Section: Anatomy

Original Research Article

SEXUAL DIMORPHISM AND AGE-RELATED VARIATIONS IN RENAL LENGTH: AN ULTRASONOGRAPHIC STUDY

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ABSTRACT

Background: Renal size is an important indicator of kidney health and functional status. Ultrasonographic measurement of renal length is widely used as it is non-invasive, cost-effective, and reliable. Renal dimensions are known to vary with demographic and anthropometric factors such as age, sex, and body mass index. Understanding these variations is essential for establishing accurate reference standards and improving clinical interpretation of renal measurements. **Aim:** To evaluate the influence of age, sex, and BMI on renal length in adults and to assess the extent of sexual dimorphism across different age and BMI categories. **Materials and Methods:** This observational cross-sectional study was conducted over two years in the Departments of Anatomy and Radiodiagnosis at BRD Medical College, Gorakhpur, India. A total of 1,000 apparently healthy adults aged 18 years and above were enrolled. Renal length was measured ultrasonographically using a Philips Affiniti 70 ultrasound system. Participants were categorized according to age and BMI. Statistical analysis was performed using Jamovi version 2.6, and sex-based differences were evaluated using independent sample t-tests, with $p<0.05$ considered statistically significant. **Results:** Males demonstrated significantly greater right and left renal lengths than females in the 18–30, 31–45, and 46–60 year age groups, with the greatest differences observed in younger adults. After 60 years of age, renal lengths were comparable between the sexes. Across BMI categories, males consistently exhibited larger kidneys than females, with the most pronounced sexual dimorphism observed among underweight individuals. The degree of sex-related difference gradually decreased with increasing BMI. The left kidney generally showed greater variation and more marked sexual dimorphism than the right kidney. **Conclusion:** Renal length is significantly influenced by age, sex, and BMI. Sexual dimorphism is evident in early and middle adulthood but diminishes with advancing age and increasing BMI. These findings highlight the need for age-, sex-, and BMI-specific reference values for accurate ultrasonographic assessment of renal size.

INTRODUCTION

The kidneys are essential organs responsible for maintaining internal homeostasis through regulation of fluid balance, electrolyte concentration, acid–base equilibrium, and excretion of metabolic waste products. Because renal size reflects both functional capacity and structural integrity, assessment of kidney dimensions forms an important part of clinical and anatomical evaluation. Among the various renal parameters, kidney length is considered the most practical and reliable indicator of renal size due to its ease of measurement and reproducibility. Ultrasonography has become the preferred method for renal morphometric assessment because it is non-invasive, widely accessible, cost-effective, and free from ionizing radiation. Consequently, sonographic measurement of renal length is routinely used in the evaluation of normal renal development as well as various renal disorders.[1]

Accurate knowledge of normal renal dimensions is important for distinguishing physiological variations

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from pathological conditions. Changes in kidney size are frequently associated with chronic kidney disease, congenital anomalies, hypertension, obstructive uropathy, and metabolic disorders. A reduction in renal length may indicate chronic parenchymal damage and nephron loss, whereas enlargement can occur in inflammatory, infiltrative, or compensatory conditions. Therefore, the establishment of normative renal measurements is necessary for appropriate clinical interpretation. However, renal dimensions are influenced by several demographic and anthropometric factors, making it difficult to apply a single reference range across all populations.

Sex is recognized as a major determinant of renal morphology. Previous studies have consistently reported larger kidney dimensions in males than females. These differences are generally attributed to greater body size, higher lean body mass, increased renal blood flow, and larger nephron volume in men. Such findings indicate the presence of sexual dimorphism in renal anatomy. Nevertheless, the magnitude of these differences may vary according to age and body composition, suggesting that sex-specific reference values may be required for accurate assessment of renal size.[1,2]

Age-related alterations in renal structure also contribute significantly to variations in kidney dimensions. Renal growth continues until early adulthood, after which kidney size remains relatively stable for several decades. Advancing age is associated with progressive nephron loss, cortical thinning, vascular changes, and reduction in renal parenchymal volume. These physiological changes may lead to gradual decreases in renal length, particularly in elderly individuals. Furthermore, evidence suggests that age-related involution may reduce the extent of sexual dimorphism, resulting in comparable renal dimensions between older males and females. Understanding the influence of age on renal morphology is therefore important for differentiating normal aging from pathological shrinkage.[1,2]

Body mass index (BMI) is another important factor influencing renal size. BMI reflects an individual's nutritional and body composition status and has been shown to correlate positively with renal dimensions. Increased body mass results in greater metabolic demands and renal workload, often leading to adaptive enlargement of the kidneys. Conversely, underweight individuals may exhibit smaller renal measurements due to reduced body mass and organ volume. Although several studies have demonstrated an association between BMI and renal dimensions, the interaction between BMI and sex-related differences in kidney size remains insufficiently explored.

In addition to age, sex, and BMI, considerable variation in renal dimensions has been reported among different ethnic and geographic populations. Genetic factors, environmental influences, nutritional habits, and socioeconomic conditions may contribute to these differences. As a result, population-specific data are essential for developing accurate reference standards and improving diagnostic precision.[1,2]

The present study was undertaken to evaluate renal length in relation to age, sex, and BMI using ultrasonography. By examining patterns of variation across different demographic and anthropometric categories, the study aims to improve understanding of factors influencing renal morphology and contribute to the development of clinically relevant reference values for renal assessment.

Aim and Objectives

Aim

To evaluate the influence of age, sex, and body mass index on renal length in adults using ultrasonography and to determine the extent of sexual dimorphism across different age and BMI categories.

Objectives

1. To measure the longitudinal length of the right and left kidneys in adult subjects using ultrasonography.
2. To compare renal lengths between males and females in different age groups.
3. To assess variations in renal length across different BMI categories (underweight, normal weight, overweight, and obese).

MATERIALS AND METHODS

This observational cross-sectional study was conducted over a period of two years in the Departments of Anatomy and Radiodiagnosis at Baba Raghav Das Medical College, Gorakhpur, Uttar Pradesh, India, after obtaining approval from the Institutional Human Ethics Committee (S.No. 009/IHEC/BRD-Gkp/Academic-2026). A total of 1,000 apparently healthy adults aged 18 years and above were included after obtaining informed consent. Individuals with known renal diseases, congenital renal anomalies, previous renal surgery, or ultrasonographic evidence of renal pathology were excluded.

Demographic data including age and sex were recorded for all participants. Renal ultrasonography was performed using a high-resolution Philips Affiniti 70 (4–8 MHz curvilinear transducer) ultrasound machine. Participants were examined in supine and lateral decubitus positions following a standardized scanning protocol. Both kidneys were visualized in longitudinal plane, and renal length was measured as the maximum pole-to-pole distance along the true longitudinal axis of the kidney.[3,4]

Participants were categorized into age groups for assessment of age-related variations in renal length. Statistical analysis was performed using Jamovi version 2.6. Descriptive statistics were calculated, and sex-based differences in renal length were evaluated using the independent samples t-test. A p-value of less than 0.05 was considered statistically significant.

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RESULTS

A total of 1,000 participants were included in study and categorized into 4 age groups: 18–30 years (n=241), 31–45 years (n=281), 46–60 years (n=275), and >60 years (n=203). Renal length was assessed ultrasonographically, and sex-based differences were analysed using independent sample t-tests.

Age-wise Variation in Renal Length

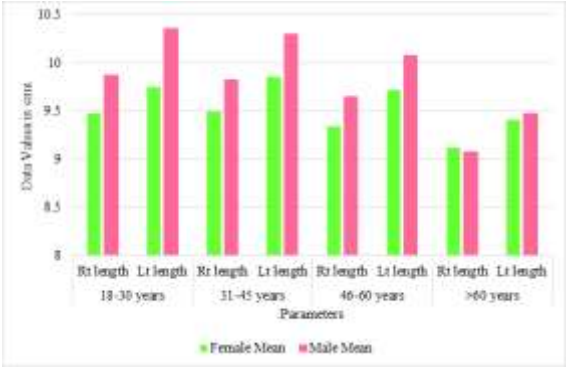
In the 18–30 years age group, males exhibited significantly greater right and left renal lengths than females ($p<0.001$). The mean difference was more pronounced for the left kidney, indicating marked sexual dimorphism during early adulthood. Similar findings were observed in the 31–45 years age group, where males continued to demonstrate significantly longer kidneys than females. However, the magnitude of the differences was slightly reduced compared to the younger age group.

Among participants aged 46–60 years, statistically significant sex differences persisted for both kidneys, although the mean differences further decreased. This finding suggests a gradual reduction in sexual dimorphism with advancing age. In contrast, among individuals older than 60 years, no significant differences were observed between males and females for either right or left renal length ($p>0.05$). Renal lengths were nearly comparable between the sexes in this age group.

These observations indicate that sex is an important determinant of renal length during early and middle adulthood. The larger renal dimensions observed in males may be related to greater body size, lean muscle mass, and renal parenchymal volume. The progressive reduction in sex-related differences with increasing age suggests that age-associated renal involution, including nephron loss and cortical thinning, affects both sexes similarly, resulting in convergence of renal dimensions in the elderly population.

Table 1: Age- and Gender-wise Mean Lengths of Right and Left Kidneys in cms

Age Category	Parameter	Female	Male
18-30 years	Rt length	9.47	9.87
	Lt length	9.75	10.36
31-45 years	Rt length	9.49	9.82
	Lt length	9.85	10.30
46-60 years	Rt length	9.34	9.65
	Lt length	9.72	10.08
>60 years	Rt length	9.11	9.08
	Lt length	9.41	9.47



Graph 1: Age- and Gender-wise Mean Lengths of Right and Left Kidneys in cms.

BMI-wise Variation in Renal Length

Participants were also classified according to BMI as underweight (n=92), normal weight (n=448), overweight (n=299), and obese (n=161). Across all BMI categories, males generally demonstrated greater renal lengths than females. The most pronounced sex differences were observed in the underweight group, where both right and left kidneys showed significantly larger dimensions in males. The left kidney demonstrated a greater degree of sexual dimorphism than the right kidney.

In the normal-weight group, sex-related differences were less marked. While the left kidney remained significantly larger in males, the difference in right renal length was not statistically significant. Among overweight participants, males continued to exhibit significantly greater renal lengths; however, the magnitude of the differences was smaller than that observed in underweight individuals. In the obese group, statistically significant differences persisted for both kidneys, although the mean differences between sexes were comparatively reduced.

The findings suggest that BMI influences the extent of sexual dimorphism in renal length. Sex-related differences were greatest among underweight individuals and progressively diminished with increasing BMI. This pattern may reflect the increasing contribution of body mass and adiposity to renal size, which partially reduces the relative influence of sex. Nevertheless, males consistently maintained larger renal lengths across most BMI categories, indicating that sex remains an independent determinant of renal morphology. The greater differences observed in the left kidney further suggest that left renal length may be more sensitive to biological and anthropometric variations than the right kidney

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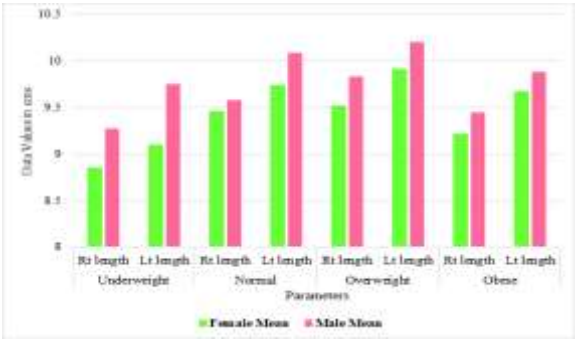
Table 2: BMI and Gender-wise Mean Lengths of Right and Left Kidneys in cms

BMI Category	Parameter	Female	Male
Underweight (<18.5)	Rt length	8.85	9.27
	Lt length	9.10	9.75
Normal (18.5-24.9)	Rt length	9.46	9.57
	Lt length	9.74	10.08
Overweight (25.0-29.9)	Rt length	9.52	9.83
	Lt length	9.91	10.20
Obese (≥30.0)	Rt length	9.21	9.44
	Lt length	9.67	9.88



Graph 2: BMI and Gender-wise Mean Lengths of Right and Left Kidneys in cms.

DISCUSSION

Table 3: Comparison of Renal Length with Other Studies (mean ± SD)

Study	n	Length (cm)
Emamian et al. 1992 Denmark(5)	665	110.5 ± 5.9
Bucholz et al. 2000 Pakistani study(6)	194	10.4 ± 0.8
Kang et al. 2007 Korean study(7)	125	11.08 ± 0.96
This study India (UP)	1000	9.69 ± 0.70

Table 3 compares the mean renal length observed in the present study with those reported in previous studies from different populations. The mean renal length in the current study was 9.69 ± 0.70 cm, which was lower than the values reported by Bucholz et al. (10.4 ± 0.8 cm) in a Pakistani population and Kang et al. (11.08 ± 0.96 cm) in a Korean population. The differences in renal dimensions across these studies may be related to variations in ethnicity, body habitus, genetic background, nutritional factors, and demographic characteristics of the study populations. In addition, methodological differences, including sample size, participant selection criteria, and measurement techniques, may have influenced the reported values. Despite these variations, the present study provides important normative data for the adult population of Uttar Pradesh and emphasizes the need for population-specific reference standards when evaluating renal size in clinical and radiological practice.

Table 4: Comparison of Rt. and Lt. Renal Length according to Age with Previous Studies (Mean ± SD)

Study	Parameter	Rt. Renal Length (cm)	Lt. Renal Length (cm)
This study India (UP)	**18-30 (n=241)**	9.64 ± 0.62	10.01 ± 0.68
	31-45 (n=281)	9.65 ± 0.59	10.07 ± 0.53
	46-60 (n=275)	9.50 ± 0.60	9.91 ± 0.68
	>60 (n=203)	9.09 ± 0.77	9.45 ± 0.78
Bhardwaj et al. 2024 North India study(8)	**20–35 yrs (n=243)**	9.67 ± 0.69	10.02 ± 0.05
	36–50 yrs (n=174)	9.61 ± 0.62	9.99 ± 0.05
	>50 yrs (n=94)	9.34 ± 0.74	9.68 ± 0.08

Table 4 compares age-wise renal lengths observed in the present study with those reported by Bhardwaj et al. in a North Indian population. The findings of both studies are remarkably similar, demonstrating a progressive decline in renal length with advancing age. In the present study, the right renal length decreased from 9.64 ± 0.62 cm in the 18–30 years age group to 9.09 ± 0.77 cm in individuals older than 60 years, while the left renal length declined from 10.01 ± 0.68 cm to 9.45 ± 0.78 cm. Bhardwaj et al. reported a comparable trend, with right renal length decreasing from 9.67 ± 0.69 cm in the 20–35 years group to 9.34 ± 0.74 cm in subjects above 50 years, and left renal length decreasing from 10.02 ± 0.05 cm to 9.68 ± 0.08 cm. Furthermore, both studies consistently demonstrated greater left renal length compared to the right across all age categories. The close agreement between the two studies suggests that age-related reduction in renal size is a consistent

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finding in North Indian populations and supports the reliability of the present observations.

CONCLUSION

The study demonstrates that renal length is significantly influenced by both age and sex. Sexual dimorphism is prominent in younger and middle-aged adults but gradually diminishes with advancing age and becomes negligible after 60 years. Additionally, BMI modifies the extent of sex-related differences, with the strongest dimorphism observed among underweight individuals. These findings emphasize the importance of considering age, sex, and body composition when interpreting ultrasonographic renal length measurements and establishing reference standards for clinical practice.

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