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Review paper

Evaluation of the fetal heart rhythm in clinical practice – review

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Abstract

Fetal heart rate (FHR) monitoring is one of the most important methods during the prenatal period to assess fetal wellbeing. An exact structural depiction of the cardiac anatomy and physiology are essential for the definitive prenatal diagnosis of normal heart anatomy and normal heart rhythm or cardiac defect or abnormalities in fetal heart rhythm. This is a literature review about the different modalities currently available for FHR assessment. Basic ultrasound examination includes an assessment of placenta, amniotic fluid index, fetal position, its biometry, and peripheral Doppler blood flows, i.e. umbilical artery and umbilical vein, and the middle cerebral artery. The next step is usually fetal anatomy evaluation: brain, neck, chest, abdomen, skeletal, and fetal heart. Fetal heart evaluation can be basic to confirm normal heart anatomy, normal intracardiac blood flows, normal heart rate, and normal heart rhythm. In case of detection of any abnormality a targeted fetal echocardiography assessment is recommended. Fetal echocardiography is considered a highly sensitive specific prenatal tool not only for detection but also diagnosis of congenital heart disease. Fetal echocardiography facilitates the prenatal diagnosis and through sequential examinations, and allows longitudinal assessment of fetal haemodynamics and cardiovascular status from the time of diagnosis to delivery. In this review we describe different methods of fetal heart rhythm assessment in the context of clinical fetal cardiology, and compare their advantages and disadvantages. This manuscript may be a didactic introduction to fetal echocardiography for beginners, before the next step: an attempt at recording and analysing fetal heart arrhythmias.

Key words: hiccup, isovolumetric time, tissue Doppler, fetal heart arrhythmias.

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The development of the fetus' heart begins about 18-19 days after fertilization. This is a very complex process, the result of which is the formation of a system that allows for proper circulation, and thus oxygenation, cell nutrition, and proper development of the fetus.

The assumption of many functions by the placenta and the necessity of rapid postnatal circulation change after birth makes the fetal circulation although temporary; however, 9 months' duration and is crucial for prenatal as well as postnatal life [1].

The components of the cardiac electrical conduction system are: 1) the sinoatrial node (SN), 2) the atrioventricular node (AV), and 3) the His-Purkinje system [2].

The development of the stimulus-conduction system begins just after the formation of 4 heart chambers and atrioventricular valves, which initiate the process of connective tissue

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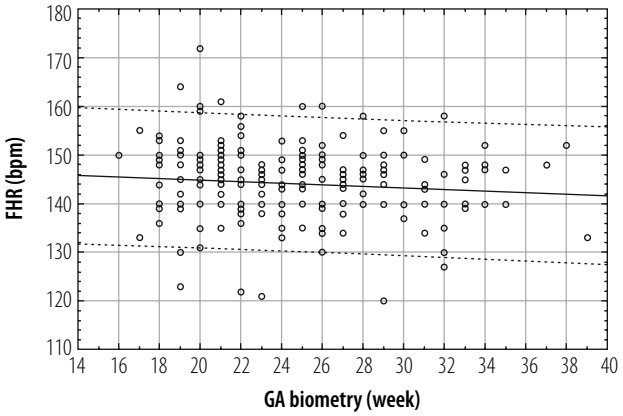

Figure 1. Scatter graph of FHR by GA (biometry) [12]

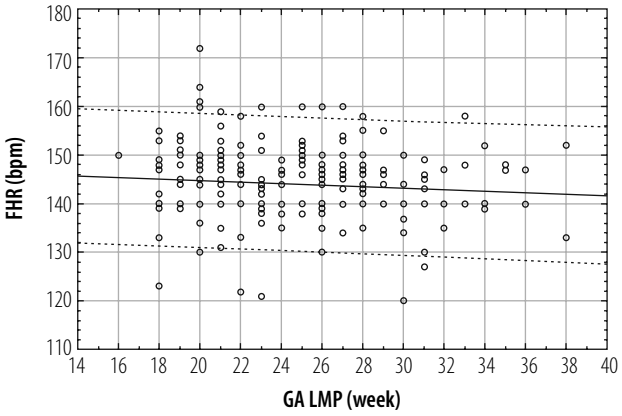

Figure 2. Scatter graph of FHR by last menstrual period (LMP) [12]

growth and formation of the fibrous skeleton. This skeleton consists of 4 rings, which are made from a specialised electrical conduction system tissue [3].

The first morphological signs of SN development are present by 5 weeks of gestation [4]. Initially, the pacemaker is located in the tail part of the left primitive heart tube, and only later the venous sinus takes over this function. During migration from the posterior cardiac field, the cells of the conduction system attain their proper position: the sinoatrial node to the left from the outlet of the superior vena cava to the right atrium and the AV node in the top of the Koch triangle [5]. The pacemaker cells are located at the base of the interatrial septum only after the venous sinus insertion into the right atrium. However, the bundle of His and its branches have a different origin from the slow-conducting tissue of the nodes. They derive from the original interventricular ring by transforming the working cells of the ventricular muscle [6]. All the above-described stages take place between 4 and 7 weeks of development. The fetal stimulus-conduction system has a similar function as in adults: it is responsible for generating active state impulses in the heart and conducting them to the working myocytes in a strictly ordered way in time and space.

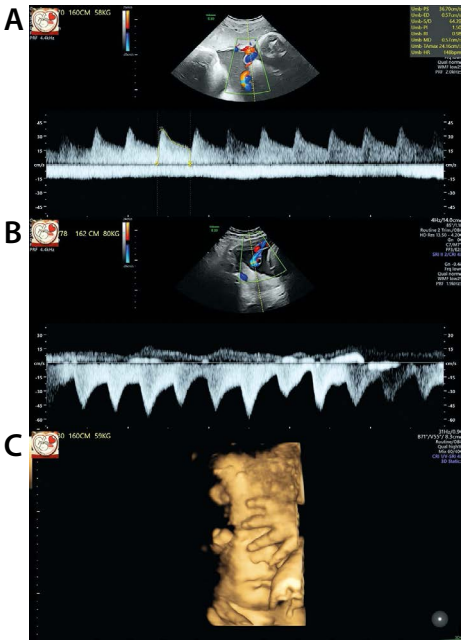

Figure 3. **A** – An example of fetal Doppler blood flow tracing in the umbilical artery and vein – normal, FHR 140/min. **B** – Abnormal fetal Doppler blood flow tracing in umbilical artery and vein – possible causes: fetal heart arrhythmia, fetal movements and compression of umbilical cord, artifacts – such tracing is an indication for targeted fetal echocardiography in prenatal cardiology referral centre. **C** – Fetal face in 3D imaging – "hiding", no umbilical cord in left hand/right hand, maybe around fetal neck or leg

There is a higher heart rate in fetal life compared to adult life. Probably this is because sympathetic innervation is not yet developed. The fetus' heart has a limited ability to increase the stroke volume, but it can increase the cardiac output by accelerating the heart rate by up to 15% [7, 8]. Therefore, the fetus' normal heart rate is higher than that of a newborn baby, who usually has a heart rate of 125 beats/min during the first week of postnatal life. However, the fetal heart rate varies depending on the stage of pregnancy and can be seen as early as in the 5-6th week of gestation. In the 5th week it is about 100 beats/min, then it increases to 170 beats/min in the 10th week and decreases to about 150-160 beats/min in the 14th week [9-11]. In the 2nd trimester, it is usually 140-150 beats/minute and in the 3rd trimester – 120-160 beats/min. There is an article with nomograms, describing this high variability of FHR according to weeks of gestation (Figure 1). The tables present data from 18 to 29 weeks of pregnancy according to fetal biometry, and 18-28 weeks of pregnancy according to LMP [12] (Figure 2). To sum up, normal prenatal sinus rhythm is 110-160 beats/minute, AV conduction < 150 ms, short-term variability (STV) > 4 ms, and long-term variability (LTV) < 30 ms [13, 14].

Fetal heart rate evaluation is indicated in every pregnant woman by every obstetrician or sonographer, whereas specialized examinations such as echocardiography are used when the screening ultrasound image shows abnormalities. The Polish Prenatal Cardiology Society in the 21st century recommends fetal echocardiography evaluation in the 1st, 2nd, and 3rd trimester of pregnancy, but the limited number of fetal cardiologists makes this difficult to achieve currently.

For detailed and full fetal heart rate assessment we require echocardiography, cardiotocography, and very rare other methods such as fetal magnetocardiography (fMCG) – which is useful, for example, in the diagnosis of long QT syndrome [15, 16],

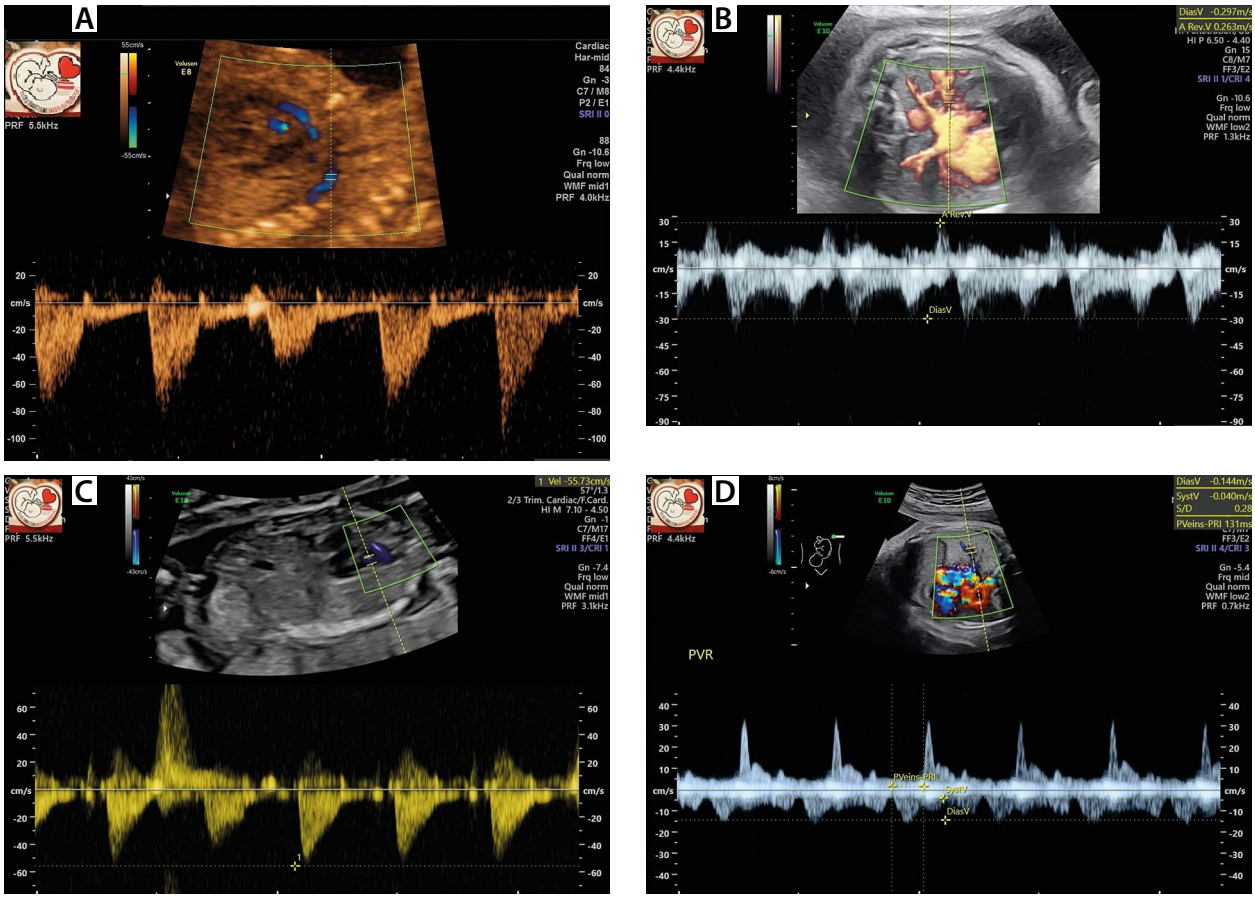

Figure 3. **A** – Longitudinal scan of fetal chest and abdomen. Doppler blood flow tracing in an aortic arch with a sudden abruption due to a hiccup of the fetus. **B** – Another example of fetal hiccup: Doppler blood flow tracing in pulmonary artery with sudden reversal flow due to hiccup. **C** – Pulsed Doppler blood flow of pulmonary vein –tracing not good enough for fetal heart rate analysis. **D** – Pulsed Doppler blood flow of pulmonary vein and small pulmonary artery – very good tracing for detailed fetal heart rate and rhythm analysis

but this method is not applicable in the majority of centres, even academic ones. Despite the development of a alternative magnetic technique (magnetocardiography), ultrasound/echocardiography remains the dominant modality to analyse fetal arrhythmias, which aids in the assessment of their haemodynamic consequences and detailed analysis of fetal cardiac anatomy [2]. The prognosis and treatment depends on an accurate and complete diagnosis [17-20].

The basic method used during ultrasound examination is Doppler blood flow assessment, for instance in the umbilical cord (Figure 3A). This method might be adequate to confirm, for instance, a normal, regular fetal heart rate (FHR) of 140 bpm at 28 weeks of gestation [21-24].

However, in the case of an abnormal Doppler pattern of umbilical artery and vein tracing (Figure 3B), other methods should be used to explain the cause of observed anomaly, for example to ascertain whether an abnormal tracing is a result of fetal movement, blood cord compression, maternal or fetal "breathing" movements, ot whether it is an abnormal fetal heart rhythm. Sometimes the fetal "behaviour" might provide an explanation for the observed abnormal Doppler patterns (Figure 3C). Transient fetal hiccup should be excluded in such cases. Nevertheless, if the abnormality, persists (despite, for instance, maternal changes her position), it should be explained by a more detailed examination (Figures 4A, B).

In prenatal echocardiography we distinguish at least 2 basic methods for fetal heart rhythm evaluation: M-mode and Doppler method. In M-mode technique a narrow ultrasound beam cuts through the heart structures, giving a motion diagram as a function of time. The M-mode technique allows the recording of multiple cardiac cycles. Fetal M-mode may be at the level of the atria (Figure 5A) or at the level of the ventricles (Figure 5B). At the level of the atria, one may assess the amplitude of right and left wall excursion and the position of the atrial septum as well as movement of the atrial septal flap, which should always be within the left atrium and should not cross the line of the atrial septum. M-mode echocardiography at the atrial level is only possible during prenatal life [25]. At the level of ventricles, the ultrasonographic beam is perpendicular to the ventricular septum and in the middle of ventricular septum, and it is possible to take measurements of the septal thickness and the size of the ventricles, both in systole and diastole. For abnormal fetal heart rate or fetal arrhythmia evaluation, one needs to change the M-mode beam in such a way that it is possible to "cut" at the same time the wall of the atrium and the wall of the ventricle. In this way it is possible to make an analysis of the sequence of atrial and ventricular contractions and make it very similar to ECG analysis (Figure 5C).

M-mode technique has some disadvantages: the onset of atrial (A) and ventricular (V) contractions are not precisely de-

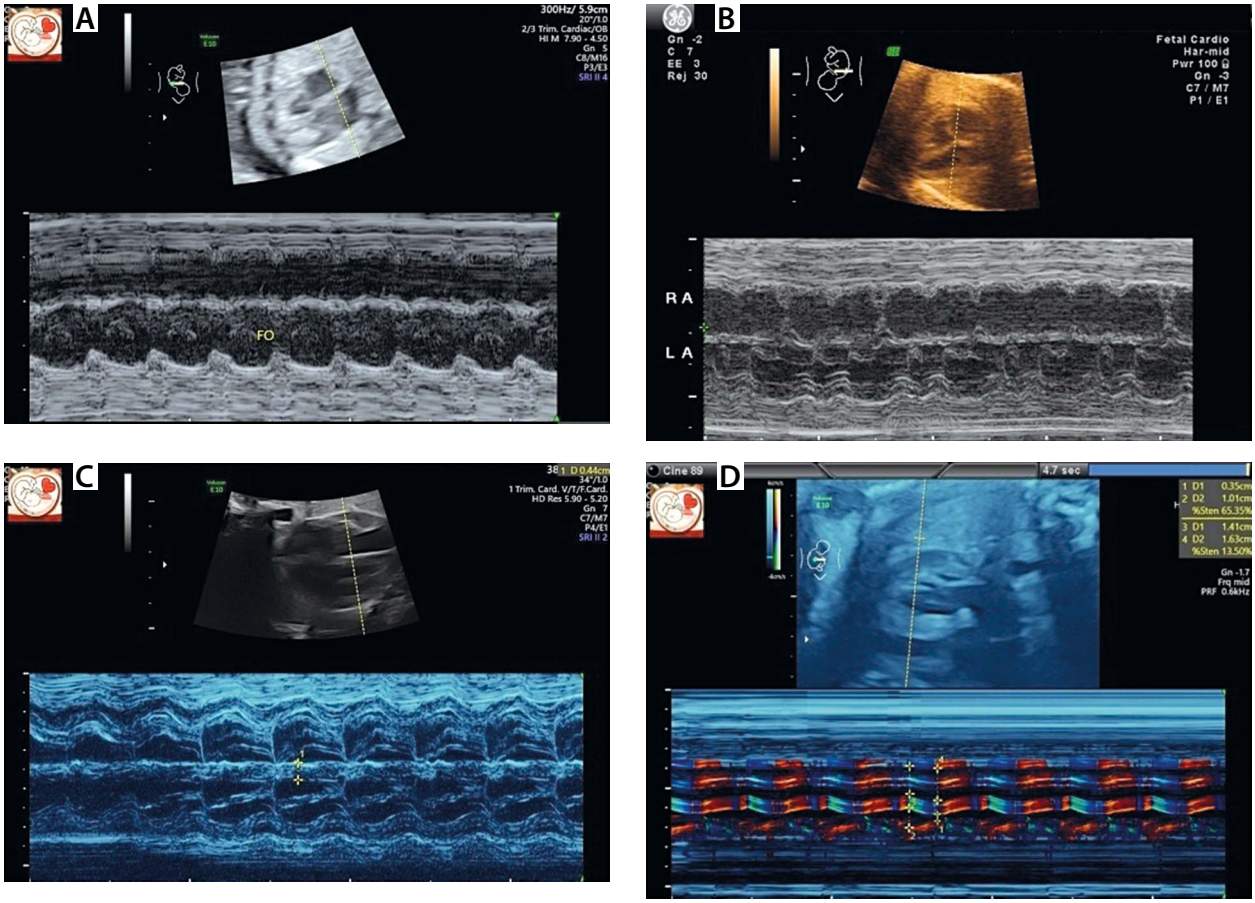

Figure 5. **A** – An example of fetal M-mode of right and left atrium (specific tracing for prenatal life). **B** – An example of fetal M-mode of right and left ventricles – proper view for measurements, for instance fetal interventricular septum, but not for fetal heart arrhythmias evaluation. **C** – Fetal M-mode of right atrium (RA) and right ventricle (RV) in case of fetal arrhythmia to show the sequence of atrial and ventricular contractions. **D** – 2D image and M-mode of tissue colour Doppler imaging to better delineate the borders of the heart walls

fined, which makes it difficult for accurately measure AV time. M-mode technique is usually not easy to obtain, because its quality depends on the fetal heart position. The optimal situation in the case fetal heart apex is at the 9 or 3 o'clock position.

There is additional technique, "colour tissue M-mode" (Figure 5D), which may be helpful for better visualization of the borders of the fetal heart, but the role of analysis in such tracing is similar to a "traditional" M-mode. It is important to use different speeds of tracing (usually high speed) for good quality of recording for further offline analysis. It is also useful to apply different modalities of M-mode tracing.

The second main option of fetal heart rate analysis and the sequence of atrial and ventricle contraction is spectral Doppler technique as a separate modality or combined with colour Doppler. Fetal blood is pumped from the atria to the ventricles and from the ventricles to the big arteries. The opening and closing of the valves is a consequence of electrical events of the cardiac cycle (atrial and ventricular systole and diastole). During atrial systole, the atria contract and pump blood to the ventricles (active ventricular filling), corresponding to the A wave in the Doppler tracing. The A wave corresponds to the P wave of the ECG. Then, the ventricular contraction begins without changing the volume of blood contained in the ventricles; this is called isovolumetric contraction. The AV and semilunar valves are closed until the fast filling phase, in which the ventricles begin to contract. This corresponds to the isovolumetric contraction time, which can be measured using Doppler ultrasound recording. Next, the ventricle pressures increase to open the aortic and pulmonary valves and eject blood (ejection phase). Ventricular systole (V wave in Doppler) corresponds to the QRS complex of the ECG. After ejection, the ventricles start to relax (isovolumetric ventricular diastole – PVCT) [26-29]. The AV valves open and the ventricles fill passively, which corresponds to the E wave in the Doppler record of the AV valve flow.

However, just recording of the blood flow through the valves in colour or in spectral Doppler is not enough. It is necessary to make a Doppler tracing showing both inflow and outflow to be able to analyse its sequence. The easiest way is to put a pulsed Doppler gate at the level of the mitral valve (inflow) and aortic valve (outflow) at the same time in the so-called 5-chamber view. With a good quality tracing without fetal movements or artefacts, one may analyse the isovolumic contraction time, ejection time, isovolumic relaxation time, and calculate also, for instance, the myocardial performance index (Tei index), which is helpful for functional assessment of the fetal left or right ventricle or both (Figures 6A, B, C) [30]. When using this technique (similar to M-mode), it is important to use proper speed of tracing and zoom, while monitor-

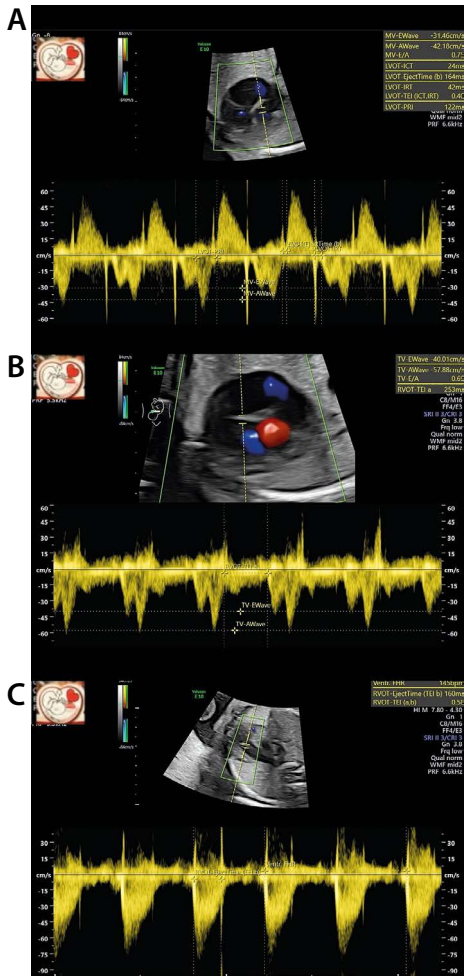

Figure 6. **A** – Tei index for left ventricle: CT, IRT, PRI, E, A. **B** – Tei index for right ventricle – Tei a. **C** – Tei index for right ventricle – Tei b: ET, E, A

ing different settings. Also, it is necessity to digitally store the examination for possible later evaluation.

The same concept might be applied to pulmonary veins and small peripheral pulmonary arteries. Again, only one side – pulmonary vein tracing – is not enough for fetal heart rhythm assessment (Figures 4C, D). It should be analysed together with arterial peaks, which might be compared to QRS complex in ECG, and "zero" flow in pulmonary veins could be compared to P wave on ECG tracing. Another location may be the superior vena cava and the ascending aorta, but this method of measurement is often technically difficult to perform [31, 32].

All the mentioned techniques: M-mode, pulsed Doppler, tissue Doppler, allow measurements of atrioventricular conduction time to be made as well as analysis of the sequence of atrial and ventricle contractions [33, 34]. The norm of atrioventricular conduction is up to 140 ms. The pulse Doppler technique is most often used. AV time can most easily be measured in the 5-chamber image of the heart with flow through the mitral valve and flow into the aorta (MV/Ao). Also, it is possible to measure atrioventricular conduction time by superior vena cava and aortic artery rotating from the 4-chamber view and by Doppler of pulmonary veins and the pulmonary artery. This is important for the detection of 1st- and 2nd-degree AV blocks. This is especially important for patients who are positive for anti-Ro (SS-A) or anti-La (SS-B) antibodies, with diagnosed systemic disease of connective tissue, e.g. rheumatoid arthritis (RA), systemic lupus erythematosus (SLE), antiphospholipid syndrome (APS), systemic sclerosis (SSc), and primary Sjogren's syndrome (PSS), but are usually asymptomatic. Anti-Ro antibodies as well the anti-La circulating in the bloodstream of a pregnant woman crosses the placenta from around week 16 of pregnancy [35]. Inducing an inflammatory response within the AV node and the muscles of the heart can damage the conductive system of the fetus, leading to the formation of atrioventricular block [36, 37].

Based on current echocardiography methods with different modalities, we would recommend, in the case of fetal heart evaluation (basic or with detected arrhythmias), extending this type of evaluation to at least the 4 methods mentioned above: M-mode technique, colour Doppler, spectral Doppler, because as we proved in the text, these are very accurate methods that allow precise differentiation of obstetric causes from cardiological causes in the case of observed abnormalities in fetal heart function.

Advances in prenatal echocardiography now lead us to a new field: prenatal arrhythmology, which deals with the precise evaluation of the heart rhythm of the fetus [38, 39].

Conflict of interest

The authors declare no conflict of interest.

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