Cyst-to-kidney volume ratio in the sonographic diagnosis of unilateral multicystic dysplastic kidney in children

Sevin Ayaz¹, Alper Dilli², Salih Sinan Gültekin³, Ümit Yaşar Ayaz⁴

¹Department of Medical Imaging Techniques, Toros University, Vocational School; Department of Nuclear Medicine, Mersin State Hospital, Mersin, ²Department of Radiology, Dişkapı Yıldırım Beyazıt Training and Research Hospital, Ankara, ³Department of Nuclear Medicine, Dişkapı Yıldırım Beyazıt Training and Research Hospital, Ankara, ⁴Department of Radiology, Mersin Women’s and Children’s Hospital, Mersin, Turkey

Abstract

Aims: To evaluate the usefulness of the cyst-to-kidney volume ratio determined by ultrasonography (US) in unilateral multicystic dysplastic kidney (MCDK) in children. Material and methods: Our study group included 21 children (average age: 431 days) with unilateral MCDK and 22 children (average age: 440 days) with unilateral grade IV hydronephrosis due to ureteropelvic junction obstruction as the control group. All the children underwent transabdominal US. In children with MCDK, we calculated cyst-to-kidney volume ratios (volume of the largest cyst/volume of the MCDK) and in the control group the volume ratios of the renal pelvis and the largest calyx (volume of the pelvis or largest calyx/volume of the ipsilateral hydronephrotic kidney). Ellipsoid formula was used to calculate kidney and pelvis volumes. Sphere volume formula was used to calculate the largest cyst and calyx volumes. Results: The mean cyst-to-kidney volume ratio (0.38±0.21) was significantly higher than the mean volume ratios of the renal pelvises (0.10±0.05) and the largest calyces (0.04±0.02) (p<0.05). There was no significant correlation between cyst-to-kidney volume ratio and the ages of the children (r=0.141, p=0.541). Conclusions: With the aid of both the qualitative sonographic criteria and the newer data that we have proposed, US is a useful tool in the initial diagnosis of MCDK and for differentiation of MCDKs from grade IV hydronephrotic kidneys in children. The cyst-to-kidney volume ratio is independent of age and thus, it can be helpful in the diagnosis of unilateral MCDK at any age. Keywords: multicystic dysplastic kidney; cysts; hydronephrosis; ultrasonography; child

Introduction

Unilateral multicystic dysplastic kidney (MCDK) is a non-hereditary, frequently unilateral congenital renal pathology [1] which is sonographically characterized by non-communicating cysts, resembling a “bunch of grapes” separated by dysplastic tissue [1-3]. The renal pelvis is absent; the ureter and renal vessels are atretic [1]. Its incidence is about 1:4300 live births and is more frequent in males, with a male-to-female ratio of about 2:1 [3]. The leading entity in the differential diagnosis of MCDK is hydronephrosis and after hydronephrosis, MCDK is the second most common cause of intra-abdominal mass in newborns [3]. Various etiologies such as genetic disturbances, teratogenic agents, prenatal infections, and obstructions in the urinary system have been proposed to explain the occurrence of MCDK [4]. There have been efforts to produce new sonographic parameters in the diagnosis of pediatric renal diseases such as “calyx to parenchyma ratio” which is obtained by dividing the depth of calyces to the parenchymal thickness [5], and the “pelvis/cortex ratio” which is a ratio of maximum anteroposterior diameter (APD) of pelvis to maximum cortical thickness [6], for quantitative evaluation of kidneys in ureteropelvic junction (UPJ) obstruction. Today, ultrasonography (US) is an essential tool for the initial diagnosis and follow-up of MCDK in children. Using
three-dimensional US, monitization of cyst volume during the follow-up of MCDK in a child was successfully performed [7]. Though King et al [8] and Sise et al [9] investigated the percentage of cyst volumes within the whole kidney volume in patients with autosomal dominant polycystic kidney disease (ADPKD) by using computed tomography, to our knowledge no kind of cyst volume ratio has been used in the evaluation of MCDKs by utilizing US.

In order to further contribute to the standardization and quantification of US data, cyst-to-kidney volume ratio in the US diagnosis of unilateral MCDK in children was introduced and we aimed to analyze the usefulness of this ratio in the differentiation of MCDKs from grade IV hydronephrotic kidneys.

**Material and methods**

**Selection of the patients and the diagnostic procedures**

In this retrospective study, a total of 25 consecutive pediatric patients with a sonographic diagnosis of MCDK were recruited in the first selection between 2008 and 2013. Our loss of contact with the patient after the initial US and also unclear US records in patients were accepted as exclusion criteria, and four patients were excluded. Our study group included the remaining 21 pediatric patients (9 females and 12 males, mean age of 431±881 days) with unilateral MCDK. Since differentiating MCDKs from hydronephrotic kidneys (due to UPJ obstruction) is important in pediatric patients [3,10], we compared sonographic parameters of MCDKs with those of grade IV hydronephrotic kidneys in which dilated pelvises and calyces mimicked or resembled the cysts of MCDKs on US images (fig 1a). Our control group included 22 pediatric patients (9 females and 13 males, mean age of 440±613 days) with 22 hydronephrotic kidneys. The reason of hydronephrosis was UPJ obstruction in all these kidneys. All the patients’ parents were informed about the procedures and informed consent was obtained. All the procedures were performed according to the World Medical Association Declaration of Helsinki (revised in 2000, Edinburgh). The children underwent gray-scale transabdominal US examination with a Logic 200 Pro US device (General Electric Medical Systems, Seongnam, Gyeonggi-do, Korea) and a Mindray DC-7 US device (Shenzhen Mindray Bio-Medical Electronics Co., Ltd., Shenzhen, China) using 3–3.5 MHz convex-array and 7.5–8 MHz linear-array transducers. To confirm the diagnosis of MCDK, seven patients (33.3%) underwent technetium-99m diethylene triamine pentaacetic acid (Tc-99m DTPA) dynamic renal scintigraphy after initial US, which revealed no function in the affected kidney. The diagnosis of MCDK was confirmed by nephrectomy in four cases (19%). The remaining 17 patients with a clinical and sonographic diagnosis of preserved MCDK were followed-up with a mean duration of 20.35±9.7 months. Within the follow-up period, each patient underwent at least one control US examination. Initial and follow-up US examinations included the assessment of the contralateral kidney. In none of the patients with MCDKs, excretory urography (EU), voiding cystourethrogram (VCUG), and/or magnetic resonance (MR) urography images could be obtained.

**Sonographic criteria and parameters**

All the US examinations were performed by a standardized technique by the same researcher who had had more than 10 years’ experience in US imaging of children. Every measurement in our study was done three consecutive times and the most repeated measurement was taken into consideration [11]. All the children were examined in the same standard supine and lateral decubitus positions with the same sonographic set-up parameters. For further standardization, US image records were
eventually evaluated together by three readers each with more than 10 years experience in image interpretation, in consensus. The following criteria were all used together in the sonographic diagnosis of unilateral MCDK: the presence of a kidney without reniform shape filled with multiple, non-communicating round or oval cysts with varying diameters, the absence of renal cortex/parenchymal tissue (not the dysplastic tissue) and the presence of a non-medially located largest cyst [10]. The maximum thickness of the echogenic solid areas representing dysplastic tissue within the MCDKs were also measured.

All the control group patients had grade IV hydronephrosis according to the criteria declared by The Society for Fetal Urology [12], which meant a prominently split renal pelvis with uniformly dilated calyces accompanied by the thinning of renal parenchyma (fig 1b) [13,14]. In our study group with MCDK, we proposed and used cyst-to-kidney volume ratio (volume ratio of the largest cyst) which was calculated as follows: volume of the largest cyst/volume of the MCDK, including the cysts (fig 1c, fig 1d). In our control group, we proposed and used volume ratios of the renal pelvis and largest calyx (pelvis-to-kidney volume ratio and calyx-to-kidney volume ratio) which were calculated as follows: volume of the pelvis or largest calyx/volume of the ipsilateral hydronephrotic kidney. The longitudinal view in coronal plane at the level of renal hilum was used to measure the length (L) and width (W) of the kidneys. The same view was also used to measure the diameter (D) of the renal pelvis. The thickness (T) of the kidneys and the APD of the renal pelvis were measured at mid-transverse sonograms [13,15].

We used the ellipsoid formula to calculate the volumes of MCDKs and grade IV hydronephrotic kidneys: \( \frac{\pi}{6} \times L \times W \times T \) in which \( \frac{\pi}{6} \) was accepted as 0.523 [16,17]. For practical purposes and to reduce the burden of calculation, we used the simplified form of prolate ellipsoid formula to obtain the volumes of the renal pelvises as follows: \( \frac{\pi}{6} \times D \times (APD)^2 \) [18]. In order to calculate the volumes of largest cysts and those of the largest calyces, we used the sphere volume formula: \( \frac{\pi}{6} \times (D)^2 \) [9]. For standardization, US examinations of all the patients with hydronephrosis were done before hydration.

**Statistical analysis**

Numerical data were expressed as means±standard deviations with confidence intervals. The ages of the patients in our study group with unilateral MCDK and of those in the control group with grade IV hydronephrosis were compared by using the \( t \) test. The sonographic parameters of MCDKs and grade IV hydronephrotic kidneys (the volumes of the largest cysts and renal pelvises-largest calyces, the volumes of the MCDKs and hydronephrotic kidneys, and the volume ratios of the largest cysts and renal pelvises-largest calyces) were compared by using the \( t \) test. The correlations between the above mentioned sonographic parameters in MCDKs and the ages of the children were evaluated by the Pearson correlation test. The correlation between the volumes of the largest cysts and the volumes of the MCDKs were evaluated by the Pearson correlation test. Also the correlation between the volumes of the renal pelvises-largest calyces and the volumes of the hydronephrotic kidneys were evaluated by the Pearson correlation test. \( P \) values < 0.05 were considered as statistically significant. All analyses were done with SPSS software (version 16.0: SPSS Inc, Chicago, IL).

**Results**

In the study group, a unilateral MCDK was demonstrated in 11 right and in 10 left kidneys. No renal tumours were demonstrated on initial or follow-up US. Among the cysts of all the MCDKs (n=21), echogenic solid areas representing dysplastic tissue with a mean maximum

<table>
<thead>
<tr>
<th>Table I. Numerical data for the study group with multicystic dysplastic kidneys (MCDKs) and for the control group with grade IV hydronephrosis.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Study group with MCDKs</td>
</tr>
<tr>
<td>Mean Age +/- SD (CI)</td>
</tr>
<tr>
<td>Mean volumes +/- SD (CI)</td>
</tr>
<tr>
<td>Mean volumes +/- SD (CI)</td>
</tr>
<tr>
<td>Mean volume ratios +/- SD (CI)</td>
</tr>
<tr>
<td>Mean volume ratios +/- SD (CI)</td>
</tr>
<tr>
<td>Mean volume ratios +/- SD (CI)</td>
</tr>
</tbody>
</table>

SD: Standard deviation, CI: 95% confidence interval,*\( p \) values <0.05 are considered as statistically significant.
thickness of 5.8±3.0 mm were detected. Of the 17 patients with preserved MCDKs, two MCDKs (11.8%) underwent complete involution, 10 MCDKs demonstrated regression (58.8%), while five of them (29.4%) did not show any change in size during the follow-up period. Of all the children with MCDKs, compensatory hypertrophy was detected in six (28.6%) contralateral kidneys, three (14.3%) of them demonstrated pelvicaliectasis in the contralateral kidney (two of them mild with APDs of renal pelvises as 6.3−6.6 mm and one severe with APD of renal pelvis as 32.5 mm). The etiology of pelvicaliectasis was 32.5 mm). The etiology of pelvicaliectasis was not identified in these patients. No other pathology by US could be identified in the contralateral kidneys. Numerical data for the study group with MCDKs and for the control group with grade IV hydronephrosis were compared and are given in Table I. The difference between the ages of the patients with unilateral MCDK and those of control group with grade IV hydronephrosis was not statistically significant (p>0.05). The mean volume ratio of the largest cysts was significantly higher than the mean volume ratios of both the renal pelvices and largest calyces (p<0.05). There was no correlation between the numerical values of the sonographic parameters in MCDKs (the volumes and volume ratios of the largest cysts, the volumes of the MCDKs) and the ages of the children (p>0.05) (tab I). The correlation between the volumes of the largest cysts and the volumes of the MCDKs was significant (r=0.988, p=0.000). The correlation between the volumes of the renal pelvices-largest calyces and the volumes of the hydronephrotic kidneys were significant (r=0.618, p=0.002; r=0.631, p=0.002, respectively).

Discussions

In MCDK, obstruction/ataresia of the ureter occurs before 8th–10th gestational weeks [3] and the ureteric part fails to unite with the renal part [1]. Maturation of the nephrons are hindered and the collecting tubules eventually enlarge to become cysts [3]. Histopathologically, normal renal tissues are lacking in MCDK, which is composed of immature glomeruli, dysplastic tubules surrounded by stroma-fibromuscular collars, dysplastic cysts and metaplastic cartilage [3,19]. In the late onset (hydronephrotic) form of MCDK, a large central cyst representing dilated pelvis which communicates with other cysts is present [3]. MCDKs in our study were not accepted as the hydronephrotic form because none of their largest cysts which were non-medially located, showed communication with other cysts.

Since contralateral renal abnormalities such as vesicoureteral reflux (VUR), long-term risk of chronic kidney disease [20-26], hypertension [4,10,21,24,25,27,28] and ipsilateral malignant renal tumours [29-31] were reported in children with unilateral MCDK, early diagnosis and regular follow-up of these patients is crucial. US was defined as an auspicious method for the fast and non-invasive evaluation of congenital kidney anomalies [14], such as MCDK. US was also reported to noninvasively demonstrate pelvicaliectasis in pediatric patients [32] as in our control group with grade IV hydronephrosis. US was declared to be the most suitable tool for the initial evaluation of children with MCDK [33], while the primary approach to the patients with MCDK was reported to be conservative follow-ups by utilizing US [20,34,35]. Though an overt tendency for MCDK to show a time-dependent regression in size has been reported [36], the results of the long-term study conducted by Aslam et al. [35] revealed that in 41% of the children with unilateral MCDK, renal remnants still persist 10 years after the initial diagnosis, which justifies the need for sonographic follow-ups. Nephrectomy was the usual treatment for unilateral MCDKs in the past; however, due to the high incidence of spontaneous regression and involution, a conservative and clinical management is preferred today [4,25,26], which includes yearly clinical evaluations and US examinations with increased intervals [20]. In our study, follow-up sonograms showed complete involution or regression in the majority of the MCDKs (70.6%) while demonstrating no size increase in the rest of them (29.4%), which helped the clinicians avoid unnecessary nephrectomies. The consequences of long-term follow-ups in pediatric patients with MCDKs demonstrate that conservative management under US control is reliable also for the contralateral kidney [36]. As an example, Kuwertz-Broeking et al [10] reported the dilatation of the urinary tract on the contralateral side to be present in 12% of the 97 children with MCDKs children included in the study, which was similar to our results. In addition to US, renal scintigraphy also plays a significant role in the diagnosis of MCDK by demonstrating functionless ipsilateral kidney.

Though the largest cysts in MCDKs are non-medially located and the cysts do not communicate with each other, it may be difficult to differentiate MCDK from severe hydronephrosis in some cases. The US criteria of unilateral MCDK which are qualitative rather than being quantitative, have been well defined in literature [10]. However, US examination of small children, particularly of the newborns and the infants can be challenging because of the time and examination quality limitations as the result of the unfavourable clinical status of some patients and their crying. In order to compensate these limitations, we aimed to use the cyst-to-kidney volume ra-
tio as a quantitative parameter, which can help diagnose MCDK in such limited conditions just by performing a few measurements and calculations. As compared with some other frequent mimickers of MCDKs which have to be considered in the differential diagnosis, our findings seem to be quite specific for multicystic dysplastic kidney disease. In their large-scale study including patients with ADPKD who were followed up for more than three years, Grantham et al [37] found that the enlargement of the cysts and the kidneys showed a continuous course in most of the cases, concluding that the increase in kidney volume was because of the increase in the cyst volume. In our study also, there was a strong correlation between the volumes of the largest cysts and the volumes of the MCDKs. However, unlike the patients with ADPKD, the age of our patients seem to have no effect on the volumes of the largest cysts and those of MCDKs. In our patients with grade IV hydronephrosis, the increase in pelvis-calyx volumes caused an increase in the hydronephrotic kidney volumes which was similar to the effect of the largest cyst volumes on MCDK volumes. However, the mean cyst-to-kidney volume ratio was higher than the mean pelvis-to-kidney and calyx-to-kidney volume ratios in our study. We consider that this can be a useful clue in differentiating MCDKs and grade IV hydronephrotic kidneys in the sonographic evaluation of some pediatric patients, particularly under unfavourable examination conditions.

We consider that the prominent difference between the above mentioned volume ratios of MCDKs and grade IV hydronephrotic kidneys result from the differences in the pathophysiology of both groups. First of all, the mean volume of the largest cysts in MCDKs was much higher than those of the renal pelvises and largest calyces of hydronephrotic kidneys, as demonstrated in Table II. Secondly, as the cyst-to-kidney volume ratio is evaluated, it can be seen that the largest (dominant) cyst makes the major contribution to the volume of MCDK. The diameters of other cysts and thus, their effects on kidney volume are much smaller. This is why the largest cyst which is a unique feature of MCDK was chosen for the calculation of the cyst-to-kidney ratio. In grade IV hydrenephrosis however, since all the calyces are affected by the same obstructive mechanism in UPJ and because of their similar anatomic structures, there is not a huge difference between the diameters of the dilated calyces which are 10-14 in number [38] and therefore, they all have a similar contribution to the volume of the hydronephrotic kidney. This decreases the share of a single calyx in the volume increase of the kidney. So the volume ratio of the calyx, even of the largest one is much smaller as compared to that of the largest cyst in MCKD. Though the renal pelvis is larger than the calyx, the contribution of a dilated renal pelvis to the kidney volume is limited compared to the total contribution of 10-14 dilated calyces with similar volumes, which hampers the competition of the pelvis-to-kidney volume ratio with the cyst-to-kidney volume ratio. And thirdly, the effect of the largest cyst on the kidney volume is also augmented by the absence of the renal cortex/parenchymal tissue in MCDKs. Unlike MCDKs, though thinner than normal, there is still parenchymal tissue in the grade IV hydronephrotic kidneys besides other tissues such as vascular structures, pelvic-calyx walls and sinus fat. This seems to be another reason why the mean volume of MCDKs is significantly lower than that of the grade IV hydronephrotic kidneys.

We had some limitations in our study. Firstly, our study population was relatively small. Nevertheless, despite the limited number of patients there was a notable difference between the numerical values of the US parameters of our study group and those of the control group which let us to obtain statistically significant results. Secondly, using the ellipsoid formula for the calculation of MCDK volumes might have revealed a little larger volume than the in vivo kidney volume. However, since a MCDK is particularly similar to a cyst-filled ovary including a dominant preovulatory follicle cyst (analogous of the largest cyst in MCDK) with regard to its shape and to it being a multicystic structure, and because the ellipsoid formula has already been used to calculate the volume of an ovary in literature [16], we considered it the most appropriate formula for the calculation of MCDK volumes. Thirdly, we could not compare our results with other cystic pathologies of kidney in children such as early-onset ADPKD, autosomal recessive polycystic kidney disease, medullary cystic kidney disease (juvenile nephronophthisis) and multiple simple cysts. Further studies are required to compare cyst-to-kidney ratios in MCDKs with those of other renal cystic pathologies mentioned above. And lastly, three-dimensional US could not be used for obtaining volumetric data, due to the retrospective design of the study and technical reasons. But with the aid of repeated measurements, the volumes obtained were thought to be as precise as possible.

Table II. Pearson correlation coefficients and p values* regarding the associations between sonographic parameters in MCDKs and the ages of the children.

<table>
<thead>
<tr>
<th>Sonographic parameters</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volumes of the largest cysts</td>
<td>r= -0.067, p=0.772</td>
</tr>
<tr>
<td>Volumes of MCDKs</td>
<td>r= -0.028, p=0.906</td>
</tr>
<tr>
<td>Cyst-to-kidney volume ratio</td>
<td>r=0.141, p=0.541</td>
</tr>
</tbody>
</table>

*p values <0.05 are considered as statistically significant.
The EU, VCUG and/or MR urography images could not be obtained in any of the patients which could have been used to evaluate the pelvicalyceal system and the ureter or to investigate VUR in the contralateral unit, but it was beyond the scope of our study.

Conclusions

US is a relatively low-cost imaging modality which is harmless to children as it is free of ionizing radiation, while providing real-time, high-resolution images. With the aid of both the qualitative sonographic criteria and the newer data that we have proposed, US is a useful tool in the initial diagnosis of MCDK and for the differentiation of MCDDs from grade IV hydronephrotic kidneys in children.

The cyst-to-kidney volume ratio is independent of age and therefore, it can be helpful in the diagnosis of unilateral MCDK at any age.

Conflict of interest: none

References


