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FULL PAPER

MRI-based reference range for the renal pelvis anterior-posterior diameter in children ages 0–19 years

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Objective: To determine the mean and normal range of anteroposterior diameter (APD) of the renal pelvis in children.

Methods: Patients aged 0–19 years with normal spinal MRIs were identified after institutional review board approval. Those with dilating uropathy or abdominal surgery/radiation were excluded. The maximum APD was measured. A mixed linear model was fit to determine the relationship between APD and age, adjusted for bladder distention. The left and right kidneys were treated independently.

Results: 283 left and 285 right renal units were included. For the left, a 3.5% increase in APD per year was predicted ($p < 0.0001$), with the average APD for infants and 18-year olds with non-distended bladders being 2.5 mm (95th percentile: 7.2 mm) and 4.6 mm (13.4 mm),

respectively. For the right, a 3.9% increase in APD per year was predicted ($p < 0.0001$), with the average APD for infants and 18-year olds with non-distended bladders being 2.8 mm (8.4 mm) and 5.5 mm (16.6 mm), respectively. Compared with a non-distended bladder, a distended bladder increased the predicted APD between 23% (right) and 38% (left) ($p = 0.01$ and $p < 0.0001$, respectively).

Conclusion: The mean and normal ranges of APD measured by MRI in children are provided. APD increases with age and bladder distension and is greater on the left.

Advances in knowledge: This article establishes normative ranges for APD, a critical component of genitourinary tract evaluation, and does so using the most precise imaging modality for this condition.

INTRODUCTION

Renal pelvic dilation can be an important predictor of a urinary pathology. The renal pelvis anteroposterior diameter (APD) is a standard measurement made in fetuses. Normal and abnormal values have been determined using routine obstetrical screening ultrasounds,^{1–3} which are used to help with prognosis and to guide patient care in the postnatal setting.^{4,5}

APD ranges have not been established in children because imaging studies are not routinely used for population-level screening of the kidneys. Investigators who have determined the APD in children indicative of urinary pathology did so using small numbers of mostly young patients who were being evaluated for potential urinary pathology.^{6,7} The paucity of data in children above 6 years of age in these studies limits their applicability to adolescents and young adults. A recent survey showing a large variation in the definitions of

“significant dilation” used by paediatric radiologists further supports the need to establish normal APD ranges in children.⁸

In order to establish a normal APD in children, a test in which the kidneys are imaged but the upper urinary tract is not the primary indication for the study would be ideal. One source of such data is spinal MRI studies, which are performed for a variety of indications for children of all ages. Strong precedent exists for use of MRI in establishing normative values for renal anatomy.⁹ Given the precision and reproducibility of its images, this modality presents a unique opportunity to measure the renal pelvic APD across the spectrum of paediatric ages.

This study aimed to determine the range of APD of renal pelvis in children aged 0–19 years undergoing spinal MRI.

METHODS AND MATERIALS

Patient selection

In this retrospective cohort study, patients aged 0–19 years who had undergone a spinal MRI with images sufficient for interpretation of kidneys (slice width ≤ 5 mm, gap width ≤ 2 mm, T_2 weighted images of entire renal pelvis) were identified by record review after institutional review board approval. Patients were excluded from the cohort if they had: any abnormal spine or spinal cord findings on the MRI; any radiologic or clinical history of a dilated renal pelvis and/or ureter (indicative of ureteropelvic junction obstruction, megaureter or dilating vesicoureteral reflux, among others); any history of abdominal or retroperitoneal surgery or radiation; any history of abdominal or retroperitoneal malignancy or inflammatory process.

Radiologic measurement

After window standardizing, two attending paediatric radiologists used the picture archiving and communication system software (Synapse® PACS v. 4.2.3; Fujifilm Medical Systems, Stamford, CT) callipers to measure the maximum left and right intrarenal APD on T_2 weighted axial images (Figure 1). Each radiologist independently measured the APD and was blind to the other's measurement. As bladder distention has been associated with hydronephrosis,¹⁰ and because complete MR images of the urinary bladder were not available to calculate bladder volume in all cases, the bladder dome position relative to the sacral promontory was used as a surrogate for bladder distension. When the bladder dome was above the sacral promontory, the bladder was classified as “distended”, whereas a position below the promontory was classified as “non-distended”. The radiologists reviewing the studies had 6 and 10 years of experience, respectively.

Statistical analysis

The primary outcome was the APD measurements, with the left and right kidneys treated independently.

APD measurements were analyzed using mixed linear models. Age and bladder distension were treated as fixed effects. To account for two APD measurements from the same renal unit (one for each radiologist) and for the correlated nature of the

measurements within a radiologist, the renal unit and the radiologist were treated as random effects. Both gender and the interaction between the main effects were considered during model building, but were not significant and were excluded from the final model. APD was log transformed to achieve a normal distribution of the model residuals. Diagnostic checks of the final fitted model were performed to verify model assumptions, as was a check of the final model sensitivity to outliers. The predicted mean APD for each year of life and amount of bladder distention were generated using the model estimates, with back transformation conducted to ease interpretation. A two-sided p -value < 0.05 was considered to be statistically significant. Data processing and statistical analysis were conducted using SAS v. 9.3 (© 2002–2010 by SAS Institute Inc., Cary, NC). Graphs were built using R v. 3.01.¹¹

RESULTS

Of the 4059 spinal MRIs performed between January 2008 and December 2009, 286 patients (representing 283 left and 285 right renal units) met the inclusion criteria. The indications for the spinal MRI were: 150 (41%) for neurologic or neuro-developmental, 111 (30%) for orthopaedic or spine, 38 (10%) for sacral anomalies and 11 (3%) for “rule out tethered cord” with no other clinical indication(s). 58 (16%) MRIs were obtained for bladder indications (including 33 MRIs for enuresis, 2 MRIs for acute urinary retention, 2 MRIs for voiding dysfunction and 1 MRI for overactive bladder) or bowel indications (20 MRIs for constipation), and 1 study was obtained to rule out Coloboma, Heart defect, Atresia choanae, Retarded growth and development, Genital abnormality, and Ear abnormality (CHARGE) syndrome. 83 patients had two or more indications for their MRI.

Figure 2 displays the raw data with superimposed fitted lines for the predicted mean and upper 95% confidence interval for non-distended and distended bladders. The derived mean APD and the upper bound of the 95% confidence interval for each year of age and bladder position are presented in Table 1 (left kidney) and Table 2 (right kidney). For the left kidney, a small but significant 3.5% increase in APD per year is predicted ($p < 0.0001$). As compared with children with non-distended bladders, the left APD in those with distended bladders is predicted to be 38% greater ($p < 0.0001$), an effect that is constant across all ages. Similarly, for the right kidney, a small but significant 3.9% increase in APD per year is predicted ($p < 0.0001$), and the APD in those with distended bladders is estimated to be 23% greater ($p = 0.01$) than that in children with non-distended bladders.

DISCUSSION

The APD of the renal pelvis was measured on normal spinal MRIs in children 0–19 years of age with no known abdominal or retroperitoneal pathology. Spinal MRI was selected because it is an imaging test in which the urinary tract is not the primary focus of investigation but one that nonetheless includes images of the kidney. Using a mixed linear model, normal mean values and ranges for the APD at each year of life between 0–19 years were calculated for each kidney and adjusted for the degree of bladder distension. Our findings suggest that the APD is not

Figure 1. A representative image of an anteroposterior diameter measurement protocol from a 7-year-old male with a non-distended bladder: the callipers are placed at the widest area of the intraparenchymal portion of the renal pelvis on a T_2 weighted image in the axial plane.

Figure 2. Predicted mean anteroposterior diameter (APD) (solid lines) and upper bound of 95% confidence interval (dashed lines) taking into account the patient age and bladder distension for the left (a) and right (b) kidneys. The thin lines are representing patients with non-distended bladders, whereas the thick lines are representing those with distended bladders.

influenced by gender but increases by approximately 3.5–4% per year in children between 0 and 19 years of age and is affected by the bladder-filling cycle. This positive association between APD and age differs from that of Tsai et al,⁷ who found no significant relationship between APD and age. We may have detected this difference owing to a wider age distribution and a greater

number of observations in our study. Alternatively, a larger data set extending further into adulthood could be used to determine the age at which APD stabilizes.

Currently, there are no standard values for normal measurements of the renal pelvis APD in children, with radiologists

Table 1. Predicted mean and upper range of left renal pelvis anteroposterior diameter (APD) at different ages

Age (years)	<i>n</i> ^a	Non-distended bladder		Distended bladder	
		Mean APD (mm)	Upper bound of 95% CI	Mean APD (mm)	Upper bound of 95% CI
0	12	2.5	7.2	3.5	10.0
1	19	2.6	7.5	3.6	10.4
2	18	2.7	7.7	3.7	10.7
3	18	2.8	8.0	3.8	11.1
4	21	2.9	8.2	4.0	11.5
5	12	3.0	8.5	4.1	11.9
6	15	3.1	8.8	4.3	12.3
7	22	3.2	9.1	4.4	12.7
8	16	3.3	9.4	4.6	13.2
9	10	3.4	9.8	4.7	13.7
10	18	3.5	10.1	4.9	14.1
11	18	3.6	10.5	5.1	14.7
12	14	3.8	10.8	5.2	15.2
13	15	3.9	11.2	5.4	15.7
14	11	4.0	11.6	5.6	16.3
15	13	4.2	12.0	5.8	16.9
16	12	4.3	12.5	6.0	17.5
17	10	4.5	12.9	6.2	18.2
18–19	9	4.6	13.4	6.5	18.9

CI, confidence interval.

^aNumber of renal units contributing data for age range.

Table 2. Predicted mean and upper range of right renal pelvis anteroposterior diameter (APD) at different ages

Age (years)	<i>n</i> ^a	Non-distended bladder		Distended bladder	
		Mean APD (mm)	Upper bound of 95% CI	Mean APD (mm)	Upper bound of 95% CI
0	12	2.8	8.4	3.5	10.4
1	19	2.9	8.7	3.6	10.7
2	18	3.0	9.0	3.7	11.2
3	18	3.1	9.4	3.9	11.6
4	21	3.3	9.7	4.0	12.0
5	12	3.4	10.1	4.2	12.5
6	15	3.5	10.5	4.3	13.0
7	22	3.7	10.9	4.5	13.5
8	16	3.8	11.3	4.7	14.0
9	10	3.9	11.7	4.9	14.6
10	18	4.1	12.2	5.1	15.1
11	17	4.3	12.6	5.3	15.7
12	14	4.4	13.1	5.5	16.4
13	15	4.6	13.6	5.7	17.0
14	12	4.8	14.2	5.9	17.7
15	13	5.0	14.7	6.1	18.4
16	13	5.1	15.3	6.3	19.2
17	11	5.3	15.9	6.6	20.0
18–19	9	5.5	16.6	6.8	20.8

CI, confidence interval.

^aNumber of renal units contributing data for age range.

using a wide range of “normal” APD values.⁸ Blane *et al*⁶ compared ultrasound with i.v. pyelograms in 28 children (51 collecting systems) with a mean age of 5.2 years. All of these patients were imaged for clearly defined urologic indications (*e.g.* haematuria, suspected ureteropelvic junction obstruction, pyelonephritis). This group concluded that an APD above 10 mm was indicative of significant pathology in these children, without specifying what the expected value for APD was in “normal” children. Another study used ultrasound to evaluate 147 children (237 renal pelves), the majority of whom were below 6 years of age.⁷ Similar to other groups, they found that 10 mm was the upper limit of the size of the normal renal pelvis. Although these studies help in defining renal pelvis APD values that indicate pathology, they are both limited by the paucity of data in children above 6 years of age. Thus, it is unclear whether the cut-offs suggested in these studies have the same meaning in adolescents as they do in young children.

APD is routinely measured in fetuses during screening obstetrical ultrasounds, and normal values are based on thousands of measurements.^{1–3} These measurements guide further prenatal imaging and help direct postnatal management decisions.^{4,5} Having a normal standard of renal pelvic diameter in children could similarly direct patient care and prevent normal patients from receiving unnecessary radiologic studies. Unlike fetuses, there are no standard renal screening protocols in children.

Ultrasounds and CT scans are often performed for abdominal or retroperitoneal pathology and thus represent a source of confounding by indication. Normal spinal MRI studies, however, are uniquely suited to determine the APD range in children because kidneys are routinely captured in these images and their indications (for the work-up of non-abdominal, non-retroperitoneal diseases) reduce selection bias. Furthermore, the precision and reproducibility of MRI studies also make them an attractive tool for this study.

Arguably, MRI produces the closest approximation of “true” anatomy of any imaging modality. We can only speculate on how our findings may translate to different imaging modalities. We would expect our results to closely correlate with APD measurements obtained by CT.¹² Ultrasound measurements of the kidneys are significantly operator dependent. One report suggested that ultrasound systematically underestimated renal length as compared with CT scans.¹³ More studies comparing ultrasound with MRI measurements of the renal pelvis could help ascertain the measurement differences and allow for the translation of our values to ultrasound studies.

This study should be viewed in light of its limitations. The patients in this cohort do not represent a true population-based sample. On the contrary, a wide range of medical indications are represented in this sample. Almost all patients in the sample

underwent MRI for specific clinical indications. Thus, the findings may not exactly reflect measurements that would be obtained in a true population of “normal” controls. To minimize this selection bias, we excluded patients with an abnormal spinal MRI or a history of dilating uropathy or other conditions that might plausibly increase urinary tract dilation. Still, the fact that all subjects had clinical indications for the MRI study (even if those indications were not directly related to the upper urinary tract) could influence the findings. Nevertheless, an MRI study analogous to the systematic sonographic scanning of fetuses would be impractical and cost-prohibitive.

We did not include subject height in our model, which has been associated with renal measurements in adults.¹⁴ However, differences in subject stature should be minimized by the relatively large number of participants in each age group. Our patient hydration status, which affects the degree of renal pelvic dilatation in fetuses and children,^{15,16} was neither known nor standardized during this study because our spinal MRI protocols did not have specific hydration requirements. Nevertheless, our values were generated from subjects with different degrees of hydration and are thus applicable to the wider population of individuals undergoing radiologic examinations.

Finally, although we have presented statistical thresholds for “normal” APD based on distributions observed in our

cohort, we are unable to define a cut-off value for APD that is indicative of significant pathology. These data are not capable of distinguishing benign from pathologic dilatation, so there will likely be patients with specific uropathology who will fall within the reference range presented here. Furthermore, while a comparison between this cohort and a group of patients who underwent MR urography for specific urologic indications could be performed, the significant uropathology in the latter group would most likely elevate the thresholds.

CONCLUSION

We have established and provided tables for the predicted mean and range of normal measurements for the APD for children 0–19 years of age. These results also show that the APD increases by 3.5–4% per year and is substantially larger when measured with distended bladders as compared with non-distended bladders.

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