VOLUMETRIC ASSESSMENT OF NORMAL ADRENAL GLANDS BY COMPUTED TOMOGRAPHY

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ABSTRACT
Background: The adrenal glands are small but vital endocrine organs responsible for the production of corticosteroids, mineralocorticoids, and catecholamines. Accurate assessment of adrenal gland volume by computed tomography (CT) provides valuable information for distinguishing normal anatomical variations from pathological conditions. However, normative volumetric data remain limited, particularly in the Indian population.
Aims: To determine the normal adrenal gland volume using multidetector computed tomography (MDCT) in adults without adrenal pathology and to evaluate the relationship of adrenal gland volume with age and gender.
Materials and Methods: This hospital-based descriptive cross-sectional study included 100 adults aged 20–40 years who underwent CT Abdomen or CT KUB at the Department of Radiodiagnosis, J.J.M. Medical College and Bapuji Hospital, Davangere, between October 2019 and October 2021. Patients with suspected adrenal disease, malignancy, or adrenal involvement were excluded. Adrenal gland volumes were calculated from axial CT images using the summation-of-areas technique. Statistical analysis was performed using IBM SPSS Statistics Version 22.0. Continuous variables were expressed as mean ± SD, while categorical variables were analyzed using the Chi-square test and Unpaired t-test. A P value <0.05 was considered statistically significant.
Results: The mean age of the study population was 28.93 ± 6.27 years, with equal representation of males and females. The mean right, left, and total adrenal gland volumes were 3.26 ± 0.45 cm^3, 3.35 ± 0.46 cm^3, and 6.60 ± 0.75 cm^3, respectively. No statistically significant differences in adrenal gland volume were observed according to age or gender (P>0.05). The right adrenal gland most commonly demonstrated a linear morphology (79%), whereas the left adrenal gland predominantly exhibited a Y-shaped configuration (71%), with no significant association with age or sex.
Conclusion: MDCT provides reliable and reproducible volumetric assessment of normal adrenal glands. The reference values generated in this study may facilitate accurate differentiation between normal anatomical variations and adrenal pathology, thereby supporting improved radiological interpretation and clinical decision-making.
Keywords: Adrenal gland, Computed tomography, Multidetector CT, Adrenal volume, Volumetric assessment, Morphology, Normal adrenal gland.
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INTRODUCTION

The adrenal glands are paired endocrine organs located in the retroperitoneum above the kidneys and play a vital role in maintaining metabolic homeostasis, electrolyte balance, blood pressure regulation, and the physiological response to stress through the secretion of glucocorticoids, mineralocorticoids, and catecholamines. Despite their relatively small size, abnormalities involving the adrenal glands have significant clinical implications, ranging from endocrine dysfunction to benign and malignant neoplasms. Accurate evaluation of adrenal morphology is therefore essential for the early diagnosis and appropriate management of adrenal disorders. Recent advances in cross-sectional imaging, particularly multidetector computed tomography (MDCT), have substantially improved the visualization of adrenal anatomy and enabled detailed quantitative assessment of adrenal size and volume, which may provide greater diagnostic accuracy than conventional linear measurements alone.[1]

Computed tomography has become the imaging modality of choice for adrenal evaluation because of its excellent spatial resolution, rapid acquisition, and widespread availability. Traditionally, adrenal assessment relied on linear dimensions such as limb thickness and gland width; however, these measurements are limited by the complex Y- or V-shaped morphology of the adrenal glands and considerable interobserver variability. Volumetric analysis overcomes these limitations by incorporating the entire three-dimensional structure of the gland, allowing a more comprehensive and reproducible estimation of adrenal size.[2],[3]

Establishing normative adrenal gland volume is increasingly important because adrenal enlargement or atrophy may reflect underlying endocrine or systemic disease before obvious structural abnormalities become apparent. Several

studies have demonstrated that adrenal volume varies with age, sex, body mass index (BMI), body surface area, and metabolic status, emphasizing the need for population-specific reference values. Accurate baseline volumetric data can improve differentiation between physiological variation and pathological enlargement, thereby enhancing diagnostic confidence in conditions such as adrenal hyperplasia, adrenal insufficiency, primary aldosteronism, Cushing syndrome, and adrenal incidentalomas.[4],[5],[6]

Recent technological developments, including semi-automated and fully automated segmentation using artificial intelligence and deep learning algorithms, have further improved the accuracy, efficiency, and reproducibility of adrenal volumetry. These innovations have reduced observer dependency and made volumetric analysis more practical for routine clinical use. In addition, personalized reference ranges generated from large CT datasets have shown promise in facilitating computer-assisted diagnosis and early detection of adrenal abnormalities.[7],[8]

Although several international studies have evaluated adrenal gland volume using CT, normative volumetric data remain limited in many populations, and significant ethnic and anthropometric variations have been reported. Consequently, there is an ongoing need to establish reliable reference standards for normal adrenal gland volume in different demographic groups. Such information would aid radiologists and clinicians in distinguishing normal anatomical variations from subtle pathological changes, ultimately improving diagnostic precision and patient management.[9],[10]

The present study aimed to establish normative volumetric measurements of the adrenal glands using computed tomography (CT) in individuals without clinical evidence of adrenal pathology. The specific objectives were to determine the adrenal gland volume in patients undergoing CT abdomen/KUB and to evaluate the association of adrenal gland volume with age and sex, while exploring the correlation between these demographic factors and adrenal volumetric variations.

MATERIALS AND METHODS

Study Design: Hospital-based descriptive cross-sectional study.

Study Population: Patients of both sexes aged 20–40 years undergoing CT Abdomen or CT KUB for indications unrelated to adrenal disease at the Department of Radiodiagnosis, J.J.M. Medical College and Hospitals, Davangere.

Sample Size: A total of 100 participants were included in the study.

Study Duration: 2 years (October 2019 to October 2021).

Study Place: Department of Radiodiagnosis, J.J.M. Medical College and Bapuji Hospital, Davangere, Karnataka, India.

Inclusion Criteria:

- Patients aged 20–40 years of either sex.
- Patients undergoing CT Abdomen or CT KUB.
- Patients with no clinical, biochemical, or radiological evidence of adrenal pathology.
- Patients who provided written informed consent for participation.

Exclusion Criteria:

- Patients with clinical or biochemical suspicion of adrenal disease.
- Patients with diseases known or suspected to involve the adrenal glands.
- Patients with known primary or metastatic malignancy.
- Patients with adrenal lesions detected on CT imaging.
- Patients with poor-quality CT images that precluded accurate adrenal volumetric assessment.

Statistical Analysis: The collected data were entered into Microsoft Excel and analyzed using IBM SPSS Statistics for Windows, Version 22.0 (IBM Corp., Armonk, NY, USA). Continuous variables were expressed as mean ± standard deviation (SD), while categorical variables were presented as frequencies and percentages. The Unpaired Student's t-test was used to compare the mean adrenal gland volumes between different age groups and between males and females. Associations between categorical variables, including adrenal gland morphology according to age and gender, were assessed using the Chi-square test. A two-tailed P value <0.05 was considered statistically significant for all analyses.

RESULT

Table 1. Demographic Characteristics of the Study Population

Variable	Category	n (%) / Mean ± SD
Gender	Male	50 (50.0)
	Female	50 (50.0)
Age Group (years)	21–30	55 (55.0)
	31–40	45 (45.0)
Age (years)	Mean ± SD	28.93 ± 6.27

Table 2. Adrenal Gland Volume According to Age and Gender

Variable	Overall Mean ±	21–30 Years	31–40 Years	P-val	Male (n=5	Female (n=	P-val

	SD	(n=55)	(n=45)	ue	0)	50)	ue
Right adrenal volume	3.26 ± 0.45	3.23 ± 0.44	3.28 ± 0.46	0.58	3.19 ± 0.51	3.32 ± 0.37	0.16
Left adrenal volume	3.35 ± 0.46	3.32 ± 0.46	3.37 ± 0.47	0.6	3.29 ± 0.48	3.41 ± 0.45	0.2
Total adrenal volume	**6.60 ± 0.75**	**6.55 ± 0.72**	**6.66 ± 0.78**	**0.5**	**6.48 ± 0.81**	**6.72 ± 0.67**	**0.1**

Table 3. Morphological Shapes of the Adrenal Glands in the Study Population

Shape	Right n (%)	Left n (%)
Linear	79 (79.0)	5 (5.0)
V-shaped	12 (12.0)	20 (20.0)
Y-shaped	0 (0.0)	71 (71.0)
Curvilinear	9 (9.0)	2 (2.0)
Triangular	0 (0.0)	2 (2.0)

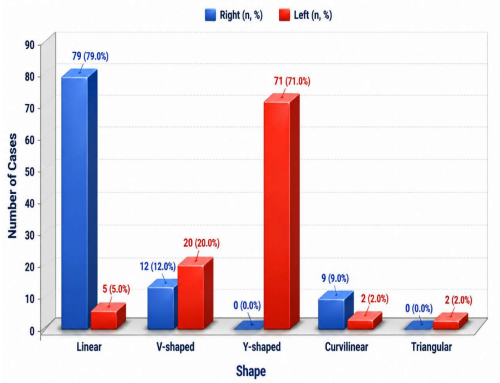
Table 4. Distribution of Adrenal Gland Shapes According to Gender

Shape	Right Male n (%)	Right Female n (%)	Left Male n (%)	Left Female n (%)
Linear	40 (80)	39 (78)	4 (8)	1 (2)
V-shaped	4 (8)	8 (16)	7 (14)	13 (26)
Y-shaped	—	—	37 (74)	34 (68)
Curviliinear	6 (12)	3 (6)	2 (4)	0
Triangular	—	—	0	2 (4)
P-value	**0.309 (NS)**		**0.102 (NS)**	

Table 5. Distribution of Adrenal Gland Shapes According to Age Group

Shape	Right 21–30 yrs n (%)	Right 31–40 yrs n (%)	Left 21–30 yrs n (%)	Left 31–40 yrs n (%)
Linear	45 (81.8)	34 (75.6)	2 (3.6)	3 (6.7)
V-shaped	6 (10.9)	6 (13.3)	10 (18.2)	10 (22.2)
Y-shaped	—	—	41 (74.5)	30 (66.7)
Curvilinear	4 (7.3)	5 (11.1)	2 (3.6)	0
Triangular	—	—	0	2 (4.4)
P-value	**0.723 (NS)**		**0.292 (NS)**	

Figure: 1. Morphological Shapes of the Adrenal Glands in the Study Population



A total of 100 participants were included in the study, with an equal distribution of males and females. There were 50 males (50.0%) and 50 females (50.0%), ensuring balanced representation of both sexes. Based on age distribution, the majority of participants belonged to the 21–30 years age group (55 participants; 55.0%), while 45 participants (45.0%) were in the 31–40 years age group. The overall mean age of the study population was 28.93 ± 6.27 years, indicating that the participants were predominantly young adults undergoing CT examination without clinical evidence of adrenal pathology.

The mean right adrenal gland volume for the entire study population was 3.26 ± 0.45 cm³. Participants aged 21–30 years had a mean right adrenal volume of 3.23 ± 0.44 cm³, whereas those aged 31–40 years had a slightly higher mean volume of 3.28 ± 0.46 cm³; however, this difference was not statistically significant (P = 0.58). Similarly, males demonstrated a mean right adrenal volume of 3.19 ± 0.51 cm³, while females showed a marginally higher value of 3.32 ± 0.37 cm³, with no statistically significant gender difference (P = 0.16).

The overall mean left adrenal gland volume was 3.35 ± 0.46 cm³. The mean volume was 3.32 ± 0.46 cm³ in the 21–30 years age group and 3.37 ± 0.47 cm³ in the 31–40 years age group, with no significant age-related difference (P = 0.60). Male

participants had a mean left adrenal volume of 3.29 ± 0.48 cm^3, compared to 3.41 ± 0.45 cm^3 in females, which also did not reach statistical significance (P = 0.20).

The total adrenal gland volume (combined right and left glands) had an overall mean of 6.60 ± 0.75 cm^3. The mean total adrenal volume was 6.55 ± 0.72 cm^3 among participants aged 21–30 years and 6.66 ± 0.78 cm^3 among those aged 31–40 years, showing no statistically significant difference (P = 0.50). Likewise, the mean total adrenal volume was 6.48 ± 0.81 cm^3 in males and 6.72 ± 0.67 cm^3 in females, with the observed difference being statistically non-significant (P = 0.10). Overall, adrenal gland volume showed minimal variation according to age and gender within the study population.

Assessment of adrenal gland morphology demonstrated considerable variation between the right and left glands. The right adrenal gland most commonly exhibited a linear configuration, observed in 79 participants (79.0%), followed by the V-shaped pattern in 12 participants (12.0%) and the curvilinear pattern in 9 participants (9.0%). None of the right adrenal glands displayed either Y-shaped or triangular morphology.

In contrast, the left adrenal gland most frequently demonstrated a Y-shaped configuration, present in 71 participants (71.0%). A V-shaped morphology was observed in 20 participants (20.0%), whereas only 5 participants (5.0%) had a linear left adrenal gland. Curvilinear and triangular configurations were uncommon, each being identified in 2 participants (2.0%). These findings indicate distinct morphological differences between the right and left adrenal glands, with the right gland predominantly linear and the left gland predominantly Y-shaped.

When adrenal gland morphology was analyzed according to gender, the right adrenal gland maintained a predominantly linear shape in both sexes, occurring in 40 males (80%) and 39 females (78%). The V-shaped configuration was identified in 4 males (8%) and 8 females (16%), while the curvilinear pattern was observed in 6 males (12%) and 3 females (6%). No right adrenal gland demonstrated a Y-shaped or triangular morphology in either sex. The association between right adrenal morphology and gender was not statistically significant (P = 0.309).

For the left adrenal gland, the Y-shaped configuration remained the most common pattern in both males and females, occurring in 37 males (74%) and 34 females (68%). The V-shaped morphology was noted in 7 males (14%) and 13 females (26%), whereas the linear configuration was observed in 4 males (8%) and 1 female (2%). Curvilinear morphology was found in 2 males (4%) but was absent among females, while a triangular configuration was identified in 2 females (4%) only. The distribution of left adrenal gland morphology also showed no statistically significant association with gender (P = 0.102).

Comparison of adrenal gland morphology between age groups revealed similar patterns. Among participants aged 21–30 years, the right adrenal gland was predominantly linear, occurring in 45 participants (81.8%), followed by V-shaped morphology in 6 participants (10.9%) and curvilinear morphology in 4 participants (7.3%). In the 31–40 years age group, 34 participants (75.6%) exhibited a linear right adrenal gland, 6 participants (13.3%) had a V-shaped gland, and 5 participants (11.1%) demonstrated a curvilinear pattern. No Y-shaped or triangular right adrenal glands were identified in either age group. The distribution of right adrenal morphology according to age was not statistically significant (P = 0.723).

For the left adrenal gland, the Y-shaped configuration remained the predominant morphology in both age groups, occurring in 41 participants (74.5%) aged 21–30 years and 30 participants (66.7%) aged 31–40 years. The V-shaped pattern was observed in 10 participants (18.2%) in the younger age group and 10 participants (22.2%) in the older age group. A linear configuration was present in 2 participants (3.6%) aged 21–30 years and 3 participants (6.7%) aged 31–40 years. Curvilinear morphology was seen only in 2 younger participants (3.6%), whereas a triangular configuration was identified in 2 participants (4.4%) in the older age group. There was no statistically significant association between age group and left adrenal gland morphology (P = 0.292). Overall, adrenal gland morphology remained consistent across different age groups, with no significant age-related variation.

DISCUSSION

The present study included 100 healthy adults with an equal distribution of males (50%) and females (50%), while the majority of participants belonged to the 21–30-year age group (55%). A balanced sex distribution was intentionally maintained to minimize gender-related bias in adrenal volumetric assessment. Similar demographic characteristics were reported by Uçar et al., who evaluated normal adrenal gland morphology using MDCT in both sexes and across a broad adult age range, ensuring comparable representation for establishing reference values.[11]

The mean right, left, and total adrenal gland volumes were 3.26 ± 0.45 cm^3, 3.35 ± 0.46 cm^3, and 6.60 ± 0.75 cm^3, respectively. Although females demonstrated slightly larger adrenal volumes than males and participants aged 31–40 years had marginally higher volumes than those aged 21–30 years, these differences were not statistically significant. These findings are in agreement with the study by Sasiwimonphan and Ariyajinda, who also observed no significant

influence of age or sex on normal adrenal gland volume among healthy adults undergoing CT evaluation.[12] Likewise, Zhang et al. demonstrated that normal adrenal volume exhibits only modest variation with demographic factors and emphasized that individualized reference ranges are more useful than simple age- or sex-based cut-offs.[13]

In the present study, the right adrenal gland was predominantly linear (79%), whereas the left adrenal gland was predominantly Y-shaped (71%). This characteristic asymmetry between the two adrenal glands closely corresponds with previous anatomical CT studies. Uçar et al. similarly reported that the right adrenal gland most frequently exhibited a linear morphology, while the left gland was commonly Y-shaped because of differences in embryological development and surrounding anatomical structures.[11] Comparable observations have also been reported in recent CT morphometric analyses of normal adrenal glands.[14]

No statistically significant association was found between adrenal gland morphology and gender for either the right (P=0.309) or left adrenal gland (P=0.102). Although minor variations in the frequency of linear and V-shaped glands were observed between males and females, the overall morphological pattern remained similar. These findings are consistent with those of Uçar et al., who concluded that adrenal gland shape is largely independent of sex and primarily reflects normal anatomical variation rather than gender-specific differences.[11] Similar conclusions were also reported by recent studies evaluating adrenal morphology using multidetector CT.[15]

The present study demonstrated no statistically significant relationship between adrenal gland morphology and age group for either the right (P=0.723) or left adrenal gland (P=0.292). Linear morphology remained the dominant pattern in the right adrenal gland, whereas the Y-shaped configuration predominated on the left across both age groups. These observations are comparable with the findings of Sasiwimonphan and Ariyajinda, who reported that adrenal gland morphology remains relatively stable throughout adulthood in individuals without adrenal pathology.[12] Furthermore, recent AI-assisted volumetric studies have also indicated that although adrenal volume may show subtle physiological variation, gland morphology remains remarkably consistent among healthy adults.[13],[16]

CONCLUSION

The present study established normative computed tomography-based volumetric measurements of the adrenal glands in healthy adults without clinical evidence of adrenal disease. The mean right, left, and total adrenal gland volumes were found to be within a narrow physiological range, providing valuable baseline reference data for routine radiological practice. No statistically significant differences in adrenal gland volume were observed with respect to age or gender, indicating that these demographic factors have minimal influence on adrenal volume in adults aged 20–40 years. Morphologically, the right adrenal gland most commonly exhibited a linear configuration, whereas the left adrenal gland predominantly showed a Y-shaped appearance, with no significant variation according to age or sex. These findings reinforce the role of multidetector computed tomography as a reliable and reproducible modality for adrenal volumetric assessment. The reference values generated from this study may assist radiologists in differentiating normal anatomical variations from early pathological changes, thereby improving the diagnostic evaluation and clinical management of adrenal disorders.

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