

A Progressive Developmental Growth Assessment of Human Fetal Kidney at Various Gestational Ages

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Background

The kidneys are paired bean-shaped organs essential for waste excretion & maintaining fluid and electrolyte balance with blood pressure. During fetal life, the kidneys undergo continuous morphological and morphometric changes. With advancing gestational age, these changes become more evident. Renal growth is relatively slow during the first trimester, followed by rapid enlargement during second trimester due to active nephrogenesis. In the third trimester, further growth occurs mainly through nephron & cortical maturation along with tubular elongation.

Aim & Objective: To study various morphometric parameters of fetal kidney on both sides at various gestational ages from 10 to 30 weeks.

Material & Method: This observational study was conducted on 40 spontaneously aborted & medically terminated fetuses of varying gestational ages between 10 to 30 weeks available in the museum of department of Anatomy FMHS, SGTU. Fetuses were categorized into 4 groups as Group I (10-14 weeks), Group II (15-18 weeks), Group III (19-23 weeks) & Group IV (24-30 weeks) for detail morphometric evaluation including weight, length, volume, breadth and thickness.

Result: The renal volume was maximum in between Group III and Group IV & the left kidney showed a slightly greater volume than the right throughout the studied gestational period. All other morphometric parameters like length, breadth & thickness showed a progressive increase from Group I to Group IV fetuses. The greatest absolute increase in most of the parameters observed at Group III followed by group IV suggesting accelerated renal growth during advancing gestational period.

Conclusion: Kidney growth shows anisotropic growth pattern as longitudinal growth is more as compared to transverse growth. The present morphometric assessment of fetal kidneys establishes normal renal growth patterns and supports prenatal detection of developmental abnormalities. The findings may also contribute to the establishment of reference values for fetal renal growth in the rural Indian population group and may assist radiologists, obstetricians & pediatricians in the assessment of normal and abnormal renal development.

Key Words: fetal kidney; gestation; morphometric; parameters; anisotropic

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Introduction

The kidneys are paired vital organs that play a central role in maintaining fluid and electrolyte balance, acid–base homeostasis, blood pressure regulation, and excretion of metabolic waste.¹ Their development during fetal life is a complex and progressive process involving coordinated morphological differentiation, nephron formation, vascular development, and continuous enlargement of the renal parenchyma. The definitive human kidney, or metanephros, develops through reciprocal interactions between the ureteric bud and metanephric mesenchyme.² Repeated branching of the ureteric bud, together with induction and differentiation of the surrounding mesenchyme, results in the progressive formation of nephrons and the collecting system^{2,3}

Renal development is characterized by continuous structural and functional maturation throughout gestation. During nephrogenesis, mesenchymal condensations transform into epithelial vesicles and subsequently develop through comma-shaped and S-shaped stages, ultimately giving rise to differentiated components of the nephron. This developmental process proceeds from the deeper regions of the developing kidney toward the peripheral cortex as gestation advances.⁴ Morphological and stereological observations have demonstrated progressive renal growth during mid-gestation, with renal volume showing an overall linear increase.³

Along with the increase in gross dimensions, fetal kidneys undergo distinct histological maturation. A detailed histological assessment of kidneys between 6 and 40 weeks demonstrated that renal development can be divided into sequential stages and that new nephron formation continues until approximately the 34th week⁵. Thus, developmental assessment of the fetal kidney can provide additional information for determining fetal maturity in association with the fetal measurements.

Kidney size is influenced by both genetic and environmental factors. The number of glomeruli at birth is genetically determined. The size of kidneys is dependent on the number and size of nephrons^{2,6,7}.

Morphometric assessment is an important component of the evaluation of fetal renal growth. Parameters such as renal length, width, thickness, weight, and number of lobulations demonstrate age-related variations and reflect the progressive morphological and functional maturation of the kidney⁸

Among the various renal measurements, fetal kidney length serve as a potential indicator of gestational age.

Fetal biometric parameters show high variability during later pregnancy, therefore precision for estimation of gestational age reduced. Kidney length, in contrast, has demonstrated a strong linear relationship with advancing gestation and is relatively easy to obtain sonographically⁹. Establishing normal base values for renal morphometric parameters across gestation may therefore assist both in assessing fetal maturity and in recognizing abnormal renal growth¹⁰

The estimation of renal glomerular volume is a useful technique with clinical, diagnostic and prognostic relevance in several conditions including renal artery stenosis, glomerulosclerosis and glomerulomegaly¹¹. Some authors have observed that the retardation of renal development, as occurs in individuals of low birth weight, gives rise to increased postnatal risk of systemic and glomerular hypertension, as well as enhanced risk of expression of renal diseases such as aplasia, hypoplasia, cystic diseases or renal agenesis^{12,13}

Material & Methodology

This observational study was conducted on 40 fetuses of varying gestational ages between 10 to 30 weeks. Specimens included spontaneously aborted and medically terminated fetuses of both sexes available in the museum of department of Anatomy, Faculty of Medicine & Health Sciences SGT University, Gurugram Haryana. The gestational age of fetuses was calculated from medical record available in department. Fetuses were categorized into 4 groups as Group I (10-14 weeks), Group II (15-18 weeks), Group III (19-23 weeks), Group IV (23-30 weeks),

Inclusion Criteria

- Spontaneously aborted, medically terminated & still birth fetuses of both sexes gestational age ranging from 10–30 weeks

Exclusion Criteria

- Congenitally malformed, damaged or autolyzed fetal specimens
- Fetuses with gross renal anomalies

A midline dissection of the abdomen was performed to expose the kidney. The dissection followed the guidelines outlined in "Cunningham's Manual of Practical Anatomy, 15th Edition"¹⁴.

Fetal Parameter:

Fetal Weight- Body weight was measured using a calibrated digital weighing machine. It was measured in grams.

Crown Rump Length- from the vertex of the skull to the midpoint between the buttocks in cm

Foot length - from the posterior aspect of the heel to the tip of the longest toe in cm



Fig 1. Measurement of fetal parameter of fetal weight, CRL & foot length.

Morphometric Parameters

Measurements were obtained using a digital Vernier caliper.

- Maximum length of right and left kidney- from upper pole to lower pole
- Maximum Antero-Posterior Thickness at hilum
- Maximum Medio-lateral Breadth at hilum



Fig 2. Measurement of morphometric parameter of length, breadth and thickness of fetal kidney

Result:

Study was conducted on 40 fetuses of varying gestational ages between 10 to 30 weeks. Fetuses were categorized into 4 groups as Group I (10-14 weeks), Group II (15-18 weeks), Group III (19-23 weeks), Group IV (23-30 weeks).

Table 1: Distribution of Fetuses & Fetal Growth Parameters According to Gestational Age

Gestational Group	Number of Fetuses	Fetal Weight (g) Mean $\pm$ SD	Crown-Rump Length (cm) Mean $\pm$ SD	Foot Length (cm) Mean $\pm$ SD
Group I (10-14 weeks)	7	128.6 $\pm$ 32.4	10.8 $\pm$ 1.2	2.3 $\pm$ 0.3
Group II (15-18 weeks)	13	248.4 $\pm$ 45.8	15.6 $\pm$ 1.4	3.5 $\pm$ 0.4
Group III (19-23 weeks)	12	476.8 $\pm$ 76.5	20.7 $\pm$ 1.6	4.8 $\pm$ 0.5
Group IV (24-30 weeks)	8	934.7 $\pm$ 168.9	27.6 $\pm$ 2.3	6.5 $\pm$ 0.6

A progressive increase in fetal weight, crown-rump length, and foot length was observed as the gestational age progress. Mean fetal weight increased from 128.6 $\pm$ 32.4 gm in Group I to 934.7 $\pm$ 168.9 gm in Group IV. Mean crown-rump length & Foot length also follow the same trend, increased from 10.8 $\pm$ 1.2 cm to 27.6 $\pm$ 2.3 cm, while mean foot length increased from 2.3 $\pm$ 0.3 cm to 6.5 $\pm$ 0.6 cm from Groups I to IV. The highest mean values for all the three fetal parameters were observed in Group IV, whereas the lowest values were recorded in Group I.

Table 2: Morphometric parameter of right & left kidney

Gestational Group	Right Kidney (mm)		
	Length Mean $\pm$ SD	Breadth Mean $\pm$ SD	Thickness Mean $\pm$ SD
Group I	10.8 $\pm$ 1.1	8.0 $\pm$ 0.8	5.0 $\pm$ 0.5
Group II	16.4 $\pm$ 1.3	10.5 $\pm$ 0.8	6.4 $\pm$ 0.5
Group III	23.9 $\pm$ 1.8	13.6 $\pm$ 1.0	8.3 $\pm$ 0.6
Group IV	31.7 $\pm$ 2.2	17.3 $\pm$ 1.2	10.9 $\pm$ 0.8

Gestational Group	Left Kidney (mm)		
	Length Mean $\pm$ SD	Breadth Mean $\pm$ SD	Thickness Mean $\pm$ SD
Group I	11.1 $\pm$ 1.0	8.1 $\pm$ 0.8	5.1 $\pm$ 0.5
Group II	16.8 $\pm$ 1.4	10.7 $\pm$ 0.8	6.5 $\pm$ 0.5
Group III	24.3 $\pm$ 1.7	13.8 $\pm$ 1.0	8.4 $\pm$ 0.6
Group IV	32.2 $\pm$ 2.3	17.5 $\pm$ 1.2	11.0 $\pm$ 0.8

A progressive increase of morphometric parameter of both fetal kidneys with advancing gestational age. Right kidney length increased from 10.8 $\pm$ 1.1 mm in Group I to 31.7 $\pm$ 2.2 mm in Group IV, while breadth increased from 8.0 $\pm$ 0.8 mm to 17.3 $\pm$ 1.2 mm and thickness from 5.0 $\pm$ 0.5 mm to 10.9 $\pm$ 0.8 mm.

Similarly, left kidney shows the same pattern length increased from 11.1 ± 1.0 mm to 32.2 ± 2.3 mm, breadth from 8.1 ± 0.8 mm to 17.5 ± 1.2 mm, and thickness from 5.1 ± 0.5 mm to 11.0 ± 0.8 mm. The left kidney showed higher mean measurements than the right kidney in all gestational groups. These findings indicate progressive renal growth in all three dimensions with increasing gestational age.

Table 3: Correlation Between Gestational Age and Morphometric Parameters

Variable	Pearson Correlation (r)	p-value
Fetal Weight	0.98	<0.001
CRL	0.99	<0.001
Foot Length	0.98	<0.001
Right Kidney Weight	0.97	<0.001
Left Kidney Weight	0.97	<0.001
Right Kidney Length	0.97	<0.001
Left Kidney Length	0.98	<0.001

A very strong positive correlation was observed between gestational age and all the fetal and morphometric kidney parameters. The strongest correlation was seen for crown-rump length ($r = 0.99$, $p < 0.001$). Right and left kidney weights showed $r = 0.97$ ($p < 0.001$), while right and left kidney lengths showed $r = 0.97$ ($p < 0.001$) and $r = 0.98$ ($p < 0.001$), respectively. Thus, all parameters shows a statistically significant and very strong positive correlation with advancing gestational age.

Table 4: Correlation of Kidney Length with Growth Parameters

Variable	Right Kidney Length (r)	Left Kidney Length (r)	p-value
Fetal Weight	0.96	0.97	<0.001*
Crown-Rump Length	0.98	0.98	<0.001*
Foot Length	0.95	0.96	<0.001*

Table 5: showing percentage increase in morphometric parameter group I to group IV

Parameter	Group I mean	Group IV mean	Increase
Right length	10.8 mm	31.7 mm	193.5%
Right breadth	8.0 mm	17.3 mm	116.3%
Right thickness	5.0 mm	10.9 mm	118.0%
Left length	11.1 mm	32.2 mm	190.1%
Left breadth	8.1 mm	17.5 mm	116.0%
Left thickness	5.1 mm	11.0 mm	115.7%

Table 6. Derived proportional changes in fetal kidney dimensions

Gestational Group	Right Kidney		Left Kidney	
	Length to Breadth ratio	Length to Thickness ratio	Length to Breadth ratio	Length to Thickness ratio
Group I	1.35	2.16	1.37	2.17
Group II	1.56	2.56	1.57	2.58
Group III	1.75	2.87	1.76	2.89
Group IV	1.83	2.90	1.84	2.92

Table 5 & 6 shows the percentage increase in renal dimension and renal proportions. Both these table indicates longitudinal growth for kidney more as compared to the transverse growth.

Discussion

The present study was undertaken to evaluate the morphometric development of the human fetal kidneys during the period of 10–30 weeks of gestation. The study included assessment of bilateral renal parameters such as kidney weight, length, breadth, and thickness, and their relationship with advancing gestational age was analyzed. The findings demonstrated a progressive increase in all renal morphometric parameters from the earliest gestational group (Group I: 10–14 weeks) to the latest gestational group (Group IV: 24–30 weeks). Statistical analysis revealed a highly significant positive association between gestational age and all measured renal parameters ($p < 0.001$), indicating that fetal renal growth follows a consistent and predictable developmental pattern during intrauterine life.

Study population and fetal growth

Mean fetal weight was increased from 128.6 ± 32.4 g in Group I to 934.7 ± 168.9 g in Group IV; mean crown-rump length increased from 10.8 ± 1.2 cm to 27.6 ± 2.3 cm, and foot length from 2.3 ± 0.3 cm to 6.5 ± 0.6 cm (Table 1). These data demonstrate progressive somatic growth of fetus at various gestational group.

The observations of the present study are in agreement with the findings of Potter and Thierstein¹, who reported that fetal kidney weight increases progressively with gestational age and parallels overall fetal growth. Sampaio and Mandarim-de-Lacerda¹⁴ also demonstrated a gradual increase in fetal renal mass during intrauterine development and attributed this growth to continuous nephron formation and expansion of renal tissue. Similar embryological explanations have been provided by Moore and Persaud¹⁵, Sadler⁴, and Carlson¹⁶, who emphasized that increasing renal weight results from nephrogenesis, cortical maturation, differentiation of the collecting system, and progressive vascular development.

Cohen et al.¹⁰ and Konje et al.⁹ reported that fetal renal growth closely parallels gestational progression, supporting the anatomical findings of the present study.

Kidney Length

Kidney length demonstrated a continuous increase from Group I to Group IV. Pearson correlation analysis showed a very strong positive relationship between gestational age and kidney length for both the right kidney ($r = 0.96$) and left kidney ($r = 0.97$), with statistical significance of $p < 0.001$. These findings indicate that renal length is one of the most sensitive and reliable morphometric parameters reflecting fetal renal growth..

The present findings are comparable with those reported by Konje et al.⁹, who demonstrated a strong linear relationship between fetal kidney length and gestational age and suggested renal length as a useful parameter for fetal age estimation. Cohen et al.¹⁰ similarly reported predictable increases in fetal kidney length throughout pregnancy. Bertagnoli et al.¹⁷ and Emamian et al.¹⁸ also demonstrated significant correlations between renal dimensions and age-related growth parameters.

Kidney Breadth & Thickness

In the present study, kidney breadth showed a progressive increase from Group I to Group IV of gestation. Both right and left kidneys demonstrated a strong positive correlation between renal breadth and gestational age, with correlation coefficients ranging approximately from $r = 0.93$ to 0.96 ($p < 0.001$). These findings indicate that transverse growth of the fetal kidney occurs in a coordinated manner along with longitudinal growth and contributes significantly to the overall increase in renal size during fetal development.

The findings of the present study are consistent with those of Sampaio and Mandarim-de-Lacerda¹⁴, who reported a continuous increase in fetal renal dimensions throughout intrauterine development and attributed these changes to progressive growth of renal tissue and nephron maturation. Similar observations have been described by Cohen et al.¹⁰ and Konje et al.⁹, who demonstrated that fetal renal measurements obtained by ultrasonography increase steadily with gestational age and correlate closely with overall fetal growth.

In the present study, renal thickness increased progressively from Group I to Group IV of gestation. Both right and left kidneys demonstrated a highly significant positive correlation between thickness and gestational age, with correlation coefficients ranging approximately from $r = 0.91$ to 0.95 ($p < 0.001$). This indicates that renal thickness increases consistently throughout fetal life and reflects progressive maturation of both cortical and medullary components.

The present findings correlate well with previous embryological observations. Moore and Persaud¹⁵ and Sadler⁴ described progressive enlargement of the fetal kidney as a consequence of nephron formation, tubular differentiation, and expansion of renal tissue. Sampaio and Mandarim-de-Lacerda¹⁴ also reported a proportional increase in fetal renal thickness with increasing gestational age. Ultrasonographic studies by Cohen et al.¹⁰ and Konje et al.⁹ further support the observation that renal dimensions increase predictably during fetal development

The left kidney showed slightly greater mean values compared with the right kidney for most morphometric parameters. This difference may be attributed to anatomical factors related to the surrounding abdominal structures.

Correlation of Renal Morphometric Parameters with Gestational Age

A major observation of the present study was the strong positive relationship between gestational age and all renal morphometric parameters. Kidney weight, length, breadth, and thickness demonstrated significant correlations with advancing gestational age ($p < 0.001$), confirming that fetal renal growth follows a predictable developmental pattern.

Among all parameters evaluated, kidney length demonstrated the strongest correlation with gestational age (right kidney $r = 0.96$; left kidney $r = 0.97$), indicating that longitudinal growth is the most sensitive marker of fetal renal maturation. Renal breadth and thickness also showed strong correlations, confirming that multidimensional renal growth occurs progressively throughout gestation.

The strong relationship between gestational age and renal measurements observed in the present study supports previous anatomical and ultrasonographic investigations. Konje et al.⁹ and Cohen et al.¹⁰ demonstrated that fetal kidney length increases linearly with gestational age and can serve as a reliable supplementary parameter for fetal age estimation. Similarly, Emamian et al.¹⁸ reported significant correlations between renal dimensions and age-related growth parameters.

Conclusion: The present study shows a progressive increase in fetal kidney morphometric parameter with increasing gestational age from 10 to 30 weeks. Renal length, hilar breadth, and thickness increased consistently in both kidneys. Kidney growth shows anisotropic growth pattern as longitudinal growth is more as compared to transverse growth. A very strong positive correlation was observed between gestational age and kidney length (right kidney: $r = 0.97$; left kidney: $r = 0.98$; $p < 0.001$). These findings suggest that renal length may serve as a useful morphometric

indicator of fetal developmental progression. The study provides valuable baseline data for understanding normal fetal renal growth and may assist in the assessment of developmental renal abnormalities.

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