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Michael Riccabona *Editor*

Pediatric Urogenital Radiology

Third Edition

Springer

Medical Radiology

Diagnostic Imaging

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Preface to the Third Revised Edition

It is an honor for me having been entrusted with editing this new third edition of the standard textbook *Pediatric Uroradiology*; however, it took quite some time and effort get everything done.

Looking back over time to the first edition of this textbook more than a decade ago, one realizes that not that much has changed for many queries in spite of ongoing discussions on varying concepts, experts' opinions and recommendations, new insights into pathophysiology, and new imaging options as well as new applications of existing modalities or refinement of existing techniques. And still, there is restricted high-level evidence for deciding on how to best image our pediatric patients for many pediatric urogenital conditions.

Nevertheless, some basic trends can be observed and are also reflected in this new edition. There is a general tendency towards reducing invasiveness and radiation burden to our pediatric patients, and it is widely recommended to more strictly adhere to a "therapeutic thinking efficacy," i.e., imaging must have an impact on patient treatment and management. Thus, the numbers of voiding cystourethrograms have in most centers significantly decreased, antibiotic treatment for uncomplicated vesicoureteric reflux is less often prescribed, or intravenous urography has been mostly outdated and replaced by modern ultrasound or MRI for the common pediatric queries.

Additionally, the growing economic pressure (in the USA with the aim of making money from health care, in Europe for saving money by restricting medical services) has led to a new thinking and concept in pediatric medicine and also pediatric radiology, i.e., only treatment and related diagnostic measures that impact further outcome, prognosis, and development are administered. Thus, imaging modalities that probably do not necessarily effect patient morbidity and mortality are questioned, particularly if they imply invasiveness or burden such as radiation, sedation, or contrast agent application.

Finally, considering the new development towards "personalized medicine" and the growing demand for interdisciplinary diagnostic and therapeutic approaches, additional in-depth knowledge on clinical basics, diagnostic needs, embryology, and pathogenesis, as well as therapeutic options and consequences, is becoming indispensable for the radiologist to enable an understanding of what imaging must provide in terms of diagnosis and management decision information. In the recent years, fetal imaging has become an established part of pediatric uroradiology, too: not only that it detects conditions that have to be addressed after birth by pediatric radiology but increasingly pediatric radiologists are performing fetal body MR imaging themselves.

Taking all these aspects into consideration, this new edition has been restructured into four main sections: the methods, the anatomy and embryology, the clinical information, and the imaging section. As such, it contains some new chapters – e.g., a completely new chapter on fetal imaging has been introduced, and dedicated clinical chapters are provided that shall offer a comprehensive insight into the various conditions and diseases. Furthermore, all old chapters have been revised or updated and some were completely rewritten. New illustrations have been added and recent new knowledge, insights, and changes in imaging approaches (e.g., contrast-enhanced ultrasonography; modern MRI applications and techniques) have been integrated. Hence, this third edition aims to address all these aspects, but without disregarding the valuable and necessary established "old" imaging procedures that may still be indicated for well-defined diseases and conditions.

As with this diversity of approaches and persisting restricted evidence in many of the pediatric uroradiology conditions, a somewhat varying and partially overlapping presentation of the individual contributors to this third edition is intended – in order to allow for an informed reflection of the continuous re-orientation process in pediatric urogenital imaging. To achieve this objective, a broad context and knowledge of all possible options and conditions that are mandatory for understanding are provided clearly to satisfy the needs of practicing pediatric radiologists, pediatricians, pediatric surgeons, urologists, and nephrologists. Furthermore, up-to-date information and reference are provided for researchers.

Only with the help of the distinguished and renowned faculty of international experts in the field of diagnostic and interventional pediatric uroradiology as well as neighboring fields (e.g., pediatric surgeons/urologists/nephrologists and pediatricians) who contributed to this revised new edition, this new edition hopefully a has become comprehensive volume containing all the latest advances thus fulfilling the demands of a textbook covering all aspects at the most modern and newest of the art.

Last but not least, I want to acknowledge the dedication and expertise of each contributor and I thank all authors sincerely for their hard efforts and their excellent contributions as well as their patience. I do hope that – as the first two editions – this new edition will again become a standard working and reference text for pediatric urogenital radiology that helps in improving our service to the pediatric patients, the future generation.

Graz, Austria Michael Riccabona
2018

Preface to the Second Edition

Never before in the history of pediatric uroradiology have concepts, expert opinions and recommendations changed as significantly and as quickly as over the last 5–7 years. Even established scientific concepts which we thought would never be debated again, are now back on the discussion table. This even applies to the treatment and imaging management of very common but serious nephrourological disorders such as urinary tract infection and vesicoureteric reflux, where the benefit of antibiotic prophylaxis and therefore the role of imaging are called in to question. These changes are not only triggered by the latest scientific findings, some of which contradict formerly established scientific concepts, but by the growing awareness of evidence-based medicine and, last but not least, also by new imaging techniques and technologies.

However, many old concepts still remain and many facts established in the last millennium are still true and pertinent today. This leads to some confusion even among experts, who are still searching for consensus-based imaging management recommendations.

Therefore, the invitation to compile a second revised and extended edition of the book *Pediatric Uroradiology* came at the right moment. In many aspects, the first edition could be used as a reliable basis for the development of the second edition. Thus this new book embraces both the new, taking recent advances in knowledge and technology into account, and the old. It is a complete rewrite where necessary, containing new contents with regard to latest developments such as genetics, and it provides the newest recommendations and discussions on clinical and imaging management of common nephrourologic disorders.

Thanks to the contributions of the distinguished and renowned international experts in the field of diagnostic and interventional pediatric uroradiology and of neighbouring fields such as genetics and pediatric nephrourology, a comprehensive volume containing all the latest advances could again be prepared, fulfilling the demands of a textbook covering all aspects of pediatric uroradiology in its broadest context. This book should satisfy the needs of the practising (pediatric) radiologist, pediatrician, pediatric surgeon and urologist; it should also offer up-to-date information and references to the researcher.

In view of the ongoing, rapid and significant changes, it was the intention of the editor to include a number of somewhat varying and overlapping views of the individual contributors for this second edition. Precisely this approach guarantees the requisite comprehensiveness and allows a degree of diversity reflecting the continuous reorientation process in pediatric uroradiology.

Again, it was a great honour and pleasure to work as an editor for this book project. I would like to acknowledge the dedication and expertise of each contributor, and I thank all of them sincerely.

Mrs. Irene Stradner, my secretary, was an indispensable member of our team; she did a marvelous job for this book project and I would like to express my warmest gratitude to her.

I hope that this second revised edition will again become a standard working and reference text for pediatric uororadiology.

Graz, Austria Richard Fotter

Preface to the First Edition

A substantial change in the diagnostic and therapeutic management of urogenital disorders in children has taken place in recent years. There are two main reasons for this phenomenon: first, the growing integration of (new) imaging modalities such as magnetic resonance imaging and helical computed tomography and of advanced ultrasound techniques into pediatric uroradiologic imaging protocols; second, dramatic advances in our knowledge on the natural history of important urogenital pathologies of childhood as a consequence of maternal–fetal screening ultrasound.

Changing indications and limitations and comprehensive multimodality interpretation should be in the field of the (pediatric) radiologist's expertise. To enhance the role of the radiologist, she/he should have a profound knowledge of urinary symptoms as well as the principles of medical and surgical treatment in children and should also be able to interpret laboratory data.

This growing challenge for the (pediatric) radiologist seems to justify the idea of a book specifically devoted to pediatric uroradiology. Therefore, we were delighted to be invited by the series editor, Prof. Baert, to write such a book. Thanks to the contributions of the well-known international experts in the field of diagnostic and interventional pediatric genitourinary radiology who wrote the different chapters, a comprehensive volume could be prepared fulfilling the demands on a textbook covering all aspects of pediatric uroradiology in its broadest context. The book is written to satisfy the needs of the practicing radiologist and pediatrician but also to offer up-to-date information and references to the researcher.

In view of the above-mentioned changes in the field, one central goal was to discuss the reorientation of diagnostic and interventional radiological approaches to problems of the pediatric genitourinary tract and to elucidate the contributions made by different diagnostic and interventional uroradiologic techniques.

The focus of this book is primarily the point of view of the (pediatric) radiologist, but it offers all the necessary information for the pediatrician, pediatric surgeon and urologist as well putting decisions on imaging management on a reasonable basis. To meet the demands on a (pediatric) radiologist today, pertinent clinical observations, important pathophysiologic concepts, operative options, postoperative complications and clinical as well as radiological normal values have been included.

Dedicated chapters are devoted to specific problems of the newborn and infant, such as imaging and interpretation of upper urinary tract dilatation, postnatal imaging of fetal uropathies, associated urinary problems with imperforate anus, epispadias–exstrophy complex and lower urinary tract anomalies of urogenital sinus and female genital anomalies.

Detailed discussions focus on the management of common problems in pediatric uroradiology such as urinary tract infection, vesicoureteric reflux and functional disorders of the lower urinary tract including enuresis and incontinence.

In dedicated contributions, embryology and the changing anatomy and physiology and pathophysiology of the growing organism are discussed to facilitate understanding of the disease processes and anticipated complications and form the rationale for interventions.

Specific chapters deal with agenesis, dysplasia, parenchymal diseases, neoplastic diseases, stone disease, vascular hypertension, renal failure and renal transplantation and genitourinary trauma in children. Specific problems of childhood neurogenic bladder are discussed.

Interventional uroradiologic procedures in children are discussed in full detail not only to show their value in treatment and diagnosis of a given problem, but also to serve as a source guiding the performance of these interventions.

It was the intention of the editor to respect the views of the individual contributors as far as possible. This is reflected in a diverse writing style and some degree of overlap and repetition. In the opinion of the editor, just this approach guarantees the necessary comprehensiveness.

After an always enjoyable time as editor I would like to acknowledge the dedication and expertise of each contributor; I thank all of them sincerely. Mrs. Renate Pammer, my secretary, was an important member of our team and I would like to express my warmest gratitude to her for the excellent job she did for this book project.

We all hope that this book will be accepted as the standard working and reference text for pediatric uroradiology. Moreover, we hope that it will prove useful to physicians in training and specialists alike as a reference source during preparation for examinations and conferences. The bibliography should readily satisfy the needs of all kinds of readers.

Graz, Austria Richard Fotter

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Part VIII Management, Guidelines, Recommendations and Beyond Including Normal Values

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Part I

Diagnostic Procedures

Diagnostic Procedures: Excluding MRI, Nuclear Medicine and Video Urodynamics

Aikaterini Ntoulia, Jean-Nicolas Dacher, and Michael Riccabona

Contents

1 Introduction

In the introduction of his course on Pediatric Uroradiology at Harvard Medical School, Prof. Robert L. Lebowitz cited the following sentence by LL. Weed: “Just as important as doing the thing right is doing the right thing”. This is an excellent introduction to this chapter.

Imaging of the urinary tract is among the most commonly requested examinations in

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paediatric radiology practice. In children, the lack of specificity of abdominal symptoms and the high prevalence of renal and urinary tract disease justify the high volume of these requests. Recent technological advances have significantly improved the diagnostic capabilities of existing imaging modalities and have further introduced advanced imaging applications in routine clinical practice, maximising the diagnostic yield. From a radiologists' perspective, it is important to know the clinical indications for the requested examination and what the referring physician expects of its results, so that the appropriate examination will be undertaken. Direct communication with the referring physician is always recommended, especially if there is any discrepancy between the examination request form, the medical records and the parents/children's interview.

This chapter aims to give a comprehensive overview of the diagnostic imaging procedures most commonly used for evaluation of the paediatric urinary tract. We hope it will provide the background for understanding the indications and the strategies on how to perform properly each examination and refresh some basic understanding of the anatomy as necessary for properly performing and reading these studies. X-ray procedures, conventional ultrasound and advanced ultrasound applications (e.g. Doppler techniques, extended field of view, harmonic imaging, contrast-enhanced ultrasound, sono-elastography) as well as computed tomography are described. Intravenous urography will only be mentioned briefly, as it has largely been replaced by magnetic resonance urography and is less frequently performed in children today, though in some, particularly low resource settings, it still may be the only available tool, and some potential indications still exist. Each subsection starts with the main indications for the study concerned, followed by updated technical and procedural recommendations and imaging strategies. Normal findings and clinical background as well as established query-defined imaging algorithms are discussed in the respective chapters of the book.

2 Kidneys-Ureter-Bladder Radiograph

2.1 Introduction

A plain film of the abdomen, known as kidneys-ureter-bladder (KUB) radiograph, is a widely available and relatively inexpensive imaging modality, frequently requested for initial evaluation of various abdominal pathologies and conditions (Dorfman et al. 2011). It is an anteroposterior radiograph, obtained in supine position and coned to include the abdomen from the diaphragm to the symphysis pubis, flank to flank.

2.2 Indications

A KUB film can provide preliminary overview information in children with suspected congenital, obstructive, traumatic, inflammatory or neoplastic processes and might be useful in differentiating gastrointestinal from urological conditions. However, it is important to mention that although KUB films are frequently and easily requested as a baseline imaging examination, they yield low diagnostic outcome in terms of accurately characterising intra-abdominal pathology. For this reason, KUB films have largely been supplanted in paediatric diagnostic practice by ultrasound as a highly sensitive and radiation-free first-line imaging modality. Other common queries for KUB films include evaluation of catheters, stents, drains and other medical device positioning, as well as search for foreign bodies (Rothrock et al. 1992).

Designated evaluation of the urinary tract on a KUB film warrants careful assessment of kidneys' soft tissue densities that provides basic information regarding their size, shape

Fig. 1 KUB radiograph, in a neonate with autosomal recessive polycystic kidney disease (ARPKD). Distention of the abdomen with bulging of both flanks, central distribution of bowel loops and medial deviation of the descending colon are highly indicative of bilateral massive renal enlargement

Fig. 2 KUB radiograph, in a 7-year-old female with persistent urinary tract infection from *Proteus mirabilis*. Partial staghorn calculus within the left kidney, forming a cast of the renal pelvis (*asterisk*) and branching within at least three major calyces (*arrows*)

and position and may reveal related abnormalities (Fig. 1). The transverse processes of the lumbar vertebrae act as anatomic landmarks for the course of the ureters. The latter insert into the urinary bladder at the level of the ischial spines.

A KUB film can reveal radiopaque stones along the urinary tract and reassess their size and position after urologic interventions (Fig. 2). Additionally it can demonstrate cortical or medullary calcifications related to a variety of metabolic, genetic or acquired pathologic conditions (Fig. 3) (Habbig et al. 2011). Urolithiasis and nephrocalcinosis should be differentiated from extra-urinary calcifications such as adrenal calcifications, appendicoliths or pelvic phleboliths (Rothrock et al. 1992) (Fig. 4). The presence of irregular calcifications associated with a soft tissue mass and bowel displacement is indicative of a neoplastic process and further dedicated imaging is typically performed for further diagnosis and staging (Fig. 5).

Fig. 3 KUB radiograph in a 16-year-old female with systemic lupus erythematosus and hypercalcaemia. Clusters of calcifications are deposited centrally within both kidneys, corresponding to the shape and position of the renal pyramids, consistent with medullary nephrocalcinosis

Fig. 4 KUB radiograph, in a 5-year-old male with prenatal history of asphyxia. Adrenal calcifications: bilateral dense calcifications, with triangular configuration, located in the region of the adrenal glands, adjacent to the spine

Fig. 5 KUB radiograph, in a 13-month-old male with palpable abdominal mass. The presence of abundant amorphous calcifications, associated with soft tissue density mass located centrally within the abdomen and extending to the level of the upper pelvis, causing displacement of bowel loops. Further diagnostic workup confirmed that the mass was consistent with neuroblastoma

Interpretation of KUB films should also include careful evaluation of the visualised skeletal structures of the spine, pelvis and lower ribs. Vertebral and genitourinary abnormalities are frequently associated due to the skeletal-genitourinary embryologic link at the early stages of development. Additionally, in cases of poor renal function, slip of the femoral epiphysis may occur, or renal osteodystrophy may become obvious.

2.3 Equipment

Significant technological innovations have resulted in the development of high-end digital radiography systems with many advantages over the traditional film-screen-based technology. The latter has been replaced in many radiology departments, although may still be present in lower resource settings. Modern radiography systems, including direct digital radiography and computed radiography, acquire images of high contrast and resolution and achieve also dose reduction, provided that the settings, filters and algorithms are adapted to paediatric needs and patients' age (Korner et al. 2007; Sorantin 2008; Don et al. 2011). Obtained radiographs are transferred to dedicated workstations and can be electronically archived and retrieved for future reference without loss of image quality. These can be further configured with advanced post-processing techniques to achieve optimal imaging display on a case-required basis. Moreover images can be readily accessible by other physicians within the hospital network and be even remotely distributed, contributing to significant workflow efficiency, provided the respective viewing stations have a diagnostically sufficient monitor resolution.

2.4 Acquisition Technique

Prior to KUB examination, all clothes should be removed, since contained metallic zippers, buttons and other clothing parts might obscure substantial findings if projected within the examined area. Diapers should also be removed, particularly if wet, in order to avoid the overlying appearance of the characteristic coalescent, nodular, radio-dense artefact caused due to urine absorption by the diaper polymer (Markowitz et al. 2009). This artefact may significantly interfere with imaging of the lower pelvis structures. Hospital gowns, if available, should be provided.

The child is positioned supine on the examination bed and is temporarily immobilised, usually with the help of the parents who can be present during the examination, with special attention to avoid overlying of artifactual densities within the imaged field of view.

Local lead shields should be used to protect radiosensitive organs, such as the thyroid, eyes, breast buds and gonads, whenever it is feasible, particularly if not interfering with the region of interest.

The wide range of paediatric body sizes plays a significant role in the radiographic technique. Selection of the appropriate image receptor size relative to the child's body size is necessary to improve image quality and decrease the amount of scattered radiation. Most KUB radiographs are obtained at 110–115 cm source image distance (SID). Proper beam collimation is required for all patients to limit the exposure to the anatomic area of interest. The use of grids, although can effectively eliminate scatter radiation in adults, is not suggested in small children. However it should be considered an option in adult-size adolescents and obese children, with body parts more than 10–12 cm in thickness (Willis 2009). Similarly, the use of automatic exposure control (AEC) sensors, although is typically preferred to deliver consistent exposure in adults, is not suggested in children, as these sensors tend to remain partially or completely uncovered and thus inactive in small-size children, leading to noise-degraded images (Goske et al. 2011). Therefore, manual selection of kVp and mAs settings in children is suggested, tailored to patient size and clinical indication, with low kVp techniques (60–75 kVp) being generally preferable depending on the detector specifications (Willis 2009; Goske et al. 2011; Don et al. 2013).

The exposure should be taken when the child is still, to avoid blurred images and potentially repeated examination. Images should be reviewed for diagnostic quality before the patient is released.

Take Away
A KUB film provides baseline overview evaluation of various abdominal pathologies and conditions, however, with quite low diagnostic yield in characterising intra-abdominal pathology. It has been largely supplanted in most of its indications with ultrasound.

3 Ultrasound

3.1 Introduction

Ultrasound (US) is a non-invasive, highly sensitive, widely available and cost-effective imaging modality that is routinely used as the first-line examination for the diagnosis of several developmental and acquired conditions and diseases of the urinary tract in children (Muller-Ording 2014; Riccabona 2014a, b). The lack of ionising radiation and the excellent anatomic resolution owing to the small amount of fat in children make US an outstanding technique for paediatric population.

Technological progress has significantly improved the diagnostic capabilities of conventional US and contributed to the development of novel US applications, such as harmonic imaging, high-resolution techniques, speckle and motion reduction filters, the various Doppler sonography options, extend field of view imaging, contrast-enhanced US imaging and sono-elastography, that have further expanded imaging potentials in clinical and research settings.

3.2 Indications

US imaging of the urinary tract is performed for a wide range of clinical indications (Riccabona et al. 2008; Muller-Ording 2014; Riccabona

2014a, b). A considerable number of children are referred for US due to a prenatal finding, most commonly urinary tract dilatation detected during maternal-foetal US. Postnatally, depending on whether or not the child requires immediate intervention, the first US is performed during the first day(s) of life or can be delayed until after 1 week of age. Therefore, in newborns with prenatally detected high-grade urinary tract dilatation, particularly if bilateral, if involving a single kidney, if associated with dysplastic renal parenchyma or if posterior urethral valves are suspected, an early US examination is recommended (Fig. 6). Other reasons for an early study are detection of a suspected ectopic kidney and complex urogenital malformations before excessive overlying bowel gas obscures the deeper structures (see respective chapters). Otherwise, in newborns with mild-to-moderate prenatal urinary tract dilatation, postnatal US can be performed later after birth (usually a period of at least 4–5 days is recommended), when the physiological immaturity and the relative dehydration of the neonatal kidney have been resolved (see chapters "Congenital Anomalies of the Renal Pelvis and Ureter" and "Upper Urinary Tract Dilatation in Newborns and Infants and the Postnatal Work up of Congenital Uro-nephropathies"). US can identify an underlying dilating abnormality of the urinary tract, often caused by obstructive uropathy (see chapters "Congenital Urinary Tract Dilatation and Obstructive Uropathy" and "Upper Urinary Tract Dilatation in Newborns and Infants and the Postnatal Work Up of Congenital Uro-nephropathies"). Alternatively, if vesicoureteral reflux (VUR) is suspected, additional imaging studies [voiding cystourethrography (VCUG) or contrast-enhanced voiding urosonography (ce-VUS)] can be further scheduled (see chapter "Vesicoureteric Reflux"). In the follow-up of children with either obstructive or refluxing abnormalities, including children who underwent surgical intervention, US can assess interval renal growth and the degree of the collecting system dilatation (Riccabona et al. 2009) (see chapters "Surgical Procedures and Indications for Surgery" and "Postoperative Imaging and Findings").

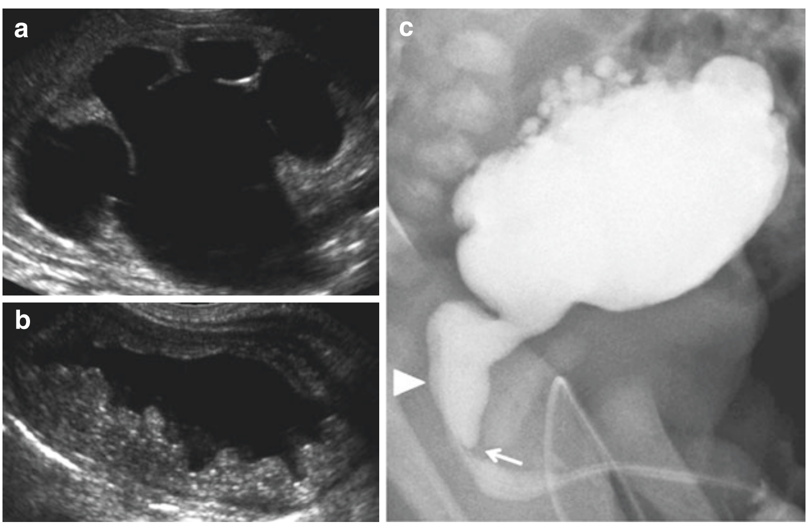

Fig. 6 Postnatal ultrasound in a neonate with prenatal diagnosis of urinary tract dilatation. (**a**, **b**) Greyscale ultrasound, performed in the first day of life, shows marked pelvicaliectasis with cortical thinning and decreased corticomedullary differentiation in both kidneys (here only the right kidney is shown), as well as diffuse bladder wall thickening and trabeculation, indicative of bladder outlet obstruction. (**c**) Voiding cysteourethrography, revealed the presence of posterior urethral valves, seen as linear filling defects in the flow of contrast during voiding (*arrow*), causing disproportional dilation of the posterior urethra (*arrowhead*) compared to the normal calibre anterior urethra. The bladder wall trabeculation and the multiple diverticula are again visualised

Urinary tract infection (UTI) is another common indication for renal US. Determination of renal involvement is of utmost importance to identify if a given patient should require intensive treatment and further imaging evaluation. The markedly improved US technology and up-to-date scanning protocols with high-resolution imaging including colour/power Doppler sonography techniques have contributed to a significant increase in US sensitivity to effectively and reliably detect early and subtle renal abnormalities in cases of UTI. These findings include focal or generalised renal enlargement, increased echogenicity of the renal parenchyma with reduced corticomedullary differentiation and focal or diffuse areas of decreased perfusion (Fig. 7). US can also play a significant role in the follow-up of these cases to confirm response to treatment or to rule out abscess formation and to search for long-term complications such as renal scarring (Dacher et al. 1996) (for details see chapters "UTI and VUR" and "Imaging in Urinary Tract Infections").

US is also very helpful in establishing the initial diagnosis of various nephropathies in children as well in the follow-up of these patients (Avni et al. 2012; Riccabona et al. 2012). US can detect the majority of nongenetic and genetic cystic kidney diseases, including cystic/multicystic dysplastic kidney, and autosomal dominant (ADPKD) or recessive polycystic kidney disease (ARPKD), respectively, and guide renal biopsy and evaluate for potential associations or complications (see chapters "Congenital Anomalies of the Renal Pelvis and Ureter", "Imaging in Prune Belly Syndrome and Other Syndromes Affecting the Urogenital Tract", and "Imaging in Renal Agenesis, Dysplasia, Hypoplasia and Cystic Diseases of the Kidney").

In children with palpable abdominal mass, US and plain abdominal films are usually sufficient to establish the diagnosis, which is then confirmed and staged by contrast-enhanced MRI or CT (see chapter "Neoplasms of the Genitourinary System"). In children with spontaneous haematuria, US can often rule out significant urolithiasis or malignancy.

In cases of acute renal failure, US can find or exclude (major) thrombosis of renal vessels (Fig. 8) or infectious disease (Hibbert et al. 1997; Moudgil 2014) (see chapters "Renal Failure and Renal Transplantation", "Neurogenic Bladder in Infants and Children" and "Imging in Renal Parenchymal Disease"). Haemolytic-uremic syndrome is one of the main causes of acute renal failure, especially in children, and US can confirm the diagnosis and monitor the recovery of these patients (Igarashi et al. 2014).

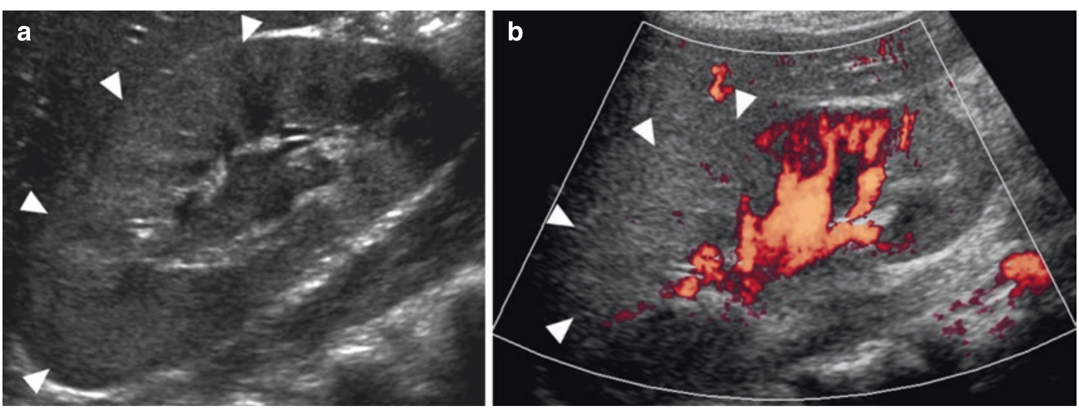

Fig. 7 Ultrasound examination in an 8-year-old female presented with fever and emesis. (**a**) Greyscale renal ultrasound. Diffusely increased echogenicity, with loss of corticomedullary differentiation, is noted in the middle and upper pole of the right kidney (*arrowheads*). (**b**) Power Doppler mode reveals decreased perfusion in the respective area of the right kidney. The constellation of these findings is suggestive of acute pyelonephritis

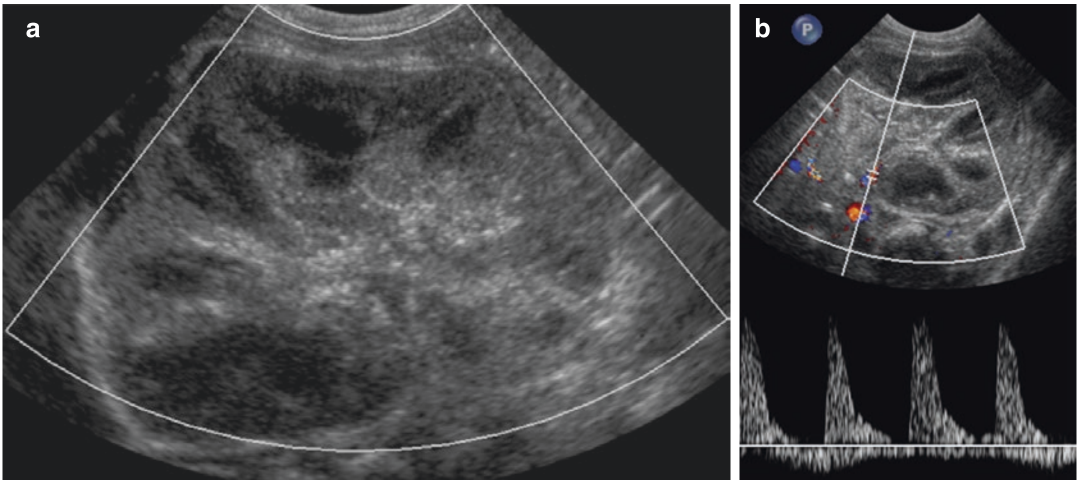

Fig. 8 Acute main renal vein thrombosis. (**a**) Power Doppler ultrasound, longitudinal plane. The kidney is enlarged with diffusely hyperechoic cortex and the absence of blood flow on power Doppler mode within the main renal vein, suggestive of acute renal vein thrombosis. (**b**) Spectral Doppler mode, transverse scan at the level of the renal hilum, reveals diminished flow into a segmental branch of the main renal artery with increased peak systolic flow velocities, indirect signs of renal vein thrombosis

In patients with arterial hypertension, US can detect renal scarring, hypoplasia or nephropathy. Colour/power Doppler sonography of renal vessels and parenchyma can orient the diagnosis toward vascular cause (see chapter "Renovascular Hypertension"); however, the variable cooperation of children may limit the contribution of Doppler sonography, and therefore renal angiography remains the reference examination.

After blunt abdominal trauma, haematuria is very common, and its grade does not correlate with the severity of the injury. Multi-detector CT is the unanimous gold-standard examination in cases of severe and multiple trauma. However, when US is optimally performed, it seems able to exclude severe renal injury and detect most relevant findings, reducing the need for CT in moderate trauma (Fig. 9) (see chapter "Urinary Tract Trauma") (Amerstorfer et al. 2015). For follow-up, US and/or MRI should be used for radiation protection issues.

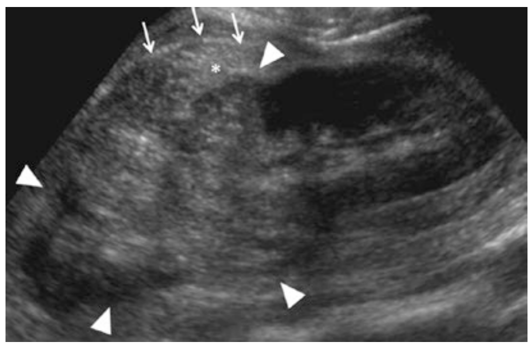

Fig. 9 Greyscale ultrasound in a 16-year-old female with history of blunt abdominal trauma. Significant disruption of the parenchymal architecture in the middle aspect and upper pole of the right kidney (*arrowheads*) is consistent with kidney laceration. The heterogeneously echogenic region (*asterisk*) extending from the subcapsular area along the Gerota's fascia (*arrows*) represents an associated perinephric haematoma

Periodic US screening is recommended in children with characteristics that are known to be associated with benign or malignant renal tumours, including aniridia, hemihypertrophy, Denys-Drash syndrome, Beckwith-Wiedemann syndrome and tuberous sclerosis (Fig. 10). In patients with malformations highly associated with renal abnormality, such as the VA(C)TER(L) association, imperforate anus, internal genital anomalies and Fanconi anaemia, US examination of the urinary tract is recommended for completing a comprehensive diagnosis.

Ultrasound imaging before and after renal transplantation is important for the evaluation of

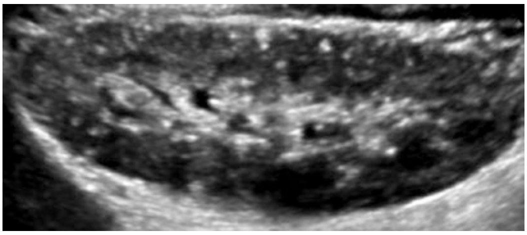

Fig. 10 Greyscale ultrasound of the right kidney, longitudinal plane, prone position. Multiple echogenic foci noted within the renal parenchyma are in keeping with angiomyolipomas in this patient with history of tuberous sclerosis

the donor and the recipient (see chapter "Imaging in Renal Failure, Neonatal Oligoanuria, and Renal Transplantation"). Non-invasive, longitudinal evaluation of renal allografts is based on serial US and colour/spectral Doppler examinations and measurement of resistance and perfusion indices (Riccabona et al. 2012).

Ultrasound can estimate bladder wall morphology and bladder capacity in children with neurogenic bladder or other non-neurogenic voiding dysfunction (see chapters "Urinary Problems Associated with Imperforate Anus", "Epispadias-Exstrophy Complex", "Non-neurogenic Bladder-Sphincter Dysfunction ("Voiding Dysfunction")", and "Neurogenic Bladder in Infants and Children").

Finally, US can be used as a guide for interventional procedures. Renal biopsy, nephrostomy tube placement and abscess drainage can be performed using real-time US guidance (Feneberg et al. 1998; Lungren et al. 2014) (see chapter "Pediatric Genitourinary Intervention").

3.3 Equipment

Advances in US technology have significantly improved the quality of an US image (Riccabona et al. 2008; Muller-Ording 2014; Riccabona 2014a, b). The availability of a wide variety of curved and linear array transducers with broad bandwidth frequency range including also higher frequencies up to 18 MHz allows high-resolution imaging and adequate penetration over the entire spectrum of children ages, body sizes and body compartments ranging from small preterm babies

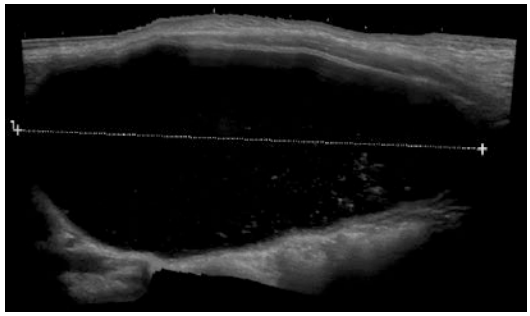

Fig. 11 Greyscale ultrasound. Extended field of view. Extended field of view for accurate measurement of bladder size thus enabling a reliable depiction of the increased capacity in this case of bladder function disorder with the presence of internal echogenic debris

to adolescents and even including obese patients. Curved array transducers are usually selected for orienting morphologic evaluation of the urinary tract and in older children, while linear transducers enable further detailed, high-resolution imaging and exquisite imaging in neonates. The examiner must select the appropriate transducer according to the age and size of the patient, the anatomic location and the tissue composition of the depicted structure and adjust image parameters in order to optimise image quality, including depth of view display, output energy and gain, focus number and zone, depth gain compensation and zoom (Muller-Ording 2014; Riccabona 2014a).

Tissue harmonic imaging is an imaging mode available in most modern US scanners and is used to increase contrast resolution reducing noise and artefacts. Thus, the image clarity is significantly improved, enabling more conspicuous visualisation of the internal echotexture and the borders of the examined structure (Bartram and Darge 2005; Darge and Heidemeier 2005). The panoramic or extended field of view imaging option can be selected if a lengthy field of view in a single scan-plane is required, such as in cases of enlarged polycystic kidneys or renal transplants (Fig. 11). Application of motion mode (M-mode) may allow evaluation and quantification of movement changes over time such as ureteral peristalsis (Fig. 12) (Riccabona et al. 1998). Power Doppler sonography (also named amplitude-coded colour

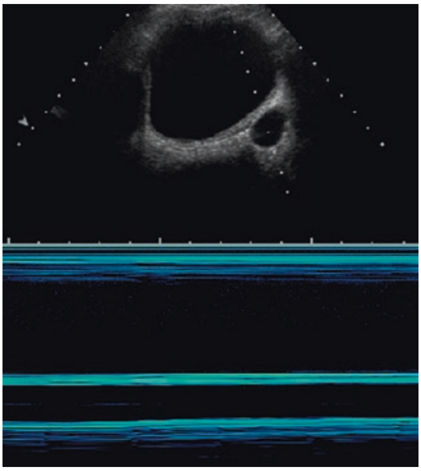

Fig. 12 M-mode sonography. In M-mode sonography, the variation of echoes motion through a single line of information is continuously displayed over time. In this case, M-mode through the plane of the dilated left retrovesical megaureter (*dotted line*) convincingly demonstrates the absence of peristaltic motion

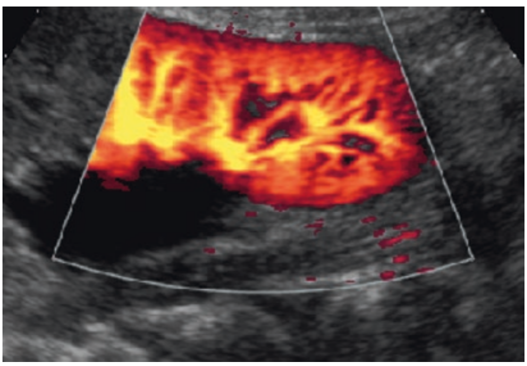

Fig. 13 Power Doppler sonography. Normal peripheral pararenchymal vascularisation at the level of the lower half of the left kidney

Doppler sonography) allows identification of blood flow within an operator-defined region of interest (Fig. 13) (Riccabona 2000; Riccabona et al. 2001). Colour Doppler sonography enables visualisation of blood flow directionality as an assigned colour in a colour-coded map superimposed into a B-mode US image. Spectral analysis based on pulsed wave Doppler sonography can be further applied, if measurements of blood flow velocities and analysis of the flow spectrum are required. These measurements include peak systolic, end diastolic, systolic/diastolic ratio or resistive and pulsatility indices. All currently available transducers have available colour and power Doppler sonography modes integrated.

3.4 Preparation

The child should be well hydrated before the examination for adequate distension of the collecting system and for proper assessment of the bladder. Oral uptake of clear liquids should be performed prior to the visit. Parents are encouraged to be present during the whole examination. Every study should start with an explanation to the parents and to the child if he or she is old enough to understand.

In case the US examination is performed in the intensive care unit, radiologists and technologists should follow basic rules of neonatal and intensive care. Incubator doors should be kept closed as much as possible, and extreme caution should be taken to prevent any catheter or tube contamination or withdrawal. Examinations should be performed as quickly and silently as possible, without omitting or missing essential aspects only for time reasons.

3.5 Scanning Technique

A generous amount of coupling agent (gel) should be applied along the entire area to be scanned, preferably prewarmed to body temperature to increase child's tolerability and comfort during the exam. Hygiene measures should be taken to avoid bacterial or fungal overgrowth.

3.5.1 Lower Urinary Tract

US examination should start with imaging of the bladder, especially in newborns and infants, since reflex micturition is frequent when the transducer is placed on the abdominal wall. Examination of the full bladder includes analysis of urine echogenicity and the bladder wall morphology. Normal bladder content should be anechoic, and the bladder wall should be smooth, with a maximum 3 mm thickness when full and 6 mm when empty (Jequier and Rousseau 1987). It is extremely important to look for dilated ureter(s) behind the bladder or an ureterocele inside it (Fig. 14). In children with normally shaped bladders, bladder capacity can be assessed by the ellipsoid equation: Volume (ml) $=0.53 \times D \times H \times W$ (D, depth; H, height; W, width in centimetres) (refer to chapter "Normal Values" for normal values) (Roehrborn and Peters 1988). Embedded software can automatically and accurately estimate bladder capacity and residual urine after micturition, provided the bladder has an ovoid shape – otherwise the correction factor has to be adapted. These estimations are particularly important in patients with neurogenic bladders or any kind of voiding dysfunction.

Ureteral jets are depicted with colour Doppler sonography "or modern non-Doppler-based flow imaging technique such as "B-flow"(GE Healthcare) or Superb Micro-Vascular Imaging, namely "SMI" (Toshiba) (Fig. 15)". Although their clinical significance has been a subject of literature debate, visualisation may be helpful in order to ascertain a degree of renal function, indicate the absence of acute obstruction or confirm the opening of a ureteral orifice within the bladder. Finally, the transperineal approach can be used to visualise the urethra, particularly in cases of posterior urethra valves in boys, and to assess lower urogenital tract malformations in girls (Fig. 16) (Teele and Share 1997; Berrocal et al. 2002; Schoellnast et al. 2004; Riccabona 2014a).

3.5.2 Upper Urinary Tract

Real-time scanning of the kidneys and ureters should then follow. Adequate access of the examined structure is obtained with the child in supine and prone positions. Curved and linear array transducers can be used alternatively during both positions, although the lower penetration of linear transducers makes prone position most preferable. In cooperative, older children instructions for inspiration and breath holding may further improve the acoustic window. However, in a moving, playing or crying child, a variety of positions, sometimes unconventional as the opportunity arises, are often necessary for the examination.

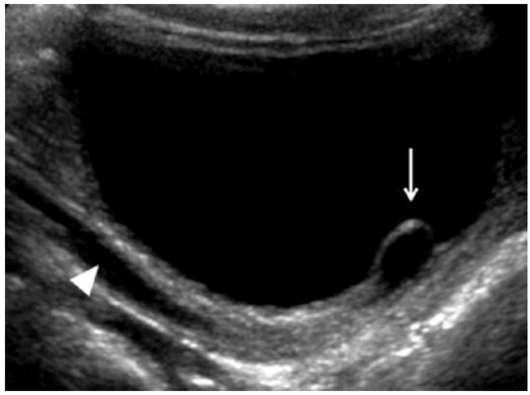

Fig. 14 Postnatal ultrasound in a neonate with prenatal diagnosis of lower urinary tract obstruction. Greyscale ultrasound shows dilation of the distal ureter (*arrowhead*) which ends into a thin-walled saccular outpouch prolapsing into the bladder, consistent with ureterocele

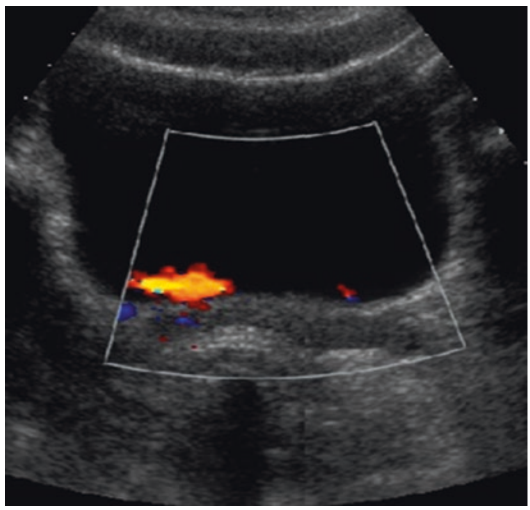

Fig. 15 Colour Doppler sonography. Transverse scanning of the bladder. Bilateral ureteral jets. Colour Doppler sonography enables the detection of urine flow arising from the ureteral orifices bilaterally – note the asymmetry

Morphologic evaluation of kidneys includes measurements of the longitudinal and transverse dimensions and calculation of the overall renal volume. The latest has been considered more sensitive to reflect changes in size compared to measurement of the length alone and can be assessed by the ellipsoid equation: Volume (ml) $=0.53 \times D \times H \times W$ (D, depth; H, height; W, width in centimetres) (refer to chapter "Normal Values" for normal values). In most modern US scanners,