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Non-contrast-enhanced MR angiography using time-spin labelling inversion pulse technique for detecting crossing renal vessels in children with symptomatic ureteropelvic junction obstruction: comparison with surgical findings

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Abstract

Objectives Investigate the feasibility and evaluate the accuracy of non-contrast-enhanced MR angiography (NC-MRA) using time-spin labelling inversion pulse (time-SLIP) to identify crossing renal vessels (CRVs) in children requiring surgical treatment of ureteropelvic junction (UPJ) obstruction and compare to laparoscopic findings.

Materials and methods Nineteen children ranging from 6 to 16 years of age underwent NC-MRA using the time-SLIP technique before surgery. Two independent readers analysed the MRA images. Number of renal arteries and presence or absence of CRVs were identified and compared with surgical findings. Image quality was assessed, as well as the presence of CRVs and measurement of renal pelvis diameter. Intra and inter-reader agreement

was calculated using Cohen's kappa coefficient and Bland–Altman plots.

Results The overall image quality was fair or good in 88% of cases. NC-MRA demonstrated CRVs at the level of the obstruction in 10 children and no CRV in 9 children. All were confirmed intra-operatively except in one of the nine children. Sensitivity, specificity, NPV, PPV for predicting CRVs were 92%, 100%, 100% and 87.5%, respectively, for both readers. **Conclusion** NC-MRA is a good alternative to contrast-enhanced MRA and CT scanning for identifying CRVs in children with symptomatic UPJ.

Key points

- Time-SLIP technique offers acceptable imaging quality for identifying crossing renal vessel.
- Time-SLIP technique is easy to apply to the renal MRA examination.
- Time-SLIP technique is an alternative to contrast-enhanced MRA and CT scanning.

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Keywords Ureteropelvic junction · Crossing vessel · MR angiography · Non-contrast-enhanced · Children

Abbreviations

CE-MRA	Contrast-enhanced magnetic resonance angiography
NC-MRA	Non contrast-enhanced magnetic resonance angiography
Time-SLIP	Time spin labelling inversion pulse
CRV	Crossing renal vessel
UPJ	Uretero pelvic junction

CDS	Colour Doppler sonography
bSSFP	Balanced steady state free precession
MAG3	Mercaptoacetyltriglycine
FSE	Fast spin echo
TSE	Turbo spin echo
BBTI	Black blood inversion time
MIP	Maximum intensity projection
ICC	Intra-class correlation coefficient

Introduction

Obstruction of the ureteropelvic junction (UPJ) is frequently associated with lower-pole renal vessels crossing at the UPJ, particularly in older children with intermittent obstruction [1]. UPJ obstruction is frequently associated with lower pole renal vessels crossing at the UPJ, particularly in older children with intermittent obstruction [2]. The presence of crossing vessels (CRV) may influence surgical management. Open dismembered or laparoscopic pyeloplasty, via a retroperitoneal approach, remains the gold standard management of UPJ obstruction in children [3, 4].

In 1949, Hellstrom first described [5] the superior relocation of a lower pole crossing vessel in UPJ obstruction. Inherent to the success of this technique were the absence of intrinsic ureteral obstruction, and the presence of extrinsic ureteral compression causing renal pelvic herniation and obstruction at the UPJ. Classically, the technique consists of exposure of the CRV using a transperitoneal approach with the patient in a lateral position. The lower pole vessels are dissected free of the UPJ and pexed in a cephalad position well away from the region of the UPJ by suturing the pelvis on either side of the vessels [6, 7]. Precise knowledge of the vessel's course at the kidneys will help to shorten surgical time and minimize the risk of bleeding complications.

Colour Doppler sonography (CDS), supplemented or not by contrast-enhanced sonography, CT angiography, and MR angiography with intravenous contrast media are available as non-invasive methods for CRV detection [8–10]. CDS appears to have poor specificity and to be highly operator dependant [11]. CT angiography has been found to be a very efficient technique to identify crossing vessels [12]. The limitations and disadvantages include radiation exposure and the need for intravenous contrast medium, with potential complications from anaphylaxis and nephrotoxicity. Contrast-enhanced MR angiography (CE-MRA) appears to be an accurate technique in the identification of CRV [13, 14], but exposes one to nephrogenic systemic fibrosis [15, 16] especially in patients with renal impairment.

Some studies have reported promising data on using non-contrast magnetic resonance angiography (NC-MRA) to evaluate the renal arteries and especially spin labelling inversion pulse (Time-SLIP) technique on 1.5 T [17, 18]. NC-MRA

Time-SLIP technique uses inversion recovery prepulse and three-dimensional (3D) balanced steady-state free precession (bSSFP) under respiratory gating. To the best of our knowledge, no published study has evaluated the identification of CRV in children with NC-MRA.

The purpose of this study was to prospectively investigate the feasibility of NC-MRA with the Time-SLIP technique at 1.5 T in the identification of CRV in children with symptomatic UPJ obstruction compare to the surgical findings.

Material and methods

Subjects

This prospective single-centre study included 19 children between August 2011 and November 2014. Informed consent was obtained from each participant or parents of the participant. Children were referred for MRI and considered eligible for the study if they satisfied three criteria:

1. UPJ obstruction defined by renal pelvic dilatation on ultrasound (US) with evidence of impaired drainage on excretory diuretic renography (Tc-99 m-MAG3 with furosemide).
2. No history of antenatal hydronephrosis, with current features suggestive of intermittent obstruction such as intermittent pain or hydronephrosis.
3. A decision made to perform surgery based on clinical and imaging findings.

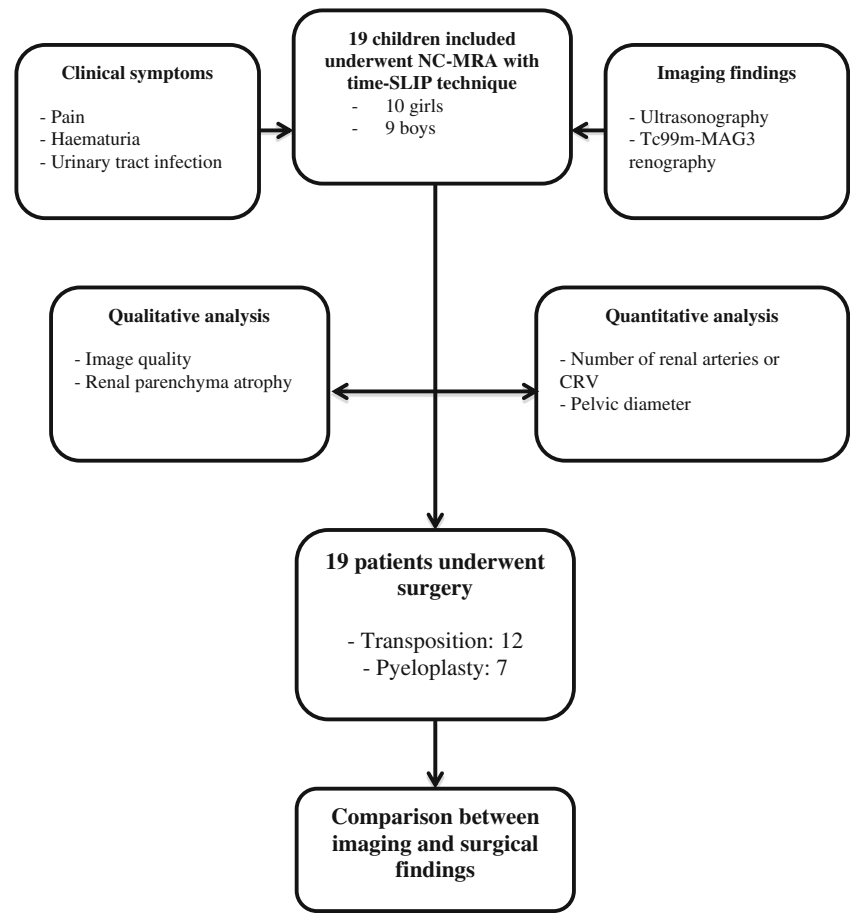
Ten girls and nine boys (age 4–16, median 9 years) who met these criteria underwent NC-MRA (Fig. 1).

Left kidneys were more often affected [11] than right ones [8]. Hydronephrosis on US was present in all children. All preoperative Tc-99 m-MAG3 renography were performed at our institution and showed evidence of impaired or absent drainage of renal pelvis.

MR Protocol

All MR images were acquired using a 1.5 T MR system (Toshiba Vantage Titan, Japan) and performed prior to surgery. All scans were performed without sedation or intravenous cannulation. The child was positioned supine on the imaging table. After scout images acquisition to determine the position of the kidneys, coronal T2-weighted (T2-W) Fast Spin Echo (FSE) and axial T2-W Turbo Spin Echo (TSE) with respiratory gating were performed. NC-MRA used a fat-suppressed 3D TSE inversion pulse with free breath under the respiratory-triggered method (Table 1). Both kidneys were covered in the coronal plane. Slice-selective inversion recovery prepulse was applied to suppress the background signal.

Fig. 1 Flow chart of study design and methodology



Targeted flow was visualised when non-inverted inflow blood came within the spatially selective inversion recovery volume by waiting for the optimised inversion time (Black Blood Inversion Time or BBTI)). The inflow delay time specified the interval between labelling the inflowing blood and image acquisition.

In general, a longer delay time allowed stronger distal vasculature signal. However, when the BBTI was too long, less background suppression occurred because of T1 relaxation and the label intensity was attenuated. A few studies reported the optimal BBTI for renal arteries, around 1200 ms [17–19].

Maximum intensity projection (MIP) images were manually generated at the end of Time-SLIP imaging.

Image analysis

All MR images were independently analysed by two readers, one junior and one senior (JV and NB who had 7 years and 1 year of paediatric MR imaging experience, respectively). The readers were blinded to patient identity. A second analysis and measurements were performed 6 weeks later by the junior radiologist. On T2-W images, the maximum axial diameter of

Table 1 Imaging parameters

	Coronal T2 FASE (Fast-Spin Echo)	Axial T2 TSE (Turbo-Spin Echo)	Axial time-SLIP (3D SSFP)
Repetition time (ms)	12600	3300	5,2
Echo time (ms)	80	90	2,6
Thickness (mm)	5	5	3
Matrix	256×256	256×256	256×256
Number of sections	20	30	50
Acquisition time	30 s	3 min	5 min 30 s
Option	Apnoea	Respiratory gating	Respiratory gating

the pelvis were determined according to the specifications of the society of foetal urology (SFU). On NC-MRA imaging using Time-SLIP technique, the number of renal arteries and presence of CRV were evaluated. To assess the image quality, a 3 point scale was used as follows: 1: good, visualisation of whole main renal artery with segmental arteries, 2: fair, visualisation of whole main renal artery from the ostium to the hilum, and 3: poor, faint visualisation of main renal artery (Figs. 2, 3, 4).

Surgical methods

Four surgeons (MJ, PG, OB and OA who had 20, 15, 6 and 4 years of paediatric surgery experience, respectively) had access to the NC-MRA images and to the routine radiology report prior to surgery. In those with CRV on NC-MRA, laparoscopy with a view to performing vessel transposition was scheduled. Consent was also obtained for Anderson-Hynes pyeloplasty in the event that intrinsic obstruction was identified at surgery. Initially described by Hellstrom in 1949 [5], the vessel transposition procedure was as follows: the surgeon recorded the presence of CRV, which were then dissected away from the UPJ. Absence of intrinsic obstruction was confirmed by careful examination of the UPJ following an IV fluid bolus.

Provided there was no evidence of intrinsic obstruction, the vessels were then sutured superiorly away from the UPJ, typically by fixation into a tunnel created from the anterior wall of the dilated renal pelvis. Those without CRVs at NC-MRA were scheduled for laparoscopic pyeloplasty.

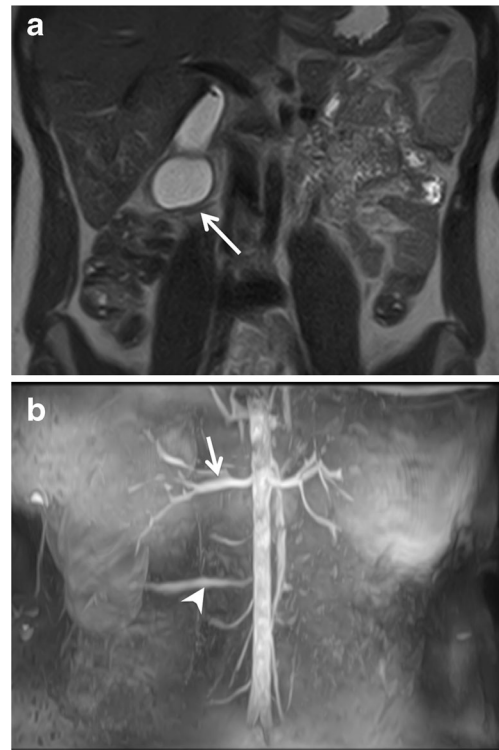


Fig. 3 A 10-year-old boy with right loin pain. (a) Coronal T2W-FASE. Right hydronephrosis with an abrupt transverse cut-off caused by a lower pole vessel crossing at the UPJ (arrow). (b) Coronal maximal intensity projection (MIP) using Time-SLIP technique depicts the main renal artery (arrow) and the CRV (arrowhead)

Statistical analysis

The sensitivity and specificity for predicting the number of renal arteries and the presence of CRVs were assessed on

Fig. 2 A 9-year-old girl with intermittent left back pain. (a) Axial T2W-TSE showing Grade 3 pyelectasis with major pelvic dilatation (arrow). (b) Axial image of NC-MRA using Time-SLIP technique with main left renal artery (arrow). (c) Axial image of NC-MRA using Time-SLIP technique demonstrates a crossing lower pole artery (arrow). (d) Laparoscopic view shows the crossing lower pole artery (arrow) and the normal UPJ (arrowhead)

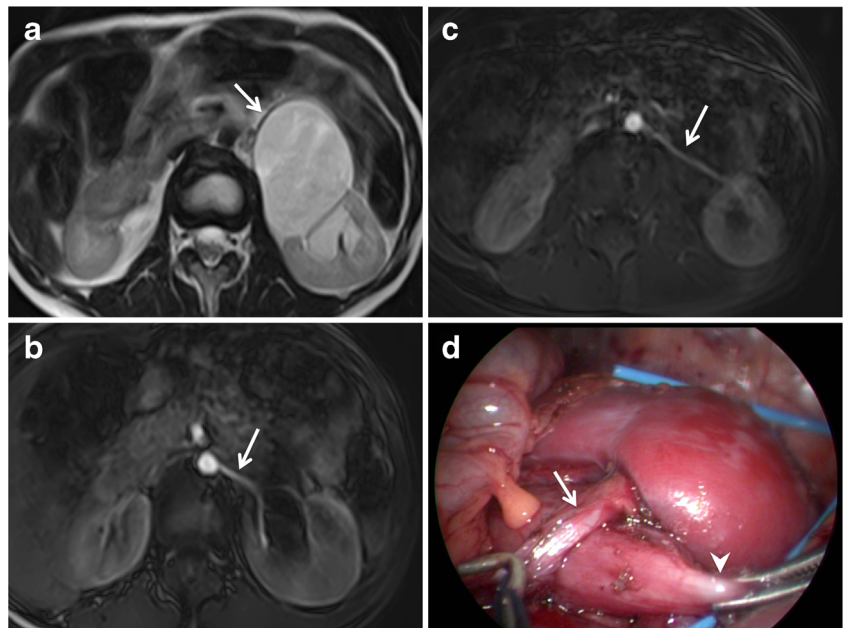
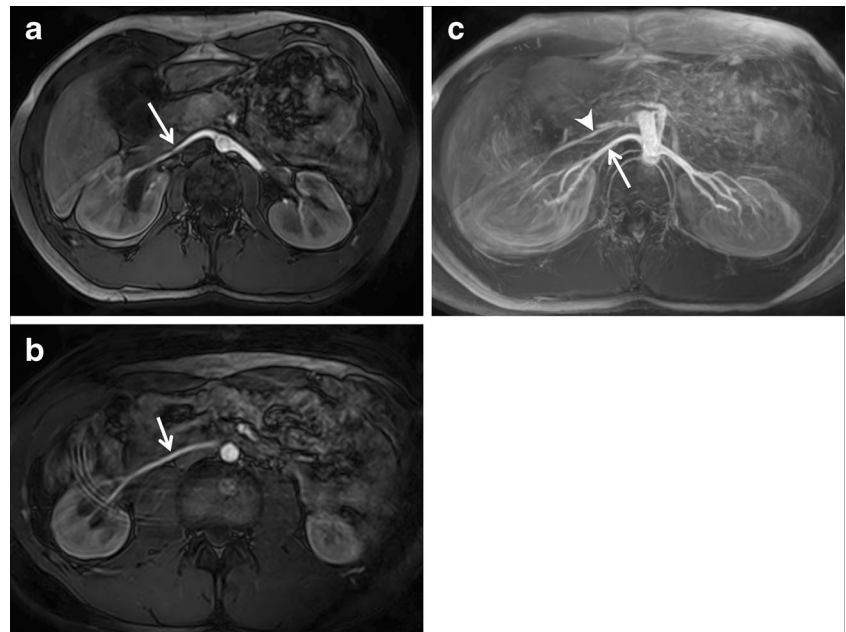


Fig. 4 A 14-year-old boy with intermittent right loin pain and one episode of pyelonephritis. Axial images of NC-MRA using Time-SLIP technique with main right renal artery (a) and a crossing lower pole artery (b). Axial maximal intensity projection (MIP) using Time-SLIP technique demonstrates the main renal artery (arrow) and the CRV (arrowhead) (c)



NC-MRA using surgical findings data as a standard reference. Cohen's kappa coefficient was used to evaluate the agreement and intraobserver and interobserver variability in the identification of CRV, estimating the image quality and parenchyma atrophy. Intraclass correlation coefficients (ICCs) and Bland Altman plots were used to evaluate the agreement of renal pelvis diameter measurement. Statistical analyses were performed using commercial MedCalc software, version 12.0 (MedCalc Software, Inc., Mariakerke, Belgium). A P value of less than 0.05 was considered significant.

Results

In 17 of 19 children, dilatation was found in single system kidneys. Duplex with dilatation of the lower system and

dilatation of a horseshoe kidney were seen in the two other children (Table 2).

Qualitative analysis

In both readers, 88 % of subjects (17/19) had good or fair image quality, and 12 % (2/19) had poor image quality [2].

Intrareader and interreader agreements were good for the image quality, with Cohen's kappa=0.789 and 0.714, respectively (Table 3).

Quantitative analysis

NC-MRA demonstrated CRV at the UPJ in 11 children, one early branching vessel from the main renal artery crossing UPJ and no crossing vessel in 7 children. For the 11 preoperatively

Table 2 Characteristics of the study population

Parameter	Average
Age	9 years 2 months (4 years 8 months to 16 years)
Female/Male	10/9
Loin pain	18
Urinary tract infection	4
Haematuria	0
Lithiasis	0
Right UPJ	8
Left UPJ	11
Modal vascularisation (1 main renal artery)	7
Lower pole crossing vessel	11
Early branching vessel	1

Table 3 Intrareader and interreader agreements and variability with NC-MRA

Parameter	Image quality	Number of CRVs	Pelvic diameter
Intra-reader	$\kappa=0.789$ (0.586–0.993)	$\kappa=0.957$ (0.873–1.000)	ICC=0.986 (0.970–0.993)
Inter-reader	$\kappa=0.714$ (0.506–0.922)	$\kappa=0.911$ (0.797–1.000)	ICC=0.977 (0.952–0.989)

diagnosed CRV and the one with early branching vessel, all vessels (except one false negative case) were confirmed intraoperatively, yielding a sensitivity of 92 % [95 % CI: 64 % to 99 %], a specificity of 100 % [95 % CI: 54 % to 100 %], a negative predictive value of 100 % [95 % CI: 73 % to 100 %] and a positive predictive value of 87.5 % [95 % CI: 42 % to 99 %] for predicting the presence of CRVs. All visualised CRV were solitary arterial vessels originating from the aorta. In one case, CRV could only be detected in the T2-W sequence because of the poor signal on Time-SLIP sequence. In one case with a poor image quality, a CRV was not seen on NC-MRA but confirmed intraoperatively. In 11 children with CRV and the one with early branching vessel, there was no evidence of intrinsic UPJ obstruction on direct inspection during surgery, and all of these children proceeded to a vessel transposition. This technique was performed too in the remaining child with a CRV not seen on NC-MRA but intraoperatively. All children with single renal arteries required an open or laparoscopic trans-peritoneal dismembered pyeloplasty.

Intrareader and interreader agreement was excellent for the identification of CRV, with Cohen’s kappa=0.957 and 0.911, respectively.

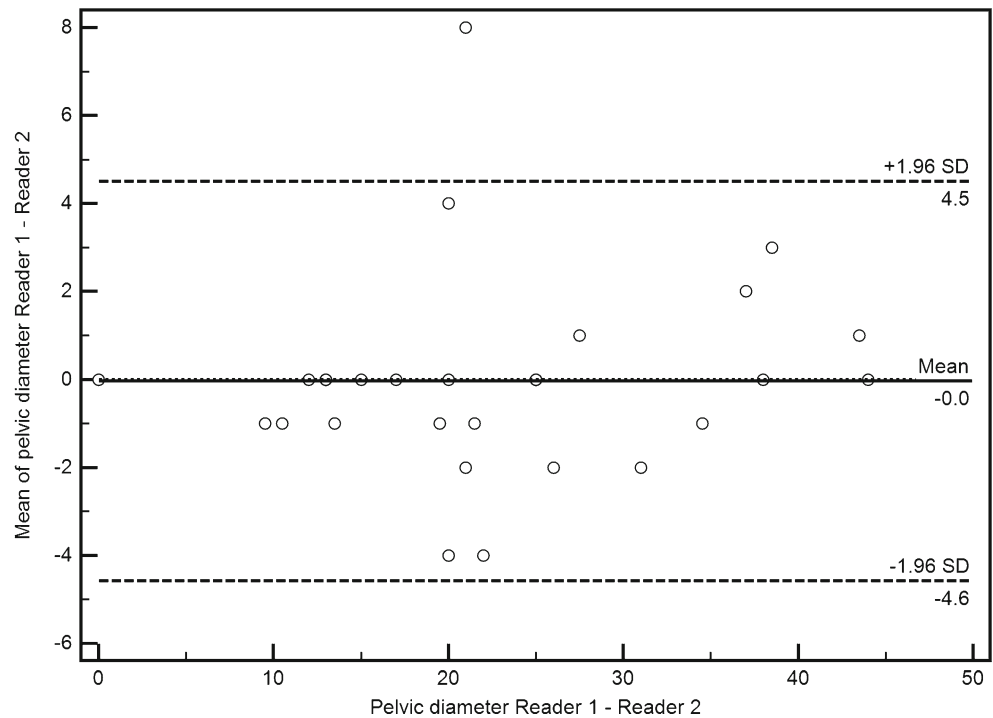
When measuring the pelvic diameter, ICC was excellent for intraobserver variability (0.986) and interobserver variability (0.977). The average difference between reader 1 (junior) and reader 2 (senior) for the pelvic diameter measurement was -0.03 mm (95% CI: -0.93 to 0.86). One value did not fall within the predefined test limits (-4.57 to $+4.50$; Fig 5).

Over a period of 3 to 24 months of clinical followup, all 12 children who underwent transposition alone showed an improvement in their symptoms. Pain either resolved completely or lessened in frequency and severity. All 12 patients showed an improvement of hydronephrosis on ultrasound with main pelvic diameter of 11.75 mm \pm 4.32 (range 6 to 29) after surgery versus 29.52 mm \pm 9.71 (range 13 to 44) preoperatively.

Discussion

UPJ obstruction due to CRV is a distinct entity separate from antenatal hydronephrosis, and manifests later in childhood. CRVs are found in children with ureteropelvic junction stenosis in 49% of cases [11, 20, 21]. Before performing surgery or

Fig. 5 Bland–Altman plots for maximum pelvic diameter show similar measurements from reader 1 and reader 2



interventional procedures in the kidney, the renal artery anatomy should be accurately assessed. Preoperative awareness of a CRV or an early branching vessel may influence surgical management. The most widely performed therapeutic procedures for UPJ obstruction in children are open and laparoscopic pyeloplasty. Endopyelotomy is a widely performed technique in adults and occasionally in older children [22, 23]. CRV represent a relative contraindication to endopyelotomy, as they lower the success rate, in addition to presenting a potential bleeding risk [24]. Pesce et al. reported a successful outcome in 60 of 61 children treated with vessel transposition alone [25]. At our institution, laparoscopic vessel transposition is offered to children with a clinical presentation of intermittent obstruction and CRV at laparoscopy, provided intraoperative inspection of the UPJ reveals no evidence of intrinsic obstruction [26]. The procedure offers the advantage of not slitting the upper urinary tract and is a considerably shorter procedure than laparoscopic pyeloplasty.

The goal of our study was to evaluate whether NC-MRA is capable of detecting CRV in children with ureteropelvic junction obstruction, and whether it is ideally also possible to evaluate the obstructive effect of these vessels on the UPJ without functional MR urography.

In this study, the use of NC-MRA at 1.5 T using the Time-SLIP technique allowed acceptable overall image quality (fair or greater image quality in 88 %) for visualising renal arteries. Of the 19 children who underwent surgery, a CRV could be diagnosed preoperatively in 11 children and an early branching vessel crossing UPJ in one case. There was no CRV in seven children. All preoperatively diagnosed CRVs were found intraoperatively and a negative MRA finding was confirmed by surgery in seven cases. A CRV that was not detected on NC-MRA was found in one child. To predict the presence or absence of CRVs, both sensitivity and specificity ranged from 92 % to 100 %. Interreader agreement on NC-MRA was good or excellent for identifying number of renal arteries. These findings indicate that the use of NCMRA at 1.5 T with Time-SLIP technique may be a feasible alternative to CDS, CT angiography, and CE-MRA for preoperative evaluation of renal artery anatomy.

Parienty et al. [17] recently reported that the image quality of NC-MRA using the 3D bSSFP technique was good in 87 % and moderate in 13 % of images using a 3-point scoring system. Another previous study reported good image quality in 88 % of NC-MRA images taken using the 3D bSSFP technique to evaluate the overall number of renal arteries [18]. These previous results are in agreement with our current study using Time-SLIP technique.

In adults, a number of imaging techniques have been employed to identify CRVs, typically as a means of excluding their presence prior to endopyelotomy. Contrast-enhanced CT examination is a popular technique owing to its relatively non-invasive nature, rapid image acquisition and excellent spatial

resolution. A number of studies have demonstrated sensitivities and specificities in excess of 90 % for CRV detection [12, 27]. However, the radiation dosage is considerable particularly in the evaluation of children, and there has been no systematic evaluation of CT techniques in children. Non-contrast-enhanced colour Doppler ultrasound has been evaluated but appears to have poor specificity and to be highly operator dependent [11]. Ultrasound with endoscopic or contrast-enhanced methods and CE-MRA appears to be accurate techniques [8, 14].

NC-MRA using Time-SLIP technique is well suited to this purpose. It can be performed reasonably rapidly (about 15–20 minutes in our experience) and uses non-ionizing radiation or intravenous contrast medium administration. Despite its potential advantages, NC-MRA has not been widely applied to the detection of CRV in either adult or children and to our knowledge there are no reports of systematic evaluation of NC-MRA in this setting in the literature.

The image quality was poor in two cases in our study. This might be attributed to the specific paediatric population. Indeed the parameters, especially BBTI, are defined for an adult population [17, 18] and may not be optimal for children, with many variations of the respiratory frequency, the heart rhythm, and the velocity of arterial circulation.

Despite the fact that hydronephrosis may be more important in the CRV group, we cannot conclude that this is a main rule. We did not perform NC-MRA studies during episodes of pain and clinically suspected obstruction. In all our patients, the MRI examination identified hydronephrosis of the symptomatic kidney, which may have led to the assumption that any CRV would have been the cause of the obstruction.

Our study has several limitations. Firstly, the surgeons were not blinded to the NCMRA findings; however, we do not believe that foreknowledge of the NC-MRA findings compromised accuracy of the surgical findings in practice. Secondly, the study cohort was relatively small. Further prospective multicentre studies with a large population are necessary. The follow-up period for the patients who underwent vessel transposition was relatively short. This study does not allow us to draw conclusions as to the effectiveness of the surgical technique, although the results to date are encouraging. However, the focus of this study was to determine the accuracy of the MR imaging with Time-SLIP technique for identifying the presence of CRV.

Conclusion

We demonstrated that NC-MRA using Time-SLIP technique at 1.5 T appears to be useful and accurate in the identification of CRV in older children with intermittent UPJ obstruction. In this selected paediatric population, the incidence of CRV is high and their presence may influence surgical management.

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