ORIGINAL RESEARCH

The Effect of the Thickness of Uterine Muscle at Placenta Attachment on Postpartum Blood Loss

Hongzhu Zhong, BM; Mingxue Zu, MM; Yinfeng Xie, BM; Yueqin Huang, BM

ABSTRACT

Objective • This study aimed to investigate the relationship between the thickness of the uterine muscle layer at placenta attachment and postpartum hemorrhage, and to evaluate the predictive value of this thickness in identifying high-risk patients. It provides a theoretical basis for early identification and screening of pregnant women at high risk of postpartum hemorrhage, and reduces the occurrence of serious complications of postpartum hemorrhage.

Method • A total of 378 pregnant women admitted to the Second People's Hospital of Shantou City from January to December 2021 were enrolled in this study. High-risk patients were defined as those with a uterine muscle layer thickness at placenta attachment greater than 2.5 cm, as measured by transabdominal ultrasound. Postpartum blood loss and hemoglobin changes were measured before and after delivery. Stratified analysis was conducted based on various patient characteristics, and the predictive value of the thickness was determined using ROC curve analysis. By providing the specific criteria for defining high-risk patients, readers can better understand the methodology used in this study.

Results • The linear regression analysis showed a significant negative correlation between the thickness of the uterine muscle layer at placenta attachment and postpartum blood loss at 2 hours (t value = -6.9848, P = 1.33E-11 < .05). There was also a significant negative correlation between the thickness and hemoglobin changes before and after delivery (t value = -2.242, P = .026 < .05). These findings indicate a robust association between uterine muscle layer thickness and both postpartum blood loss and hemoglobin changes. ROC curve analysis revealed that the thickness of the uterine muscle layer at placenta attachment had predictive value for postpartum hemorrhage. This suggests that measuring the thickness of the uterine muscle layer can serve as a reliable predictor for identifying women at risk of postpartum hemorrhage. Additionally, stratified analysis showed that the thickness had significant predictive value in certain subgroups of patients.

Conclusion • The findings of this study demonstrate that the thickness of the uterine muscle layer at placenta attachment is a critical indicator for predicting postpartum hemorrhage. Specifically, the study shows a robust negative correlation between uterine muscle layer thickness and postpartum blood loss, as well as significant predictive value for identifying high-risk patients for postpartum hemorrhage. These results have important practical implications for clinical practice. With early identification of high-risk groups based on uterine muscle layer thickness measurements, clinicians can implement interventions to reduce the incidence and severity of postpartum hemorrhage, which may lead to improved patient outcomes and reduced healthcare costs. Overall, this study provides a theoretical basis for the development of targeted prevention strategies and risk management protocols, which may help reduce serious complications of postpartum hemorrhage and improve maternal and neonatal health. (*Altern Ther Health Med.* 2024;30(6):110-121).

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INTRODUCTION

Postpartum haemorrhage (PPH) is a serious complication of labor and delivery, with an incidence of approximately 5-10% and a mortality rate of 0.5-1%.[1] In recent years, the liberalization of the "second" and "third" child policies has led to an increase in the number of pathological obstetric cases, increasing the incidence of PPH. This trend has made preventing and treating PPH an unprecedented challenge.[1]

A significant proportion of deaths due to PPH can be attributed to a lack of standardization in assessing bleeding volume. Clinically assessing bleeding volume through visual inspection underestimates the actual bleeding volume, and effective countermeasures are often not taken in time. By the time haemodynamic abnormalities are detected, it may already be too late. Identifying pregnant women at risk of PPH prior to delivery is crucial, as early intervention and timely prognosis would result in fewer PPH cases and maternal deaths.[2]

Risk factors for PPH and its four main causes, including weak uterine contractions, soft birth canal lacerations, placental factors, and coagulation abnormalities, have been relatively well studied, and the mechanisms of action and countermeasures are well understood both nationally and internationally.[2,3] However, few studies have investigated the effect of placental attachment on the thickness of the myometrium and its correlation with PPH. By exploring the potential correlation between thinner myometrium at the placenta and a higher incidence of PPH, our study addresses a critical knowledge gap in the field. The findings from this research could contribute to a better understanding of the complex mechanisms underlying PPH development and potentially provide clinicians with a valuable tool for identifying individuals at higher risk. Overall, this study adds to the existing literature by highlighting the significance of investigating the impact of placental attachment on myometrial thickness in the context of PPH. It underscores the need for further research in this area to advance our understanding of PPH etiology and improve patient care strategies. In the author's clinical experience over the years, thinner myometrium at the placenta has been associated with a higher incidence of PPH. While the existing literature highlights various risk factors and causes of postpartum hemorrhage (PPH), my clinical experience over the years has led me to investigate the potential impact of myometrial thickness at placental attachment on the incidence of PPH. In my practice, I have observed that patients with thinner myometrium at the placenta tend to have a higher likelihood of developing PPH, even in the absence of other known risk factors. This personal insight has highlighted a potential research gap and the need to investigate this association more rigorously. If there is indeed a significant correlation between myometrial thickness and PPH, identifying this marker could help clinicians better identify high-risk patients and implement targeted prevention strategies. Therefore, this study aims to build on my clinical experience and investigate the hypothesis that a negative correlation exists between the thickness of the uterine muscle layer at placenta attachment and the incidence of PPH.

This study aims to investigate the relationship between the thickness of the myometrium at the placenta and the amount of PPH by measuring it via ultrasound before delivery. Predicting the amount of PPH using this method will enable the identification of pregnant women at high risk of PPH early, and a personalized PPH prevention program could be implemented for pregnant women at high risk before delivery. This could help reduce the incidence of PPH and its serious complications. The research in this paper can be used to predict the risk of childbirth and postpartum recovery of pregnant women, can effectively optimize the personnel allocation, blood volume allocation, equipment preparation, etc., in the process of childbirth, and can alleviate the tension of blood volume and personnel in hospitals.

MATERIALS AND METHODS

Study subjects

A cohort of 378 pregnant women with an average gestational age of 38.5 ± 0.8 weeks and an average age of 28.67 ± 3.8 years were selected from those admitted to Shantou Second People's Hospital from January to December 2021.To prioritize patient confidentiality, strict measures were implemented. All data collected during the study were anonymized, with any identifying information removed or coded to ensure participant privacy. Confidentiality agreements were signed by all research team members involved in data handling, ensuring the secure storage and restricted access to participant information. By following these ethical practices, we aimed to protect the rights and welfare of the participants and maintain the highest standards of research integrity throughout the study. To ensure the study's focus on myometrial thickness and its correlation with postpartum hemorrhage (PPH), specific exclusion criteria were applied. Participants meeting any of the following criteria were excluded from the study: Severe hematological disorders that could cause abnormal coagulation, Placental implantation abnormalities or placental abruption, Uterine anomalies, including congenital or acquired structural abnormalities. The implementation of these exclusion criteria aimed to streamline the study population and minimize confounding factors that could potentially influence the association between myometrial thickness and PPH. By excluding individuals with these specific conditions, the study sought to create a more homogeneous sample for analysis, enhancing the validity and reliability of the findings.

Methodology

The primary ultrasound device employed in the study was a Philips EPIQ5 equipped with a high frequency probe (5-12 MHz) to measure the thickness of the myometrium at the site of placental attachment within a time frame of 1-5 days before delivery. The patient was positioned supine, and fetal and umbilical cord examinations were performed before assessing the placenta's size, thickness, and location and measuring the thickness of the myometrium at the attachment point.

In order to measure postnatal bleeding, the following procedures were employed: (1) For vaginal deliveries, a blood collection basin was placed under the mother's buttocks to collect blood after delivery of the placenta. Additionally, the amount of blood in the nursing pad used for 2 hours after the procedure was included in the calculation of bleeding. (2)If the baby was delivered via cesarean section, the posterior amniotic fluid was aspirated promptly after delivery, and the blood bag was replaced in the negative pressure aspirator. The bleeding volume was calculated by weighing the blood-

Table 1. Table of linear regression parameters

term	estimate	std.error	statistic	*P* value	2.50%	97.50%
(Intercept)	405.7116	24.04982	16.86963	9.13E-48	358.4201	453.0031
`Uterine muscle thickness`	-41.7311	5.974556	-6.9848	1.33E-11	-53.4794	-29.9827

soaked gauze and the amount of blood in the nursing pad within 2 hours after delivery. (3) Haemoglobin testing was conducted before and after delivery by taking venous blood 1-5 days before delivery and 1 day after delivery to determine the haemoglobin value.

Statistical analysis

Linear regression models were fitted to establish linear relationships between specific variables. In addition to linear regression, other statistical tests and adjustments were performed to further analyze the data. These may have included t-tests, chi-square tests, or controlling for potential confounders. Please provide more details about the specific tests and adjustments conducted. The statistical analysis was conducted using R software, version 4.2.2. Including the specific software version ensures transparency and reproducibility of the analysis. The availability of the data used in this study should be clearly mentioned. Please state whether the data will be made accessible to other researchers upon request or if it will be deposited in a publicly accessible data repository. Throughout the section, ensure that consistent and appropriate units of measurement (e.g., weeks, years, mm, mL, g) are consistently used to avoid any confusion or ambiguity.

RESULTS

Linear Regression Analysis of Postpartum Hemorrhage and Myometrial Thickness at Placenta Attachment Site

A linear regression analysis was conducted to investigate the association between the amount of postpartum haemorrhage and the thickness of the uterine muscle at the site of placental attachment. The results in Table 1 indicated a significant effect of myometrial thickness at the placental attachment on postpartum haemorrhage, as evidenced by a *t* value of -6.9848 and a $P = 1.33E-11 < .05$. The linear regression model was examined for assumptions, and the results were presented in Figure 1. The plot of Residuals vs. Fitted showed a linear relationship, Normal Q_Q plot showed that the residuals were normally distributed, Scale-Location plot showed homoscedasticity, and Residuals vs. Leverage plot indicated no outliers. Furthermore, Figure 2 illustrated the linear relationship between postpartum haemorrhage and uterine muscle thickness at the placental attachment site.

Linear Regression Analysis of Postnatal Haemoglobin Changes and Myometrial Thickness at Placenta Attachment Site

Linear regression was conducted to assess the relationship between postpartum hemoglobin changes and uterine muscle thickness at the placental attachment site. The results showed a statistically significant effect of uterine muscle thickness at the placental attachment on postpartum hemoglobin changes,

Figure 1. Model diagnostic diagram

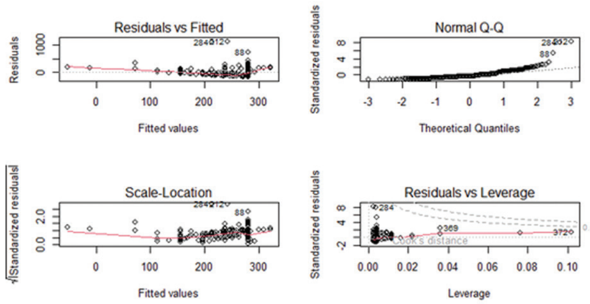


Figure 2. Dot plot illustrating the relationship between bleeding volume and uterine muscle thickness at the placental attachment site. Each dot represents a single patient, with the y-axis indicating the amount of bleeding volume in milliliters (ml) and the x-axis indicating uterine muscle thickness in millimeter (mm). The red line represents the best fit linear regression line. The data show a trend of decreasing bleeding volume with increasing uterine muscle thickness.

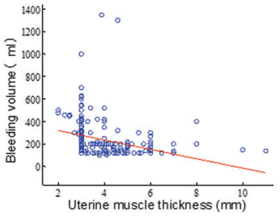


Table 2. Table of linear regression parameters

term	estimate	std.error	statistic	*P* value
(Intercept)	1.558	0.162	9.641	1.436e-19
`Uterine muscle thickness`	-0.09	0.04	-2.242	.026

Table 3. Table of ROC curve parameters

Area	Std. Error[a]	Asymptotic Sig.[b]	Asymptotic 95% Confidence Interval	
			Lower Bound	Upper Bound
0.634	0.039	0.002	.557	.711

[a]under the nonparametric assumption
[b]null hypothesis: true area = 0.5

Figure 3. Scatter plot (change in hemoglobin after delivery). Scatter plot displaying the linear relationship between postpartum hemoglobin changes and uterine muscle thickness at the placental attachment site. The x-axis represents the thickness of the myometrium at the placental attachment site (in millimeters), and the y-axis represents the change in hemoglobin levels from before to after delivery (in grams per deciliter). Each dot represents a participant in the study, and the red line represents the fitted linear regression model.

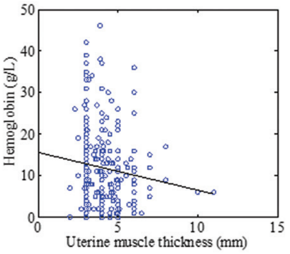


Figure 4. ROC curve for ultrasound measurement of myometrial thickness at placental attachment to predict postpartum haemorrhage. The ROC curve illustrates the sensitivity and specificity of using myometrial thickness at the placental attachment site as a predictor for postpartum haemorrhage. The area under the curve (AUC) is 0.634, with an asymptotic significance of 0.002.

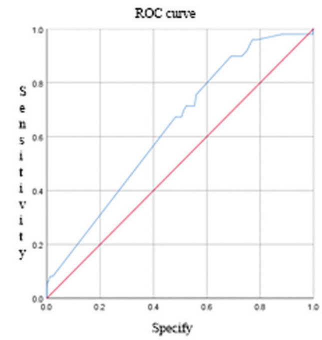


Table 4. Table of linear regression parameters (age ≤ 35 years)

term	estimate	std.error	statistic	*P* value	2.50%	97.50%
(Intercept)	409.6974	24.99823	16.38906	2.73E-45	360.5332	458.8616
\`Uterine muscle thickness\`	-42.5667	6.199781	-6.86584	2.99E-11	-54.7599	-30.3736

Figure 5. Diagnostic plots of linear regression model for postpartum hemorrhage and myometrial thickness at placental attachment in women aged ≤35 years. Residuals vs. Fitted plot (top left) indicates that the linear regression model is appropriate, with residuals randomly distributed around zero. The Normal Q_Q plot (top right) shows that the residuals conform to a normal distribution. The Scale-Location plot (bottom left) demonstrates that the model has homoscedasticity, with residuals equally distributed across the range of fitted values. Residuals vs. Leverage plot (bottom right) shows that there are no outliers that unduly influence the regression analysis.

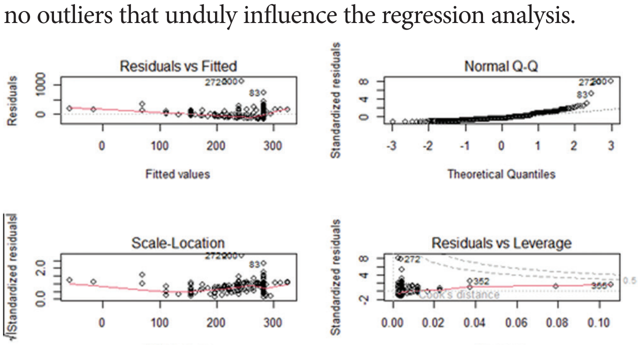


Table 5. Table of linear regression parameters (age > 35 years)

term	estimate	std.error	statistic	*P* value	2.50%	97.50%
(Intercept)	317.8432	60.8196	5.226	.000103	188.2093	447.4771
\`Uterine muscle thickness\`	-22.4501	15.66734	-1.43292	.172393	-55.8442	10.94408

with a *t* value of -2.242 and a *P* = .026 < .05 (Table 2). Figure 3 displays the linear relationship between postpartum hemoglobin changes and uterine muscle thickness at the placental attachment site.

Analysis of ROC Curve for Thickness of Myometrium at Placental Attachment in Predicting Postpartum Hemorrhage

In order to predict postpartum hemorrhage, a ROC curve was constructed for the thickness of the myometrium at the placental attachment, as depicted in Figure 4, and the corresponding parameters shown in Table 3. The analysis yielded an AUC of 0.634 with an asymptotic significance of 0.002, indicating a predictive value of the thickness of the myometrium at the placental attachment in predicting postpartum hemorrhage.

Effect of maternal age on the association between uterine muscle thickness at placental attachment and postpartum haemorrhage

The age of over 35 years is considered advanced maternal age, thus, we stratified the analysis by age, creating two tiers: age ≤35 years and age >35 years. For ages ≤35 years, a linear regression was performed between postpartum haemorrhage and uterine muscle thickness at the placental attachment site (Table 4). The results showed a *t* value of -6.86584 and a *P* = 2.99E-11 < .05, indicating a statistically significant effect of myometrial thickness at the placental attachment on postpartum haemorrhage. Residuals vs. Fitted in Figure 5 indicate that the linear regression satisfies the linear relationship. Normal Q_Q in Figure 5 shows that the model's residuals conform to a normal distribution. Scale-Location in Figure 5 shows that the model has homoscedasticity, and Residuals vs. Leverage in Figure 5 shows that there are no outliers.

For the analysis of women over 35 years of age, a linear regression was conducted to assess the association between postpartum hemorrhage and uterine muscle thickness at the placental attachment site (Table 5). The results revealed a non-significant effect, as indicated by a *t* value of -1.43292 and a *P* = .172393>0.05. Residuals vs. Fitted in Figure 6 show that the linear regression model conforms to a linear relationship, Normal Q_Q in Figure 6 demonstrates that the residuals of the model follow a normal distribution, Scale-Location in Figure 6 indicates that the model has homoscedasticity, and Residuals vs. Leverage in Figure 6 shows that there are no outliers. Figure 7 displays the linear relationship between postpartum hemorrhage and uterine muscle thickness at the placental attachment site, stratified by age.

Linear Regression Analysis of Postpartum Hemorrhage and Uterine Muscle Thickness Stratified by Delivery Time

The analysis was stratified by mode of delivery, with one tier for cesarean delivery, one tier for labor lasting less than 10 hours, and one tier for labor lasting 10 hours or longer. A linear regression was performed on postpartum haemorrhage and uterine muscle thickness at the placental attachment site for deliveries by cesarean section. The results in Table 6 indicated a *t* value of -6.47321 and a *P* = 2.90E-09 < .05, signifying a statistically significant effect of placenta-attached uterine muscle thickness on postpartum haemorrhage. Residuals vs. Fitted in Figure 8 showed that the linear

Figure 6. Diagnostic plots for linear regression of postpartum hemorrhage on uterine muscle thickness at placental attachment site in women aged over 35 years. Residuals vs. Fitted plot shows that the model satisfies the linear relationship assumption. Normal Q-Q plot indicates that the residuals of the model follow a normal distribution. Scale-Location plot demonstrates that the model has homoscedasticity, which means that the variance of the residuals is constant across the range of predicted values. Residuals vs. Leverage plot shows that there are no outliers, suggesting that no individual observation is having a disproportionate influence on the regression results.

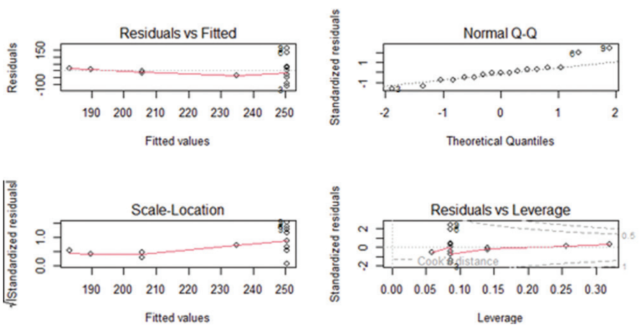
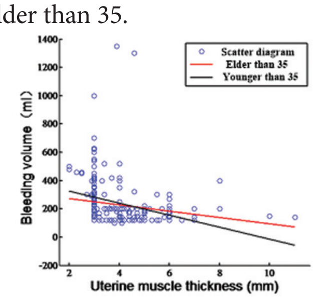


Figure 7. Linear relationship between postpartum hemorrhage and uterine muscle thickness at the placental attachment site, stratified by age. The x-axis shows the thickness of the uterine muscle at the placental attachment site, and the y-axis shows the amount of postpartum hemorrhage. The black line represents the linear regression line for women aged 35 or younger, and the red line represents the linear regression line for women older than 35.



regression fulfilled the linear relationship; Normal Q_Q in Figure 8 demonstrated that the residuals of the model followed a normal distribution; Scale-Location in Figure 8 indicated that the model exhibited homoscedasticity; Residuals vs. Leverage in Figure 8 demonstrated that there were no outliers. A linear regression analysis showed that a bleeding volume of 500 ml at 2 hours postpartum was associated with a myocardial thickness of 2.78 mm.

In the case of labor lasting less than 10 hours, a linear regression was conducted to investigate the relationship between postpartum hemorrhage and the thickness of the uterine muscle at the placental attachment site (Table 7). The findings revealed a *t* value of -4.16887 and a P = .32E-05 < .05, indicating a statistically significant effect of the thickness of the uterine muscle at the placental attachment site on the amount of postpartum hemorrhage. Residuals vs. Fitted in

Table 6. Table of linear regression parameters (cesarean delivery)

term	estimate	std.error	statistic	*P* value	2.50%	97.50%
(Intercept)	538.8124	36.26598	14.85724	7.31E-28	466.927	610.6979
\`Uterine muscle thickness\`	-58.919	9.101965	-6.47321	2.90E-09	-76.9606	-40.8773

Figure 8. Residuals vs. Fitted (top left) demonstrated that the linear regression model fulfilled the linear relationship assumption; Normal Q_Q (top right) showed that the residuals of the model followed a normal distribution; Scale-Location (bottom left) indicated that the model exhibited homoscedasticity; Residuals vs. Leverage (bottom right) demonstrated that there were no outliers.

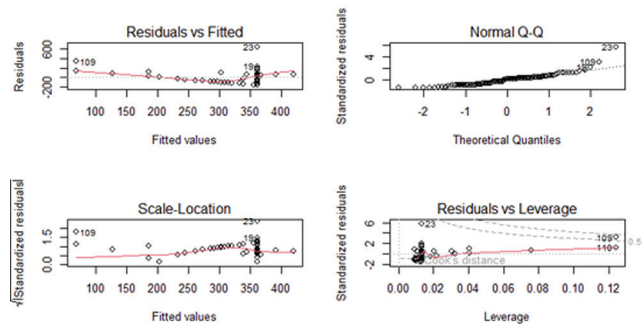


Table 7. Table of linear regression parameters (for birth <10 h)

term	estimate	std.error	statistic	*P* value	2.50%	97.50%
(Intercept)	337.7016	30.70302	10.99897	6.39E-23	277.2093	398.194
\`Uterine muscle thickness\`	-31.4398	7.541557	-4.16887	4.32E-05	-46.2984	-16.5811

Figure 9. Diagnostic diagram of the model (labour <10 h). Residuals vs. Fitted (top left) demonstrated that the linear regression model fulfilled the linear relationship assumption; Normal Q_Q (top right) showed that the residuals of the model followed a normal distribution; Scale-Location (bottom left) indicated that the model exhibited homoscedasticity; Residuals vs. Leverage (bottom right) demonstrated that there were no outliers.

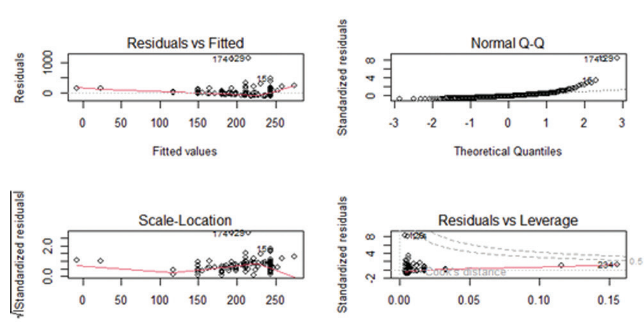


Figure 9 illustrate that the linear regression model satisfies the linear relationship; Normal Q_Q in Figure 9 indicates that the residuals of the model follow a normal distribution; Scale-Location in Figure 9 suggests that the model has homoscedasticity; and Residuals vs. Leverage in Figure 9 indicates that there are no outliers present.

When labor was ≥10h, a linear regression analysis was conducted to examine the association between postpartum

Table 8. Table of linear regression parameters (≥10 h of delivery)

term	estimate	std.error	statistic	*P* value	2.50%	97.50%
(Intercept)	424.5489	69.26793	6.129084	1.77E-06	282.1667	566.9312
\`Uterine muscle thickness\`	-55.6817	18.258	-3.04971	0.005215	-93.2115	-18.1518

Figure 10. Diagnostic diagram of the model (labour ≥10 h). Residuals vs. Fitted (top left) demonstrated that the linear regression model fulfilled the linear relationship assumption; Normal Q_Q (top right) showed that the residuals of the model followed a normal distribution; Scale-Location (bottom left) indicated that the model exhibited homoscedasticity; Residuals vs. Leverage (bottom right) demonstrated that there were no outliers.

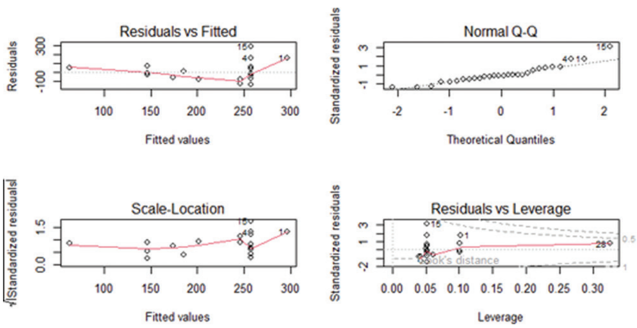


Table 9. Table of linear regression parameters (neonatal weight <2.5 kg)

term	estimate	std.error	statistic	*P* value	2.50%	97.50%
(Intercept)	511.0678	107.6954	4.745494	.00011	287.103	735.0327
\`Uterine muscle thickness\`	-67.4543	27.6891	-2.43613	.023837	-125.037	-9.87166

Figure 12. Model diagnostic chart (neonatal weight <2.5 kg). The figure presents four diagnostic plots for a linear regression analysis. The Residuals vs. Fitted plot confirms the linearity assumption, while the Normal Q-Q plot demonstrates the normality of residuals. The Scale-Location plot indicates that the assumption of homoscedasticity is met, and the Residuals vs. Leverage plot shows no outliers in the model.

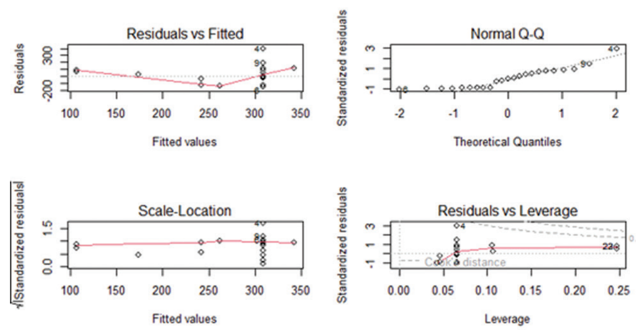
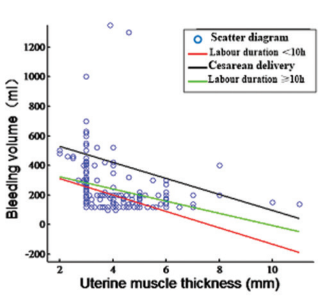


Figure 11. A scatterplot with regression lines showing the linear relationship between postpartum haemorrhage and uterine muscle thickness at the placental attachment site, stratified by total labour duration. The x-axis represents uterine muscle thickness at the placental attachment site, and the y-axis represents postpartum haemorrhage. Each point on the graph represents an individual patient. The red line represents the regression line for labour duration <10 h, the green line represents the regression line for labour duration ≥10 h, and the dark line represents the regression line for caesarean delivery. The figure demonstrates the relationship between postpartum haemorrhage and uterine muscle thickness at the placental attachment site in different modes of delivery and labour durations.



haemorrhage and myometrial thickness at placental attachment (Table 8). The results indicated a statistically significant effect of placenta-attached uterine muscle thickness on the amount of postpartum haemorrhage, with a *t* value of -3.04971 and a $P = 0.005215 < .05$. Residuals vs. Fitted in Figure 10 shows that the linear regression satisfied the linear relationship; Normal Q_Q in Figure 10 demonstrated that the residuals of the model followed a normal distribution; Scale-Location in Figure 10 indicated that the model exhibited homoscedasticity; and Residuals vs. Leverage in Figure 10 showed that there were no outliers. Figure 11 presents the linear relationship between postpartum haemorrhage and uterine muscle thickness at placental attachment when stratified by total labor.

Linear Regression Analysis of Postpartum Hemorrhage and Uterine Muscle Thickness at the Placental Attachment Site Stratified by Neonatal Weight

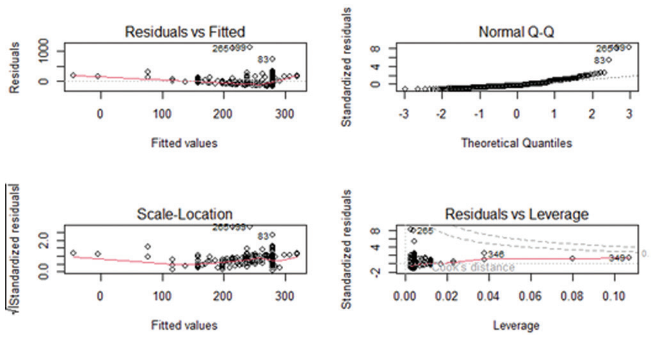
The weight of a newborn typically falls within the range of 2.5-4 kg, with fewer instances of newborns weighing more than 4 kg in the original data set. Stratification by neonatal weight was performed with two levels, one for neonates weighing <2.5 kg and one for those weighing ≥2.5 kg. For neonates weighing <2.5 kg, a linear regression was conducted between postpartum haemorrhage and uterine muscle thickness at the placental attachment site (Table 9). The results revealed a *t* value of -2.43613 and a *P* value of $0.023837 < .05$, indicating a statistically significant effect of placenta-attached uterine muscle thickness on postpartum haemorrhage. Residuals vs. Fitted in Figure 12 confirms that the linear regression conforms to the linear relationship, while Normal Q_Q in Figure 12 demonstrates that the model's residuals adhere to a normal distribution. The Scale-Location plot in Figure 12 indicates that the model exhibits homoscedasticity, and the Residuals vs. Leverage plot shows that there are no outliers.

In the present study, a linear regression was conducted to examine the relationship between postpartum haemorrhage and uterine muscle thickness at the placental attachment for neonates with a weight ≥2.5 kg (Table 10). The analysis revealed a *t* value of -6.59046 and a $P = 1.63E\text{-}10 < .05$,

Table 10. Table of linear regression parameters (neonatal weight ≥ 2.5 kg)

term	estimate	std.error	statistic	*P* value	2.50%	97.50%
(Intercept)	399.9213	24.71895	16.17873	2.88E-44	351.3034	448.5391
\`Uterine muscle thickness\`	-40.3823	6.127394	-6.59046	1.63E-10	-52.4339	-28.3308

Figure 13. Model diagnostic chart (neonatal weight ≥ 2.5 kg). The Residuals vs. Fitted plot confirms the linearity assumption, while the Normal Q-Q plot demonstrates the normality of residuals. The Scale-Location plot indicates that the assumption of homoscedasticity is met, and the Residuals vs. Leverage plot shows no outliers in the model.

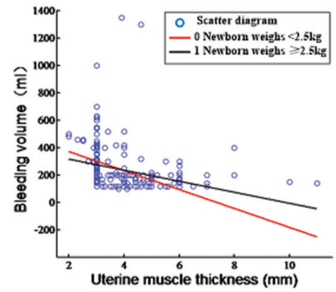


indicating a statistically significant impact of uterine muscle thickness at the placenta attachment site on postpartum haemorrhage. The Residuals vs. Fitted plot in Figure 13 confirmed that the linear regression satisfied the linear relationship assumption. In contrast, the Normal Q_Q plot in Figure 13 demonstrated that the model's residuals followed a normal distribution. The Scale-Location plot in Figure 13 indicated that the model exhibited homoscedasticity, and the Residuals vs. Leverage plot showed no outliers. Additionally, Figure 14 displays the linear relationship between postpartum haemorrhage and uterine muscle thickness at placental attachment when stratified by neonatal weight.

Linear Regression Analysis of Postpartum Hemorrhage and Uterine Muscle Thickness at Placental Attachment Stratified by Maternal Weight

In the study, the median maternal weight was determined to be 64 kg. The data were then stratified based on maternal weight, with those having maternal weight <64 kg in one stratum and those with maternal weight ≥64 kg in another. Linear regression analysis was performed on postpartum haemorrhage and uterine muscle thickness at the placental attachment site for those with maternal weight <64 kg. The statistical results (Table 11) showed a *t* value of -5.25922 and a P = 4.16E-07 < .05, indicating a statistically significant relationship between the placenta-attached uterine muscle thickness and the amount of postpartum haemorrhage. Additionally, Residuals vs. Fitted in Figure 15 displays the conformity of the linear regression to the linear relationship, Normal Q_Q in Figure 15 exhibits the normal distribution of the model's residuals, Scale-Location in Figure 15 shows that the model has homoscedasticity, and Residuals vs. Leverage in Figure 15 confirms the absence of outliers.

Figure 14. A linear relationship between postpartum haemorrhage and uterine muscle thickness at the placental attachment site when stratified by neonatal weight. The figure provides a scatterplot with regression lines for neonates weighing less than 2.5 kg and those weighing 2.5 kg or more. The x-axis represents the thickness of the uterine muscle at the placental attachment, while the y-axis displays the amount of postpartum haemorrhage. The regression lines demonstrate the relationship between these two variables, with their slopes and intercepts varying based on neonatal weight stratification.



Note: When Infant weight is 0, the newborn weighs ≥2.5 kg; when Infant weight is 1, the newborn weighs <2.5 kg.

Figure 15. Model diagnostic chart (maternal weight <64 kg). The Residuals vs. Fitted plot confirms the linearity assumption, while the Normal Q-Q plot demonstrates the normality of residuals. The Scale-Location plot indicates that the assumption of homoscedasticity is met, and the Residuals vs. Leverage plot shows no outliers in the model.

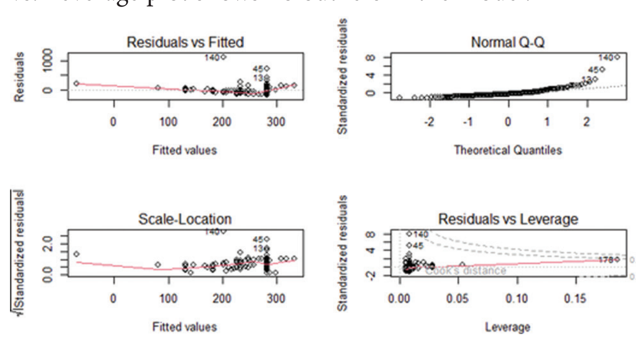


Table 11. Table of linear regression parameters (maternal weight < 64 kg)

term	estimate	std.error	statistic	*P* value	2.50%	97.50%
(Intercept)	433.3088	37.77628	11.47039	4.22E-23	358.756	507.8616
\`Uterine muscle thickness\`	-50.3095	9.565967	-5.25922	4.16E-07	-69.1883	-31.4307

Table 12. Table of linear regression parameters (maternal weight ≥ 64 kg)

term	estimate	std.error	statistic	*P* value	2.50%	97.50%
(Intercept)	387.5571	31.08582	12.46732	1.60E-26	326.2435	448.8706
\`Uterine muscle thickness\`	-35.9139	7.592708	-4.73006	4.34E-06	-50.8898	-20.9381

A linear regression analysis was further conducted to investigate the relationship between postpartum haemorrhage and myometrial thickness at the placental attachment site in women with maternal weight ≥64 kg. The results showed a statistically significant effect of placenta-attached uterine muscle

Figure 16. Model diagnostic chart (maternal weight ≥ 64 kg). The Residuals vs. Fitted plot confirms the linearity assumption, while the Normal Q-Q plot demonstrates the normality of residuals. The Scale-Location plot indicates that the assumption of homoscedasticity is met, and the Residuals vs. Leverage plot shows no outliers in the model.

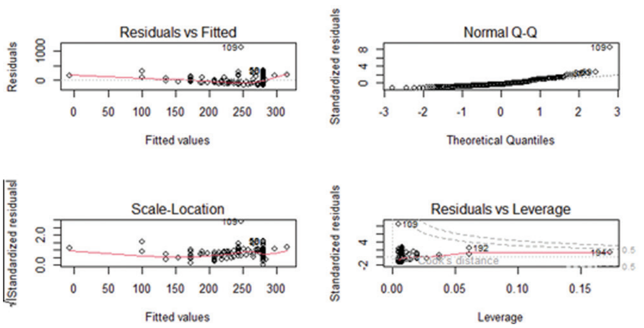


Figure 17. A scatterplot illustrates the linear relationship between postpartum hemorrhage and uterine muscle thickness at the placental attachment site, stratified by maternal weight. The x-axis represents the thickness of the uterine muscle at the placental attachment, while the y-axis displays the amount of postpartum haemorrhage. The red line represents maternal weight is <64 kg and the dark line represents maternal weight is ≥64 kg.

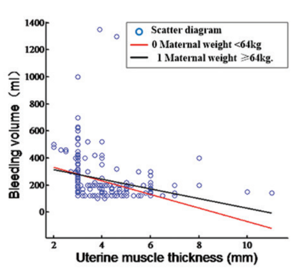


Table 13. Table of linear regression parameters (scarred uterus)

term	estimate	std.error	statistic	*P* value	2.50%	97.50%
(Intercept)	411.6695	53.65646	7.672318	7.81E-09	302.5046	520.8344
\`Uterine muscle thickness\`	-35.5334	11.89641	-2.9869	0.005282	-59.7368	-11.3299

thickness on postpartum haemorrhage, with a t-value of -4.73006 and a $P = 4.34E\text{-}06 < .05$ (Table 12). Residuals vs. Fitted in Figure 16 confirms that the linear regression satisfies the linear relationship, while Normal Q_Q in Figure 16 demonstrates that the residuals of the model adhere to a normal distribution. The Scale-Location plot in Figure 16 indicates that the model exhibits homoscedasticity, and the Residuals vs. Leverage plot shows that there are no outliers. Furthermore, Figure 17 displays the linear relationship between postpartum haemorrhage and uterine muscle thickness when stratified by maternal weight at the placental attachment site.

The maternal uteri were stratified based on the presence of uterine scarring, with scarred and non-scarred uteri forming separate layers. Linear regression was performed on postpartum haemorrhage and uterine muscle thickness at the placental attachment site when a scarred uterus was present.

Figure 18. Diagnostic diagram of the model (scarred uterus). The Residuals vs. Fitted plot confirms the linearity assumption, while the Normal Q-Q plot demonstrates the normality of residuals. The Scale-Location plot indicates that the assumption of homoscedasticity is met, and the Residuals vs. Leverage plot shows no outliers in the model.

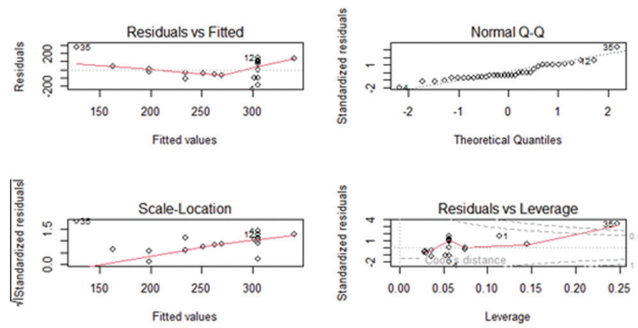
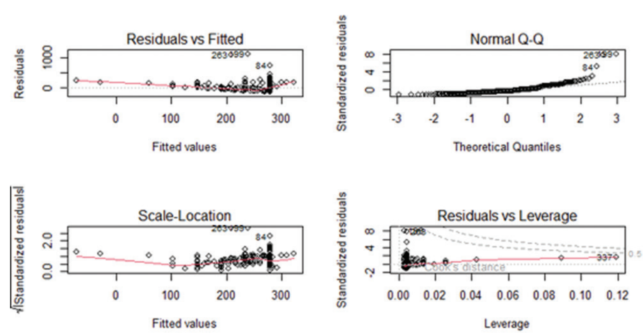


Figure 19. Diagnostic diagram of the model (non-scarred uterus). The Residuals vs. Fitted plot confirms the linearity assumption, while the Normal Q-Q plot demonstrates the normality of residuals. The Scale-Location plot indicates that the assumption of homoscedasticity is met, and the Residuals vs. Leverage plot shows no outliers in the model.



The results (Table 13) showed a statistically significant effect of uterine muscle thickness at the placental attachment site on the amount of postpartum haemorrhage, with a *t* value of -2.9869 and a $P = .005282 < .05$. Residuals vs. Fitted in Figure 18 demonstrates that the linear regression conforms to the linear relationship. In contrast, Normal Q_Q in Figure 18 indicates that the residuals of the model adhere to a normal distribution. The Scale-Location plot in Figure 18 suggests that the model exhibits homoscedasticity, and the Residuals vs. Leverage plot shows that there are no outliers.

Furthermore, a linear regression was conducted between postpartum hemorrhage and uterine muscle thickness at the site of placental attachment in cases where a non-scarred uterus was present. The analysis revealed a statistically significant effect of placenta-attached uterine muscle thickness on the amount of postpartum hemorrhage, with a *t* value of -6.66339 and a $P = 1.10E\text{-}10 < .05$. The residual plots in Figure 19 demonstrate that the linear regression meets the assumptions of linearity, normality, and homoscedasticity, and there are no outliers. Additionally, Figure 20 displays the linear relationship between postpartum hemorrhage and

Figure 20. A scatterplot illustrates the linear relationship between postpartum hemorrhage and uterine muscle thickness at the placental attachment site, stratified by scarred or non-scarred uterus. The x-axis represents the thickness of the uterine muscle at the placental attachment, while the y-axis displays the amount of postpartum haemorrhage. The red line represents non-scarred uterus and the dark line represents scarred uterus.

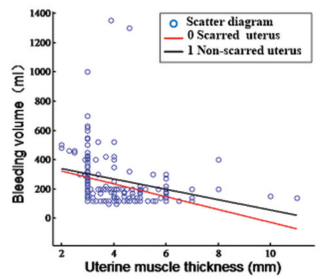


Table 14. Table of linear regression parameters (non-scarred uterus)

term	estimate	std.error	statistic	*P* value	2.50%	97.50%
(Intercept)	410.5558	26.16458	15.69128	5.52E-42	359.0882	462.0234
\`Uterine muscle thickness\`	-43.8977	6.587891	-6.66339	1.10E-10	-56.8565	-30.9388

Table 15. Table of linear regression parameters (weeks of gestation at full term)

term	estimate	std.error	statistic	*P* value	2.50%	97.50%
(Intercept)	406.4736	24.96414	16.2823	6.92E-45	357.3769	455.5703
\`Uterine muscle thickness\`	-41.9212	6.216819	-6.74318	6.32E-11	-54.1477	-29.6946

Figure 21. Model diagnostic chart (full term gestational weeks). The Residuals vs. Fitted plot confirms the linearity assumption, while the Normal Q-Q plot demonstrates the normality of residuals. The Scale-Location plot indicates that the assumption of homoscedasticity is met, and the Residuals vs. Leverage plot shows no outliers in the model.

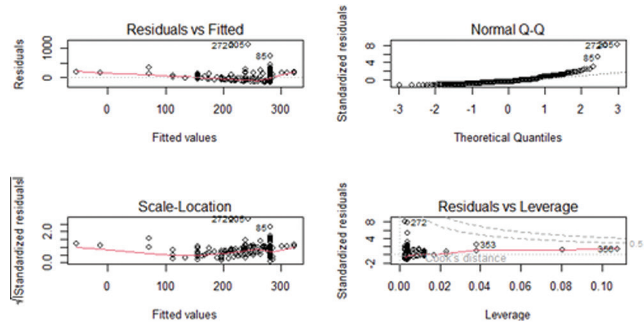


Figure 22. Residuals vs. Fitted, Normal Q_Q, Scale-Location, and Residuals vs. Leverage plots, which evaluate the assumptions of the linear regression model. The Residuals vs. Fitted plot shows the linearity of the relationship between the predictor and response variables. The Normal Q_Q plot assesses the normality assumption of the residuals. The Scale-Location plot examines the homogeneity of variance across the range of predicted values. Lastly, the Residuals vs. Leverage plot helps to identify any influential observations in the data. Together, these plots demonstrate that the linear regression satisfies the linear relationship, has a normal distribution of residuals, exhibits homoscedasticity, and has no outliers.

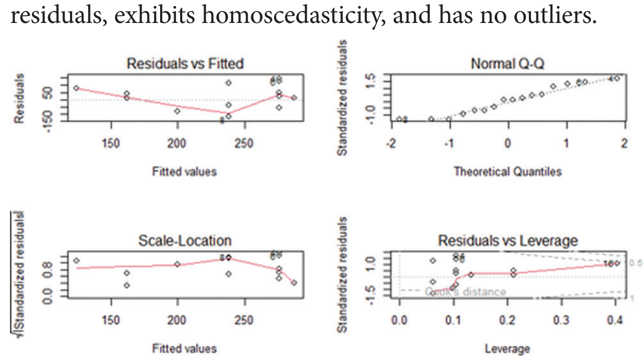


Table 16. Table of linear regression parameters (weeks of gestation less than full term)

term	estimate	std.error	statistic	*P* value	2.50%	97.50%
(Intercept)	389.9627	75.65077	5.154775	.000146	227.708	552.2175
\`Uterine muscle thickness\`	-38.0124	17.85308	-2.12918	.051472	-76.3035	0.278621

uterine muscle thickness at the site of placental attachment when stratified by a scarred uterus.

Investigating the Relationship between Myometrial Thickness at Placental Attachment and Postpartum Hemorrhage Stratified by Gestational Week

The stratification was based on whether the gestational week was full term, with one layer for less than full term and one layer for full term. When the gestational week was full term, a linear regression analysis was conducted to examine the relationship between postpartum hemorrhage and uterine muscle thickness at the placental attachment site. The results (Table 15) indicated a statistically significant effect of myometrial thickness at the placental attachment site on postpartum hemorrhage, with a *t* value of -6.74318 and a *P* = 6.32E-11 < .05. The residual plots showed that the linear regression model met the assumptions of a linear relationship, normality of residuals, homoscedasticity, and no outliers, as depicted in Figure 21.

A linear regression was conducted between postpartum haemorrhage and myometrial thickness at placental attachment when the gestational week was less than full term. The analysis revealed a non-significant effect of myometrial thickness at placental attachment on postpartum haemorrhage, as indicated by a *t* value of -2.12918 and a *P* = 0.051472 > .05. Figure 22 displays Residuals vs. Fitted, Normal Q_Q, Scale-Location, and Residuals vs. Leverage plots, demonstrating that the linear regression satisfies the linear relationship, has a normal distribution of residuals, exhibits homoscedasticity, and has no outliers. Furthermore, Figure 23 illustrates the linear relationship between postpartum haemorrhage and uterine muscle thickness at the placental attachment site when stratified by gestational week less than a full term (Figure 24-26).

Figure 23. Scatterplot (stratified by weeks of gestation less than full term) A scatterplot illustrates the linear relationship between postpartum hemorrhage and uterine muscle thickness at the placental attachment site, stratified by weeks of gestation less than full term. The x-axis represents the thickness of the uterine muscle at the placental attachment, while the y-axis displays the amount of postpartum haemorrhage. The red line represents full gestational age and the dark line represents less than gestational week less than full term.

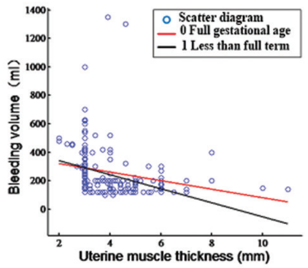


Figure 24. Thickness of myometrium at placental attachment compared to myometrium at non-placental attachment. During a cesarean section surgery, it was observed that the uterine muscle layer at the site of placental attachment was weak, with a noticeable decrease in thickness compared to the non-placental attachment area.

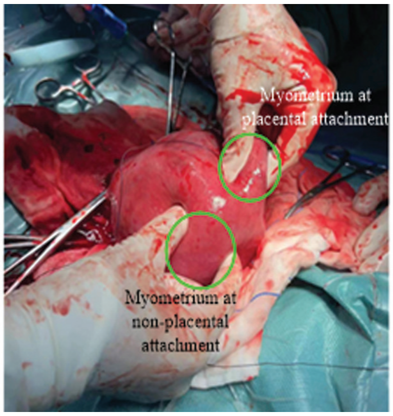


Figure 25. "U" suture anterior view. For cases of weak uterine muscle layer at the site of placental attachment and excessive bleeding from the placental separation surface, we employ a "U-shaped" simple continuous suturing technique. If the bleeding area is large, multiple "U-shaped" simple continuous sutures may be applied. In this illustration, three "U-shaped" simple continuous sutures are used. This view shows the front side.

Figure 26. "U" suture posterior view

DISCUSSION

Postpartum hemorrhage is a life-threatening labor complication most commonly caused by weak uterine contractions, accounting for approximately 75% of cases. When the myometrium is thin, the muscle fibers have less capacity, which affects contractility and leads to postpartum hemorrhage due to weak uterine contractions. This study found a negative correlation between the thickness of the uterine muscle at the placental attachment site and the amount of postpartum hemorrhage. Thinner myometrium has difficulty producing sufficient uterine contraction during labor, which makes it challenging to restrict maternal blood flow to the placental bed after placental abruption, reducing the ability to control bleeding in a timely manner. Additionally, thinning of the myometrium may lead to prolonged placental abruption, affecting uterine contractions and increasing postpartum bleeding. Myometrial thinning may be a direct sign of placental villi proliferation into the myometrium, resulting in placental adhesions or even placental implantation, wide malformation of some of the proliferating migrating vessels, and weaker uterine contractions that prevent effective closure of the proliferating vessels, ultimately leading to increased hemorrhage. Ultrasound measurements were used to compare the correlation between the thickness of the uterine muscular layer at the placental attachment site and the amount of bleeding at 2 hours postpartum to assess its predictive value for postpartum hemorrhage. This study will provide a basis for the early identification of postpartum hemorrhage in clinical practice, standardize management during labor, and further reduce maternal perinatal mortality. Although studies of myometrial thickness have been widely used in obstetrics to predict maternal conditions or pregnancy outcomes, mostly in the lower uterine segment, fundus, anterior, and posterior walls, studies on myometrial thickness at the placental attachment site have rarely been reported.

The study demonstrated a negative correlation between myometrial thickness at the placental site and bleeding at 2 hours postpartum, indicating that thinner myometrial thickness was associated with increased bleeding. These findings are consistent with previous studies conducted in China and abroad. For instance, Chen et al. used magnetic resonance imaging to show that myometrial thickness and the volume of the dark band within the placenta were negatively and positively correlated with postpartum hemorrhage, respectively. Another study by M. Boucher indicated that cabergoline, an oxytocin analogue, promoted uterine contraction and maintenance of uterine tone, increasing myometrial thickness and decreasing intraoperative bleeding during caesarean section.

In the current study, ultrasound measured myometrial thickness at the placental site was 2.78 mm when postpartum hemorrhage reached 500 ml in mothers undergoing caesarean section. This value was lower than that reported in similar studies, possibly due to differences in measurement location, ultrasound probe frequency, and clarity of measurement. While previous studies have identified a negative correlation between myometrial thickness and postpartum hemorrhage, this study did not determine a specific myometrial thickness value that could predict postpartum hemorrhage, limiting its clinical value. Nonetheless, ultrasound is a safe, non-invasive, and cost-effective method for measuring myometrial thickness, and the high-frequency probe used in this study provided accurate and reproducible results.

An effective approach to prevent postpartum haemorrhage (PPH) is to identify high-risk groups prenatally, perform early warning assessments, and develop corresponding risk plans. However, the accuracy and validity of existing PPH warning scales are limited due to the lack of standardization in quantifying haemorrhage and identifying risk factors. To improve the antenatal warning assessment system for PPH, a recent study found a negative correlation between the thickness of the myometrium at the placenta and the amount of postpartum haemorrhage.

Quantifiable methods of measuring blood loss, such as direct measurement using collection bags, polyclots, and weighing dressings, are preferable and objective compared to visual estimates of blood loss. Direct measurement of blood loss has shown a high correlation with postoperative haemoglobin differentials and enables timely detection of PPH caused by chronic blood loss. A linear regression analysis of the thickness of the myometrium at the placental attachment site and the change in haemoglobin before and after delivery has been found to be linearly correlated.

Various methods, such as the Cho suture and the Ouahba compression suture, can be used to suture bleeding sites at the site of placental abruption due to localized uterine contraction or placental causes. The purse-string uterine suture has been found effective in preventing PPH and suitable for dissemination at the primary level. Modified Cho suture has also been shown to have a high hemostatic effect and clinical promotion value. During caesarean section, the "U" type simple penetrating suture is used when a weak myometrium is found at the placental attachment site and there is a lot of bleeding on the placental detachment surface. If the bleeding area is large, multiple "U" shaped simple penetrating sutures may be given.

In this study, a simple "U" type penetration suture was employed, resulting in a reduced number of stitches required for the procedure compared to other sutures. This technique also lowered the likelihood of malignant fluid obstruction, uterine adhesions, infection, and necrosis. Furthermore, the suture method was observed to be efficient, straightforward, and quick, and no complications were reported during the post-operative follow-up. To further comprehend the effectiveness of the "U" type suture with regard to haemostasis and complications and to evaluate its clinical usefulness, the study will be refined in the future. Future studies should aim to evaluate its clinical usefulness in a larger sample size with rigorous methodology and comprehensive evaluation of outcomes. However, certain limitations of this study must be acknowledged. The visual method is the most common method used to measure postpartum blood loss in clinical practice. Still, its accuracy is questionable, and there is no consensus on how to improve it. In contrast, the direct measurement method used in this study was more accurate, but there remains the possibility of missed or mismeasured measurements. Future research should focus on comparative studies, long-term follow-up, standardization of measurement, economic impact assessment, and patient-reported outcomes to enhance our understanding of the "U" type penetration suture technique and its clinical implications. The "U" type penetration suture technique offers improved surgical efficiency, reduced complications, enhanced blood loss measurement, and potential cost-effectiveness, providing important clinical implications for patient care. In summary, our study highlights the effectiveness and clinical benefits of the "U" type penetration suture technique in obstetrics and maternal care. With its potential to improve surgical efficiency, reduce complications, enhance blood loss measurement, and potentially lower costs, this technique has the potential to significantly impact the field and improve patient outcomes.

ETHICAL COMPLIANCE

This study was approved by the ethics committee of Shantou No.2 People's Hospital, adhering to the principles outlined in the Declaration of Helsinki (or relevant ethical guidelines). All participants involved in the study provided written informed consent, ensuring their voluntary participation and understanding of the study's objectives, procedures, and potential risks.

CONFLICT OF INTEREST

The authors have no potential conflicts of interest to report relevant to this article.

AUTHOR CONTRIBUTIONS

HZ and MZ designed the study and performed the experiments, YX collected the data, YH analyzed the data, HZ and MZ prepared the manuscript. All authors read and approved the final manuscript. HZ and MZ contributed equally to this work

FUNDING

This work was supported by the Shantou Medical Health Science and Technology Project (210412216497197) "Subject name the placenta to the research on the effects of uterine muscle layer thickness of postpartum haemorrhage amount"

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