Determination of Placental Weight Using Two-dimensional Sonography and Volumetric Mathematic Modeling

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ABSTRACT

An abnormally decreased placental weight has been linked to increased perinatal complications, including intrauterine fetal demise (IUFD) and fetal growth restriction (IUGR). Despite its promise, determining placental weight prenatally using three-dimensional systems is time-consuming and requires expensive technology and expertise. We propose a novel method using two-dimensional sonography that provides an immediate estimation of placental volume. Placental volume was calculated in 29 third-trimester pregnancies using linear measurements of placental width, height, and thickness to calculate the convex-concave shell volume within 24 hours of birth. Data were analyzed to calculate Spearman's rho (r_s) and significance. There was a significant correlation between estimated placental volume (EPV) and actual placental weight ($r_s = 0.80$, $p < 0.001$). Subgroup analysis of preterm gestations ($n = 14$) revealed an even more significant correlation of EPV to actual placental weight ($r_s = 0.89$, $p < 0.001$). Placental weight can be accurately predicted by two-dimensional ultrasound with volumetric calculations. This method is simple, rapid, and accurate, making it practical for routine prenatal care, as well as for high-risk cases with decreased fetal movement and IUGR. Routine EPV surveillance may decrease the rates of perinatal complications and unexpected IUFD.

KEYWORDS: Placenta, volume, ultrasound, IUFD, IUGR

A healthy baby at term is the product of three important factors: a healthy mother, normal genes, and good placental implantation and growth.[1] Currently the focus of prenatal surveillance is the fetus.[2–4] Much effort has been directed toward the detection and assessment of intrauterine growth restriction (IUGR).[5–8] The many cases of IUGR have traditionally been subdivided into fetal, placental, and maternal. It is clear that a normally functioning placenta is critical for normal fetal growth and development.[9,10] Adequate fetal growth depends on the efficient delivery of nutrients from the mother to the fetus and therefore requires normal uterine perfusion, normal transplacental exchange of nutrients and waste, and normal umbilical blood flow.[11–13] Placental

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thickness[14] and volume have been used to predict chromosomal anomalies[15] and diseases such as preeclampsia,[16] thalassemia,[17] and other complications of pregnancy.[18–20]

Currently, sonographic assessment of placental volume is time-consuming and requires expensive technology. The best approach thus far has been three-dimensional ultrasound measurements; but this technique requires specialized training.[15,16,21] Placental volume assessment is therefore uncommon in routine obstetric practice, a lack that prevents obstetricians from identifying their patients with extremely small placentas. This is a population who are at risk of sudden intrauterine fetal demise.[22]

We propose a new method of calculating placental volumes using widely accessible two-dimensional ultrasound measurements and a mathematical equation. The aim of our study was to correlate the results of this new sonographic method to the actual placental weight and volume at birth. We also investigated technical aspects of these measurements to assess their reliability and reproducibility.

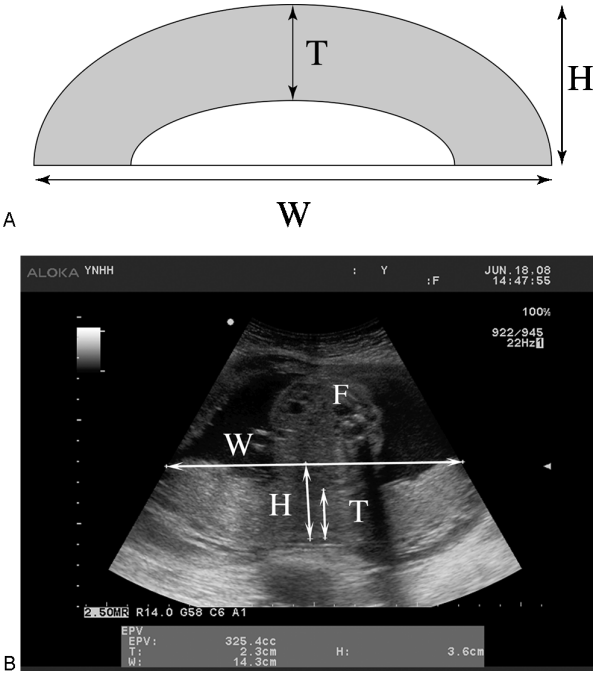

Figure 1 (A) Diagram showing parameters measured to calculate estimated placental volume (EPV). (B) Representative scan used to generate EPV. W, maximal width; H, height at maximal height; T, thickness at maximal height; F, fetus.

METHODS

We prospectively studied singleton pregnancies in women with indicated elective cesarean sections or in patients at risk of preterm delivery. Informed consent was obtained and the study was approved by the Human Investigation Committee at Yale University (protocol number 0610001963).

A total of 38 patients consented to participate in this study. Fourteen studies were performed in preterm (<37 weeks) and 24 in full-term (≥ 37 weeks) pregnancies. For preterm participants, inclusion criteria consisted of singleton pregnancy, uterine contractions refractory to tocolysis, and advanced cervical dilatation (3 cm or more). For full-term participants, inclusion criteria consisted in a singleton pregnancy scheduled for a cesarean section in less than 24 hours after the volume estimation. Exclusion criteria included presence of fibroids, rupture of membranes, oligohydramnios, placenta previa and other placental anomalies, history of vaginal bleeding less than 1 month before the study, and maternal medical complications. In all cases, gestational age was established based on an ultrasonographic examination before 20 weeks. All ultrasounds were performed by the same operator (H.A.) at Yale New Haven Hospital with an Aloka ProSound α10 system (Aloka, Tokyo, Japan) equipped with a 4- to 8-MHz curved array transducer.

Placental location and shape were assessed using standard two-dimensional ultrasound techniques. Placental thickness was measured, when possible, at the level of the cord insertion, thus maintaining close proximity to the perpendicular of the placental surface. Maximal width and height were acquired in an image of the placenta using the scheme illustrated in Fig. 1. If necessary, the probe was slightly angled to allow full visualization of both placenta edges simultaneously.

Measurements to estimate placental volume used the following convex-concave shell formula: $V = (\pi T/6) * [4H(W - T) + W(W - 4T) + 4T^2]$, where V = volume; W = maximal width; H = height at maximal height; T = thickness at maximal height. Harmonic imaging was used as needed to provide clear contrast between tissue structures. We optimized the probe to achieve the maximum angle and varied the depth of penetration to optimize the field of view of the placenta. We collected the length measurements only when we were able to visualize both edges of the placenta evenly. Reproducibility was assessed by performing three independent estimated placental volume (EPV) assessments at different times on five different patients. Amniotic fluid was evaluated, obtaining the sum of the maximal vertical pocket in four quadrants and expressed as amniotic fluid index.

After delivery, the umbilical cord was immediately clamped at its placental insertion to prevent loss of fetal blood, the maternal surface was dried with a towel, and the membranes were carefully trimmed at the placental margin. Each placenta was weighed within 24 hours of EPV measurement and within 15 minutes from delivery, with an accuracy of ± 5 g (Scale-tronix 4800; Wheaton, IL). Major (A) and minor (B) diameters

and height (H) were measured on a flat surface, which were then used to calculate actual placental volume using the formula for an elliptical cylinder, where $V = \pi ABH$. Data were collected on an Excel spreadsheet (Microsoft, Redmond, WA) and analyzed using SPSS for windows, version 15.0 (Chicago, IL). A scatter graph was obtained, and Spearman's rho (r_s) was used to compare the EPV to the actual placental weight (APW) and volume (APV). The coefficients of variation were calculated by performing five repeated measurements on three patients, using the formula: standard deviation/mean $\times$ 100. The mean error was calculated by taking the mean value of all the positive and negative errors without regard to sign.

RESULTS

Among the 38 patients who consented, nine placentas could not be evaluated properly either due to a body mass index >35 ($n = 3$) or a very large placenta that did not fit in the ultrasound screen ($n = 6$). The acquisition of the placenta volume was successfully achieved in the remaining patients ($n = 29$) in ~1 to 2 minutes for each patient. The maternal age of the study population ranged between 20 and 42 years, gestational age ranged between 29 and 40.7 weeks, and the amniotic fluid index ranged from 8 to 26 cm (Table 1). The intraobserver reproducibility was excellent for placenta volume calculations (intraclass correlation coefficient: 0.99).

There was a significant positive correlation between EPV and APW ($r_s = 0.80$, $p < 0.001$) at all gestational ages examined (Fig. 2A). In the preterm pregnancies, the correlation between EPV and APW was even stronger ($r_s = 0.89$, $p < 0.001$; Fig. 2B). There was also a significant positive correlation between EPV and APV ($r_s = 0.76$, $p < 0.001$). Subanalysis of the full-term placentas revealed a lower correlation between EPV and APW ($r_s = 0.68$, $p < 0.001$). The mean error was 16% among all the patients, 19% for the term cases, and 13% for the preterm cases. When placental location was analyzed regarding the difficulty of visualization, no differences were found between fundal, anterior, or posterior placentas. The placentas examined in this study were minimally elliptical, with a mean minor to major axis ratio of 0.96 ± 0.08.

Table 1 Demographic Characteristics of the Study Population ($n = 29$)

Variable	Median	Range	SD
Maternal age (y)	32.9	20–42	4.7
Parity	1	0–3	0.8
Gravidity	2.4	1–6	0.4
Gestational age at scan	36.2	29–40.7	3.5
Amniotic fluid index (cm)	12.5	8–26	3.7

SD, standard deviation.

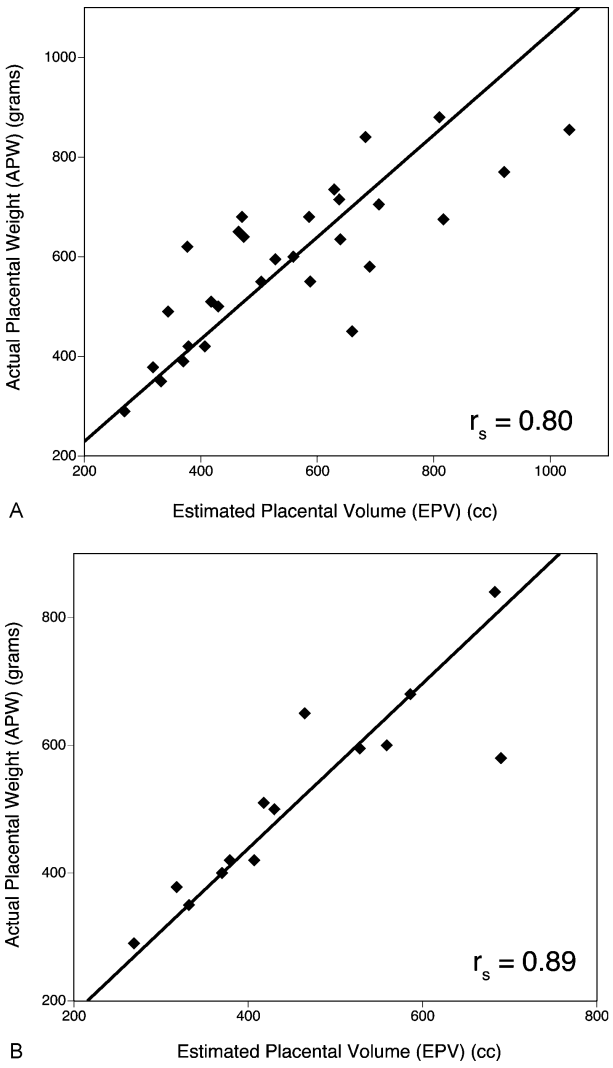

Figure 2 Correlation of estimated placental volume to actual placental weight. (A) Graph of all 29 patients examined revealing a Spearman's rho (r_s) of 0.80. Note that as placental weight increases, the data scatter increases. (B) Graph of only patients at less than 37 weeks' gestation. Note that Spearman's rho (r_s) is now 0.89 due to the fact that it was significantly easier to visualize these placentas in one ultrasound field.

DISCUSSION

As is well known, the human placenta is essential for the exchange of substances between the mother and the fetus.[23] It facilitates the transfer of oxygen and nutrients from the maternal circulation into the umbilical vein and transports all the metabolic waste and CO_2 from the fetal umbilical arteries into the maternal venous circulation. Its normal development during gestation ensures the necessary support for the formation of a healthy fetus.[10] Prior to the general use of ultrasound in prenatal surveillance, placental hormonal levels were used to assess placental function.[24] In the early days of

ultrasound, Grannum et al developed a method of placenta grading in an attempt to evaluate placental-fetal maturation.[25] This approach was displaced by more accurate methods of fetal well-being assessment.[2,26] These assessments have helped reduce the rate of stillbirth from 11.5 per 1000 births in the 1960s to around 5.1 per 1000 births in the 1980s.[27] Despite these improvements in fetal surveillance, stillbirth rates in the United States have been relatively stable over the last 20 years, reaching a plateau of 6.4 per 1000 births in 2002.[28] Advances in prenatal surveillance have focused mainly on the fetus, with little attention paid to the placenta.[5,29–32] However, it is apparent that a significant fraction of stillbirths are secondary to very small placentas.[22,33–36] Therefore, though it is known that prenatal evaluation of placental volumes using ultrasound imaging has the potential to decrease the number of unexpected fetal demises as recognized by Jauniaux et al,[37] accurate assessment of placental volume is not widely available.

Several methods for evaluating placental volume during pregnancy have been tested, including magnetic resonance imaging and three-dimensional ultrasound.[15,38–42] These methods require expensive equipment and specialized training. Furthermore, the time needed to complete such studies may prevent an appropriately speedy response. Due to these factors, placental volume evaluation has not been a standard of daily clinical practice.

Our study validates a simple method to calculate placental volume using widely available two-dimensional ultrasound equipment. Although we have demonstrated that EPV assessment correlates well with actual placental weight, technical difficulties remain, especially with large placentas and in patients with a high body mass index. In 100% of the cases with compromised placental visualization, the gestational age was over 36 weeks. Image quality and accuracy of our measurements were improved when we performed the study at earlier gestational ages (Fig. 2B). Because the method will most likely be targeted to the first and second trimesters of pregnancy, the inability to measure placental volume at advanced gestational ages should not be clinically detrimental.

Because the majority of placentas examined for this study were close to being circular, we cannot comment on the utility of this method on placentas with markedly abnormal shapes. It is possible, for example, that an EPV using either the minor or major axis alone of a very oblong placenta, or one lobe of a bilobed placenta, may result in an erroneous estimate. It would therefore behoove the operator in such cases to examine more closely any placenta that is either significantly large or small for expected placental volume for gestational age to rule out placental shape anomalies.

Current prenatal ultrasound surveillance entails a scan in the first trimester followed by an anatomic evaluation of the fetus between 18 and 20 weeks of gestation.[43] In some cases, this is followed by a growth evaluation of the fetus in the third trimester. Because EPV measurement is simple and rapid, we propose including this procedure to rule out the presence of a placenta that is small for gestational age whenever a patient is evaluated by ultrasound.

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