STATE OF ART OF MRI OF FETAL HEART

Author:
Lucia Manganaro

Department of Radiological Oncological and Anatomopathological Sciences, Umberto I Hospital, "Sapienza" University of Rome

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Abstract

Congenital heart defect (CHD) is one of the most common type of fetal malformations. Tissue-Doppler imaging, dynamic three-dimensional (4D) echocardiography and fetal cardiac magnetic resonance imaging (MRI) are advanced modalities for the assessment of cardiac structure and function. MRI can study the cardiac morphology using T2-weighted half-Fourier single-shot turbo spin-echo sequence (HASTE) and steady-state free precession (True FISP) sequences. Also a dynamic study can be performed, through the acquisition of cine-MR sequences with real-time steady-state free precession (SSFP) oriented according to the standard projections used in fetal echocardiographic scanning. If the challenges relating to motion and cardiac gating can be overcome, MRI has the potential to provide high-resolution imaging of the fetal heart.

Key words: *magnetic resonance imaging, MRI, fetal heart defects, CHD*

Congenital heart defect (CHD) is one of the most common types of fetal malformations and early detection along with accurate diagnosis of these fetal anomalies is a central approach in perinatal medicine. Major CHD has an incidence of two to three per 1000 live births and accounts for 40% of perinatal mortality. The detection rates of CHD vary greatly across the world from 16% to 65% with a reported overall prenatal detection rate of 25% in European countries [1].

Tissue-Doppler imaging, dynamic three-dimensional (4D) echocardiography and fetal cardiac magnetic resonance imaging (MRI) are advanced modalities for the assessment of cardiac structure and function. Implementation of these new technologies is far from routine, but these approaches have already shown promising results and may allow a more detailed evaluation of cardiac function.

Although fetal echocardiography is the screening modality of choice for cardiac evaluation, there are circumstances in which ultrasonography has been reported to have limitations, such as in the presence of oligohydramnios, bone ossification, unfavorable fetal position, maternal abdominal wall scar, especially during the third trimester. Furthermore, maternal obesity has been shown to impair correct visualization of cardiac anatomy on echocardiography in about half of cases, which has led to a search for alternative techniques for imaging the fetal heart [1].

For these reasons, fetal MRI is a third-level diagnostic tool in the evaluation of fetal malformations and in particular for the diagnosis and confirmation of fetal central nervous system (CNS) and non-CNS, placental and uterine diseases.

At the moment, there is no evidence that short-term exposure to electromagnetic fields of 1.5 T or less harms the fetus [2, 3].

According to the last international guidelines (Safety Committee of the Society for Magnetic Resonance Imaging), fetal MRI is recommended to be performed after the II trimester of pregnancy when other nonionizing methods are inadequate or when the MR examinations will provide critical information [4].

The application of MRI to the fetal heart has been limited because of the small size of fetal cardiac structures, random fetal motion, and the rapidly beating fetal heart in the absence of a fetal electrocardiogram reduces the quality of the examination. In addition the low spatial resolution represents an important limit.

Furthermore, in contrast to conventional ultrasound technology, MRI is an expensive tool of investigation.

Further developments of new realtime sequences during

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Corresponding author: lucia.manganaro@uniroma1.it, lmanganaro@sirm.org

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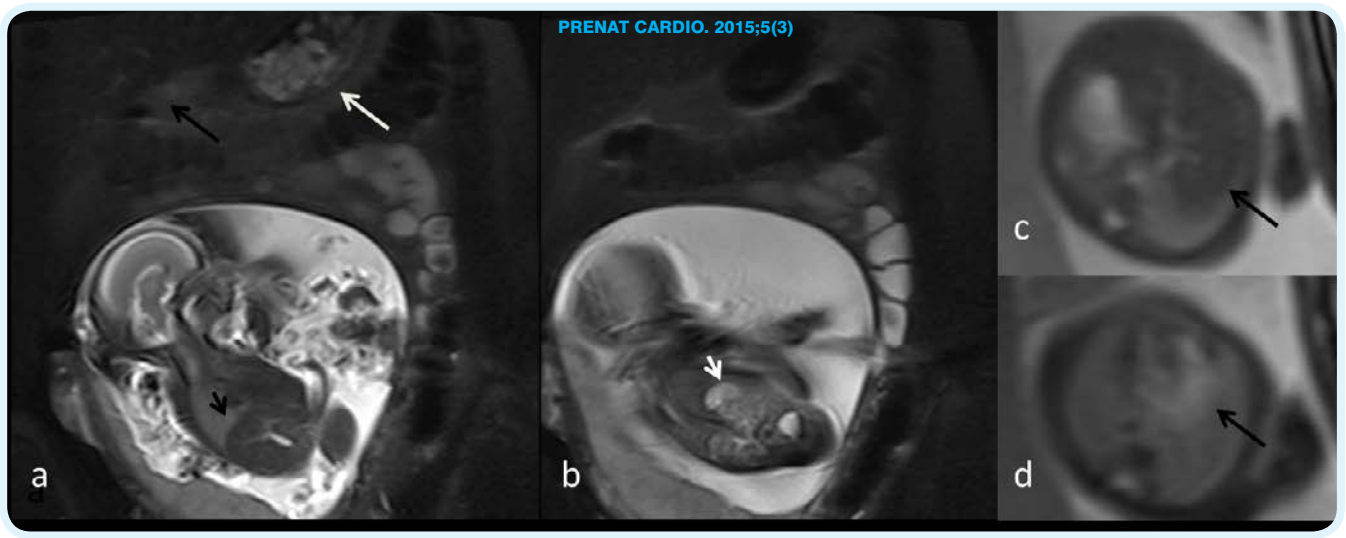

Figure 1: 27-week gestation fetus with complete situs inversus. Fetus position is transversal with head on the right side of the mother as indicated by the position of the liver (black arrow) and stomach (white arrow) (a). a) posterior plan of the coronal view acquired on the mother shows the liver (small black arrow) instead of the stomach, which is endeed shown on an anterior plane of the coronal view (b, small white arrow). c) Liver is located on the left side of the fetus (arrow). d) heart is located on the right side (arrow).

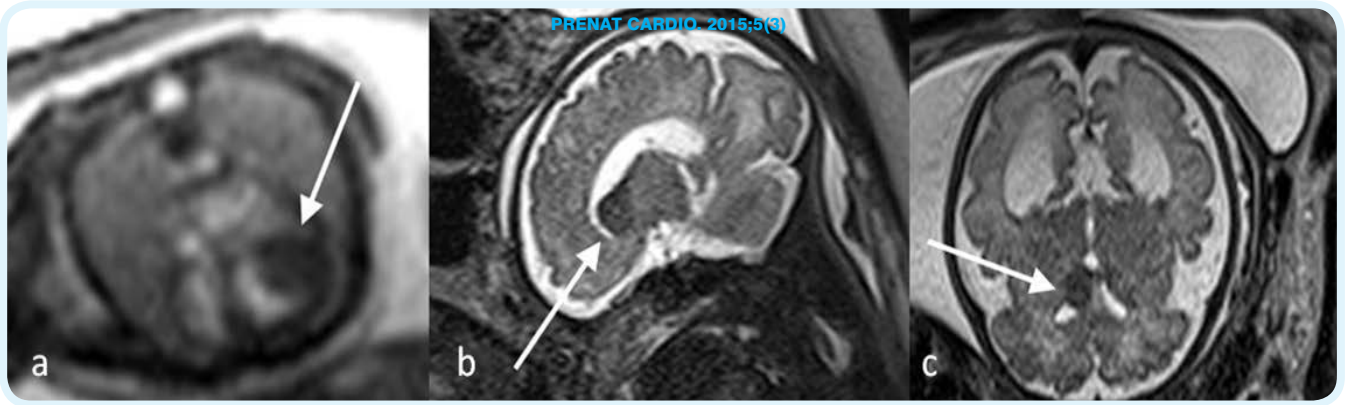

Figure 2: 33-week gestational age fetus affected by tuberous sclerosis a) nodular hypointense rhabdomyoma (arrow) located in the right ventricle. b-c) subependymal rhabdomyoma located next to the lateral ventricle (arrows).

free breathing without cardiac triggering [5,6] establish the potential role of MRI in the study of fetal heart [7,8,9]: MRI can study the cardiac morphology using T2-weighted half-Fourier single-shot turbo spin-echo sequence (HASTE) and steady-state free precession (TrueFISP) sequences.

HASTE T2-weighted images allow the assessment of the fetal position comparing with the mother, by checking the fetal head and spine and verifying the correct disposition of the stomach on the left side (Figure 1) and are highly sensitive to flow; moreover, heart and blood-filled vessels are visualized as a lack of signal.

Short echo time of True-FISP sequences allow the evaluation of the myocardial thickness and interventricular septum, thanks to the higher contrast resolution blood-tissue on endocardium. Also a dynamic study can be performed, through the acquisition of cine-MR sequences with real-time steady-state free precession (SSFP) [10] oriented according to the standard projections used in fetal echocardiographic scanning.

MRI can analize the normal anatomy by sagittal, coronal and axial planes, orthogonally oriented to the fetal diaphragm as to identify the viscero-atrial situs (Figure 1), the heart and its axis [10] and then by transverse, long axis and angulated views to visualize the main cardiac structures.

In particular, by the four-chamber view TrueFISP sequences allow evaluation of the: heart size compared to the thorax, tracing heart and thorax areas and calculating their ratio; position of the cardiac apex; the ventricular septum angulation to the sagittal midline of the thorax; structure of the cardiac chambers with the anatomical measurements of the area and the length of the atria and the ventricles; thickness of the ventricular septum and ventricular walls at midcavity; mitral and tricuspid valves. However, pulmonary veins or the moderator band into the right ventricle apex and the patent foramen ovale are rarely detected [10].

The three-vessel view show the size and position of the pulmonary artery (PA), Ao, superior vena cava (SVC) and the ductus arteriosus.

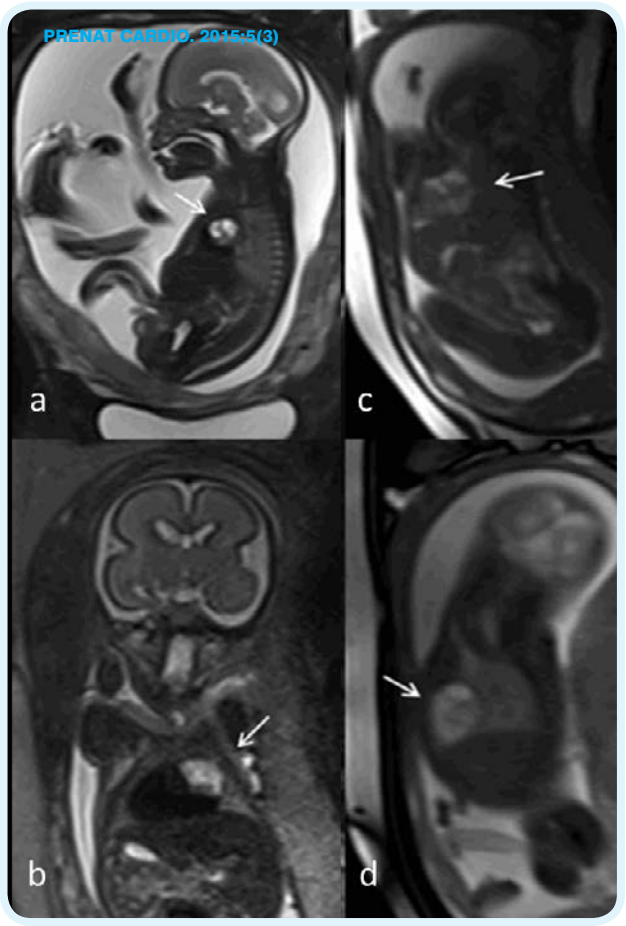

Figure 3: 25 week gestation fetus affected by perycardial teratoma. Multilobulated lesion with inhomogeneous signal in T2W sequences (arrow), located in the perycardium.

By the five-chamber view the position of aorta (Ao) is identified, according to heart and thorax.

The tricuspid-aortic view demonstrate the position of the two right chambers with the aortic outflow between them and the SVC and inferior vena cava (IVC) inflow into the right atrium. Also the long-axis view of the ductus arteriosus is obtained and the right ventricle identified with the origin of the PA [10,11].

The long-axis view of the aortic arch identify ventrally the ascending Ao that continues with the aortic arch, with the origin of the three head and neck vessels and successively with the descending Ao. Also angulated views are usually performed: the long-axis of the left ventricle shows the aortic origin from the left ventricle and the long-axis of the arch and ductus arteriosus visualized simultaneously the arch and the ductus arteriosus comparing their size [10].

Fetal MRI has been used to diagnose most of the main forms of CHD such as cardiac rhabdomyoma (Figure 2), cardiac teratoma (Figure 3), truncus arteriosus, isolated levocardia, cardiomegalies, malrotations, hypoplastic left heart syndromes, tetralogies of Fallot (Figure 4), ventricular septal defect (VSD) (Figure 5), pericardial effusions, right-sided aortic arch, spongiosus cardiomyopathy, transposition of the great vessels, pulmonary stenosis, atrial septal defect (ASD), coarctation of the aorta, atrioventricular canal and trilocular biventricular heart [9, 11, 14].

The analysis of fetal CHD can be made by direct and indirect signs: volumetric abnormalities of the heart and the cardiac chambers, abnormalities of the structure, thickness and signal intensity of the myocardial walls, anomalies of the cardiac axis orientation, defects of the ventricular and atrial septa and the anomalies of the origin, size and course of the great arteries represent the direct signs of fetal CHD. The difficulty to recognize a "normal" anatomical structure in the reference projections, the increase of the vascular size before a vascular stenosis and the presence of cardiomegaly and pericardial effusion are instead considered indirect signs of fetal CHD [11, 12].

Votino et al. demonstrated that the use of SSFP sequences at MRI allowed visualization of the four-chamber view in nearly all cases with a high sensitivity and showed that visualization of the outflow tracts, the aortic arch and venous return is possible in about three-quarters of cases. In the absence of fetal movements, visualization of these cardiac structures increased to more than 90%, with a moderate sensitivity but high specificity in detecting abnormalities of these structures [13].

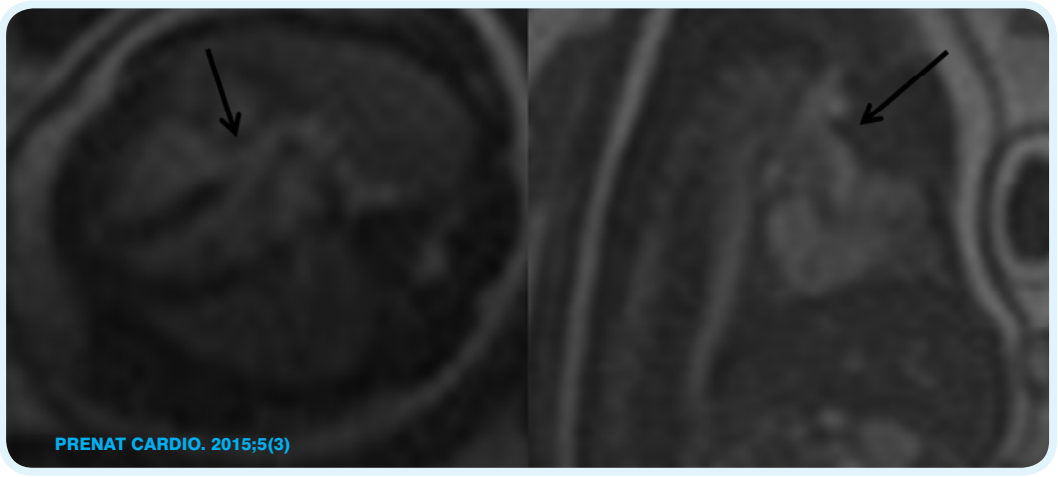

Figure 4: 38-week gestational age fetus with Fallot tetralogy. Aorta exiting the heart overriding ventricles (arrows).

Because of the number of other associated structural defects (Figure 2) that affect fetuses who have cardiac defects, MRI may represent a useful addition to US (ultrasound) in the evaluation of these fetuses [13, 14].

If the challenges relating to motion and cardiac gating can be overcome, MRI has the potential to provide high-resolution imaging of the fetal heart

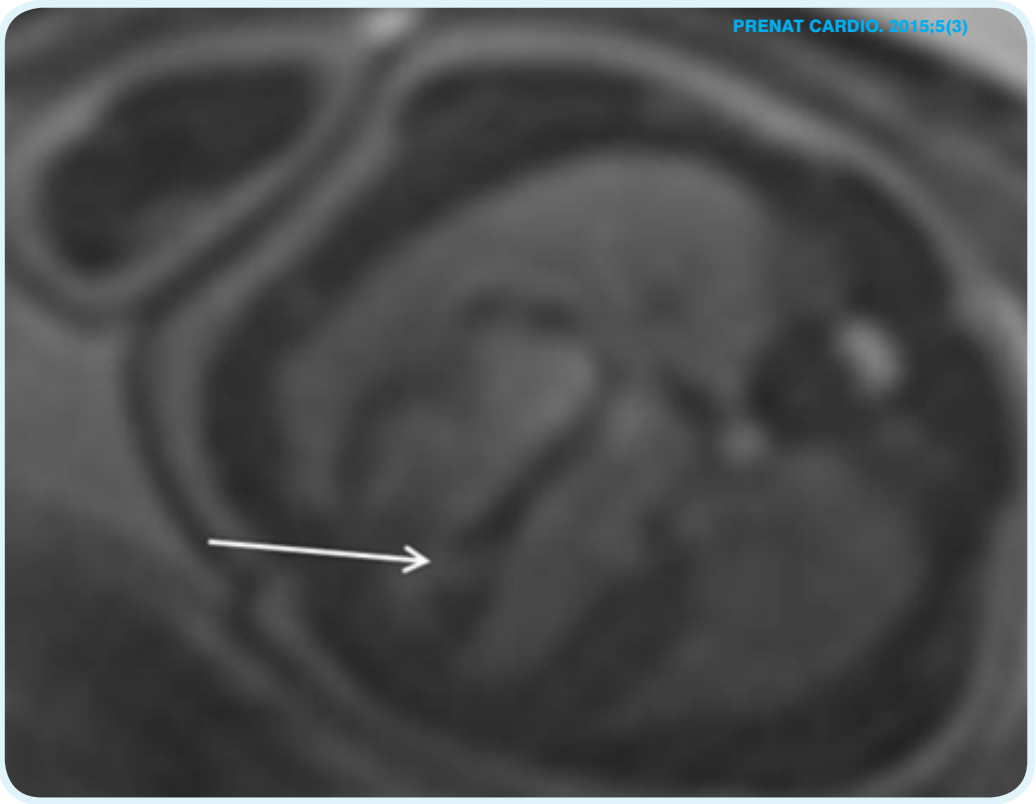

Figure 5: 32-week gestational age fetus with septal ventricle defect. Lack of continuity in the lower septal part (arrow)

in multiple planes and to generate volume data sets, offering the potential to provide quantitative evaluation of cardiac function and chamber volumes and to provide unique perspectives on venous and arterial anatomy, visceroatrial situs, extracardiac malformations affecting fetal cardiovascular structure/function.

Recently, the American Heath Association has published a scientific statement for Diagnosis and Treatment of Fetal Cardiac Disease published on Circulation 2014 and MRI of Fetal Heart has been included as a adjunctive tool of investigation to evaluate, in particular, associated malformations (brain, pulmonary hypoplasia and placenta).

In addition, some Authors [12] have published a pilot study about the employment of Phase-Contrast Magnetic Resonance in Fetal MRI for the measurement of fetal blood flow.

Although other studies with significantly large population may offer standardization, fetal MRI seems to be a promising diagnostic method also for further assessment of the fetal heart as well.

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