MEDICAL RADIOLOGY
Diagnostic Imaging

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Foreword

Six years after the successful first edition of this comprehensive textbook on pediatric uroradiology, a second edition was mandatory.

Indeed, due to the rapid advances in imaging modalities and technology, as well as new therapeutic procedures, an update was needed on several important areas of pediatric urology such as vesicoureteric reflux, urinary tract infection and upper urinary tract dilatation.

I am very much indebted to Prof. Dr. R. Fotter, chairman of the department of radiology at the university of Graz and internationally renowned pediatric uroradiologist, not only for his personal contributions, but in particular for his expert, expeditious and efficient editorial coordination of this superb volume. I would also like to express my appreciation to the large group of individual authors, all recognised leaders in the field of pediatric uroradiology, for their excellent chapters.

This second revised edition is highly recommended not only to pediatric radiologists and radiologists in training, but also to pediatricians, pediatric surgeons and urologists who will find in this book excellent guidance for the clinical management of their patients.

Leuven

Albert L. Baert
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 uroradiology.

Graz                    Richard Fotter
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
– extrophy 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.
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1.1 Diagnostic Procedures Excluding MRI, Nuclear Medicine and Video-Urodynamics

JEAN-NICOLAS DACHER

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1.1.1 Introduction

In the introduction of his course on Pediatric Uroradiology at Harvard Medical School, Prof. Robert L. Lebowitz, MD, cited the following sentence by L.L. Weed: “Just as important as doing the thing right is doing the right thing.” This seems an excellent opening to this chapter about technique. As a matter of fact, many techniques compete today in the field of pediatric uroradiology, and we radiologists should be familiar with all of them. Indications, limitations, and of course interpretation should be within the field of our expertise. Overall, radiologists involved in this field should be familiar with the anatomy of the normal and malformed urinary tract, urinary symptoms in children, and the principles of medical and surgical treatment. Of course, radiologists should also be able to interpret biological data such as urinary culture and blood studies. At least, even if one does not practice any kind of examination, one should know the indications for it and the risks and stresses involved.

The requirements play a role in the success of any procedure. It is extremely important to know what the problem is and also to know what the parents (and the child, when old enough) expect of the test and its results. If the question is unclear, if there is any discrepancy between the requisition sheet, the medical records, and the parents’ interview, direct communication should be established with the referring physician before proceeding.
In this section of Chapter 1, ultrasound, X-ray procedures, and computed tomography (CT) are analyzed. Each subsection starts with the main indications for the study concerned. Then the technique as we perform it in our institution is described, as well as the limitations and risks. Normal findings and imaging strategies are beyond the scope of this chapter; they are discussed in the relevant parts of the book. A short paragraph on radiological reports concludes this section.

1.1.2 Ultrasound and Doppler

Ultrasound (US) is usually the first examination to be performed in a child presenting with any urinary tract or renal disease. Lack of ionizing radiation, low cost, wide feasibility, and excellent anatomic resolution owing to the small amount of fat in children all contribute to making US an irreplaceable technique.

1.1.2.1 Indication

First of all, exploring the kidneys and urinary tract is routine when performing abdominal ultrasound in any Department of Pediatric Radiology. In children, the lack of specificity of abdominal symptoms and the high prevalence of renal and urinary tract disease both justify this practice.

Nowadays, most cases of urinary tract malformation are detected by maternal-fetal US. Postnatal US became the cornerstone examination in following up infants who had the prenatal diagnosis of hydronephrosis. Comparative sonograms even represent the only imaging modality required by most situations. The first postnatal ultrasound examination is recommended by day 4 of life. The rationale to perform sonography several days after birth is the relative dehydration of neonates. Dehydration decreases diuresis; hence, a dilated segment of the urinary tract would be under-evaluated by a precocious sonogram. A second US study is commonly performed for comparison by 6 weeks of life (İsmaili 2004). Further studies [isotope studies, voiding cystourethrography (VCU), MR urography] can be scheduled depending on clinical symptoms and the results of serial ultrasound studies (aggravation vs. improvement of dilatation, presence vs. absence of associated renal dysplasia). An excellent communication between the prenatal ultrasound staff and the radiologists, pediatricians, and surgeons taking care of children is of utmost importance. The decision-making process is facilitated when images can be stored and retrieved via a PACS.

A very common indication for renal US is urinary tract infection. Primarily performed to rule out hydronephrosis, abscess or calculus, US can also detect (or confirm) underlying malformation. It is usually combined with other studies, especially VCU. The great success of US over the past few years has been in detecting malformation and preventing infection, which is known to be life-threatening in neonates and devastating for function in growing kidneys (Berg and Johansson 1982). However, in a recent study, the role of US in the evaluation of UTI in children was critically evaluated (Hoberman et al. 2003). Hoberman et al. reported a 12% rate of sonographic abnormalities in a population of children with UTI. Moreover, these authors have stated that prenatal US could detect most children with urinary tract malformation. They concluded that in a child referred for UTI, renal US would not be relevant if his/her prenatal US examinations were normal. This approach can be criticized for several reasons. First of all, prenatal US was shown to be unable to detect all children with congenital vesicoureteric reflux, the most frequent malformation associated with UTI (Anderson et al. 2003; Phan et al. 2003; Moorthy et al. 2003). Secondly, hydronephrosis as a consequence of uretero-pelvic junction obstruction can be diagnosed at any age of life in patients who had had normal prenatal sonograms and can become complicated with severe infection. Thirdly, communication between pre- and postnatal medical teams can fail for several different reasons (Dacher et al. 1992). The main drawback of US in the context of pediatric UTI is its reported sensitivity. US sensitivity varied among the different published studies regarding acute pyelonephritis (Hoberman et al. 2003; Dacher et al. 1996; Morin et al. 1999; Hitzel et al. 2002). This may be explained by different operators (expert pediatric radiologists involved in this field in some studies vs. young residents or sonographers in others), different techniques (using a ventral scanning approach or dorsal, lateral and ventral ones, using B-mode only or B-mode plus color/power Doppler, allowing sedation in non-cooperative children, allowing contrast medium injection, using high frequency/har-
monic techniques, considering the subtle reflectivity abnormalities of acute pyelonephritis, etc.), as well as variable equipment. Even under optimal technical conditions, the diagnostic accuracy of color Doppler US for APN ranged from 80 to 90% (Morin et al. 1999; Hitzel et al. 2002) and remained below that of DMSA scintigraphy, enhanced CT, or MRI. A normal US examination cannot definitely eliminate renal involvement in a child with acute pyelonephritis.

In follow-up of children with refluxing or obstructive malformation, sonography has replaced intravenous urography (IVU) in assessing renal growth and dilatation.

After blunt abdominal trauma, hematuria is very common, and its grade does not correlate with injury (Mayor et al. 1995). CT is the unanimous gold-standard method, but has been shown not to be cost effective (Filiatrault and Garel 1995). When US can be performed in satisfactory conditions, it seems able to exclude severe renal injury. Of course, any clinical or sonographic abnormality should lead to CT. Patients with multiple injuries are also investigated by enhanced CT on an emergency basis.

In children with spontaneous hematuria, US can rule out urolithiasis or tumor. In renal failure, US can exclude renal vein or artery thrombosis (Laplante et al. 1993). Doppler US can confirm diagnosis and help follow-up of hemolytic-uremic syndrome (Patriquin et al. 1989). In children with palpable abdominal mass, US and plain film of the abdomen are usually sufficient to establish the diagnosis, which is then confirmed by enhanced CT or MRI. In patients with arterial hypertension, B-mode US can detect renal scar, hypoplasia, or nephropa-thy. Then, Doppler examination of renal vessels and parenchyma can orient diagnosis toward vascular cause. Renal angiography remains the reference examination (Garel et al. 1995).

Periodic screening US is recommended in children with characteristics that are known to be associated with renal benign or malignant tumors (aniridia, hemihypertrophy, Drash syndrome, Beckwith-Wiedemann syndrome, tuberous sclerosis). In patients with malformation known to be associated with renal abnormality (the VATER association, imperforate anus, internal genital anomalies, Fanconi anemia), one postnatal US examination is recommended. However, abnormal external ears, unique umbilical artery, hypospadias, and descended testis have not been proven to be associated with renal malformation and do not represent indications for renal screening (Currarino et al. 1993).

Longitudinal evaluation of renal allografts is based on comparative US and Doppler examinations. Estimation of bladder wall and capacity in neurogenic bladder and voiding dysfunction can be made by US. Association with perineal electromyography and flowmetry helps understanding and management of functional voiding anomalies (Pfister et al. 1999). Finally, US can be used as a guide for interventional procedures. Renal biopsy, nephrostomy tube, and abscess drainage can be performed using real-time US guidance.

1.1.2.2 Technique

1.1.2.2.1 Equipment

Results intimately depend on technique. Recent equipment–high-frequency transducers with duplex color and power Doppler modes—is recommended. Harmonic imaging may be useful, especially when exploring obese children or adolescents, for detection of reflux after intravesical injection of contrast medium, and even for improving visualization of the bladder and kidneys from a dorsal approach (Bartram and Darge 2005). Most examinations of the urinary tract can be performed with a 5- to 7.5-MHz sector or phased-array transducer. A high-quality scanner is especially useful for severely ill patients who need bedside and emergency examinations. This point should be kept in mind by radiologists and hospital managers when purchasing a new scanner and by the radiology staff when planning daily schedules.

1.1.2.2.2 Neonates

Since the advent of maternal fetal US, many children have to be examined during the neonatal period, some of them still inpatients in the intensive care unit. In ICU practice, radiologists and technologists should follow basic rules of neonatal 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. Sterile preheated jelly should be used, and studies should be performed as quickly and silently as possible. Direct communication with the ICU staff and proper addressing of the medical question at hand always contribute greatly to the avoidance of handling mistakes.
1.1.2.2.3
Older Children

Cooperative children are first scanned in the supine position, then in the right and left lateral decubitus positions. The examination is completed with the patient in the prone position. A variety of positions, sometimes unconventional as the opportunity arises, are often necessary for the examination of a moving, playing, or crying child. Imaginative games can be useful at this time.

Absence of cooperation can sometimes compromise the quality of study. Medications are usually not used for US scanning, but light sedation (equimolecular mixture of nitrous oxide and oxygen, midazolam, hydroxyzine) could be considered in some circumstances, such as Doppler recordings. For further information on sedation, refer to VCU and CT sections in the same chapter.

1.1.2.2.4
Lower Urinary Tract

A basic study of the urinary tract should start with an explanation to the parents, and to the child if he or she is old enough to understand. The bladder is studied first, especially in infants, since reflex micturition is frequent when the transducer is placed on the abdominal wall (avoid unheated jelly). Examination of the full bladder includes analysis of urine echogenicity and the bladder wall. It is extremely important to look for dilated ureters(s) behind the bladder (Fig. 1.1.1) or an ureterocele inside it. It should be remembered that US approximates bladder capacity, which is best assessed by VCU (Koff 1983; Berger et al. 1983). Bis and Slovis (1990) proposed the following equation:

$$\text{Volume (ml)} = 0.9 \times \text{DHW}$$

(DHW stands for depth $\times$ height $\times$ width in centimeters) to obtain the bladder capacity from US in children with normally shaped bladders. Automatic devices are very useful and seem accurate to estimate bladder capacity and residual urine after micturition (Bladder Scan®), especially in patients with neurogenic bladders or any kind of voiding dysfunction.

When the shape is abnormal or the bladder is empty, capacity should not be inferred from US measures (Bis and Slovis 1990). The transperineal approach can be useful to visualize dilated posterior urethra in boys with valves (Teele and Share 1997). Finally, ureteral jets into the bladder can be detected with color Doppler (Leung et al 2007).

1.1.2.2.5
Upper Urinary Tract

Measurements include longitudinal (Fig. 1.1.2) and transverse size of each kidney and renal pelvis AP diameter. Results have to be compared to those of prior examinations (sonographic, prenatal, or others) as well as to normal values (Siegel 1995). Echogenicity
of both the cortex and medulla is assessed and compared to that of the liver. High-frequency examination can sometimes be useful to increase spatial resolution. A vascular map is preferably performed in the prone position in color or power Doppler mode (Fig. 1.1.3) with adapted filter and pulse repetition frequency. In some instances, duplex Doppler recordings are necessary. Parenchymal indices are taken at three locations (upper and lower pole, middle part). Then, renal artery waveforms can be recorded in the prone position at the ostium and hilum.

1.1.2.2.6
US Detection of Reflux

Several studies (Atala et al. 1993; Darge et al. 1999) have shown potential value for voiding sonography in detection of reflux. A contrast agent can be instilled in the bladder. An increase in echogenicity of the renal pelvis and the ureter appears in cases of reflux. There is no ionizing radiation, but examination time is longer than that required for voiding cystourethrography (VCU), and voiding sonography does not eliminate the need for a bladder catheter. This practice remains unused in some countries (e.g., in France) mainly for financial reasons. Voiding sonography could become part of the diagnostic algorithm of reflux and would thus decrease the need for VCU. Voiding sonography appears inadequate for imaging the urethra (first reflux study in boys), but follow-up examinations and family screening appear to be excellent indications. However, widespread use of this technique will remain difficult as long as contrast media continue to be so expensive.

1.1.3
Voiding Cystourethrography (VCU)

Contrary to IVU, which was supplanted by sonography, MRI and nuclear medicine, VCU remains the gold-standard examination for imaging the bladder and the urethra and detecting vesicoureteral reflux.

1.1.3.1
Indication and Scheduling

Detecting vesicoureteral reflux in children with a history of urinary tract infection (Lebowitz 1992) or prenatal diagnosis of abnormal dilatation (Avni et al. 1998; Zerin et al. 1993) is the primary role for VCU. Alternative techniques are radionuclide cystography (Willi and Treves 1983) and voiding urosonography (see above). Radionuclide cystography delivers less ionizing radiation than VCU, allows permanent recording, and, for this reason, is probably more sensitive to transient reflux. However, the anatomic detail provided by radionuclide cystography and voiding urosonography is poor, and therefore none can be recommended as a first-step examination. First evaluation of children with urinary tract infection is usually made by US and VCU. Then, if reflux is shown, antibiotic prophylaxis is prescribed, surgery is considered, and follow-up is based on either voiding urosonography or radionuclide cystography. Follow-up VCU should be limited to medical centers where none of these techniques is available.

Up to now, there was no consensus on the age/gender conditions that should lead to VCU after a first episode of urinary tract infection. A European group has suggested performing VCU in children aged less than 4 years who had a proven urinary tract infection (Riccabona et al. 2006). In older children, the prevalence of reflux being less important, the decision to perform VCU or not could be taken on an individual basis.

There has been a lot of debate on the optimal timing of VCU relative to the infectious episode. Should examination be performed during acute infection or 1–2 weeks later? There is no scientific consideration to sustain one hypothesis or the other. In our opinion, VCU is an important examination in children with a history of infection simply because reflux has been shown to be
associated with infection, and it can devastate the kidney. Experience shows that the longer the delay is between infection and examination, the higher the rate of people who do not show up. On the other hand, it does not seem reasonable to conduct VCU in children with either fever or persistent dysuria.

In summary, we would recommend performing the examination as soon as clinical symptoms have disappeared.

With modern antibiotic therapy, urine is usually sterile by the time of VCU, and catheterization can present a good opportunity to analyze a specimen. However, it should be kept in mind that bacteriuria can be physiological, especially in girls. Hence, there is no reason to postpone VCU when the dipstick test is positive for nitrites.

If reflux is suspected and VCU has been decided upon, the patient should be maintained on antibiotics until the examination is performed (antibiotic therapy if VCU is performed quickly, antibiotic prophylaxis if VCU is performed later on).

Other indications are rarer. Imaging of urethral malformation or trauma remains based on the voiding part of VCU. Patients with cloacal anomalies, ambiguous genitalia, or imperforate anus can be explored. On the other hand, the role of VCU in investigating pelvic or bladder tumors has decreased since the advent of cystoscopy and MRI.

1.1.3.2 Technique

Both digital fluoroscopy and fluorography provide excellent diagnostic quality and require a lower radiation dose. They have advantageously replaced the film-screen combination, which should no longer be used to perform VCU in children.

1.1.3.2.1 Information

Before proceeding, it is important to take time to give information to the parents and to the child if he or she is old enough. The family can be given an information sheet before the study. Drawing a diagram of VCU is an excellent means to provide effective information. Psychological consequences of urethral catheterization should not be underestimated.

1.1.3.2.2 Plain Film

An AP radiograph of the entire abdomen is taken unless one has been obtained recently for any reason and there was no breakthrough event. An additional film in upright position is unnecessary. Abnormal calcification, nephrocalcinosis, spinal deformation, bony abnormality, spinal surgery, pubic symphysis abnormality, and the position of prosthesis (VP shunt, JJ tube, bladder catheter, nephrostomy tube or other) all can easily be shown prior to administration of contrast medium. Attention should be paid to extra urinary anatomy (think of congenital hip dislocation).

1.1.3.2.3 Pain and Sedation

In many cases, no sedation is required except that provided by sterile Xylocaine (lidocaine) jelly that lubricates the catheter in boys. A quick examination performed by an experienced radiologist should not be painful. Postprocedural minor discomfort can occur, and it seems less worrisome when announced. Improvement by hydration and local care is the rule. In some children, major anxiety can be present. Inhalation of an equimolecular mixture of nitrous oxide and oxygen (Entonox) in fasting children can be helpful (Schmit and Sfez 1997). In uncooperative children who are too young to breathe gas, rectal midazolam can occasionally be used (Hypnovel; 0.3 mg/kg, maximal dose 5 mg). For safety, sedation procedures should preferably be organized in collaboration with the department of anesthesiology.

1.1.3.2.4 Retrograde or Suprapubic?

Retrograde access seems to be the most frequently used procedure and has a very low rate of complications; its main risk is post-procedural infection. The suprapubic approach is mainly used in neonates with posterior urethral valves and in children in whom catheter placement can be difficult or painful (urethral trauma, hypospadias, cloacal malformation). Suprapubic access requires preliminary bladder US. It can fail when the child voids during puncture. Leakage around the catheter in the prevesical space is common and benign. The risk of post-procedural infection decreases when using the supra-pubic approach.
1.1.3.2.5
Catheter Risks

Urinary tract infection is rare, but it represents the main risk of VCU. Parents should be informed of this possibility. The risk of developing infection seems higher in children presenting with a urinary tract malformation predisposing to urine stagnation (high-grade reflux, intrarenal reflux, megacystis-megaureter association, posterior urethral valve, ureteropelvic junction syndrome associated with ipsilateral reflux) (Dacher et al. 1992). In patients with such abnormalities, post-procedural infection can be life-threatening. While performing VCU, sterility is extremely important in all patients, since one cannot know at the time of catheterization that such a malformation is present (Fig. 1.1.4). Urethral trauma has been described, but we have never observed a case since we have been using feeding tubes in boys.

Fig. 1.1.4. Accidental introduction of the tube in the ectopic orifice of the upper pole ureter of a duplicated kidney. No consequence was observed. Catheter was withdrawn, then introduced again in the bladder. This type of accident illustrates the importance of sterility in any maneuver while performing VCU.

1.1.3.2.6
Catheter Placement and Filling

When possible, the child should void his/her bladder prior to examination. One of the child’s parents can make a first cleaning of the perineum. Clinical examination by the radiologist before introducing the catheter is a unique occasion to have a thorough look at the child’s perineum/genitalia with a powerful lighting. Proceeding in this way can allow difficult diagnoses such as fused labia, phimiosis, male or female hypospadias, or permanent dribbling. In the case of fused labia, gentle manual opening can be performed. Another treatment consists in applying an estrogenic cream for several days preceding the examination. A second sterile cleaning is performed and then the catheter is placed. In all cases, the urethral meatus should be visualized before placing the catheter. In girls, the meatus is close to the vagina. In young boys, the foreskin should not be forced. Resistance is usually perceived when the tip of the catheter reaches the external sphincter. Continuous pressure overcomes this resistance, and efflux of urine confirms the proper position of the catheter inside the bladder. Vaginal insertion of the catheter is common. In such cases, the misplaced catheter can be left in place in order to facilitate positioning of the second one. The catheter is safely taped on the medial aspect of the thigh, and the child is centered under the X-ray tube. The bladder is filled with a bottled dilute contrast medium (120 mgI/ml concentration is recommended) under 30 cm H2O pressure. Bladder capacity is evaluated. It can be compared to the theoretical volume (Koff 1983):

\[
\text{Bladder capacity (ml)} = \left[ \text{age (years)} + 2 \right] \times 30
\]

Flow should be continuous until bladder repletion is attained. Interruption or backflow can be due to contractions of the detrusor muscle when an unstable bladder is present (see Chap. 14). Spot films are taken during filling in order to detect passive reflux.

1.1.3.2.7
Radiation Dose

The ALARA principle (As Low a radiation dose As Reasonably Achievable) should be applied. If a reflux study is required, the non-radiating voiding urosonography should be preferred, except if anatomic depiction is necessary. In such case, low-dose fluoro-
scopic VCU (Avni et al. 1994; Kleinman et al. 1994) should be encouraged. Diagnostic yield was shown to be sufficient in diagnosing reflux while delivering a dose that competes with that of radionuclide cystography.

1.1.3.2.8 Cyclic VCU

Cyclic VCU has been shown to be more efficient in detecting reflux (Jéquier and Jéquier 1989; Paltiel et al. 1992; Gelfand et al. 1999). In our institution, we have chosen to perform three cycles of filling in non-toilet-trained children and only one in older children. In the cyclic technique, the child voids twice around the catheter. Then, when the third micturition starts, the catheter is removed, and voiding pictures are taken (Fig. 1.1.5).

1.1.3.2.9 Micturition

A good micturition study requires sequential film-

Fig. 1.1.5a–c. Cyclic VCU in a male neonate who had urinary tract infection. a First voiding, no abnormality. b On second filling, right reflux was identified. c On third filling, bilateral high-grade reflux was demonstrated
der contraction and external sphincter opening) or urethral abnormality. Centered AP views in girls and oblique views in boys are adequate to analyze the urethra (Fig. 1.1.6). If reflux is detected during micturition (active reflux), oblique bladder views are useful to completely visualize the refluxing ureter including its retrovesical portion. The relationship of the refluxing ureter and a bladder diverticulum is analyzed on this film. AP views of kidneys should be taken to grade reflux (Lebowitz 1985), to look for intrarenal reflux (Fig. 1.1.7), and to analyze the anatomy of the excretory system (reflux into the lower or upper pole of a duplex system, association of reflux, and ureteropelvic junction obstruction in the same renal unit) (Fig. 1.1.8). A post-voiding film is taken to assess residual urine; it can also be useful to detect a bladder diverticulum (Fig. 1.1.6). In case of reflux, a 5-min delayed film is valuable to evaluate its clearance. Reflux associated with prolonged stasis is thought to increase the risk of severe infection.

![Fig. 1.1.6. VCU in a 7-year-old boy who complained of dysuria. Oblique view during micturition. Slightly irregular bladder cannot be interpreted as abnormal during micturition. Bladder diverticulum (the same was shown on the opposite side). Moderate dilatation of the posterior urethra. Valves were suspected. Cystoscopy confirmed the diagnosis, and coagulation was performed. However, the orifices of the diverticula were not seen by the surgeon](image)

![Fig. 1.1.7. VCU in a girl with a history of urinary tract infection. Bilateral reflux. Note intrarenal reflux on both upper and lower poles of the left kidney](image)

![Fig. 1.1.8. VCU in a girl with prenatal diagnosis of a duplex system on the right side. A huge right ureterocele was shown by ultrasound. Reflux into the lower pole is inferred from the visualization of the incomplete kidney. Ectopic ureterocele was everted during the procedure](image)
1.1.4 Retrograde Urethrography

Retrograde urethrography is rarely indicated, and retrograde or suprapubic VCU should be preferred in most patients. Such an examination is usually performed to rule out a ruptured urethra in an adolescent. A Foley catheter is inserted in the distal urethra. The balloon is then inflated in the fossa navicularis, and the urethra is slowly and retrogradely injected. Lateral and oblique pictures are taken. In most instances, the posterior urethra is not opacified. This should not be considered abnormal.

1.1.5 Intravenous Urography

During the 1990s, the development of US, nuclear medicine, and MRI had substantially diminished the impact of intravenous urography (IVU) in pediatric uroradiology. Multi-detector computed tomography (MDCT) and MR have now replaced IVU in its remaining indications such as tuberculosis, papillary necrosis, or permanent urinary dribbling in girls. If IVU belongs now to history, its physiology-based principles should not be forgotten. In postoperative children, AP view of the abdomen 10 min after IV injection of iodinated contrast medium remains a possible technique to approach the renal function.

1.1.6 Multi-Detector Computed Tomography (MDCT)

1.1.6.1 Indications

Because MDCT can deliver a substantial amount of ionizing radiation (CORDOLIANI et al. 1999), it should rarely be performed as a first line investigation of the urinary tract in a child. Children with multiple injuries are an exception to this rule. Other indications for CT are tumor, urolithiasis, severe or unusual urinary tract infection, and evaluation of parenchymal disease (SIEGEL 1999). Any condition requiring an excellent anatomic depiction should consider MDCT due to its spatial resolution, volume acquisition, and multiple plane reformatting (MPR) capabilities.

1.1.6.2 Technique

1.1.6.2.1 IV Access, Contrast Medium, and Allergy

A safe IV line is always necessary, and our preference goes to an antecubital catheter. The largest possible size is chosen. Placement of the catheter is ideally performed by a nurse in the outpatient suite after skin preparation with anesthetic cream (lidocaine–prilocaine, Emla®). This catheter makes it possible to use a power injector. Power injection provides an excellent examination quality, and continuous flow decreases the risk of extra vascular passage. The injection should be visually monitored and stopped in case of extra-vascular passage. In younger children, hand injection under visual control seems safer.

Central lines should not be routinely used. However, in some patients with malignancy, peripheral veins are severely damaged, and a central catheter is the only possible venous access. In such cases, catheter handling and rinse should be performed by a trained nurse. Epicranial needles can be occasionally used in young children (placed on the radial aspect of the wrist, the ankle, or scalp veins). The external jugular vein should be considered the last possible alternative, since its puncture is uncomfortable, it usually causes inelegant ecchymosis, and the procedure is quite impressive for the parents or accompanying persons.

Nonionic iodinated contrast media (2 ml/kg) are preferred because they have been shown to decrease the incidence of minor events (KATAYAMA et al. 1990). Diluted barium sulfate can be administered per os (the preferred drink of the child is recommended for dilution) or by enema to beacon the digestive tract. A child with a proven history of a severe accident with iodinated contrast medium should be referred to an allergist and an anesthesiologist who will make medical decisions about any further injection. In case a new injection is mandatory, a different contrast medium
has to be injected. Patients with common allergies or asthma can be given an antihistamine medication (hydroxyzine, Atarax®) for 24 h before examination. Latex allergy is a frequent occurrence in children with a history of multiple surgical procedures. Latex-free materials and gloves should be used in such patients.

Adverse reactions are extremely rare in pediatric practice. However, preventive measures should be taken, and any reactions that do occur should be managed in collaboration with anesthesiologists. Adverse events justify the presence of at least two persons during any examination with contrast medium injection (one to take care of the patient and one to call the anesthesiologist).

Vasovagal reaction (bradycardia, pallor, and loss of consciousness) is related to pain rather than contrast medium. The lower limbs are elevated; atropine is sometimes useful. Mild allergic accident (itching, urticaria) can be treated by corticoids and an antihistaminic medication.

Severe allergic accidents can occur (tachycardia, severe hypotension) and radiologists and technicians should be aware of first-aid principles (good venous access, perfusion of saline solution, oxygen, preparation of a syringe of diluted adrenaline). The emergency phone number should be visible from anywhere in the CT suite and dialed as soon as possible. Adrenaline can induce severe side effects. For this reason, it would be safer to have only anesthesiologists administer it.

1.1.6.2.2 Sedation

Natural sleep is the safest. Sleep deprivation during the hours preceding CT (or MR) is often successful. However, except in rare instances in children under 6 months old, natural sleep is rarely obtained in a busy noisy CT room. Immobilization is strongly recommended even in sedated children (the venous access needs to be maintained visible). Immobilization avoids undesirable movement by the patient and keeps him or her warm. Sedation is rarely useful to examine the urinary tract by MDCT. Any sedation protocol should be discussed and written with anesthesiologists. In our institution, we occasionally use rectal midazolam (Hynovel®, 0.3 mg/kg body weight), but heart rate and pulse oxymetry have to be monitored during the procedure and later. Hydroxyzine (Atarax®) decreases anxiety and is fairly sedative.

A fasting period is only required for sedated children (not for contrast medium injection). It should be limited to 3 h in young children and to 4 h in older ones. Dehydration should always be prevented.

1.1.6.2.3 Imaging Protocol

Attention to radiation should be a priority in pediatric CT (VADE et al. 1996; SCHECK et al. 1998). The ALARA principle is applied, and pediatric protocols of quality-controlled CT equipment should be applied. Substitution by a non-radiating procedure (MRI, US) when feasible should be encouraged. The exposition length should be limited to the organs of interest. The kVs should be limited to the 80–100 range in most children. Attention should be paid to the mAs level, which often can be reduced with no image degradation. The detector configuration should be adapted to the explored pathology. The CT dose index and dose length product should be mentioned in the report.

Pre- and post-contrast series are combined. Time delay should be adapted to pathology; arterial time should be acquired in the context of trauma or tumor. Very delayed acquisition can sometimes be necessary to look for stagnant iodine within the parenchyma in acute pyelonephritis (ISHIKAWA et al. 1985; DALLA PALMA et al. 1995) or a peri-renal leak in cases of renal fracture. Two-dimensional reformatting is especially useful in evaluating renal fractures or retroperitoneal tumors (Fig. 1.1.9). Maximal intensity projection images in the coronal and sagittal planes advantageously replace IVU at any time of the examination.

Fig. 1.1.9. MDCT Evaluation of an adrenal tumor. Multipla-
nar reformatting of arterial phase acquisition
1.1.7 Antegrade Pyelography

Antegrade pyelography has lost much of its interest since the advent of MR urography (BORTHNE et al. 1999) and MAG3-Lasix scintigraphy, which respectively investigate urinary tract anatomy and renal function and excretion. Antegrade pyelography (Fig. 1.1.10) can be performed in patients with poorly functioning and dilated kidneys. In such cases, association with urodynamic study (the Whitaker test) can help in decision making (surgical repair versus nephrectomy) (DACHER et al. 1999) (Figs. 1.1.11, 1.1.12). In the Whitaker test, pelvic, bladder and differential (pelvic minus bladder pressures) pressures are recorded under general anesthesia. A Foley catheter is placed in the bladder. The patient is then placed in the prone position. One or two needles are placed within the renal pelvis under sonographic guidance. Obstruction is considered when differential pressure rises above 22 cm H$_2$O (normal pressure should remain below 15 cm H$_2$O).

Fig. 1.1.10. Antegrade pyelography combined with the Whitaker test on general anesthesia in a 6-month-old baby. No reflux. Slight dilatation on ultrasound and IVU. Diuresis renography had not been conclusive, and the Whitaker test showed obstruction at the ureteropelvic junction. Surgery was subsequently performed.

1.1.8 Renal Biopsy

In our institution, US-guided renal biopsies are performed under general anesthesia in the operating room. The child is in the prone position. Conventional US is performed first targeting the lower pole of the right kidney. Two or three fragments are taken in the most peripheral location. Post-procedural US is performed. A second US examination is performed 24 h later, before the child is allowed to leave the hospital. The risk of post-procedural arteriovenous fistula justifies a color-/power-Doppler examination of the biopsy site.

1.1.9 Renal Angiography

Nowadays, Doppler US and gadolinium-enhanced MR angiography tend to replace renal angiography in most diagnostic procedures. Angiography is a complex procedure in children. Risks are that of general anesthesia and arterial puncture. Renal angiography is usually justified by a therapeutic procedure (angioplasty in renovascular hypertension, occlusion of posttraumatic fistula, embolization of arteriovenous malformation).

1.1.10 Reports

The end product of any examination is the radiological report. A successful examination includes a clear and well-built report. BLAIS and SANSON (1995) published an excellent guide for reports that refers to the model of a scientific article. Introduction puts examination in the clinical context. The referring physician can check that the question was properly understood. The “Patients and Methods” section describes the technique. The procedural features, amount and nature of contrast medium, venous access, and incidents are indicated. Such information is valuable in case of follow-up. Then, in the “Results” section, pertinent radiological
findings are provided. Finally, the conclusion synthesizes the findings. Diagnostic hypotheses are classified in this section in decreasing order of probability. The report can be written differently depending on who the referring physician was (different information can interest the family doctor and the surgeon).

**Conclusion**

As well as performing a good imaging examination, it is important to minimize irradiation, pain, and risk; the chosen technique must also be well adapted to the patient (age, condition, disease) and the question posed by the referring physician.
References


1.2 MR Urography in Children

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1.2.1 Introduction

MR urography provides a comprehensive evaluation of the urinary tract in a single examination that does not use ionizing radiation and represents the next step in the evolution of uroradiology in children. Over the last 7 years there have been rapid development and refinement of imaging protocols for evaluating the urinary tract in children using MR urography (Grattan-Smith et al. 2003; Jones et al. 2004; Perez-Brayfield et al. 2003; Jones et al. 2005; McDaniel et al. 2005). This work builds on the efforts of several authors who recognized the potential utility of MR imaging in the evaluation of renal tract disease (Avni et al. 2002; Borthne et al. 1999; Borthne et al. 2000; Nolte-Ernsting et al. 2001; Riccabona 2004; Riccabona et al. 2004; Riccabona et al. 2004; Rohrschneider et al. 2000; Rohrschneider et al. 2003; Rohrschneider et al. 2002; Rohrschneider et al. 2000). MR urography combines intrinsically high spatial and contrast resolution with rapid temporal resolution. In addition to high-resolution anatomic images of the entire urinary tract, functional information about the concentration and excretion of the individual kidneys can be obtained. By scanning dynamically after injection of contrast agents, the signal changes related to perfusion, concentration and excretion of the contrast agent can be evaluated sequentially both in the renal cortex and medulla. Urinary tract anatomy is assessed using a combination of both T2-weighted and contrast-enhanced images. The functional information obtained routinely includes renal transit time calculation, graphs of signal intensity versus time curves, differential renal function calculation and estimation of individual kidney GFR using a Patlak plot.

The improved anatomic and functional information obtained with MR urography will provide new insights into the underlying pathophysiology of urinary tract disorders. As a result, it is likely that MR urography will replace renal scintigraphy in the evaluation of renal tract disorders in children in the near future.

1.2.2 Technique

The imaging protocols used for clinical studies consist of conventional T1, FSE T2-weighted sequences...
prior to contrast administration and dynamic 3D gradient echo sequences after contrast administration (Grattan-Smith et al. 2003; Jones et al. 2004; Perez-Brayfield et al. 2003; Jones et al. 2005) (Figs. 1.2.1–1.2.3). There is a fundamentally complex relationship between signal intensity and gadolinium concentration, with T1 effects predominating at lower concentrations and T2* effects at higher concentrations, which may lead to signal loss. Phantom studies have shown that the relationship between signal intensity and gadolinium concentration is relatively linear at low concentrations (Jones et al. 2005). To stay within this linear portion of the curve, we keep the gadolinium concentration low by hydrating the patient, by giving furosemide 15 min before the contrast is administered and by infusing the contrast agent slowly for the dynamic series.

For our protocols, all children are hydrated prior to the study with an intravenous infusion of lactated Ringer’s solution; for sedated children the volume infused is calculated to replace the NPO (nothing per mouth) deficit; otherwise, the volume is calculated using a guideline of 10 ml/kg. Typically, all children less than 7 years of age require sedation for the examination, and the department’s standard sedation procedures are followed. A bladder catheter is placed to eliminate the possibility of reflux and to ensure free drainage of the bladder. Once the patient is positioned in the scanner, scout images are acquired to determine both the positioning of the kidneys and bladder and the combination of spine coil elements required to optimize the signal-to-noise ratio (SNR) for these anatomical structures. After the scout images were completed, axial T2-weighted (TR=5,600, TE=160, ETL=23) TSE images through the kidneys are obtained.

Furosemide (1 mg/kg, max. 20 mg) is then administered intravenously. We administer furosemide 15 min before we inject contrast for three reasons: (1) the urinary tract is distended, (2) the gadolinium concentration is diluted, which reduces the susceptibility artifacts and helps maintain the contrast-induced signal changes to within the range where they are linearly related to contrast agent concentration (Jones et al. 2005) and (3) the examination time is shortened. Coronal, 2D, flow-compensated T1-weighted (TR=475, TE=17) and T2-weighted (TR=5,500, TE=210, ETL=29) series and a respiratory gated, heavily T2-weighted 3D sequence (TE=600, ETL=109) are then acquired. The 2D series served to provide detailed anatomical reference scans, while the heavily T2-weighted 3D scan provided the basis for a pre-contrast maximum intensity projection (MIP) of the collecting system, ureters and bladder. In order to create the MIP other T2 structures with long T2 relaxation times, such as CSF and the gall bladder, are manually edited out from the images. The T2-weighted images are particularly useful to define the anatomy of non-functioning or poorly functioning systems. These systems are generally associated with marked hydronephrosis or cystic changes, and heavily T2-weighted images are able to delineate the anatomy even if little contrast excretion occurs (Fig. 1.2.3).

Once the above sequences are complete the acquisition of a 3D, coronal, dynamic, gradient echo sequence (TR=3.4 ms, TE=1.5 ms, flip angle=30°) oriented along the axis of the kidneys and including the bladder begins. The start of the dynamic series is approximately 15 min after the injection of furosemide, which coincides with the maximum effect of the furosemide (Brown et al. 1992). There is significant diuretic effect from about 5 min to 30 min after injection, so there is considerable latitude in the timing of the furosemide administration. A dose of 0.1 mmol/kg Gd-DTPA (Magnevist; Berlex Laboratories, WAYNE, NJ) is slowly infused using a power injector. Previously we had administered a compact bolus of contrast, but this results in an aortic signal well above the linear range of gadolinium concentration. We now instill the contrast typically at a rate of 0.25 ml/s so that the injection lasts more than 30 s. Each time point of the dynamic sequence consisted of 36 slices, with the outer 3 slices on each side being discarded in order to limit variations in the flip angle related to the slice profile, and also to limit wrap-around artifacts. Parallel imaging with an acceleration factor of 2 is used to reduce the acquisition time per volume to 9 s. The scans are acquired contiguously for the first 3 min; subsequently intervals of progressively increasing duration are inserted between the scans until the scans are at 1-min intervals. For each volume acquisition, a maximum intensity projection (MIP) of the whole volume is automatically generated. If both ureters are clearly visualized 10 min after the injection of contrast media, no further dynamic series are acquired. Otherwise, the acquisition of dynamic images is continued for a further 5 min at 1 min intervals. After the completion of the dynamic series sagittal, axial and coronal 3D images with high spatial resolution are acquired for the purpose of reformatting and volume rendering on a 3D workstation. These images provide exquisite anatomic evaluation of the
Fig. 1.2.1a–f. Normal MR urogram in 3-month-old boy with antenatal hydronephrosis. Images a–c show same slice from each of three separate volume acquisitions, whereas d–f show MIP projections derived from the same three separate time points. a and d show the cortical phase. b and e were acquired 60 s later and demonstrate enhancement of both the cortex and medulla with the signal intensity of the medulla exceeding that of the cortex. c and f were acquired 115 s after the vascular phase and show excretion into the calyces, renal pelvis and ureters. The renal transit time was 2 min and 20 s bilaterally and the volumetric DRF was 51:49.
Fig. 1.2.2a,b. Functional evaluation for 3-month-old boy shown in Figure 1.2.1. a Relative signal intensity versus time curve showing curves for the aorta and both kidneys. Note the symmetric parenchymal curves with equivalent perfusion, concentration and excretion of contrast agent. b The Patlak plot is used as an index of the individual kidney GFR. The slope of each plot reflects the GFR of each kidney (12.7 ml/min on left and 12.1 ml/min on right). The y intercept represents the fractional blood volume of each kidney. The body surface area corrected Patlak (BSA Patlak) is 102 ml/min. The Patlak DRF is calculated at 50:50

Fig. 1.2.3a,b. Volume-rendered T2-weighted images. a Volume-rendered T2 images of duplex system with poorly functioning and obstructed upper pole moiety. Despite minimal excretion of contrast agent, anatomic images of the duplex system can be obtained that show the ectopic insertion of the upper pole ureter. b Volume-rendered T2 images of poorly functioning hydronephrotic kidneys in a boy with posterior urethral valves. Even with poor renal function exquisite anatomical images are easily obtained
kidneys and ureters. In cases where poor drainage from the renal pelvis means that no contrast is seen in the ureters during the 15 min of dynamic scanning, the patient may be turned prone to promote mixing of the contrast agent in the collecting system prior to the acquisition of high spatial resolution coronal and sagittal images. The total imaging time for non-obstructed patients is typically 45 min, for poorly draining kidneys the imaging time is typically 1 h.

The MIP images from each volume acquisition are placed in a single cine sequence to provide a rapid overview of the transit of the contrast agent through the kidney. The delayed high-resolution anatomic images are particularly valuable in the evaluation of congenital malformations including ureteric strictures and ectopic ureteric insertion as well as complex postoperative anatomy (Fig. 1.2.3).

1.2.3 Post-Processing

Differential renal function (DRF) is among the most widely used measures of renal function. The DRF as measured by dynamic renal scintigraphy (DRS) is based on the integration of the tracer curve over a range of time points at which the tracer is assumed to be located predominately in the parenchyma. Due to the limited spatial resolution of DRS studies, fixed time points are used since the exact location of the tracer cannot be confirmed by visual inspection of the images. Since DRS measurements are based on projection images of the whole kidney, they measure the activity in the whole kidney. The majority of techniques developed for measuring the DRF with MRI have attempted to duplicate this approach by combining the area under the time-intensity curve obtained from either a single slice, or a few slices, with a separate volume measurement (HUANG et al. 2004; LEE et al. 2003; TAYLOR et al. 1997; TEH et al. 2003). We use a slightly different approach since the 3D volumes used in this study cover the full extent of both kidneys and the uptake of the contrast in each kidney can be followed volumetrically. We make the assumption that voxels represent either functional or non-functional tissue and that by summing the voxels that show a significant uptake of contrast one can calculate the functional volume of each kidney and hence the split renal function. The dynamic series are visually inspected to determine the volumes in which contrast is first seen in the collecting system of each kidney; the volume prior to this is then used for the calculation of the functional volume of each kidney (Fig. 1.2.4). In this way, possible differences between the two kidneys are taken into account, and it is not necessary to assume a particular time point, or range of times, for the calculation. In previous studies several authors have shown that the calculation differential renal function based on renal volume agrees well with the DRF calculated using nuclear medicine (GRATTAN-SMITH et al. 2003; PEREZ-BRAYFIELD et al. 2003; HEUER et al. 2003). The volume of functioning tissue has also been shown to be well correlated with creatinine clearance rates (VAN DEN DOOL et al. 2005). For the dose of contrast and the pulse sequence parameters used in our studies, the segmentation of the kidneys at this homogeneous enhancement phase is straightforward and can be performed using semi-automatic segmentation. While the renal volume

Fig. 1.2.4. Volumetric differential function. The time point for calculation of renal volumes is determined visually by defining the time when the kidneys have enhanced maximally and before contrast has been excreted into the collecting systems. At this time the kidneys are easily separated from the background with semi-automated techniques that produce volume calculations for each kidney depending on a user-defined threshold.