age in both genders. Several factors have been presented in the literature that could affect cranial development, including malnutrition, access to medical care and health status.[1,3,12,16] Medical care and healthcare resources in the kingdom were limited when first started, which may have limited access to clinics and medical centers.[30] Nevertheless, undernourishment was also reported among children during the 1970s–80s; these factors can influence growth in general and cranial measurements as well.

The current study contained useful information on the volumetric capacity of the cranium and can aid to better understand the differences between populations. However, the limitations of this study should be highlighted: the number of subjects in the younger age groups is smaller than that in older age group, and the males group is larger than the females group. The nature of the sample and the way in which the sample was drawn may have affected the results in which a retrospective style was undertaken. However, recruiting volunteers, x-raying them, and exposing them to ionizing radiation for no clinical reason are harmful.

Implications for future research include the need to establish a complete reference range for cranial capacity in the Saudi population, including both males and females across different age groups. Further investigation could explore potential factors influencing cranial capacity, such as genetics, environment, and lifestyle, as well as potential associations with neurological disorders. Additionally, research could investigate the use of 3D computed tomography scans and other imaging technologies to measure cranial capacity in a more accessible and cost-effective manner. These efforts could provide valuable insights into the development, function, and health of the brain, as well as contribute to the understanding of individual and population differences in cranial capacity.

Conclusions. In our sample of the Saudi Arabian population, the cranial capacity of males was larger than that of the females. Over the last decades, both genders have shown an increase in cranial volume, although males showed a statistical significant increase. This study's results can aid to establish reference data and norms for the cranial capacity of the Saudi population. Nevertheless, further work should be carried out to establish a reference data for the current Saudi population.

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