Aortic Isthmus Doppler For Fetal Assessment

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Doppler assessment of fetal arteries provides information on regional blood flow and perfusion of individual organs, as well as giving insights into the fetal circulatory state in health and disease. Despite its important role in the fetal circulation, unlike ductus arteriosus; the aortic isthmus is not essential for intrauterine fetal survival. As gestation progresses, forward flow through the isthmus progressively decrease. Isthmic flow index (IFI), which reflects both the amount and direction of blood through this vascular segment, has 5 types. Positive and negative signs are assigned to antegrade and retrograde velocity values, respectively. Doppler flow recording in the aortic isthmus is a reliable indicator of fetal individual ventricular performance. In IUGR; an inverse association was found between IFI and postnatal neurodevelopmental outcome. Recent work on AoI Doppler and postnatal neurodevelopmental outcome indicates that predominant reversed diastolic blood flow. Further prospective studies correlating AoI indices and other arterial and venous Doppler indices with perinatal outcome are required prior to incorporating this index into clinical practice so as to avoid unnecessary preterm deliveries.

Key Words: Aortic isthmus, Doppler, Intrauterine growth restriction, Ultrasonography, Perinatal outcome

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Introduction

Arterial Doppler waveforms are related to both input pressure and downstream vascular resistance. Fetal arterial Doppler assessment has predominantly utilized the umbilical artery, fetal aorta, and middle cerebral artery. Doppler assessment of these and other, fetal arteries provides information on regional blood flow and perfusion of individual organs, as well as giving insights into the fetal circulatory state in health and disease.[1]

Fetal Circulation

Anatomy and physiology

In the human fetus, aortic isthmic segment is short (2-3 mm) and is narrower than the ascending aorta, descending aorta, and ductus arteriosus. However, the diameter of the aortic isthmus relative to other vessels is not as small as reported in the animal models.[2-4] The aortic isthmus has a mean diameter of approximately 1 to 1.5 mm at the end of first trimester, 2 to 2.5 mm at midgestation, and 4 to 5 mm close to term.[5,6]

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Differential blood flow

Under normal conditions, the blood ejected by the right ventricle (RV) perfuses the subdiaphragmatic organs and body, with approximately 10-15% going into the pulmonary circulation, while the cephalic part of the fetus receives blood exclusively from the left ventricle (LV) 1-2. Another generally accepted characteristic of the fetal circulation is the presence of intracardiac and extracardiac shunts; among the latter is the ductus arteriosus (DA).[7] In utero, the arterial vascular segment that conforms to the definition of, and behaves like, a shunt is the aortic isthmus. Indeed, the isthmus, located between the origin of the left subclavian artery and the aortic end of the DA, establishes communication between the two arterial outlets that perfuse in parallel the upper and lower body of the fetus.[8]

Despite its important role in the fetal circulation, the aortic isthmus is not essential for in utero fetal survival. Absence of blood flow through the aortic isthmus (e.g., in case of an interrupted aortic arch) is easily compensated by the blood supplied to the lower part of the body and placenta by the right ventricle via the ductus arteriosus. However, aortic isthmus is essential for survival when the ductus arteriosus is closed postnatally.[5]

Normal isthmic flow patterns

Due to the disposition of the two arterial circuits on each side of the aortic isthmus, blood ejected by the fetal LV and RV has opposite effects on the direction of flow through the

isthmus (Figure 1a). Left ventricular stroke volume will cause forward flow while right ventricular ejection will have the opposite effect (Figure 1b). The final systolic pattern of isthmic flow will be determined by the relative contributions of left and right ventricular stroke volumes as well as the balance between vascular impedances of the upper and lower body. In diastole (Figure 1c), when the two semilunar valves are closed, the direction of isthmic blood flow will be influenced only by the two downstream vascular impedances, especially in the brain for the upper body, and in the placenta for the subdiaphragmatic vascular system. Doppler flow velocity studies have confirmed that in the normal fetus, forward flow is present through the isthmus, both in systole and diastole, because of the low placental vascular impedance.[9,10]

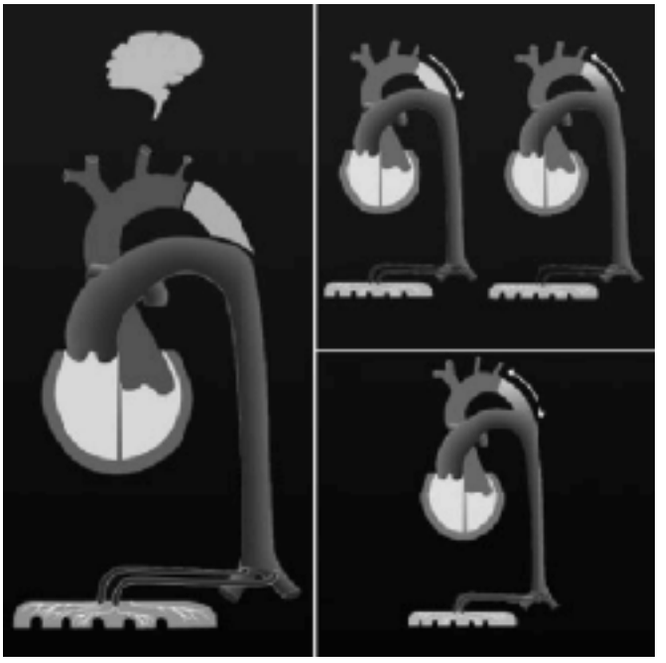

Figure 1: (a) Diagram of the fetal circulation, illustrating the unique position of the aortic isthmus, between the aortic and pulmonary arches. (b) During systole the left and right ventricular stroke volumes have opposite effects on the direction of flow through the isthmus. (c) During diastole the two downstream vascular impedances are the only determinants of the direction of the isthmic flow.[10]

A progressive decrease of forward flow through the isthmus as gestation progresses; among them the right ventricular preponderance which increases during the second half of gestation and placental vascular resistance which reaches a plateau in the last months of gestation, while cerebral vascular resistance follows a curvilinear pattern, peaking at mid-gestation and declining progressively at the end. This reduction in flow could explain the relative narrowing of the isthmus observed in term fetuses (Figure 2).[10,11]

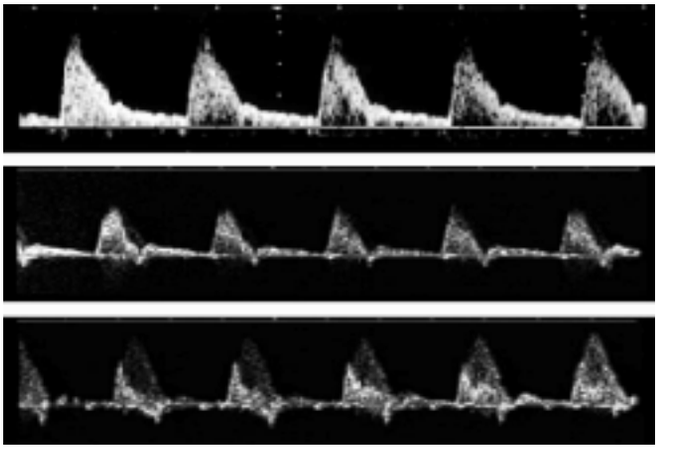

Figure 2: Doppler flow velocity patterns in the fetal aortic isthmus throughout gestation. (a) During the first half of pregnancy, forward flow is present both in systole and diastole. (b) During the second half of pregnancy, a brief reversal of flow appears at the end of systole as illustrated in this 32-week fetus. (c) In the same fetus a delayed onset and longer acceleration time of the ductal wave are observed at the isthmus–ductus junction, explaining the late systolic reversal of flow in the isthmus.[10]

Technique

Isthmic flow index (IFI), which reflects both the amount and direction of blood through this vascular segment, used to objectively monitor the flow pattern through the fetal aortic isthmus.[11] The proposed index was obtained by dividing the sum of the systolic (S) and diastole (D) Doppler flow velocity integrals by the systolic flow integrals: IFI = S + D/S. Positive and negative signs are assigned to antegrade and retrograde velocity values, respectively. For clinical purposes, five types of IFI are possible (Figure 3).[10,12]

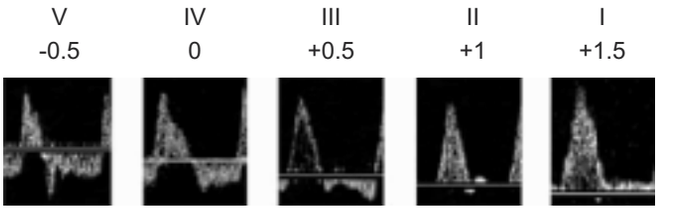

Figure 3: Illustrations of the five possible types (I-V) of the isthmic flow index. The Doppler flow waveforms at the bottom of the figure are taken from fetuses with placental circulatory insufficiency.[10]

Type I: IFI>1 meaning that antegrade flow is present both in systole and diastole. Normal fetuses have a Type I flow pattern in their aortic isthmus. Progressive decrease of the IFI is observed throughout the second half of pregnancy.

Type II: absence of diastolic flow. (IFI=1)

Type III: 1<IFI<0, expressing some diastolic flow reversal but with predominant antegrade flow. The closer the index is to 0, the greater is the retrograde flow.

Type IV: IFI=0

Type V: the index becomes negative, net flow to the isthmus is retrograde.

Intra- and interobserver variability for the IFI was found to be very low, irrespective of the origin of the recordings.[5,7] Similarly, recent studies have suggested that the feasibility of AoI measurement may be limited due to the challenges posed by proper positioning of the Doppler sample volume in the longitudinal view of the aortic arch. However, its evaluation at the level of the three vessels and trachea view substantially improves feasibility.[7,13] It would be especially useful later in gestation, when the spine is calcified and visualization of the aortic arch is technically more difficult and challenging, making the study of this segment of the aorta accessible to the majority of examiners (Figure 4).[14,15]

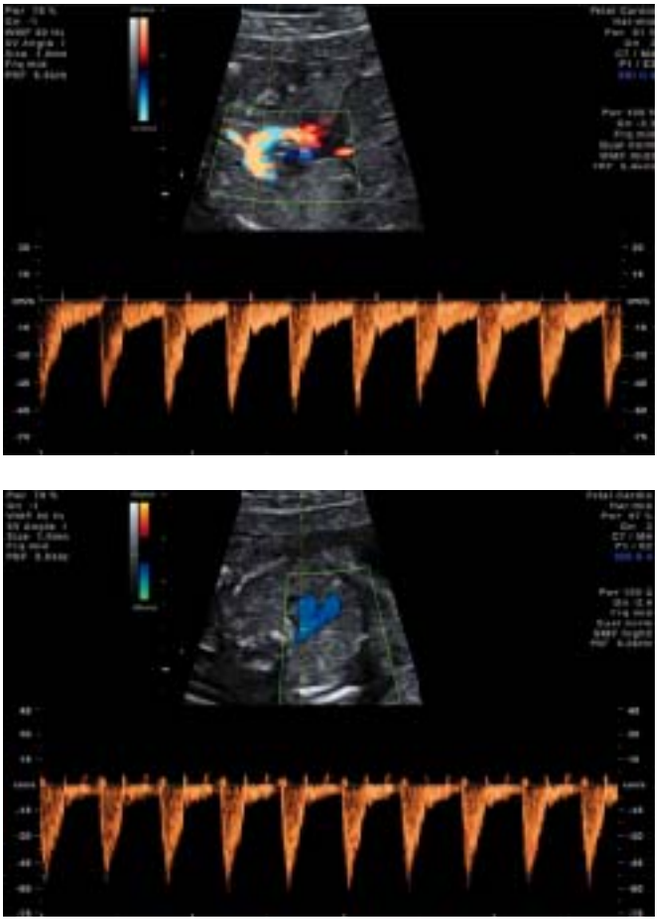

Figure 4: Aortic isthmus velocity waveforms recorded in the same fetus at the level of the LLA (A) and 3V (B) views 11(Doppler measurements of the pulsatility index (PI) from the AoI were performed in 70 fetuses (20 IUGR and 50 normally grown) between 20 and 34 weeks' gestation. All measurements were sampled in both the LAA and 3V views by the same investigator. Reliability was evaluated with intraclass correlation coefficients (ICCs), and Bland-Altman plots were generated. The time required to complete the measurements was compared.)[15]

Clinical Uses

Left ventricular dysfunction or stenosis is associated with a decrease of LV output and of normal forward flow through the isthmus. If the reduced isthmic flow remains antegrade (IFI> 1) this would mean that despite the stenosis, left ventricular stroke volume is still sufficient to maintain perfusion of both the upper body and part of the subdiaphragmatic circulation (Figure 5a). Reverse isthmic flow (IFI <1) associated with LV functional impairment indicates a significant fall in LV output, causing compensatory perfusion of at least part of the upper body circulation by blood coming from the RV (Figure 5b). The extreme of this condition is the hypoplastic left heart syndrome where the functioning RV perfuses not only the isthmus but also the entire aortic arch, including the coronary arteries.[10,15]

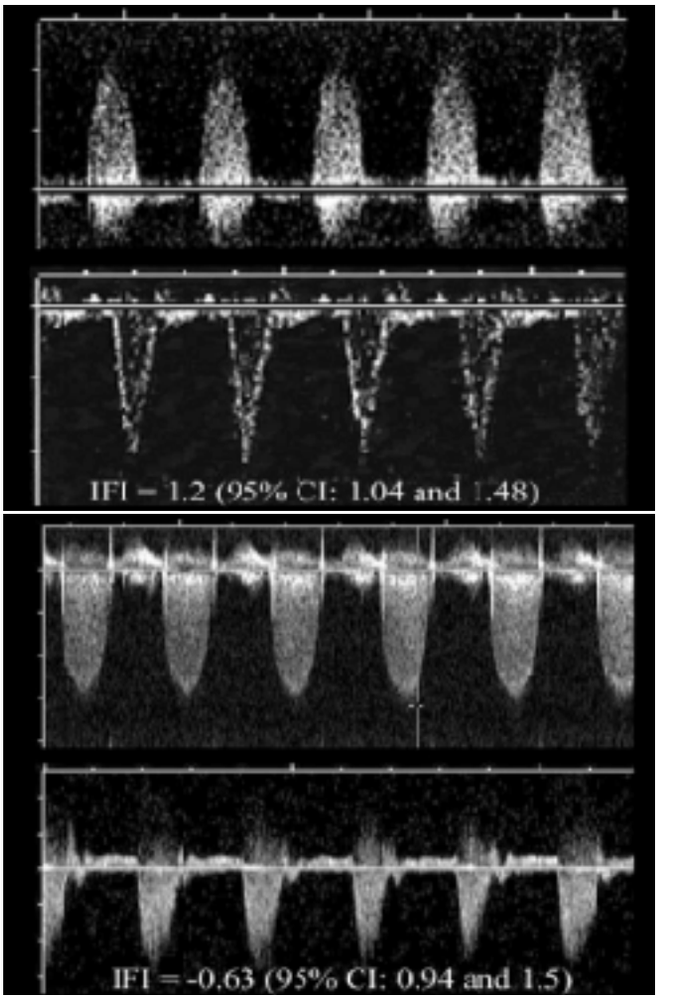

Figure 5: (a) Moderate aortic stenosis. The flow velocity patterns through the aortic valve (upper trace) and isthmus (lower trace) are illustrated. A peak systolic velocity of 2.2 m/s is recorded through the aortic valve. Flow through the isthmus is decreased but remains antegrade both in systole and diastole. (b) Severe aortic stenosis. The peak velocity of the transvalvular jet is 4m/s (upper trace) and a reverse systolic flow is recorded through the isthmus (lower trace). (IFI: isthmic flow index).[10]

Right ventricular dysfunction or outlet stenosis increases forward flow through the isthmus, a greater portion of the combined cardiac output is made up of blood coming from the LV. The rise in volume flow through the isthmus explains the similarity in size between the isthmus and the adjacent aorta, as observed in term fetuses with prenatal pulmonary stenosis or tetralogy of Fallot. For the time being the appearance of systolic flow reversal in the pulmonary arch during fetal life remains the most reliable predictive criterion of postnatal ductal dependency to maintain an adequate pulmonary circulation.

Cerebral arteriovenous (AV) fistulae demonstrates the presence of reverse diastolic flow in their aortic isthmus .This pattern explains the marked increase of flow through the pulmonary arch in prenatal life and the right ventricular hypertrophy classically observed in the postnatal electrocardiograms. It is worth mentioning that, as in critical left ventricular dysfunction, normal forward diastolic flow is still recorded in the aortic isthmus of fetuses with cerebral AV fistulae since their placental vascular impedance is normal.

Intrauterine growth restriction (IUGR): Placental resistance, which is normally the lowest in the whole fetal circulation, increases in IUGR fetuses. This alone could be responsible for at least a decrease in forward diastolic flow or in more severe cases a reversal of this flow through the isthmus. The same changes in diastolic velocities described in the umbilical artery also occur in the isthmus. In IUGR, therefore, the amount of flow going through the fetal aortic isthmus can be considered to be a good indicator of placental flow.[7,16] Absent or reversed end-diastolic velocity (ARED) in the aortic isthmus while forward flow was present in the umbilical artery appears to be an early sign of blood flow redistribution in growth-restricted fetuses.[7,17] Absolute velocities in the AoI are decreased in growth-restricted fetuses.[18] Retrograde flow in the AoI in growth-restricted fetuses correlates strongly with adverse perinatal outcome.[18]

There are presently no signs that could help the attending physician to identify the fetus whose defense mechanisms against hypoxemia are about to fail. Experimentally, a stepwise increase in resistance to placental flow causes a fall in oxygen delivered to the brain only when predominant reverse diastolic flow is observed through the aortic isthmus.[1,19] There is some evidence in the literature that the changes in aortic isthmus Doppler velocity waveforms appear before the ductus venosus a wave reversal and that an abnormal PI in the aortic isthmus is noticed on an average 1 week before the ductus venous.[20]

Since the IFI is an indicator of the amount and direction of the shunt through the fetal isthmus, it could be used as a clinical marker for the identification of IUGR fetuses who need to be delivered before evidence of cerebral hypoxia. The greater the reverse isthmic flow, the lower is the IFI and the higher should be the risk of prenatal cerebral damage.[21] An inverse association was found between IFI and postnatal neurodevelopmental outcome, and an IFI cutoff value of 0.7 had the highest overall predictive value.[21-23] Recent work on AoI Doppler and postnatal neurodevelopmental outcome indicates that predominant reversed diastolic blood flow through the AoI is associated with suboptimal neurodevelopmental outcome (Figure 6).[21,23]

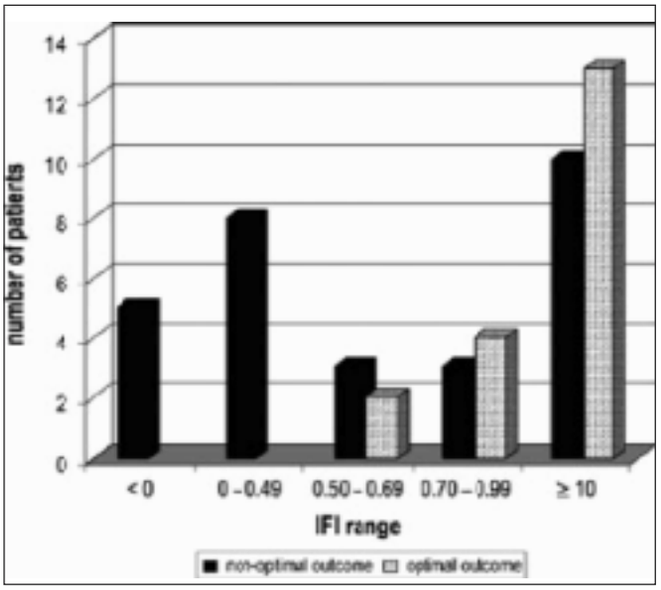

Figure 6: Profile of aortic IFI and neurodevelopmental outcome.[23]

No change in vessel diameter was noted during the four levels of umbilical vein compression, a simple comparison between forward and reverse flow velocity integrals through the isthmus would be sufficient to quickly and reliably evaluate the severity of impairment of umbilical blood flow.[14] The current literature suggests that AoI Doppler waveform assessment may be an important component of fetal assessment of IUGR with abnormal UA Doppler.[24] Further prospective studies correlating AoI indices and other arterial and venous Doppler indices with perinatal outcome are required prior to incorporating this index into clinical practice so as to avoid unnecessary preterm deliveries.[22,25]

Absence of aortic isthmus

A hypoplastic aortic isthmus is usually associated with obstructive malformations of the LV and represents a secondary event related to the decreased left ventricular output with a marked fall in the amount of blood shunting through the isthmus. Complete absence of the aortic isthmus represents one of the types of interruption in the aortic arch. A decrease or absence of shunt through the isthmus can be easily compensated for by a proportional increase in right ventricular flow through the pulmonary arch, maintaining the normally elevated turnover of blood in the umbilical circulation. This explains

why marked right ventricular preponderance is classically observed in neonates with obstructions such as coarctation of the aorta. The aortic isthmus, therefore, is not an essential component of the fetal circulation, and its absence does not justify an aggressive approach during intrauterine life.

Summary and Recommendations

- The aortic isthmus, not the DA, is the only arterial shunt in the fetal circulation.
- A simple recording of the isthmic flow velocity pattern can provide information on global fetal cardiocirculatory dynamics.
- Despite its important role in the fetal circulation, the aortic isthmus is not essential for in utero fetal survival, is essential for survival when the ductus arteriosus is closed postnatally.
- A progressive decrease of forward flow through the isthmus as gestation progresses, this reduction in flow could explain the relative narrowing of the isthmus observed in term fetuses.
- Isthmic flow index (IFI), which reflects both the amount and direction of blood through this vascular segment, used to objectively monitor the flow pattern through the fetal aortic isthmus, has 5 types.
- Aortic isthmus evaluation at the level of the three vessels and trachea view substantially improves feasibility.[26]
- Doppler flow recording in the aortic isthmus is a reliable indicator of fetal individual ventricular performance.[27]
- In IUGR, flows through the placenta and the aortic isthmus are closely related. In IUGR, monitoring of blood flow through the aortic isthmus allows indirect assessment of cerebral oxygenation.[10]
- An inverse association was found between IFI and postnatal neurodevelopmental outcome, and an IFI cutoff value of 0.7 had the highest overall predictive value.
- Recent work on AoI Doppler and postnatal neurodevelopmental outcome indicates that predominant reversed diastolic blood flow through the AoI is associated with suboptimal neurodevelopmental outcome.[10]
- Further prospective studies correlating AoI indices and other arterial and venous Doppler indices with perinatal outcome are required prior to incorporating this index into clinical practice so as to avoid unnecessary preterm deliveries.[23]

Fetal İyilik Halinin Değerlendirilmesinde Aortik Istmus Dopplerinin Rolü

Fetal arterlerin Doppler ile değerlendirilmesi bölgesel kan akımı ve perfüzyon hakkında bilgi verdiği gibi, fetal dolaşımın sağlıklı ve hastalıklı durumlardaki hali hakkında da bilgi verebilir. Duktus arteriosusun fetal dolaşımdaki öneminin tersi olarak aortik istmus fetal yaşam için gerekli bir yapı değildir. Gestasyon haftası arttıkça aortik istmustaki anterograd olan akımda dereceli olarak azalma olur. İstmik akım indeksi, bu vasküler segmentteki kan akım yönü ve miktarını yansıtır ve 5 tipi vardır. Pozitif ve negatif sonuçları anterograd ve retrograd akımları gösterir. Aortik istmustaki Doppler akımının ölçümü fetal ventriküler performansı tek başına gösteren güvenilir bir belirteçtir. Aortik istmus Doppleriyle ilgili son yapılan çalışmalarda IUGR'da, istmik akım indeksi ve postnatal nörogelişimsel sonuç arasında ters bir ilişki bulunmuştur. Hem preterm doğumları önlemek için hem de perinatal sonuçların daha iyi değerlendirilmesi için aortik istmus ve diğer arteriyel ve venöz Doppler indeksleriyle ilgili ek çalışmalara ihtiyaç vardır.

Anahtar Kelimeler: Aortic istmus, Doppler, İntrauterine gelişme kısıtlılığı, Ultrasonografi, Perinatal sonuçlar

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