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Diagnosing Postpartum Hemorrhage: A New Way to Assess Blood Loss in a Low-Resource Setting

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Abstract *Introduction* Postpartum hemorrhage (PPH) is the leading cause of maternal mortality worldwide. The largest barriers to treating PPH are symptom recognition and timely diagnosis. The SAPHE (Signaling a Postpartum Hemorrhage Emergency) Mat was constructed so that each square on the Mat absorbs up to 50 mL of blood. The objective of this study was to evaluate the correlation of visually estimated blood loss (EBL) using the SAPHE Mat with actual blood loss. *Methods* Thirty-six patients gave birth via vaginal delivery using the SAPHE Mat. Visual estimation of blood loss using the SAPHE Mat was calculated by multiplying the number of blood- saturated squares or partial squares by 50 mL. The visual EBL was compared with the actual blood loss calculated based on Mat weight before and after use (volume blood loss). *Results* Visual blood loss estimations were within 100 mL of the volume blood loss 69 % of the time and within 200 mL 97 % of the time. The mean difference between the visual EBL and volume blood loss (Mat weight change) was 80.91 mL. The Pearson correlation coefficient for visual EBL and volume blood loss was positive at 0.96 ($p < 0.001$). *Discussion* The SAPHE Mat is able to provide a visual estimate of blood loss that is highly correlated with the actual blood loss on the mat. Future studies will assess the ability to deploy the SAPHE Mat in low-resource settings as a potential guide for estimating blood loss to assist in improved management of PPH.

Keywords Estimated blood loss · Postpartum hemorrhage · SAPHE Mat · Vaginal delivery · Low-resource setting

Significance

We searched PubMed for articles published with the terms "maternal blood loss measurement", "blood loss AND pregnancy", "postpartum bleeding OR hemorrhage", "absorbent pad AND blood", "postpartum hemorrhage AND blood loss measurement." From 248 publications, we identified 30 related to postpartum hemorrhage and measurement of blood loss. Our study demonstrates that visual estimation of blood loss using the SAPHE Mat is highly correlated with actual blood loss. The SAPHE Mat does not require formal medical knowledge or extensive training, making it suitable for low-resource settings. The SAPHE Mat has the potential to be used for blood loss measurement clinically.

Introduction

Postpartum hemorrhage (PPH), the leading cause of maternal death worldwide, occurs in nearly 14 million births and is responsible for approximately 140,000 maternal deaths each year (World Health Organization 2014). This burden is not distributed evenly across nations. Over 99 % of maternal deaths take place in the developing

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world in large part due to the lack of access to skilled birth attendants and medical supplies.

The largest barriers to treating postpartum hemorrhage are symptom recognition and accurate, timely diagnosis (Schorn 2010; Berg et al. 2005). While the resources available in developed countries allow for laboratory diagnosis of postpartum hemorrhage by measuring blood hemoglobin concentration, limited economic, infrastructure and personnel resources preclude the use of these tests in many areas of the developing world. As a result, the most common method of measuring blood loss is unguided visual estimation, which has been suggested to be inaccurate in at least 23 different studies (Lewis 2007; Bose et al. 2006).

In light of these challenges, the SAPHE (Signaling a Postpartum Hemorrhage Emergency) Mat was developed by a group of undergraduate students at Rice University in the Global Health Technologies program to rapidly and accurately diagnose postpartum hemorrhage through improved visual estimation of blood loss. The 41 × 63 cm Mat is comprised of a bottom layer of nylon, a middle layer of cotton batting, and a top layer of quilted fabric sewn with black thread to delineate quilted squares (Fig. 1).

The Mat was constructed so that each square of the quilted layer contains sufficient superabsorbent polymer to absorb up to 50 milliliters (mL) of blood; quilted blocks are staggered to prevent blood from running rapidly off the Mat. The objective of this study was to evaluate the correlation of visually estimated blood loss using the SAPHE Mat with actual blood loss following a vaginal delivery measured by weighing the Mat before and after delivery.

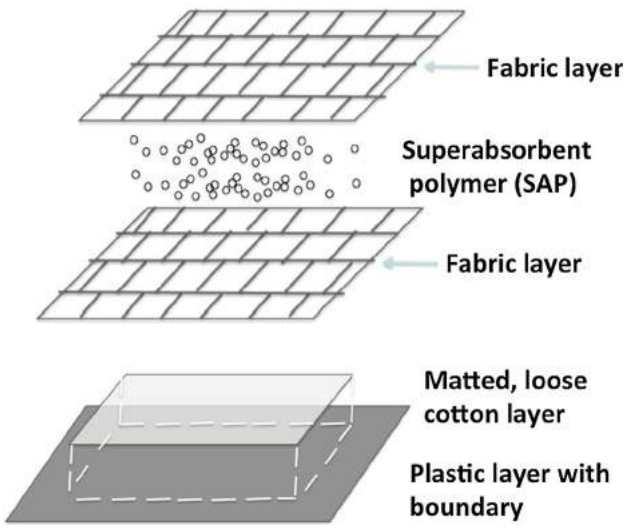

Fig. 1 SAPHE Mat components

Methods

The need for a new method to measure postpartum blood loss was identified through a partnership with the Rice 360° Institute for Global Health and Baylor College of Medicine. Faculty at both institutions collaborated to develop the problem statement. A team of undergraduate students was tasked with the development and testing of an easy-to-use device that would effectively measure maternal blood loss in deliveries in low-resource settings. This project served as the Senior Design Capstone project for the students' minor in Global Health Technologies. They worked closely with mentors in the Rice University Global Health Institute as well as the Obstetrics and Gynecology Department at Baylor College of Medicine. Students followed a structured engineering design protocol to brainstorm solutions, including the use of a super absorbent polymer in a grid format. Upon final optimization of the design, a detailed pictorial manual was made so that all SAPHE Mats could be sewn from commercially available fabric in the Oshman Engineering Design Kitchen at Rice University.

The study was approved by the Institutional Review Boards of Baylor College of Medicine, the Harris Health System, and Rice University. The study was conducted at Ben Taub General Hospital, a large county hospital in Houston, Texas. Informed consent in either English or Spanish was obtained from all women prior to enrollment. Medical care was not withheld or affected if women chose not to participate in the study. The study size of 36 participants was limited by the number of available SAPHE Mats. All patients who were given the option to participate in the study agreed to participate. Women were consented and enrolled in the study after being admitted to the Labor and Delivery ward. All women were enrolled who met the inclusion criteria and who were admitted while the principal investigator was available to oversee the study. Women were excluded from participation if they were under the age of 18, did not understand either English or Spanish, or if they were undergoing a caesarean section.

After enrollment into the study, each subject was assigned a study identification number that corresponded to the SAPHE Mat identification number to be used at their delivery. Each SAPHE Mat and the plastic bag that held the SAPHE Mat were labeled with the corresponding identification number. Demographic data were collected on each patient, which included age, gravida, parity, weight, body mass index (BMI), degree of vaginal laceration, and ethnicity. Each SAPHE Mat and chux pad, which is a type of commercial absorbent pad routinely used in deliveries in both low- and high-resource settings, was sterilized via an autoclave machine prior to use. The SAPHE Mat in its

corresponding packaging was weighed in kilograms using the baby scale in the Labor and Delivery unit and the pre-delivery weight was recorded. Prior to use of the SAPHE Mat, the midwives and any assisting personnel were given a short tutorial on the purpose and use of the SAPHE Mat (Fig. 2).

The SAPHE Mat was placed under the subject's buttocks prior to delivery. A chux pad was placed over the Mat to absorb any amniotic fluid, meconium, or stool that may have affected the final weight of the SAPHE Mat during the labor process. Following the delivery of the baby, the chux pad was removed from covering the SAPHE Mat. The placenta was delivered and any laceration was repaired in the usual fashion. After laceration repair was complete and uterine bleeding noted to be minimal, the SAPHE Mat was removed. The timing between original placement and removal of the SAPHE Mat varied depending on the time it took to complete the laceration repair. The Mat was placed on a flat surface and a picture was taken with its corresponding identification number using a camera or mobile device for documentation purposes (Fig. 3).

The principal investigator at the delivery analyzed the SAPHE Mat and estimated the blood loss based on the number of squares saturated on the Mat. Determining square saturation includes determining how 'full' or 'puffy' and also how 'red' each square is, as puffier and darker red squares suggest more blood has been absorbed than flatter and lighter red squares. The SAPHE Mat was placed back in its corresponding packaging and weighed again using the same scale and the post-delivery weight was recorded.

The primary outcome was the correlation between the blood loss volume visually estimated by the SAPHE Mat and the measured blood loss volume calculated using the difference in the post- and pre-delivery Mat weight. The difference in weight of the SAPHE Mat in grams (g) after use was converted to volume of blood loss in milliliters (mL) using the equation [(weight of Mat post-delivery (g)-

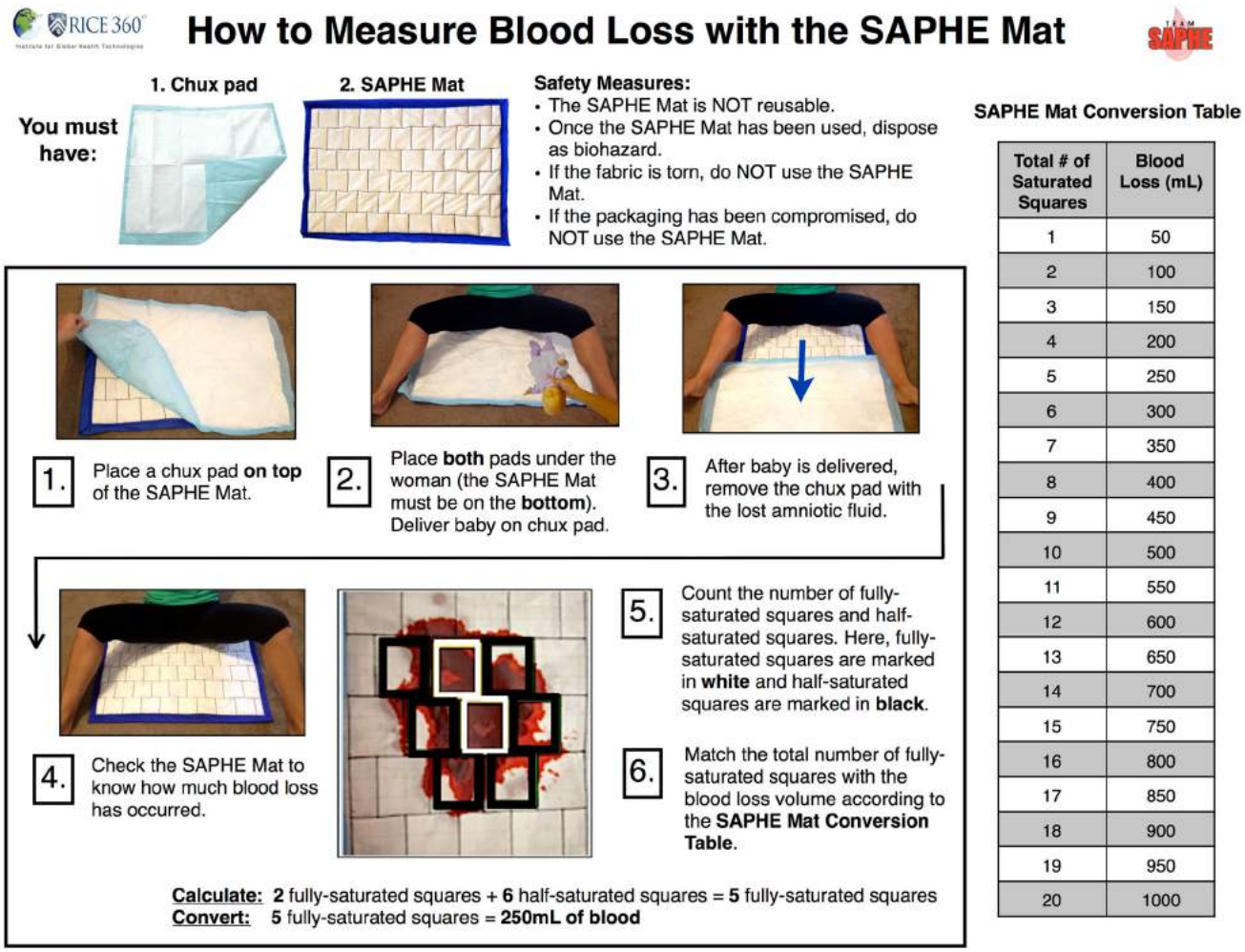

Fig. 2 SAPHE Mat protocol

Fig. 3 Pre- and post-delivery SAPHE Mat

weight of Mat pre-delivery (g))/density of blood (1.06 g/mL)] (Johar and Smith 1993). The visual estimate using the SAPHE Mat was based on the number of full squares or partial squares with absorbed blood multiplied by 50 mL (maximum absorption of each square on the Mat) to give a final estimation of blood loss in mL. Saturation of less than 50 % of a square was not counted. In a preliminary laboratory study using whole blood, it was verified that each square of the SAPHE Mat could absorb up to 50 mL of blood. The visually estimated blood loss (EBL) using the SAPHE Mat was compared to the blood loss estimated based on the weight of the SAPHE Mat. A flow chart of the research design is provided in Fig. 4.

Statistical Analysis

Data were recorded on paper forms, then entered into Microsoft Excel and analyzed. The mean and range of relevant demographic variables for study participants were calculated. The mean ±95 % Confidence Intervals (CIs) and range of the visual EBL and weight-based blood loss measurement using the SAPHE Mat were calculated. A paired, two-sample *t* test for equality of means was performed to determine whether there was a significant difference between the means of the visual EBL and weight-based SAPHE Mat blood loss measurement. We calculated the mean percent error ±95 % CIs based on the absolute value of the difference of the visual EBL and the weight-based SAPHE Mat blood loss measurement. A correlation coefficient using the Pearson test was calculated to determine the linear dependence between the visual EBL and the weight-based SAPHE Mat blood loss measurement. Univariate regression analysis was performed to estimate the relationship between the visual EBL and weight-based SAPHE Mat blood loss measurement.

Results

Forty-eight patients were recruited from our institution for this study between October 2013 and March 2014. Of the 48 patients recruited, 36 gave birth via spontaneous vaginal delivery using the SAPHE Mat. The other 12 enrolled subjects did not give birth with the SAPHE Mat secondary to need for caesarean section or operative vaginal delivery, precipitous delivery, or the principal investigator not being available at time of delivery. Operative vaginal delivery was excluded because the patient was not in adequate positioning for use of the SAPHE Mat. Patients were recruited until the last SAPHE Mat available was used. Patient demographics were obtained from the medical record. All 36 patients who gave birth with the SAPHE Mat identified themselves as Hispanic/Latino which is reflective of the obstetric patient population at our hospital where over 70 % of the patients identify themselves as Hispanic/Latino. Table 1 summarizes the mean demographic information of study subjects giving birth with use of the SAPHE Mat.

As shown in Table 2, the mean difference between the visual estimation using the SAPHE Mat and the weight-based blood loss measurement was 81 mL (range: 7–281 mL).

Table 2 depicts the correlation coefficient between these two study measures which was determined to be significant (0.96, $p < 0.0001$). Figure 5 shows the visual EBL vs weight-based blood loss measurements for all 36 subjects. The coefficient of determination (R^2) 0.905 was linear showing minimal variance. The visual SAPHE Mat estimations were within 100 mL of the weight-based blood loss measurement in 69 % of cases and within 200 mL in 97 % of cases.

Discussion

This pilot study suggests that the SAPHE Mat may be a useful tool in the estimation of maternal blood loss following delivery. The study demonstrates that a visual

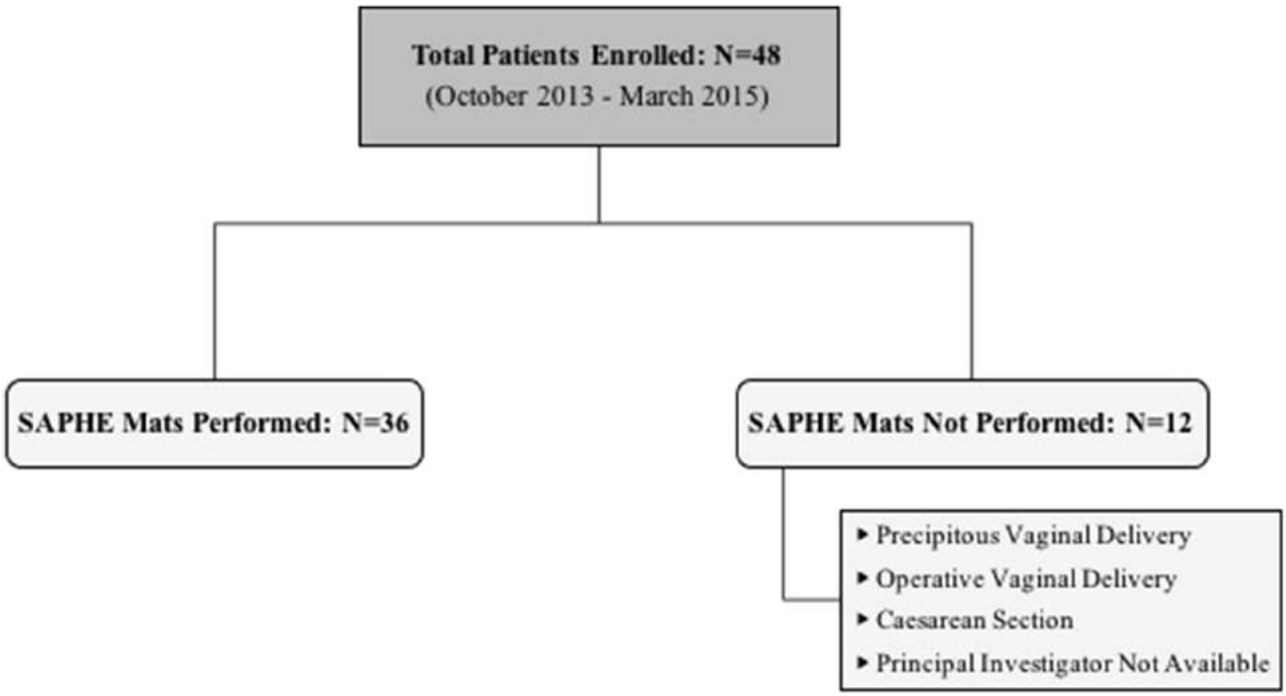

Fig. 4 Research design

Table 1 Study demographics

N = 36	Mean
Age (years)	27.1
Gravida	2.7
Parity	2.5
Degree of laceration (0–4)	1.1
Body mass index (BMI)	41.3
Weight (kg)	72.5

estimate of blood loss using the SAPHE Mat is highly correlated with the actual blood loss measured by weighing the Mat before and after delivery. Using the SAPHE Mat's known absorbency and grid like structure, the Mat has the potential to provide a simple, rapid, and accurate method to estimate blood loss during delivery.

The risk factors for postpartum hemorrhage include but are not limited to: multiparity, multiple gestation, polyhydramnios, coagulation abnormalities, prolonged labor, and vaginal lacerations. However, not every woman who has risk factors will develop a postpartum hemorrhage. It is important therefore to know which patients are at risk and to look for signs and symptoms of postpartum hemorrhage so that diagnosis can be made rapidly. Often the acute care that is needed, such as medications (oxytocin and misoprostol), medical equipment (balloon catheters for atony), and functioning theatres with trained personnel is not widely available, especially in low-resource settings. Unfortunately, there are frequently delays in providing appropriate care to women with postpartum hemorrhage due to an inability to accurately estimate blood loss appropriately and some individuals die as a result (Prasertcharoensuk et al. 2000).

Table 2 Mean difference of estimated and weight-based blood loss

	Mean (SD) (mL)	95 % Confidence interval (±) (mL)	Minimum (mL)	Maximum (mL)	Correlation coefficient (mL)	*p* value (mL)
Visual SAPHE Mat estimated blood loss (EBL)	347 (46.6)	90	100	1375	–	–
Weight-based SAPHE Mat blood loss measurement	283 (40.3)	79	57	1094	–	–
Absolute value of difference between visual EBL and weight-based blood loss measurement	81 (11.2)	22	7	281	0.96	<0.0001

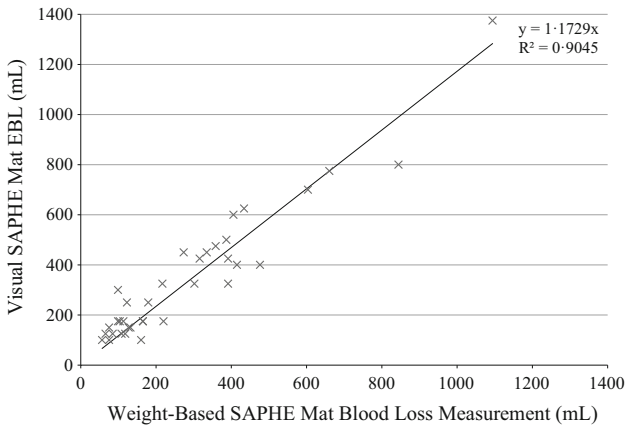

Fig. 5 Coefficient of determination

Prior to initiation of this pilot study we conducted a preliminary survey of both lay people and medical personnel to determine the accuracy of visual estimation of blood volume using the SAPHE Mat. The online survey was distributed to 166 people. Before beginning estimation, participants were given a 5 min online tutorial explaining how to estimate blood loss using the SAPHE Mat and shown pictorial examples of how to estimate fully- and partially-saturated squares, similar to those on the SAPHE Mat Manual (Fig. 2). Participants were asked to view and estimate blood loss for pictures in which a known amount of blood had been poured onto a SAPHE Mat, a regular chux pad, and a chux pad with drawn gridlines. Participants were more accurate in blood loss estimation (within 100 mL of actual blood loss volume) using the SAPHE Mat (95.13 % of the time) compared to the chux with grid lines (83.16 %, $p = 0.001$) or chux pad alone (46.64 %, $p < 0.00001$). This initial survey validated the ability to use the SAPHE Mat for visual estimation of blood loss and led to use of the Mat for our pilot study.

The results of this pilot study support the hypothesis that a device like the SAPHE Mat could be used by health care professionals in rural communities and in low-resource settings to more easily and accurately estimate blood loss following a vaginal delivery. In many low-resource settings, there are no standardized protocols for estimating blood loss following a vaginal delivery. Oftentimes, cloth bags and garbage bags are placed under the patient during delivery and there is no way to accurately estimate blood loss (Al Kadri et al. 2011; Razvi et al. 1996; Lilley et al. 2015). Without a trained health worker or proper resources available for blood testing, diagnosis of PPH may not be made until the woman shows obvious symptoms, such as unconsciousness, at which point intervention is often too late (American College of Obstetricians and Gynecologists 2006). Vital signs that are taken during delivery may be unreliable after more than 1500 mL of blood is lost and physiological compensatory mechanisms of pregnancy and postpartum may mask decompensation until late in hypovolaemic shock (American College of Obstetricians and Gynecologists 2006, Nathan et al. 2015). Results of this study suggest that visual estimations based on the SAPHE Mat allow providers to estimate blood loss to within 100–200 mL which compares favorably to other methods (chux pad, cloth, etc.). By accurately estimating blood loss, communities and birth attendants would be able to more effectively and quickly diagnose PPH. Immediate estimation would allow for more timely and appropriate allocation of medication such as misoprostol and oxytocin and also for more efficient referral to a higher level care facility where available.

Currently, SAPHE Mats are manufactured by hand, requiring about 2 h to produce each Mat, thus limiting the number of Mats available for our study. Efforts are underway to improve manufacturing. The cost of materials to manufacture a single Mat at production volumes of 1–50 Mats is just under 5 USD. We estimate that the materials cost could be reduced to 0.50–2.50 USD per Mat at higher production volumes. This reduced cost of the SAPHE Mat may ultimately be of similar price to a 600 μg dose of misoprostol (about 1 USD) used for primary prevention of PPH (Creinin et al. 2005), suggesting the Mat may be a cost-effective strategy, especially if accurate measurement by the SAPHE Mat prevents inappropriate usage of misoprostol or uterine contracting agents.

Community based approaches for the treatment and prevention of postpartum hemorrhage have been explored (Dabash et al. 2012). One strategy has been suggested for universal treatment with misoprostol at time of delivery which has not been seen to be cost effective. Another strategy that has been suggested involves secondary prevention where a threshold of an estimated blood loss of 350 mL could be used to administer misoprostol treatment (Raghavan et al. 2015). Universal prophylaxis for 1000 deliveries would use 3000 pills whereas secondary prevention would use 480 pills for 1000 deliveries. The cost savings would cover the cost of the Mats which could assist the provider in determining when to administer the misoprostol. Furthermore, accurate blood loss measurement also prevents inappropriate usage of misoprostol, which has been shown to have serious iatrogenic effects when used inappropriately (Nelson et al. 2013).

Our study has several limitations, including a small sample size based on availability of SAPHE Mats. Only six of the 36 participants in the study had a weight-based blood loss measurement of over 500 mL (ranging from 505 to 1036 mL) which would be considered a postpartum hemorrhage. Though the visual EBL and weight-based blood loss measurement was highly correlated, for all six of these subjects it would be beneficial to know if the correlation

would remain as strong at higher volumes of blood loss, with women with low BMIs, or with women with documented anemia. This data would be particularly interesting as numerous studies have shown that higher measured blood loss is associated with greater visual underestimation (Stafford et al. 2008). It has also been shown in previous studies that the amount of blood loss after a spontaneous vaginal delivery exponentially increases with the degree of vaginal laceration (Leveno et al. 2003). The majority of our subjects had a first degree laceration. It should be noted that degrees of perineal laceration after a vaginal delivery can vary based on a specific population's risk factors. In a large multi-country study performed in developing nations, the prevalence of third and fourth degree lacerations was noted to be 0.1–1.4 %, making this a rare event. The risk factors for these high grade lacerations were the same as those in developed nations, including operative vaginal delivery, multiparity, and increased birthweight. Therefore, with a larger sample size we might have had an increased number of higher degree lacerations and thus increased blood loss. However, because of the rarity of these lacerations, it may not affect the overall data (Hirayama et al. 2012).

Our study was conducted in a county hospital in the United States with trained healthcare professionals and essential resources present which poses a limitation to extrapolating the performance of the SAPHE Mat in low-resource settings with untrained birth attendants. Although the SAPHE Mat was designed to be an accurate, easy-to-use and low-cost solution to the challenge of estimating blood loss during delivery, further work is needed to compare its performance to that of other similar solutions such as the International Centre for Diarrhoeal Disease Research, Bangladesh (ICDDRB) blood mat (Prata et al. 2012) and kanga (Prata et al. 2005). As with these devices, there is a minimal amount of training necessary to use the SAPHE Mat, however the Mat is slightly more sophisticated as it requires counting and simple visual estimation. While we have demonstrated the accuracy of the SAPHE Mat in a high-resource setting, we recognize that translating its use to a low-resource setting requires more work to identify the most appropriate cadres of health care workers and to establish its accuracy in their hands.

It should be noted that the blood collected on the SAPHE Mat does not always capture the total postpartum blood loss. The Mat was kept in place during the delivery of the placenta and throughout any laceration repair and was removed prior to cleaning of the patient at the end of the delivery. Several patients were noted to have passed clots with application of fundal massage up until one to 2 h post-delivery when the Mat was not in place. This blood loss was therefore not accounted for when the Mat was weighed or a visual estimate was taken.

Though we tried to control for substances that might increase the weight of the Mat such as amniotic fluid and meconium/fecal matter by using the overlying chux pad, it was impossible to completely eliminate this as a factor. Therefore, the difference between the visual EBL and weight-based blood loss measurement may have been significantly smaller if we were able to completely control for this variable. Additionally, we recognize that those squares under 50 % are not counted, which may seem like a source of underestimation. The majority of squares are either more than 50 % filled and counted or are less than 25 % filled and not counted. Thus, the number of squares that are less than 50 % filled are negligible to the overall total estimation of blood loss. The design of the squares in the Mat is intentionally staggered, as a result blood applied to the Mat tends to saturate a square more than 50 % before flowing to the next square. From our testing of the absorptive capacity of the mat, we estimate that the error in measurement attributable to <50 % filled squares is less than 100 mL of blood.

In conclusion, results of this small pilot study conducted in a high-resource setting suggest that the SAPHE Mat may provide a useful tool to improve estimation of blood loss during delivery and thus may lead to more timely diagnosis of postpartum hemorrhage. Together with appropriate interventions, this may contribute to decreased maternal morbidity and mortality. We recommend that further studies be undertaken to assess the SAPHE Mat's efficacy in diagnosing and managing postpartum hemorrhage cases as well as its implementation in low-resource settings where risk of maternal death associated with postpartum hemorrhage is high.

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Compliance With Ethical Standards

Conflict of Interest There are no conflicts of interest to disclose.

Ethics Committee Approval The study was approved by the Institutional Review Boards of Baylor College of Medicine, the Harris Health System, and Rice University.

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