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Original Article

Continuous transverse scanning of the fetal heart using a cross-sectional image database of common fetal congenital heart deformities

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ABSTRACT

Objective: To provide an anatomical basis for continuous transverse scanning of the fetal heart by analyzing the typical cross-sectional characteristics of different types of congenital heart deformities (CHDs) using an anatomical image database.

Materials and methods: The database consisted of cross-sectional images obtained from 45 cases of common fetal CHDs, which were continuously displayed by the three-dimensional software Amira 5.3.1. The following anatomical parts were observed from the database of heart samples in a bottom-to-top manner: the coronary sinus, four chambers, left ventricular outflow tract, right ventricular outflow tract, and transverse ductal and aortic arches. The anatomical characteristics of these sections were analyzed and compared with the ultrasonic transverse views obtained from the same fetuses.

Results: During the display of the anatomical database of 45 cases of common fetal CHDs, the aforementioned typical cross sections were successively revealed, along with the corresponding pathological features. These sections also exhibited a very good correspondence with the ultrasonic transverse views of the same cases.

Conclusion: The database of cross-sectional anatomical images of fetal CHDs provided an anatomical basis for continuous transverse scanning of the fetal heart.

Introduction

Fetal cardiac malformations are the most common congenital anomalies [1,2], with an incidence of 6.8% to 10.0% among live births [3]. The incidence of these malformations is 6.5 and 4 times higher than those of chromosomal anomalies and neural tube defects, respectively. In addition, 4% of live births are expected to be affected by severe congenital cardiac malformations; this figure accounts for 20% of total neonatal deaths and up to 50% of infant deaths attributed solely to congenital anomalies [4]. The prenatal detection of congenital heart disease may improve the outcome of fetuses with specific types of cardiac lesions [5–8].

Fetal echocardiography (FECG) is the only prenatal diagnostic approach for congenital heart deformity (CHD) [9,10]. Although FECG was reportedly first used in 1980 [11], prenatal ultrasonologists prior to that time used to observe the fetal cardiac structure using the views of adult echocardiography (AECG) [12–14], such as the long-axis left and right ventricular outflow tract (LVOT and RVOT, respectively) views. However, these views are technically more difficult to obtain through FECG than through AECG because of the effect of fetal position and other circulatory issues [15]. Consequently, FECG has not been widely applied, and prenatal detection rates still vary considerably [16].

In contrast to images seen in adults, the acoustic shadow of the ribs and sternum is not obvious in images of the fetal heart obtained in the second trimester. The lack of gas in the lungs, however, facilitates FECG.

In 2001, Yagel et al [4] introduced a method for a comprehensive cardiac evaluation of the fetal heart through five short-axis views: upper abdomen transverse, four-chamber, LVOT, RVOT, and trachea [three vessels and trachea (3VT)] views. This method is completed through a continuous transverse scan along the fetal thorax. In 2013, the International Society of Ultrasound in Obstetrics and

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Gynecology [17] further highlighted the transverse sweep technique, which has become popular and increasingly accepted in recent years [18–23].

Understanding the cross-sectional anatomical views of different types of CHDs is important when using the transverse sweep technique. This study represents the first attempt to establish a cross-sectional anatomical image database of various types of common CHDs, which provides an anatomical foundation for the continuous transverse scan of a fetal heart.

Materials and methods

Specimen

A total of 45 fetal CHD samples were collected in this study from 2006 to 2013. The samples were obtained from CHD cases diagnosed in our prenatal diagnosis center following maternal induction of labor, either due to poor prognosis or combined with other serious malformations. The five ultrasonic short-axis views were obtained during FECG from all 45 cases. This study was conducted in accordance with the declaration of Helsinki and with approval from the Ethics Committee of Peking University People's Hospital (IRB no. 2012-30). Written informed consent was obtained from all participants.

Construction of fetal CHD database

The CHD fetal samples were fixed in a solution containing 4% formaldehyde for 4 weeks. The thymus, lungs, heart, trachea, esophagus, diaphragm, part of the descending aorta, and tissues from the inferior vena cava and cervix were separated and removed from the fetal samples and were continuously fixed in the same solution for 2 to 4 weeks. The heart sample was removed with a 0.2- to 0.5-cm-thick border of lung tissue on the sides to maintain the maximum size that fits the freezing microtome. The bottom of the heart sample consisted of a cross section of the chest along the apical edge. The top of the heart sample consisted of a transverse section of the cervix along the lower edge of the thyroid gland. Two to four logo bars were implanted and the heart samples were cut transversely into a 60-μm-thick layer from bottom to top. Each section was microphotographed with a digital camera (Canon EOS 5D Mark II; camera lens, EF180 mm f/3.5 L Macro, Japan).

The original database of the anatomical, ultra-thin cross-sectional images of different CHDs was constructed. The CHDs included the tetralogy of Fallot, complete endocardial cushion defect, pulmonary artery atresia, transposition of the great arteries, persistent truncus arteriosus, Ebstein's anomaly, hypoplastic left heart, pulmonary stenosis, atrial myxoma, anomalous pulmonary venous drainage, noncompaction of the ventricular myocardium, rhabdomyoma of the heart, and kollonema.

Each database contained 500 to 700 cross-sectional images with a resolution of 3744 pixels × 5616 pixels. The images were originally saved in JPEG format. Each image had two to four identification points produced by the logo bar, which was used for the reconstruction.

Analysis of anatomical characteristics

Using the identification points in each image as reference points, Photoshop or MATLAB software was used to register each image, which eliminated the shift and rotation caused by photography. The JPEG format was converted into PNG format, and the database of different kinds of fetal CHD was imported into Amira 5.3.1, a three-dimensional (3D) software, and displayed continuously. The anatomical characteristics of the typical cross sections were analyzed during the continuous display and compared with the five ultrasonic short-axis views, which were obtained during the FECG of the same fetuses.

Results

General information

The 45 cases included in the cross-sectional database of fetal CHD not only clearly represented the atrioventricular cavity and great vessels, but also distinctly showed the cardiac valves, chordae tendineae, papillary muscle (musculus papillaris), coronary sinus, and coronary artery and its branches.

During the continuous display of the typical cross sections from the anatomical database, the following were observed from the bottom to the top of the heart samples: coronary sinus section (CSS), four-chamber section (FCS), left ventricular outflow tract section (LVOTS), right ventricular outflow tract section (RVOTS), transverse ductal arch section (TDAS), and transverse aortic arch section (TAAS). These sections reflected the pathological features of various kinds of

Table 1
Sections reflecting the pathological features of various kinds of fetal CHD.

CHD (*n*)	CSS	FCS	LVOTS	RVOTS	TDAS	TAAS
TOF (6)	−	−	+	+	+	+
TOF + ECD (1)	−	+	+	+	+	+
TOF + PAA + A-PCA (1)	−	+	+	+	+	+
TGA (3)	−	−	+	+	+	+
TGA + TA + VSD (1)	−	+	+	+	+	+
TGA + TA + HLHS + MA (1)	−	+	+	+	+	+
PTA (2)	−	−	+	+	+	+
COA + VSD + HLHS (1)	−	+	+	+	+	+
DORV (1)	−	+	+	+	+	+
ECD (3)	−	+	+	+	−	−
ECD + TOF + APVD (1)	−	+	+	+	+	−
ECD + APVD (1)	−	+	+	+	+	−
APVD (1)	−	+	−	−	−	−
EA (3)	+	+	−	−	+	−
EA + NVM (1)	−	+	+	+	−	−
EA + VSD (1)	−	+	+	+	−	−
TA + VSD (1)	−	+	+	+	−	−
MA + VSD (1)	−	+	+	−	−	−
HLHS (2)	−	+	−	−	−	−
Dextrocardia + HLHS + ECD (1)	−	+	+	+	−	−
HRHS (1)	−	+	+	+	+	−
NVM + PLSVC (1)	+	+	+	+	−	−
HCM (1)	−	+	+	+	−	−
AM (1)	−	+	−	−	−	−
SA + SV (1)	−	+	+	+	+	+
SV + PTA (1)	−	+	+	+	+	+
VR + TOF (1)	−	+	+	+	+	+
IAA (1)	−	−	−	−	+	+
DA (1)	−	−	−	−	+	+
IVCI (1)	−	+	+	+	+	−
PLSVC (2)	+	+	+	+	−	−

− = normal in the section; + = visible lesions in the section; AM = atrial myxoma; A-PCA = aortopulmonary collateral artery; APVD = anomalous pulmonary venous drainage; CHD = congenital heart deformity; COA = coarctation of the aorta; CSS = coronary sinus section; DA = dextroaortic arch; DORV = double-outlet right ventricle; EA = Ebstein's anomaly; ECD = endocardial cushion defect; FCS = four-chamber section; HCM = hypertrophic cardiomyopathy; HLHS = hypoplastic left heart syndrome; HRHS = dextrocardia, hypoplastic right heart syndrome; IAA = interruption of aortic arch; IVCI = inferior vena cava interruption; LVOTS = left ventricular outflow tract section; MA = mitral atresia; *n* = Number of CHD; NVM = noncompaction of ventricular myocardium; PAA = pulmonary artery atresia; PLSVC = persistent left superior vena cava; PTA = persistent truncus arteriosus; RVOTS = right ventricular outflow tract section; SA = single atrium; SV = single ventricle; TA = tricuspid atresia; TAAS = transverse aortic arch section; TDAS = transverse ductal arch section; TGAs = transposition of the great arteries; TOF = tetralogy of Fallot; VR = vascular ring; VSD = ventricular septal defect.