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Determination of the Volume of Early Hypotonic Hemorrhage by 3D Modeling of Ultrasound Investigation Results

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An original method for determining the volume of early hypotonic hemorrhage is presented. The method is based on clinical application of 3D modeling of results obtained by ultrasound investigations of the uterine cavity and gravimetric assessment of the volume of external blood loss. A scheme for computation is described, a method for 3D modeling of the postpartum uterus is created, and the effectiveness of using this method for determining the volume of hemorrhage is assessed.

Introduction

Obstetric bleeding is currently the most frequent cause of maternal mortality. The volume and severity of blood loss are assessed by visual evaluation, the gravimetric method, and clinical interpretation of the symptoms of hypovolemia [1]. The visual method underestimates the blood loss volume (BLV) by an average of 30% because of its subjectivity. The errors of the visual method increase with increasing BLV, so clinical practice must be oriented to the general state of the patient. The gravimetric method is based on direct collection of lost blood in a graduated vessel (collection bags, cylinders, or Cell Saver systems), and by weighing blood-soaked bandages and surgical garb. This method is more accurate (about 90%) than the visual approach, though it too does not give accurate data on actual BLV [1]. This leads to the need for dynamic evaluation of uterine cavity volume (UCV) during the early postpartum period, along with assessment of the volume of external bleeding by the gravimetric method.

Undoubtedly, the most significant methods for assessment of organ volume are computed tomography (CT) and magnetic resonance imaging (MRI) [2]. However, MRI and CT scans cannot be used in routine practice because of the large distance between the birth room and the investigation facilities, as well as the high cost of these investigations. The volume of an organ cavity is conventionally calculated using formulas created for regular geometrical shapes (ellipses) and based on two-dimensional ultrasound scans. Wide use is currently made of three-dimensional ultrasonography, which is a more accurate method for assessing the volumes of organs and cavities with uneven surface contours than two-dimensional methods [2]. However, three-dimensional ultrasound imaging in the conditions of a regional hospital is not as widely available as conventional two-dimensional scanning.

Casikar et al. described a solution to this problem in the form of 3D modeling, allowing a virtual model of the uterine body to be constructed with automatic computation of its volume. The virtual model was built on the basis of tracing six sections of the uterine body obtained with rotations 30° apart [3]. However, this method has a number of drawbacks:

1) inadequate accuracy (the results indicated an error rate of 18%), probably because computed organ volume was compared with final weight, while these values are not comparable if tissue density is not taken into account ($V = m/\rho$);

2) the complexity of the method (construction of the model requires tracing of six sections of the uterus);

3) the low availability of the method (special software is required);

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4) the high laboriousness of the procedure (manual tracing of six sections of the uterine body takes a significant amount of time).

Furthermore, the method presumes assessment of the volume in conditions of planned removal without consideration of measurement of UCV when there is limited time available for the assessment.

Thus, the aim of the present work was to determine the volume of early hypotonic blood loss (EBL) by combined application of the gravimetric method and 3D modeling of the results of ultrasound scan (USS) of the postpartum uterus.

Materials and Methods

A prospective trial of assessment of BLV in women whose deliveries were accompanied by EBL was run at the State Healthcare Institution District Clinical Hospital, Chita, in 2018-2019. Exclusion criteria were: trauma to the birth canal accompanied by abundant hemorrhage, retained placental tissue, and primary blood clotting disorders. A total cohort of 60 patients was studied. BLV was assessed in new mothers by four physicians working in parallel using four different methods to assess BLV. This resulted in four equal study groups: BLV was assessed in group 1 (15 patients) using the visual method; BLV was assessed in group 2 (15 patients) using the gravimetric method (collection bags); total BLV was assessed in group 3 (15 patients) as the sum of total UCV measured by two-dimensional ultrasonography using the standard formula and the volume of blood collected in a measuring cylinder; total BLV was assessed in group 4 (15 patients) by complex analysis of the results of 3D modeling of the postpartum uterus USS and the data obtained by the gravimetric method (measuring cylinder). Informed voluntary consent was obtained prior to carrying out the required investigations.

At the first stage of the study, the formula for calculating UCV was determined. Criteria for determining UCV were selected on the basis of the following computations:

– organ cavity volumes are determined in ultrasound practice using the following standard formula: $V = A{\cdot}B{\cdot}C{\cdot}\pi/6$, where A is organ length, cm; B is organ thickness, cm; C is organ width, cm; $\pi \approx 3.14$; and V is organ volume, cm^3 [4];

– as the uterine cavity has an uneven geometric shape (especially when deformed by myomas), the cross-sectional areas of sections of the cavity have to be determined [5];

– the cross-sectional area of an ellipsoidal body is $S = a{\cdot}b{\cdot}\pi$, where a and b are the first (large) and second (intermediate) semiaxes of the ellipsoid;

– thus, $S = a{\cdot}b{\cdot}\pi = A{\cdot}B{\cdot}\pi/4$, where A and B are the first (large) and second (intermediate) axes of the ellipsoid;

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

– the width of the ellipsoid is given by $C = 4S_2/(B\pi)$, where B is the thickness and S_2 is the area of the transverse section of the ellipsoid;

– the volume of the cavity of the ellipsoid can be calculated as:

$$V = \frac{4S_1}{B\pi}\cdot\frac{4S_2}{B\pi}\cdot B\cdot\frac{\pi}{6} = \frac{8S_1S_2}{3B\pi} \approx \frac{0.85\cdot S_1S_2}{B},$$

where S_1 is the area of the longitudinal section, S_2 is the area of the transverse section, and B is the second (intermediate) axis;

– UCV is obtained as $V = 0.85{\cdot}S_1S_2/h$, where S_1 is the area of the maximal longitudinal section of the cavity, cm^2; S_2 is the area of the transverse section of the cavity, cm^2; h is the maximum anteroposterior size of the cavity of the postpartum uterus, cm; and $0.85 \approx 8/3\pi$ is a coefficient. Using this formula hypothetically decreases the error of two-dimensional visualization, which will undoubtedly be of value for assessment of EBL volume.

The second stage in the study was to carry out USS of the uterus in the early postpartum period in study patients. Echographic investigations were performed using a portable high-performance MySono U6 Samsung Medison ultrasound scanner (Samsung Medison, Korea). USS was performed using a convex probe with a frequency of 3.5-5 MHz via transabdominal access. Measurements were made with the patient lying on her back. The transabdominal probe was initially placed in the paraumbilical area in the sagittal position for visualization of the fundus of the uterus. Moving the probe in "search" mode imaged the largest possible longitudinal section of the uterine cavity in the stop frame, after which tracing was used to determine the area of the maximal longitudinal section of the cavity, and the maximum anteroposterior size of the cavity of the postpartum uterus was measured. Then, at the visualization point, the probe was rotated through 90° to obtain the transverse section of the cavity. The transverse section of the cavity of the postpartum uterus was also determined by tracing (Fig. 1).

The third stage in the study consisted of creating a 3D model of the cavity of the postpartum uterus, changing dynamically depending on the input USS parameters [2]. These data were used to write program code in the C++-based (ISO) Unreal Engine 4 Blueprint visual scripting system (Epic Games, USA). Initiating the pro-

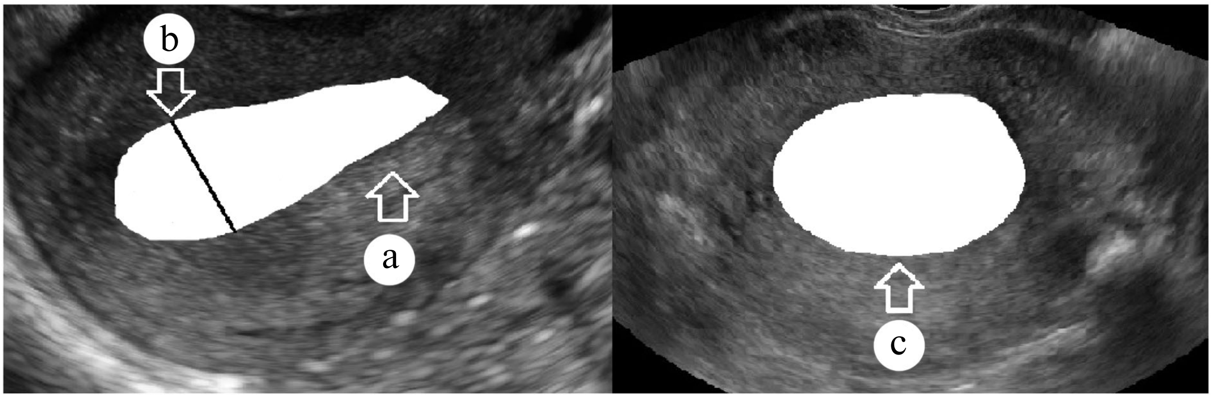

Fig. 1. Method for determining the maximum longitudinal (a) and transverse (b) sections and the maximum anteroposterior size (c) of the cavity of the postpartum uterus using a transabdominal ultrasound probe.

gram opens a dialog box with rows for inputting USS data: length (*A*), width (*B*), maximum anteroposterior size (*C*), and the areas of the maximum longitudinal (S_1) and transverse (S_2) sections of the cavity of the postpartum cavity (Fig. 2).

A set of actions is created automatically in a special operating mode in the user window. The input window and the projection window interact with each other by linking the input window variables with the polygonal parts of the model with different weighting levels for the areas of the polygon group. This results in determination of UCV (*V*) and assessment of the severity of total blood loss.

Study results were processed statistically in IBM SPSS Statistics Version 25.0 (IBM Corp., USA). Data were presented as medians and significant intervals. Statistical significance was assessed using the Kruskal–Wallis test (*H*) with subsequent determination of the significance level *p*. More precise description of trends was obtained using the Mann–Whitney test (*U*), which provides evaluation of differences in values on pairwise comparison of groups. Relationships between measurement methods and true values for blood loss volume were assessed using the Spearman ranked correlation coefficient, and the strength of links was determined using the Chaddock scale [6].

Results

EBL volume in group 1 was 750 mL (95% CI 700-825), compared with 1050 mL (95% CI 95-1150) in group 2, 1100 mL (95% CI 1055-1220) in group 3, and 1230 mL (95% CI 1150-1280) in group 4 ($H = 41.58$, $p < 0.001$) (Fig. 3).

Pairwise comparison of groups drew attention to the low diagnostic value of the visual method of evaluating BLV in group 1 ($p_{1\text{-}4} < 0.001$). Comparison of the results of assessment of BLV in groups 2 and 3 showed that there was no statistically significant difference ($U = 66.5$, $p = 0.056$). This is probably due to the low diagnostic value of the standard ultrasound formula for assessment of UCV due to the irregular geometric shape in conditions of hypotonia. In addition, the effectiveness of assessing BLV in group 4 was significantly different from that in group 2 ($U = 26.5$, $p < 0.001$), which supports the value of using 3D modeling of USS results from the postpartum uterus and assessment of external blood loss using a measuring cylinder. Collecting bags undoubtedly provide adequate assessment of BLV during the physiological course of the early postpartum period. However, the drawbacks become

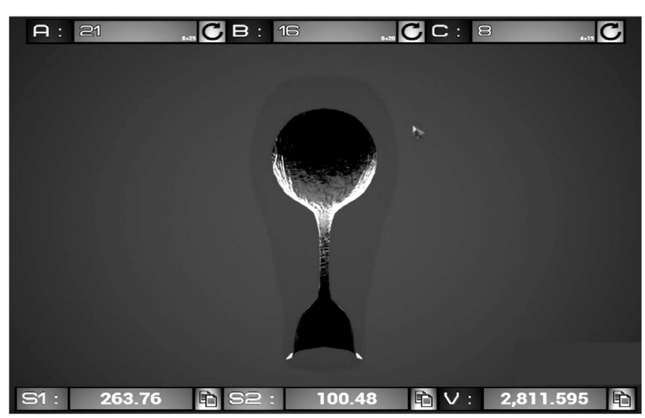

Fig. 2. 3D model of postpartum uterus, view from above, and the working window of the developed program.

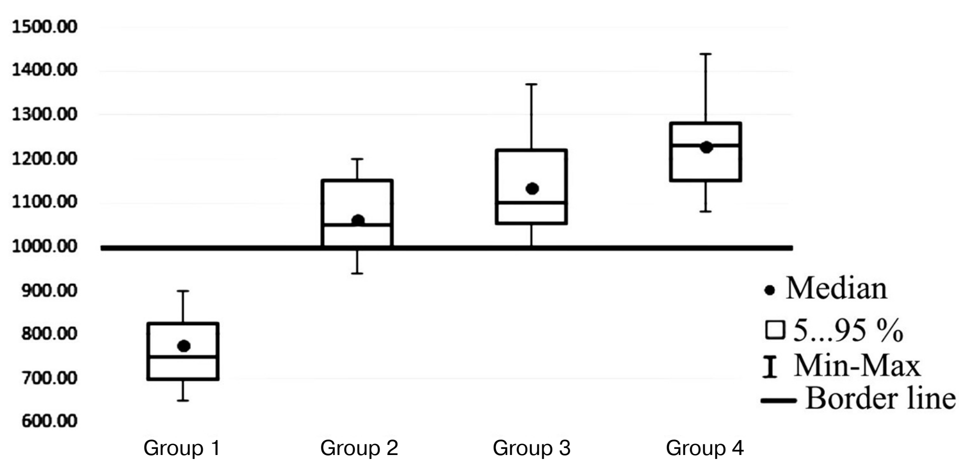

Fig. 3. Differences in assessments of the volume of early hypotonic hemorrhage in the study groups, mL.

apparent on development of EBL: collecting bags have only intermediate divisions, with the result that they do not provide adequate assessment of BLV. The diagnostic value of the formula developed here is demonstrated by the high significance of differences in BLV assessment in groups 3 and 4 ($U = 55.5$, $p = 0.018$).

The errors of the methods were evaluated by determining for the study groups the ratio of BLV at the moment of diagnosis to BLV at the moment of completing manual examination of uterine cavity. Error levels were 34.6% in group 1, 10.4% in group 2, 4.6% in group 3, and 3.4% in group 4 ($H = 51.63$, $p < 0.001$). Use of the standard formula for calculating UCV led to underestimation of BLV, while use of the formula developed here led to overestimation of BLV ($U = 5.0$, $p < 0.001$). Overestimation of BLV probably results from the friability of clots in the cavity of the hypotonic uterus. However, this fact has positive rather than negative significance: use of this method tells the physician that there is an urgent need for the proactive approach directed to preventing the development of a critical situation.

TABLE 1. Levels of Correspondence between Results Obtained Using the Suggested Method and True Blood Loss Volumes

Study groups	Spearman correlation coefficient	Two-tailed significance	Connection strength, Chaddock scale
Group 1	0.543	0.036	Moderate
Group 2	0.817	<0.001	High
Group 3	0.823	<0.001	High
Group 4	0.943	<0.001	High

The relationship between values calculated in group 4 and true values of blood loss volume was close to functional (Table 1).

The method described here can be implemented in small regional hospitals, as it does not require high-tech equipment. It is based on the use of two-dimensional ultrasonography and computation of UCV using the formula described. The method described here can be used in new mothers at high risk of developing impaired uterine contractility [1]. During the two hours following separation of the placenta, the obstetric physician should repeatedly (every 20 min during the first hour, every 30 min during the second) carry out ultrasound scans of the uterus using a portable ultrasound apparatus and determine UCV using the formula described here with a calculator and compute total BLV allowing for external hemorrhage. When the acceptable blood loss level is exceeded, the physician proceeds to carry out emergency procedures. When there is a need for visualization of changes in UCV, the program described here can be used — the authors will provide this on request.

Conclusions

3D modeling of the results of ultrasound investigations of the uterine cavity in the early postpartum period and gravimetric assessment of the volume of external blood loss with a measuring vessel provides effective assessment of the volume of early hypotonic hemorrhage, which will lead to reductions in the incidence of massive obstetric hemorrhages and optimize the tactics of managing such patients.

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