

Early ultrasound evaluation for fetal cardiovascular congenital abnormalities

Costin Berceanu¹,
Elvira Brătîlă²,
Sabina Berceanu¹,
Ioana Andreea Gheonea³,
Monica M. Cîrstoiu²,
Claudia Mehedințu²,
Răzvan Ciortea⁴,
Octavian Munteanu⁵,
Roxana Bohâlțea⁵,
Irina Horhoianu⁵,
Simona Vlădăreanu²

1. Department of Obstetrics and Gynecology, University of Medicine and Pharmacy of Craiova, Romania
2. Department of Obstetrics, Gynecology and Neonatology, "Carol Davila" University of Medicine and Pharmacy Bucharest, Romania
3. Department of Radiology and Imaging, University of Medicine and Pharmacy of Craiova, Romania
4. Department of Obstetrics and Gynecology, "Iuliu Hațieganu" University of Medicine and Pharmacy Cluj-Napoca, Romania
5. Department of Obstetrics and Gynecology, Bucharest Emergency University Hospital, Romania

Correspondence:
Dr. Elvira Brătîlă
e-mail: elvirabarulea@gmail.com

Received:
September 05, 2016
Revised:
October 12, 2016
Accepted:
October 27, 2016

Abstract

The spectacular evolution of the ultrasound equipment and techniques has allowed the assessment of the fetal heart increasingly earlier during the gestation, as well as the diagnosis of the fetal abnormalities in the first trimester of pregnancy. Transvaginal ultrasound and transabdominal ultrasound are used in early fetal echocardiography. Studies have shown that the heart defects diagnosed early in gestation are more complex and have a high degree of association with chromosomal abnormalities, compared to those diagnosed in the second trimester of pregnancy. There are many studies on the correlation between the increase in the nuchal translucency (NT) and congenital heart defects, NT being one of the most frequently studied and efficient screening parameters in maternal-fetal medicine. The morphology of the umbilical cord can be assessed in the first trimester of pregnancy by colour Doppler examination. Numerous anomalies associated with single umbilical artery are described. The principles of fetal echocardiography in the first trimester are similar to those of the morphological examination in the second trimester of pregnancy, with certain peculiarities and differences. The complete examination of the fetal heart, with minimal false results, can be done under the conditions of a trained and experienced examiner within the range of 12-13 gestational weeks. The examination route must be adapted to the particularities of the case. Early fetal echocardiography should be recommended only in the presence of a precise medical indication.

Keywords: fetal echocardiography, first trimester, Doppler, single umbilical artery, heart defects

Introduction

Congenital heart defects are the group of severe congenital malformations, the most frequent ones affecting 0.8-1% of newborns^(1,2).

Approximately half of them can be considered severe heart malformations⁽²⁻⁴⁾.

The purpose of this paper is to systematically present the key elements of the fetal ultrasound examination in the first trimester of pregnancy, through comprehensive review of the literature and from the authors' imaging perspective.

The risk of association of fetal heart defects with chromosomal abnormalities ranges between 15-25%^(1,5-9).

Gomez et al. considers that the risk of associating the heart defects with chromosomal anomalies or genetic syndromes is also high and even more significant, if the heart defects are also associated with other structural abnormalities⁽¹⁾.

The first description of a heart abnormality in 11 gestational weeks dates since 1990⁽³⁾.

The spectacular evolution of the ultrasound equipment and techniques has allowed the assessment of the fetal heart increasingly earlier during the gestation, as well as the diagnosis of the fetal abnormalities in the first trimester of pregnancy.

The unanimous adoption of first trimester screening by nuchal translucency (NT) and other key markers led to the increase in the interest and enhancement of the fetal medical research and practice in the field of early fetal echocardiography.

The NT screening for the detection of chromosomal abnormalities is a key factor in the development of the fetal echocardiography in the first trimester of pregnancy for at least two reasons: association of chromosomal abnormalities with fetal heart defects and the association between the increased NT and the risk of identifying a heart abnormality⁽¹⁰⁻¹⁶⁾.

The structural abnormalities detected in one or several organs or systems increase the risk of identifying cardiac abnormalities on the one hand and the incidence of chromosomal abnormalities on the other hand^(2,17-19).

Most of the fetal heart defects (>90%) occur yet pregnancies without any significant history or associated risk factors⁽²⁾.

Early Fetal Echocardiography

There are many opinions on clearly defining this examination in the first trimester of pregnancy or early during the second trimester of pregnancy⁽¹⁷⁻²⁰⁾. Without essential differences, but only in the perspective of the maternal-fetal medicine schools where they come from, they are summarised in Table 1.

Examination route

Transvaginal ultrasound (TVUS) and transabdominal ultrasound (TAUS) are used in early fetal echocardiography. It is widely recognised both that the transvaginal route provides superior resolution and high image quality, as well as that depending on the particularities of each case, they can be used either selectively, or complementarily (Table 2)^(1,2,6,8,14,16).

Table 1 Gestational age window to perform early fetal echocardiography

Early Fetal Echocardiography	<16 gestational weeks ⁽²⁰⁾	Bronshtein M et al., 1991 ⁽²⁰⁾
	11-13 ⁺⁶ gestational weeks ⁽²¹⁻²⁴⁾	Matias et al., 1999 ⁽²⁴⁾ Becker R et al., 2006 ⁽²³⁾
	10-16 gestational weeks ^(25,26)	Yagel S et al., 2003 ⁽²⁵⁾

Table 2 Fetal echocardiography - transvaginal and transabdominal examination

TVUS	TAUS
Image resolution and quality ↑	Image resolution and quality ↓
More laborious examination ■ conditions ■ Preparing the transducer ■ examiner's experience ↑↑	Technically easy examination
■ preferably <13 gestational weeks (CRL* <70 mm) ■ low transverse fetal position	■ >13 gestational weeks, the foetus is in most cases in longitudinal position
Examination according to the gestational age, the maternal physical status, fetal position. Examiner's experience. TVUS** + TAUS***	

*CRL= crown-rump length; **TVUS= transvaginal ultrasound; ***TAUS= transabdominal ultrasound

Ultrasound of the cardiovascular system in the first trimester screening

Studies have shown that the heart defects diagnosed early (early gestation) are more complex and have a high degree of association with chromosomal abnormalities (Table 3), compared to those diagnosed in the 2nd trimester of pregnancy⁽²⁰⁻²⁶⁾.

Fetal echocardiography in the first trimester of pregnancy brings benefits equally to practitioners and patients, on the one hand, to those with an increased risk for cardiac abnormalities, when the fetal heart is normal and, on the other hand. In the context to diagnosing a major cardiac abnormality it will make possible to interrupt the pregnancy in the first trimester, with the net reduction of morbidity compared to the therapeutic interruption of the pregnancy in the second trimester^(2,27,28).

The association between the increased values of the nuchal translucency and diagnosis of heart defects is unanimously recognised⁽²⁾.

Recent studies show a 40% sensitivity for the detection of major cardiac abnormalities, in the context of identifying a value of the NT at the level of the 99th percentile or more, in the consistent conditions of the crown-rump length^(11,14).

There are many studies on the correlation between the increase in the NT and congenital heart defects, NT being

one of the most frequently studied and efficient screening parameters in maternal-fetal medicine.

The values of NT measured in standard conditions between 11-14 gestational weeks, greater than or equal to 3.5 mm are an indication for the fetal echocardiography (Table 4)^(10,11,14,30-32).

Doppler flow in the ductus venosus (DV)

DV from the placental bloodstream goes through the umbilical vein to the liver, where only a small part oxygenates the liver, the main flow going towards the second line of the fetal circulation - DV - mixing with the desaturated circulating flow in the inferior vena cava. The DV measures approximately 2 mm in 13 gestational weeks^(33,34).

In terms of Doppler ultrasound - DV is normally a pulsed three phase flow. The systolic S-wave, the diastolic D-wave and atrial A-contraction (Figure 1 A and B). Normally, there is no retrograde flow during the atrial contraction in the DV^(2,8,14).

Reversing the flow during the atrial contraction, inverted a-wave, is the main abnormal element (Figure 1 C and D), related to the presence of aneuploidies and cardiac malformations. The inverted a wave is present in approximately 3% of euploid fetuses^(2,8,14).

The Fetal Medicine Foundation (FMF) protocol for assessing the DV implies⁽³⁵⁾: gestational age (GA) 11-13+6 weeks,

Acknowledgments:
The imaging experience of Associate Professor Ioana Andreea Gheonea MD, PhD, are gratefully acknowledged as an equal contribution with the first author of the paper.

Table 3

Congenital heart malformations detectable in the first trimester/Early fetal echocardiography (adapted after Comas et al., 2002, 2006)^(27,29)

Malformation	Related signs
Atrioventricular septal defect	↑ NT ^a Cystic hygroma
VSD ^b	↑ NT
Hypoplastic right ventricle	SUA ^c
Tricuspid atresia	SUA ^c
Abnormal large arteries	SUA ^c
HLHS ^d	Kidney abnormalities ↑ NT ^a Exencephaly
DORV ^e	↑ NT ^a
Pulmonary atresia	Exencephaly
Common arterial trunk	Plurimalformative
Tetralogy of Fallot	↑ NT ^a Kidney abnormalities Omphalocele
Coarctation of the aorta	Cystic hygroma Hydrops
Transposition of the great vessels	Normal
Pulmonary stenosis	Normal
Single ventricle	Normal
Tricuspid dysplasia	↑ NT ^a
Tricuspid atresia	↑ NT ^a
Hypoplastic right ventricle	SUA ^c Situs inversus
Ectopia cordis	↑ NT ^a
VSD ^b + Tricuspid atresia	↑ NT ^a
DORV ^e + Mitral atresia	↑ NT ^a
VSD ^b + pulmonary atresia	↑ NT ^a
HLHS ^d + Situs inversus	↑ NT ^a

aNT= nuchal translucency; bVSD= Ventricular septal defect; cSUA= single umbilical artery; dHLHS= Hypoplastic left heart syndrome; eDORV= Double outlet right ventricle.

Table 4

Indications for the fetal echocardiography (adapted after Gomez et al., 2012 and Abuhamad & Chaoui, 2016)^(1,2)

Maternal indications	<ul style="list-style-type: none"> ■ Increased risk for aneuploidies in the absence of previous prenatal invasive testing (including maternal or paternal balanced translocations) ■ Metabolic syndrome (pregestational diabetes, phenylketonuria) ■ Exposure to teratogens: alcohol, ionising radiations ↑↑, drugs - anticonvulsants, lithium, warfarin, antidepressives and anxiolytics^a, retinoic acid ■ Maternal fever >38° C in the first trimester ■ Maternal congenital heart malformations ■ Maternal rheumatologic pathology (anti-Ro or anti-La antibodies) ■ ART*
Fetal indications	<ul style="list-style-type: none"> ■ Cardiac malformation suspected on the first trimester screening ■ NT** > percentile 99 at 11-14 sg ■ DV*** with absent or reversed wave a at 11-14 sg ■ Monochorionic multiple gestation ■ Abnormal cardiac axis ■ Tricuspid regurgitation ■ Extracardiac malformation ■ Intrauterine growth restriction ■ Chromosomal abnormalities ■ Fetal hydrops ■ Fetal infections: TORCH, syphilis, coxsackievirus, other viral infections ■ Polyhydramnios ■ Fetal arrhythmias ■ Antiinflammatory treatment with risk of restriction on the ductus arteriosus
Family/family history indications	<ul style="list-style-type: none"> ■ Family syndromes strongly associated with malformations ■ second degree relative with congenital cardiac malformations ■ Child with congenital heart malformations ■ Paternal congenital heart malformations
^a even if they have been prescribed by the physician	
*ART = assisted reproductive technology, **NT= nuchal translucency; ***DV = ductus venosus.	

the fetus at rest, image magnification so as the fetal thorax and the abdomen occupy the entire image, right medial-sagittal ventral image of the fetal trunk. The Doppler image must include: the umbilical vein, DV and fetal heart. The volumetric Doppler 0.5-1 mm gate to avoid the adjacent venous contamination placed in the turbulent yellow-orange area. The angle of insonation smaller than 30 degrees, low frequency (50-70 Hz), high sweep speed (2-3 cm/s)⁽³⁵⁾.

Doppler flow in the tricuspid valve

In normal conditions, the tricuspid valve closes during the systole, preventing the blood to return into the right atrium during the ventricular contraction (Figure 2, A and B). Tricuspid regurgitation (tricuspid insufficiency) involves the backward blood outflow into the right atrium during the systole (Figure 2, C and D). This hemodynamic event can be detected by pulsed and/or colour Doppler assessment^(2,8,14,23,24,33).

The FMF protocol for assessing the tricuspid flow implies⁽³⁶⁾: GA 11-13+6 weeks, image magnification so as the

fetal thorax occupies most of the image, apical 4-chamber image of the heart, the volumetric Doppler gate of 2-3 mm must be positioned in the tricuspid so as the angle to the circulating blood flow would be less than 30 degrees, from the interventricular septum. The tricuspid regurgitation is diagnosed if identified during at least half of the systolic interval and having a velocity of more than 60 cm/s, high sweep speed (2-3 cm/s). The tricuspid valve can be insufficient on one or several cusps, so that the Doppler gate should be placed in the valve at least three times, in order to fully assess the valve⁽³⁶⁾.

Doppler flow in the umbilical cord

The morphology of the umbilical cord can be assessed in the first trimester of pregnancy by colour Doppler examination. Identifying the umbilical arteries along the lateral wall of the bladder in longitudinal section on each side of the bladder can diagnose the single umbilical artery (SUA) (Figure 3) or conversely certifies the trivascularity of the umbilical cord⁽²⁸⁾.

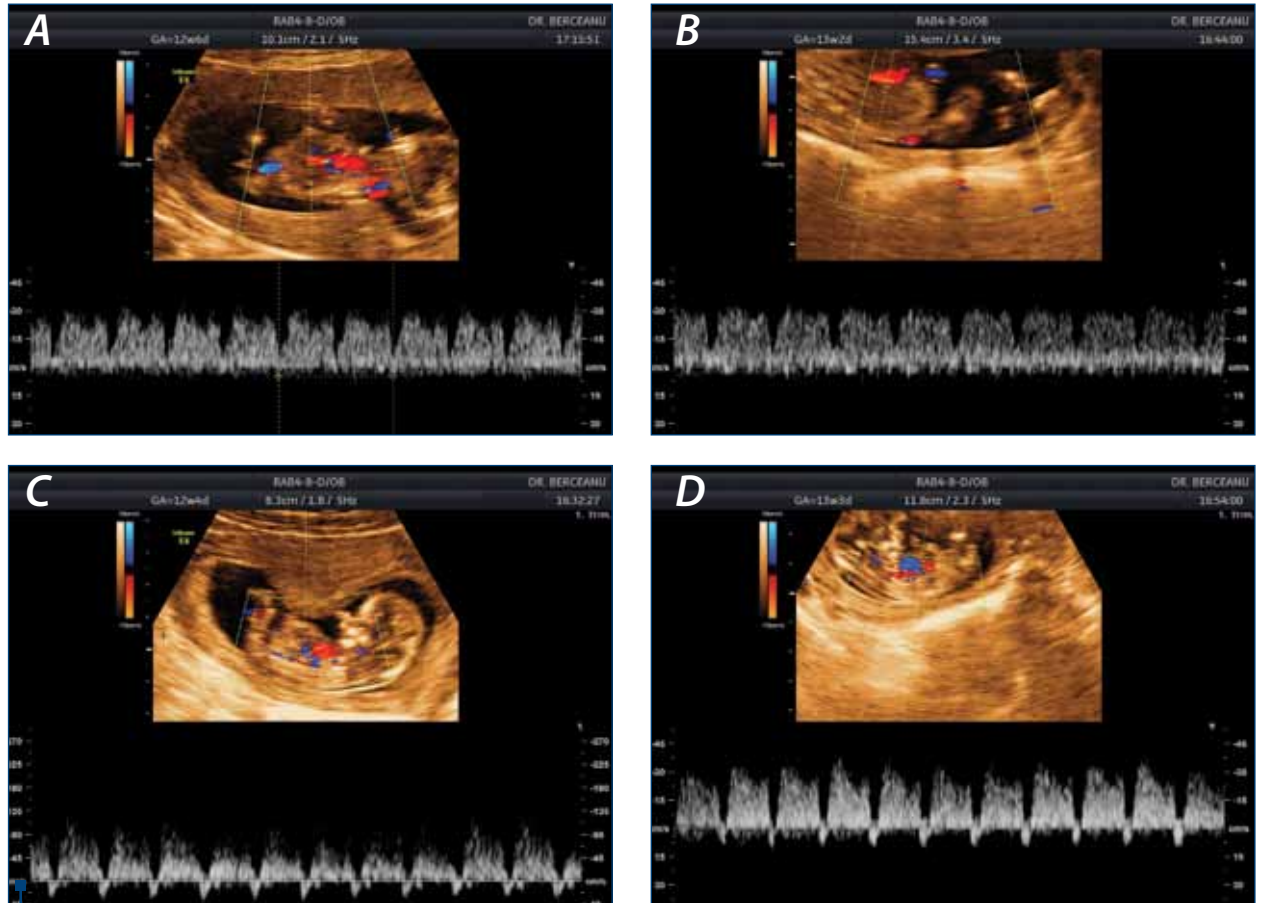


Figure 1 A, B. Normal pulsed three phase flow in DV at 12-13 gestational weeks. C, D. Abnormal Doppler flow in DV at 12-13 gestational weeks (inverted a-wave) with reverse flow during the atrial contraction (personal collection)

Bianchi et al. describe a number of abnormalities correlated with SUA: The ADAM sequence, urogenital malformations, cranio-spinal malformations, Meckel syndrome, non-immune hydrops or complex congenital (musculoskeletal, cardiovascular, gastrointestinal, central nervous system, skin, respiratory) abnormalities^(28,37-58).

The essential of fetal echocardiography in the first trimester of pregnancy

The plans of cardiac examination - the principles of fetal echocardiography in the first trimester are similar to those of the morphological examination in the second trimester of pregnancy, with certain peculiarities and differences^(2,8,14, 59-61).

The fetal echocardiography in the first trimester mandatorily begins with the fetal position and orientation^(2,14) (Figure 4A).

It should be started from the premise that the resolution and clarity of the image, in direct relation to the sizes of the fetal structures that should be examined are much more limited at this gestational age^(1,2,8,14).

The colour Doppler examination has a dominant role in the fetal echocardiography in the first trimester^(2,14).

The fetal position plays a decisive role, just like the fetal mobility characteristic to the gestational age^(2,3,8).

The essential images in the early fetal echocardiography are: the transverse image of the fetal abdomen (Figure 4A), the axial and apical 4-chamber view of the heart (Figure 4, B and C), the right outflow tract (the image in the short axis) and the left outflow tract (five chamber image) (Figure 4, D and E), requiring the change in the insonation angle and alignment of the great vessels in transverse position, the image of the aortic arch and ductal arch ("v" left lateral sign compared to the position of the trachea) (Figure 4F).

Conclusions

Early fetal echocardiography requires the thorough examination of the fetal heart in the range of 11-16 gestational weeks. The full examination of the fetal heart, with minimal false results, can be done under the conditions of a trained and experienced examiner within the range of 12-13 gestational weeks. The examination route must be adapted to the particularities of the case, TVUS and TAUS could be alternative or complementary. The colour Doppler examination has a decisive role in the fetal echocardiography in the first trimester. The evaluation of the aortic and ductal arches cannot be completed without the

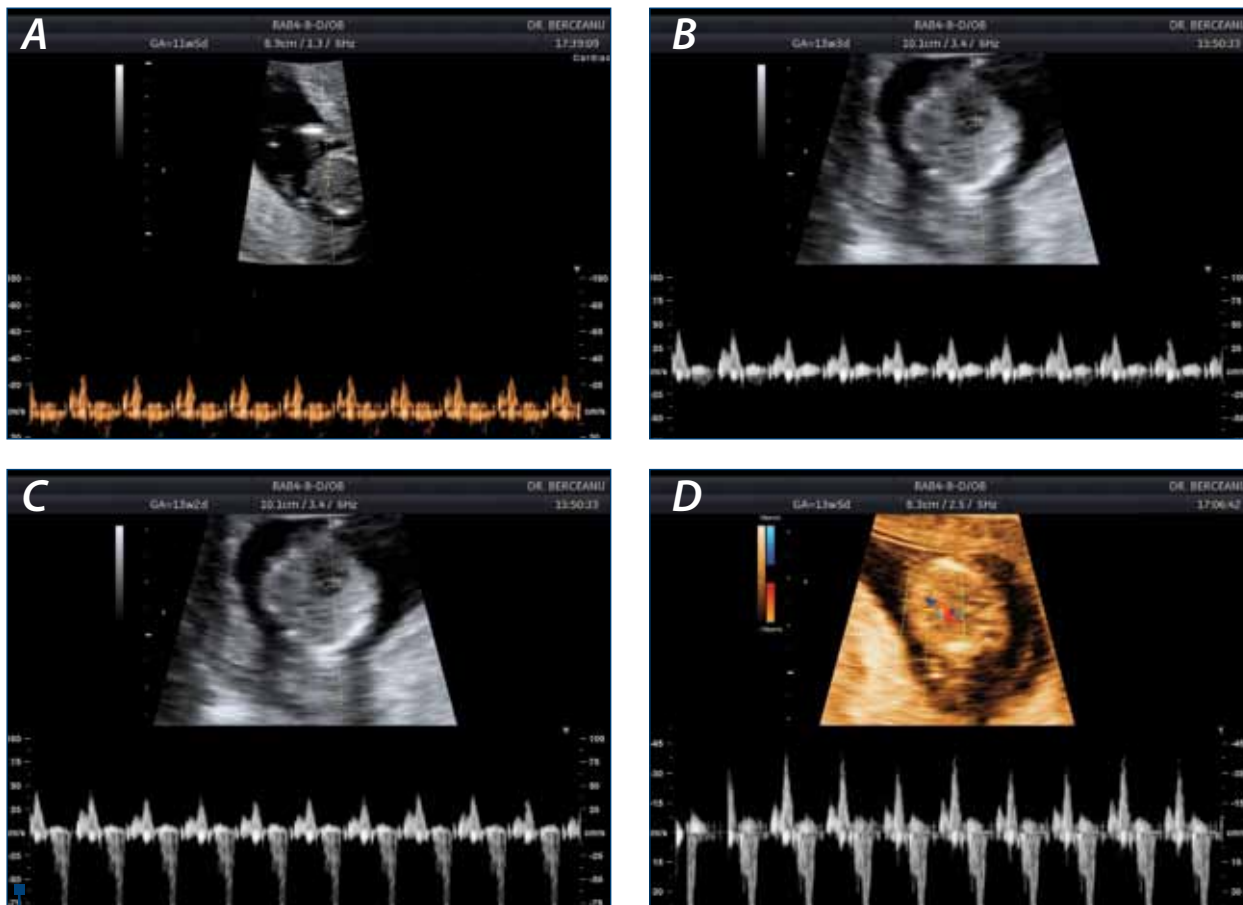


Figure 2 A, B. Normal flow in the tricuspid valve at 11-13 gestational weeks. C, D. Tricuspid regurgitation (tricuspid insufficiency) with backward blood outflow into the right atrium during the systole at 13 gestational weeks (personal collection)

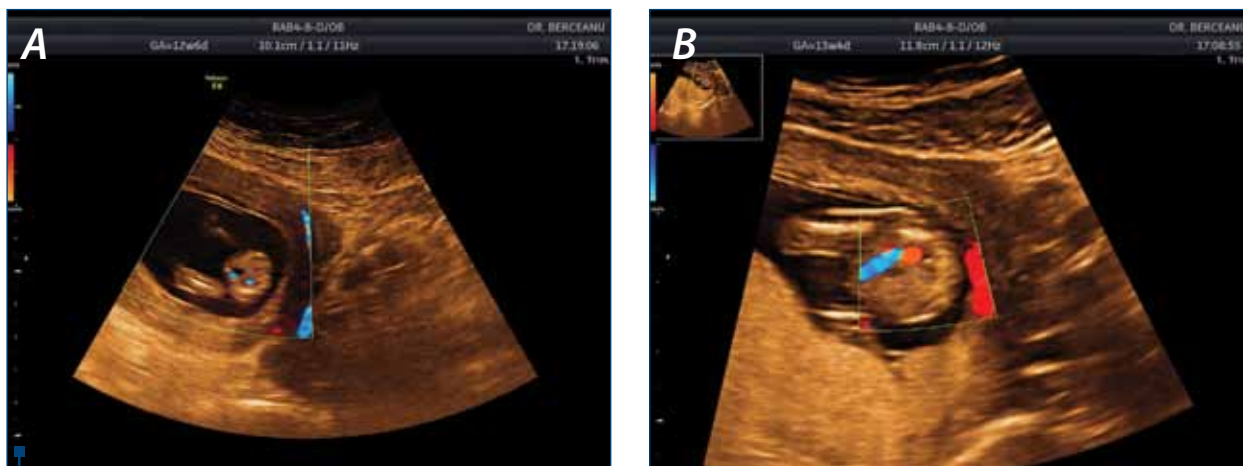


Figure 3 A. Single umbilical artery, unilateral Doppler flow along the lateral wall of the bladder at 12 gestational weeks. B. Longitudinal image at the aortic bifurcation proving the single umbilical artery at 13 gestational weeks (personal collection)

Doppler examination. Early fetal echocardiography should be recommended only in the presence of a precise medical indication. The resolution and clarity of the image, in direct relation to the sizes of the fetal structures that should

be examined are much more limited at this gestational age, so as the practitioners of early fetal echocardiography should be trained very well previously in classical echocardiography in the second trimester of pregnancy. ■

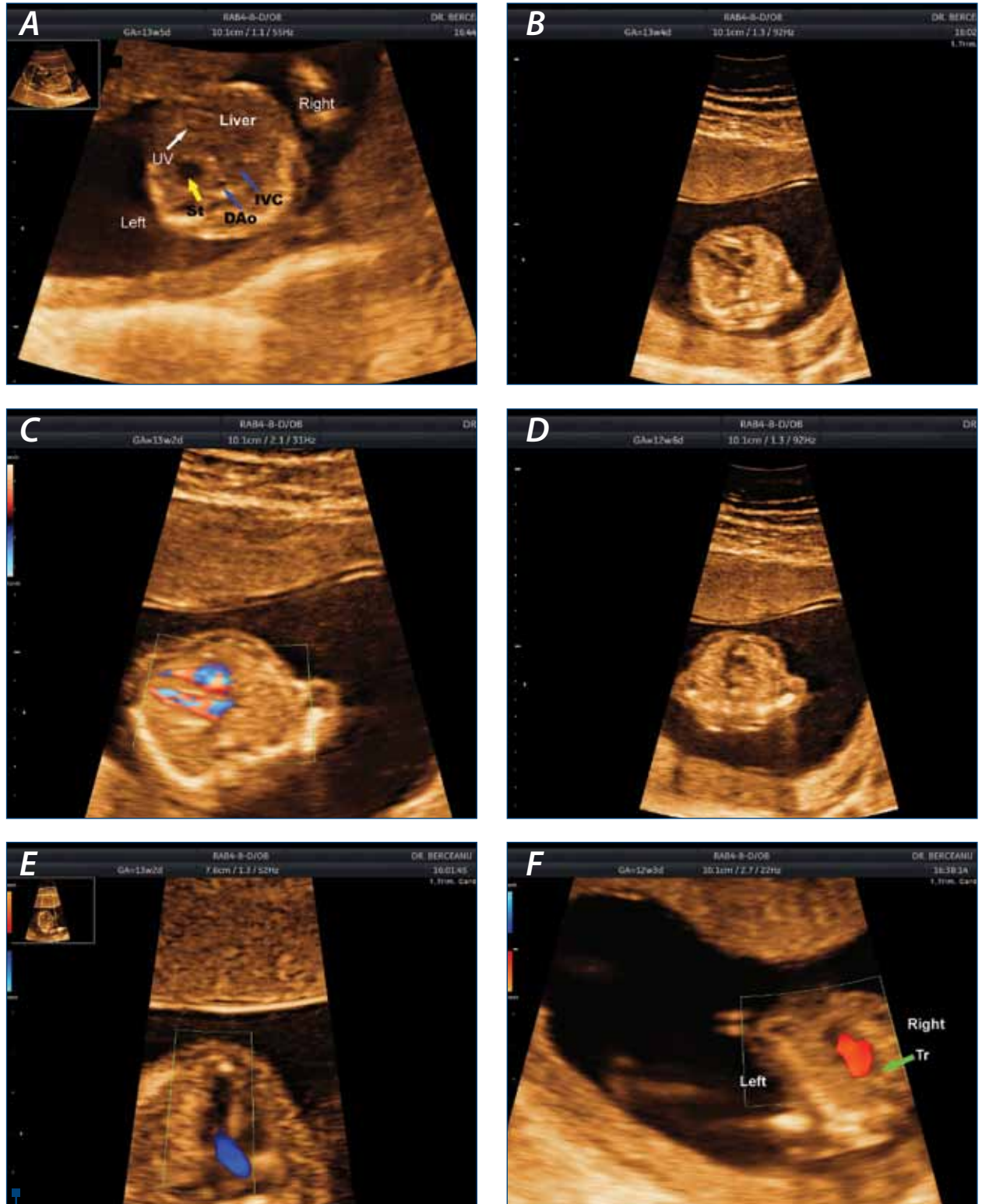


Figure 4 A. Transversal section in the upper fetal abdomen at 13⁽⁺⁵⁾ gestational weeks proving the normal anatomical conformation: stomach and descending aorta located on the left and the inferior vena cava and the liver placed on the right. B. Normal axial four chamber image of the heart in 13⁽⁺⁴⁾ gestational weeks. C. High-definition color Doppler transabdominal examination - Normal axial four chamber image of the heart in 13⁽⁺²⁾ gestational weeks. D. Conventional transabdominal examination - the right ventricular outflow tract - 12⁽⁺⁶⁾ gestational weeks. E. Color Doppler transabdominal examination - left ventricular outflow tract - 13⁽⁺²⁾ gestational weeks. F. Power Doppler transabdominal examination 12⁽⁺³⁾ gestational weeks in a normal fetus where the transverse aortic arch and isthmus merge with the pulmonary artery and ductus arteriosus into the descending aorta - the V-sign configuration to the left of the trachea (Tr from Figure 4F), (personal collection)

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