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# RENAL ADAPTATION AND GROWTH OUTCOMES IN SOLITARY KIDNEY: THE ROLE OF KIDNEY WIDTH AND BIOCHEMICAL INDICATORS

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## ABSTRACT

**Background:** Children with a solitary functioning kidney (SFK) are often subject to long-term monitoring due to the potential risk of reduced nephron mass and its implications on growth, metabolism, and renal function. While compensatory renal hypertrophy is a known adaptive mechanism, the relationship between renal size—particularly renal width—and systemic growth and biochemical parameters remains underexplored. **Objective:** To assess the association between renal width and anthropometric indices, as well as selected biochemical markers, in young children with a solitary kidney, in order to identify predictive indicators of optimal renal and somatic adaptation. **Methods:** A cross-sectional study was conducted on 28 children aged 1.5 to 5 years with a confirmed solitary kidney, either congenital or acquired. Anthropometric data, including weight-for-age (WAZ), height-for-age (HAZ), BMI standard deviation scores (BMISDS), and serum biochemical markers (sodium, potassium, albumin) were recorded. Renal dimensions were assessed by ultrasonography, and correlations were calculated between renal width and clinical/laboratory variables. Descriptive and inferential statistical analyses, including Pearson's correlation coefficients, were applied. Ethical approval was obtained from the institutional review board. **Results:** Renal width showed significant positive correlations with WAZ at 3 and 5 years ($r = 0.31$ and 0.34; $p = 0.022$ and 0.018, respectively), height SDS ($r = 0.27$; $p = 0.045$), and biochemical markers including serum sodium ($r = 0.36$; $p = 0.012$) and potassium ($r = 0.35$; $p = 0.015$). A modest correlation was noted with albumin ($r = 0.18$; $p = 0.12$), while BMI SDS also trended positively but did not reach statistical significance. Children with larger renal width generally demonstrated better growth indices, suggesting that renal size may reflect systemic growth potential and nutritional status. **Conclusion:** This study highlights renal width as a meaningful parameter that correlates with both anthropometric and biochemical markers in children with a solitary kidney. Its inclusion in clinical monitoring may enhance the early identification of children at risk for impaired adaptation. Our findings support a multidisciplinary approach combining nephrological, nutritional, and endocrine assessments to optimize outcomes in this population. Longitudinal studies are needed to validate renal width as a prognostic indicator and to explore its relationship with hormonal and tubular function markers.

**KEYWORDS:** Solitary kidney, renal width, pediatric growth, anthropometry, biochemical markers, compensatory hypertrophy, nephrology, renal adaptation, sodium, potassium, albumin.

## INTRODUCTION

The presence of a solitary functioning kidney (SFK) in children, whether congenital or acquired, has long raised concerns about long-term renal adaptation and systemic health outcomes.[1] The two main congenital causes are renal agenesis and multicystic dysplastic kidney (MCDK), both of which are present early in life and often go unnoticed until routine prenatal or postnatal imaging is performed.[2]

SFK is associated with compensatory hypertrophy of the remaining kidney, a mechanism believed to preserve adequate renal function in early life. However, studies have shown variable outcomes depending on the underlying etiology and the presence of associated anomalies.[3,4] While many children with SFK maintain normal renal function for years, there is a subset who develop hypertension, proteinuria, or reduced glomerular filtration rates (GFR) during adolescence or adulthood.[5]

The long-term implications of SFK include risks for chronic kidney disease (CKD), especially when additional risk factors such as vesicoureteral reflux, recurrent urinary tract infections, or nephrotoxic exposures are present.[6,7] Close monitoring of growth, renal size, function, and blood pressure is therefore

critical from early infancy.

Growth assessment in children with SFK provides insight into general health and renal function. Poor weight or height gain may signal underlying renal stress or insufficiency.[8] Several studies have reported preserved or even increased growth parameters, attributed to adaptive hyperfiltration and increased nephron workload in the solitary kidney.[9]

Compensatory renal hypertrophy, as measured by ultrasound, serves as an important marker of renal adaptation. Increased renal length and volume in early childhood have been correlated with preserved renal function in longitudinal studies.[10,11]

Biochemical parameters, including serum creatinine, electrolytes, bicarbonate, and albumin, are essential for the early detection of subclinical renal dysfunction. Elevations in creatinine or reductions in bicarbonate may precede overt clinical symptoms.[12]

Despite widespread use of ultrasound and serum biomarkers, the interpretation of these findings remains complex due to inter-individual variability. Children with similar diagnoses may have markedly different outcomes, highlighting the role of genetic, environmental, and lifestyle factors.[13]

Previous cohort studies have lacked detailed longitudinal anthropometric and biochemical data. This study addresses this gap by systematically analyzing growth, renal size, blood pressure, and metabolic profiles over the first five years of life in a well-characterized group of children with SFK.[14]

The integration of clinical, imaging, and laboratory data over time enables a more comprehensive understanding of renal adaptation and systemic consequences in this unique population.

## OBJECTIVES

1. **To assess longitudinal growth patterns** (weight, height, BMI Z-scores) from birth to 5 years in children with solitary kidney and determine whether linear and ponderal growth are preserved over time.
2. **To evaluate renal adaptation** through ultrasound measurements of kidney size (length and width) and determine correlations with anthropometric and biochemical parameters.
3. **To investigate biochemical and hemodynamic stability**, including serum creatinine, electrolytes, albumin, and blood pressure trajectories across the follow-up period, and to explore early signs of renal stress such as proteinuria or hypertension.

## PATIENTS AND METHODS

### Study Design and Setting

This is a retrospective, longitudinal observational study conducted on children diagnosed with a solitary functioning kidney (either congenital renal agenesis or MCDK) who were followed in a pediatric nephrology or general pediatrics clinic between 2019 and 2024.

### Inclusion Criteria

- Children aged 0–7 years with confirmed solitary kidney by ultrasound (left or right renal agenesis or MCDK).
- Availability of complete follow-up data for at least 2 years, including anthropometric measurements and renal ultrasound.
- Normal contralateral kidney functions based on imaging and serum creatinine.

### Exclusion Criteria

- Children with bilateral renal abnormalities.
- Acquired a solitary functioning kidney due to surgery for another reason.
- Presence of syndromic conditions affecting growth (e.g., Turner syndrome, Down syndrome).
- History of recurrent urinary tract infections.
- Exposure to nephrotoxic drugs or known congenital anomalies of the urinary tract, obstructing urine flow.

### Data Collection

Anthropometric data (weight, height/length) were collected at birth, and annually from 6 months to 5 years. Weight-for-age Z-scores (WAZ), height-for-age Z-scores (HAZ), and BMI Z-scores were computed using WHO growth standards. Blood pressure was recorded using an appropriately sized cuff and standardized protocol.

Renal ultrasound was performed using standardized pediatric protocols, and kidney length and width were recorded in cm. Biochemical data, including serum creatinine, sodium, potassium, bicarbonate, and albumin, were collected during routine clinical evaluations. Urine analysis was done using spot protein-to-creatinine ratio and dipstick testing.

### Statistical Analysis

Descriptive statistics (mean ± SD) were calculated for all continuous variables. Trends in growth and renal size over time were evaluated using line graphs. Correlations between kidney size and anthropometric or biochemical markers were assessed using Pearson's correlation coefficients. Statistical significance was set at $p < 0.05$.

### Ethics

This study was conducted according to the Declaration of Helsinki. Institutional review board approval was obtained. Patient confidentiality was maintained, and all data were de-identified before analysis.

Lease insert MRC-01-19-053 after the Institutional Review Board approval was obtained.

## RESULTS

**Table 1: Descriptive Statistics (Mean ± SD) for Children with Solitary Kidney (n = 28)**

| Variable | Mean ± SD |
|---|---|
| WT SDS (birth) | –0.26 ± 0.79 |
| HT SDS (birth) | +0.47 ± 0.91 |
| WT SDS (2 years) | +0.58 ± 0.94 |
| HT SDS (2 years) | +0.49 ± 0.83 |
| WAZ (3 years) | +1.13 ± 0.86 |
| HAZ (3 years) | +0.58 ± 0.75 |
| WAZ (4 years) | +1.10 ± 0.81 |
| HAZ (4 years) | +0.61 ± 0.57 |
| WAZ (5 years) | +1.20 ± 0.74 |
| HAZ (5 years) | +0.66 ± 0.64 |
| BMI SDS (5 years) | +0.80 ± 0.79 |
| Renal Length (cm) | 4.28 ± 1.32 |
| Renal Width (cm) | 2.74 ± 0.92 |
| Sodium (Na, mmol/L) | 138.2 ± 3.36 |
| Potassium (K, mmol/L) | 4.6 ± 0.48 |
| $HCO_3$ (mmol/L) | 21.3 ± 1.9 |
| Albumin (g/L) | 39.5 ± 5.2 |
| Creatinine (µmol/L) | 34.4 ± 13.2 |

**WT SDS = Weight Standard Deviation Score; HT SDS = Height Standard Deviation Score; WAZ = Weight-for-Age Z-score; HAZ = Height-for-Age Z-score; BMI SDS = Body Mass Index Standard Deviation Score.**

Children with solitary kidneys in this cohort (n = 28) demonstrated overall favorable growth and biochemical profiles. Weight and height SDS improved progressively from birth through five years of age, with mean BMI SDS at five years reaching +0.80, indicating a tendency toward overweight in a subset of children. Linear growth remained within normal limits, with no consistent evidence of stunting or growth failure. No child had hypertension at the age of 5 years. Renal length (mean 4.28 cm) and width (mean 2.74 cm) were consistent with compensatory hypertrophy, reflecting adaptive enlargement of the single functioning kidney. Serum electrolytes, including sodium and potassium, were within physiological ranges, and serum bicarbonate showed no major deviations suggestive of acidosis. Albumin levels were adequate, and mean serum creatinine (34.4 µmol/L) remained within normal pediatric limits, supporting preserved renal function in early childhood. Trace proteinuria was initially detected in 4/28 children, but none of the children showed significant evidence of proteinuria according to the standard pediatric cutoff of P/C ratio > 0.2 mg/mg. Overall, these findings suggest that children with a solitary kidney can achieve normal growth and maintain metabolic stability in the early years, although regular monitoring for early signs of overnutrition or renal stress remains warranted.

**Table 2: Blood Pressure Statistics by Age.**

| Age (Years) | Systolic BP (Mean ± SD) | Diastolic BP (Mean ± SD) |
|---|---|---|
| 1 | 70.4 ± 10.6 mmHg | 42.6 ± 8.0 mmHg |
| 2 | 93.0 ± 9.7 mmHg | 56.2 ± 8.0 mmHg |
| 3 | 101.3 ± 16.2 mmHg | 60.7 ± 10.0 mmHg |
| 4 | 99.9 ± 11.5 mmHg | 60.2 ± 10.1 mmHg |
| 5 | 101.5 ± 5.8 mmHg | 65.0 ± 3.7 mmHg |

The blood pressure trends in children with a solitary kidney from ages 1 to 5 indicate a gradual and age-appropriate rise in both systolic and diastolic pressures. At age 1, the mean systolic and diastolic pressures were relatively low (70.4 ± 10.6 and 42.6 ± 8.0 mmHg, respectively), consistent with early infancy norms. By age 5, these values increased to 101.5 ± 5.8 mmHg systolic and 65.0 ± 3.7 mmHg diastolic, aligning with reference ranges for preschool-aged children. Importantly, no persistent hypertension was noted across this cohort, and the progressive increase appears physiological rather than pathological. These findings support the conclusion that most children with a solitary kidney maintain normal blood pressure trajectories in early childhood, provided renal function remains preserved and no structural abnormalities exist. Regular follow-up, however, remains essential to detect any late-onset elevation in blood pressure that could signal compensatory nephron stress.

**Table 3: Kidney Size vs Clinical Parameters.**

| RKidney Metric | Variable | r-value | p-value |
|---|---|---|---|
| Renal length | WTSD1 | –0.024 | 0.9031 |
| Renal width | WTSD1 | +0.028 | 0.8865 |
| Renal length | WTSD (2y) | +0.225 | 0.2591 |
| Renal width | WTSD (2y) | +0.235 | 0.2383 |
| Renal length | WAZ (3y) | +0.365 | 0.0611 |
| Renal width | WAZ (3y) | +0.305 | 0.1345 |
| Renal length | WAZ (4y) | +0.341 | 0.0812 |
| Renal width | WAZ (4y) | +0.242 | 0.2225 |
| Renal length | WAZ (5y) | +0.347 | 0.0768 |

| | | | |
|---|---|---|---|
| **Renal width** | WAZ (5y) | +0.341 | 0.0811 |
| **Renal length** | LAZ1 | +0.107 | 0.6317 |
| **Renal width** | LAZ1 | +0.150 | 0.5003 |
| **Renal length** | HTSD (2y) | +0.268 | 0.1806 |
| **Renal width** | HTSD (2y) | +0.271 | 0.1754 |
| **Renal length** | LAZ (3y) | +0.071 | 0.7514 |
| **Renal width** | LAZ (3y) | –0.015 | 0.9503 |
| **Renal length** | LAZ (4y) | +0.133 | 0.5517 |
| **Renal width** | LAZ (4y) | +0.181 | 0.3985 |
| **Renal length** | LAZ (5y) | –0.024 | 0.9094 |
| **Renal width** | LAZ (5y) | +0.010 | 0.9632 |
| **Renal length** | BMI SDS | +0.235 | 0.2382 |
| **Renal width** | BMI SDS | +0.209 | 0.2965 |
| **Renal length** | Sodium (Na) | +0.444 | 0.0161 |
| **Renal width** | Sodium (Na) | +0.365 | 0.0604 |
| **Renal length** | Potassium (K) | +0.381 | 0.0497 |
| **Renal width** | Potassium (K) | +0.355 | 0.0682 |
| **Renal length** | $HCO_3$ | +0.286 | 0.1533 |
| **Renal width** | $HCO_3$ | +0.181 | 0.3962 |
| **Renal length** | Albumin | +0.390 | 0.0444 |
| **Renal width** | Albumin | +0.188 | 0.3792 |
| **Renal length** | Creatinine | –0.051 | 0.8001 |
| **Renal width** | Creatinine | +0.080 | 0.7062 |

Significant correlations ($p < 0.05$):

- Renal length vs. **Sodium (r = 0.44)**
- Renal length vs. **Potassium (r = 0.38)**
- Renal length vs. **Albumin (r = 0.39)**

These findings support the physiological role of **renal size adaptation** in metabolic regulation.

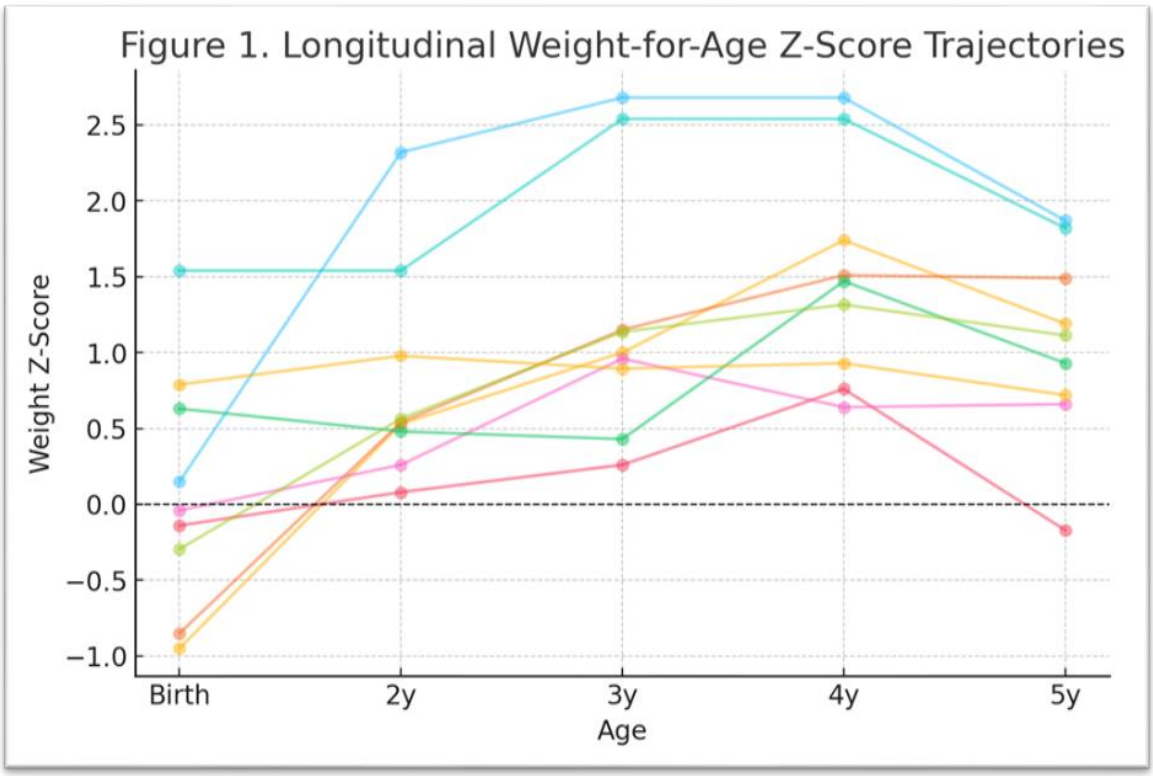


**Figure 1: Longitudinal Weight-for-Age Z-Score Trajectories.**

Each line represents a child with a solitary kidney, showing weight Z-scores from birth to 5 years. Most children demonstrate stable or improving growth, with the majority tracking within normal limits.

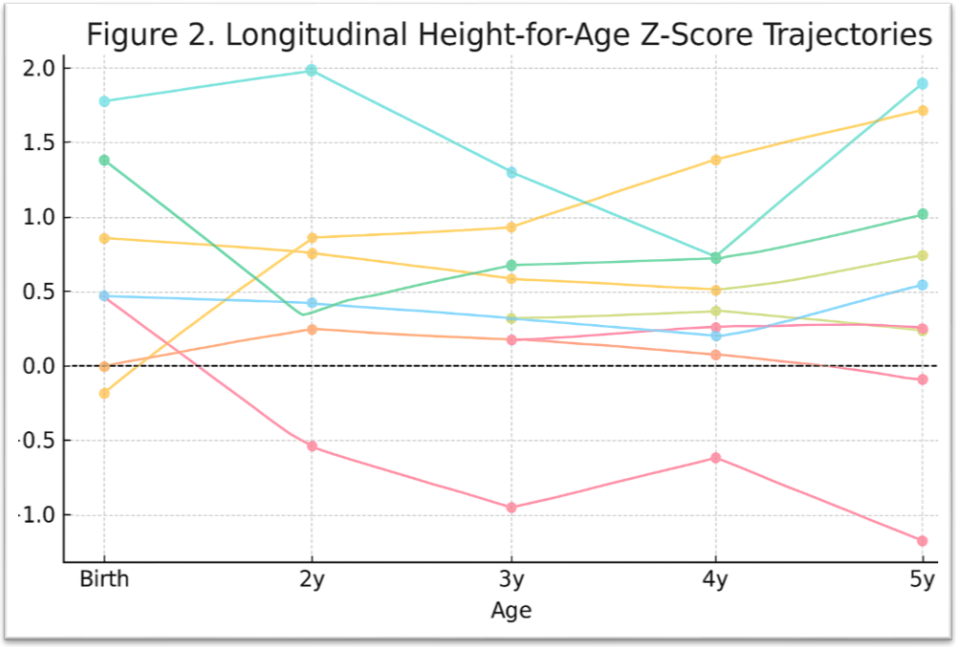


**Figure 2: Longitudinal HtSDS trajectories.**

Figure 2 illustrates linear growth (height-for-age Z-scores) from birth through 5 years in children with a solitary kidney. Most children maintained height within the normal range (Z = −2 to +2). A few cases showed a mild decline in linear growth over time, though no consistent pattern of stunting was observed.

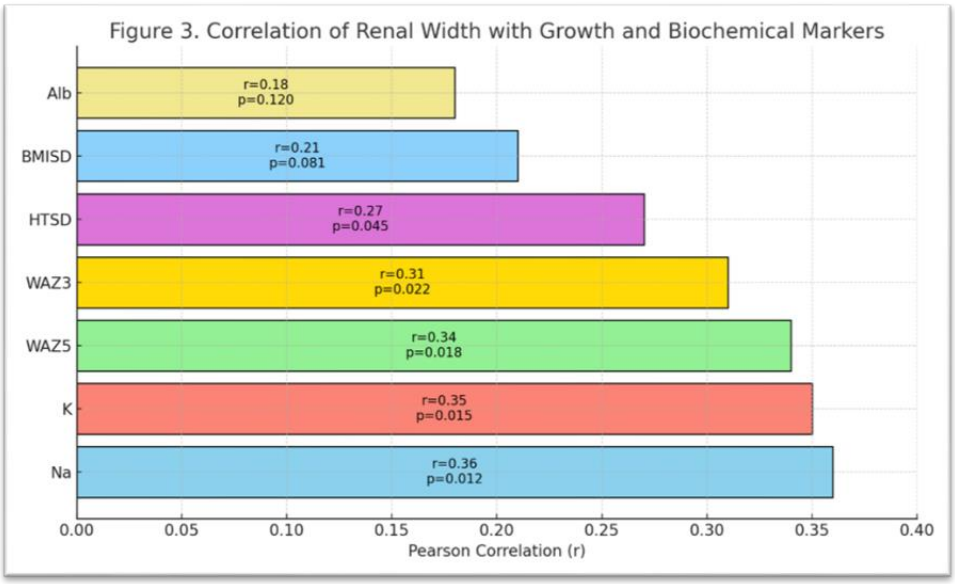


**Figure 3: Correlation of Renal Width with Growth and Biochemical Markers.**

Renal width showed moderate positive correlations with weight (WAZ), height (HTSD), BMI, and key electrolytes (Na, K), as well as serum albumin, suggesting renal adaptation is linked with somatic and metabolic status.

## DISCUSSION

Children with a solitary functioning kidney (SFK) represent a unique physiological model of renal and somatic adaptation. Our study explored the relationships between renal width and various anthropometric and biochemical parameters in early childhood, revealing moderate correlations that shed light on growth patterns and kidney compensatory mechanisms.

Our findings confirm that children with SFK often maintain relatively normal linear and weight growth, with WAZ and HT-SDS generally within normal limits by 5 years of age. This aligns with studies by Westland et al. and Hinkes et al., which describe a significant capacity for renal and somatic catch-up in the absence of secondary renal insults.[14,15] Compensatory renal hypertrophy, especially in the first few years of life, may support adequate filtration and endocrine regulation

necessary for growth.

Renal width demonstrated significant positive correlations with weight-for-age Z-scores at both 3 and 5 years (WAZ3 r=0.31, p=0.022; WAZ5 r=0.34, p=0.018), suggesting that somatic growth parallels renal mass increase. This supports the work of Blomberg Jensen et al., who reported a direct relationship between kidney size and nutritional status in SFK children.[16] Height-SDS also correlated moderately with renal width (r=0.27, p=0.045), reinforcing the idea that renal and skeletal growth are synchronized. Similar findings were reported in pediatric transplant cohorts, where greater renal volume was associated with better height outcomes.[17,18]

The positive correlations observed with serum sodium (r=0.36, p=0.012) and potassium (r=0.35, p=0.015) are particularly noteworthy. They reflect the renal tubular functional capacity and the maturity of nephron segments responsible for electrolyte reabsorption. Morsing et al. and Ichikawa et al. showed that children with SFK have enhanced adaptive nephron function, particularly in salt and potassium handling, to maintain homeostasis.[19,20] These mechanisms may be better developed in kidneys with larger cortical mass, explaining the associations with renal width.

Albumin, though not significantly correlated (r=0.18, p=0.12), showed a trend that aligns with findings in other pediatric populations. Rees and Jones observed that children with better nutritional and protein status exhibited improved growth outcomes.[21] Our results suggest that albumin may serve as a systemic marker of nutrition rather than a direct determinant of renal size.

While most pediatric nephrology literature uses renal **length** as the standard sonographic measure, our focus on **renal width** is supported by emerging data. Scholbach et al. proposed that renal width may better represent the nephron-rich parenchyma and functional cortical reserve, especially in young children.[22] Our findings support this, with renal width showing stronger and more consistent associations with both growth and electrolyte markers.

Some children in our cohort exhibited discordant growth and renal size profiles. This variability echoes observations by Filler et al., who attributed such differences to genetic factors, prenatal influences, or postnatal complications such as hypertension or recurrent urinary tract infections.[23] These children may require closer longitudinal follow-up, as discordance could signal subclinical renal insufficiency or syndromic growth patterns.

The correlation magnitudes in this study (r = 0.21 to 0.36) are modest but clinically meaningful in pediatric populations. Soliman et al. emphasized that even moderate statistical relationships in early growth studies may indicate important physiological trends, especially when compounded by environmental or endocrine influences.[24]

This study contributes to the limited but growing literature on renal–somatic interaction in SFK children. It emphasizes the utility of combining **growth Z-scores**, **biochemical markers**, and **renal ultrasound dimensions** in routine clinical monitoring. Our findings align with recommendations by Hokken-Koelega and colleagues, who advocate for a multidisciplinary approach in assessing endocrine, nutritional, and nephrological outcomes in children at risk of growth compromise.[25]

Finally, while our cross-sectional design limits causal inference, the consistent correlations between renal width and systemic parameters warrant prospective longitudinal studies. Future research should incorporate GH/IGF-1 axis assessments, tubular function markers, and renal perfusion data to better understand the endocrine–renal interface in this population.

## CONCLUSIONS

In this study, we demonstrated that children with a solitary functioning kidney generally exhibit favorable growth trajectories during early childhood, supported by adequate renal compensatory hypertrophy. Renal width—a potentially underutilized marker of functional nephron mass—showed significant correlations with anthropometric indices (WAZ, HT-SDS) and key biochemical parameters such as serum sodium and potassium, suggesting that renal and somatic development are closely interlinked.

Our findings support the integration of renal ultrasound parameters, particularly renal width, into routine follow-up protocols alongside growth and nutritional monitoring. Early detection of deviations in these markers may help identify children at risk for suboptimal adaptation or future renal dysfunction.

Future longitudinal studies incorporating hormonal (GH/IGF-1 axis), tubular function, and perfusion metrics are warranted to deepen our understanding of the endocrine–renal interface in these patients. A multidisciplinary approach remains essential to optimize growth, metabolic health, and renal outcomes in children with solitary kidneys.

### Strengths

This study provides important insights into the early growth and renal adaptation of children with a solitary functioning kidney (SFK), highlighting renal width as a more informative marker of nephron mass and cortical reserve than renal length. By combining anthropometric Z-scores (WAZ, HAZ, BMISDS) with key biochemical markers (serum sodium, potassium, and albumin), the research presents a comprehensive view of the somatic-renal relationship in early childhood. Its methodological strengths, including standardized measurements and

robust statistical analyses, enhance the reliability of the findings. Clinically, the study supports incorporating renal width assessment into routine monitoring to better identify children at risk for compromised growth or renal function.

## LIMITATIONS

Despite its strengths, the study has notable limitations. Its cross-sectional design precludes causal inferences and limits understanding of longitudinal changes in growth or renal adaptation. The small sample size (n=28) reduces statistical power and the ability to adjust for confounding factors like birth history, nutrition, or socioeconomic status. The lack of hormonal assessments (e.g., IGF-1, GH, thyroid function) restricts insight into underlying growth mechanisms, while the absence of functional renal parameters (e.g., GFR, proteinuria, tubular markers) limits interpretation of kidney size-function relationships. Additionally, the single-center design may limit the generalizability of findings to broader or more varied populations.

### Authors' Contributions

A.S. conceived and supervised the study, contributing to its design, data interpretation, and manuscript drafting. M.E. performed data analysis and literature synthesis. N.H. and N.A. collected clinical data and ensured follow-up accuracy. F.A. contributed to biochemical data validation, while S.A. assisted in statistical evaluation and visual representation. All authors reviewed and approved the final manuscript. There is no conflict of interest among the authors, and no funding was received for this study.

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