Determination of the Pressure Gradient in Children with Coarctation of the Aorta by Low-Field Magnetic Resonance Imaging

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Abstract. During the past few years magnetic resonance imaging (MRI) has gained increasing importance in the noninvasive examination of congenital heart defects. Practically all existing examinations have been carried out with a magnetic field strength exceeding 1 T (high-field MRI). Flow quantification is considered to be an advanced MRI application and, in the past, has been available for high-field systems only. Therefore until recently, functional examinations such as MRI tomographic flow quantification were reported exclusively for high-field MRI units. From December 1998 to December 1999, nine patients (five girls and four boys, mean age 130 ± 3.6 months, range 62–185 months) were investigated by means of MRI after a previous surgical repair or interventional balloon dilatation of a coarctation of the aorta (mean postinterventional time period 23 ± 0.4 months). The examination was carried out without sedation in an open low-field unit (Siemens Magnetom Open 0.2 T). Cardiac-triggered spin-echo sequences were used with a 3-mm to 7-mm slice thickness in an axial and a double oblique plane. The measurement of the immediate poststenotic flow velocity was done by flow-sensitive sequences developed for the study (phase-sensitive flow measurement sequences: TE, 6–12 msec; TR, 50 msec; flip angle, 60°; \( V_{\text{max}} \), 200–1200 cm/sec; two acquisitions). All patients were examined on the same day with comparative echocardiographic procedures. In all cases, an excellent anatomical evaluation of the aortic arch was possible. The diameters of the residual stenosis were measured by MRI and correlated well \( r = 0.95; p \leq 0.001; \) mean difference \( 0.44 \pm 2.47 \) mm) with echocardiographic results. No wall damage was observed in any of the cases studied. The pressure gradient of the stenosis calculated from the flow sequence was between 17 and 50 mmHg and corresponded well \( r = 0.93; p = 0.001; \) mean difference \( 0.67 \pm 11 \) mmHg) with the results obtained from echocardiography. The study demonstrates that examination of the aortic arch is possible in a low-field MRI system, with its significant advantages (lower patient discomfort and more cost-effective examination). In addition, a quantitative flow measurement in low-field MRI was realized for the first time. Low-field MRI therefore seems to be a good, noninvasive method for examining patients with a poor echocardiographic representation of the aortic arch.

Key words: Aortic coarctation — Magnetic resonance imaging — Echocardiography

Magnetic resonance imaging (MRI) was introduced as a cardiac diagnostic tool in 1984 [2]. Examinations have been reported almost exclusively in adults investigated by high-field strength MRI systems [2, 8, 14]. Investigation of children with congenital heart defects was performed in the past only to a very limited extent [4, 5, 10, 11, 13]. Almost all studies were conducted by high field systems with a field strength higher than 1 [7, 8, 12, 13]. Until recently, quantitative functional examinations in the pediatric age group were restricted to high-field systems [11]. Low-field MRI has been increasingly used in addition to the conventional high-field systems in clinical applications [4, 5, 13]. An open-unit design with low-field strengths offers considerable advantages for pediatric patients. These include easier surveillance of the patient by sight and body contact with parents.

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and the surveillance personnel. The disadvantage is a physically conditioned, lower signal-to-noise ratio and, as a result, a slightly extended examination time. Flow quantification is considered an advanced MRI application and in the past has been available for high-field systems only. Therefore, functional cardiac studies have been reported for high-field systems only. We developed and tested flow-sensitive sequences for a low-field magnetic resonance system (Magnetom Open, 0.2 T, Siemens AG) in children with coarctation of the aorta and compared it with functional studies by means of echocardiography. The initial results are reported.

**Patients and Methods**

Nine patients (five girls and four boys, aged 62–185 months, mean age 130 ± 3.6 months) were investigated by means of MRI as a follow-up after surgical repair and later interventional balloon dilatation of coarctation of the aorta (average time after intervention was 23 ± 0.4 months). The examinations were carried out without sedation in our pediatric low-field MRI unit (Siemens Magnetom Open) at 0.2 T field strength (gradient strength 15 mT/ m, slew rate = max gradient strength/time to reach the maximum = 25 T/m/sec). Cardial-triggered spin-echo sequences were used with 3-mm to 7-mm slice thickness in axial and double oblique planes (Fig. 1A). The measurement of the immediate poststenotic flow velocity was done by newly implemented flow-sensitive FLASH sequences (phase-sensitive flow mapping; TE, 6 msec; TR, 50 msec; flip angle, 60°). The measurement consists of a flow-compensated sequence followed by a flow-coded sequence; the difference of the phase images of both represents the velocity phase map. The gray-scale values of the phase image represent the flow velocities from −V_max to V_max according to the chosen sensitivity range − V_max. In the present study, sequences with a sensitivity from 200 cm/sec to 1200 cm/sec were used. The turbulent jets were identified as a signal void within the magnetic images and the planes for blood flow velocity quantification were selected distal to those jets, avoiding areas of turbulent flow. Flow quantification was performed using the ‘Flow Evaluation Package’ of the Siemens Numaris 3b software, tested and released as a standard option on 1.0 T and 1.5 T scanner which was modified for the Magnetom Open system. Depending on the heart rate, 11 to 15 flow measurements were possible during the cardiac cycle. The mean acquisition time was dependent on the heart rate and lasted about 8 to 10 minutes in our patients.

All patients were examined on the same day with comparative echocardiographic procedures. Anatomic investigation of the aortic arch Fig. 1) was performed by triggered spin-echo sequences in axial and double oblique planes.

Aortic measurements were obtained at three points echocardiographically and by MRI. Figure 1 demonstrates the typical measurements points. The flow measurement plane was placed orthogonally to the blood flow of the descending aorta approximately 1 or 2 cm below the stenosis (Fig. 1). The measurement volume of the velocity measurement was placed and adjusted according to the measurement volume of the Doppler echocardiography (about 0.25 cm³) in the center of the examined vessel. Velocity determination was made from the gray-scale coded phase image. From the velocity spectrum of the entire heart cycle the maximum systolic velocity was determined in the same way as the

**Fig. 1.** (A) MRI examination of the aortic arch in double oblique plane in a 12-year-old girl with aortic recoarctation after cardiac surgery in the neonatal period (cardiac triggered spin echo sequence). The flow measurement plane is placed orthogonally to the blood flow of the descending aorta approximately 1 or 2 cm poststenotic. Morphological measurement points are indicated by lines 1–3: 1, aortic diameter distal from the origin of the brachiocephalic trunk; 2, aortic diameter distal from the origin of the left carotid artery; and 3, minimal stenosis caliper. Velocity measurement area was placed and adjusted according to the measurement volume of the Doppler echocardiography about (0.25 cm³) in the middle of the examined vessel. (B) Peak velocity spectrum during one cardiac cycle calculated from the gray scale-coded phase images by the flow calculation software package. The peak systolic flow velocity of 463 cm/sec in this patient represents (according to the modified Bernoulli equation) a maximum pressure gradient of 86 mmHg.