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REVIEW

Specifics of cardiac magnetic resonance imaging in children

Spécificités de l'IRM cardiaque en pédiatrie

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Summary This review points out three specific features of cardiac magnetic resonance imaging (MRI) in children: the small size of the heart modifies the usual balance between signal-to-noise ratio and spatial resolution; the higher and more variable heart rate limits tissue characterization and temporal resolution; and motion artefacts (notably respiratory motions) must be dealt with. In the second part of this review, we present the current and future practices of cardiac magnetic resonance (CMR) in children, based on the experience of all French paediatric cardiac MRI centres.

Abbreviations: 2D, two-dimensional; 3D, three-dimensional; BB, black blood; CMR, cardiac magnetic resonance; CT, computed tomography; ECG, electrocardiogram; GRICS, generalized reconstruction by inversion of coupled systems; LGE, late gadolinium enhancement; MRI, magnetic resonance imaging; Nex, number of excitations; SNR, signal-to-noise ratio; SPECT, single photon emission computed tomography; SSFP, steady-state free precession; TR, repetition time; TSE, turbo spin echo.

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Résumé Cette revue met l'accent sur trois particularités de l'imagerie par résonance magnétique (IRM) cardiaque pédiatrique : la petite taille du cœur imagé induit une modification de la balance habituelle entre rapport signal/bruit et résolution spatiale ; le rythme cardiaque plus rapide et plus variable limite la caractérisation tissulaire et la résolution temporelle ; et les mouvements (notamment mouvement respiratoires) doivent être pris en compte. Dans une deuxième partie, nous présentons la pratique clinique actuelle et future en IRM cardiaque pédiatrique, présentation basée sur l'expérience des centres français.

Introduction

Cardiac magnetic resonance (CMR) has developed considerably in the past few years. Hardware and sequences are improving very fast. Higher and more homogeneous fields and stronger gradients allow theoretically higher spatial resolution. Parallel imaging and compressed sensing allow theoretically higher temporal resolution. All conditions seemed aligned to witness the advent of paediatric CMR as one of the most promising available investigation tools in paediatric cardiology [1]. However, paediatric CMR is part of routine clinical practice in only a few centres in Europe. Its own intrinsic limitations and the need for double specific cardiological and radiological expertise make its use difficult in clinical practice. Most cardio-paediatricians are not familiar with the concepts of CMR. The first part of this review aims at clarifying the specific features of CMR in the paediatric population. In the second part, we present the current and future practices of paediatric CMR.

Specifics of paediatric CMR

Three specific features of paediatric CMR will be discussed. Each one is the direct consequence of technical aspects of CMR that encounter limits in children:

- the magnetic resonance signal is produced by the heart, and paediatric hearts are small;
- the magnetic resonance imaging (MRI) process is relatively slow, and paediatric hearts beat rapidly;
- the acquisitions require absence of motion and breath-holding that children cannot comply with.

Heart size and the relationship between voxel size and signal-to-noise ratio

Since paediatric hearts are much smaller than adult hearts, a compromise between two solutions must be chosen. First, the boundaries of the field of view may be reduced to adjust to the child's anatomy. If the number of voxels of the image is preserved, this will result in a smaller voxel containing fewer protons and ultimately a lower MRI signal. Second, the spatial resolution of the image (size of the k-space matrix) may be reduced. This will result in less informative images. The consequence of the compromise is that the images have a lower signal-to-noise ratio (SNR) and/or a lower spatial resolution. SNR is actually proportional to the product of the voxel dimensions. To counter this, the acquired data can be averaged over multiple excitations, with SNR being proportional to the square root of the number of excitations (Nex) [1]. For instance, let us consider imaging with a single excitation (Nex = 1) and a voxel size set to $1 \times 1 \times 8\,mm^3$; if the voxel size is reduced to $0.7 \times 0.7 \times 8\,mm^3$, the same SNR will be obtained with Nex = 4, which implies increasing the scan time fourfold.

Another element that is of utmost importance with regard to SNR is the receiver coil. MRI scanners are equipped with a great variety of multiple-channel surface coil arrays to fit all shapes of the average adult anatomy (head, torso, knee coils, etc.). However, they cannot be adapted to the dimensions of each individual patient. Radio-frequency coil receivers can be thought of as simple coil loops. The diameter of these loops should be large enough to capture signals from protons deep inside the body, but as small as possible to capture less noise coming from the rest of the body. In general practice, only conventional adult coils are available, leading to a suboptimal SNR. Dedicated or scalable coils would be an interesting field for future research.

Heart rate and cardiac synchronization

The normal heart rate in infants (90—180 bpm) is higher than in adults (60—100 bpm). For cardiac MRI, higher heart rates have two general consequences. Firstly, the heart rest phase (diastasis in mid-diastole) shortens and disappears after 90 bpm [2]. Shorter diastasis implies that a smaller portion of the k-space can be acquired during each cardiac cycle to avoid motion blurring. The use of end-systole (40% of the cardiac cycle), instead of mid-diastole (75% of the cardiac cycle), has been advocated when heart rate is > 70 bpm [3], but this has not been validated in children. The use of systole may not be compatible with all preparation pulses as they may require a certain amount of time before the readout. Those pulses can be performed in anticipation, during the previous cardiac cycle, but it could require a prospective guess of the next cardiac cycle length [4]. Secondly, the cardiac cycle length becomes very short with regard to the corresponding cardiac time constants (T1 and T2). For T1-sensitive sequences, it is preferable to wait between consecutive MRI excitations (ideally $3 \times T1$ of the organ of interest, i.e. at least 2—3 s or several