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RARE-MR-urography in the diagnosis of upper urinary tract abnormalities in children

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Abstract. RARE-MR-urography (*R*apid *A*cquisition with *R*elaxation *E*nhancement) is a fast MR imaging technique (6.4 s/acquisition) that selectively depicts fluid by heavy T2-weighting. From 9/1989 to 11/1990, RARE-MR urograms were prospectively evaluated in the diagnosis of upper urinary tract abnormalities in 55 children. The method is performed in several planes and combined with a coronal, T1-weighted spin-echo sequence. Forty out of 42 kidneys with dilated renal pelvis, and 21 out of 24 dilated ureters were identified, only the mildly dilated ones were missed. Even in non-functioning kidneys the urinary tract was clearly depicted by RARE-MR-urography. However, no differentiation could be made with this technique between vesicoureteral reflux and non-refluxing dilatation of ureter and/or renal pelvis. All 19 pelviureteric obstructions and all eight renal duplications with a dilated segment were identified. RARE-MR-urography is a new tool for diagnosing urinary tract abnormalities in children without having to employ ionizing radiation, contrast media, or general anesthesia. A dilated urinary tract can be shown in one image displaying the entire urinary system, similar to excretory urography. The technique is presently not able to provide the information of voiding cystourethrography or renal scintigraphy, nor is it as easy to perform as ultrasound. However, in certain cases it may replace excretory urography.

The RARE technique (*R*apid *A*cquisition with *R*elaxation *E*nhancement), including the special variant *RARE-MR-urography,* is being used on our 0.23 Tesla MR system (Bruker Tomikon R 23) since 1984 [1–3]. It employs no ionizing radiation, requires no contrast medium application, and has already been proven helpful in adults [4, 5]. In the present study the method was evaluated in children with upper urinary tract abnormalities by comparing its results with those of conventional methods such as US, EU, VCUG, and renal scintigraphy. The aim of the study was to find out whether one of the conventional methods could be replaced by MRI.

Abbreviations: EU = excretory urography, MR = magnetic resonance, MRI = magnetic resonance imaging, RARE = *R*apid *A*cquisition with *R*elaxation *E*nhancement, TR = repetition time, TE = echo time, US = ultrasound, VCU = voiding cystourethrography.

Patients and Methods

Patients

From September 1989 to November 1990, 55 consecutive children (35 boys, 20 girls) with suspected morphologic pathology of kidneys and urinary tract were prospectively examined by MRI. No other patient-selection criteria were applied. In 25 of the cases suspicion had been aroused by an abnormal finding on an ultrasound screening examination. 22 patients were examined due to a pathologic finding on US which had been performed because of urinary tract infection, and/or due to other reasons like multiple malformations with expected kidney involvement (8 cases). Four children were evaluated twice-yielding a total of 59 examinations. These four repeated exams were scheduled for control of therapy and are not included in this presentation. The patients were between 2 days and 13.2 years old, half of them were less than 6 months old.

Thirty-four received an oral sedative 45 minutes prior to the scan, one child was examined under general anesthesia because a cystoscopy was to follow immediately. Twenty children were given no medication at all (Table 1).

All the children had undergone US. In 27 an EU was performed, in 39 a VCUG, and in 41 renal scintigraphy using technetium-99m mercaptoacetyltriglycine (Tc-99m MAG_3) with furosemide intervention. Three kidneys were non functional (scintigraphy: excretory function $\leq 2\%$ on the respective side), 7 had a very low excretory function (scintigraphy: 5–14% on the respective side; almost "silent" on EU), and in three renal duplications one of the two segments was non functional.

In 20 patients subsequent urinary tract surgery was carried out, six children are scheduled for cystoscopy and/or operation, and one child with related cardiac and other malformations died of urosepsis.

At the time of the MR examination, only the provisional sonographic diagnosis was given to the MRI readers. The quality of the images was subjectively classified as: *excellent,* if virtually no motion artifacts and a high signal-to-noise ratio was present; *satisfactory,* if there were motion artifacts and considerable noise, but the images were still diagnostic; *poor,* if images were deemed non-diagnostic.

Table 1. Preparation of pediatric patients and image quality. ($n = 59$ examinations)

Preparation	Quality of RARE-MR-urography		Quality of T1-weighted sequence
Oral/rectal sedative[a] 45/20 min prior to scan: ($n = 38$)	Excellent:	32	25
	Satisfactory:	4	8
	Poor:	2	5
General anesthesia[b]: ($n = 1$)	Excellent:	1	1
No medication:			
Feeding in infants: ($n = 9$)	Excellent:	8	6
	Satisfactory:	1	2
	Poor:		1
School-age children: ($n = 11$)	Excellent:	9	8
	Satisfactory:	1	1
	Poor:	1	2

[a] Oral Promazine 3–5 mg/kg bd.wt. (Protactyl®, Wyeth, Münster), in 4 cases Chloral Hydrate 600 mg per rectum (Chloralhydrat-Rectiole®, Dentinox, Berlin); [b] because of subsequent cystoscopy

For final diagnosis surgery/cystoscopy (if performed), and/or the combination of all imaging modalities were used as reference.

Methods

The *RARE* technique uses long echo-trains with *different* phase encoding for *each* echo, thereby the number of excitations necessary for a 256^2 matrix is reduced compared to conventional spin-echo sequences. Thus, heavily T2-weighted images are generated in a reasonable acquisition time. A modification of this technique called *RARE-MR-hydrography* has a T2-weighting such that only substances with a T2 relaxation time of 500 ms and longer will produce a signal, resulting in aqueous fluid-specific images ("water pictures"). The special advantage of this modification is the even shorter acquisition, with a total scan time of 6.4 s per slice using one excitation (TE = 25 ms, 256^2 matrix, total scan time = 256×25 ms = 6400 ms = 6.4 s). Routinely, two averages are used for one RARE-MR-hydrography slice, with a recovery time of 10 seconds. Thus, total scan time with TR/TE = 10 s/25 ms is 23 s [6.4 s (first acquisition) + 10 s (recovery) + 6.4 s (second acquisition) = 22.8 s ≈ 23 s]. The RARE sequences including *RARE-MR-hydrography* belong to the standard software of our resistive midfield system (Bruker Tomikon R 23 operating at 0.23 Tesla; Bruker Medizintechnik, Karlsruhe). Recent developments in hardware have also enabled the use of this method on a high-field system [6, 7]. Technical details of RARE and its variants are described elsewhere [1–3, 6]. For the most common clinical applications the technique is referred to as "RARE-MR-myelography" [1, 8] or "RARE-MR-urography" [4], although "RARE-MR-hydrography" (or simply "water pictures") is the most comprehensive term.

In this study, RARE-MR-urograms in coronal, sagittal, and transversal planes were obtained in each case. The smallest fitting coil was used: Adult's knee or head coil for the infants, neck or body coil for the older children.

Finally, a coronal T1-weighted conventional spin-echo sequence (7 min/12 slices) was performed, in selected cases sagittal T1-weighted slices were also acquired.

Results

The quality of the images was subjectively classified by two observers based on freedom from motion artifacts and good signal-to-noise ratio (see above). Thus, 56 of the 59 RARE-MR-urograms and 51 of the T1-weighted sequences were regarded as satisfactory or excellent (Table 1). At least one of the two techniques could be evaluated in each patient, allowing a diagnosis to be made in each case.

All 19 hydronephrotic kidneys resulting from pelviureteric obstruction were clearly demonstrated (Table 2, Fig. 1). Twenty-one out of 24 dilated ureters (mildly dilated or megaureter) and 21 out of 23 associated dilated pelvicaliceal systems (mildly dilated with normal renal parenchyma or hydronephrosis) were identified (Table 2, Figs. 2, 3), including those without excretory function. A differentiation could not be made between non-refluxing dilatation and dilatation due to vesicoureteral reflux.

In one case with vesicoureteric reflux II° the MR image suggested reflux because of a mild dilatation of the ureter (but not of the renal pelvis). A vesicoureteric reflux I° on the opposite side was missed.

Severely reduced excretory function could be suspected due to the loss of corticomedullary differentiation and atrophy of the renal parenchyma on the T1-weighted images (Fig. 2).

Eight out of nine renal duplications were identified (Fig. 4). In the one false negative there was no dilatation of either segment. Size and multiplicity of renal cysts were shown in all eight cases, including even small cystic lesions of Potter I polycystic nephropathy. In one case only the calices were dilated, with the renal pelvis appearing otherwise normal (differential diagnosis: megacalices/pelvicalyceal obstruction). As yet, surgical intervention in this child has been postponed; however, the US and MRI findings are in full agreement. The morphology of one crossed dystopia (Fig. 3) and another dysplasia were correctly described, two children with borderline sonographic findings were correctly identified as normal. Two ureteroceles were detected by RARE-MR-urography, two smaller ones were missed.

Incidentally, a fibrous band forming a horseshoe kidney, and a small urachal cyst were found upon surgery per-

Table 2. Correct MRI diagnosis of urinary tract dilatation (../.. = number correctly described by MR/total number:)

Final diagnosis[a]	Hydronephrosis/ dilated pelvis	Megaureter/ dilated ureter
Pelviureteric obstruction – including 6 on both sides	19/19	–
Dilatation of ureter and associated collecting system		
– Due to vesicoureteric reflux III°–V°: – including 2 renal duplications	10/12	9/12
– Due to vesicoureteric reflux II°:	–	1/ 1
– Non-refluxing – including 6 renal duplications	11/11	11/11
Total	40/42	21/24

[a] based on surgery, cystoscopy, and/or combination of all other imaging studies

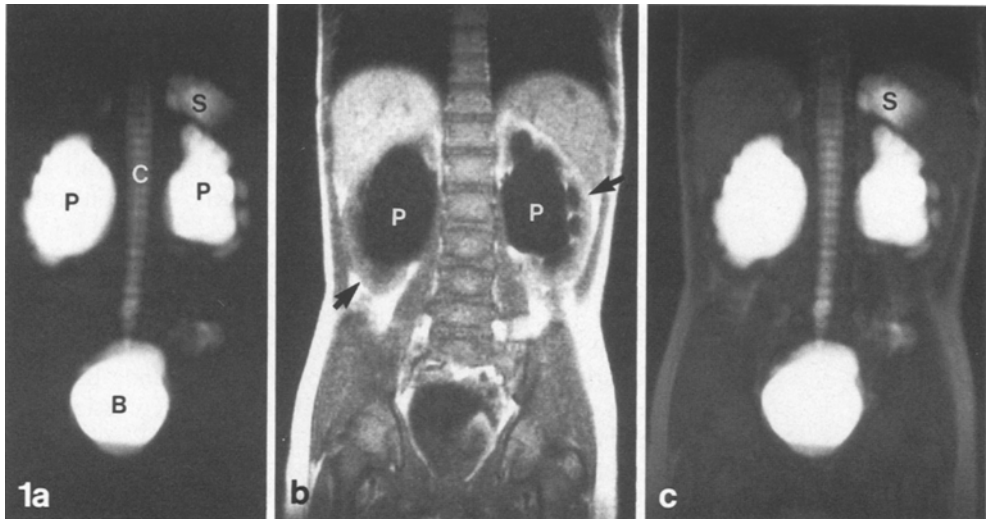

Fig. 1a–c. 2.5-year-old boy with mild urinary tract infection. **a** Coronal RARE-MR-urography: Massive dilatation of renal pelvis (P) and calices on both sides. S = fluid-filled stomach, C = cerebrospinal fluid, B = urinary bladder. Ureters are not delineated, i.e. not dilated. **b** Representative T1-weighted slice shows thin parenchyma (→), but no severe atrophy. Urine is depicted dark (long T1 = low signal). **c** Algebraic addition of (**a**) and (**b**). Image postprocessing allows for better anatomical-topographic orientation, e.g. to locate the fluid in the stomach (S)

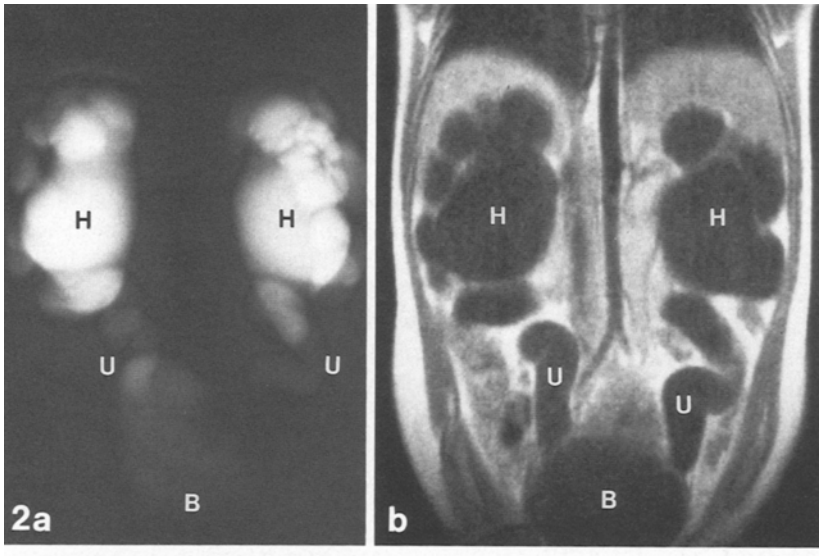

Fig. 2a–b. 9.9-year-old neglected boy with untreated urethral valves, vesicoureteric reflux V° on both sides, and yet compensated renal insufficiency. **a** Coronal RARE-MR-urography, **b** coronal T1-weighted image: Bilateral massive hydronephrosis (H) with severe parenchymal atrophy and bilateral megaureters (U), B = bladder

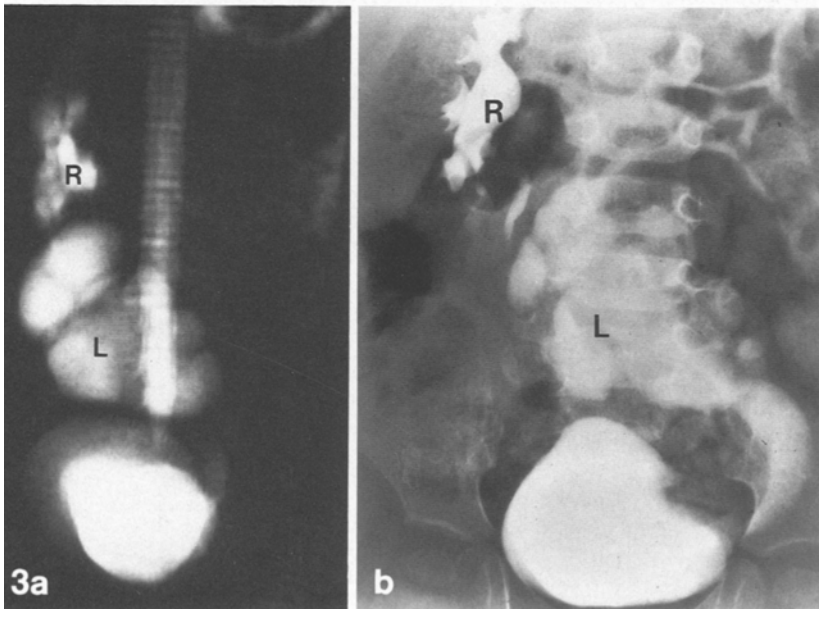

Fig. 3a–b. 3-year-old boy with crossed dystopia of hydronephrotic "left" kidney (L) and associated megaureter (scintigraphy: 15% excretory function). The right kidney (R) shows mild dilatation due to pelviureteric obstruction (however, 85% of excretory function). Similar morphologic information of coronal RARE-MR-urography (**a**) and conventional excretory urography (**b**)

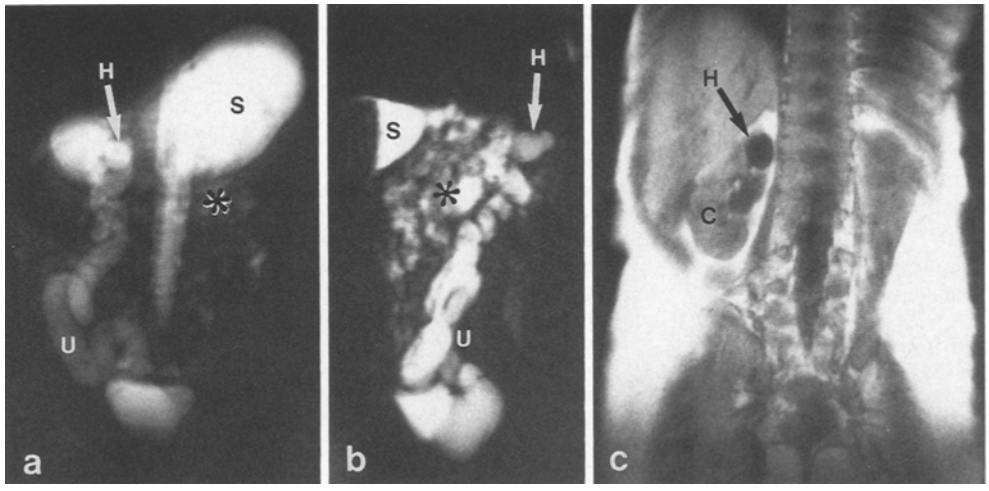

Fig. 4a–c. 2-month-old boy with urinary tract infection.
a Coronal RARE-MR-urography,
b right sagittal RARE-MR-urography – corresponding to a lateral view,
c coronal T1-weighted image: renal duplication on the right with hydronephrotic cranial segment (H) and draining megaureter (U), normal caudal segment (C) without dilatation of lower collecting system. Fluid in the gastrointestinal tract (S = stomach – with air-fluid level in **b** –, * = small bowel), which leads to superposition in (**a**), but can be ascribed to stomach and small bowel in (**b**)

formed because of other reasons. These secondary findings had been missed preoperatively by all imaging methods.

On the other hand, no false positive MRI findings were encountered in this study.

Discussion

The outstanding feature of *RARE-MR-urography* is that it rapidly and selectively images fluid in cysts, calices, renal pelvis, dilated ureter, and urinary bladder. In contrast to conventional T1-weighted multislice sequences, *one* 5–10 cm-thick slice is sufficient to depict the *entire* collecting system with minimal superposition. Only structures that are filled with fluid can cause superposition, such as the subarachnoid space, the gastrointestinal tract, the gallbladder, the urinary bladder, or the tortuous ureter itself. By choosing other slice orientations or thinner slices, these minor superpositions can be ascribed to the respective organ system or be completely faded out. Solid tissues and gas produce no signal at all and therefore cannot cause any superposition. Thus, bowel-motion or -gas do not interfere with the quality of the RARE-urogram. This feature and the visualisation of the *entire* collecting system in *one* slice represent the main advantages of RARE-MR-urography over US.

The coronal RARE-MR-urogram resembles the AP view of an ordinary EU, however, it is *independent of excretory function.* And again it has the advantage that no bowel gas interferes with quality of the image.

The coronal T1-weighted spin-echo sequence can provide additional information on the renal parenchyma, especially in non-dilated segments, and on the corticomedullary differentiation [9]. Furthermore, image post-processing, that is, the addition of a RARE-MR-urogram to an appropriate T1-weighted slice, allows for better anatomical-topographic orientation.

What are the major limitations? – The RARE-MR-urogram is a static image, so that at present it is not possible to diagnose a vesicoureteric reflux. Only the morphologic changes, i.e. megaureter and hydronephrosis, can be visualized, but they cannot be distinguished from dilatation due to obstruction or other causes. However, the same drawback applies to US, even with additional Duplex or color Doppler equipment [10, 11]. Thus, for diagnosing vesicoureteric reflux *voiding cystourethrography* is still considered to be the *gold-standard.*

Spatial resolution of RARE-MR-urography is inferior to X-ray urography, so that only a dilated ureter can be clearly demonstrated. Of course, MR is inferior to sonography in terms of costs and time resolution, too. Regarding morphology, the cheaper ultrasound will be sufficient for diagnosing pathologies such as hypoplastic or dystopic kidneys, parenchymal damage, cysts, stones, and ureteroceles, where MRI could not yield additional information. A result that is of major relevance for MR imaging in infants and young children in general is that there is virtually no need for general anesthesia or deep sedation. For young babies normal feeding often produces sufficient sedation.

Conclusions

RARE-MR-urography is a new diagnostic tool to examine urinary tract abnormalities in children – including newborns. Besides being independent of excretory function, it requires no contrast medium and employs no ionizing radiation, which is a major benefit, especially in the case of infants. The total scan time of 23 s per slice (6.4 s/single acquisition) is very short.

The main advantage of the method is that in contrast to ultrasound, one slice provides an image of the entire urinary tract without interference caused by bowel motion or gas. By combining RARE-MR-urography with T1-weighted images, additional information on the renal parenchyma can be obtained in non-dilated segments, for example, and anatomical-topographic orientation is facilitated. At present, it is not possible to identify a vesicoureteric reflux, so that VCUG is still mandatory for the differential diagnosis.

However, these preliminary results suggest that MR can replace EU in certain cases such as pelviureteric ob-

struction, renal duplication, and megaureter and hydronephrosis, if US, VCUG and renal scintigraphy have produced corroborating findings. In this way, one examination with radiation exposure can be eliminated.

References

1. Hennig J, Friedburg H, Ströbel B (1986) Rapid nontomographic approach to MR-myelography without contrast agents. J Comput Assist Tomogr 10: 375
2. Hennig J, Nauerth A, Friedburg H (1986) RARE imaging: A fast imaging method for clinical MR. Magn Res Med 3: 823
3. Hennig J, Friedburg H (1988) Clinical applications and methodological developments of the RARE technique. Magn Res Imag 6: 391
4. Friedburg H, Hennig J, Frankenschmidt A (1987) RARE-MR-urography: Imaging of the urinary tract with a new fast non-tomographic MR technique. Radiologe 27: 45 (In German, with English summary)
5. Friedburg H, Westenfelder M, Roeren T, Hennig J (1987) MR of the urinary tract in pregnancy. RoeFo 147: 430 (In German, with English summary)
6. Hennig J (1988) Multiecho imaging sequences with low refocusing flip angles. J Magn Res 78: 397
7. Mulkern RV, Wong STS, Winalski C, Jolesz FA (1990) Contrast manipulation and artifact assessment of 2D- and 3D-RARE sequences. Magn Res Imag 8: 557
8. Friedburg HG, Hennig J, Schumacher M (1987) Clinical application of RARE-MR-myelography as a routine MR examination: Experience with 175 cases. RoeFo 146: 584 (In German, with English summary)
9. Dietrich RB, Kangarloo H (1986) Kidneys in infants and children: evaluation with MR. Radiology 159: 215
10. Jequier S, Paltiel H, Lafortune M (1990) Ureterovesical jets in infants and children: Duplex and color Doppler US studies. Radiology 175: 349
11. Marshall JL, Johnson ND, DeCampo MP (1990) Vesicoureteric reflux in children: Prediction with color Doppler imaging. Work in progress. Radiology 175: 355

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Literature in pediatric radiology (continued from p. 412)

Musculoskeletal problems in association with cloacal exstrophy. Greene, W.B. et al. (Div. of Orthopaedic Surg., Univ. of North Carolina Sch. of Med., Campus Box 7055, 242 Burnett-Womack Bldg., Chapel Hill, NC 27599-7055, USA) **73-A,** 551 (1991)

Metachronous osteoid-osteomas. Report of a case. Larsen, L.J. et al. (Children's Hosp. of San Francisco, 3700 California St., San Francisco, CA 94118, USA) **73-A,** 612 (1991)

Current concepts review. The role of ultrasound in the diagnosis and management of congenital dislocation and dysplasia of the hip. Harcke, H.Th., Kumar, S.J. (Alfred I. du Pont Inst., P.O. Box 269, 1600 Rockland Road, Wilmington, Delaware 19899, USA) **73-A,** 622 (1991)

Journal of Computer Assisted Tomography (Bethesda)

High dose chloral hydrate sedation for children undergoing CT. Greenberg, S.B. et al. (Dept. of Rad., St. Christopher's Hosp. for Children, Front at Erie St., Philadelphia, PA 19134-1095, USA) **15,** 467 (1991)

Journal of Neurosurgery (Rochester)

Intracranial germ-cell tumors in children. Hoffman, H.J. et al. (Div. of Neurosurg, The Hosp. for Sick Children, 555 Univ. Ave., Toronto, Ontario M5G 1X8, Canada) **74,** 545 (1991)

Familial occurrence of arteriovenous malformation of the brain. Yokoyama, K. et al. (Dept. of Neurosurg., Takayama Red Cross Hosp., 3–11, Tenmancho, Takayama-Shi, Gifu-Ken 506, Japan) **74,** 585 (1991)

Fusiform dilatations of the carotid artery following radical surgery of childhood craniopharyngiomas. Sutton, L.N. et al. (Surgical Associates of the Children's Hosp. of Philadelphia, One Children's Center, 34th St. and Civic Center Blvd., Philadelphia, PA 19104-4399, USA) **74,** 695 (1991)

Benign intrinsic tectal "tumors" in children. May, P.L. et al. (H.J. Hoffman, Div. of Neurosurg., The Hosp. for Sick Children, 555 Univ. Ave., Toronto, Ontario, M5G 1X8, Canada) **74,** 867 (1991)

Journal of Nuclear Medicine (New York)

Radioimmundetection of neuroblastoma with iodine-131-3F8: Correlation with biopsy, iodine-131-metaiodobenzylguanidine and standard diagnostic modalities. Yeh, S.D.J. et al. (Dept. of Med. Imaging, 1275 York Ave., New York, NY 10021, USA) **32,** 769 (1991)

Glomerular filtration rate in children: Where we have been? Where we are going? Shore, R.M. (The Children's Mem. Hosp., Chicago, Il, USA) **32,** 1297 (1991)

Journal of Pediatrics (St. Louis)

Role of chlamydia pneumoniae in acute chest syndrome of sickle cell disease. Miller, S.T. et al. (Dept. of Ped., State Univ. of New York, Health Sci. Center at Brooklyn, Box 49, 450 Clarkson Ave., Brooklyn, NY 11203, USA) **118,** 30 (1991)

Asymmetric growth of the lateral cerebral ventricle in infant with posthemorrhagic ventricular dilation. Brann, B.S., IV, et al. (Dept. of Ped., Children's Hosp. of New Mexico, Univ. of New Mexico Sch. of Med., 2211 Lomas Blvd., Albuquerque, NM 87131, USA) **118,** 108 (1991)

Persistent crying in infancy as a presentation of Chiari type I malformation. Listernick, R., Tomita, T. (Dept. of Ped., Northwestern Univ. Med. Sch., Div. of General Acad. and Emergency Ped., Children's Mem. Hosp., 2300 Children's Plaza, Chicago, IL 60614, USA) **118,** 567 (1991)

Journal of Pediatric Surgery (New York)

Distal congenital esophageal stenosis associated with esophageal atresia. Neilson, I.R. et al. (Guttman, F.M., Ped. General Surg., Children's Hosp., 2300 Tupper, Montreal, Quebec H3H 1P3, Canada) **26,** 478 (1991)

Biliary atresia and the polysplenia syndrome. Karrer, F.M. et al. (Children's Health Center, 1950 Ogden St, B323, Denver, CO 80218, USA) **26,** 524 (1991)

Experience with bilateral renal artery stenosis as a cause of hypertension in childhood. Guzzetta, Ph.C. et al. (Dept. of Ped. Surg., Children's National Med. Center, 111 Michigan Ave NW, Washington, DC 20010, USA) **26,** 532 (1991)

Magnetic resonance imaging for localizing the nonpalpable undescended testis. Miyano, T. et al. (Dept. of Ped. Surg., Juntendo Univ. Sch. of Med., 2-1-1 Hongo, Bunkyoku, Tokyo 113, Japan) **26,** 607 (1991)

Diagnosis of H-type tracheoesophageal fistula. Benjamin, B., Pham, T. (FRACS, FAAP, 231 Macquarie St, Sydney, New South Wales 2000, Australia) **26,** 667 (1991)

Acquired tracheoesophageal fistula in infancy and childhood. Szold, A. et al. (Dept. of Ped. Surg., Hadassah Univ. Hosp. Mount Scopus, POB 24035, Jerusalem, Israel) **26,** 672 (1991)

Failure of duplex sonography to diagnose hepatic artery thrombosis in a high-risk group of pediatric liver transplant recipients. McDiarmid, S.V. et al. (R.W. Busuttil, UCLA Dept. of Surg., Room 77-132 CHS, 10833 Le Conte Ave, Los Angeles, CA 90024, USA) **26,** 710 (1991)

Giant hemangioma of the arm associated with cardiac failure and the Kasabach-Merritt syndrome in a neonate. Currie, B.G. et al. (FRACS, Dept. of Paed. Surg., Prince of Wales Children's Hosp., Randwick, NSW 2031, Australia) **26,** 734 (1991)

Primary lesser saphenous vein aneurysm in a child. Ramadan, F., Johnson, G. Jr. (Div. of Vascular Surg., Univ. of North Carolina Sch. of Med., 210 Burnett-Womack, Campus Box 7210, Chapel Hill, NC 27599-7210, USA) **26,** 738 (1991)

Journal of Urology (Toronto)

The detection of reflux nephropathy in infants by ^{99m}technetium dimercaptosuccinic acid studies. Farnsworth, R.H. et al. (Dept. of Urol., The Prince Henry Hosp., Sydney, Australia) **145,** 542 (1991)

(continued on p. 427)