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Lower-dose CT urography (CTU) with iterative reconstruction technique in children – initial experience and examination protocol

Authors' Contribution:
A Study Design
B Data Collection
C Statistical Analysis
D Data Interpretation
E Manuscript Preparation
F Literature Search
G Funds Collection

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Summary

Background: Conventional X-ray urography is one of the basic imaging techniques in urinary tract diseases in children. CT urography (CTU) employing standard Filtered Back Projection (FBP) reconstruction algorithms is connected with higher radiation dose. Advanced iterative reconstruction techniques enable lowering the radiation dose to the level comparable with conventional X-ray urography with better visualization of the urinary tract. Study protocol and indications for this modified technique should be discussed.

Material/Methods: Introduction of iterative image reconstruction techniques allowed to significantly reduce the radiation dose delivered during examinations performed at our Department, including CT examinations of urinary tract in children. During the last two years, CT urography replaced conventional X-ray urography and became the basic imaging technique in our Department. We discuss the study protocol regarding pediatric CTU examinations. The main goal is to receive an optimal image quality at reduced radiation dose.

Results: CTU examinations performed using the standard filtered back projection (FBP) reconstruction technique are associated with radiation doses about 1.5 times higher than those in conventional X-ray urography. Implementation of iterative reconstruction algorithms in advanced CT scanners allow to reduce the radiation dose to a level comparable or even lower than that in X-ray urography. In addition, urinary tract can be evaluated more precisely in multiplanar reformatted (MPR) and volume rendered (VR) images.

Conclusions: 1. Advanced iterative reconstruction techniques allow to reduce radiation dose in CT examinations and to extend indications for CT urography in children. 2. Urinary tract can be evaluated more precisely in multiplanar reformatted and volume rendered images. 3. CTU may replace conventional X-ray urography in children.

MeSH Keywords: Child • Diagnostic Techniques, Urological • Multidetector Computed Tomography • Pediatrics • Radiology • Urography

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Background

Urography facilitates the assessment of the excretory function of kidneys and the anatomy of the urinary tract. For many years, it has been one of the basic imaging methods used in the diagnostics of the urinary system in children; however, it was never performed as the examination of choice. Urographic examinations are complementary to other imaging techniques such as ultrasonography,

scintigraphy or voiding cystourethrography that comprise the current gold standard in pediatric urology [1].

Conventional urography consists of series of abdominal X-rays at different time intervals following intravenous administration of a contrast agent. Two-dimensional images of the contrast-enhanced urinary tract are often obscured by artifacts, mostly associated with the presence of gases and stool masses within the intestines.

Computed tomography urography (CTU) provides more diagnostic information [1–5]. The disadvantage of examinations performed at CT scanners employing standard image reconstruction algorithms connects with higher X-ray radiation exposure as compared to conventional X-ray urography [6]. Modern-day computed tomography scanners employing iterative image reconstruction techniques allow to perform CTU examinations with radiation doses comparable to conventional urographic examinations. This is consistent with the As Low As Reasonably Achievable (ALARA) principle [7,8] stating that the X-ray radiation doses in imaging studies should be minimized while maintaining the diagnostic value of examinations. However, the new method requires verification of indications and discussion on the study protocol itself [9,10].

This study presents the experience of the Department of Pediatric Radiology of the Medical University of Warsaw in years 2011–2013 in CTU examinations performed with iterative image reconstruction techniques.

Material and Methods

A total of 77 CTU examinations were performed in the period of June 2011–July 2013 in 75 pediatric patients (46 boys, 29 girls) aged 1 week – 18 years (Table 1). In all cases, CTU was a successive imaging examination performed to precisely assess the anatomy of the urinary tract so as to complement the previous diagnostic examinations (ultrasound scans, dynamic or static scintigraphy of kidneys and voiding cystourethrography in some patients).

Indications for the CTU examinations are listed in Table 2. In 2 children, indications for follow-up examinations included the assessment of complications following the surgical treatment. In most cases, indications for CTU examinations were determined in collaboration by an urologist, a nephrologist and a radiologist. In the youngest patients, examinations were performed under general anesthesia.

Study protocols, including acquisition parameters, were changed as our experience grew. In 44% of cases, scans were acquired only in the excretory stage; in the remaining cases, various protocols were used, including late phase scans as part of multiphase examinations. Acquisition parameters in the excretory phase were modified by reducing the kV and/or mAs values. Bone window reconstructions were performed and the scans were assessed in transverse planes, as well as in multiplanar and volume rendering reconstructions. Additional plain images or late scans were acquired if urinary stasis was detected or if urine leakage from the urinary tract was suspected. A diuretic (furosemide) was used in selected cases of pyelocalyceal contrast retention.

Table 1. Age of patients.

Age (years)	Number of patients
0–1	19
1–5	25
5–10	18
10–15	10
15–18	3

Table 2. Indications for 77 CTU examinations in 75 children.

Indication	Number of examinations
Diagnostics of urinary tract defects	48 examinations: • hydronephrosis – 24 • upper urinary tract duplication – 14 • giant ureter – 9 • bilateral simple ureteroceles – 1
Post-operative follow-up (assessment of outcomes and/or diagnostics of complications)	11 examinations: • following surgical treatment of hydronephrosis (HA pyeloplasty) – 4 • following ureterocutaneostomy (giant ureter) – 3 • following lower heminephroureterectomy – 2 • following ureter suturing – 1 • following nephrectomy – 1
Abnormalities of kidney structure, shape and location	8 examinations
Diagnostics of renal cysts	7 examinations
Urinary tract injuries	3 examinations: • extensive kidney injury – 2 • suspected ureter injury – 1

Table 3 presents the obtained values of CTDIvol, DLP and effective dose E (with consideration of the pediatric effective dose conversion coefficients [11]).

Results

In all patients, CTU examinations allowed to precisely visualize the urinary tracts, make the correct diagnosis and select an appropriate management method.

In children with hydronephrosis (Figure 1), CTU was performed if no correlation was observed between the results of ultrasound and dynamic scintigraphy scans. Ten out of 24 children with hydronephrosis were qualified for surgical treatment, while the remaining group was followed up (11 patients with single system hydronephrosis, 1 patient with hydronephrosis of the lower system in a duplicated kidney, 1 patient

Table 3. Obtained values of CTDIvol, DLP and effective dose E (with DLP conversion coefficients [11]).

Patient weight (kg)	kV	mAs	CTDIvol (mGy)	DLP (mGy*cm)	Phantom (mm)	E (mSv)
<10	80	80	3	65.5	16	3.2
10–30	80	50	1.9	59.4	16	1.8
30–50	80	80	3	106	16	1.59
50–70	80	86	1.63	38	32	1.14

Table 4. Diagnosis of abnormalities in kidney structure, shape and location.

Diagnosis	Management
Pelvic horseshoe kidney (fusion of upper poles) + bilateral grade V vesicoureteral reflux	Endoscopic vesicoureteral reflux treatment
Pelvic kidney (multicystic dysplasia)	Follow up
Horseshoe kidney	Follow up
Crossed displacement of the right kidney with L-shaped fusion of both kidneys and ureter bifidus (fusion of both ureters in the subpelvic segment) in a child with rectal athresia and rectourethral fistula	Surgical treatment of rectal athresia with damaged ureter suturing, ureter transplant
Small cirrhotic kidney (status post renal vein thrombosis)	Abandoned nephrectomy
Improper focal renal interstitial structure (status post cyst trauma)	Follow up
Multifocal nephritis	Follow up
Inflammatory kidney tumor (xantogranulomatosis pyelonephritis)	Nephrectomy

with hydronephrosis in a horseshoe kidney and 1 patient with CTU-verified diagnosis of single system dilatation instead of dilatation of the lower system in a duplicate kidney).

In the group of 14 pediatric patients examined for suspected upper urinary tract duplication, CTU examinations allowed to make the correct diagnosis. In 2 out of 7 patients with suspected duplication of the pyelocalyceal system without pathological changes in the lower urinary tract, CTU examination confirmed the diagnosis. Out of 5 patients with suspected ureteral ectopia and duplication, CTU confirmed the diagnosis in 1 patient (Figure 2). In the remaining 4 patients, duplication only (no ectopia) was confirmed in 1 patient, and neither duplication nor ectopia was diagnosed in the other 2 patients; bilateral single systems with bilateral ureteral ectopia into the urethra was diagnosed in one patient. In another 2 children with duplication and grade V vesicoureteral reflux into the lower system, CTU examinations were performed before lower heminephroureterectomy for precise visualization of the anatomy of both pyelocalyceal systems.

In 9 children with giant ureters CTU allowed to correctly assess the degree of ureteral dilation and anatomy: 5 children were qualified for further follow-up, 2 children were qualified for ureterocutaneostomy as the first stage of a two-stage surgical treatment, and 2 children were qualified for a one-stage surgical treatment, i.e. ureter transplant.

In 1 child with bilateral simple ureterocele CTU allowed to confirm the diagnosis before endoscopic cyst incision.

In a group of 8 children, CTU was performed to assess abnormalities of the structure, shape and location of kidneys. in all cases, the examination allowed to make a precise diagnosis – see Table 4. Follow-up CTU examinations were performed in 2 children of this group: one child after nephrectomy for an inflammatory kidney tumor (xantogranulomatosis pyelonephritis) due to persistent abundant drainage of fluid from the kidney bed with the objective to assess the other kidney and ureter, and one child with crossed kidney displacement and incomplete duplication of urinary tracts after rectal athresia and suturing of an ureter damaged during the surgery with the objective to assess the tightness of the junction.

In 7 children with isolated renal cysts, CTU examinations were performed as basic diagnostic procedure – giant cysts were removed surgically from 3 children.

In 2 children with extensive renal damage, CTU results facilitated the choice of a conservative treatment method. In another patient after appendectomy and with suspected right ureter injury, the examination revealed no urine leaking out of the urinary tract.

Eleven CTU scans were performed as post-surgical assessments to estimate the treatment results and/or to diagnose complications: in 4 children after surgical treatment of hydronephrosis (Hynes-Anderson's pyeloplasty) due to persistent significant degree of pyelocalyceal dilatation – no anatomical causes were identified in either case; in 3



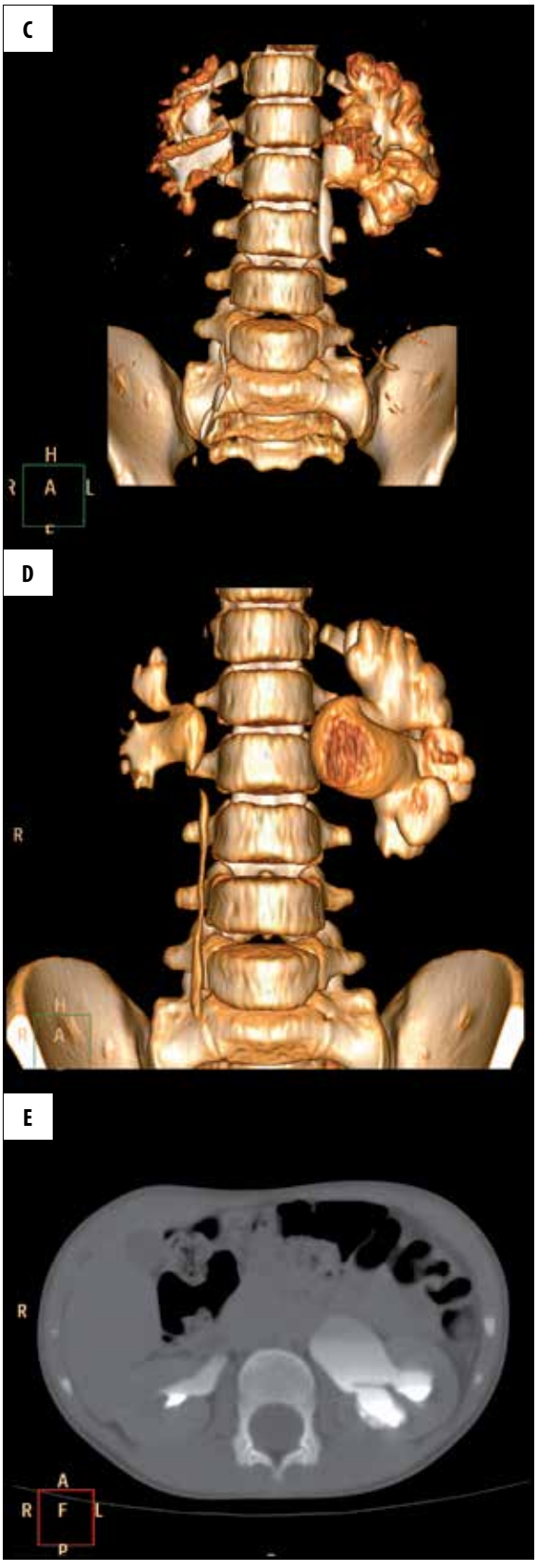


Figure 1. A boy with left-sided hydronephrosis (**A**) revealed accidentally in US examination in the 5th month of life. VCUG revealed no vesicoureteral reflux. X-ray urography (**B**) and dynamic scintigraphy revealed dilatation of pyelocalyceal system with urinary obstruction. CTU performed in the 4th year of life before qualification to surgical intervention revealed dilatation of pyelocalyceal system (**C**) with dilatation grade significantly increasing after administration of a diuretic – furosemide (**D, E**) – active obstruction. Patient was qualified for surgical treatment, Hynes-Anderson pyeloplasty was performed, intraoperationally revealing marked narrowing of the proximal ureteric segment with an elbow bend.

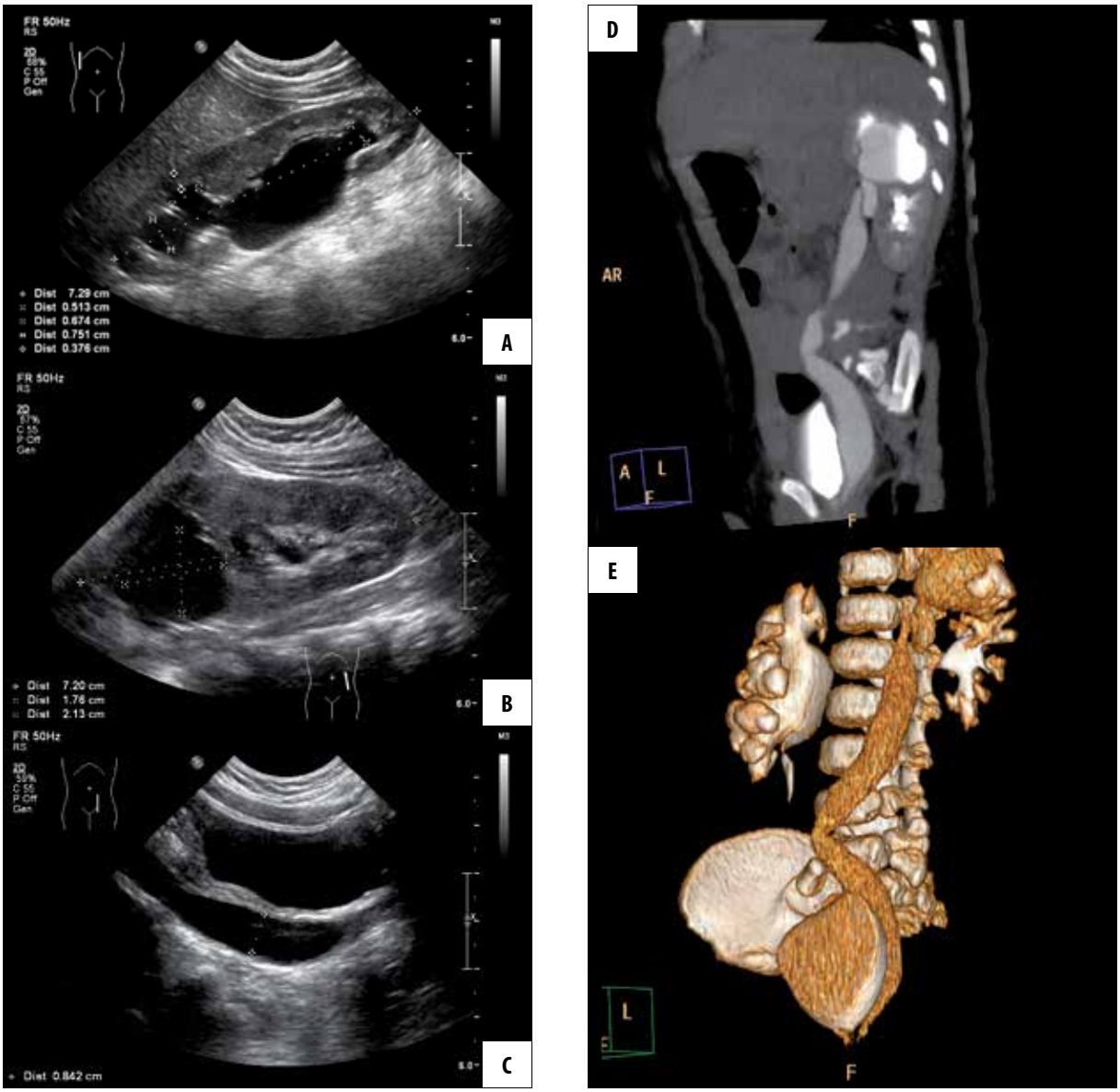


Figure 2. US examination of a 6-month old girl after acute pyelonephritis in the 4th month of life, revealed (**A–C**): hydronephrotic dilatation of the right kidney pyelocalyceal system and duplication of the left kidney pyelocalyceal system with hydronephrotic dilatation of the upper part and the entire length of the upper ureter. Voiding cystouretrography revealed no vesicoureteral reflux. Scintigraphic examination revealed impaired parenchymal secretory function of the upper pole of the left kidney. CTU (**D, E**) revealed obstruction of right-sided ureteropelvic junction and obstruction of left-sided ureterovesical junction of the upper ureter with ectopic urethral orifice. Patient was qualified to cystoscopy and follow-up scintigraphy before the final decision regarding left upper heminephrectomy.

children with giant ureters and unsatisfactory functioning of the ureterocutaneostomy no significant ureteral dilation was identified; and in 2 children after lower heminephroureterectomy due to post-operational complications – in one patient with abundant drainage of urine from the Redon drain an urine leakage was identified along with its precise location in the resection area, and in another patient with persistent fluid accumulation below the lower pole of the retained part of the kidney no connection with the retained pyelocalyceal system or urine leakage was detected (Figure 3). Two examinations were performed as follow-up in 2 children with structural kidney abnormalities with the objective to assess possible post-operational complications within the urinary tract.

Discussion

Implementation of the iterative image reconstruction techniques requires a revision of CT protocols in pediatric population.

Standard image reconstruction algorithms employed for a long time in computed tomography (Filtered Back Projection – FBP) require appropriately high radiation doses to reduce random effects such as noise and artifacts. Iterative reconstruction techniques employ different, modern statistical algorithms that allow to reduce random effects at reduced radiation doses while maintaining high image quality. There is an increasing number of published studies assessing the

Table 5. Number of conventional X-ray Urography and CTU examinations in the period 2010–07.2013.

	2010	01–06.2011	07–12.2011	2012	01–07.2013
Conventional urography	35	12	5	0	0
CTU	0*	3**	13	36	25

* Installation of a multislice CT apparatus – December 2010; ** introduction of iDose4 iterative reconstruction software – June 2011.

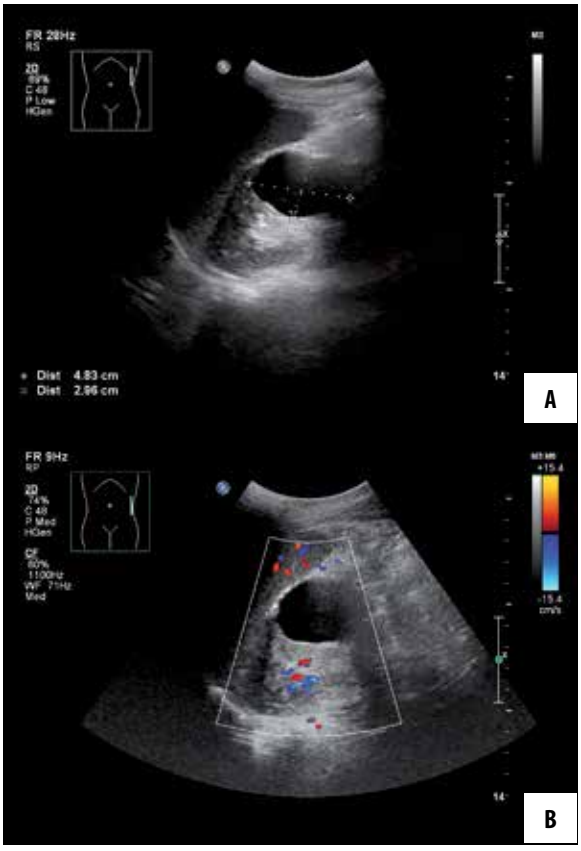




Figure 3. A 14-year old girl after left lower heminephrectomy due to duplicated pyelocalyceal system within the left kidney – grade V vesicoureteral reflux. Surgical intervention was performed at age of 12, accumulation of fluid below the remaining part of the left kidney observed in subsequent US examinations (**A, B**). Single-phase CT urography (**C, D**) performed with split-bolus technique (protocol: 1st portion of i.v. contrast – 30 mL; interval – 30 minutes; 2nd portion of i.v. contrast – 40 mL; 50 s scan delay) revealed accumulation of fluid without contrast enhancement, not connected with renal parenchyma and collecting system. The fluid accumulation was left for further observation.

degree of dose reduction and the quality of computed tomography scans in children using both reconstruction techniques [12,13]. Taking into consideration also the data obtained in adult patients, one may expect dose reductions of 25–45% or more with comparable or even better image quality [12–16]. Radiation doses used in our abdominal and thoracic CT scans are similar to those reported in the literature.

According to the guidelines of the European Society of Urogenital Radiology [4], CTU is defined as an examination optimized for the assessment of kidneys, ureters and the urinary bladder, involving the early or late excretion phase as a compulsory element of the examination. Excretion phase facilitates visualization of contrast-enhanced urinary tracts. According to these guidelines, CTU is the examination of choice in patients with macroscopic hematuria at high risk of urothelial cancer. In the remaining cases, urography is used to complement the diagnostics after other examinations have been performed. This pertains particularly to pediatric population where suspected congenital defects of urinary tract are the most common indications. According to the guidelines of the European Society of Pediatric Radiology [1], basic diagnostic methods should include those not exposing children to X-ray radiation, i.e. ultrasonography and magnetic resonance imaging.

According to the guidelines, indications for CT scans include complications in the natural course of urinary tract lithiasis and infections, diagnostics of tumors and vascular pathologies and severe injuries of the urinary system. At the same time, however, low availability of MRI examinations in children is being highlighted. Competently performed CTU scans are an alternative method when MRI examinations are not available.

In less than one year since the introduction of iterative image reconstruction techniques in the CT scanner (iDose4), CTU became a basic method to replace conventional X-ray urography at our Department. Table 5 presents the number of X-ray urography and CTU examinations performed between the year 2010 and July 2013.

Low acquisition parameters at level of 80 kV and 80–90 mAs in pediatric CTU examinations allowed to obtain diagnostic images with quality acceptable for the assessing radiologists. The scans were much better in visualizing the anatomy of urinary tract compared to X-ray urography, which was highlighted by pediatric urologists, particularly when used prior to scheduled surgical treatment. The study protocol involved scanning in the excretion phase starting from the diaphragm to the symphysis pubic level, optimally 10–15 minutes after intravenous contrast administration (1–1.5 ml/kg of body weight). Due to the specificity of examinations in pediatric patients, in whom suspected urinary system defects are the most common indications, single phase scanning was sufficient in a large percentage of cases. In selected cases requiring further assessment of the contrast agent retention within the urinary tract, plain abdominal X-ray was considered instead of another CT scan.

The radiation dose used in CTU examinations with iterative image reconstruction techniques was reduced to the level comparable or even lower than that used in X-ray urography. When performed with standard image reconstruction algorithms (Filtered Back Projection – FBP), CTU exposes the patient to a radiation dose ca. 1.5-times higher than in X-ray urography [6]. Iterative reconstruction techniques allow to reduce the dose by 25–45% or more while maintaining image quality that is at least comparable with standard algorithms (FBP) [12–16].

One of the most important factors that impact the computed tomography dose reduction in children is proper determination of indications and proper design of the study protocol. In our material, the most common indications were suspected congenital defects of the urinary tracts, particularly those qualified for surgical treatment (Table 2). CTU scans performed in suspected urinary tract lithiasis remain disputable. Provided that deposits could not be visualized by other methods, particularly by ultrasound scans, a CT scan without contrast may be considered. Contrast administration should be limited to special cases such as the assessment of the level of obstruction or suspected external modeling of the urinary tract.

Diagnostic difficulties are most commonly associated with incomplete contrast enhancement within the urinary tract. Most common causes include ureteral peristalsis (no contrast enhancement of some ureter segments), no excretory function or impaired excretory function of the kidney and significant dilatation of urinary tract making uniform distribution of contrast difficult and reducing its concentration.

In standard examinations of the abdomen involving the scans performed in the excretory phase, a split bolus (mixed phase) technique should be considered (Figure 3) [4,5]. A split bolus of the contrast agent, combining the parenchymal and excretory phases, can be used. The contrast is administered in two portions, with a several minutes interval between the portions. The scan is acquired soon after the second dose of the contrast. This allows to obtain two examination phases during one scan, thus reducing the radiation dose while maintaining the diagnostic value of both phases. Different protocols are used that differ by contrast volume per portion and by the intervals between portions. It appears that the method may become important in pediatric urinary tract examinations; however, optimum protocol should be developed and indications for use should be identified first. As shown by preliminary observations, lower contrast volumes may be insufficient in some cases for correct enhancement of a particular urinary tract segment in a particular phase.

Magnetic resonance urography is an alternative method [1–5]. Low availability and much longer examination time, requiring long-term sedation in some cases, remain the limitations for the use of this technique.

Conclusions

1. Implementation of the iterative image reconstruction techniques results in radiation doses reduction in computed tomography examinations, thus extends the range of indications for CTU in pediatric patients.
2. An advantage of CTU compared to conventional X-ray urography is more precise assessment of the urinary tract, including multiplanar and volume rendering reconstructions.
3. CTU is an examination that replaces conventional X-ray urography in children.

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