

INSTITUTO POLITECNICO DE LISBOA

ESCOLA SUPERIOR DE TECNOLOGIA DA SAUDE DE LISBOA

The Role of T₂ SPACE in urological diagnosis

Daniela Brizida Ribeiro Vicente

Orientadora: Ana Luísa Vieira, PhD

Mestrado: Radiações Aplicadas às Tecnologias da Saúde

Ramo de Especialização: Ressonância Magnética

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ABSTRACT

Abstract: Duplex collecting systems or duplicated collecting systems are one of the most common findings of the upper urinary system. This pathology is often found unintentionally and not because of a specific symptom but when performing imaging techniques for other reasons – usually during ultrasonography (US), which is normally the first imaging exam on renal assessment. After, the pathology can be demonstrated using other imaging techniques such as CT scan, MRI scan or renal scintigraphy. All these techniques provide detailed information on kidneys anatomy and function.

Objectives: The aim of this project is to assess the value of MRI scans for duplex collecting systems diagnosis with T₂ SPACE sequence. **Methods:** This study is being performed on 1.5T MRI equipment from SIEMENS at University Hospital of Southampton (UHS), United Kingdom, where eleven patients underwent an MRI scan. A questionnaire was performed to study the opinion of four radiologists about T₂-weighted SPACE sequence and to find out how helpful this MRI sequence can be in urological diagnosis. The kappa Fleiss statistical test was used to verify the agreement within the observers. **Results:** With *kappa* and *p* values it is shown that in 50% of cases there is a poor agreement between raters but, when analysing Tables 2 to 12, questions 1 to 5 (contrast resolution, spatial resolution, SNR and MPR's) were mainly rated between “likely”, “somewhat likely” or “very likely” (positive classification); in questions 6.1. to 6.5. raters have rated mainly as “non-applicable”, “very unlikely” or “somewhat unlikely” what means that the mentioned artefacts (phase wrap, phase shift, respiratory movement, bowel movement and urinary bladder movement) do not have a significant effect in imaging quality. **Conclusion:** This study demonstrates that T₂ SPACE sequence has a very high potential in duplex collecting system diagnosis, being one of the most important advantages the possibility of MPR's in any plane. MPR is very helpful in case of surgery, so surgeons can have a better idea how to access renal anatomy. Due to the small sample in this study, it is important to keep studying T₂ SPACE sequence to improve UHS MR urogram protocol and to provide the best diagnosis possible.

Keywords: Duplex Collecting System; Paediatric MR urography; MR T₂ SPACE sequence.

RESUMO

Resumo: A duplicação do sistema renal coletor é um dos achados mais comuns do sistema urinário superior. Esta patologia é muitas vezes descoberta de forma não intencional e sem a apresentação de um sintoma em específico, mas sim aquando da realização de outras técnicas de imagem por razões variadas – normalmente durante a realização de ecografia, que é por norma a primeira técnica de imagem utilizada no estudo do sistema urinário. Posteriormente, esta patologia pode ser avaliada através de outras técnicas de imagem como a tomografia computadorizada, a ressonância magnética ou cintigrafia renal. Todas estas técnicas fornecem informação em detalhe sobre a anatomia e função renal. **Objetivos:** O objetivo deste projeto é avaliar o valor da ressonância magnética no diagnóstico da duplicação do sistema coletor renal utilizando a sequência T₂ SPACE. **Métodos:** Este estudo está a ser realizado no University Hospital of Southampton (UHS) no Reino Unido sendo utilizado um equipamento de 1,5T da SIEMENS, em que 11 pacientes foram sujeitos à realização de uma ressonância magnética. Foi construído um questionário para estudar a opinião de quatro médicos radiologistas sobre a sequência T₂ SPACE e para se perceber o quão útil esta sequência pode ser no diagnóstico urológico. Foi usado o teste estatísticos Kappa Fleiss para verificar a concordância entre os observadores. **Resultados:** Com os valores de *kappa* e com os valores de *p* mostra-se que em 50% dos casos há uma concordância fraca entre os observadores, mas, ao analisar as Tabelas de 2 a 12, as questões de 1 a 5 (resolução de contraste, resolução espacial, relação sinal-ruído e reformatações multiplanares) foram maioritariamente classificadas como “provável”, “relativamente provável” ou “muito provável” (classificação positiva); nas questões de 6.1. a 6.5. os observadores deram classificações de “não aplicável”, “muito improvável” ou “pouco provável”, o que significa que os artefactos mencionados (phase wrap, phase shift, movimento respiratório, movimento intestinal e movimento da bexiga) não tem um efeito significativo na qualidade de imagem. **Conclusão:** Este estudo demonstra que a sequência T₂ SPACE possui um elevado potencial no diagnóstico da duplicação do sistema coletor renal, sendo uma das principais vantagens a possibilidade de realização de reformatações em qualquer plano. Reformatações multiplanares são úteis em caso de cirurgia uma vez que permite que os cirurgiões tenham uma melhor ideia da anatomia renal facilitando o

seu acesso. Devido à pequena amostra deste estudo, é importante continuar a estudar a sequência T₂ SPACE de forma a melhorar o protocolo utilizado no UHS e providenciar o melhor diagnóstico possível.

Palavras-chave: Duplicação do sistema coletor; Urografia por RM; RM sequência T₂ SPACE.

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LIST OF ABBREVIATIONS

A&E	Accident and Emergency department
BH	Breath Hold
CT	Computed Tomography
DMSA	^{99m} Tc-dimercaptosuccinic Acid
DTPA	^{99m} Tc-diethyenetriaminepentaacetic Acid
eGFR	Estimated Glomerular Filtration Rate
ETL	Echo Train Length
FOV	Field of View
HASTE	Half-Fourier Acquisition Single-shot Turbo Spin Echo
IP OP	In and Opposed-phase
IRMER	Ionizing Radiation (Medical Exposure) Regulations
IV	Intravenous
IVU	Intravenous Urogram
KUB	Kidneys, Ureters and Bladder
MAG-3	^{99m} Tc-mercaptoacetyltriglycine
MIP	Maximal Intensity projection
MPR's	Multiplanar Reformats
MRI	Magnetic Resonance Imaging
NEX	Number of Excitations
PACS	Picture Archiving and Communication System
PROPELLER	Periodically Rotated Overlapping Parallel Lines with Enhanced Reconstruction
RF	Radiofrequency
SNR	Signal to Noise Ratio
SPACE	Sampling Perfection with Application Optimized Contrasts using different flip angle Evolution
TR	Time of repetition
TRUFI	True Fast Imaging
US	Ultrasonography
UHS	University Hospital of Southampton
VIBE	Volumetric Interpolated Breath-hold Examination
WIP	Work in Progress

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1. Introduction

The incidence of duplex kidney collecting system is less than 1% in adult population and when considering both adults and children is between 0.7% to 4% of the world population, being the female gender commonly the most affected one (1,2). From the several ways that this pathology can be presented, double ureter is more common in girls than in boys in a ratio of 6:1 (3). Nowadays, childhood detection of different renal abnormalities has been increasing because of more innovative fetal imaging. On the other hand, there are still a considerable number of undiagnosed adults which can result in an increase of recurrent episodes of tract urinary infections and pyelonephritis (2).

Duplicated kidney collecting systems are often found unintentionally and not because of a specific symptom, when performing imaging techniques such as ultrasonography (US), which is normally the first exam on renal access imaging because of its low cost and it is free from ionizing radiation (1,4). Ultrasonography gives us valuable information about renal anatomy, but its sensitivity is reduced as it is not able to differentiate between bifid renal pelvis and complete two ureters. The ultrasound examination consists on the assessment of the presence, location and size of both kidneys as well as the evaluation of their structure and echogenicity (5).

Cross sectional imaging includes Computed Tomography (CT) and Magnetic Resonance Imaging (MRI) and allows the analysis of the complex anatomy, ectopic kidneys that cannot be seen at US, duplex collecting systems and other complications that may include malignancies (6).

CT can be helpful for determination of any obstruction and is very useful in assessing renal parenchyma, being much more helpful than ultrasonography if there is a poor or an absent renal function. In duplex collecting system, CT scanning is used to determine if the insertion of the duplex ureter is intravesical or extravesical. An MRI scan is indicated in case of an ectopic ureter or whenever an upper pole is suspected. The main advantage of this technique is not using ionizing radiation. On the other hand, there are a few disadvantages such as the requirement of sedation in children or claustrophobic patients, cost and availability (5,6).

In order to assess renal function, scintigraphy is useful as it allows the assessment of renal function and the detection of renal scars (7,8). DMSA (^{99m}Tc-

dimercaptosuccinic acid) is a renal cortical imaging radiopharmaceutical commonly used in children to evaluate urinary tract infections. As in other imaging techniques like intravenous urogram (IVU), CT, MRI and other renal scans as MAG-3 (^{99m}Tc-mercaptoacetyltriglycine) or DTPA (^{99m}Tc-diethylenetriaminepentaacetic acid), it is not possible to visualize the duplex systems on DMSA (^{99m}Tc-dimercaptosuccinic acid) cortical scans. On the other hand, DMSA (^{99m}Tc-dimercaptosuccinic acid) allows the diagnosis or is highly suggestive of duplication due to several changes in the renal cortex (8,9).

Magnetic resonance imaging has higher values of sensitivity and specificity comparing with ultrasound imaging when speaking of detection of urogenital anomalies in children. MR sensitivity vary between 92% to 100% while sensitivity values for ultrasound can vary between 40% and 100% but for specific pathologies (i.e., abdominoscrotal hydrocele) this imaging technique is useless as it has not enough capacity to reach profound structures. MR specificity in most of the cases is around 100% while ultrasound has a specificity of 91-93% (10).

MR urography is already a well-established imaging technique in the evaluation of urinary tract in infants and children (11,12). Duplicated collecting systems is not a very common pathology and most of the times is accidentally found as patient's present symptoms related with other pathologies such as urinary infections. Many of the cases are detected in an early age (children), the reason why is so important trying to figure out which imaging techniques are the best is the possibility of avoiding the use of ionizing radiation. MRI scans do not involve the use of ionizing radiation being an advantage when comparing with renal scintigraphy or CT scans. Ultrasound is also a free ionizing radiation imaging technique but is not as specific as MRI scans. The T₂ SPACE sequence is being studied since it allows the reconstruction of images acquired in any plane as voxel size is the same in any direction (isotropic). With these characteristic radiologists can have access to a very detailed anatomy(13–15).

The most common MR pulse sequences performed to study renal system are: nonenhanced T₁-weighted, T₂-weighted and post contrast T₁-weighted sequences(12,16). With these sequences it is possible to study renal anatomy but not with so much detail as it is possible with T₂ SPACE sequence pulse due to its isotropic characteristic (voxel size is the same in any direction) providing multiplanar reformats in any plane. When the administration of paramagnetic contrast medium is not

possible due to an early age, this sequence enables anatomic display but information about kidney function is not provide(16,17).

Ultimately, the aim of this project is to study the MR pulse sequence known as T₂ SPACE evaluating its characteristics and understand if it gives valuable information in renal diagnosis without using examinations that involve the use of ionizing radiation.

This thesis contains different sections, in section 1 it is made a brief introduction about the pathology in study and imaging techniques used to study that pathology; section 2 is about renal anatomy and a more specific description of duplicated collecting system pathology; in section 3 it is possible to find out more about MR urography itself, which MR pulse sequences are part of the MR urography protocol used at University Hospital of Southampton and what kind of artefacts can occur and it is presented what is made to keep patients' safety. Materials and methods is the forth section where it is described how many patients are part of this study and its images acquired and how it was performed to evaluate the T₂ SPACE sequence. The fifth section is where can be found the results of this study after post process of data. Analysis and discussion of results is in section number six and finally, section number 7 is where can be find the conclusion of this study. Section number 8 lists the articles used to support this thesis.

2. Renal Anatomy and Duplex collecting system pathology

2.1 Renal Anatomy

The urinary system also known as the excretory system is where the production, storage and elimination of the urine occur. Kidneys produce the urine and keep it in its pelvic zone, and the excretory urinary tract which is composed by the ureters, the bladder and the urethra, is responsible for the elimination of the urine (18).

The kidneys develop from three main structures that succeed each other known as: the pronephros, the mesonephric and metanephric ducts. The first structure, the pronephros, develops from intermediate mesoderm (being the most immature form of kidney) towards the end of 3rd week of gestation. The mesonephros arise in the mesonephric duct which later will form the portion of the female and male genital tracts. It is during the 4th week of gestation that the union of the ureteric bud with the metanephric mass of intermediate mesoderm occurs and the kidneys then develop at the level of the first or second sacral segment. Initially, the kidneys lie close to each other and during the 4th to 8th weeks of gestation both kidneys ascend to the lumbar region moving forward apart and rotate with the hila facing anteromedially (5,15).

Incomplete duplication develops from early bifurcation of a single ureteral bud before it meets the metanephric blastema at approximately 5-6 weeks while complete duplication results from two separate ureteral buds arising from the mesonephric duct. As the distal portion of the mesonephric duct is being absorbed into the developing bladder, the ureter to the lower segment of the metanephros separates earlier from the mesonephric duct and is absorbed into the bladder. The ureter to the upper part of the metanephros separates later after it has been carried medially and inferiorly by the migrating mesonephric duct and after the two ureters have crossed (19). In Figure 1 it is shown how the embryogenesis of ureteral duplication develops itself.

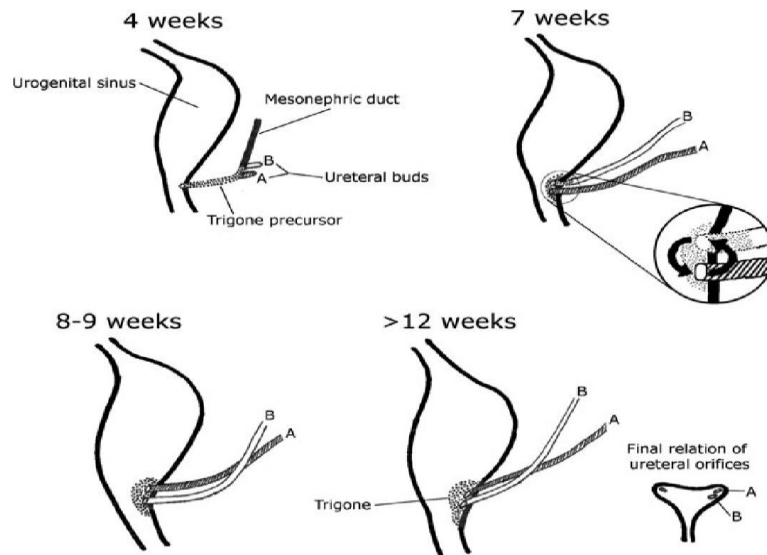


Figure 1: Embryogenesis of ureteral duplication. Two ureteral buds arise from the mesonephric ducts at approximately 4 weeks. The lower pole ureter bud (a) contacts the urogenital sinus by 7 weeks and the upper pole ureter bud (b) does the same by 8 weeks. As the lower pole ureter contacts the urogenital sinus earlier, its orifice achieves a slightly more cranial and lateral position than the upper pole ureter during migration and rotation (Weigert-Meyer law) (19).

The average size of the kidneys is approximately 10-11 centimetres (cm) in the cranio-caudal direction and about 4cm in the anterior-posterior direction but renal size mainly depends on body size. The kidneys consist of an inner medullar part that includes the renal pyramids that are surrounded by calyces that merge into the renal pelvis where the ureter originates from and the superficial renal cortex. The functional unit of the kidney is the nephron and finally, collecting ducts lead the urine to the renal pelvis. Full renal system anatomy is shown in Figure 2.

It is in the medullar part of the kidney where a significant amount of sodium's reabsorption occurs, although it occurs in almost all parts of the nephron. In the Henle's loop there is a large degree of activity which explains the high medullary oxygen demand. Due to limited perfusion and due to the exchange of oxygen in favour of the ascending vasa recta, oxygen delivery is restricted in medulla. In consequence, kidney's medulla can be susceptible to hypoxic damage that can be avoid by pharmacological inhibition of oxygen demanding processes increasing the medullary oxygenation (20).

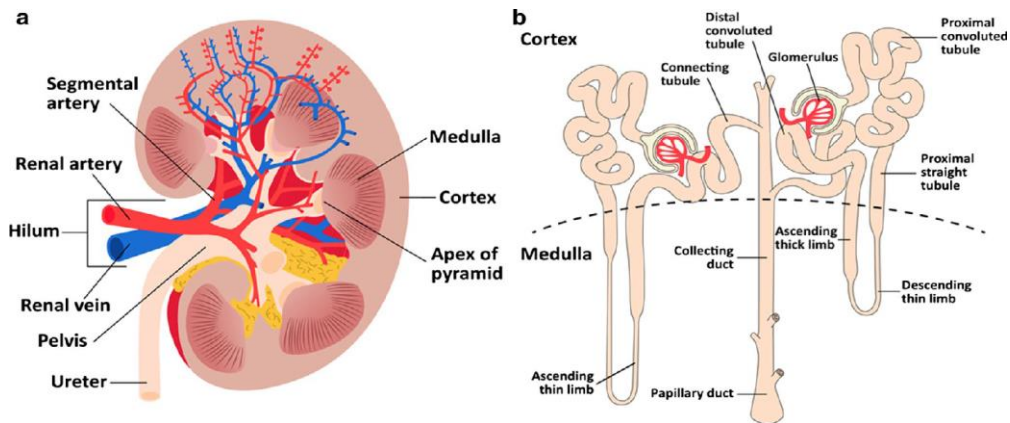


Figure 2: a) Anatomy of the kidney and **b)** the nephron. The blood is filtered in the glomerulus. In the proximal convoluted tubule, is where most of filtrate, i.e., water and ions, are reabsorbed. The loop of Henle that consists of the proximal straight tubule, the descending thin limb, and ascending thin and thick limb, and concentrates the pre-urine. The distal tubule is where more sodium is reabsorbed (20).

2.2 Duplex collecting system pathology

Duplex collecting systems or duplicated collecting systems (figure 3) are one of the major anomalous findings of the upper urinary system and can be associated with other anomalies like ectopic ureter (figure 4), ureterocele (figure 5), and vesicoureteral reflux (figure 6) (21,22). Despite these anomalies, duplex collecting systems can also appear as a normal functioning kidney with complete or incomplete duplication (23).

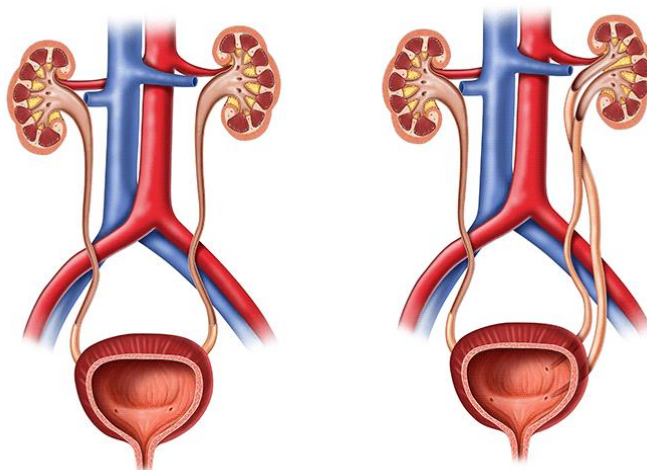


Figure 3: First image represents a normal collecting system and the second image represents a duplex collecting system (24).

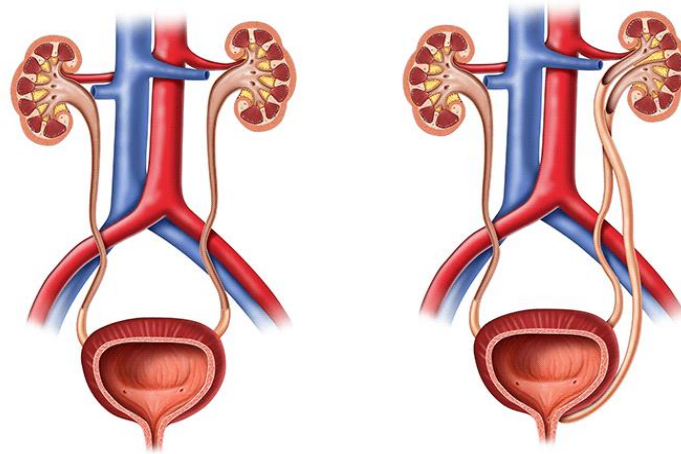


Figure 4: Representation of a normal collecting system (left) vs. ectopic ureter (right)(24).

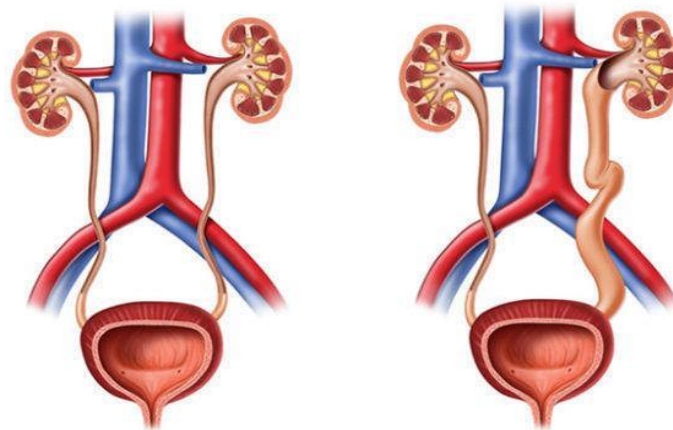


Figure 5: Image on the left represents a normal urinary system while image on the right represents an ureterocele (24).

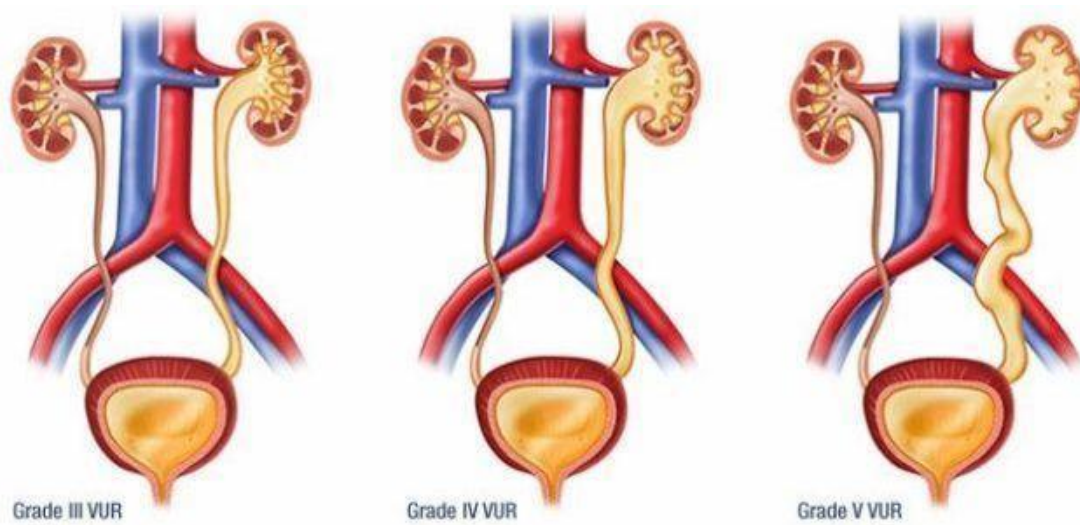


Figure 6: This figure shows three distinct stages of vesicoureteral reflux in a collecting system (24).

A classification as a complete or incomplete duplication is based on its ureter status. The Committee on Terminology, Nomenclature, and Classification of the Section of Urology of the American Academy of Paediatrics suggests the use of the following terms:

- **Duplex kidney** – there is a single renal parenchyma that is drained by two pyelocaliceal systems;
- **Upper or lower pole** – each pole represents an individual component of a duplex kidney;
- **Duplex system** – the kidney (can be unilateral or bilateral) has two pyelocaliceal systems and is associated with a single ureter or with a bifid (partial duplication) or, in case of a complete duplication, there are two ureters that drained separately into the urinary bladder;
- **Bifid system** – when two pyelocaliceal systems join at the ureteropelvic junction designed bifid pelvis, or two ureters join before drain into the urinary bladder called bifid ureters;
- **Double ureters** – two ureters open separately into the renal pelvis superiorly and drain separately into the bladder or genital tract;
- **Upper and lower pole ureters** – upper and lower pole of the duplex kidney, are drained by upper and lower ureters, respectively (25).

Both complete and incomplete duplications most of the time are asymptomatic but, complete duplication is more likely to be symptomatic (26). When it happens to be a complete duplication, the affected kidney is typically divided into two moieties (upper and lower), as mentioned previously. Depending on gender, the consequences of this abnormality are different: in girls, the ectopic ureter that inserts into the vagina or into the urethra below the level of the sphincter mechanism can manifest as a permanent wetness; in boys, the ectopic upper moiety ureters normal insert into the posterior urethra above the level of the sphincter or even into the genital tract, i.e., seminal vesicles or epididymis, which it will manifest often with recurrent urinary tract infections or pelvic pain (21,25,27).

3. MR Urography

3.1 Introduction

In infants and small children, the most frequent indication for MR urography is for the evaluation of hydronephrosis (28). This condition happens when kidney become stretched and swollen due to the existence of a blockage or an obstruction and so urine cannot drain out from the kidneys to the bladder (29,30).

MR urography allows us to evaluate the urinary tract with the advantage over other examination that it doesn't use ionizing radiation which presents an improvement and development of uroradiology in paediatric patients (31). Nowadays it is known by general and scientific population that children are more sensitive to radiation than adults. Due to this sensitivity, there is a higher relative risk of cancers to happen to children such as: leukaemia, brain, breast, skin and thyroid cancers after exposure to ionizing radiation (32). This way it is very important trying to avoid the use of imaging techniques involving ionizing radiation.

Allied to the use of non-ionizing radiation, MR imaging is a technique with high quality images, high spatial and contrast resolution, high temporal resolution in any orthogonal plane. All these factors represent advantages compared with other imaging techniques that require ionizing radiation such as CT scans and scintigraphy, or ultrasound that doesn't provide acute anatomy details (20,21).

In children, MR urography is used in the preoperative anatomic assessment of vascular anatomy, in the evaluation of duplicated collecting systems, renal dysplasia, ectopic ureter and to distinguish hydronephrosis from cystic renal disease. Additionally, MR urography can be used to obtain physiological information about the collecting systems, such as estimated glomerular filtration rate (eGFR) and renal transit time avoiding the exposure to ionizing radiation as when performing nuclear scintigraphy (33).

Per *Leyendecker, et al., Dillman, et al., and Chua, et al.* the most common MRI sequences performed to study the urinary tract can be divided in two groups: 1) static-fluid MR urography (T2-weighted) and 2) excretory MR urography (T1-weighted). The first group can be obtained with single-shot fast spin-echo techniques allowing the acquisition of multiple images in a brief period and played in cine. To the second group it is administrated a contrast agent (gadolinium-based) and images are acquired

during the excretion phase, being the first image a 3D gradient-echo sequence (31,34,35).

A fast or turbo spin echo pulse sequence has shorter acquisition times than the conventional spin echo pulse sequence where a 90° excitation pulse is induced followed by a 180° rephasing pulse where only one line of k -space is filled per time of repetition (TR). To reduce the acquisition time and, as this sequence depends on TR, NEX (number of excitations) and number of phase encodings, at least one of these factors should be reduced.

Reducing the mentioned factors, it is important to keep in mind its consequences to the image quality. By reducing the TR and the NEX affects image weighting and SNR (signal to noise ratio). On the other hand, decreasing the number of phase encodings reduces the spatial resolution. To achieve a fast spin echo pulse sequence, it is necessary filling more than one line of the k -space per TR and, for that it must be used several 180° rephasing pulses to produce a train of echoes. At each rephasing pulse an echo is produced, and a different phase encoding step is performed.

In fast spin echo pulse sequence, the number of 180° rephasing pulses applied per TR corresponds to the number of echoes produced and the number of lines of k -space filled. This number is called the turbo factor or the echo train length. The scanning time it will be shorter as the higher the turbo factor as more phase encoding steps will be performed per TR.

The main advantages of fast spin echo pulse sequence are the reduction of scans time, high resolution matrices and the use of multiple NEX as well as an improvement of image quality and increased T_2 information. In contrast, there are some disadvantages such as some flow and motion artefacts, fat with bright signal on T_2 weighted images as well as blurred images with very long echo trains.

When performing MRI scans with contrast enhancement, it is possible to evaluate renal function by concentration and excretion of contrast, especially in renal cortex and medulla. To study urinary tract anatomy, it is normally performed T_2 sequences and post contrast T_1 sequences (32,36). After the administration of the IV (Intra Venous) contrast it is performed a scan at the time of the arterial phase (30/35

seconds delay), a second scan at the time of the porto-venous phase (60/65 seconds delay) and a delayed scan at around five minutes after injection.

MR scanning provides quantitative information of renal function on kidney perfusion, excretion velocity and drainage. Three dimensional (3D) images can be helpful to surgeons as it provides morphologic information of the urinary tract condition (16,37).

Magnetic resonance urography has an inflated cost due to its time-consuming and expertise-demanding imaging modality. Also, it has some associated limitations as it is quite sensible to a wide range of artefacts. On the other hand, it also has many advantages including the high contrast resolution, good sensitivity for contrast media (gadolinium) and, the last but more important advantage, its safety as it does not involve the use of ionizing radiation(8).

The main challenge of MR urography is to obtain diagnostic quality images of the kidneys, ureters and bladder within a reasonable period even with the effects of respiratory motion, ureteral peristalsis and urine flow (38).

3.2 MR urography protocol at UHS

MR urography has been well studied in 1.5T MR scanners. Despite of a few studies published regarding the use of 3T equipment, there is no straightforward evidence of obtaining better images between 1.5T and 3T examinations (as the availability of 3T scanners is still limited) and, 3T magnetic resonance equipment has been shown some inherent problems including the worsening of some artefacts and longer T_1 relaxation times (33,39).

Before the scan, it is necessary to proceed for a patient preparation that must follow a few steps:

1. Patient must be MRI safety checked (by answering the MRI safety questionnaire that will be shown forward in this paper) and patient also must get changed (taking of all clothes except underwear that can be kept if there is no metal and dress two gowns provide by the department);

2. Check protocol for whether contrast or IV (intravenous) saline is required, and cannulate if necessary;
3. If IV saline is required: it is injected 50ml of normal saline at 3 minutes' interval over 15 minutes (250ml injected in total to encourage diuresis). Patient should empty their bladder immediately before entering in the scan room;
4. Patient lies head first in a supine position on scan table;
5. The body array coil is placed on the top of the patient (anterior) with a portrait orientation over the abdomen and pelvis ensuring the bladder and kidneys are covered. The coil is secured to the body with straps.

This project is being performed at University Hospital of Southampton (UHS) on 1.5T MRI equipment from SIEMENS.

The MR urography protocol at UHS is still in progress so the Cross-Sectional Department is still testing which kind of sequences are better for renal diagnosis. In case of duplication of renal system, the T₂ SPACE sequence has been tested in all patients. Following it will be described the MR urography protocol.

MR urography protocol (WIP – Work in progress) at UHS:

Routine series:

- Localiser;
- T₂ Truffi – Coronal plan with BH (Breath hold) covering KUB (Kidneys, Ureters and Bladder);
- T₂ Truffi – Axial plan with BH covering KUB;
- T₁ IP OP (In and Opposed-phase) – Axial plan covering kidneys and adrenals only;
- T₂ SPACE triggered with fat saturation – Coronal plan covering KUB;
- T₁ VIBE with fat saturation – Axial plan covering KUB (pre-contrast administration);
- Care Bolus (table position must be copied from VIBE pre-contrast);
- Axial T₁ VIBE with fat saturation – Arterial phase (30/35 seconds) covering KUB;

- Axial T₁ VIBE with fat saturation – Venous phase (60/65 seconds) covering KUB;
- Axial T₁ VIBE with fat saturation – at 5 minutes covering KUB;
- Coronal T₁ VIBE – immediately after covering KUB;
- Axial T₂ HASTE (upper and/or lower abdomen).

TRUFI is the acronym used to describe a *true fast imaging with steady-state free precession*. Steady-state sequences are a group of rapid magnetic resonance imaging techniques based on fast gradient echo acquisitions in which both longitudinal and transversal magnetization are kept constant. This MR imaging technique is mainly used for cardiac studies, but it is also useful in abdominal and fetal imaging because of its good signal-noise ratio (SNR) and contrast-noise ratio (CNR) and increased speed of acquisition (28).

In and Opposed-phase is a T₁ weighted MR gradient echo pulse sequence used to identify common pathologic conditions such as diffuse or focal steatosis and focal fatty sparing. Images obtained with this sequence demonstrate a sharply defined black border around organs with fat-water interface (40,41).

Volumetric Interpolated Breath-hold Examination (VIBE) is a gradient-echo magnetic resonance sequence that allows short acquisition times without losing image quality being useful in abdominal, brain and chest imaging. The images produced with this sequence are T₁ weighted using interpolation and/or partial Fourier techniques. Additionally, by performing VIBE sequence it is possible to obtain dynamic and high-resolution imaging under 30 seconds (40).

HASTE stands for **Half-Fourier Acquisition Single-shot Turbo Spin Echo** imaging being an echo planar fast spin echo sequence. This sequence uses a single-shot technique which means that all the *k*-space is obtained after a single 90° excitation pulse, requiring very long echo trains (i.e. 128 or 256). With this sequence it is possible to apply the half Fourier method where only a little bit more than half of *k*-space data is acquired while the remaining lines can be estimated by phase-conjugate symmetry. This way, echo times are quite long what makes HASTE sequence T₂ weighted (40,42).

In focus is the 3D fast spin-echo sequence named **SPACE** which stands for: *Sampling Perfection with Application Optimized Contrasts using different flip angle Evolution*. The study is being conducted with a T2-weighted SPACE in both axial and coronal planes.

This sequence consists of an isotropic 3D fast spin echo sequence optimized by other imaging techniques like half Fourier, parallel imaging, uses long echo trains, low flip angles, and low specific absorption rates. The fact of this sequence being an isotropic acquisition means that the *voxels* generated measure the same in each direction allowing the images to be reformatted with equal resolution in any direction (17).

Among the 11 patients scanned, there were slight differences in parameters values' as this is a sequence that it is still being tested at UHS. As mentioned before, this is a 3D MR acquisition type and in these scans it was tried several values for parameters such as *slice thickness* (1mm or 0,9mm), *flip angle* with a range between 120° and 180°, *echo train length* (ETL) or *turbo factor* value' varies between 67 and 180 (acquisition time is inversely proportional to ETL); *repetition time* is one of the parameters that mainly changes along the 11 patients scanned (minimum of 1430ms (milliseconds) and the highest one is of 4471ms; echo times vary between 111ms up to 802ms; and finally there is no spacing between slices.

All the above parameters will impact on image quality (spatial resolution, contrast resolution, signal-noise ratio (SNR)) and they will also affect acquisition time. This last parameter is one of the most important parameters when performing MRI scans, especially when many patients are paediatric and most of the times involve the use of general anaesthesia that also have a few risks itself.

As this study is still in an early stage at UHS, what means that radiographers and radiologists are still trying to find out values for each parameter that do not compromise image quality and subsequent diagnosis, the value for each parameter can be very different from one patient to another. That is why along with the T₂ SPACE sequence, it has been performed other sequences always thinking about what is best for the patient. This way, besides testing this sequence, an accurate diagnosis is still provided as UHS/TRUST Foundation has three main values:1 - "patient first" - what means that we always want to make sure that patient will get the best healthcare

possible; 2 – “always improving” as there is always room to learn more and new things; and finally, 3 – “working together” since as UHS staff member every single professional work with different people, with different personalities, different jobs and different roles but everyone is working having in mind the very first value - “patient first”.

While the exams are being performed, as this protocol is still being studied, it is required the presence of a radiologist (consultant or registrar) during the scan, as they can evaluate depending on their concerns about patient’s pathology which pulse sequences they need for each patient. Despite being described post-contrast sequences, those were not performed in all patients considered for this study. This happen whether the radiologist thinks that the sequences performed without contrast administration are useful and enough for diagnosis. Since most of these patients have poor renal function, radiologists tend to avoid the injection of gadolinium (contrast agent used in MR imaging).

3.3 MR urography artefacts

The MR imaging is a result of the interaction of the nuclear spins with a magnetic field. A MR scanner is composed by several components such as: a static magnetic field (B_0) responsible for generating the magnetization, radiofrequency (RF) fields (B_1) that will make the magnetization vary on the axial planes and, magnetic field gradients which have the function of spatial encoding. In case of a leak of the main parameters/components, it will be produced artefacts (43).

Due to the complexity of the MR imaging with all the parameters plus the motion in the abdominal region, it is possible to have some artefacts during the imaging acquisition, more specifically motion from the respiration and bowel peristalsis, susceptibility effects due to bowel gas, and the need to cover a large field of view (38).

It is very important to recognize an artefact to avoid false diagnoses, as artefacts and foreign bodies can be confused with a pathology or just reduce the quality of the image which can be a disadvantage when the radiologists are reporting (44).

In children, artefacts are more likely to happen due to the inability to hold still justified by a lack of understanding or anxiety and also the inability to breath hold for a reasonable length of time(12).

The type of artefacts can be divided in distinct groups: tissue heterogeneity and foreign bodies, hardware and room shielding, software, patient and physiologic motion and, the last, Fourier transform and Nyquist sampling theorem. In this thesis it will be described artefacts that are more likely to happen during MR urogram.

3.3.1 Aliasing and Wrap around artefacts

This artefact occurs when the field of view (FOV) is smaller than the part of body being scanned and so the structure that lies outside of the FOV is projected to the opposite side as it is possible to see in figure 7.

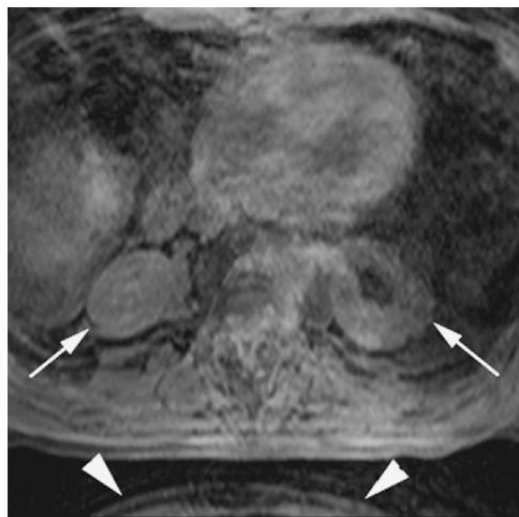


Figure 7: 3D gradient-echo T₁-weighted image without gadolinium showing tissue aliasing in the phase encoding direction (anterior-posterior) with anterior subcutaneous tissue wrapping around posteriorly (arrowheads); there is also slice direction aliasing with kidneys appearing to be in the lungs (arrows)(45).

There are a few things that allow the correction of this image artefact such as the addition of oversampling data. The oversampling data can be applied at the frequency encode direction where the signal is sampled faster. It is also possible to apply the oversampling in the phase direction but here there will be an increasing of

the scanning time. There is other way to avoid this artefact without increasing the scanning time, is to increase the FOV but keep matrix size the same, and at the same time reduce the number of excitations to half (38,44).

Both ways of avoiding the wrap around artefact are used by radiographers at UHS.

3.3.2 Phase-encoded motion artefact

There are many reasons that justify the presence of this artefact: arterial pulsations, breathing, peristalsis, swallowing and actual physical movement of the patient. In figure 8 it is represented as ghosting in the phase encoding direction which is normally at the shortest axis of the anatomy.

If the movement that causes the artefact is periodic such as respiratory or cardiac/vascular pulsation, it will be produced discrete and well-defined ghosts (Figure 8); on the other hand, if the artefact is caused by random motion as the patient moving it will produce a spread in the phase direction (Figure 9)(38).

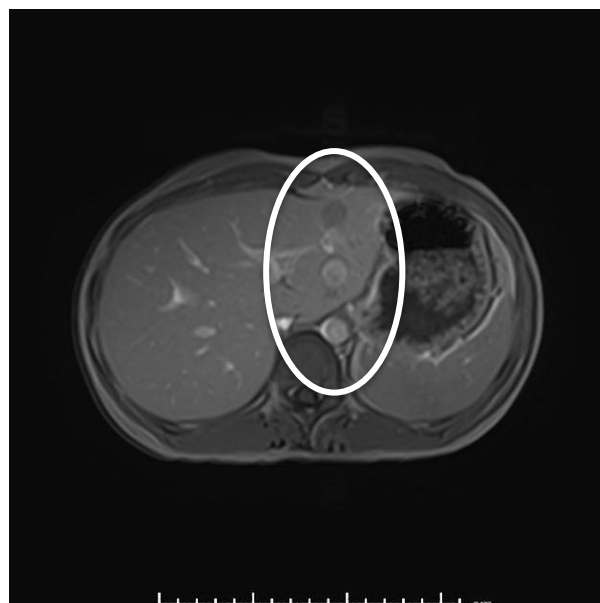


Figure 8: Abdominal MR, Axial T₁ weighted image with Ghosting artefact (white circle) from aorta artery (46).

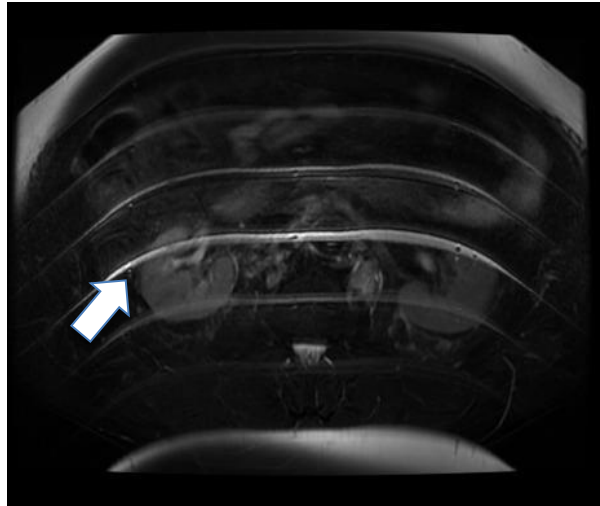


Figure 9: Abdominal MR, Axial T₂ weighted image fat saturated with phase encoded motion artefact (white arrow) (46).

To correct this type of artefact most of the times radiographers at UHS must repeat the sequence affected by this artefact changing some parameters: phase-encoding direction (i.e. if initially is right to left, change to head to foot) but this way we need to add or increase the percentage of oversampling normally up to 100%.

In case of respiratory/breathing movement artefact (Figure 10), it can be avoided by respiratory triggering sequences using the navigator technique. With this technique it is placed a navigator box at the surface, between the bottom of the right lung and the top of the liver, that will detect respiratory movement and will define when to acquire images.

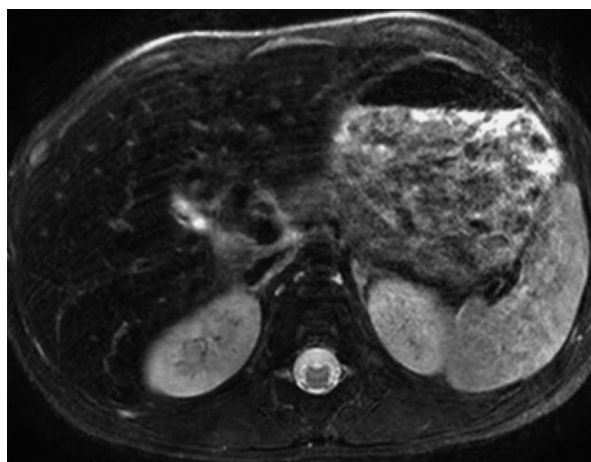


Figure 10: Axial T₂-weighted FSE image shows breathing artefacts that degrade the image(12).

In paediatric patients the navigator technique may not work, making scans even longer and because of it, most children who undergo MR imaging are evaluated under general anaesthesia. By doing this, it is possible to control apnea and eliminate respiratory motion in small children.

Other way to reduce motion artefact is performing BLADE (Siemens) or PROPELLER (Periodically Rotated Overlapping Parallel Lines with Enhanced Reconstruction - GE). The principle of this sequence is to sample k -space with radial filling and this way movement artefacts do not propagated in the phase-encoding direction as it changes with each radial section(12).

3.3.3 Chemical Shift Artefact

This artefact is a consequence of the difference between resonance frequencies of fat and water (Figure 11). As the fat resonates at a slightly lower frequency than the water, it is produced a shift on the frequency encoding direction. This mis registration can be visualized in the MR images as a bright band on one side and a dark band on the other side of a fat-soft tissue interface. The amount of chemical shift is expressed in parts per million (ppm) of the magnetic field strength and for water and fat it equals 3,5ppm (33,36).

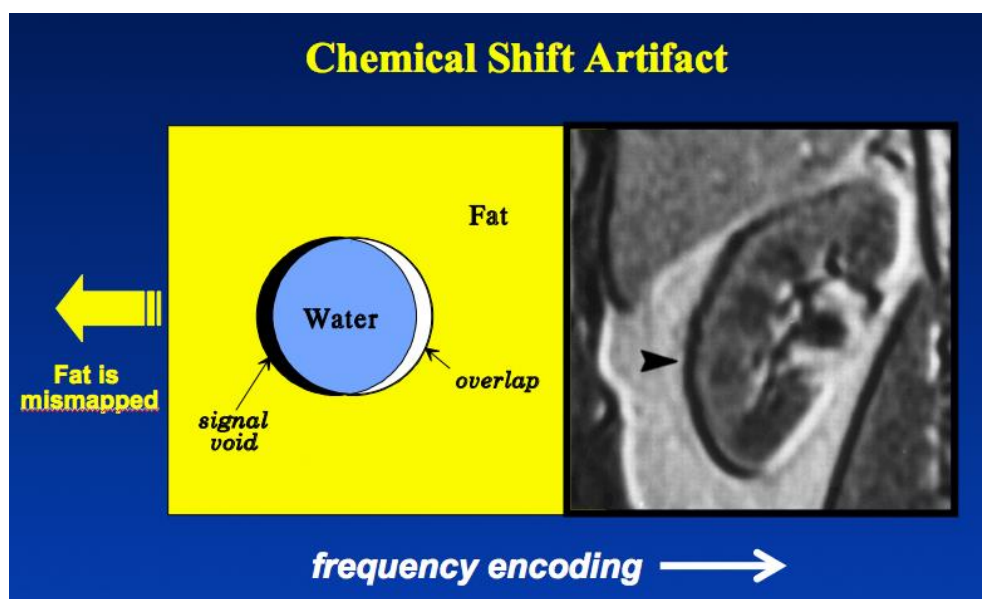


Figure 11: An example of the chemical shift artefact in a kidney where there is an interface fat/water (37).

At UHS, when this artefact shows up at the images acquired, radiographers tend to increase the bandwidth or reducing the FOV. There is another way to avoid or correct this artefact by applying a fat saturation imaging technique. This artefact is even more likely to happen when using stronger magnetic fields (i.e.,3T). In this case, it is avoided to scan in 3T scanner where the magnetic susceptibility is even higher.

3.4 MR safety at UHS

At University Hospital of Southampton (UHS), when it is requested an MRI scan, it will not be performed straight away. Instead, MRI scans requests need to be reviewed, justified and accepted by a radiologist before the scan be performed. In order to follow the IRMER - the Ionizing Radiation (Medical Exposure) Regulations – all scans must be justified by the practitioner which, in the MRI department will be the radiologist (47).

Generally, after the justification of the examination requested and, as soon as it is possible to the department, the scan will be performed but there is one more safety rule that needs to be done: every patient (outpatients with an appointment or inpatients including the ones on the ward or from the Accident and Emergency (A&E) department) with no exception, before going inside the scanner room need to go through a safety questionnaire (Attachment 2). This safety questionnaire should be answered by the patient himself but, if not possible for any medical reason or just because it is a paediatric patient that sometimes is not able to answer all the questions, this safety check list can be answered by a relative or by the healthcare professional (i.e. doctors or nurses) responsible for the patient.

One of the most important safety checks is to make sure that it is the right patient having the right scan. First thing is to confirm patients' identity asking about name, date of birth, address, as well as what part of the body is he having scan and why. Afterwards, we can proceed with more specific questions, as it is shown in the questionnaire attached.

The safety questionnaire performed at UHS includes the concern about any metal devices such as, metal dentures, cardiac pacemakers, cardiac monitors, stents, valve replacements, joints replacements, metal plates, screws, hearing aids or

cochlear implants. Beside those devices, it is also a question of concern if the patient may be pregnant or not. As it was mentioned before, until today there is no known biological effects of MRI on the foetus but, there are several mechanisms that could potentially cause adverse effects since during the first trimester of pregnancy cells are going through multiple divisions which make them more susceptible because of the interaction of electromagnetic fields with the foetus. In case of pregnancy the tendency is to delay the scan for after birth(48).

In situations of patients under general anaesthesia, as they must be monitored, all the devices must be MR safe to avoid any accident as the devices can be very close to the magnet.

When a patient has had any procedure/operation involving the use of metal plates, screws, joints replacements or any other kind of metal, mechanical or magnetic device is referred for a MR scan, it must be checked before patient goes into the scanner and everything must be arranged (i.e. cardiac physiologist must be called in case of a patient with a cardiac pacemaker that must be switch off or put on standby mode) to avoid accidents or delays.

MRI safety is not just about the patient but also about the health of professionals that work with MRI scanners as they must make sure that they are not carrying any metal object that can go into the scanner (i.e. phones, cards, pens, jewellery, hair clips).

Finally, it is not just the risk of projectile devices but also the risk of burns and the acoustic noise that must be taken into consideration. To avoid those risks: patient must not cross legs or hands and ear plugs must be providing to protect their ears.

4. Materials and Methods

4.1 Research Question

The main question of this study is to understand how helpful is T₂ SPACE sequence in diagnosing duplex collecting system in paediatric patients.

4.2 Hypothesis Test

Hypothesis tests are used to test the validity of a claim that is made about a population. The claim that is on trial is called *null hypothesis*. The *alternative hypothesis* are the ones that we believe in case of the *null hypothesis* is concluded to be untrue.

H₀: There is not an agreement between raters confirming that MRI urography is valuable in duplex collecting system diagnosis.

H₁: There is an agreement between raters confirming that MRI urography is valuable in duplex collecting system diagnosis.

4.3 Objectives

The aim of this project is to evaluate the performance of MRI, namely the T₂ SPACE sequence in the diagnosis of the duplicated renal collecting systems and perhaps to evaluate the possibility of replacing nuclear medicine examinations (i.e. renal scintigraphy) in renal diagnosis to avoid the use of ionizing radiation specially in paediatric patients.

4.4 Type of study

Data collection was made personally by me at UHS between January and June of 2018 once I have got access to PACS (Picture Archiving and Communication System) as a member of staff. Despite of data collection being performed in this period, MRI scans considered to this study were performed between 2016 and 2018 what makes this a retrospective study.

4.5 Population and sample

The selection of the sample was based on the diagnosis of duplex collecting systems, either patients with confirmed diagnosis but still need this scan to understand, or if a surgery is necessary or any other treatment or patients that didn't have a final diagnosis but presented some symptoms related with duplicated collecting systems. At the beginning it was supposed to consider paediatric patients only, but as this is not a very common condition, we had to consider a few adult patients that presented identical symptoms. In a total of 11 patients, three of them in adult age (27,3%), what means they are aged above 18 years old; and the other eight patients are paediatric patients (72,7%), what means those patients are aged below 18 years old. The range of ages of the 11 patients is between 7 months old and 68 years old. On average the age of this group is around 14 years old. When it comes to gender, this type of pathologies is mainly found in female patients and this study proves that. In a total of 11 patients only one is male gender (9%) and the other ten patients are female (91%).

4.6 Data collection

To evaluate the quality of the scans performed and, specially, the quality of the images acquired by performing the pulse sequence T₂ SPACE, it was built a questionnaire. This questionnaire consists in six questions where radiologists from UHS that agreed to participate in this study had to visually evaluate a few parameters regarding T₂ SPACE pulse sequence, such as: its value in renal diagnosis, contrast resolution, spatial resolution, SNR (Signal-Noise Ratio), how helpful are multiplanar reformats and finally, which kind of artefacts can be observed in the 11 scans performed. To answer to this questionnaire three paediatric consultant radiologists plus a consultant radiologist with more than 15 years of experience had to login to PACS so they could have proper equipment (software and hardware) to analyse and evaluate images' quality. The images analysed by the four radiologists are the ones shown in section 5 (Results).

In this questionnaire it was used a *Likert* scale which consists in a survey questions that offer a range of answer options from one extreme attitude to another. For each question four radiologists had to pick one option from 1 to 5, where 1 means

“very unlikely”, 2 “somewhat unlikely”, 3 “likely”, 4 “somewhat likely” and 5 “very likely” considering ONLY the T₂ SPACE sequence. In question number 6 there was an extra option N/A which means “Non-applicable”.

The parameters of the T₂ SPACE sequence are not the same for all the patients that underwent an MR urography as this MRI pulse sequence is still being tested by both doctors and radiographers at UHS.

4.7 Variables

This study has several variables that are list below:

- Gender: female and male – dichotomous variable (nominal variable that only have two categories or levels);
- Age: discrete numerical variable;
- Contrast resolution, spatial Resolution, SNR and artefacts: those variables are considered ordinal variables as they are classified in more than two categories (*Likert* scale) ranked.

4.8 Ethic

First, it was necessary to ask the lead of Radiology department at UHS if it would be possible to access patients’ files (images) who agreed with this if the patients’ confidentiality was kept safe. To keep patients’ confidentiality any data that could reveal patients’ identity was removed from images used in this thesis or in the questionnaire answered by doctors that only had hospital numbers provided to have access to patients’ images, so they could answer to the questionnaire. Also, and after data collection and results being finished, all kind of paper with hospital numbers, name, address and date of birth were disposed in the confidential bin to be destroyed.

4.9 Methods of data processing/treatment

To analyse the data collection, it was used the statistic test named Fleiss’ Kappa. This test is an extension of Cohen’s Kappa that is a measure of agreement

between two raters, where agreement due to chance is factored out. With Fleiss' Kappa the number of raters can be more than two.

If a fixed number of people assign numerical ratings to several items, then the *kappa* will give a measure for how consistent the ratings are. The *kappa* can be defined as:

$$k = \frac{(\bar{P} - \bar{Pe})}{(1 - \bar{Pe})}$$

$(\bar{P} - \bar{Pe})$: degree of agreement that achieves above chance;

$(1 - \bar{Pe})$: degree of agreement that is attainable above chance.

If the raters are in complete agreement, then $\hat{k} = 1$; if there is no agreement among the raters then $\hat{k} < 0$.

On the following table (Table 1) it is possible to find the meaning of each *kappa* (\hat{k}) value:

\hat{k}	Interpretation
< 0	Poor agreement
0,01 – 0,20	Slight Agreement
0,21 – 0,40	Fair Agreement
0,41 – 0,60	Moderate Agreement
0,61 – 0,80	Substantial Agreement
0,81 – 1,00	Almost perfect

Table 1: Interpretation of \hat{k} values.

$$P_j = \frac{\text{total of each column}}{\text{sum of cells}}$$

To calculate the \bar{P} , we need to know the sum of P_i :

$$P_i = \frac{1}{n(n-1)} * \text{sum of each}(n_{ij})^2$$

$$\bar{P} = \frac{1}{N} * \sum_{i=1}^N P_i$$

In this study, four raters (n) assigned eleven subjects (N) to a total of five categories (k) for 5 of the 6 questions from the questionnaire and six categories (k) for question number 6.

$n = 4$ (number of doctors that answered the questionnaire) $k = 5$ or 6 (N/A, 1, 2, 3, 4, 5) where:

- N/A means "Non-applicable";
- 1 means "Very unlikely"
- 2 means "Somewhat unlikely";
- 3 means "Likely";
- 4 means "Somewhat likely";
- 5 means "Very likely".

$N = 11$ (total number of patients)

Sum of all cells = $(N \times n) = 4 \times 11 = 44$ P_j is the portion of all assignments (44).

The statistic test (Fleiss' Kappa) used in this project was performed through an excel document. When performing a hypothesis test, a p -value helps determining the significance of the results obtained.

The significance level can be also named *alpha* and it is the probability of rejecting the null hypothesis when it is true. The significance level used in this study was 0.05 that indicates a 5% risk of concluding that a difference exists when there is no actual difference.

The p -value weights the strength of evidence and it is a number between 0 and 1 being interpreted in the following way:

- A small p -value (typically ≤ 0.05) indicates strong evidence against the null hypothesis, so null hypothesis is rejected;
- A large p -value (> 0.05) indicates weak evidence against the null hypothesis, this way we accept the null hypothesis;

When p -value very close to the cut off (0.05) is marginal what means it can go either way.

5. Results

As the main goal of this project is to study T₂ SPACE sequence, following it will be presented the images obtained by performing this sequence on 11 patients. The difference between the images for the same sequence depends in which plane the sequences have been performed. In coronal plane images is possible to observe anatomy from an anterior to posterior position, in sagittal plane is visualize anatomy position from right to left (or *vice-versa*) and in axial plane is visualize the anatomy from top (superior) to bottom (inferior). The planes performed for each patient were asked by the radiologist at the time of the scan. In this way the planes performed for each patient can vary depending who is supervising and reporting the MRI scan.

To some of the patients is was administrated *Buscopan* which is a drug used to slow down bowel's movement in order to acquire pictures with the best imaging quality reducing movement artefacts. As most of the patients considered to this study had a poor renal function, before the performance of the scans some of them had intravenous hydration (sodium chloride) and also because with T₂ SPACE sequence fluids show up with bright signal so it could be not necessary the performance of post contrast scans.

Patient 1 is a two years old female patient diagnosed with bilateral duplex kidneys associated with ureterocele on the left side and vesicoureteral reflux at the right side. As result of DMSA it was possible to conclude that the lower pole of the right kidney is poorly functioning (18%). It was also possible to observe a discrepancy in dilation on the right kidney between upper and lower pole according with ultrasound studies. To have better image quality this MR urogram was performed under general anaesthesia.

Below it is shown a sequence of images of T₂ SPACE pulse sequence with a voxel size of 0,9x0,9x0,9mm³ (Table 23) on coronal (Figure 12) and sagittal (Figure 13) planes:

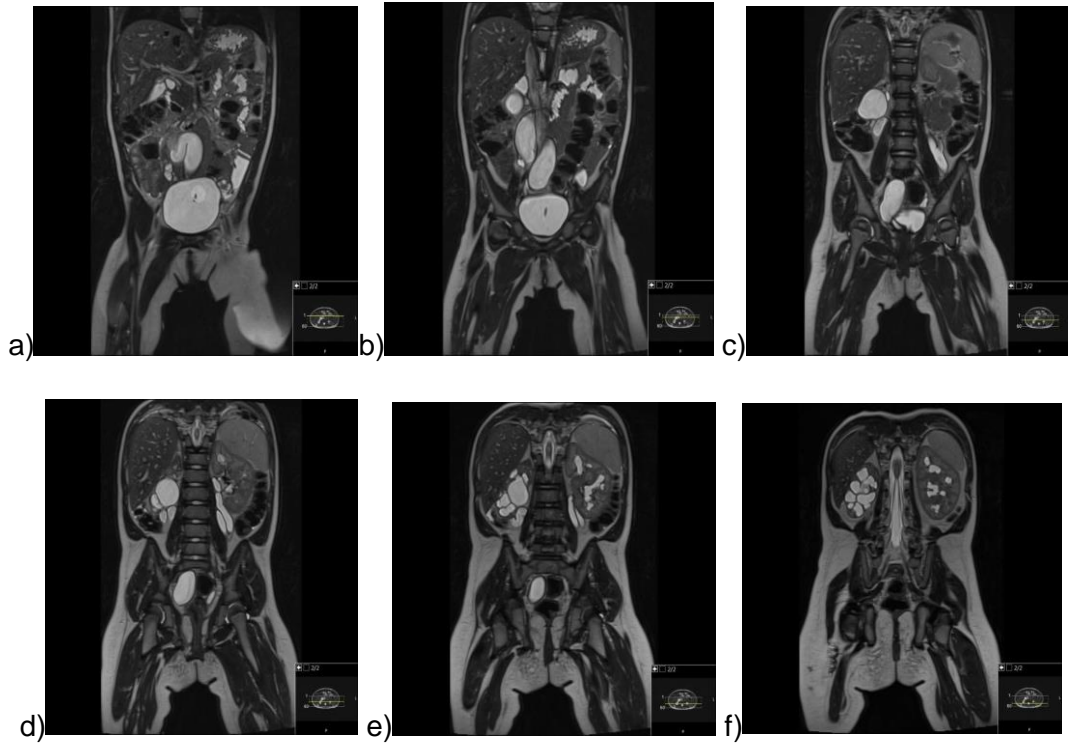


Figure 12 (a-f): Patient 1 – 2 years old female patient. Coronal T₂ SPACE pulse sequence. Under general anaesthesia.

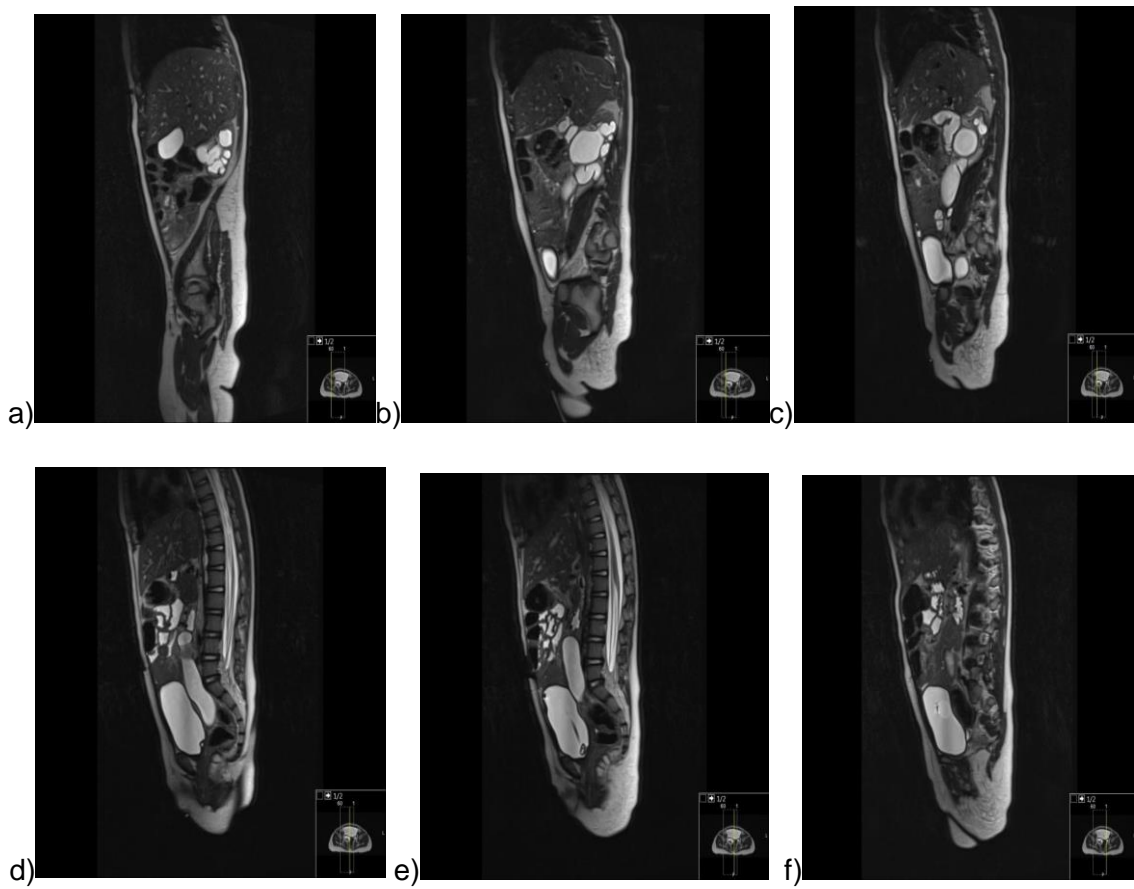


Figure 13: Patient 1 - 2 years old female patient. Sagittal T₂ SPACE pulse sequence.

In the following table (Table 2) it is shown the answers selected by the doctors involved in this study considering T₂ SPACE sequence images for patient 1. The scale used is the one described previously in section “Material and Methods”.

Patient 1							
		N/A	1	2	3	4	5
1. Is the T2 SPACE sequence valuable in renal diagnosis for this patient?			0	0	0	2	2
2. Is the contrast resolution enough for an accurate diagnosis of duplex collecting system?			0	0	0	2	2
3. Is the spatial resolution enough for duplex collecting system diagnosis?			0	0	0	2	2
4. Does the SNR (Signal to Noise Ratio) of this patient's images give sufficient diagnostic quality?			0	0	0	2	2
5. The T2 SPACE sequence is an isotropic acquisition which means the voxels generated measure the same in each direction. How helpful are MPR's in duplex collecting system diagnosis?			0	0	0	2	2
6. How much can the following artefacts affect image quality?	6.1. Phase Wrap	0	2	0	1	1	0
	6.2. Phase Shift	1	3	0	0	0	0
	6.3. Respiratory Movement	0	3	1	0	0	0
	6.4. Bowel Movement	0	3	1	0	0	0
	6.5. Urinary bladder movement	0	3	1	0	0	0

Table 2: Answers to the questionnaire given by three consultant paediatric radiologists plus one consultant radiologist considering patient 1.

Patient 2 is a 5 years old female patient with duplication of the left kidney with possible upper moiety ectopic ureter. This MR urogram was performed to evaluate the possibility of bilateral duplication. This MR scan was performed under general anaesthesia. Before the scan patient had a pre-hydration with IV (intravenous) fluids and it was used *Prohance* (*gadolinium-based* contrast) enhancement and IV Buscopan was administrated. It was used a 6 French catheter inserted prior to imaging under aseptic technique.

Below it is shown a sequence of images of T₂ SPACE pulse sequence with a voxel size of 0,9x0,9x0,9mm³ (Table 23) on coronal plane (Figure 14):

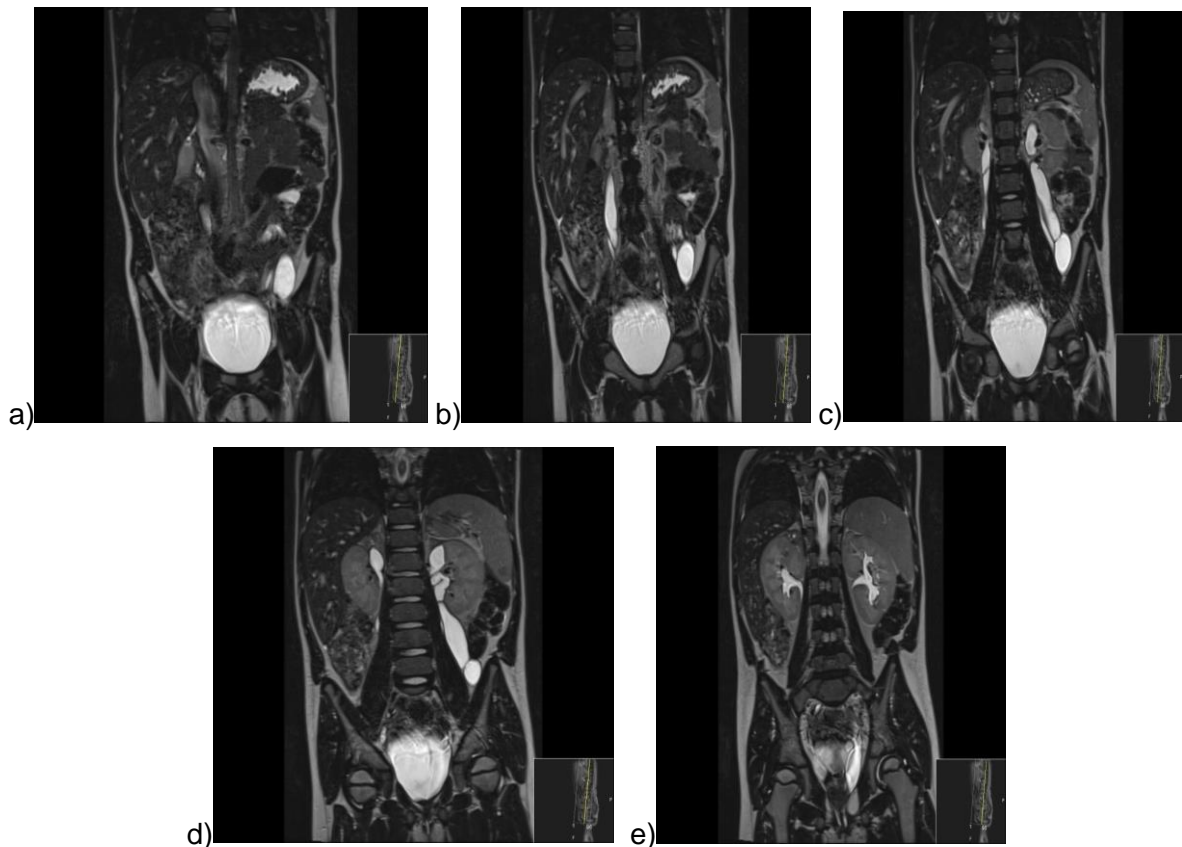


Figure 14(a-e): Patient 2 – 5 years old female patient. Coronal T₂ SPACE pulse sequence. Under general anaesthesia.

In the following table (Table 3) it is shown the answers selected by the doctors involved in this study considering T₂ SPACE sequence images for patient 2. The scale used is the one described previously in section “Material and Methods”.

Patient 2							
		N/A	1	2	3	4	5
1. Is the T2 SPACE sequence valuable in renal diagnosis for this patient?		/	0	0	0	2	2
2. Is the contrast resolution enough for an accurate diagnosis of duplex collecting system?		/	0	0	0	2	2
3. Is the spatial resolution enough for duplex collecting system diagnosis?		/	0	0	0	2	2
4. Does the SNR (Signal to Noise Ratio) of this patient's images give sufficient diagnostic quality?		/	0	0	0	2	2
5. The T2 SPACE sequence is an isotropic acquisition which means the voxels generated measure the same in each direction. How helpful are MPR's in duplex collecting system diagnosis?		/	0	0	0	2	2
6. How much can the following artefacts affect image quality?	6.1. Phase Wrap	1	2	1	0	0	0
	6.2. Phase Shift	2	2	0	0	0	0
	6.3. Respiratory Movement	0	3	1	0	0	0
	6.4 Bowel Movement	0	2	1	1	0	0
	6.5. Urinary bladder movement	0	2	1	0	1	0

Table 3: Answers to the questionnaire given by three consultant paediatric radiologists plus one consultant radiologist considering patient 2.

Patient 3 is a 4 years old female patient with symptoms of dribbling incontinence. It was advised a MR urogram due to a left duplex kidney and possible ectopic upper moiety ureter.

Below it is shown a sequence of images of T₂ SPACE pulse sequence with a voxel size of 1,0x1,0x1,0mm³ (Table 23) on coronal (Figure 15) and axial (Figure 16) planes:

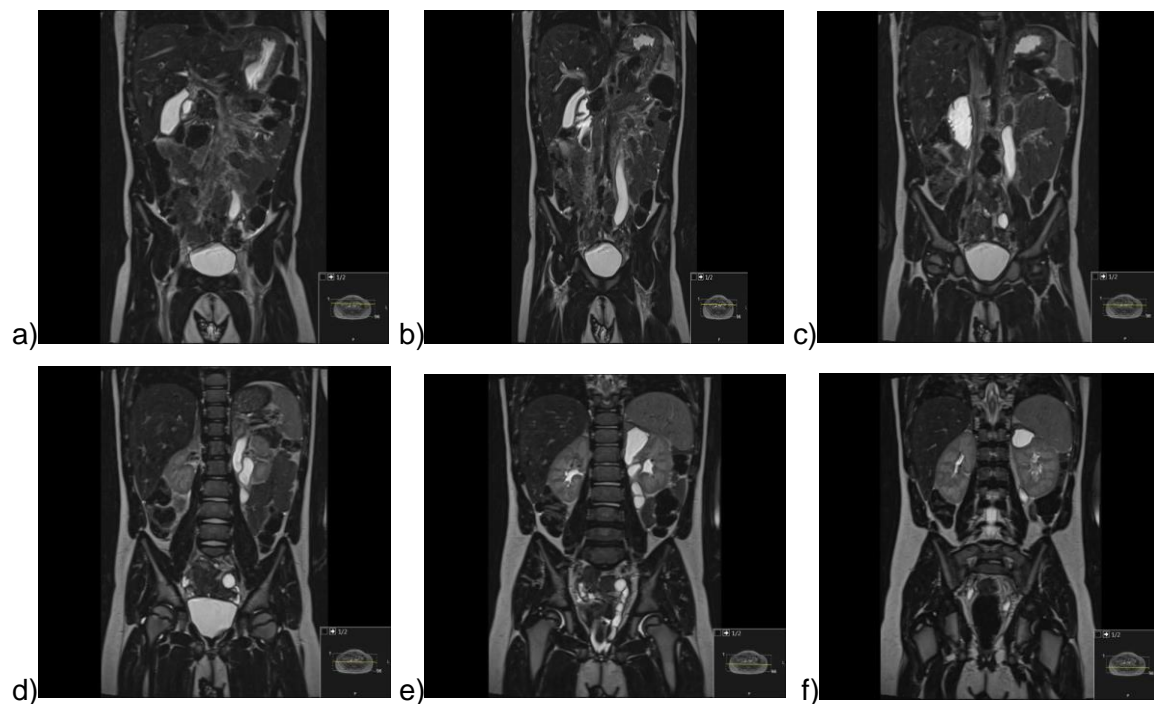


Figure 15(a-f): Patient 3 – 4 years old female patient. Coronal T₂ SPACE pulse sequence.

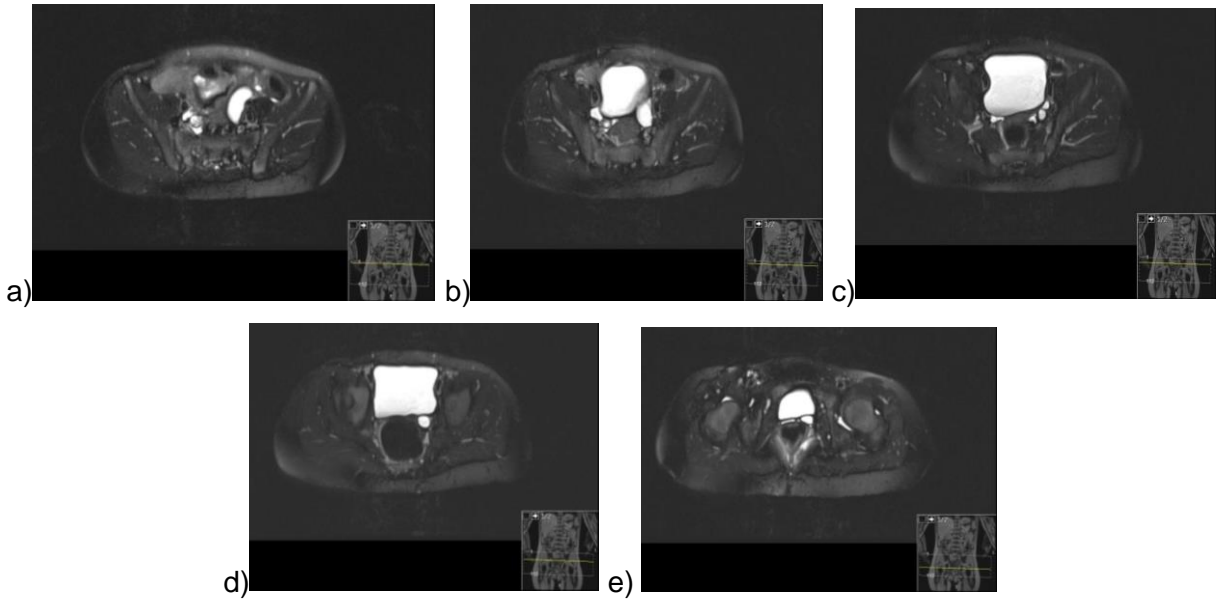


Figure 16 (a-e): Patient 3 – 4 years old female patient. Axial T₂ SPACE pulse sequence of the lower abdomen. Under general anaesthesia.

With this scan, it was possible to confirm that the left kidney is duplex being the lower moiety not hydronephrotic and there is no dilatation of the lower moiety ureter. It is shown a dilatation of the upper moiety collecting system with a dilated and tortuous upper moiety ureter. The dilated ureter can be seen to pass inferiorly and below the level of the bladder neck. The dilated ureter tapers posterior to the expected position of the vagina. According to the report the insertion of the ectopic ureter cannot be clearly identified but is likely to be the vagina.

Patient 3						
	N/A	1	2	3	4	5
1. Is the T2 SPACE sequence valuable in renal diagnosis for this patient?		0	0	1	1	2
2. Is the contrast resolution enough for an accurate diagnosis of duplex collecting system?		0	0	0	2	2
3. Is the spatial resolution enough for duplex collecting system diagnosis?		0	0	0	2	2
4. Does the SNR (Signal to Noise Ratio) of this patient's images give sufficient diagnostic quality?		0	0	0	2	2
5. The T2 SPACE sequence is an isotropic acquisition which means the voxels generated measure the same in each direction. How helpful are MPR's in duplex collecting system diagnosis?		0	0	0	0	4
6. How much can the following artefacts affect image quality?	6.1. Phase Wrap	2	2	0	0	0
	6.2. Phase Shift	2	2	0	0	0
	6.3. Respiratory Movement	1	3	0	0	0
	6.4 Bowel Movement	1	1	2	0	0
	6.5. Urinary bladder movement	1	1	2	0	0

Table 4: Answers to the questionnaire given by three consultant paediatric radiologists plus one consultant radiologist considering patient 3.

Patient 4 is a 25 years old female patient with recurrent urinary tract infections. A MR urogram was advised due to the ultrasound' results where both kidneys show up as externally rotated so duplex renal system could be confirmed.

Below it is shown a sequence of images of T₂ SPACE pulse sequence with a voxel size of 1,0x1,0x1,0mm³ (Table 23) on coronal plane (Figure 17):

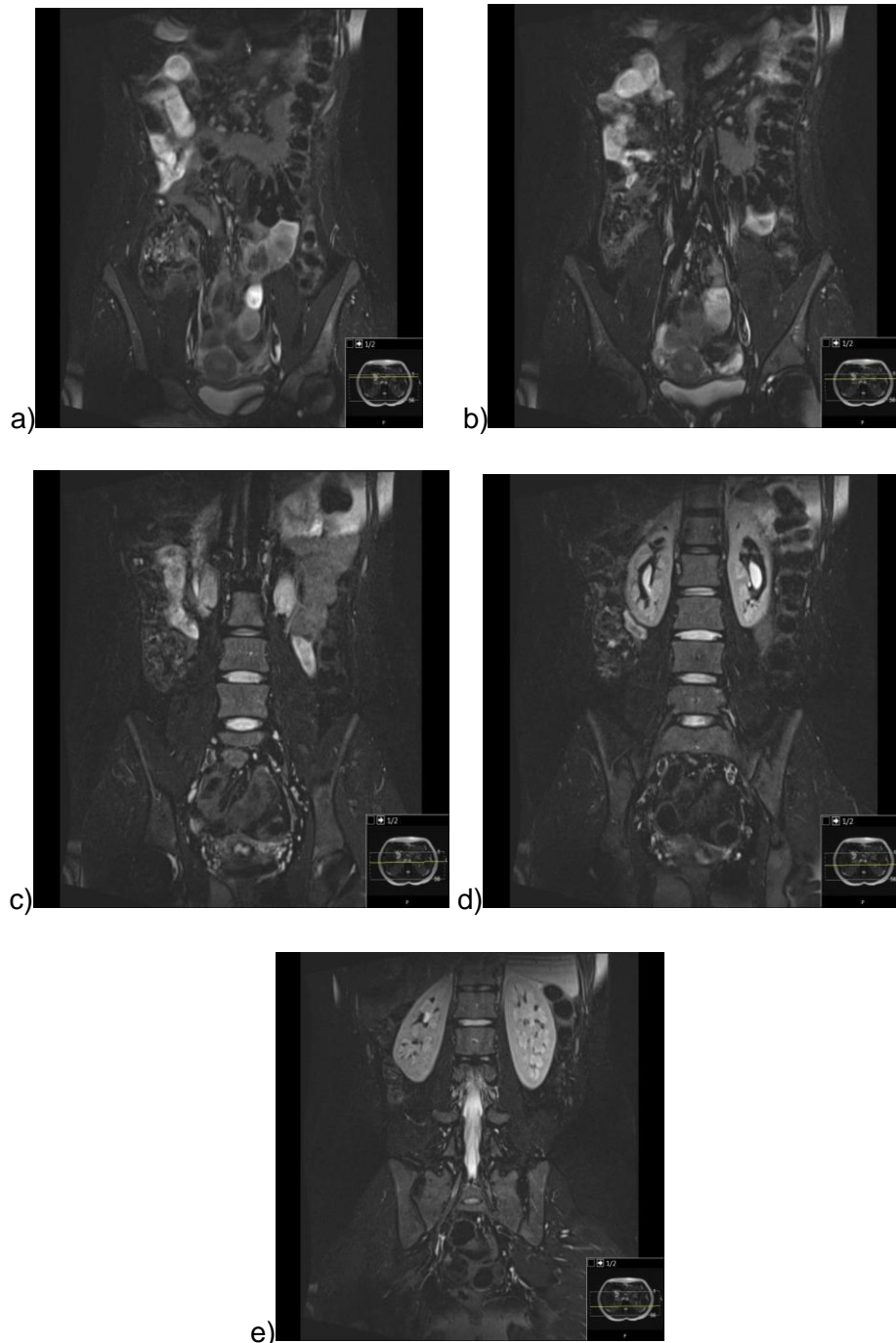


Figure 17 (a-e): Patient 4 – 25 years old female patient. Coronal T₂ SPACE pulse sequence with fat saturation applied.

Patient 4						
	N/A	1	2	3	4	5
1. Is the T2 SPACE sequence valuable in renal diagnosis for this patient?		0	0	2	0	2
2. Is the contrast resolution enough for an accurate diagnosis of duplex collecting system?		0	0	1	1	2
3. Is the spatial resolution enough for duplex collecting system diagnosis?		0	0	1	0	3
4. Does the SNR (Signal to Noise Ratio) of this patient's images give sufficient diagnostic quality?		0	0	0	2	2
5. The T2 SPACE sequence is an isotropic acquisition which means the voxels generated measure the same in each direction. How helpful are MPR's in duplex collecting system diagnosis?		0	0	2	1	1
6. How much can the following artefacts affect image quality?	6.1. Phase Wrap	2	2	0	0	0
	6.2. Phase Shift	2	1	1	0	0
	6.3. Respiratory Movement	1	2	1	0	0
	6.4. Bowel Movement	1	1	2	0	0
	6.5. Urinary bladder movement	1	2	1	0	0

Table 5: Answers to the questionnaire given by three consultant paediatric radiologists plus one consultant radiologist considering patient 4.

Patient 5 is an 8 years old female patient with symptoms of dribbling incontinence. This MRI scan was request due to possible bilateral duplex collecting system and possible left upper moiety ectopic ureter to vagina. This scan was performed without anaesthesia.

Below it is shown a sequence of images of T₂ SPACE pulse sequence with a voxel size of 0,9x0,9x0,9mm³ (Table 23) on coronal plane (Figure 18):

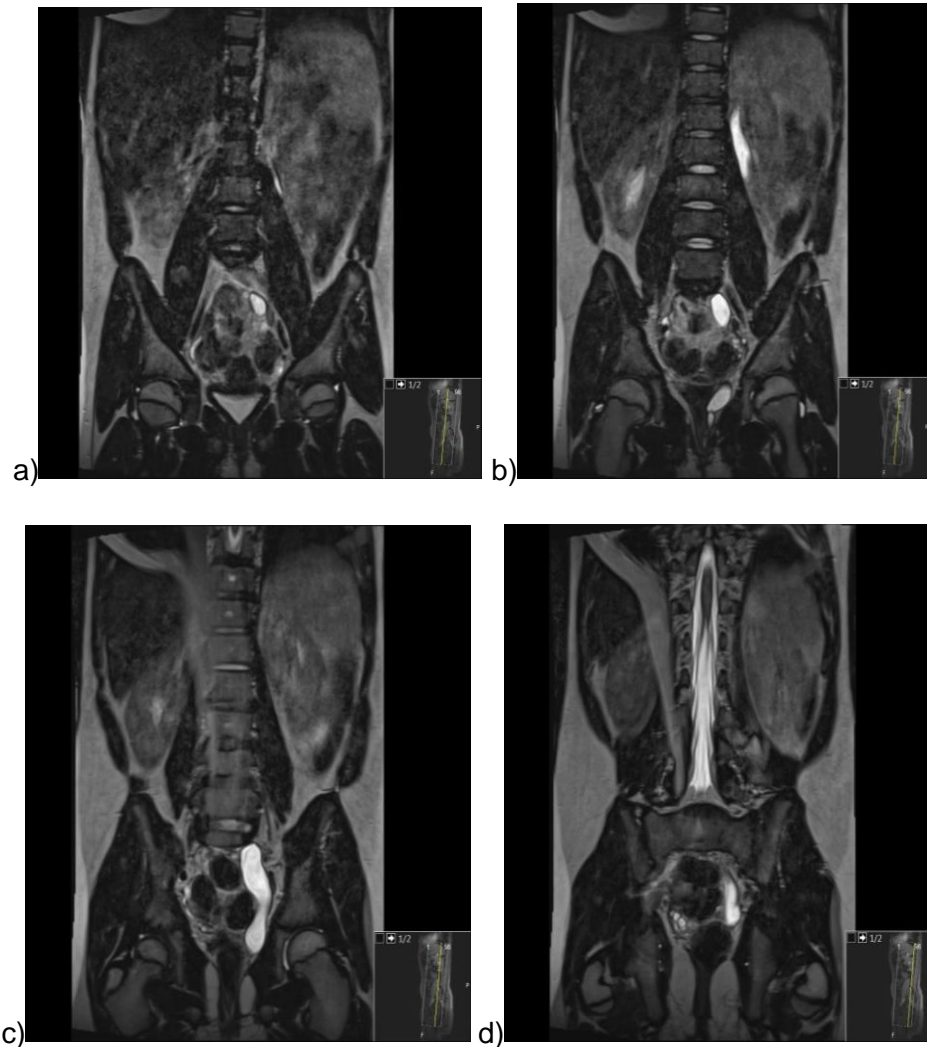


Figure 18 (a-d): Patient 5 – 8 years old female patient. Coronal T₂ SPACE pulse sequence. No general anaesthesia was used.

One of the main problems of not using general anaesthesia in paediatric patients is that these patients have more difficulties keeping their breathing regular, so their respiratory rate and depth of inspiration varies a lot also due to the long acquisition times. One way to avoid breathing artefacts is the use of triggered

sequences that allows the scanner to identify diaphragm movement with patients' breathing and thus way it will define when to acquire the pictures. This can be set up on scanner by applying a small box called *navigator* that is placed at the interface lung/liver.

With this MRI scan it was possible to observe that both kidneys are duplicated being a complete duplication on the right side. There is an impression of dysplastic upper pole moiety on the left side.

Patient 5						
	N/A	1	2	3	4	5
1. Is the T2 SPACE sequence valuable in renal diagnosis for this patient?		1	3	0	0	0
2. Is the contrast resolution enough for an accurate diagnosis of duplex collecting system?		1	1	1	0	1
3. Is the spatial resolution enough for duplex collecting system diagnosis?		2	1	0	1	0
4. Does the SNR (Signal to Noise Ratio) of this patient's images give sufficient diagnostic quality?		1	2	1	0	0
5. The T2 SPACE sequence is an isotropic acquisition which means the voxels generated measure the same in each direction. How helpful are MPR's in duplex collecting system diagnosis?		1	0	0	3	0
6. How much can the following artefacts affect image quality?	6.1. Phase Wrap	0	0	1	1	1
	6.2. Phase Shift	1	2	1	0	0
	6.3. Respiratory Movement	0	0	2	0	0
	6.4. Bowel Movement	0	0	1	1	1
	6.5. Urinary bladder movement	1	2	1	0	0

Table 6: Answers to the questionnaire given by three consultant paediatric radiologists plus one consultant radiologist considering patient 5.

Patient 6 is a 7 months old male patient with possible bilateral duplex collecting system where there is a querying about: left upper moiety dilatation as well as right upper moiety dilatation. This MRI urography was requested to access anatomy of the ureters and the drainage and it was performed under general anaesthesia.

Below it is shown a sequence of images of T₂ SPACE pulse sequence with a voxel size of 0,9x0,9x0,9mm³ (Table 23) on coronal plane (Figure 19):



Figure 19 (a-h): Patient 6 – 7 months old male patient. Coronal T₂ SPACE sequence pulse. Patient scanned under general anaesthesia.

For this patient it was administrated Furosemide (1mg per kilogram) which function is a powerful diuretic to inhibit reabsorption from the ascending limb of the loop of Henle in the renal tubule. It was observed a duplex system with tortuous and dilated ureters in all moieties.

Patient 6							
		N/A	1	2	3	4	5
1. Is the T2 SPACE sequence valuable in renal diagnosis for this patient?			0	0	1	1	2
2. Is the contrast resolution enough for an accurate diagnosis of duplex collecting system?			0	0	0	1	3
3. Is the spatial resolution enough for duplex collecting system diagnosis?			0	0	1	1	2
4. Does the SNR (Signal to Noise Ratio) of this patient's images give sufficient diagnostic quality?			0	0	1	1	2
5. The T2 SPACE sequence is an isotropic acquisition which means the voxels generated measure the same in each direction. How helpful are MPR's in duplex collecting system diagnosis?			0	0	0	2	2
6. How much can the following artefacts affect image quality?	6.1. Phase Wrap	2	2	0	0	0	0
	6.2. Phase Shift	2	2	0	0	0	0
	6.3. Respiratory Movement	1	3	0	0	0	0
	6.4. Bowel Movement	1	2	1	0	0	0
	6.5. Urinary bladder movement	1	1	0	1	1	0

Table 7: Answers to the questionnaire given by three consultant paediatric radiologists plus one consultant radiologist considering patient 6.

Patient 7 is a 68 years old female patient with recurrent haematuria being this scan requested as patient is allergic to contrast used in CT scans.

Below it is shown a sequence of images of T₂ SPACE pulse sequence with a voxel size of 1,0x1,0x1,0mm³ (Table 23) on coronal plane (Figures 20 and 21):

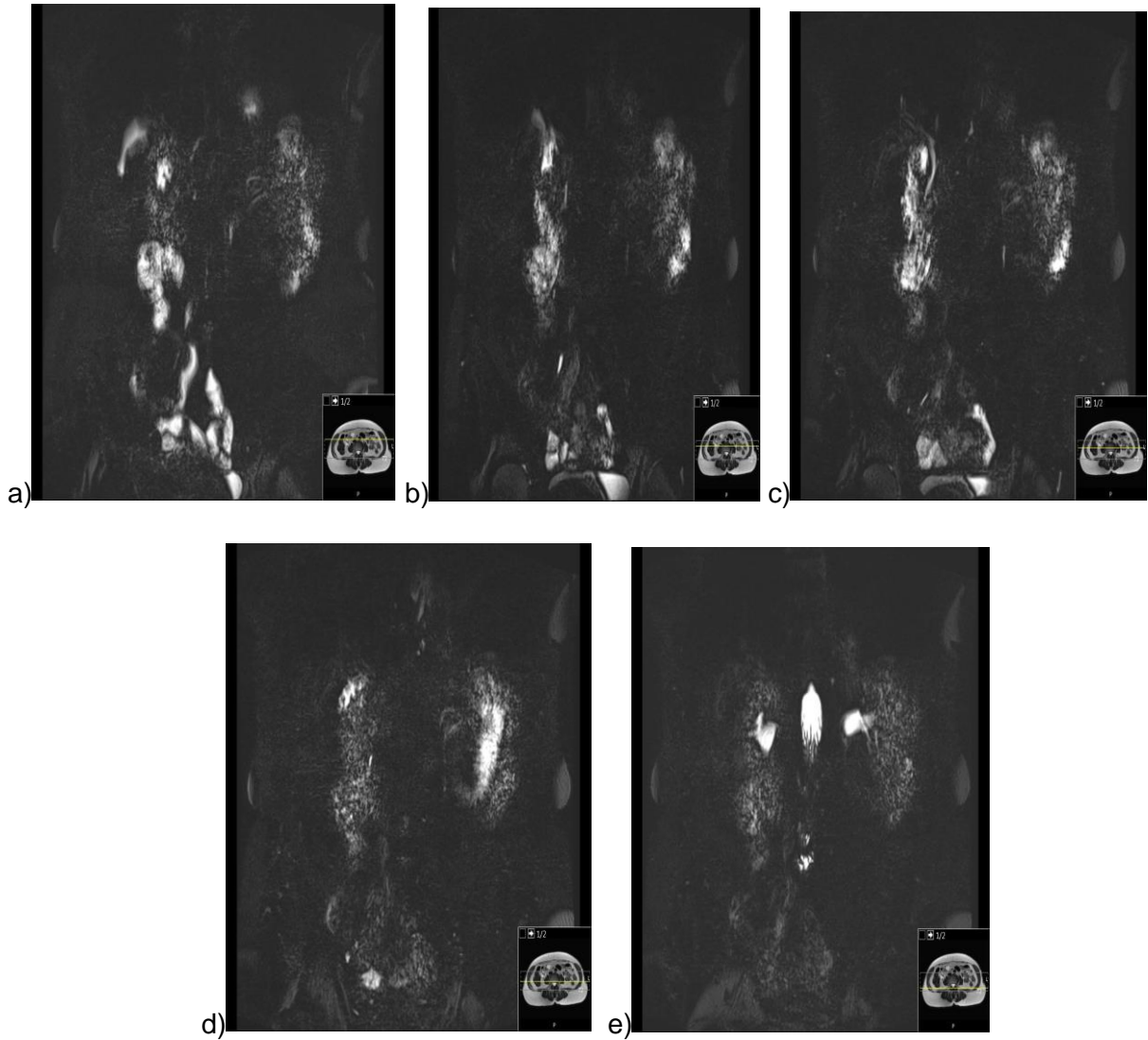


Figure 20 (a-e): Patient 7 – 68 years old female patient. Coronal T₂ SPACE pulse sequence with fat saturation.

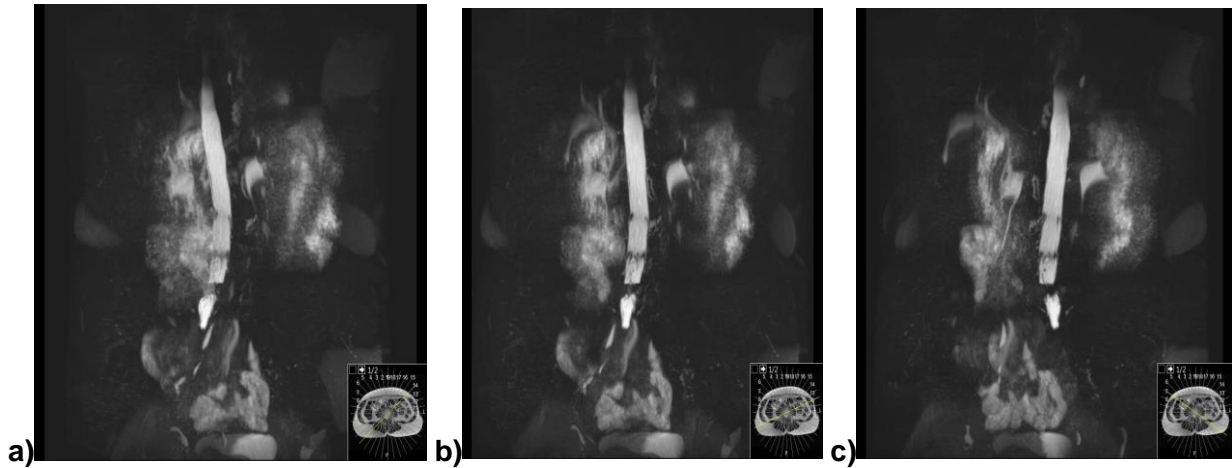


Figure 21 (a-d): Patient 7 – 68 years old female patient. MIP's (Maximum Intensity Projection) of Coronal T₂ SPACE pulse sequence with fat saturation.

Patient 7						
	N/A	1	2	3	4	5
1. Is the T2 SPACE sequence valuable in renal diagnosis for this patient?		1	3	0	0	0
2. Is the contrast resolution enough for an accurate diagnosis of duplex collecting system?		0	2	0	1	1
3. Is the spatial resolution enough for duplex collecting system diagnosis?		0	3	1	0	0
4. Does the SNR (Signal to Noise Ratio) of this patient's images give sufficient diagnostic quality?		2	2	0	0	0
5. The T2 SPACE sequence is an isotropic acquisition which means the voxels generated measure the same in each direction. How helpful are MPR's in duplex collecting system diagnosis?		0	2	1	1	0
6. How much can the following artefacts affect image quality?	6.1. Phase Wrap	2	2	0	0	0
	6.2. Phase Shift	3	1	0	0	0
	6.3. Respiratory Movement	0	2	1	1	0
	6.4. Bowel Movement	0	1	1	1	0
	6.5. Urinary bladder movement	1	1	2	0	0

Table 8: Answers to the questionnaire given by three consultant paediatric radiologists plus one consultant radiologist considering patient 7.

Patient 8 is a 11 years old female patient with onset of urinary leak. MRI scan was requested to identify cryptic duplex, which means a possibility of duplex kidneys with ectopic ureters.

Below it is shown a sequence of images of T₂ SPACE pulse sequence with a voxel size of 1,0x1,0x1,0mm³ (Table 23) on coronal plane (Figures 22 and 23):

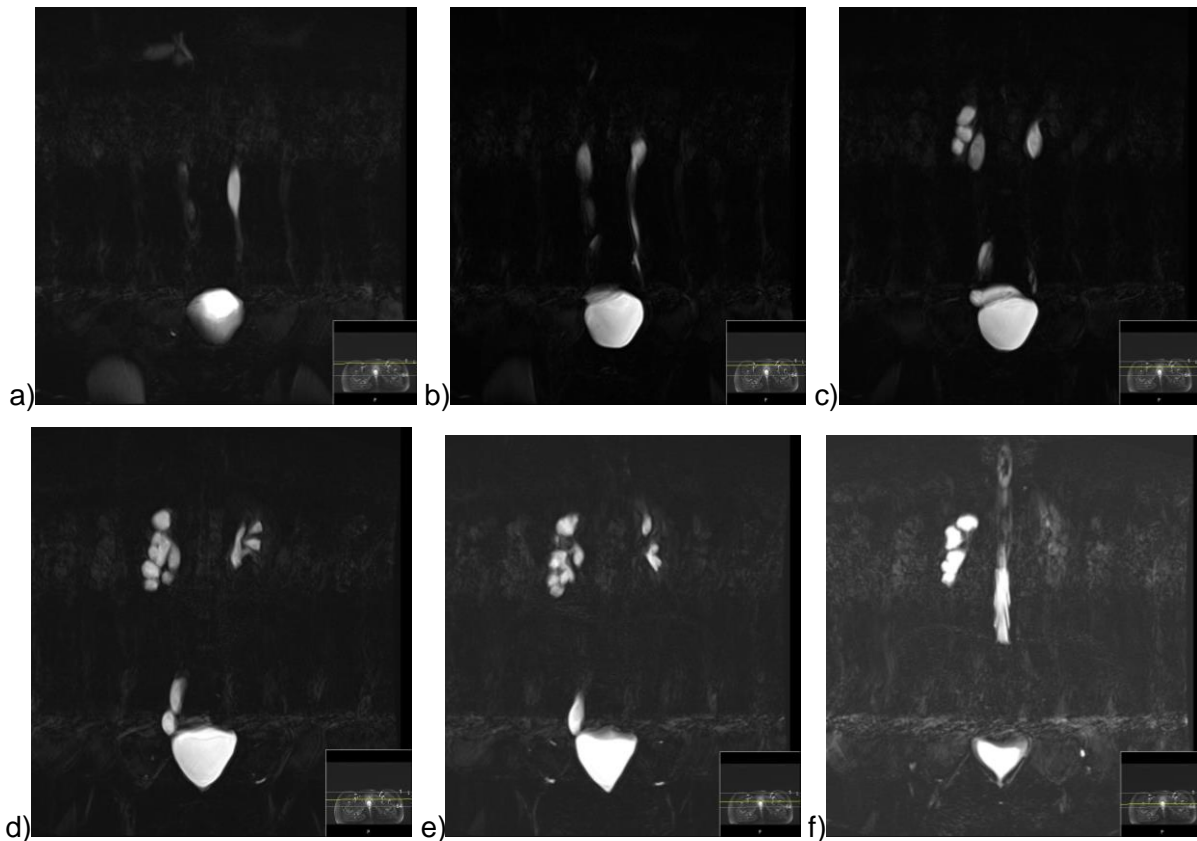


Figure 22 (a-f): Patient 8 – 11 years old female patient. Coronal T₂ SPACE pulse sequence with fat saturation.

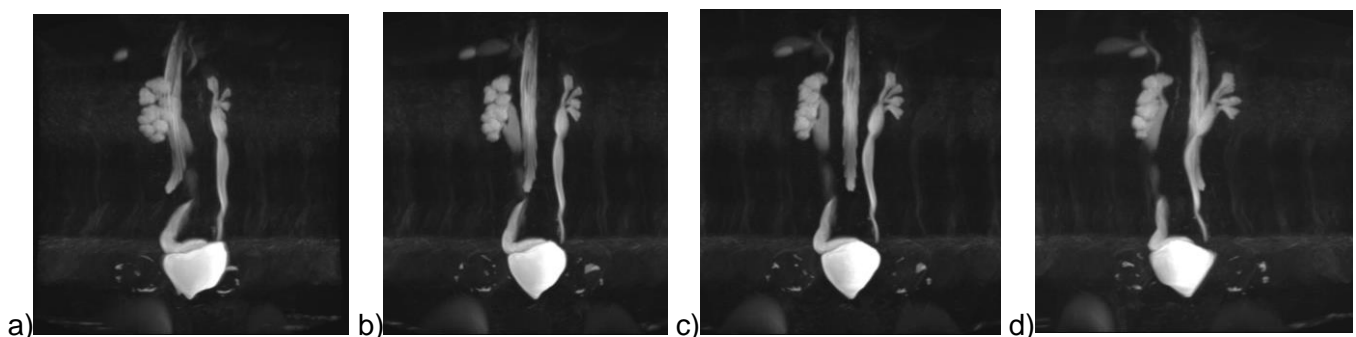


Figure 23 (a-d): Patient 8 – 11 years old female patient. MIP's of Coronal T₂ SPACE pulse sequence with fat saturation.

By performing this MR urogram scan, it was possible to observe that there is no duplex system and both kidneys drain via solitary ureters.

Patient 8							
		N/A	1	2	3	4	5
1. Is the T2 SPACE sequence valuable in renal diagnosis for this patient?		/	0	0	3	1	0
2. Is the contrast resolution enough for an accurate diagnosis of duplex collecting system?		/	0	0	3	0	1
3. Is the spatial resolution enough for duplex collecting system diagnosis?		/	0	1	2	1	0
4. Does the SNR (Signal to Noise Ratio) of this patient's images give sufficient diagnostic quality?		/	0	2	1	1	0
5. The T2 SPACE sequence is an isotropic acquisition which means the voxels generated measure the same in each direction. How helpful are MPR's in duplex collecting system diagnosis?		/	0	1	0	2	1
6. How much can the following artefacts affect image quality?	6.1. Phase Wrap	1	1	1	1	0	0
	6.2. Phase Shift	3	1	0	0	0	0
	6.3. Respiratory Movement	0	3	1	0	0	0
	6.4 Bowel Movement	0	2	2	0	0	0
	6.5. Urinary bladder movement	0	3	0	1	0	0

Table 9: Answers to the questionnaire given by three consultant paediatric radiologists plus one consultant radiologist considering patient 8.

Patient 9 is a 12 years old female patient whether doctors are querying if there is cyst on the lower pole of the left duplex kidney.

Below it is shown a sequence of images of T₂ SPACE pulse sequence with a voxel size of 0,9x0,9x0,9mm³ (Table 23) on coronal plane (Figure 24):

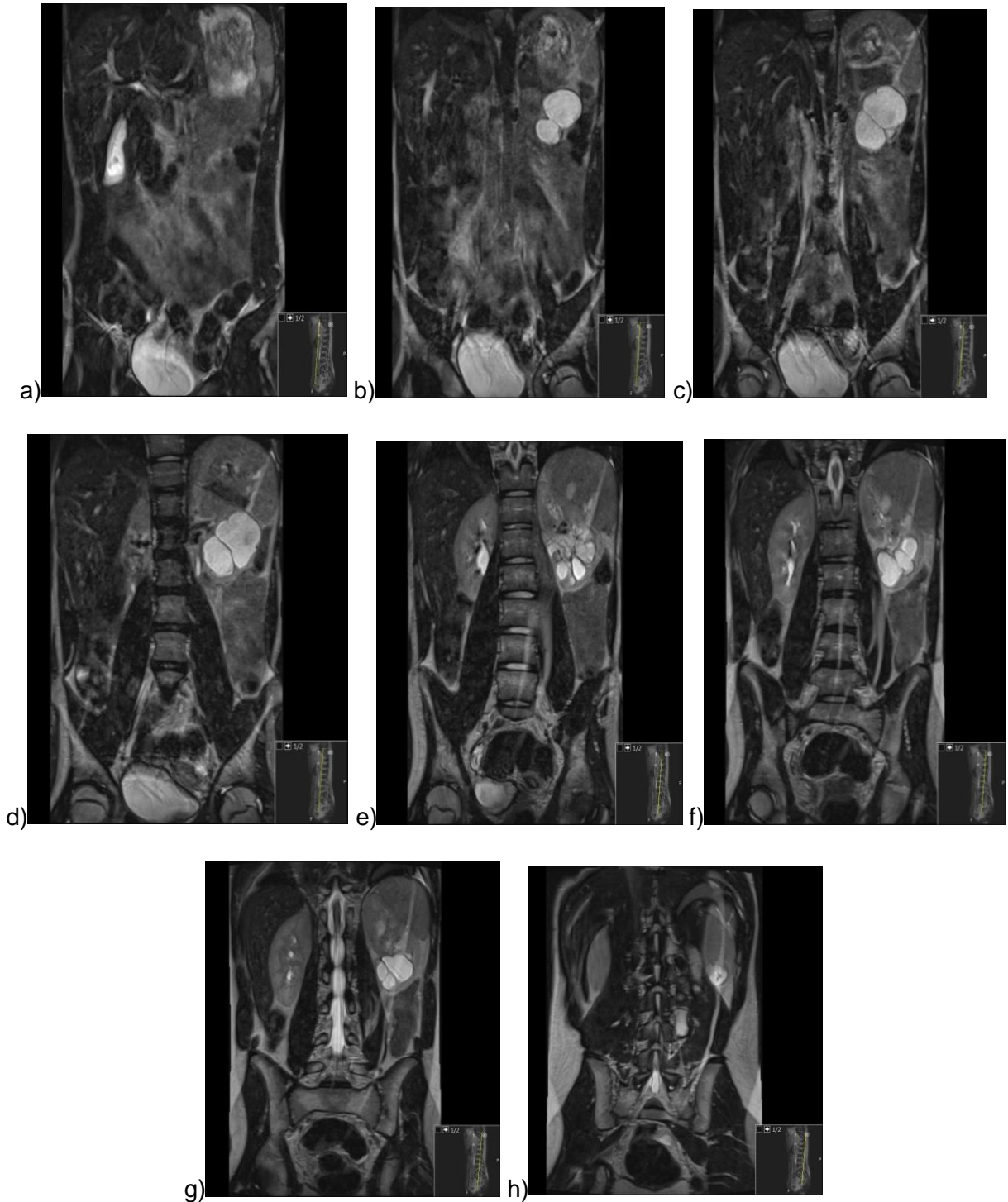


Figure 24 (a-h): Patient 9 – 12 years old female patient. Coronal T₂ SPACE pulse sequence with respiratory triggering. Scan performed without general anaesthesia.

Due to irregular breathing there is a significant movement artefact on the respiratory triggered images.

Patient 9						
	N/A	1	2	3	4	5
1. Is the T2 SPACE sequence valuable in renal diagnosis for this patient?		1	0	1	1	1
2. Is the contrast resolution enough for an accurate diagnosis of duplex collecting system?		0	0	2	0	2
3. Is the spatial resolution enough for duplex collecting system diagnosis?		0	1	1	0	2
4. Does the SNR (Signal to Noise Ratio) of this patient's images give sufficient diagnostic quality?		1	0	1	0	2
5. The T2 SPACE sequence is an isotropic acquisition which means the voxels generated measure the same in each direction. How helpful are MPR's in duplex collecting system diagnosis?		0	1	0	1	2
6. How much can the following artefacts affect image quality?	6.1. Phase Wrap	0	0	1	1	1
	6.2. Phase Shift	2	2	0	0	0
	6.3. Respiratory Movement	0	2	2	0	0
	6.4. Bowel Movement	0	1	1	0	1
	6.5. Urinary bladder movement	1	1	2	0	0

Table 10: Answers to the questionnaire given by three consultant paediatric radiologists plus one consultant radiologist considering patient 9.

Patient 10 is a 21 years old female patient with symptoms of constant urine loss. Patient underwent through a CT scan urogram, where it was possible to confirm a duplex system on the right side with duplicated ureters. An MRI scan was suggested to find out whether patient has a congenital ureteric anomaly. This scan was performed without the use of general anaesthesia.

Below it is shown a sequence of images of T₂ SPACE pulse sequence with a voxel size of 1,0x1,0x1,0mm³ (Table 23) on coronal plane (Figure 25 and 26):

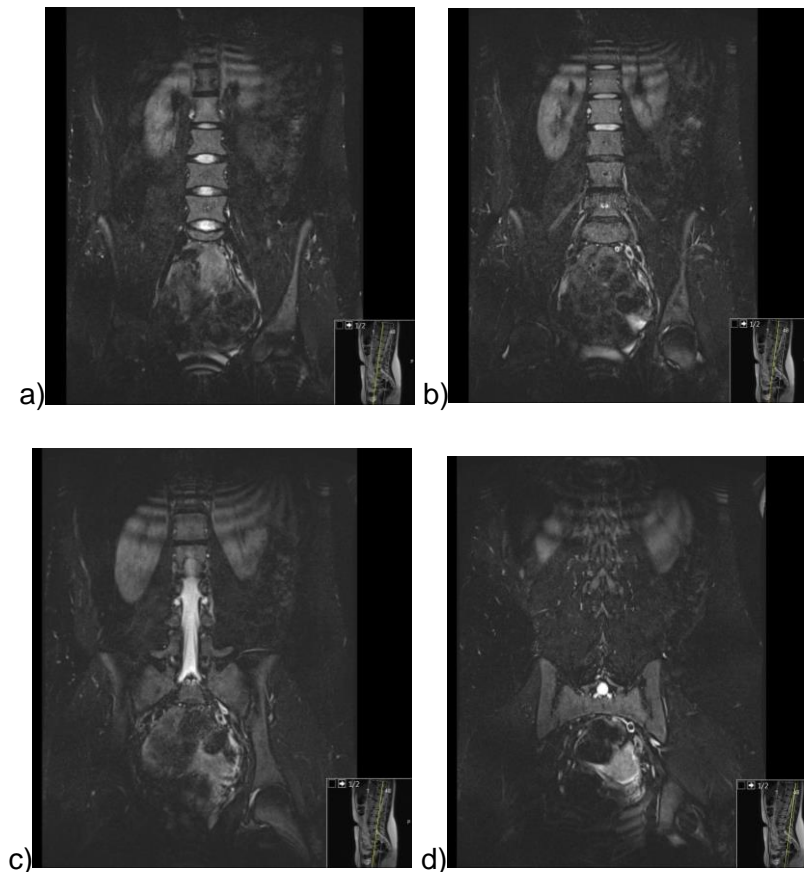


Figure 25 (a-d): Patient 10 – 21 years old female patient. Coronal T₂ SPACE pulse sequence with respiratory triggering. Scan performed without general anaesthesia.

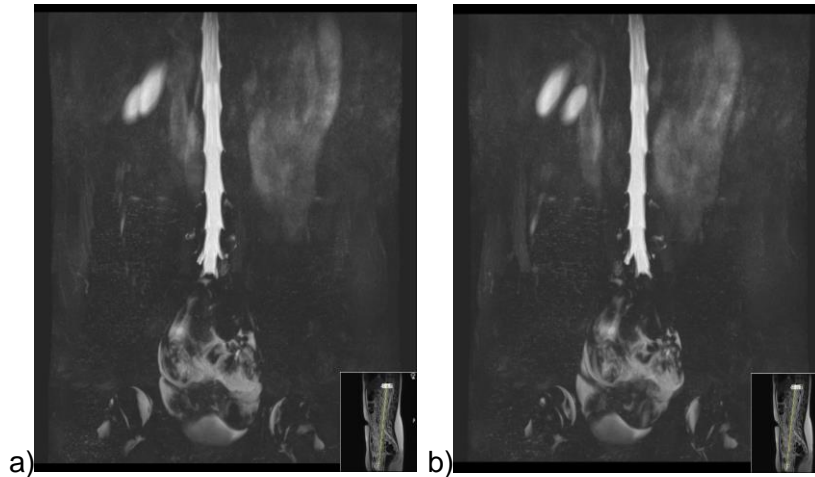


Figure 26 (a-b): Patient 10 – 21 years old female patient. MIP's of Coronal T₂ SPACE pulse sequence.

With this MRI scan it was possible to observe the normality of the right upper pole moiety and its normal excretion. It was not observed any evidence of obstruction or atrophic change within either moiety of the right kidney. The left kidney appears normal.

The MR urogram confirms the duplicated ureter is just about traceable to the level of the pelvic brim but it is not traceable beyond. Otherwise, the overall picture is of a normally functioning upper moiety with no upper tract ureteric dilatation and no fluid is appreciated within the vaginal vault as might be expected.

Patient 10							
	N/A	1	2	3	4	5	
1. Is the T2 SPACE sequence valuable in renal diagnosis for this patient?		2	0	1	1	0	
2. Is the contrast resolution enough for an accurate diagnosis of duplex collecting system?		1	1	1	0	1	
3. Is the spatial resolution enough for duplex collecting system diagnosis?		1	1	2	0	0	
4. Does the SNR (Signal to Noise Ratio) of this patient's images give sufficient diagnostic quality?		2	0	2	0	0	
5. The T2 SPACE sequence is an isotropic acquisition which means the voxels generated measure the same in each direction. How helpful are MPR's in duplex collecting system diagnosis?		1	1	0	2	0	
6. How much can the following artefacts affect image quality?	6.1. Phase Wrap	0	2	1	1	0	0
	6.2. Phase Shift	3	1	0	0	0	0
	6.3. Respiratory Movement	0	2	0	0	0	2
	6.4. Bowel Movement	0	1	0	3	0	0
	6.5. Urinary bladder movement	1	2	1	0	0	0

Table 11: Answers to the questionnaire given by three consultant paediatric radiologists plus one consultant radiologist considering patient 10.

Patient 11 is an 11-month-old female patient with left duplex kidney. This MRI scan was requested to access left kidney anatomy to understand whether it is a complete duplex kidney in which case where does the second ureter insert; or if it is an incomplete duplex kidney.

Below it is shown a sequence of images of T₂ SPACE pulse sequence with a voxel size of 0,9x0,9x0,9mm³ (Table 23) on coronal plane (Figure 27):

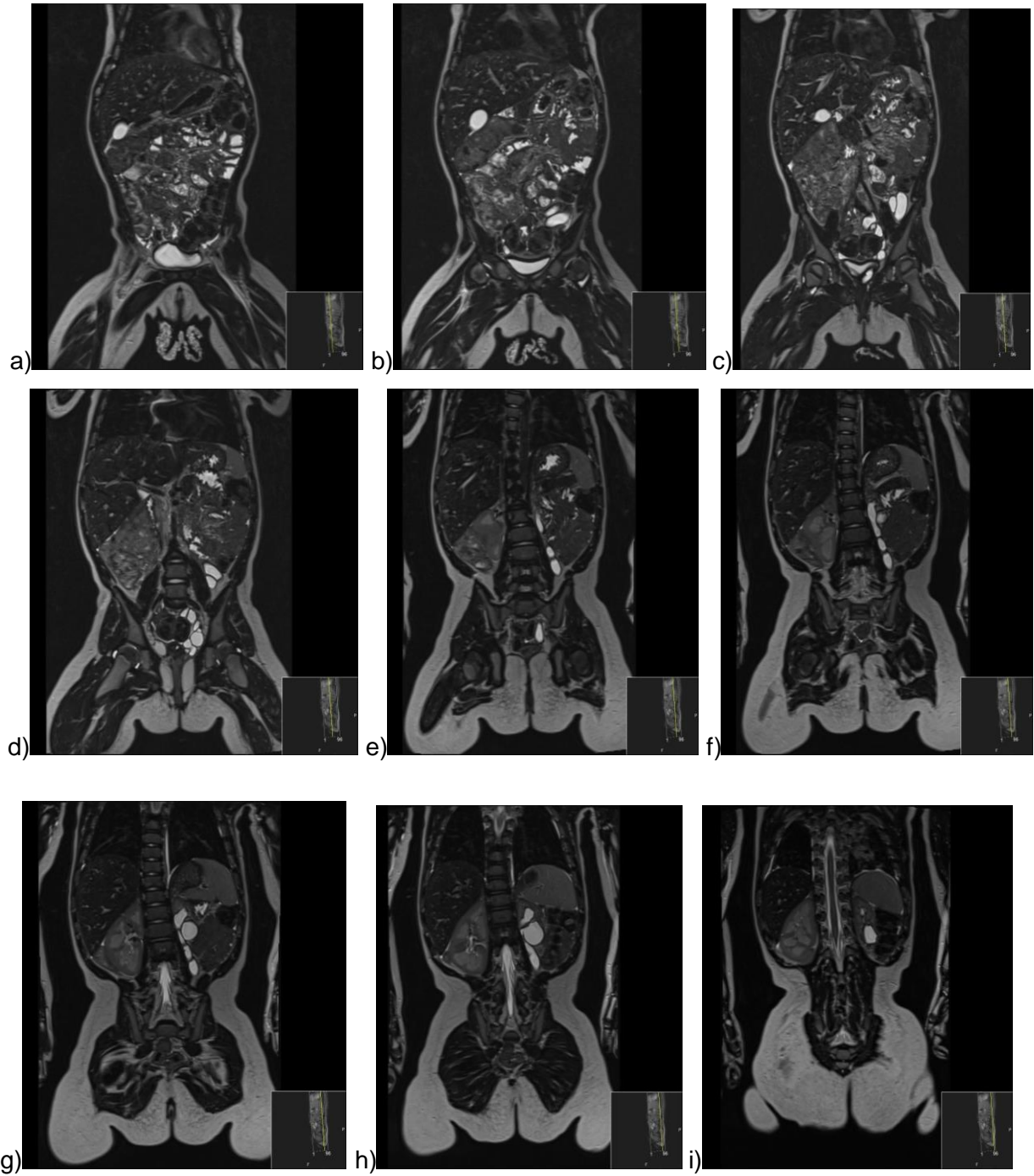


Figure 27 (a-j): Patient 11 – 11-month-old female patient. Coronal T₂ SPACE pulse sequence. MR urogram scanned under general anaesthesia. (There is no report available as the scan was performed a week before this thesis has been written.)

Patient 11						
	N/A	1	2	3	4	5
1. Is the T2 SPACE sequence valuable in renal diagnosis for this patient?		0	0	0	1	3
2. Is the contrast resolution enough for an accurate diagnosis of duplex collecting system?		0	0	0	2	2
3. Is the spatial resolution enough for duplex collecting system diagnosis?		0	0	0	2	2
4. Does the SNR (Signal to Noise Ratio) of this patient's images give sufficient diagnostic quality?		0	0	0	2	2
5. The T2 SPACE sequence is an isotropic acquisition which means the voxels generated measure the same in each direction. How helpful are MPR's in duplex collecting system diagnosis?		0	0	0	2	2
6. How much can the following artefacts affect image quality?	6.1. Phase Wrap	2	2	0	0	0
	6.2. Phase Shift	2	2	0	0	0
	6.3. Respiratory Movement	1	3	0	0	0
	6.4. Bowel Movement	1	2	1	0	0
	6.5. Urinary bladder movement	1	3	0	0	0

Table 12: Answers to the questionnaire given by three consultant paediatric radiologists plus one consultant radiologist considering patient 11.

Following it is possible to observe the results obtained for each question of the questionnaire (available in the attachments section) answered by three paediatric consultant radiologists plus a consultant radiologist after the application of Fleiss' Kappa test.

Question 1					
	1	2	3	4	5
1	0	0	0	2	2
2	0	0	0	2	2
3	0	0	1	1	2
4	0	0	2	0	2
5	1	3	0	0	0
6	0	0	1	1	2
7	1	3	0	0	0
8	0	0	3	1	0
9	1	0	1	1	1
10	2	0	1	1	0
11	0	0	0	1	3
	5	6	9	10	14
q	0.113636	0.136364	0.204545	0.227273	0.318182
b	0.100723	0.117769	0.162707	0.17562	0.216942
k	0.03	0.51	-0.43	-0.93	-0.96
s.e.	0.123091	0.123091	0.123091	0.123091	0.123091
z	0.235884	4.14183	-3.50813	-7.57262	-7.83669
p	0.813523	3.45E-05	1.999549	2	2

m	4
n	11
Pa	0.318182
Pe	0.22624
kappa	0.118825
s.e.	0.089632
z	1.3257
p-value	0.184939
alpha	0.05
lower	0.164535
upper	0.073115

Table 13: Fleiss' Kappa test applied to question 1 for all the 11 patients (N) considering 4 doctors ($n=4$) and using the scale from 1 to 5. Mode = 5 ("very likely" in *Likert* scale).

Question 2					
	1	2	3	4	5
1	0	0	0	2	2
2	0	0	0	2	2
3	0	0	0	2	2
4	0	0	1	1	2
5	1	1	1	0	1
6	0	0	0	1	3
7	0	2	0	1	1
8	0	0	3	0	1
9	0	0	2	0	2
10	1	1	1	0	1
11	0	0	0	2	2
	2	4	8	11	19
q	0.045455	0.090909	0.181818	0.25	0.431818
b	0.043388	0.082645	0.14876	0.1875	0.245351
k	0.55	0.25	-0.21	-0.87	-1.91
s.e.	0.123091	0.123091	0.123091	0.123091	0.123091
z	4.502553	2.034965	-1.72142	-7.07273	-15.517
p	6.71E-06	0.041854	1.914825	2	2

m	4
n	11
Pa	0.272727
Pe	0.292355
kappa	-0.02774
s.e.	0.110371
z	-0.25131
p-value	1.198425
alpha	0.05
lower	0.028549
upper	-0.08402

Table 14: Fleiss' Kappa test applied to question 2 for all the 11 patients (N) considering 4 doctors ($n=4$) and using the scale from 1 to 5. Mode = 5 ("very likely" in *Likert* scale).

Question 3					
	1	2	3	4	5
1	0	0	0	2	2
2	0	0	0	2	2
3	0	0	0	2	2
4	0	0	1	0	3
5	2	1	0	1	0
6	0	0	0	1	3
7	0	3	1	0	0
8	0	1	2	1	0
9	0	1	1	0	2
10	1	1	2	0	0
11	0	0	0	2	2
	3	7	7	11	16
q	0.068182	0.159091	0.159091	0.25	0.363636
b	0.063533	0.133781	0.133781	0.1875	0.231405
k	0.47	-0.13	-0.27	-0.87	-0.98
s.e.	0.123091	0.123091	0.123091	0.123091	0.123091
z	3.837289	-1.07206	-2.21243	-7.07273	-7.95197
p	0.000124	1.716309	1.973063	2	2

m	4
n	11
Pa	0.318182
Pe	0.25
kappa	0.090909
s.e.	0.097386
z	0.933495
p-value	0.350564
alpha	0.05
lower	0.140573
upper	0.041245

Table 15: Fleiss' Kappa test applied to question 3 for all the 11 patients (N) considering 4 doctors ($n=4$) and using the scale from 1 to 5. Mode = 5 ("very likely" in *Likert* scale).

Question 4					
	1	2	3	4	5
1	0	0	0	2	2
2	0	0	0	2	2
3	0	0	0	2	2
4	0	0	0	2	2
5	1	2	1	0	0
6	0	0	1	1	2
7	2	2	0	0	0
8	0	2	1	1	0
9	1	0	1	0	2
10	2	0	2	0	0
11	0	0	0	2	2
	6	6	6	12	14
q	0.136364	0.136364	0.136364	0.272727	0.318182
b	0.117769	0.117769	0.117769	0.198347	0.216942
k	-0.05	0.09	-0.19	-0.95	-1.10
s.e.	0.123091	0.123091	0.123091	0.123091	0.123091
z	-0.41965	0.720721	-1.56002	-7.71032	-8.97706
p	1.325258	0.471081	1.881245	2	2

m	4
n	11
Pa	0.272727
Pe	0.231405
kappa	0.053763
s.e.	0.090566
z	0.593638
p-value	0.552754
alpha	0.05
lower	0.09995
upper	0.007577

Table 16: Fleiss' Kappa test applied to question 4 for all the 11 patients (N) considering 4 doctors ($n=4$) and using the scale from 1 to 5. Mode = 5 ("very likely" in *Likert* scale).

Question 5					
	1	2	3	4	5
1	0	0	0	2	2
2	0	0	0	2	2
3	0	0	0	0	4
4	0	0	2	2	0
5	1	0	0	3	0
6	0	0	0	2	2
7	0	2	1	1	0
8	0	1	0	2	1
9	0	1	0	1	2
10	1	1	0	2	0
11	0	0	0	2	2
	2	5	3	19	15
q	0.045455	0.113636	0.068182	0.431818	0.340909
b	0.043388	0.100723	0.063533	0.245351	0.22469
k	0.55	0.03	0.47	-1.77	-0.76
s.e.	0.123091	0.123091	0.123091	0.123091	0.123091
z	4.502553	0.235884	3.837289	-14.3766	-6.18515
p	6.71E-06	0.813523	0.000124	2	2

m	4
n	11
Pa	0.348485
Pe	0.322314
kappa	0.038618
s.e.	0.115975
z	0.332984
p-value	0.739146
alpha	0.05
lower	0.097762
upper	-0.02053

Table 17: Fleiss' Kappa test applied to question 5 for all the 11 patients (M) considering 4 doctors ($n=4$) and using the scale from 1 to 5. Mode = 4 ("somewhat likely" in *Likert* scale).

Question 6						
6.1. Phase wrap						
	N/A	1	2	3	4	5
1	0	2	0	1	1	0
2	1	2	1	0	0	0
3	2	2	0	0	0	0
4	2	2	0	0	0	0
5	0	0	1	1	1	1
6	2	2	0	0	0	0
7	2	2	0	0	0	0
8	1	1	1	1	0	0
9	0	0	1	1	1	1
10	0	2	1	1	0	0
11	2	2	0	0	0	0
	12	17	5	5	3	2
q	0.272727	0.386364	0.113636	0.113636	0.068182	0.045455
b	0.198347	0.237087	0.100723	0.100723	0.063533	0.043388
k	0.006944	-0.11837	-5.20513	-5.20513	-4.90244	-0.04762
s.e.	0.123091	0.123091	0.123091	0.123091	0.123091	0.123091
z	0.056417	-0.96167	-42.2867	-42.2867	-39.8276	-0.38686
p	0.95501	1.663784	2	2	2	1.301139

m	4
n	11
Pa	0.19697
Pe	0.256198
kappa	-0.07963
s.e.	0.123091
z	-0.64691
p-value	1.482313
alpha	0.05
lower	-0.32088
upper	0.161625

Table 18: Fleiss' Kappa test applied to question 6.1 (Phase Wrap Artefact) for all the 11 patients (M) considering 4 doctors ($n=4$) and using the scale from 1 to 5. Mode = 1 ("very unlikely" in *Likert* scale).

Question 6						
6.2. Phase Shift						
	N/A	1	2	3	4	5
1	1	3	0	0	0	0
2	2	2	0	0	0	0
3	2	2	0	0	0	0
4	2	1	1	0	0	0
5	1	2	1	0	0	0
6	2	2	0	0	0	0
7	3	1	0	0	0	0
8	3	1	0	0	0	0
9	2	2	0	0	0	0
10	2	2	0	0	0	0
11	2	2	0	0	0	0
	22	20	2	0	0	0
q	0.666667	0.606061	0.060606	0	0	0
b	0.222222	0.238751	0.056933	0	0	0
k	-0.22727	-0.27	-0.06			
s.e.	0.174078	0.174078	0.174078	0.174078	0.174078	0.174078
z	-1.30558	-1.54661	-0.37062			
p	1.808305	1.878043	1.289077			

m	3
n	11
Pa	0.227273
Pe	0.815427
kappa	-3.18657
s.e.	0.174078
z	-18.3054
p-value	2
alpha	0.05
lower	-3.52775
upper	-2.84538

Table 19: Fleiss' Kappa test applied to question 6.2. (Phase Shift Artefact) for all the 11 patients (N) considering 4 doctors ($n=4$) and using the scale from 1 to 5. Mode = N/A ("Non-applicable" in *Likert* scale).

Question 6						
6.3. Respiratory Movement						
	N/A	1	2	3	4	5
1	0	3	1	0	0	0
2	0	3	1	0	0	0
3	1	3	0	0	0	0
4	1	2	1	0	0	0
5	0	0	2	0	0	2
6	1	3	0	0	0	0
7	0	2	1	1	0	0
8	0	3	1	0	0	0
9	0	2	2	0	0	0
10	0	2	0	0	0	2
11	1	3	0	0	0	0
	4	26	9	1	0	4
q	0.090909	0.590909	0.204545	0.022727	0	0.090909
b	0.082645	0.241736	0.162707	0.022211	0	0.082645
k	-0.1	-0.06553	-4.88995	-0.02326		0.266667
s.e.	0.123091	0.123091	0.123091	0.123091	0.123091	0.123091
z	-0.8124	-0.53234	-39.7261	-0.18893		2.16641
p	1.58344	1.405513	2	1.149853		0.03028

m	4
n	11
Pa	0.393939
Pe	0.408058
kappa	-0.0233
s.e.	0.123091
z	-0.18925
p-value	1.150106
alpha	0.05
lower	-0.26455
upper	0.217959

Table 20: Fleiss' Kappa test applied to question 6.3 (Respiratory Movement Artefact) for all the 11 patients (N) considering 4 doctors ($n=4$) and using the scale from 1 to 5. Mode = 1 ("very unlikely" in *Likert* scale).

Question 6						
6.4. Bowel Movement						
	N/A	1	2	3	4	5
1	0	3	1	0	0	0
2	0	2	1	1	0	0
3	1	1	2	0	0	0
4	1	1	2	0	0	0
5	0	0	1	1	2	0
6	1	2	1	0	0	0
7	0	1	1	1	1	0
8	0	2	2	0	0	0
9	0	1	1	0	1	1
10	0	1	0	1	2	0
11	1	2	1	0	0	0
	4	16	13	4	6	1
q	0.090909	0.363636	0.295455	0.090909	0.136364	0.022727
b	0.082645	0.231405	0.208161	0.082645	0.117769	0.022211
k	-0.1	-0.1131	-0.20099	-0.1	0.099415	-0.02326
s.e.	0.123091	0.123091	0.123091	0.123091	0.123091	0.123091
z	-0.8124	-0.91879	-1.63287	-0.8124	0.807653	-0.18893
p	1.58344	1.641795	1.897504	1.58344	0.41929	1.149853

m	4
n	11
Pa	-0.30303
Pe	0.255165
kappa	0.255165
s.e.	0.123091
z	2.072973
p-value	0.038175
alpha	0.05
lower	0.01391
upper	0.49642

Table 21: Fleiss' Kappa test applied to question 6.4 (Bowel Movement Artefact) for all the 11 patients (N) considering 4 doctors (n=4) and using the scale from 1 to 5. Mode = 1 ("very unlikely" in Likert scale).

Question 6						
6.5. Urinary Bladder Movement						
	N/A	1	2	3	4	5
1	0	3	1	0	0	0
2	0	2	1	0	1	0
3	1	1	2	0	0	0
4	1	2	1	0	0	0
5	1	2	1	0	0	0
6	1	1	0	1	1	0
7	1	1	2	0	0	0
8	1	3	0	0	0	0
9	1	1	2	0	0	0
10	1	2	1	0	0	0
11	1	3	0	0	0	0
	9	21	11	1	2	0
q	3.375	7.875	4.125	0.375	0.75	0
b	8.01563	-54.1406	-12.8906	0.234375	0.1875	0
k	1.03	1.01	1.02	0.90	0.76	
s.e.	0.12	0.12	0.12	0.12	0.12	0.12
z	8.33135	8.166099	8.252949	7.336253	6.154575	
p	0	2.22E-16	2.22E-16	2.2E-13	7.53E-10	

m	4
n	11
Pa	0.242424
Pe	91.125
kappa	-119.965
s.e.	0.123091
z	-974.6
p-value	2
alpha	0.05
lower	-120.206
upper	-119.724

Table 22: Fleiss' Kappa test applied to question 6.5 (Urinary Bladder Movement Artefact) for all the 11 patients (N) considering 4 doctors (n=4) and using the scale from 1 to 5. Mode = 1 ("very unlikely" in Likert scale).

At the following table (Table 23) it is shown the T₂ SPACE parameters used for each patient:

DICOM elements Patients	MR acquisition type	Voxel Size	Flip angle	Echo train length	Repetition Time (TR)	Echo Time
1	3D	0,9mm	140°	74	4430ms	159ms
2	3D	0,9mm	140°	74	2691ms	159ms
3	3D	1,0mm	140°	74	2409ms	159ms
4	3D	1,0mm	120°	134	3712ms	203ms
5	3D	0,9mm	140°	74	4471ms	159ms
6	3D	0,9mm	140°	118	2399ms	113ms
7	3D	1,0mm	130°	180	3053ms	701ms
8	3D	1mm	140°	180	6528ms	802ms
9	3D	0,9mm	10°	68	3377ms	113ms
10	3D	1,0mm	120°	132	3220ms	201ms
11	3D	0,9mm	140°	74	3000ms	159ms

Table 23: T₂ SPACE sequence parameters used for the eleven patients involved in this study.

Values presented in Table 23 are testing values for parameters mentioned in the same table. This means that all parameters with different values have the propose to achieve the best imaging quality (contrast resolution, spatial resolution, SNR) considering the scanning time that must be as short as possible.

6. Analysis and Discussion of results

From Table 2 to Table 12 it is possible to analyse all the answers given by the four raters for each question and each patient.

When analysing Table 2 it is possible to state that T₂ SPACE sequence was valuable for a renal diagnosis (question 1); the contrast resolution (question 2) was enough for an accurate diagnosis of duplex collecting system as well as the spatial resolution (question 3) to patient 1. The SNR (question 4) in this patient is sufficient for a diagnostic quality and MPR's (question 5) were helpful in this patient as 2 out of 4 doctors choose to rate it as "very likely" and the other 2 doctors rated it as "likely" for the five first questions. About how much can the artefacts affect this patients' images it can be observed that 3 out of 4 doctors agree that phase shift, respiratory movement, bowel movement and urinary movement are "very unlikely" to happen. The phase wrap artefact is the one rated with two "very unlikely", one "likely" and one "somewhat likely" to happen in this study.

In Table 3 it is possible to state that T₂ SPACE sequence was valuable for a renal diagnosis (question 1), contrast resolution (question 2) was enough for an accurate diagnosis of duplex collecting system as well as the spatial resolution (question 3) to patient 2. The SNR (question 4) in this patient is sufficient for a diagnostic quality and MPR's (question 5) were helpful in this patient as 2 out of 4 doctors choose to rate it as "very likely" and the other 2 doctors rated it as "likely" for the five first questions. About how much can the artefacts affect this patients' images it can be observed that 3 out of 4 doctors agree that respiratory movement is "very unlikely" to happen. The phase wrap artefact is the one rated with two "very unlikely", one "likely" and one "non-applicable" to happen in this study. After analysing this patients' images one of the doctors rated the urinary bladder movement "somewhat likely" to happen in this patient.

In Table 4 it is possible to state that T₂ SPACE sequence in a global vision was valuable for a renal diagnosis (question 1) never rated below "likely"; contrast resolution (question 2) was enough for an accurate diagnosis of duplex collecting system as well as the spatial resolution (question 3) to patient 3. The SNR (question 4) in this patient is sufficient for a diagnostic quality and MPR's (question 5) were very

helpful in this patient as all the doctors agreed to rate question 5 with “very likely”. In this patient all the artefacts possible to happen were rated as “non-applicable” at least for one of the raters which means it wasn’t observed any of those artefacts in this patient.

In Table 5 it is possible to state that T₂ SPACE sequence in a global vision was valuable for a renal diagnosis (question 1) never rated below “likely”; contrast resolution (question 2) was enough for an accurate diagnosis of duplex collecting system as well as the spatial resolution (question 3) to patient 4. The SNR (question 4) in this patient is sufficient for a diagnostic quality and MPR’s (question 5) helpful in this patient but two of the doctors rated this one as “likely”, other as “very likely” and only one as “very likely” what means that MPR’s in this patient weren’t so helpful as in the previous patients. In this patient all the artefacts possible to happen were rated as “non-applicable” at least for one of the raters which means it wasn’t observed any of those artefacts in this patient.

For patient 5, the overall view of his questionnaire is not as positive as the previous patients as it is shown in Table 6 since doctors rated question 1 between “very unlikely” and “somewhat unlikely” what means the T₂ sequence wasn’t valuable in renal diagnosis for this patient, contrast resolution generally wasn’t enough for an accurate diagnosis as well as the spatial resolution. On the other hand, MPR’s are still considered helpful in duplex collecting system since 3 out of 4 doctors rated this question with “somewhat likely”. In this patient and considering the answers given by doctors, it was possible to observe all artefacts except urinary bladder movement.

After analysing Table 7, it is possible to state that the pulse sequence in study is reasonable valuable in renal diagnosis for patient 6, contrast resolution is “very likely” enough for an accurate diagnosis of duplex collecting system, spatial resolution is rated twice as “very likely” to be enough as well as the SNR gives sufficient diagnostic quality. MPR’s are rated as “somewhat likely” and “very likely” what means it is very helpful in duplex collecting system diagnosis. Considering question 6, all artefacts were mainly classified as N/A (“Non-applicable” or with category 1 (“very unlikely”)) what means those artefacts haven’t affected image quality.

Once again, T₂ SPACE sequence is rated as “very unlikely” by three out of four doctors to be valuable in renal diagnosis for patient 7. In Table 8, it is possible to

analyse that there is a moderate agreement in question 2 between raters as two of them rated this question as “somewhat unlikely” meaning that the contrast resolution is not enough for an accurate diagnosis but one of the raters answered “somewhat likely” and another one said it is “very likely” to be enough. In question 3, the majority of the raters agree that spatial resolution is not enough for duplex collecting system. The opinions about SNR is 50% “very unlikely” and 50% “somewhat unlikely”. In this case, MPR’s were rated with two doctors saying that this is “somewhat unlikely” to be helpful for duplex collecting system diagnosis. Generically, all artefacts mentioned in the questionnaire were rated as “non-applicable” or “very unlikely” to happen what means it wasn’t clear its appearance in this case. The artefact caused by bowel movement was rated once as “somewhat likely” what means it was observed by one of the doctors. Both respiratory and bowel movement were rated once as “likely”.

In Table 9 (patient 8), it is confirmed that T₂ SPACE sequence was valuable in renal diagnosis for this patient, contrast resolution is enough for an accurate diagnosis as well as the spatial resolution, SNR gives sufficient diagnostic quality and MPR’s were helpful in duplex collecting system diagnosis but in this case all those parameters weren’t rated with such strong answers as in previous patients. It is possible to observe that in this patient case all of the four raters agreed rating almost all artefacts as “very unlikely” to affect this patient’ image quality.

Despite of the diverse range of answers to the same question, after analysing Table 10 it is possible to state that the sequence in study was valuable for renal diagnosis in patient 9. The contrast resolution, the spatial resolution, the SNR and MPR’s were rated by 50% as “very likely” In this patient’ images it was observed both phase wrap and bowel movement being the other three artefacts rated between “non-applicable” to “somewhat unlikely” which means they couldn’t confirm its present at the images acquired.

In patient 10 (Table 11), two out of four doctors involved in this study rated question 1 as “very unlikely” and that means that they think T₂ SPACE sequence wasn’t valuable for this patient’ renal diagnosis. Analysing Table 21 it can be conclude that all of four doctors agreed (even if in distinct levels) when talking about contrast resolution, spatial resolution and SNR rating all this three questions from “very unlikely” to “likely” which is not very satisfactory. About question 5, 50% of the doctors found it “somewhat likely” in duplex collecting system diagnosis. Respiratory movement was the only

imaging artefact rated as “very likely” by 50% of the raters and all the others imaging artefacts were rated from “non-applicable” (more significant in phase shift artefact what means almost all the doctors had the same opinion) to “likely” (more significant for bowel movement artefact).

In this case it is possible to confirm with Table 12 that T₂ SPACE was valuable in renal diagnosis for patient 11 considering doctors’ answers as well as it is possible to state that generally, they were all very happy with contrast and spatial resolution. The SNR in this patient’ images was sufficient for a diagnostic image quality and MPR’s were very helpful in duplex collecting system diagnosis. In this patient any of the artefacts mentioned above could be found what means they did not affect image quality.

Relatively to *kappa* value that provides the degree of agreement between raters, for question 1 *kappa* is equal to 0,12 (slight agreement); for question 2 *kappa* is -0,03 (poor agreement); question 3 *kappa* is 0,09 (slight agreement); question 4, *kappa* has a value of 0,05 (slight agreement); question 5 *kappa* value is 0,04 (slight agreement); 6.1.) *kappa* value is -0,08 (poor agreement); question 6.2.) has a *kappa* value of -3,1 (poor agreement); question 6.3.) has a *kappa* value of -0,02 (poor agreement); question 6.4.) with a *kappa* value of 0,26 (fair agreement) and question 6.5.) with a *kappa* value of -119 (poor agreement) (Table 24). When considering *p*-value (Table 24) the only question where there is a strong evidence (H_0 is rejected as $p \leq 0,05$) is question 6.4.) about bowel movement where there is a fair agreement between raters. When $p > 0,05$, that indicates a weak evidence against H_0 and when *p*-value has a value out of the range between 0 to 1 (questions 2, 6.1., 6.2., 6.3. and 6.5.) it means that there is no agreement between raters. Once again, these values are individual values (for each question) and it does not mean that raters have evaluated questions in a negative way.

Question	<i>Kappa</i>	<i>Interpretation</i>	<i>p-value</i>
1	0,12	Slight Agreement	0,18
2	-0,03	Poor Agreement	1,20
3	0,09	Slight Agreement	0,35
4	0,05	Slight Agreement	0,55
5	0,04	Slight Agreement	0,74
6.1	-0,08	Poor Agreement	1,48
6.2	-3,1	Poor Agreement	2
6.3	-0,02	Poor Agreement	1,15
6.4	0,26	Fair Agreement	0,04
6.5	-119	Poor Agreement	2

Table 24: *Kappa* and *p* values of each question obtained after applying Fleiss' *Kappa* test.

Despite of 50% of the questions having a poor agreement between raters as i.e. question 2, it does not mean that raters think that the contrast resolution is not enough for an accurate duplex collecting system diagnosis; all the raters think contrast resolution is enough for an accurate diagnosis but they can have rated in diverse levels (3 – likely; 4 – somewhat likely; 5 – very likely).

The small sample' size and the number of radiologists available to participate in this project were the two main difficulties. Apart from these difficulties, there was a delay in processing data since it took several weeks for doctors to answer the questionnaire and afterwards the post processing of data collection (application of statistic tests and its analysis). Other worry in this project is the associated cost to general anaesthesia as MRI scans can take a quite long time and small children are not able to keep immobile or to follow breathing instructions that can be necessary during MR urogram.

Unfortunately, I did not have access to renal scintigraphy or anaesthetic team prices in NHS (National Health System). The only value that I managed to know was the value of a reported MRI scan (192£).

In case of MR urogram being approved as a replacement of renal scintigraphy in renal diagnosis and specifically in duplex collecting system diagnosis and if it is adopted as part of diagnostic, follow-up and treatment protocol of this pathology instead of renal scintigraphy, it would be important to know the cost of this change to the hospital considering type of examination (MRI or renal scintigraphy) and healthcare professional staff required in this process: the cost of radiologists to report these examinations, the anaesthetic team (including anaesthetists and nurses, as most of the children will need general anaesthesia) and radiographers to perform the scan.

It would be interesting, in the future, to evaluate the relation between raters classification and the parameters of T₂ SPACE sequence used for each patient. Due to the small size of the sample and few patients with same acquisition parameters, the statistical analysis would not be relevant.

7. Conclusions

This study shows a tendency for the T₂ SPACE sequence, with specific parameters (contrast resolution, spatial resolution and SNR) described along this thesis, be valuable in renal diagnosis and more specifically in duplex collecting system diagnosis, even if the degree of agreement between raters is not always as high as we would like. The poor agreement can be justified in part due to the small sample.

The great advantage of this MRI sequence is the fact of being an isotropic sequence allowing MPR's in any plane. The reformats can be very helpful to surgeons in the case a surgery is needed or even in case of treatment, as radiologists as well as surgeons have good access to renal anatomy.

Besides all the advantages and good image quality provide by MRI scan to perform an MRI scan in small children most of the times requires general anaesthesia which includes extra costs to the hospital.

To develop this project as a UHS MR urogram protocol, it is important to keep performing this sequence in as many patients as possible when querying duplex collecting system to understand what can be improved. It is also important to know if the hospital where this study has been performed has economic capacity to support scans under general anaesthesia.

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9. Attachments

MRI Safety Questionnaire

Patient Name: **Date of Birth:**

Address:

Hospital Number:.....**Height:**.....**Weight:**.....

Body Part to be scanned:.....

**PLEASE COMPLETE THE QUESTIONS ON THIS SIDE OF THE FORM
TELEPHONE US ON 023 8120 6588 IF YOU ANSWER YES TO ANY OF THE
QUESTIONS ON THIS SIDE OF THE PAGE.
BRING THE FORM WITH YOU TO YOUR SCAN APPOINTMENT.**

1	Have you had any type of electronic, mechanical or magnetic implant added to any part of your body? <i>For example neurostimulator, implanted drug pump, programmable shunt.</i> Please give details.	Y/N	
2	Have you had any operations or procedures in the last 6 weeks? Please give details.	Y/N	
3	Have you ever had any operations or procedures on your heart? <i>For example stents, valve replacement, closure devices.</i> Please give details.	Y/N	
4	Do you have/ have you ever had a cardiac pacemaker, defibrillator, cardiac monitor? Please give as much detail as possible. <i>For example make, model, when it was fitted, which hospital?</i>	Y/N	
5	Do you have any hearing aids or a cochlear implant?	Y/N	
6	Have you ever had any operations or procedures on your head, eyes or ears? Please give details.	Y/N	
7	Have you ever had any operations involving the use of metal implants? <i>For example coils, clips, filters, screws, metal plates, joint replacements.</i> Please give details.	Y/N	
8	Have you ever been asked to swallow a capsule camera, "pillcam" to investigate your bowel?	Y/N	
9	Have you EVER had any accidents where metal has gone into your eyes? (E.g. welding, metalwork or other accidents)	Y/N	
10	Have you ever had any metal fragments in any other part of your body?	Y/N	
11	Is there any possibility that you may be pregnant? OR are you breast-feeding?	Y/N	
12	Have you ever had an allergic reaction to a contrast injection for an MRI scan?	Y/N	

Questionnaire

This questionnaire is carried out within the scope of the research project entitled "The role of T2 SPACE in urological diagnosis". This study is being performed at University Hospital of Southampton (UHS), United Kingdom, where eleven patients underwent an MRI scan. The main goal of this project is to assess the usefulness of the T2-weighted SPACE (3D) sequence in renal diagnosis, namely the duplication of renal collecting system. Ultimately, the aim of this project is to understand if it is possible to perform MRI scans instead of nuclear medicine examinations such as the renal scintigraphy primarily for the study of duplicated renal collecting systems. This avoids the use of ionizing radiation, especially important in paediatric patients.

For the following questions, I would like to ask you to access PACS, so you can look through the patient's images with best monitor quality. For this questionnaire you will be provided with patient's hospital numbers, but the numbers will not be published. For each question select one option from 1 to 5 where 1 means "very unlikely", 2 "somewhat unlikely", 3 "likely", 4 "somewhat likely" and 5 "very likely" considering ONLY the T₂ SPACE sequence.

1. Is the T₂ SPACE sequence valuable in renal diagnosis for this patient?

1	2	3	4	5
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

2. Is the contrast resolution enough for an accurate diagnosis of duplex collecting system?

1	2	3	4	5
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

3. Is the spatial resolution enough for duplex collecting system diagnosis?

1	2	3	4	5
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

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4. Does the SNR (Signal-Noise Rate) of this patient's images give sufficient diagnostic quality?

1	2	3	4	5
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

5. The T₂ SPACE sequence is an isotropic acquisition which means the voxels generated measure the same in each direction allowing the images to be reformatted with equal resolution in any direction. How helpful are MPR's in duplex collecting system diagnosis?

1	2	3	4	5
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

6. How much can the following artefacts affect image quality? For this question select one option where N/A means "Non-applicable", 1 "very unlikely", 2 "somewhat unlikely", 3 "likely", 4 "somewhat likely" and 5 "very likely"

	N/A	1	2	3	4	5
Phase Wrap	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Phase Shift	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Respiratory movement	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Bowel movement	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Urinary bladder movement	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

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Attachment 2: Questionnaire about T₂ SPACE sequence answered by four radiologists regarding 11 patients.