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Diagnostic imaging in pediatric hydronephrosis

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ABSTRACT
Modern imaging techniques are an extremely important part of the diagnostic and therapeutic process for both children and adults. In some cases, they are even the key tool in decision-making. However, the special characteristics of pediatric patients should be kept in mind. Examinations and procedures are routine and well-tolerated by adults, but often cannot take place without the presence of an anesthesiologist. Hydronephrosis is often diagnosed in prenatal ultrasound but is an significant socioeconomic problem. The selection of patients who absolutely require surgical intervention is an aspect to which special attention should be paid. In many centers, for children with hydronephrosis, ultrasound and scintigraphic tests play a dominant role in diagnosis and monitoring. So far, however, no unanimously accepted algorithms have been developed for performing imaging tests, one of the basic diagnostic tools in this group.
Keywords: hydronephrosis; urology; diagnostic imaging; pediatrics.

INTRODUCTION

Hydronephrosis is defined as an enlargement of the pelvicalyceal system and is a common problem in the pediatric population [1, 2, 3]. There are 2 main causes of this condition. The 1st group of causes includes pathologic entities associated with mechanical outflow obstruction. The 2nd group includes functional abnormalities that also lead to urinary retention in the collecting system. In both cases, lack of appropriate treatment can lead to a progressive loss of kidney function [4, 5, 6]. Obstructive uropathies are one of the most common groups of urinary tract diseases in children [7]. In boys under 1 year of age they are the main cause of renal failure requiring transplantation, and were diagnosed in 23% of all children who underwent kidney transplantation [8]. However, not every dilatation of the pelvicalyceal system requires radical surgical treatment. A wide spectrum of congenital anomalies are associated with obstruction, and their differentiation is a great clinical challenge. Some patients undoubtedly require early intervention to prevent impairment of renal function and to preserve its normal development. In others, conservative treatment, observation alone and a series of imaging studies may be sufficient [9, 10, 11, 12]. The majority of malformations are detected prenatally. The decision regarding surgical intervention in some centers is based on the progression of dilatation of the pelvicalyceal system, decrease of renal function or clinical symptoms of obstruction [13, 14]. The differences in management algorithms and follow-ups among the various centers are an additional source of confusion and ambiguity. In neonates and infants, hydronephrosis is often asymptomatic [15]; therefore, both the qualification for surgery and postoperative monitoring based on symptoms, e.g. pain, are associated with the risk of impairment or loss of some renal function before appropriate measures are taken.

METHODS OF IMAGING THE GENITOURINARY SYSTEM

Ultrasonography

Ultrasonography is the backbone of diagnostic imaging of the genitourinary system in children. The examinations are painless, non-invasive, widely available and generate relatively low costs. It is particularly noteworthy that this method does not use ionizing radiation, which means that the examinations can be repeated quite freely. Obtained images are characterized by good mapping of kidney and bladder anatomy. One disadvantage of this imaging method is the subjective evaluation of the obtained images, largely dependent on the skill and experience of the physician performing the examination. Unfortunately, not all types of urogenital anomalies can be diagnosed based on this modality alone. In the ultrasound examination, hydronephrosis appears as branching anechoic areas in the renal collecting system (Fig. 1). Additionally, the Doppler ultrasound measurement of resistive index is useful in differentiating obstructive from non-obstructive hydronephrosis [16].

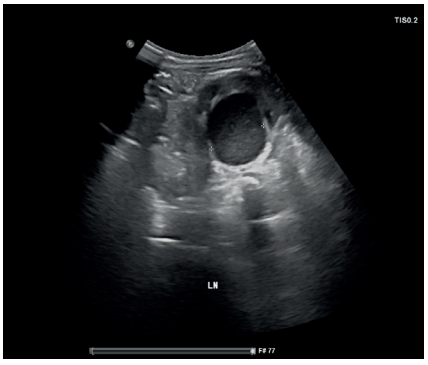

FIGURE 1. Ultrasonographic presentation of hydronephrosis (transverse view)

Voiding cystourethrography

Fluoroscopic examination of the genitourinary system is most commonly performed in order to exclude retrograde vesicoureteral reflux [17, 18]. However, they can also be used to evaluate micturition disorders or urethral abnormalities. In order to perform the examination, a catheter is inserted into the urinary bladder through which a contrast agent is administered. Before administration, the pelvis and the position of the kidneys are visualized. During administration of the contrast agent, the urinary bladder is evaluated. The predicted bladder capacity in children under the age of 1 can be calculated by multiplying the weight in kilograms by 7. In children over 1 year of age, we add 2 to the age in years and multiply the sum by 30 [19, 20]. After optimal filling, we should make oblique projections in order to detect possible abnormalities of the uretero-bladder connections. At a later stage, we observe the urethra during micturition and again the entire region of the pelvis and kidneys to exclude reflux and other anomalies. The major disadvantage of this method is exposure of the children to radiation. Voiding urosonography is an alternative option in the diagnostic imaging of vesicoureteral reflux and has turned out to be a topic of intense discussion in pediatric radiology [21].

Nuclear medicine

Nuclear medicine diagnostic methods are a widely used and accepted tool for urinary tract evaluation in children [22, 23, 24, 25]. In addition to raw data on anatomy with the help of radiopharmaceuticals, valuable quantitative and qualitative assessment of the urinary tract can be performed. Dynamic scintigraphy is widely used to monitor the evolution of hydronephrosis and to evaluate surgical success. It allows determination of the differential renal function of the altered kidney compared to the normal kidney, and qualitatively assesses outflow by analyzing the radioactivity change curve (Fig. 2). The most commonly used radiopharmaceuticals for this purpose are technetium-labeled mercaptoacetyltriglycerol, ethylenedicysteine, and diethylenetriamine-pentaacetic acid. Additionally, obstructive and non-obstructive hydronephrosis can be determined with furosemide [22]. Static scintigraphy, on the other hand, evaluates the distribution of tracer accumulation within the renal parenchyma to exclude scarring, inflammatory changes and to determine the amount of active parenchyma.

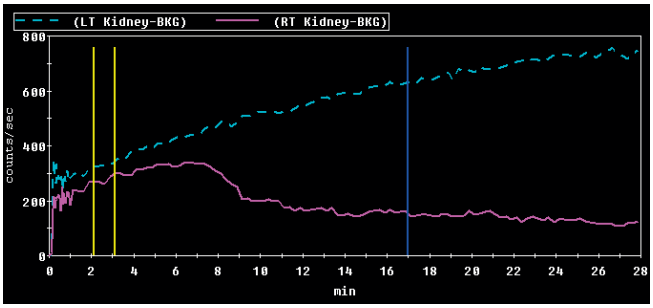

FIGURE 2. Obstructive type of renoscintigraphic curve – increasing activity in the left kidney throughout 28-min acquisition. No reaction to the diuretic administered in the 17th minute

Computed tomography

Modern computed tomography is a powerful diagnostic tool. The examination can be performed in patients of any age, and the size of the patient, bones or gas in the gastrointestinal tract are not an obstacle as in ultrasound examinations. The strength of computed tomography lies in the faithful reproduction of anatomical detail and the high-resolution multiplanar reconstructions that can evaluate all floors of the genitourinary system. Despite these numerous advantages, computed tomography is not as widely and routinely used in the imaging of genitourinary disorders in children, mainly because of the relatively high dose of ionizing radiation and the need for intravenous administration of a contrast agent in most cases [26, 27]. General anaesthesia or sedation is necessary for proper examination in the youngest of children. This method is usually reserved for post-traumatic patients, or those in whom ultrasound examination does not provide clear answers and magnetic resonance imaging is for various reasons unavailable.

Magnetic resonance tomography

Magnetic resonance imaging allows a detailed assessment of the anatomy of the genitourinary system and the wide spectrum of abnormalities associated with it, thanks to the high contrast and spatial resolution of the tissues [28, 29, 30, 31, 32]. Moreover, the developments in technology and protocols has allowed the creation of an examination called magnetic resonance urography, in which, as in dynamic scintigraphy, we obtain in addition to purely anatomical information, the possibility of quantitative assessment of renal function. This is possible due to the dynamic recording of signal intensity changes after intravenous administration of a contrast medium. These changes are related to the perfusion, accumulation and excretion of contrasted urine by the kidneys. In addition to the images and morphological evaluation, time-dependent signal intensity plots of the 3 aforementioned factors are generated, as well as information about the resolving function of the kidneys. Based on the data obtained, the glomerular filtration rate can also be calculated individually for each kidney. It should be emphasized that all this information is obtained without exposing the patient to ionizing radiation, since this imaging technique is based on the phenomenon of nuclear magnetic resonance. The imaging protocols used for clinical studies consist of conventional T1, fast spin-echo T2-weighted sequences prior to contrast administration and dynamic 3D gradient echo sequences after contrast administration.

CONGENITAL ANOMALIES OF THE URINARY SYSTEM CAUSING HYDRONEPHROSIS

Stenosis of the ureteropelvic junction

Stenosis of the ureteropelvic junction is the most common cause of prenatally detected hydronephrosis. The estimated incidence in pediatric populations is ~1 per 1,000 newborns, with a male predominance (M:F = 2:1) [33, 34, 35]. The etiology of the condition is attributed to abnormal smooth muscle

arrangement, abnormal innervation of the proximal ureter or crossing by the lower polar vessel of the kidney [36]. This causes a mechanical obstruction, impaired initiation of peristalsis or its propagation in the ureter resulting in impaired passage of urine and its accumulation in the proximal part of the collecting system, with subsequent dilatation visible in imaging tests (Fig. 3). Before the widespread use of prenatal imaging, some patients with ureteropelvic junction obstruction were only diagnosed properly after the development of clinical symptoms, such as recurrent urinary tract infections, stone formation or palpable flank mass. Currently, most cases are detected by routine ultrasound [37]. In the majority of congenital cases no surgical intervention is required, but in more severe forms pyeloplasty or stenting may be necessary.

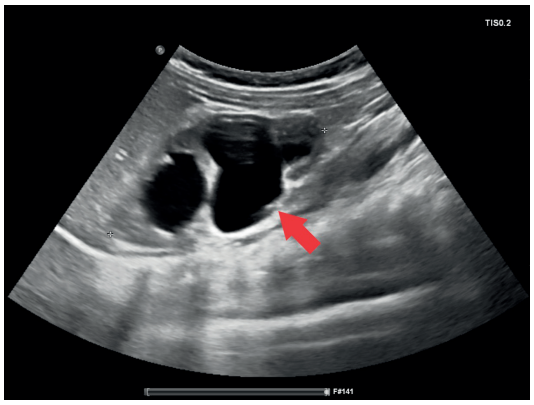

FIGURE 3. Dilatation of the urinary collecting system of the kidney and a transition point in the region of the ureteropelvic junction stenosis (arrow)

Ureteral obstruction

The ureteral obstruction causing hydronephrosis most often takes the form of an abnormal uretero-bladder junction. The cause of the disease is a malfunction and lack of peristalsis in the short distal segment of the ureter, which results in impaired normal urine flow. Most often it leads to widening of the ureter itself, and when the compensation possibilities are exceeded, the pressure gradient is transmitted back to the renal collecting system, causing hydronephrosis. The histopathological findings showed various abnormalities of the terminal ureter, including, inter alia, circular smooth muscle hypertrophy, muscular dysplasia and disturbances in the internal architecture of the muscularis [38, 39, 40]. Patient profile, diagnostic and therapeutic approach changed similarly to the obstruction in the pelvic-ureteral junction. Before the introduction of prenatal testing, patients were diagnosed on the basis of clinical symptoms, such as recurrent abdominal pain, frequent urinary tract infections or hematuria [41].

Ureterocele

Ureterocele is a cystic dilatation of the terminal or intravesical segment of the ureter (Fig. 4). It occurs in ~ 1 in 5,000 children, and is more common in cases of a duplicated collecting system of the kidney [42]. When the lesion affects the normal ureter leading to the bladder, ureterocele is described as simple, and in the case of an outlet located outside the bladder triangle as ectopic. There is also a division based on the location of the dilated segment into intravesical and extravesical ureterocele [43]. Regardless of the type, each ureterocele may be an obstacle in the outflow of urine with subsequent dilatation of the proximal segment of the ureter and the renal pelvicalyceal system. Management of ureterocoeles depends on the degree of associated reflux or obstruction. Most symptomatic cases need surgery.

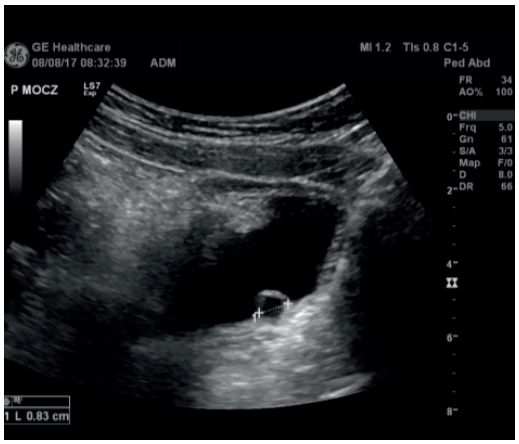

FIGURE 4. Rounded, anechoic structure within the bladder. The appearance is characteristic of a ureterocele (caliper)

Posterior urethral valves

Posterior urethral valve is referred to when there is hypertrophy or adhesion of the physiological folds of mucosa in the prostatic urethra between the walls and the seminal tubercle (Fig. 5). This defect was diagnosed for the first time by Young et al. in 1919 using endoscopic methods [44]. The 1st endoscopic treatment was performed a year later by Randall [45]. This anomaly affects only boys (~1:5000 liveborn) and makes it difficult to drain urine from the bladder, which, depending on the degree of obstruction, leads to bilateral expansion of the proximal levels of the urinary tract. Posterior urethral valves can have a wide spectrum of clinical manifestations. The most severe cases are detected during prenatal testing and appropriate treatment is started after birth [46]. In infancy, clinical presentation includes urinary tract infection, sepsis, urinary retention, poor urinary stream, failure to thrive.

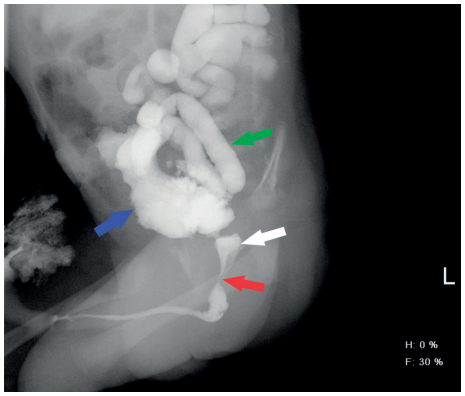

FIGURE 5. Lateral voiding cystourethrography in a newborn shows posterior urethral valve (red arrow), dilated posterior urethra (white arrow), massive unilateral vesicoureteral reflux (green arrow) and thickening of the bladder wall (blue arrow)

Vesicoureteral reflux

Hydronephrosis is not always a result of physical, structural obstruction in the form of stenosis located at different levels of urinary outflow tract. Retrograde vesicoureteral reflux is an example of a functional disorder, which may manifest as dilatation of the pelvicalyceal system (Fig. 6). It is usually discovered during work-up of febrile urinary tract infection. Of children who have urinary tract infection, between 25–40% are found to have vesicoureteral reflux [47]. Under normal conditions, the ureters have several specific features that allow the urine to drain properly in the physiological direction. The 1st safeguard is the anatomical structure of the vesicoureteral junction forming a unique valve mechanism [48, 49]. The next is the neuromuscular activity responsible for the formation of peristaltic waves consistent with the expected direction of urine outflow. The causes of malfunctions of these protective mechanisms are seen in the abnormal architecture of the connection between the ureters and the bladder, muscular abnormalities and neural activity [50]. Increased pressure in the bladder itself e.g. due to posterior urethral valve, can also lead to abnormal outflow [51, 52]. Low-grade reflux may be treated with prophylactic antibiotics. Higher grades should undergo surgical reimplantation to prevent reflux nephropathy.

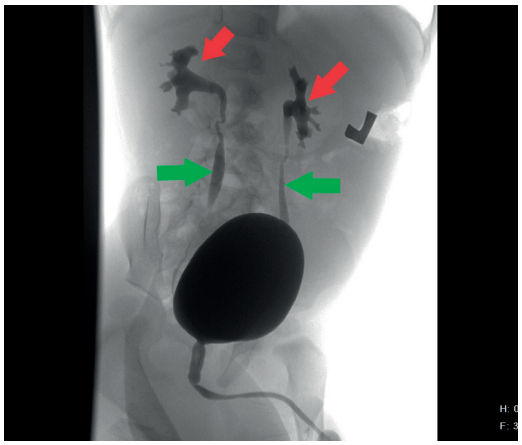

FIGURE 6. Voiding cystourethrogram in an infant shows bilateral reflux into ureter (green arrows) reaching renal collecting system (red arrows)

Other congenital and secondary causes

Hydronephrosis may also be one of the elements of the clinical picture of several fairly rare complexes of congenital malformations. In prune belly syndrome, apart from the irregularities of the urinary tract which most often take the form of strictures in the urethra followed by a significant enlargement of the bladder and subsequent higher levels of the urinary tract, there is a lack of muscles of the anterior abdominal wall, which results in a characteristic skin appearance [53, 54]. Berdon's syndrome also includes anomalies of the urinary system accompanied by abnormalities of the gastrointestinal tract in the form of colon hypoplasia and peristalsis disorders [55]. Secondary causes of impaired urinary outflow can be located both inside the urinary tract (e.g. deposits or, less frequently, neoplastic lesions) and outside them, exerting pressure, modeling or even closing the flow channel, an example of which may be a tumor located in the retroperitoneal space.

DISCUSSION

Not every dilatation of the pelvicalyceal system is associated with a loss or impairment of renal function. The concept of obstruction was created in order to divide patients into those who would require surgical intervention and those for whom kidney damage would not likely result. The widely used definition by Koff and Campbell, i.e. "a condition leading to a restriction of urine flow resulting in a loss of renal function" [11, 56] is now more often replaced by a slightly newer proposal by Peters, where obstruction is defined as "a condition of impaired urine outflow that, uncorrected, will limit the functional potential of the developing kidney" [12]. Thus, one can have both obstructive and non-obstructive hydronephrosis. How to distinguish between these 2 conditions? This has been a subject of debate and controversy in pediatric urology for many years, and different centers use their own algorithms because there is no single universally accepted and standardized diagnostic tool that allows unambiguous determination of obstruction. Some urologists rely on a series of scintigraphic tests, while others use a combination of clinical signs and imaging findings. Yagci et al. demonstrated that kidneys with severe ureteropelvic junction obstruction tended to have more elevated RI and PI values in a Doppler ultrasound examination than a non-obstructed or equivocally obstructed junction [57]. Great hopes have been placed on biomarkers related to the pathophysiology of obstruction, based on the observation that normally developing kidneys are characterized by a specific set of proteins analyzable from urine samples. This characteristic set would be altered when obstruction occurs [58]. Several potential biomarkers have been demonstrated in experimental studies, but further multicenter clinical trials are needed to establish a standardized panel of tests with adequate predictive value. Thus, imaging tests remain the primary diagnostic tool to aid in the diagnosis of obstruction.

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