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REVIEW

Urinary tract imaging in infancy

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Introduction

Imaging of the kidney and urogenital tract (UGT) in infancy requires dedicated imaging techniques and specific knowledge as well as training of the radiologist. Besides standard imaging procedures, new applications and imaging modalities have been introduced into paediatric uroradiology within the last decade that need to be acknowledged when discussing state of the art imaging of the infant UGT. Furthermore, new knowledge and increasing insight into pathophysiology and the natural course of many neonatal UGT conditions have altered management approaches requiring adaptation of imaging algorithms to meet modern demands in term of diagnostic accuracy, radiation protection, and efficacy.

Imaging techniques

There are a number of imaging techniques available, established methods that may have undergone refinements and new methods where their use partially depends on availability and expertise.

Ultrasonography

US has been an accepted first-line imaging tool for decades. With maturing techniques and improved transducers, US has overcome its initial role as an orienting imaging modality and is now considered a reliable high-end imaging method that allows accurate diagnosis of many conditions, thus reducing the need for additional examinations [1, 2]. Modern US examinations of the UGT in infancy demand high-resolution curved- and linear-array (multifrequency) transducers (14–4 MHz). These transducers, with new technology allowing modern beam formation and image compounding, enable detailed evaluation of the infant kidney that (particularly in neonates) sonomorphologically differs from the adult kidney. A thorough UGT US study should always consist of a detailed assessment of the urinary bladder, of the perivesical space and (inner) genitalia, of potential pelvicalyceal and ureteral dilatation, and of renal size, position and parenchyma [3, 4]. A thorough investigation requires a hydrated child with a sufficiently filled bladder, as well as a post-void assessment. However, US remains operator dependent and the more modern US applications require skilled and experienced operators.

There are some new applications that have a particular importance in paediatric urosonography:

- M-mode enables semiquantitative assessment and documentation of ureteric peristalsis [5].
- Harmonic imaging (HI) is a new US technique based not on the reflected fundamental frequency but the harmonic response generated by the tissue or by the specific contrast medium response. It improves border delineation, particularly in liquid-filled structures such as the dilated collecting system, reduces artefacts, and improves depiction of US contrast media [6, 7].
- Sonographic contrast medium instilled into the bladder via a catheter enables a reliable sonographic assessment of vesico-ureteric reflux (VUR) without radiation exposure (contrast-enhanced voiding urosonography; ce-VUS) [7–

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15]. Established detailed procedural recommendations enable a standardised procedure that at present is considered indicated for screening purposes, VUR assessment in girls, and for follow-up investigations—provided there is local availability of the contrast medium for infants and children [3]. This technique can also be used as a supplement to sonographic genitography [16]. Intravenous ce-US has presently only very few indications in infants [17].

- The various Doppler techniques allow a semiquantitative assessment of renal blood flow and perfusion. Colour Doppler sonography (CDS) gives a quick and comprehensive overview of vessel anatomy as well as flow velocity and direction in the renal vessels. The twinkling sign has improved US potential for the assessment of urolithiasis [2, 18, 19], and CDS improves assessment of the ureteric inflow jet [2, 20–22].
- Duplex Doppler sonography (DDS) provides detailed information of flow profiles with a physiologically lower flow velocity, a higher resistive index (RI) and relatively lower diastolic flow velocity in infants and neonates. DDS is especially valuable in evaluating indirect signs for perfusion disturbances, e.g., in renal vein thrombosis with consecutively elevated arterial RI in the affected renal segment, or for depicting renal artery stenosis as well as flow changes in renal failure [2, 20, 23–27].
- Amplitude-coded CDS (aCDS; 'power Doppler') is based on the totally integrated Doppler spectrum. This CDS technology demonstrates blood flow volume rather than blood flow velocity. The increased sensitivity for blood flow allows depiction of peripheral renal vasculature and diagnosis of diffusely impaired cortical perfusion (e.g., the 'halo sign') or focal perfusion defects (e.g., infarction, segmental acute pyelonephritis; aPN) [2, 24, 28]. High-level equipment is essential, and an experienced operator is needed to apply the correct aCDS settings (e.g., filter, gain, sample size) [2, 20, 29, 30].
- Three-dimensional US (3-DUS) is a relatively new technique for imaging the paediatric UGT and provides a multi-axial demonstration of the entire kidney. It is applicable also to neonates as a bedside investigation and offers improved standardisation and documentation. It improves renal parenchymal volume calculation, particularly in irregularly shaped kidneys or in hydronephrosis (HN), as the dilated collecting system can be deducted from the overall kidney volume [31]. The potential of creating rendered views (e.g., of the dilated collecting system) may serve as an excellent tool for comprehensive demonstration of complex pathology with results comparable to IVU or MRU images [32, 33]. 3-DUS-based virtual cystoscopy allows a completely new US-approach to visualisation of the inner bladder surface [34, 35].
- Functional evaluation at present is limited to aspects of perfusion and peristalsis assessment. Other sonographically accessible aspects can only indirectly be extrapolated and are limited; for example, pelvicalyceal dilatation does not equal obstruction (a severely dilated kidney can have better function than some kidneys with only little distension due to reduced renal urine production). There are some other functional US applications still in the research stage, e.g., real-time 4-DUS virtual cystoscopy for assessment of ostial and bladder function, or urethral assessment during voiding using a perineal approach [36–39].

Voiding cystourethrography

VCUG is a classic established examination in paediatric uroradiology. A bladder catheter is placed and radio-opaque contrast medium instilled into the emptied bladder. Detailed anatomy of the bladder and the urethra (as well as of refluxing ureters) can be obtained; lateral views of the male urethra are mandatory for evaluation of a posterior urethral valve (PUV) [3, 13, 40]. If VUR is present then details of the ureter and the pelvicalyceal system are also seen; intrarenal reflux (a factor increasingly considered important for scarring) and drainage dynamics of the refluxed contrast medium need to be assessed. Findings have been standardised [41]. Using a physiological filling pressure for the contrast medium infusion, additional functional information can be obtained and fluoroscopy can be guided [42, 43]. Cyclic filling enables a higher VUR detection rate and has become standard in infants [44, 45]. Modern pulsed fluoroscopy and digital systems with image amplification and last image hold options have helped to significantly reduce the radiation burden [46]. However, the examination still delivers considerable exposure, particularly in cases with severe pathology where a longer fluoroscopy time and more spot images may become necessary. Thus one should adhere to strict indications, particularly if ce-VUS is available for some of the queries, and in general the number of VCUGs performed is decreasing [47].

Nuclear medicine investigations

These are functional imaging studies using a short-lived radionuclide attached to a tracer, usually ^{99m}technetium (^{99m}Tc) [48–50].

For dynamic or diuretic renography, mercaptoacetyltriglycine (MAG3) is administered intravenously and is taken up by the kidney and excreted into the urine. The parameters that can be estimated include renal blood flow

(RBF), differential renal function (DRF), and renal transit or urinary drainage, the latter especially important in HN and obstructive uropathy. RBF is estimated during the period between 0 s and 20 s after the bolus injection; DRF is estimated during the period between 60 s and 120 s. The drainage function is evaluated when dilatation is present using a loop diuretic (usually furosemide). Quantification of drainage should account for DRF as well as allow gravity to have its effect, and the bladder should be empty [21, 23, 40, 41]. Note that this technique has limitations during the first month(s) of life and in kidneys with poor function.

A static renogram using dimercaptosuccinic acid (DMSA) will allow estimation of DRF and focal parenchymal defects [48–50]. DMSA is extracted by the proximal tubules and fixed in these cells, allowing imaging 2–4 h after injection. The main advantage of this scan over the dynamic renogram is the lower background activity, enabling a more reproducible DRF estimation and better depiction of small lesions (e.g., scarring, aPN, etc). Note that DMSA has limitations in poorly functioning and severely obstructed or dilated systems, and only allows an orienting result during the first months of life. Improved anatomical detail can be acquired when using SPECT techniques, without the need for a higher dose in older children when using modern equipment.

The direct isotope cystogram (DIC) is carried out in a very similar way to the VCUG, but instead of using radiopaque contrast medium, ^{99m}Tc is installed into the urinary bladder via a catheter [49]. The radiation dose is much lower, and the longer observation period results in an increased VUR detection rate. The disadvantage of DIC is the loss of anatomical detail, especially of the urethra. An indirect isotope cystogram can be obtained in the late phase of a diuretic MAG3 renogram in toilet-trained patients. The bladder is filled by the radiotracer in the natural way (excretion via the kidneys) after intravenous injection, and increase in or reoccurrence of activity in the position of the ureters or pelvicalyceal systems indicates VUR [49].

Intravenous urography

The IVU is no longer used in the neonatal period and very rarely during infancy because the anatomical and functional information from US, nuclear medicine and MR-urography (MRU) offer a great deal more at no or less radiation. The rare indications are pre- and postoperative imaging, restricted availability of MRU or isotope studies, some trauma conditions (suspected urinoma or ureteral injury with no CT or MR available), and some queries in urolithiasis.

Computed tomography

CT has become the mainstay of uroradiology in adults, both ce-CT-urography as well as non-enhanced "stone-CT". However, CT delivers a relatively high radiation dose and its potential in adults cannot be converted to infants who have less fat, smaller structures, different diseases (e.g., far less malignancy, stones are very rare and smaller, etc) and tissue composition (e.g., stones are less calcified and smaller making them more difficult to depict). Furthermore, infants have higher radiation sensitivity. Therefore, uro-CT has not achieved the same importance in paediatric uroradiology, and at present is only used for imaging in severe and multiple trauma, in complications of inflammatory or stone disease, for CT-angiography, and in the assessment of suspected tumours, particularly if MR(U) is not available [51–53]. If CT is indicated, dedicated age- and weight-adapted paediatric protocols for contrast medium and exposure parameters together with properly adjusted timing should be used; the scan area and range should be kept as small as possible and restricted to the clinically necessary size, and multiphasic scans should be avoided. Never just "try a CT"; if you perform CT in an infant; always make sure that the scan will deliver the requested and therapeutically relevant information at the lowest achievable radiation burden.

Magnetic resonance urography

MRU was introduced into paediatric uroradiology more than a decade ago [54–63]. However, still only a few centres routinely use MRU to examine the infant UGT, although its use is constantly increasing. In infants there are sedation needs, restricted availability, and lack of familiarity with this modality from radiologists as well as clinicians and surgeons. Nevertheless, fast sequences with strong gradients, respiratory gating and triggering techniques, multi-canal imaging, and the improved spatial as well as temporal resolution provide excellent anatomical and functional imaging, even in infancy. Furthermore, MRA allows good depiction of the major vessels (e.g., crossing additional renal artery in UPJO) [64]. Thus MRU is a perfect tool for comprehensive UGT imaging, simultaneously offering anatomical and functional information without radiation, and is considered the ideal "one-stop-shop" imaging for many paediatric UGT queries and conditions, in infants particularly for assessing congenital UGT malformations and obstructive uropathy [65–75]. Unenhanced T2-W MRU sequences ('water-MRU', or 'static fluid urography') usually reveal all relevant anatomical information, particularly of the collecting and draining urinary tract structures [61, 67, 72, 76]. Dynamic functional MRU uses serial fast T1-W acquisitions (usually 3-D gradient-echo techniques) after intravenous application of gadolinium that can be used for quantification of various renal functional parameters such as glomerular filtration, split renal function, or renal transit time; calculations are based either on a similar approach as

scintigraphy or use the "Rutland-Patlock plot" [62, 63, 67–69, 74, 75, 77–79]. In HN, diuretic stimulation with furosemide also allows a semi-quantitative assessment of urinary drainage, and the early arterial phase of this dynamic sequence can be used as MRA that allows assessment of major renal vessels [64, 69, 80–83]. Appreciating this vast potential, MRU has practically replaced IVU in paediatric uroradiology [54, 56, 57, 60, 61, 66]. MRU has also become the first-line imaging tool in the assessment of cystic kidney disease if US cannot reliably answer the clinically relevant question [84]. Additionally, MR is increasingly applied to queries such as complicated urinary tract infection (UTI), differential diagnosis in equivocal renal lesions, evaluation of complex posttraumatic conditions (e.g., urinoma), or assessment of UGT tumours. Additionally there are some observations indicating the potential value of MRU in complicated stone disease [59, 67, 73, 80, 84–86].

There are other imaging procedures that may incidentally need to be applied in infants, such as image guidance for biopsy or nephrostomy [37, 87–89]. In very rare cases, conventional catheter angiography may be indicated, particularly when an interventional procedure is anticipated, such as balloon dilatation of renal artery stenosis or embolisation of an arteriovenous fistula or a bleeding tumour.

Indications and timing of imaging, and specific imaging algorithms

Before imaging the UGT in infants, the clinician must be clear as to why the investigation is being requested. They should know which results are possible, and if the potential findings impact management. The timing of the investigations is important: some infants are severely ill and others are relatively well; some pathologies have a short time course, and some conditions cannot be imaged too early, such as moderate fetal HN, which will be underestimated during the first days of life; or immature or impaired renal function may obviate diagnostically accurate functional investigations and the use of intravenous contrast medium (i.e., IVU, scintigraphy, ce-MRU). In most conditions, the first examination is a full US examination of the UGT in a well hydrated infant. Other investigations are then selected depending on these findings and the underlying clinical query, as well as potential earlier results, e.g., from the family history or from prenatal US. In order to facilitate standardised imaging of comparable quality that meets today's demands, various procedural recommendations and imaging algorithms, as well as a standardised HN grading have been developed and proposed for most common queries in the UGT of infants [3, 4, 28, 90, 91].

Antenatally diagnosed hydronephrosis

Postnatal imaging of antenatally diagnosed HN is stratified according to the severity of prenatal findings [92–98]. In neonates with bilateral (severe) HN, US is required on the first day of life, especially with hydroureteronephrosis and/or bladder abnormalities or suspicion of PUV. In boys, UGT US should be complemented by a perineal scan of the urethra and a VCUG. In girls with such findings one should consider a neurogenic bladder, and a spinal and/or cranial US, as well as, potentially, a ce-VUS should be performed. If an obstruction is diagnosed, adequate drainage must be established, but additional imaging is usually postponed until prior to surgery or after the sixth to eighth week (or even the third month) of life when the kidney has matured and MAG3 or ce-MRU will reveal reliable results [3, 23, 90].

In neonates with moderate and/or unilateral prenatal HN (with or without a dilated ureter) and a contralateral normal kidney, the initial US usually is postponed to between the fifth and seventh day of life in order not to underdiagnose potential disease. If the first US is normal, a repeat US study at 1–2 months of age may be considered, but no additional imaging is required. If significant unilateral renal pelvic dilatation is found, as in UPJO, a follow-up US at 3–6 weeks and a dynamic diuretic MAG3 renogram (or ce-MRU) is required at 6–8 weeks of age. If (additionally) a dilated (mega)ureter or other indirect signs of VUR are detected (e.g., thickened pelvic wall, 'extended US criteria') a VCUG (or, in girls, a ce-VUS) should be undertaken. In complex urogenital anomalies and preoperatively, MRU may be helpful and has replaced IVU.

Acute neonatal conditions

The acute conditions in neonates are suspected PUV, pyonephrosis or urosepsis, (acute) renal failure (ARF), and perfusional kidney disturbances such as renal vein thrombosis; rarely a congenital renal tumour or (associated) adrenal gland haemorrhage may occur.

ARF may be pre-renal (systemic causes, e.g., asphyxia, circulatory arrest, hypotension, etc), post-renal (e.g., severe obstructive uropathy), or intrinsic. The differential diagnosis of intrinsic ARF includes perfusional disorders such as haemolytic-uraemic syndrome or renal venous thrombosis, toxic renal damage, and involvement in metabolic/systemic disease (e.g. hyperoxaluria), neonatal (glomerulo-)nephritis, acute tubular necrosis and cortical and/or medullary necrosis, as well as pre-existing conditions such as renal hypo-/dysplasia or infantile polycystic kidney disease. These conditions may coexist and may be accompanied by any degree of ARF [20, 23, 24]. In all of them an urgent US is required, and mostly allows differentiation of the subtypes, or may give hints toward the specific disease entity; usually

(sequential) US suffices and no other imaging is indicated. Note that in these US studies evaluation of renal perfusion by Doppler US is essential, and that in an anuric or oliguric neonate the absence of dilatation does not exclude obstruction; thus a perineal US scan after bladder filling or a VCUG, as well as follow-up US may become mandatory. After ARF or in chronic renal failure (CRF), DMSA (or in the future, increasingly MRU) will help to determine prognosis and potential sequelae by assessing renal function and defects or scars.

Urinary tract infection and VUR

In infants with acute symptomatic UTI and fever or clinical signs of septicaemia, an immediate US should be undertaken to exclude an obstructive uropathy and find signs for renal involvement such as increased renal size, altered echogenicity, thickened endothelium, urolithiasis, or focal perfusion defects on aCDS [3, 4, 99–102]. If no dilatation is seen, no renal involvement is detected even using extended US criteria, and there is good response to treatment, then further imaging can be delayed. In all infants with renal scars (or renal involvement) a VCUG or ce-VUS will be undertaken when the infection has been cleared [103]. Usually a DMSA scan is performed after 6–9 months for assessment of scarring; in unclear situations an early DMSA (or kidney MRI) may be indicated, as detection of renal involvement is the key feature for further imaging and monitoring, or for deciding on the necessity of antibiotic prophylaxis—although this concept is increasingly under discussion. Imaging of complications can also be performed by US, sometimes ce-CT or (better) ce-MRU may be necessary.

Vesico-ureteric reflux has lost some of its importance, particularly if mild and without UTI. Imaging algorithms reflect this new approach acknowledging the high spontaneous regression rate of mild-to-moderate VUR with no long-term sequelae or therapeutic consequences. Only in infants with significant neonatal HN (for differentiating obstruction from reflux, and for assessment of the urethra), with congenital dysplasia (potentially indicating congenital "reflux nephropathy"), with complex UGT malformations or syndromic disease (e.g., duplex kidney with dysplasia or HN, myelomeningocele with neurogenic bladder, etc), or in infants with upper UTI (where VUR is a risk factor for renal scarring, with all its implications) a thorough search for VUR (by VCUG, ce-VUS or DIC) is still considered indicated; whereas in all other conditions invasive imaging is no longer recommended.

Obstructive uropathy

Once an obstructive uropathy has been diagnosed (usually after prenatal HN and neonatal exploration), the important task is to preserve bladder and kidney function. In PUV, early drainage and surgery is performed. In megaureter and UPJO, the aim of imaging is to detect those kidneys that are endangered, i.e., those that will deteriorate in function and loose growth potential if left untreated. At present there is no imaging tool that allows a reliable a priori pro-futuro assessment, and thus regular monitoring is performed to early depict deterioration of obstruction and renal function, though it may difficult to properly distinguish those who will benefit from surgery from those who can be managed conservatively [21, 23, 82, 83, 92, 95, 96, 104–106]. Usually one tries to accomplish this task by repeated US examinations (as US is readily available and free of radiation burden) and intermittent MAG3 studies (particularly if US indicates potential deterioration, such as increasing dilatation with parenchymal thinning and loss of corticomedullary differentiation, contralateral hypertrophy, asymmetrically altered perfusion, etc) [23, 25, 26, 49, 90]. Increasingly, dynamic diuretic MRU is used, partially replacing MAG3 in some centres, and in infected systems a (sonographically guided) percutaneous nephrostomy may become necessary [28, 61, 64, 67–70, 77–79, 82, 83, 87, 88, 107–109].

Other (complex) malformations and conditions

(Hypo-)dysplasia is a congenital condition and different from acquired renal scarring, e.g., after hypoxia or infection. US shows a small kidney, the parenchyma may look echogenic with reduced corticomedullary differentiation, with or without cysts, and often without any HN. Perfusion can be impaired, with reduced vascularity on aCDS and lower flow velocities or altered RI on DDS, sometimes (in duplex systems) supplied by a separate renal artery. If (hypo) dysplasia is unilateral, overall renal function remains normal and even small kidneys may have some residual function. Often dysplasia is encountered in the upper pole system of a duplex kidney that drains—sometimes via a ureterocoele—with an (ectopically inserting) megaureter. The lower pole system of a duplex kidney tends to reflux, thus VCUG or ce-VUS is often used in the work-up of these conditions, particularly if infants are clinically symptomatic. Additionally, as well as for assessment of (functional) single kidneys, ectopic kidneys and/or suspected ectopic ureteral insertion, MRU has become the complementing imaging modality of choice [58, 65, 66, 67, 71, 72, 109–112]. Note that kidney malformations, and particularly a single kidney, may be associated with genital malformations and a thorough early and focused investigation of particularly the female inner genitalia is advisable as potential malformations are best identified during the first months of life. This is usually achieved by (sonographic) genitography, potentially complemented by fluoroscopy and MRI [16, 58, 73, 80, 113].

Cystic kidneys

There are a number of cystic renal diseases that may occur in infancy [23, 24, 84]. The most common condition is (non-functioning) multicystic kidney disease (MCKD). MCDK is defined by multiple cysts of different sizes without communication and potentially some central residual dysplastic parenchyma. Differentiation from the most sever UPJO may be difficult in some cases as MCDK may represent the endpoint of an antenatally decompensated obstructive uropathy. Bilateral MCDK is incompatible with life. If the changes are just segmental (segmental MCDK is difficult to differentiate from cystic nephroma) or the other kidney is normal, prognosis is good although there are important associated abnormalities of the opposite kidney such as VUR, UPJO, or (mid) ureteric stenosis/obstructive megaureter; therefore, these conditions are usually actively sought for.

If one discovers bilateral renal cysts of different size in an otherwise sonographically normal renal parenchyma in an infant with normal creatinine, the most probable diagnosis is autosomal dominant polycystic kidney disease (ADPKD). This familial condition may manifest by just a single initial cyst; thus renal cysts in infancy must prompt a thorough clinical and family assessment. Alternative diagnoses of syndromic kidney disease, such as tuberous sclerosis, must also be considered. Note that in ADPKD cysts may also occur in other abdominal organs.

Bilateral large kidneys with sonographically diffuse but non-homogeneously increased parenchymal echogenicity ("salt and pepper appearance") may indicate infantile autosomal recessive polycystic kidney disease (ARPKD). Initially, the microcysts often are too small to be depicted on imaging. Note that if ARPKD is suspected an US of the liver for liver fibrosis should be added, as in general one should always perform an orienting US of the entire abdomen in every child submitted for the first time to an US investigation [3].

Other cystic changes in the kidney are the rare simple renal cysts and post-inflammatory or post-traumatic cysts, which need to be differentiated from calyceal diverticula or tertiary calices, urinoma, as well as rare renal tumours such as cystic nephroma, cystic Wilms tumour, necrotic renal carcinoma, renal teratoma, or post-haemorrhagic angiomyolipoma. These conditions may indicate sectional imaging, preferably MRI, and acquisition of a delayed scan (using an MRU technique) or delayed abdominal radiograph after CT is advisable not to miss late contrast medium accumulation in a calyceal diverticulum.

Haematuria

In adults, haematuria is an alarming symptom potentially indicating malignancy. This justifies aggressive and sometimes invasive imaging. Infants are different; only very rarely is haematuria the result of a renal or bladder tumour. Although haematuria is one of the typical symptoms in some paediatric UGT tumours, these are usually perfectly accessible by US in infants. The majority of infants with microhaematuria suffer from many other conditions, such as familial haematuria, (glomerulo-)nephritis, other nephropathies, UTI, hypercalciuria and urolithiasis, etc; even VUR and obstructive uropathy may exhibit haematuria [114–119]. Thus the imaging algorithm in infants with haematuria is different and often an US investigation suffices, together with a thorough clinical assessment including a detailed family history and laboratory assessment of urine and serum parameters [90]. Depending on these findings additional imaging can be then initiated if necessary, referring to the respective imaging algorithm.

Urolithiasis

Urolithiasis is much rarer in infancy than in adulthood, and as infants have significantly higher radiation sensitivity than adults that hinders the presently booming liberal use of CT, standard adult imaging algorithms cannot be blindly applied to children. Furthermore, other aspects need to be considered: infants tend to have smaller and poorly calcified stones (e.g., cystinuria, infective stones)l and the small dimensions of the child's ureter surrounded by only little fat impairs the diagnostic capabilities, particularly of unenhanced low-dose CT techniques. But infants offer ideal US conditions and the majority of stones are easily accessible by US as they are situated in the pelvicalyceal system or in the proximal and the distal ureter relatively close to or at the PUJ or UVJ. Thus, using the entire spectrum of modern techniques, US can reliably make the diagnosis in most of the queries provided the infant is sufficiently hydrated and has an adequately filled bladder [18, 20, 28, 90, 120]. In some cases an abdominal radiograph can be helpful for assurance or for proper localisation (e.g., prior to lithotripsy). Follow-up usually is performed by US. If IVU is still used for this query, it should be focused using a reduced number of films that are properly coned to the targeted area, resulting in a significant dose reduction compared to standard (adult) IVU protocols. As there is hardly any data available on low-dose uro-CT in children, and as we do not know whether (ultra-)low dose CT has the same diagnostic capability in infants as reported for adults, uro-CT is used reluctantly in infants. At present, CT is considered a problem-solving tool in those cases with a non-diagnostic US study, with mismatch between clinical findings and US, for infants who exhibit indirect US signs without proper sonographic stone localisation, for assessment of complications, and for differential diagnosis in complex cases [52, 53, 121, 122], as well as for preoperative imaging (e.g. prior to percutaneous lithoapraxy).

Renal trauma

Minor renal trauma and trauma restricted to the UGT tract is rare in infancy. In these conditions US (always including CDS) is usually performed, complemented by CT or MRU for assessment of complex findings [28, 52, 123]. US is also the first-line follow-up technique. Urethrography and cystography are used for assessment of bladder and urethral injuries that may raise the suspicion of child abuse. Today, IVU is no longer used for trauma queries; rarely a single delayed film for documentation of ureteral integrity or differentiation of a potential urinoma may be indicated if MR or CT is not available. Severe and multiple trauma, however, is primarily assessed by ce-CT.

Urogenital tract tumours

In neonates the most common entity is the benign mesoblastic nephroma; Wilms tumour constitutes the majority of renal tumours in infancy. Other conditions such as rhabdoid kidney tumour or nephroblastomatosis and angiomyolipoma also need to be considered [73, 80, 86, 124–128]. For tumour queries, US is always complemented by contrast-enhanced sectional imaging, usually MRI—if available.

Conclusion

By applying modern imaging and updated algorithms using standardised imaging techniques the presently restricted evidence-based knowledge in many paediatric nephrourological conditions may be broadened enabling future new approaches allowing improved imaging of the infant UGT based on profound data. Modern US and VCUG or ce-VUS still represent the mainstay of routine paediatric uroradiology in infancy. IVU is hardly used, and CT is applied reluctantly in infancy due to its radiation burden and the specific disease spectrum of this age group. Scintigraphy and MRU are complementary methods indispensable for the proper work-up of many conditions. To properly exploit the vast potential of currently available imaging, appropriate equipment and adequate training is needed. Interdisciplinary interaction, communication and cooperation are necessary to individually adapt imaging protocols and to optimally exploit what modern imaging offers. This might also inspire research and help focus developments on clinical needs as well as health system oriented efficacy. The still restricted access to MRU, the need for sedation, the relatively high costs, and the good results from US and scintigraphy that presently limit the indications for MRU and MRA may be overcome. Then MRI will not be considered just a ‘problem-solving’ tool, but will offer standard non-invasive and non-ionising anatomical and functional imaging that may impact on the existing imaging algorithms.

For the future, further developments in US such as new transducer techniques or 4-DUS, an improved assessment of apoptosis, ischaemia or nodal involvement by nuclear medicine and MRI, as well as the development of new contrast media, radiotracers and image fusion techniques may allow improved non-invasive imaging and monitoring of these phenomena, impacting upcoming new research and clinical concepts.

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