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REVIEW ARTICLE

Fetal Dual Doppler Echocardiography

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ABSTRACT

Dual Doppler echocardiography is a recently developed technique performed using an instrument with two separate sample gates, allowing simultaneous recording of signals from two locations. We describe the use of dual Doppler echocardiography to assess fetal cardiac rhythm. Fetal arrhythmias are common and encountered in 1 to 2% pregnancies. They often resolve spontaneously and do not require treatment, but sometimes lead to severe morbidity and mortality. Fetal arrhythmias are responsive to fetal therapy and require appropriate management through accurate diagnosis. Pulsed wave Doppler and M-mode echocardiography are widely used to assess fetal cardiac rhythm. Both methods have advantages and limitations, which are influenced by fetal position, image resolution, and the complexity of the arrhythmia. We developed a new technique that records pulsed wave Doppler signals in the hepatic vein (HV) and the descending aorta (DAo) simultaneously using dual Doppler. This method is less influenced by fetal position and the complexity of the arrhythmia, and the images have better resolution than those acquired using conventional Doppler methods in most cases. Although, electrical parameters, such as the QT interval cannot be evaluated, dual Doppler recording of flows in HV and DAo is an efficient and effective method for assessing fetal cardiac rhythms, allowing precise diagnosis of cardiac arrhythmias.

Keywords: Dual Doppler, Fetal echocardiography, Fetal arrhythmia, Hepatic vein, Descending aorta.

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INTRODUCTION

Congenital heart disease is a major cause of infant morbidity and mortality.[1-3] Accurate prenatal diagnosis offers potential clinical benefits with regard to infant outcome. Fetal arrhythmias are common and affect 1 to 2% pregnancies.[4] Although, most fetal arrhythmias resolve spontaneously and do not require treatment, they may lead to fetal hydrops and even death. Fetal arrhythmias are generally responsive to fetal therapy but require appropriate management after accurate diagnosis. After birth, the classification of arrhythmias is based on electrocardiographic findings. In the fetus, the assessment of arrhythmias is more challenging, because conventional electrocardiography (ECG) cannot be used. Fetal ECG and magnetocardiography can provide electrophysiological cardiac signals, but these modalities are not widely available and remain investigational.[5,6] Alternatively, pulsed wave Doppler and M-mode echocardiography are standard techniques used to assess fetal cardiac rhythm. However, both methods have advantages and limitations. In the present paper, we describe the assessment of fetal arrhythmias using a dual Doppler technique. This novel technique can acquire fetal Doppler signals more easily and enable more precise assessment of fetal arrhythmias than conventional methods.

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WHAT IS DUAL DOPPLER?

The dual Doppler instrument has two separate sample gates, which emit beams in two directions and allow for simultaneous recording of signals from two locations. This technology thus allows the simultaneous display of flow or tissue Doppler waveforms from the two locations, which has conventionally been impossible.[7,8]

DUAL DOPPLER IN ADULT ECHOCARDIOGRAPHY

Atrial fibrillation is one of the most frequent arrhythmias in elderly adults.[9] The evaluation of left ventricular diastolic function is vital in patients with atrial fibrillation, but it is difficult to make an accurate assessment because of irregular RR intervals. Dual Doppler allows simultaneous recording of early diastolic transmitral flow velocity (E) and mitral annular velocity (e′). It enables the calculation of E/e′ during a single heartbeat, one of the most important parameters of diastolic function.[7,8] The single heartbeat E/e′ is correlated with the plasma B-type natriuretic peptide (BNP) level and pulmonary capillary wedge pressure (PCWP).[7,8]

ASSESSMENT OF FETAL RHYTHM

Pulsed Doppler Techniques

Cardiac rhythm analysis involves simultaneous recording atrial and ventricular contractions. Fouron and Reed introduced simultaneous pulsed Doppler interrogation of flow in the superior vena cava (SVC) and ascending aorta (AAo) to assess fetal cardiac rhythms.[10,11] The SVC-AAo method is widely used to assess fetal arrhythmias. A-wave reversal in SVC during atrial systole and forward flow in AAo indirectly define the mechanical relationship between the atria and the ventricles. However, numerous factors can influence the success of this method. Doppler interrogation of low-velocity SVC atrial systolic flow depends on an optimal angle of insonation and a low set wall-motion filter, rendering the signal susceptible to contamination. Furthermore, the A wave in SVC can be hidden within the arterial systolic flow spectrum in AAo, and as a result can be difficult to interpret. When atrial systole coincides with ventricular systole in arrhythmias, the A wave may not be distinguishable from the arterial systolic flow spectrum or *vice versa*.

The Doppler gate can be placed simultaneously over other arteries and veins, e.g. the pulmonary and renal arteries and veins.[12-14] These approaches are less limited by fetal position than the SVC to AAo method. However, as with the SVC to AAo method, the venous A wave can be hidden within the arterial systolic flow spectrum, when atrial systole coincides with ventricular systole.

Dual Doppler Technique

We previously reported simultaneous recording of pulsed wave Doppler signals in the hepatic vein (HV) and descending aorta (DAo) using dual Doppler to assess fetal arrhythmias.[15] Hepatic veins were visualized in color flow mode in a transverse section of the fetal abdomen, spreading out from the inferior vena cava (IVC) (Fig. 1). Descending aorta was simultaneously visualized anteriorly and to the left of the spine. One sample gate was placed over a HV about 5 mm from IVC at an insonation angle of nearly 0° and another gate was placed over DAo. Each pulsed Doppler signal was displayed simultaneously and separately (Fig. 2). The retrograde A wave in HV during atrial systole and the aortic ejection wave in DAo indirectly define the relationship between the atrial and the ventricular contractions.

Fetal hepatic venous Doppler was reported to be useful for the evaluation and diagnosis of fetal extrasystoles.[16] An optimal angle of insonation is nearly always obtained for HVs because of the multiplicity and different orientations of these vessels in the liver, allowing a wide range of insonation windows through a transverse section of fetal abdomen. In addition, retrograde atrial systolic flow velocity is usually higher in HVs than in SVC and IVC, such that the A wave in HVs is more distinct and easier to recognize during atrial contractions. However, ventricular contractions are not clearly defined by hepatic venous Doppler, greatly limiting its ability to evaluate cardiac arrhythmias other than extrasystoles.

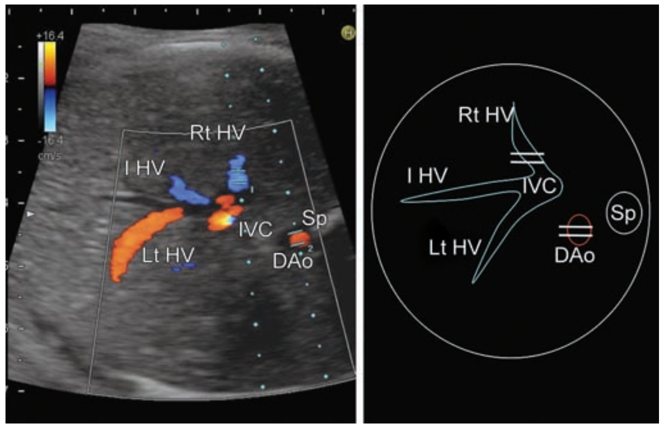


Fig. 1: Transverse color Doppler image of the fetal abdomen showing HV draining into the IVC and the DAo anterior to the spine

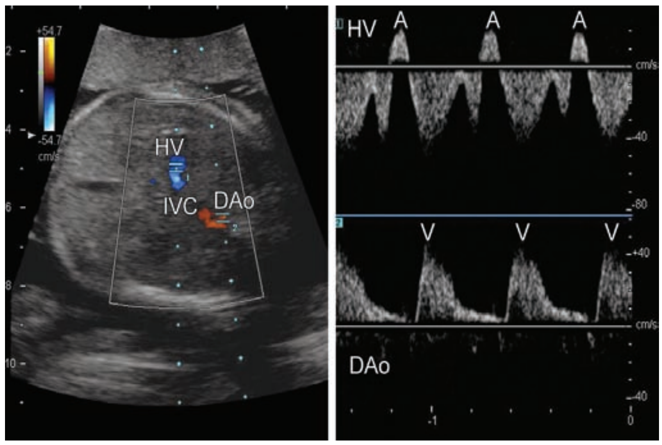


Fig. 2: Dual Doppler recordings of the HV and DAo from a normal fetus. Right; one sample gate is placed over one of HVs about 5 mm from the inferior vena cava (IVC), and another gate is placed over DAo. Left; Doppler waveforms in HV (above) and DAo (below). The reversed atrial systolic flow in HV (denoted by A) and the ventricular systolic flow in DAo (denoted by V) can be assessed

Descending aorta is consistently visualized in transverse sections of the upper abdomen containing HVs. However, DAo is not adjacent to HV. Simultaneous recording of pulsed wave Doppler signals in HV and DAo is not feasible using one sample gate. Therefore, we used dual Doppler to simultaneously record pulsed wave Doppler signals in HV and DAo, to evaluate the relationship between atrial and ventricular contractions. The advantage of this method is that A waves are usually detected clearly, even when atrial systole coincides with ventricular systole, because dual Doppler displays pulsed signals in HV and DAo separately, making them easy to distinguish.

FETAL ARRHYTHMIA

Extrasystoles (Premature Contractions)

Extrasystoles are the most common fetal arrhythmia. Premature atrial contractions (PACs) account for 90% extrasystoles and are usually identified in second or third trimester fetuses.[17] PACs are defined as premature beats originating from the atria, which might be either conducted (generating a ventricular contraction) or blocked (not conducted through the atrioventricular node) (Figs 3A and B). Premature atrial contractions are usually benign, resolving before or shortly after birth, but 1 to 5% fetuses with PACs develop supraventricular tachycardia, which can lead to compromise.[12,18,19]

Premature ventricular contractions are rare in fetuses.[16] Although, PVCs can potentially progress to ventricular tachycardia, fetal ventricular tachycardia is rarely observed. Serial prenatal assessment and further evaluation after birth is essential to confirm the nature of the ectopy and to exclude intermittent runs of more sinister ventricular tachycardia. Premature ventricular contractions are diagnosed when a premature ventricular contraction is observed without alternation of the atrial contraction rate (Fig. 4). Figures 5 and 6 show fetal trigeminy. In both cases, the ventricular contractions are trigeminal. In trigeminy with PVCs, the rhythm of atrial contractions is regular, although the ventricular contractions are trigeminal (Fig. 5A). In conventional pulsed Doppler recording of SVC and AAo from the same fetus, the ventricular systolic flow spectra in AAo are nearly hidden behind the high-amplitude A waves

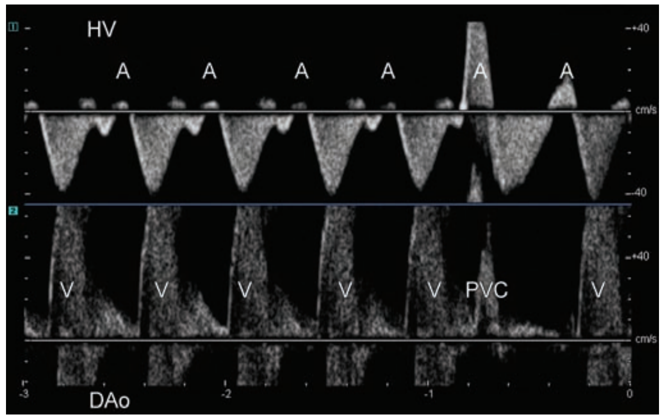
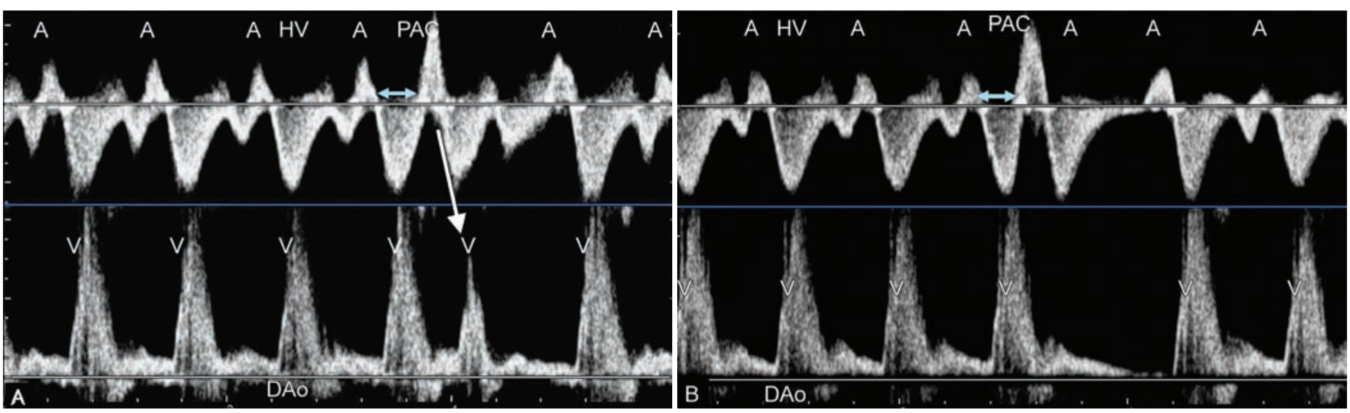


Fig. 4: Dual Doppler recordings of the HV and DAo from a fetus with PVC. Doppler waveforms in HV (above) and DAo (below) are shown. The sixth ventricular contraction occurs prematurely without alternation of the atrial contraction rate

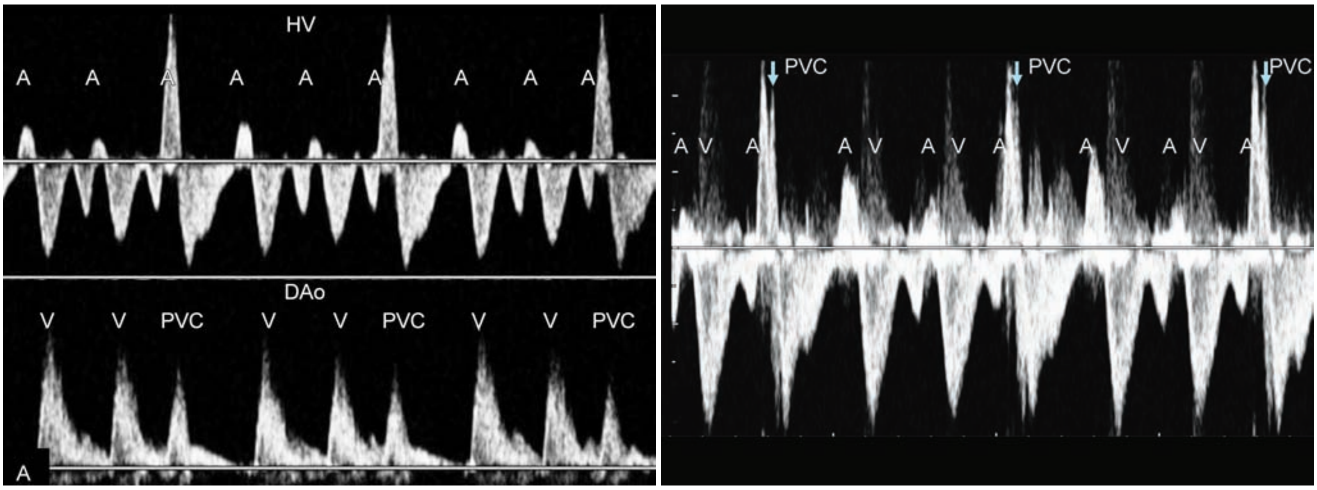
(cannon waves) in SVC when PVCs occur coincidentally with atrial systole. This makes it difficult to distinguish the PVCs from the cannon A waves (Fig. 5B). In trigeminy with PACs, both ventricular systolic flow in DAo and atrial systolic flow in the hepatic vein are trigeminal (Fig. 6).

Bradycardia

Fetal bradycardia is usually diagnosed when the ventricular rate is slower than 110 bpm. Blocked atrial bigeminy and second-degree or third-degree atrioventricular block (AVB) are common causes of fetal bradycardia. It is extremely important to differentiate blocked atrial bigeminy from 2:1 AVB. Blocked atrial bigeminy is usually not associated with the development of cardiac failure and spontaneously resolves before delivery. On the other hand, 2:1 AVB often progresses to complete AVB before or after birth. In fetuses with 2:1 AVB every other atrial contraction is blocked (not followed by a ventricular



Figs 3A and B: Dual Doppler recordings of the HV and DAo from a fetus with PAC. Doppler waveforms in HV (above) and DAo (below) are shown (A) Conducted PAC. The fifth atrial contraction occurs prematurely, indicating PAC. The subsequent ventricular contraction also occurs prematurely and (B) blocked (nonconducted) PAC: The fourth atrial contraction occurs prematurely, not followed by the ventricular contraction. The atrial contraction occurs too early to be conducted to the ventricles, indicating nonconducted PAC



Figs 5A and B: Trigeminy with PVC: (A) Dual Doppler recordings of the HV and DAo from a fetus with trigeminy with PVC. Doppler waveforms in HV (above) and DAo (below) are shown. The rhythm of atrial contractions is regular, although ventricular contractions are trigeminal, (B) pulsed Doppler recording of the SVC and AAo from the same fetus with trigeminy with PVC. The ventricular systolic flow spectra in AAo are nearly hidden behind the high-amplitude A waves (cannon waves) in SVC when PVCs occur coincidentally with atrial systole, which then makes it difficult to distinguish the PVCs from the cannon A waves

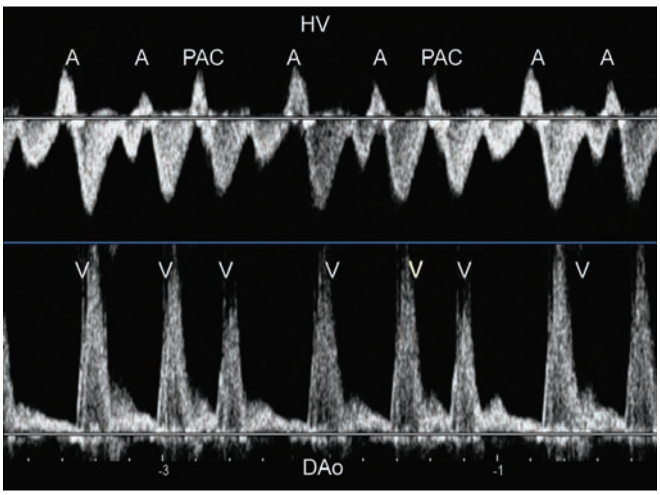


Fig. 6: Dual Doppler recordings of the HV and DAo from a fetus with trigeminy with PAC. Doppler waveforms in HV (above) and DAo (below) are shown. Both ventricular systolic flow in DAo and atrial systolic flow in HV are trigeminal

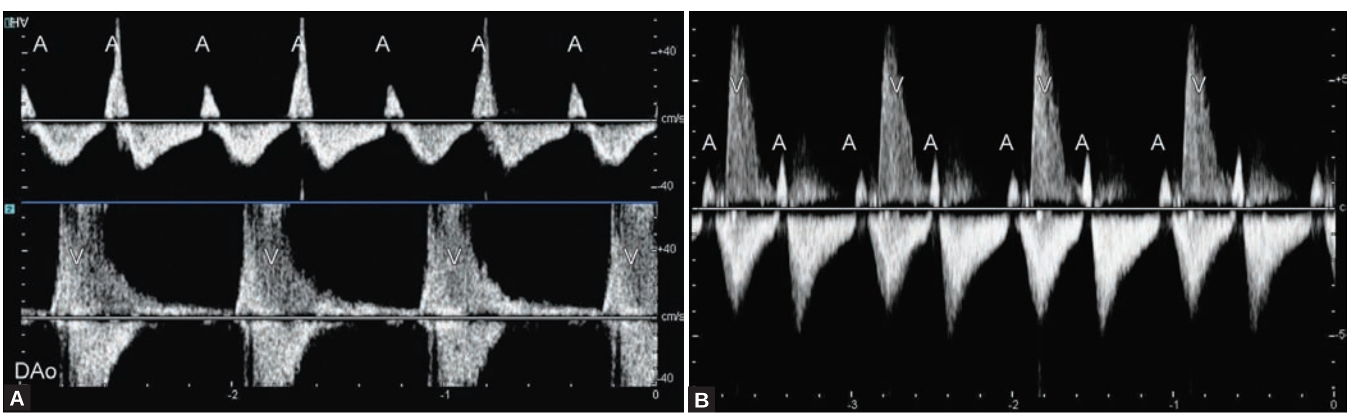
contraction), resulting in bradycardia, although the rhythm of atrial contractions is regular (Figs 7A and B).

Blocked atrial bigeminy is diagnosed when every second atrial contraction is premature and every premature atrial contraction is blocked (not followed by a ventricular contraction), resulting in bradycardia (Fig. 8A).[20] Figure 8B shows a simultaneous recording of SVC and AAo using conventional Doppler from the same case as in Figure 8A. The A wave during PACs, which is almost hidden behind the V wave, is difficult to identify.

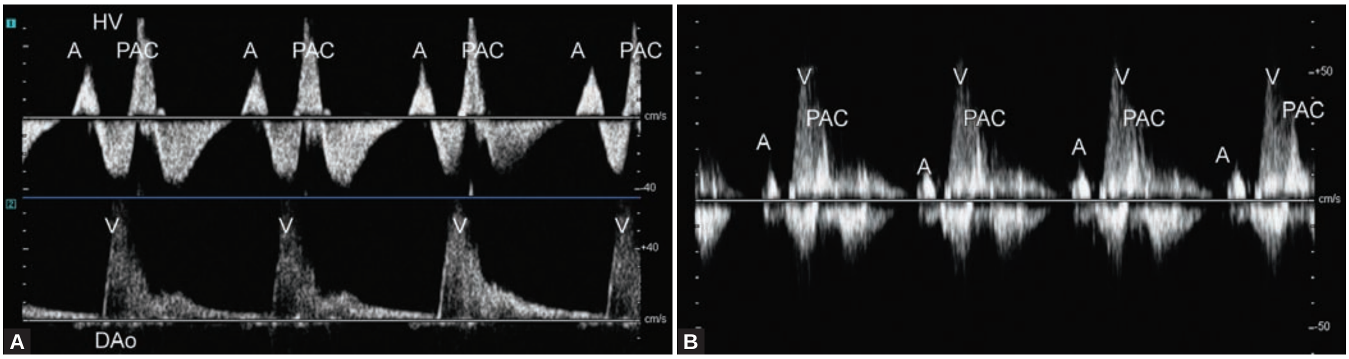
Complete atrioventricular block (third-degree AVB) is easily diagnosed, when there is a lack of atrioventricular synchrony in fetuses with bradycardia (Fig. 9).

Tachycardia

Fetal tachycardia is defined by a sustained ventricular rate faster than 180 bpm. Sustained tachyarrhythmia can cause



Figs 7A and B: 2:1 AVB: (A) Dual Doppler recordings of the HV and DAo from a fetus with 2:1 AVB. Every other atrial contraction is blocked (not followed by ventricular contraction), resulting in bradycardia, although the rhythm of atrial contractions is regular. (B) pulsed Doppler recording of the SVC and AAo from the same fetus with 2:1 AVB



Figs 8A and B: Blocked atrial bigeminy: (A) Dual Doppler recordings of the HV and DAo from a fetus with blocked atrial bigeminy. Every second atrial contraction is premature and every PAC is blocked (not followed by ventricular contraction), resulting in bradycardia, (B) pulsed Doppler recording of the SVC and AAo from the same fetus with blocked atrial bigeminy. The A waves by PAC in SVC are almost hidden behind the V waves in AAo

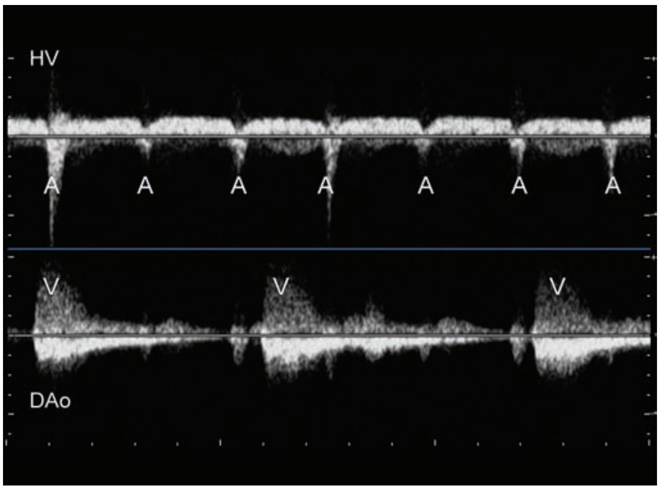


Fig. 9: Dual Doppler recordings of the HV and DAo from a fetus with complete AVB. There is lack of atrioventricular synchrony with an atrial rate of 136 bpm and ventricular rate of 58 bpm

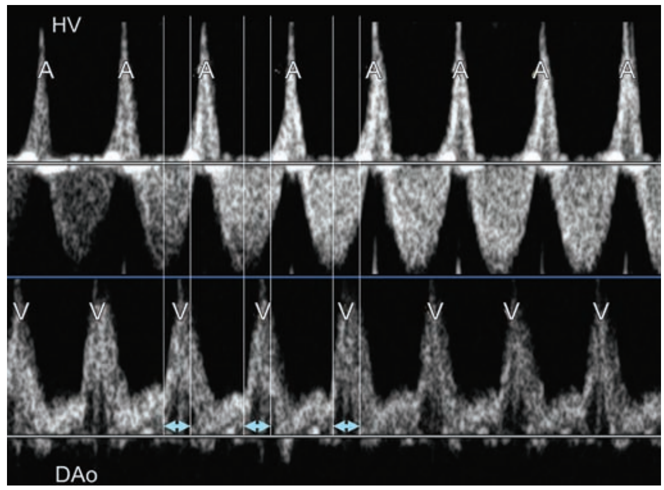


Fig. 10: Dual Doppler recordings of the HV and DAo from a fetus with SVT. Tachycardia at a rate of 212 bpm with a 1:1 ratio of atrioventricular conduction is evident. The VA interval is shorter than the AV interval

significant morbidity and mortality. Supraventricular tachycardia (SVT) is the most common fetal tachycardia, accounting for up to 90% cases.[21] Supraventricular tachycardia is characterized by a regular rate that is typically between 220 and 260 bpm and a 1:1 ratio of atrioventricular conduction. The most common mechanism for fetal SVT is an atrioventricular reentrant tachycardia through an AV accessory pathway.[6] In this case, the VA interval (the time interval from the ventricular contraction to the following atrial contraction) is shorter than the AV interval (Fig. 10).[22-24]

LIMITATION IN DUAL DOPPLER RECORDING OF HV AND DAo

It should be noted that, like conventional Doppler methods, dual Doppler recording of HV and DAo diagnoses arrhythmias indirectly from blood flows created by atrial and ventricular contractions, and therefore is unable to evaluate electrical parameters, such as the QT interval.

CONCLUSION

Dual Doppler recording of HV and DAo has advantages not only for visualizing images but also for evaluating arrhythmias. Unlike conventional Doppler methods, the venous and arterial flows are displayed separately during dual Doppler recording. The A waves and V waves are displayed in the upper and lower frames, respectively, making it easy to grasp the individual rhythms of atrial and ventricular contractions. The simultaneous display of the A waves and V waves also facilitates understanding of the relationship between the atrial and ventricular contractions. In fetal arrhythmias, atrial and ventricular contractions often occur almost coincidentally. With conventional Doppler methods, it is sometimes difficult to distinguish the A wave from the V wave. Similar difficulties are also encountered in ECG and magnetocardiography, where it is sometimes difficult to distinguish the P wave from the QRS and T waves. However, in the dual Doppler recording of HV and DAo, the A waves and the V waves are displayed separately, even when atrial systole coincides with ventricular systole, making it easy to identify atrial and ventricular contractions and facilitating the assessment of arrhythmias. Although, there are some limitations, such as the inability to evaluate electrical parameters, such as the QT interval, dual Doppler recording of HV and DAo is an effective and efficient method of assessing fetal cardiac rhythms, allowing precise diagnosis of cardiac arrhythmias in most cases.

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