REVIEW ARTICLE

Placental Doppler Microvasculature in Normal and Abnormal Pregnancy

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Abstract

Superb microvascular imaging (SMI) is a new ultrasound Doppler technique that enables the assessment of fine and low-velocity blood flow profiles. This article reviews the sonographic anatomy of the normal placental microvasculature using SMI and the clinical applications for evaluating pathological conditions during pregnancy. The basal plate shows a single layer of blood flow with decidual flows and flows extending into the placenta, on which arterial Doppler waveforms can be detected, indicating jet flows from the spiral arteries into the intervillous space. Several studies have demonstrated the potential for diagnosing the placenta accreta spectrum based on direct SMI findings, including missing decidual tissues and direct invasion of the placenta into the myometrium in the lesion. In a normal pregnancy, the placental villous flows show tree forms by SMI, which is considered blood flow embedded in the stem villi. Because the stem villi provide mechanical stability for the villous trees and control autoregulation of the fetoplacental blood flow in the peripheral villi, the abnormal vasculature characteristics observed by SMI reflect morphological changes in the placenta and dysfunction of the peripheral villous vessels, such as fetal/maternal malperfusion of the placenta.

Keywords: Doppler, Placenta, Pregnancy, Ultrasonography.

Introduction

Superb microvascular imaging (SMI) is a new ultrasound Doppler technique that enables the assessment of fine and low-velocity blood flow profiles with high frame rates, which cannot be achieved by conventional color/power Doppler techniques.¹ To date, SMI has been applied to a range of organs including the thyroid, mammary gland, and subcutaneous tissues.¹–⁴ By contrast, in the field of obstetrics, SMI has been used to examine the placenta and the fetus.⁵–¹⁷ This review describes the sonographic anatomy of the normal placental microvasculature using SMI and the clinical applications for evaluating pathological conditions during pregnancy.

Myometrial and Placental Villous Vessel Vasculature in Normal Pregnancy

In the nonpregnant uterus, radial vessels and their peripheral vessels including the spiral arteries run through the myometrium almost perpendicularly (Fig. 1). Up to the eighth week of pregnancy, the spiral arteries cross the uterine wall almost perpendicularly. However, with elongation of the uterus as pregnancy advances, the course of the peripheral arteries becomes oblique and by 10 weeks the distal segments run almost parallel to the basal plate.¹⁸ By observing the myometrium during pregnancy in the second to the third trimester using transabdominal SMI (3.5 MHz; Aplio i800; Canon Medical Systems), a few layers with pulsatile flows and layers with non-pulsatile flows can be found (Fig. 2). On the basal plate, where the maternal uteroplacental vessels traverse, there is a single layer of blood flow, with flows also extending into the placenta that shows arterial Doppler waveforms (Figs 3 and 4). These two flow patterns are thought to represent decidual flows vs jet flows from the spiral arteries into the intervillous space, respectively.

In the third trimester of normal pregnancy, the placental villous flows are recognized by SMI as “tree” or “bush” forms in which the vessels run through the placental parenchyma from the primary, secondary, and tertiary branches (Fig. 3). Additional

Fig. 1: Normal myometrial vasculature in a case during the puerperal period (left, B-mode imaging; right, superb microvascular imaging). The arrow indicates a radial artery running through the myometrium
tiny branching vessels can also be detected by high-resolution SMI (11–18 MHz; Fig. 5). In the mid-to-late second trimester, the branching patterns of the villous vessels are largely similar to those in the third trimester (Fig. 6). By contrast, in the early second trimester, only primary and secondary branching vessels are observed. Histologically, the chorionic villi can be classified into three types: stem villi, intermediate villi, and terminal villi. Stem villi are the most centrally located, show 10–16 generations of branching, and makeup 20–25% of the total villous volume of the normal term placenta. The stem villi are important for providing mechanical support to the villous trees. The calibers of stem villi vary from approximately 80–3,000 μm and are further classified depending on the villi size: type I (250–3,000 μm), type II (120–300 μm), and type III (80–150 μm). Based on the resolution of SMI, the observed villous vessels are assumed to mainly correspond to type I stem villi.

**Age-related Changes of the Placental Villous Vessel Vasculature in Normal Pregnancy**

Since the stem villi function as scaffolds to maintain the villous tree structure, changes in the characteristics of the villous vessels observed by SMI with advances in gestation represent the development of placental morphometry during pregnancy. We used SMI to examine the longitudinal changes in the placental villous vessels of a normal singleton pregnancy at 19–21, 29–31, and 36–38 weeks of gestation. Since the entirety of the tertiary villous vessels (TVVs) is not always detected, the characteristics of the primary villous vessels (PVVs) and the secondary villous vessels (SVVs) were analyzed using the distance between the PVVs on the chorionic plate and the lengths of the PVVs and...
SVVs (Fig. 7). The distances between the PVVs increased from 19–21 to 29–31 weeks, while there was no further change by 36–38 weeks (Fig. 7). The lengths of the PVVs/SVVs also increased from 19–21 to 29–31 weeks, while there was no further change thereafter. The PVVs and SVVs grew horizontally and vertically until 29–31 weeks, but did not change thereafter. These findings are compatible with the fact that placental volume increases up to the beginning of the third trimester and stabilizes around the 30th week of gestation. 20

Figs 4A to C: Blood flows extending into the placental parenchyma (arrows) showing the jet from a spinal artery (A and C, superb microvascular imaging; B, bidirectional color Doppler imaging). Images were obtained from several normal cases at 33–38 weeks of gestation. Note that the flows run downward into the placenta with pulsatility.

Figs 5A and B: Normal placental microvasculature in a case at 29 weeks of gestation obtained with conventional (3.5 MHz; A) and high-resolution (11 MHz; B) transabdominal probes.

CLINICAL APPLICATION OF MYOMETRIAL AND PLACENTAL BLOOD FLOW PROFILES IN ABNORMAL PREGNANCY

Placenta Accreta Spectrum

B-mode and color Doppler ultrasonography can provide useful information for the diagnosis of placenta accreta spectrum (PAS), such as non-visualization of the normal retroplacental clear zone, irregularity and attenuation of the uterine–bladder interface, and
the presence of an intraplacental lacunar space and bridging vessels between the placenta and the bladder. Since PAS is diagnosed histologically by the absence of decidual tissues between the myometrium and villous tissues, these imaging findings are indirect signs of PAS.

Hata et al. showed irregular minimal invasion of the placenta into the myometrium and/or disruption of the decidual vessels in two cases of retained placenta with PAS using high-resolution SMI (18 MHz transabdominal linear probe). Hasegawa et al. also reported abnormally dilated villous vessels at the placenta increta lesion using high-resolution SMI. Furthermore, we previously reported a case of PAS after cesarean section in which the decidual flows were missing using conventional SMI (Fig. 8). These findings indicate the potential for diagnosis of PAS based on direct imaging findings including missing decidual tissues and direct invasion of the placenta into the myometrium in the lesion. However, further studies are required to confirm the feasibility of SMI for the diagnosis of PAS.

Abnormal Flow Profiles of the Placental Vasculature

Superb microvascular imaging can provide unique information on the minute placental chorionic vasculature, with several reports of pathological angiogenesis including chorioangioma and aberration of the chorionic vascularity in placental infarctions and thick placentas. The villous vessels observed by SMI are predominantly the stem villi, which are not directly involved in gas exchange at the placenta–maternal interface, but rather are considered to control fetal blood flow at the fetomaternal exchange area located in the peripheral villi. In the case of fetal/maternal malperfusion of the placenta, it is conceivable that the abnormal vasculature in the stem villous vessels will reflect the pathological changes in the peripheral villous vessels.

We reported a case of systemic lupus erythematosus with long-term steroid therapy that included myometrial thinning,
Superb microvascular imaging at 35 weeks of gestation showed abnormal patterns of the myometrial vasculature and the placental villous vessels (Fig. 9). Specifically, in the placenta underneath the normal-appearing myometrium where myometrial and decidual blood flows were detected, the placental vasculature looked normal except for elongation of the PVVs. However, in the placenta underneath an area of thin myometrium where myometrial and decidual blood flows were not detected, the vascular density was sparse (i.e., the PVVs were narrow, the SVVs were sparse, while no TVVs were visualized). We speculated that the peculiar VV flow profiles were partially related to intervillous under-perfusion/low intraplacental oxygenation depending on the blood flow supply from the myometrium.
CONCLUSION
Microscopic analysis of the placenta, including the chorionic villous tissues and their vasculature, is currently only performed after delivery. Although SMI can only detect the chorionic microvasculature, further studies assessing the correlations between SMI-based microvascular profiles and placental pathology will improve the diagnostic capacity of SMI and advance the goal of “sonopathology” of the placenta.

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