CLINICAL RESEARCH

Real-time three-dimensional foetal echocardiography using a new transabdominal xMATRIX array transducer

Échocardiographie cardiaque fœtale 3D temps réel par voie trans-abdominale avec une nouvelle sonde matricielle

Philippe Acar a,∗, Laia Battle b, Yves Dulac a, Marianne Peyre a, Hélène Dubourdieu b, Sébastien Hascoet a, Marion Groussolles b, Christophe Vayssière b

a Department of Paediatric Cardiology, Children’s Hospital, 330, avenue de Grande-Bretagne, 31059 Toulouse cedex 9, France
b Department of Obstetrics and Gynaecology, Mother’s Hospital, Toulouse, France

Received 5 August 2013; received in revised form 18 October 2013; accepted 24 October 2013 Available online 22 December 2013

KEYWORDS
Fetal echocardiography; 2D echocardiography; 3D echocardiography; Congenital heart defect; STIC

Summary
Background. — Foetal echocardiography has been used to diagnose congenital heart disease. However, conventional foetal echocardiography can only display two-dimensional (2D) structural images of the intricate three-dimensional (3D) foetal heart.
Aim. — The purpose of this study was to report the first use of a new transabdominal xMATRIX array transducer and to describe its ability to perform all 3D modalities: intelligent spatiotemporal image correlation (iSTIC) acquisition, xPlane imaging and 3D surface imaging.
Methods. — Eighty foetuses without congenital heart disease were included consecutively, with a gestational age between 20 and 37 weeks. 2D and 3D scans were performed with a transabdominal xMATRIX array transducer. Cardiac-STIC volume datasets were acquired and postprocessed with new automatic software (the ‘Fetal Heart Navigator’).
Results. — A total of 224 iSTIC acquisitions were performed (mean time for each, 2 seconds). Only 78 iSTIC acquisitions (35%) were able to detect the ductal arch automatically. ‘Fetal Heart Navigator’ feasibility varied according to foetal position, including the descending aorta. Live

Abbreviations: 2D, two-dimensional; 3D, three-dimensional; CHD, congenital heart disease; FHN, ‘Fetal Heart Navigator’; iSTIC, intelligent spatiotemporal image correlation; STIC, spatiotemporal image correlation.
∗ Corresponding author.
E-mail address: acar.p@chu-toulouse.fr (P. Acar).

1875-2136/$ — see front matter © 2013 Elsevier Masson SAS. All rights reserved.
http://dx.doi.org/10.1016/j.acvd.2013.10.003
Background

Congenital heart disease (CHD) is one of the most common congenital anomalies and is the leading cause of neonatal and infant mortality. Prenatal diagnosis of CHD has benefits for parental counselling, decision making during pregnancy, prenatal interventions, site and mode of delivery, and postnatal management [1]. The detection rate of prenatal cardiac lesions has increased significantly during the past two decades with the improvement in foetal echocardiography [2]. Two-dimensional (2D) foetal echocardiography has been used to screen, diagnose, monitor and treat congenital heart defects and rhythm abnormalities [3]. However conventional echocardiography can only display 2D structural images of the intricate three-dimensional (3D) foetal heart. 3D echocardiography has been shown to enhance the diagnosis of CHD in children [4,5]. Spatiotemporal image correlation (STIC) was first introduced for 3D foetal echocardiography using mechanical transducers [6,7]. STIC acquires a series of volume data that can be displayed in any plane. However, postprocessing of the volume dataset requires expertise [8,9]. Real-time 3D echocardiography in the foetus was recently introduced with the development of the cardiac xMATRIX array transducer [10,11]. This type of transducer enables visualization and examination of the pulsating foetal heart in real time, without the need for gating, and is unaffected by motion artefacts. Live 3D surface and xPlane imaging are modalities of this new technology [12]. However, STIC and live 3D imaging have never been produced by the same ultrasound system.

We report for the first time on a new transabdominal xMATRIX array transducer. Our aim was to describe its ability to perform the three modalities of 3D imaging: STIC acquisition, xPlane imaging and 3D surface imaging. New automatic software for displaying STIC planes was tested.

Methods

Eighty women with singleton pregnancies (gestational age between 20 and 37 weeks) were studied consecutively at Toulouse University Hospital from July to October 2012. All patients had undergone previous 2D ultrasound examinations that excluded any malformations. Informed consent was obtained in all cases.

Transabdominal real-time 3D echocardiography was performed using an iU22 ultrasound machine (Philips Medical Systems, Bothell, WA, USA) equipped with an x6-1 PureWave xMATRIX array transducer (Fig. 1). All 3D echocardiography was performed by two experienced operators (P.A. and C.V.). Three modalities of 3D imaging were performed.

Intelligent STIC (iSTIC) acquisition

With the full volume angle set at 20° and an acquisition time of only 3 seconds, this fast acquisition is obtained thanks to the electronic phasing of the x6-1 xMATRIX transducer (versus 10 seconds with the conventional STIC method on a mechanical transducer). The acquisition was started from a four-chamber view during a foetal quiescent period. Two to three sets of volume data were collected for each case...
and saved on the hard disk of the machine. All volume datasets were analysed off-line using dedicated software by two independent observers (L.B. and M.G.). Postprocessing was performed using the ‘Fetal Heart Navigator’ (FHN) software (plug-in within QLAB 9.0 software; Philips Medical Systems, Bothell, WA, USA; 2011). The FHN software automatically detects the ductal arch as the initial view no matter what position the iSTIC data set or STIC data set is acquired in (Fig. 2). For the next step, the user was guided in obtaining the views recommended by the ISUOG guidelines on foetal cardiac screening: the four-chamber view and the left and right ventricular outflow tract views [3]. At the end of the protocol, all four views were displayed on one screen.

**Live xPlane imaging**

The xMATRIX array transducer allows the simultaneous display by using a split-screen format of two high-resolution real-time views: a primary reference imaging plane and a secondary imaging plane selected by electronic rotation of the ultrasound beam (Fig. 3). A rotation through a full 360°

---

**Figure 1.** x6·1 PureWave xMATRIX array transducer containing 9000 active elements (35 times more elements than conventional transducers), allowing different imaging modes, such as iSTIC acquisition, live xPlane imaging and live 3D imaging.

**Figure 2.** A. ‘Fetal Heart Navigator’: acquisition with the x6·1 xMATRIX array transducer on the iU22 ultrasound system (Philips Medical Systems, Bothell, WA, USA) on the normal heart of a 24-week foetus. Extraction of the four-chamber view (1), left ventricular outflow tract (2), right ventricular outflow tract (3) and ductal arch (4). B. ‘Fetal Heart Navigator’: acquisition with the x6·1 xMATRIX transducer on the iU22 ultrasound system on the normal heart of a 30-week foetus. The system cannot find the required ductal arch view.
was applied from the reference image plane. A lateral tilt from $-45^\circ$ to $+45^\circ$ was added to the rotated image plane. From the reference plane, an elevation tilt was performed from $-30^\circ$ to $+30^\circ$.

**Live 3D surface imaging**

The system acquired 3D data using a $40^\circ \times 20^\circ$ pyramidal imaging volume of the target organ (Fig. 4). Two orthogonal reference planes were used to localize cardiac structures in the volume. Navigation by cropping inside the volume allowed surface rendering of the intracardiac structures.

**Results**

A total of 224 iSTIC acquisitions were performed in 80 foetuses. The mean time for each acquisition with the xMATRIX array transducer was 2 seconds. All the volume datasets were analysed using the FHN software. We defined the feasibility of the FHN as the ability to depict the ductal arch view from the initial acquisition. Only 78 iSTIC acquisitions were able to detect the ductal arch automatically, resulting in a feasibility of 34.8% for FHN. Feasibility varied according to foetal position (either apical, right-sided or left-sided insonation of the four-chamber view of the foetal heart), including the descending aorta.

Live xPlane imaging had excellent feasibility (95%) regardless of foetal position. Using rotation, lateral and elevation (vertical) tilts, all normal cardiac structures were identified from a unique reference image plane: the atrial cavity and septum; the atrioventricular valves; the ventricular cavity and septum; the left and right ventricular outflow tracts; the ascending aorta; and the main pulmonary artery and its bifurcation.

The feasibility of live 3D surface imaging varied depending on the target structure. Only 10% of the volume dataset offered comprehensive imaging. By cropping and rotating the 3D pyramid, intracardiac en face views of the atrioventricular valves were obtained, including dynamic motion.

**Discussion**

This is the first report using a transabdominal xMATRIX array transducer applying all modalities of 3D imaging to the foetal
heart: STIC acquisition, xPlane imaging and 3D surface imaging.

**iSTIC acquisition and postprocessing**

STIC was first introduced for 3D foetal echocardiography in 2003 using mechanical transducers [6]. STIC is an automated volume acquisition in which the array inside the transducer performs a slow single sweep, recording a 3D volume dataset. The major limitations of STIC technology acquired with mechanical transducers are that the image is not acquired in real time, making foetal movement a problem during the acquisition time [7–9]. Such motion can generate some degradation in image quality from the 2D image.

Here, we report the first study of iSTIC acquisition performed using an electronic xMATRIX array transducer. We acquired a high-resolution loop of volumes over a foetal cardiac cycle in only 2 seconds (as opposed to 10 seconds with conventional STIC), unaffected by motion artefacts. Whatever the mode of STIC or iSTIC acquisition, the acquired volume dataset needs off-line re-examination. Postprocessing of the volume dataset requires time and expertise. We used new protocol-driven workflow FHN software. It does not matter in which position the iSTIC or STIC data set is acquired for the FHN software. A major limitation of the software is the difficulty in detecting the ductal arch (dependent on the foetal position and the acquisition box). Feasibility could be increased by using right-sided or left-sided insonation of the four-chamber view of the foetal heart, including the descending aorta. However by following the ISUOG guidelines, the FHN should simplify foetal heart examination from the STIC volume [3]. Even if STIC modalities have limited value in the foetal diagnosis of CHD, many studies have reported its usefulness in assessing cardiac function, atrial morphology, vessels and atrioventricular valve measurements [13–16]. STIC by telemedicine is also a promising modality [17]. The advantage of the xMATRIX array transducer comes from its ability to switch to other 3D modalities, such as live xPlane and 3D surface rendering.

**Live xPlane imaging**

Whereas a conventional 2D foetal echocardiogram typically requires several minutes to obtain multiple views from different sweeps, xPlane imaging is a new mode that allows a total scan of the foetal heart without moving the transducer. Live xPlane imaging (or ‘biplane imaging’) is the scanning of two image planes of the foetal heart at different angles. The Live xPlane imaging technique does not require cardiac monitoring of the foetal cardiac cycle and avoids the potential artefacts produced by the cardiac gating method. Use of this method to display two cardiac planes simultaneously — namely, the four-chamber and ventricular outflow planes — without needing to move the transducer, has been previously described [10,18]. The rotation angle depends on the position of the foetal heart and on the normality of the outflow tract.

Xiong et al. reported a live xPlane imaging study in the foetus to visualize simultaneously the four-chamber and in-plane views of the interventricular septum; they concluded that this method may be a useful tool for the assessment of ventricular septal defects [19]. In our study, live xPlane imaging was able to identify a normal foetal heart with a single position of the transducer, despite the foetus being in a difficult position, even if we only used the lateral xPlane view and the elevation mode available on the xMATRIX system.

**Live 3D surface imaging**

Live 3D surface imaging provides real-time volumetric examination of the target organ. 3D volume rendering provides unique views of cardiac anatomical structures, which are not easily understood on conventional 2D imaging. The use of live 3D surface imaging has been extensively reported in paediatric and adult cardiology; it has been shown to be particularly useful in the assessment of valvular diseases and CHD [4,5].

Studies using live 3D surface imaging in foetal echocardiography are still limited. We and others previously reported that using a cardiac xMATRIX array transducer for 3D surface imaging could more precisely describe the size of patent foramen ovale as well the location of intracardiac tumours [10,20]. Using the same xMATRIX transducer, Xiong et al. reported the ability of the *en face* view of the interventricular septum to better visualize ventricular septal defect in the foetus [21]. However, this imaging is limited by the low penetration of the high-frequency transducer as well as the narrow scanning angle [22]. Further studies are necessary to explore the role of this new xMATRIX transabdominal transducer in foetal echocardiography.

Our study is the first report of live 3D surface imaging using the transabdominal xMATRIX transducer. Volume scans are less dependent on the angle of acquisition, which means that obtaining the requisite data may be dependent on foetal lie or operator expertise. As the resolution of real-time 3D volume display remains inferior to that of conventional 2D imaging, its application in foetal echocardiography is still limited [10,12–24]. Further studies are required to compare the abilities of 3D versus 2D in foetuses that are challenging, in terms of acoustic window and foetal position. Moreover, these studies should include foetuses with cardiac malformations.

As this sentence speaks to the cardiac xMATRIX transducer. Can we suggest to move it up to the position indicated before the sentence starting with ‘Further studies are necessary’.

**Disclosure of interest**

The authors declare that they have no conflicts of interest concerning this article.

**Acknowledgments**

Philips loaned an iU22 xMATRIX ultrasound system to the prenatal department of the University Hospital of Toulouse.
References


