DOI 10.1007/s10527-019-09870-8
Biomedical Engineering, Vol. 53, No. 1, May, 2019, pp. 22-27. Translated from Meditsinskaya Tekhnika, Vol. 53, No. 1, Jan.-Feb., 2019, pp. 16-20.
Original article submitted October 16, 2018.

Measurement of Placental Volume by 3D Modeling of Ultrasound Placentometry Results

V. A. Mudrov* and A. K. Lyapunov

An original method of determining placental volume by 3D modeling of the results of ultrasound placentometry is presented. Calculations and methods for creating 3D models of the placenta are given and the effectiveness of using this method for measurement of placental volume is assessed.

Introduction

There is currently no reliable method for measuring placental volume during pregnancy [1]. Over many years, the occurrence of placental hypoplasia and hyperplasia has been assessed by analysis of placental thickness using ultrasound investigations, though this method is unreliable [1, 2]. As a result, 3D ultrasound placentometry has entered wide use; the sensitivity of this method in the first trimester of pregnancy is 95-100% [3, 4]. However, this method does not provide for assessment of placental volume in the second and third trimesters of pregnancy because of significant increases in the size of the organ [1, 3, 4]. Use of computerized tomography (CT) does not avoid the possibility that X-rays will have effects on the mother and fetus, so it cannot be used in routine obstetric practice for placentometry [5]. Among existing methods, MRI is the most accurate, informative, and safe, and provides complete radiation safety, yields slices in any plane, lacks projection magnification, is simple, and gives highly accurate measurements [1]. However, MRI scans are expensive and their use is not a routine diagnostic procedure. Data reported by Mertz indicate that ultrasound results obtained using contemporary probes can be comparable with CT and MRI results [1].

The aim of the present work was to study the possibility of determining placental volume by 3D modeling of the results of ultrasound placentometry. This was addressed by developing a method for mathematical calculation of placental volume from ultrasound measurements of the area defined by the maximal longitudinal and transverse sections of the placenta, measured by tracing images, and placental thickness. In addition, the studies created a program for calculation of placental volume on the basis of construction of a 3D model of ultrasound placentometry parameters.

Materials and Methods

Studies at the City Maternity Hospital and the Perinatology Center of The District Clinical Hospital, Chita, were performed over the period 2013-2017 and included retrospective and prospective analysis of 150 birth histories, which were divided into three groups: group 1 were pregnant women with delayed fetal growth, group 2 were pregnant women with normal development, and group 3 consisted of pregnant women with fetal somatomegaly. Informed voluntary consent was obtained from patients before carrying out the required investigations. Fetal weight was assessed on the basis of ultrasound fetometry data [1].

The first stage in the study was determination of the formula for calculating placental volume. Criteria for determining placental volume were selected on the basis of the following mathematical calculations:

– the volume of the hollow organs in ultrasound practice is determined as $V = A \cdot B \cdot C \cdot 0.523$, where A is the length of the organ, cm, B is the thickness of the organ, cm, C is the width of the organ, cm, 0.523 is a coefficient, and V is the volume of the organ, cm^3 [6];

Chita State Medical Academy, Ministry of Health of the Russian Federation, Chita, Russia; E-mail: mudrov_viktor@mail.ru
* To whom correspondence should be addressed.

0006-3398/19/5301-0022 © 2019 Springer Science+Business Media, LLC

– as the placenta is an organ of irregular geometrical shape, the cross-sectional area of the placenta should be determined [7, 8];

– the cross-sectional area of an organ of ellipsoidal shape is given by $S = a \cdot b \cdot \pi$, where a is the first (long) semiaxis, b is the second (intermediate) semiaxis, and S is the cross-sectional area of the ellipsoid;

– the area of an organ of ellipsoidal shape is given by $S = a \cdot b \cdot \pi = A \cdot B \cdot \pi/4$, where a is the first (long) semiaxis, A is the first (long) axis, b is the second (intermediate) semiaxis, B is the second (intermediate) axis; and S is the cross-sectional area of the semiellipsoid;

– the length of an organ of ellipsoidal shape is given by $A = 4 \cdot S_1/(B \cdot \pi)$, where A is the length of the organ, B is the thickness of the organ, and S_1 is the area of the longitudinal section of the organ;

– the width of an organ of ellipsoidal shape is given by $C = 4 \cdot S_2/(B \cdot \pi)$, where C is the width of the organ, B is the thickness of the organ, and S_2 is the transverse cross-sectional area of the organ;

– thus, the volume of an organ of ellipsoidal shape can be calculated as $V = [4 \cdot S_1/(B \cdot \pi)] \cdot [4 \cdot S_2/(B \cdot \pi)] \cdot B \cdot 0.523 = 0.8487 \cdot S_1 \cdot S_2/B$, where S_1 is the longitudinal cross-sectional area of the organ, S_2 is the transverse cross-sectional area of the organ, and B is the thickness of the organ;

– as the placenta is an organ of semiellipsoidal shape, the volume of the placenta is determined as $V = 0.4243 \cdot S_1, \cdot S_2/h$, where S_1 is the area of the largest longitudinal cross-sectional area of the placenta, cm^2, S_2 is the transverse cross-sectional area of the placenta, cm^2, and h is the thickness of the placenta, cm.

The second stage in the study consisted of ultrasound placentometry in patients. Echocardiographic investigations were performed using a Toshiba Aplio 500 diagnostic ultrasound apparatus (Toshiba, Japan) in real-time scanning mode. Ultrasound placentometry was performed using a convex transabdominal probe with a 3.5-5 MHz frequency transducer. Measurements were made with the patient lying on her back. The transabdominal probe was initially positioned paraumbilically for visualization of the patient's transverse section. Moving the probe in "seek" mode yielded an image of the placental section at its largest size, which included a "stop frame," after which tracing was used to determine the area of the largest longitudinal section of the placenta and the maximum thickness of the placenta was measured. The probe was then rotated through 90° at this visualization point to obtain the transverse cross section of the placenta. The transverse section of the placenta was also determined by the tracing method (Fig. 1).

When the placental cross section was not visualized in the window, the complete cross-sectional image of the placenta was obtained on two adjacent screens, aligning the image boundaries on the two screens using anatomical markers providing arbitrary orientation points (placental vessels, sites of attachment of the umbilicus to the placenta, outline of the cross section of the placenta, symphysis) (Fig. 2).

The third stage in the study included creation of a 3D model of the placenta based on ultrasound placentometry data. Using local systems for changing the positions of points, lines, and polygons to primitives, the program Autodesk 3ds Max (Autodesk Inc., USA) was employed

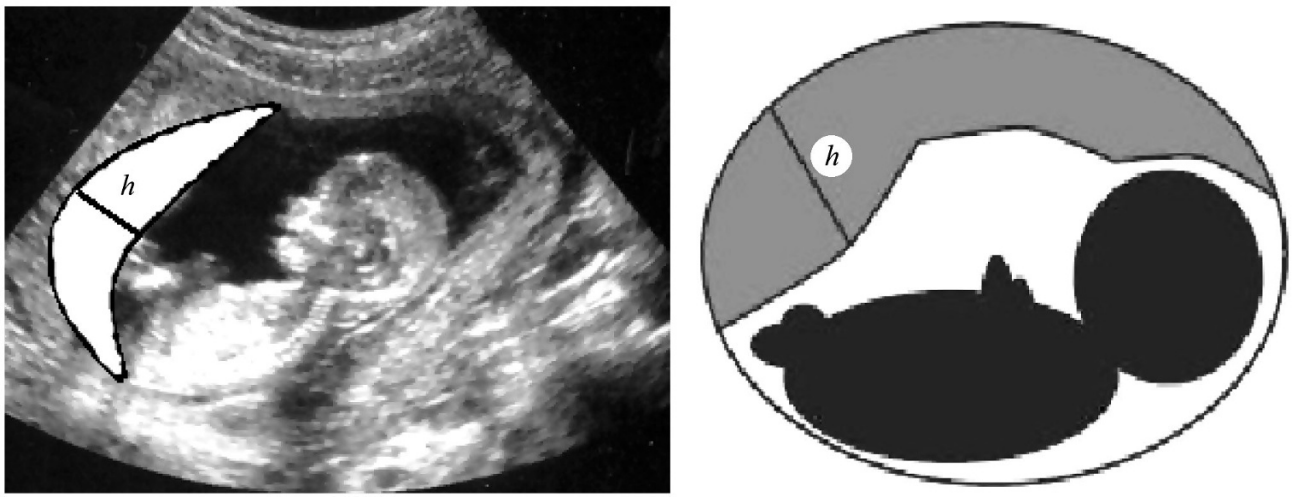

Fig. 1. Method of determining the thickness and cross-sectional area of the placenta using a transabdominal ultrasound probe.

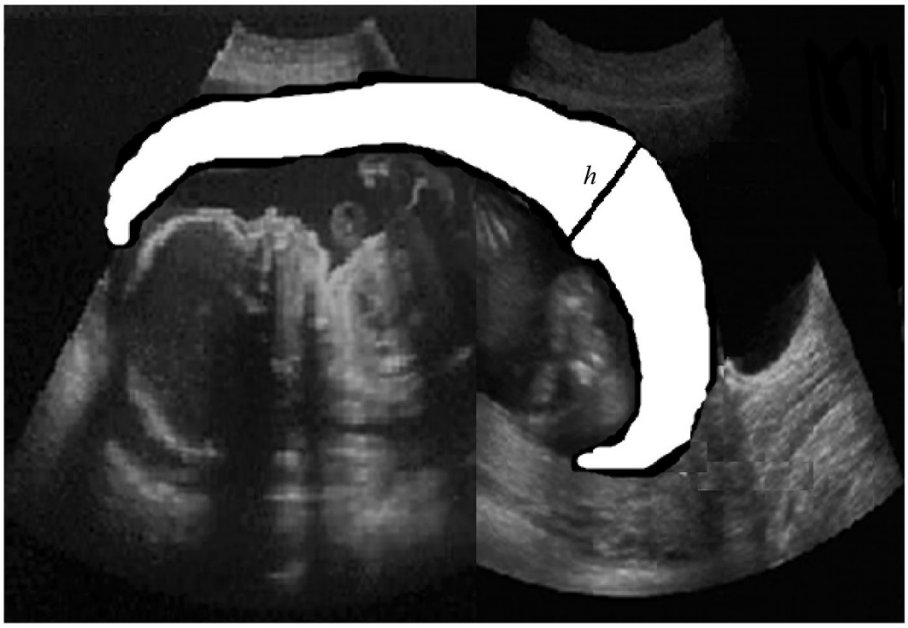

Fig. 2. Method for determining the thickness and cross-sectional area of the placenta using two adjacent screens.

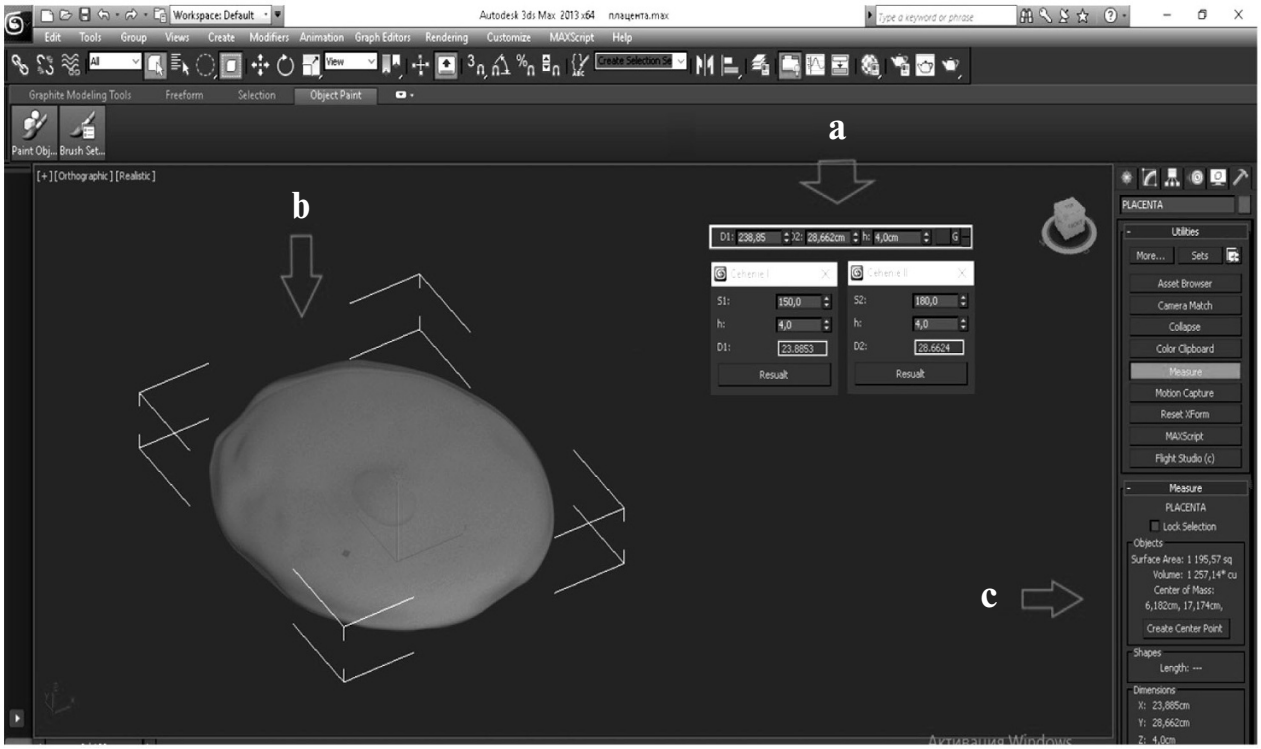

Fig. 3. Appearance of 3D model of the placenta seen from above and the working windows of the program used to create the 3D model of the placenta: a) input pane; b) projection window; c) measurement pane.

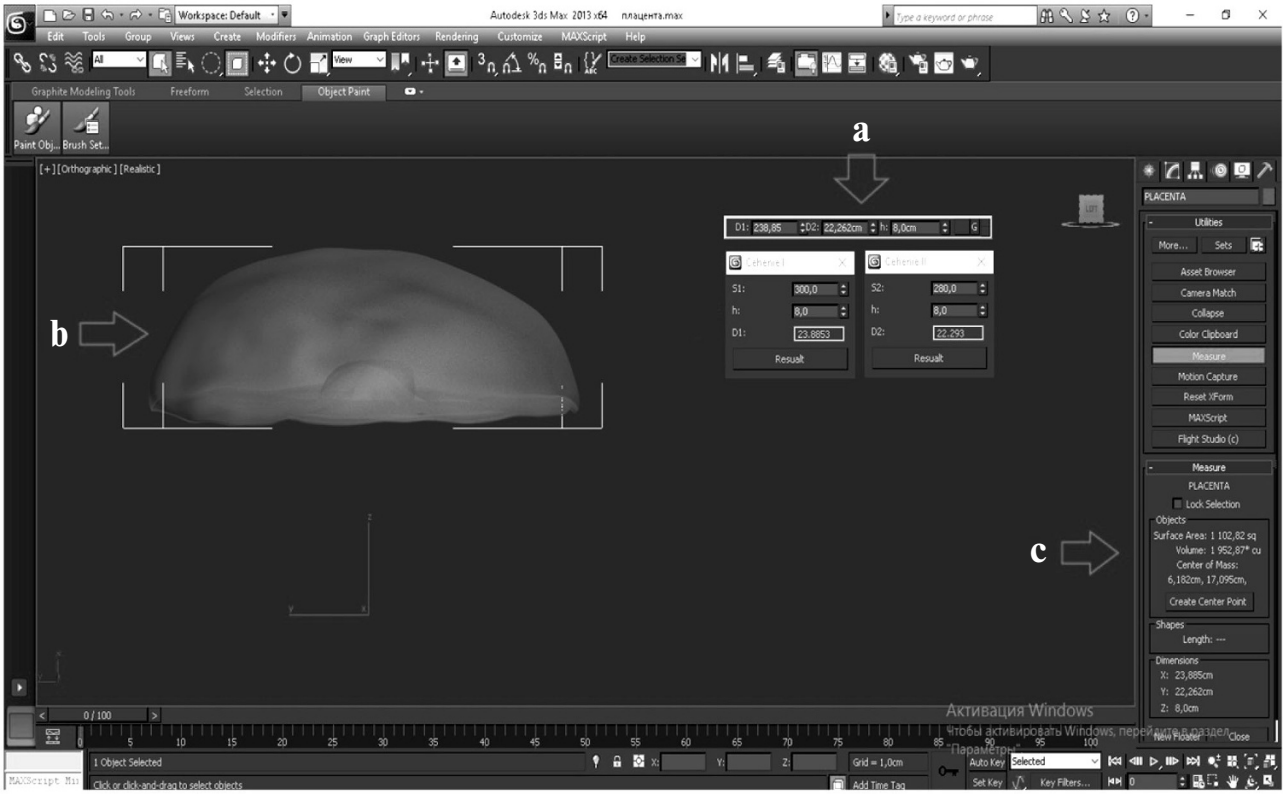

Fig. 4. Appearance of 3D model of the placenta seen sideways and working windows of the program used to create the 3D model of the placenta: a) input pane; b) projection window; c) measurement pane.

to specify the shapes of real objects: the maternal and fetal surfaces of the placenta, the areas of the maximum longitudinal and transverse sections of the placenta, and the thickness of the placenta. The objects made up the whole of the virtual shell and CAT skeleton. A program was written in MAXScript (Autodesk Inc., USA) on the basis of the resulting data for the three-dimensional modeling program Autodesk 3ds Max (Autodesk Inc., USA). Launching the program opens a dialog box containing rows for inputting ultrasound placentometry data: the area of the maximal longitudinal section of the placenta, the area of the transverse section of the placenta, and the thickness of the placenta (Fig. 3a; Fig. 4a). The input window and the projection window interact with each other by binding the input window with the polygonal areas of the model and individual parts of the CAT skeleton (Fig. 3b; Fig. 4b).

This interaction was used to recreate a virtual map of the relationships of the placental surface [9]. When the object (placenta) is selected, its volume appears in the measurement window (Fig. 3c; Fig. 4c).

Statistical processing of the study results was run in IBM SPSS Statistics Version 20.0 (International Business Machines Corporation, USA). The resulting data are presented as the median and mean values and the significance interval. Pairs of independent groups were compared using the Mann–Whitney U test and sets of three groups were compared by Kruskal–Wallis rank analysis followed by pairwise comparison of groups using the Mann–Whitney test with the Bonferroni correction and assessment of the p value. Statistically significant differences were identified using Student's test and the critical level of significance (p) was taken as 0.05. Corrected coefficients of determination were then calculated, these showing the proportion of the relationship explained [10].

Results

In group 1, births occurred at 37-40 weeks of pregnancy in 74% of cases (37 cases), compared with 84% (42

cases) in group 2 and 76% (38 cases) in group 3. The proportion of primiparous women in group 1 was 44% (22 cases) compared with 54% (27 women) in group 2 and 48% (24 women) in group 3. Mean birth weight in group 1 was 2425 ± 47 g (95% CI 1953-2848 g), compared with 3421 ± 54 g (95% CI 3025-3841 g) in group 2 ($p < 0.05$) and 4195 ± 35 g (95% CI 4114-4541 g) in group 3 ($p < 0.05$).

Signs of fetal hypoxia were detected during pregnancy in 32% of cases (16 cases) in group 1, which was twice the frequency seen in group 3, i.e., 14% (seven cases) ($p < 0.05$) and comparable with the level in group 2, i.e., 25% (13 cases) ($p > 0.05$).

TABLE 1. Percentile Placental Volumes at Different Periods of Pregnancy

Stage of pregnancy	Placental volume, cm^3 Percentiles		
	10	50	90
14	75.6	111.2	126.7
15	79.3	118.3	135.3
16	83.4	126.0	144.8
17	87.8	133.9	166.0
18	93.1	139.1	194.3
19	99.6	145.4	226.7
20	109.2	150.4	258.4
21	111.5	163.3	277.2
22	118.3	179.4	294.4
23	125.7	183.5	315.4
24	127.3	199.2	343.1
25	132.4	212.6	360.3
26	136.9	216.4	388.3
27	143.1	221.3	395.6
28	149.3	228.1	413.2
29	155.8	236.5	430.7
30	162.0	246.2	448.8
31	172.4	257.1	465.2
32	178.9	271.3	482.7
33	185.3	288.8	500.3
34	191.8	310.5	527.5
35	207.3	333.4	555.6
36	218.2	339.3	570.2
37	231.5	353.0	588.2
38	251.4	393.2	606.6
39	272.4	437.2	615.2
40	294.0	484.4	624.2
41	311.9	518.0	638.5

TABLE 2. Placental Volume in Study Groups

Study groups	Placental volume		
	Hypoplasia	Normal volume	Hyperplasia
Group 1	76% (38)*	20% (10)	4% (2)*
Group 2	12% (6)*	66% (33)	22% (11)*
Group 3	0% (0)*	40% (20)	60% (30)*

Note: *$p < 0.05$

In group 1, 28% of women (14 women) gave birth by Caesarean section, due primarily to a combination of delayed growth and chronic fetal hypoxia; Caesarean section was performed in 20% of women (10 women) in group 2 and 34% (17 women) in group 3.

The studies reported here identified the percentile placental volume at different stages of gestation (Table 1).

With the aim of determining the error in the method developed here, the afterbirth was placed in a measuring beaker after delivery. The error in the method averaged 10% (± 35 cm^2), which may be due to the absence of blood filling of the afterbirth as a result of its detachment.

Placental hypoplasia was most frequently found in patients of group 1, while hyperplasia was commonest in those of group 3 (Table 2).

Increases in placental volume should be regarded as the manifestation of a compensatory reaction of the uterine-placental complex to the need to increase the blood supply to the fetus.

Conclusions

The complex use of mathematical methods and 3D modeling of the results of ultrasound placentometry provides for reliable determination of placental volume (the coefficient of determination $r^2 = 0.89$), which in turn allows the development of complications of pregnancy such as delayed growth or fetal macrosomia to be predicted.

REFERENCES

1. Merz, E., Ultrasound Diagnosis in Obstetrics and Gynecology [Russian translation], MEDpress-inform, Moscow (2016).
2. Smith, N. C. and Smith, A. P. M., Obstetric Ultrasound Made Easy [Russian translation], Prakticheskaya Meditisina, Moscow (2014).

3. Paula, C. F. S., Ruano, R., Bonini Campos, J. A. D., and Zugaib, M., "Placental volumes measured by 3-dimensional ultrasonography in normal pregnancies from 12 to 40 weeks' gestation," J. Ultrasound Med., No. 27, 1583-1590 (2008).
4. Rizzo, G., Capponi, A., Cavicchioni, O., Vendola, M., and Arduini, D., "First trimester uterine Doppler and three-dimensional ultrasound placental volume calculation in predicting preeclampsia," Eur. J. Obstetr. Gynecol. Reprod. Biol., **138**, 147-151 (2008).
5. ACOG Practice Bulletin No. 22, American College of Obstetricians and Gynecologists Washington, D.C. (2000).
6. Zmitrovich, O. A., Ultrasound Diagnosis in Numbers. A Reference and Practical Guide [in Russian], SpetsLit, St. Petersburg (2014).
7. Kolesov, V. V., Mathematics for Medical Institutions. A Textbook [in Russian], Feniks, Moscow (2015).
8. Remizov, A. N., Medical and Biological Physics [in Russian], GEOTAR-Media, Moscow (2012).
9. Autodesk, Official Training Course in 3ds MAX [Russian translation], NT Press (2007).
10. Levin, I. A., Manukhin, I. B., Ponomareva, Yu. N., and Shumetov, V. G., Methodology and Practice of Data Analysis in Medicine. A Monograph [in Russian], APLIT, Tel Aviv (2010).