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Predicting successful vaginal birth after Cesarean section using a model based on Cesarean scar features examined by transvaginal sonography

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KEYWORDS: Cesarean section scar; transvaginal sonography; vaginal birth after Cesarean section; vaginal delivery; VBAC

ABSTRACT

Objective *To develop a model to predict the success of a trial of vaginal birth after Cesarean section (VBAC) based on sonographic measurements of Cesarean section (CS) scar features, demographic variables and previous obstetric history.*

Methods *We used transvaginal sonography (TVS) to examine the CS scar of 320 consecutive pregnant women. TVS was carried out at 11–13, 19–21 and 34–36 weeks' gestation and prospective measurements of the scar were recorded at each visit according to a defined protocol. A logistic regression model to predict success of VBAC was developed for those patients with a visible scar on ultrasound and only one previous CS. The model was evaluated using bootstrap validation.*

Results *There were 131 women with one previous CS and a visible scar, of whom 10 underwent CS prior to labor and were excluded from analysis. Successful VBAC was achieved in 74/121 (61%) of the remaining cases. The prediction model developed was based on patient age, previous history of VBAC, residual myometrial thickness (RMT) and the change in RMT from the first to the second trimester (ΔRMT). The internally validated area under the receiver–operating characteristics curve was 0.62 when measurements of RMT and ΔRMT were excluded, but 0.94 when scar information was incorporated into the model.*

Conclusion *Ultrasound measurements of CS scar, namely RMT and the change in RMT from the first to the second trimester of pregnancy, when incorporated into a mathematical model, can predict accurately a successful trial of labor in patients with one previous CS.* *Copyright © 2013 ISUOG. Published by John Wiley & Sons Ltd.*

INTRODUCTION

The rate of vaginal birth after Cesarean section (VBAC) is defined as the number of vaginal births to women with one previous Cesarean section (CS) per 100 such deliveries[1]. Attempts have been made to predict which patients are more likely to undergo successful VBAC using various parameters, including clinical history and physical examination at the time of admission for delivery[2]. Flamm and Geiger[3] developed a scoring system to predict the success of a trial of labor in these patients, in which they allocated points for maternal age, a history of previous vaginal delivery, the indication for the previous CS delivery and cervical effacement and dilation. When the system was tested, they found that 18% of women scored ≤ 3, corresponding to a lower than 60% likelihood of VBAC, whilst only 29% of women scored ≥ 6, leading to an estimated 88% likelihood of VBAC. However, the fact that higher scores in their model were applicable to fewer than 30% of the study population limits its utility. Dinsmoor and Brock[4] tested the Flamm and Geiger model retrospectively on 153 cases, finding that a score of ≥ 7 gave a 100% likelihood of VBAC, whilst a score of ≤ 4 reduced the chances to 53%. They concluded that an unfavorable score might be helpful when counseling patients considering a trial of labor. However, this system does not give a calibrated spectrum of risk and leaves any decision regarding VBAC until a woman is admitted to

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the delivery room in labor. A better system, able to predict the success or failure of a trial of labor at an earlier stage in pregnancy, is lacking.

Accurately predicting the outcome of a trial of VBAC is clinically useful as failure is associated with increased maternal and fetal morbidity[5]. There is a growing body of evidence to suggest that complete healing of the CS scar and myometrial thickness of the lower uterine segment are related to the chance of achieving a vaginal delivery in a subsequent pregnancy[6]. Over the last 10 years there have been multiple attempts to study the prevalence and clinical significance of apparently 'defective' CS scars visualized using ultrasonography[7–14]. In these studies the prevalence of visible CS scars ranged from 19% to 88% and, despite similar imaging protocols, there was no agreement regarding the definition of apparent scar 'defects'.

Despite this interest in CS scar morphology, there have been no longitudinal studies to evaluate the potential relationship between scar appearance on ultrasound imaging across all three trimesters of pregnancy and pregnancy outcome. Furthermore, no study has evaluated whether the rate of change in size of different scar parameters over the course of pregnancy may predict the likelihood of successful VBAC.

In the current study we aimed to use single measurements of CS scar dimensions in the second trimester of pregnancy, as well as the change in these dimensions from the first to the second trimester, to predict the likelihood of success in women selected for a trial of VBAC.

METHODS

This study was conducted at the ultrasound department of a London university teaching hospital between June 2010 and July 2011. The local Research and Ethics Committee approved the protocol. Written informed consent was obtained from all participating women. In total, 320 women with a singleton pregnancy were recruited; we used this cohort in our previous publication to develop reference data relating to the changes in CS scar size seen over the course of pregnancy[15]. All women in this cohort who had a history of one previous CS were considered suitable for a trial of VBAC and were referred to a specialized VBAC clinic, where appropriate counseling was offered. Women with two or more previous CS were booked for an elective CS, as per hospital policy.

Women were scanned transvaginally by one of two operators (O.N. and A.Sm.), using a Voluson® E8 Expert (GE Healthcare Ultrasound, Milwaukee, WI, USA) ultrasound system equipped with a 5–9-MHz transvaginal probe, at 11–13, 19–21 and 32–34 weeks' gestation. This coincided with their routine scans for measurement of fetal nuchal translucency thickness, anomaly screening and, when indicated, growth assessment. At the first scan, demographic data were recorded and an obstetric history was obtained. Operators performing the scans were blinded to this clinical information.



Figure 1 Ultrasound image (sagittal view) of pregnant uterus at 20 weeks, showing both hypoechoic part and residual myometrial thickness (RMT) of a Cesarean section scar.

A CS scar was defined as being visible when it showed a hypoechoic indentation representing myometrial discontinuity at the anterior wall of the lower uterine segment, with or without underlying residual myometrium. The lower uterine segment was assessed using real-time sonography to identify the area likely to contain the CS scar, and the delineation and measurement of the scar were carried out according to methods reported previously[14–16] (Figure 1). The part of the scar contained in any residual myometrium, expressed for measurement purposes as residual myometrial thickness (RMT) was measured in the sagittal plane. As a relationship between scar appearance and function has not been shown, we chose to avoid using the term 'defect' as a morphological descriptor.

Scar measurements were obtained at each of the three scan visits, and patients were followed-up until the final pregnancy outcome was known. Clinicians responsible for the care of these women in labor were blinded to the ultrasound features of the CS scar. All data were transmitted weekly to a designated research database and were checked for missing, out-of-range and inconsistent values. For the purposes of this study, uterine scar rupture was defined as a full-thickness separation of the uterine wall and overlying serosa observed at CS[1].

Statistical analysis

The factors considered for use in the prediction model were selected on the basis of expert opinion. They included two demographic variables (patient age and pre-pregnancy body mass index (BMI)), one variable related to previous obstetric history (prior successful VBAC) and two CS scar variables (RMT measured at the second trimester and change in RMT from first to the second trimester (ΔRMT)). A logistic regression model was built. Because the sample size was small relative to the number of predictors, penalized maximum likelihood based on the corrected Akaike's Information Criterion (AIC) was used to obtain reliable regression coefficients for prediction[17].

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We did not find non-linear predictor effects or outliers, nor did we detect strong relationships among the predictors.

The area under the receiver–operating characteristics curve (AUC) and the sensitivity and specificity at a range of cut-off values for predicted probability were computed to assess the discriminative performance of the model. A calibration plot was produced to investigate the agreement between observed and predicted probabilities.

The clinical utility of the model obtained was assessed with decision curves that plot the net benefit for a range of cut-off values for predicted probability[18,19]. A cut-off of 0.7 was often used in earlier studies[2]. Using this methodology, the clinical utility of a model at a given cut-off to classify patients as suitable for vaginal delivery is quantified as the net benefit, which is calculated as the difference between the proportion of true positives and the proportion of false positives weighted by the odds of the probability cut-off. The odds of the cut-off value represents the relative misclassification cost, with a value above 1 indicating that an emergency CS (i.e. a false positive) is worse than is an unnecessary elective CS (i.e. a false negative). For example, using a probability cut-off of 0.7 implies a weight of 0.7/0.3. = 2.3, such that avoiding one emergency CS is equivalent to 2.3 unnecessary elective CS deliveries.

A model has clinical utility at a given cut-off if its net benefit is higher than the net benefit of two default strategies for which no model is needed: in this case attempting vaginal delivery in all patients or performing elective CS in all patients. The desired cut-off (of probability of success) in order to attempt vaginal delivery, and thus the relative importance of false-positives and false-negatives, is not the same for every clinician or patient. We therefore investigated the relevant range between 0.3 and 0.9, and plotted the results in a decision curve.

To validate the prediction models internally we did not split the data into training and test sets due to the limited sample size; instead, the regular bootstrap was used to estimate performance on new patients[20,21].

Analyses were performed using R (http://www.r-project.org/; R Foundation, Vienna, Austria). The 'rms' package was used to fit the logistic regression model, calculate the penalized coefficients and the AUC and produce the calibration plot[16].

RESULTS

The CS scar was visible in 284/320 (89%) cases. Of the 36 women in whom the scar was not visible, 22 had undergone one previous CS and of these 18 (82%) subsequently had a successful vaginal delivery. As the 'non-visible scar' group did not have measurable scar features, subsequent analysis in this article is focused on the 'visible scar' group (Figure 2).

In the visible scar group, 153 women had a history of more than one previous CS and were therefore assigned to have an elective CS at ≥ 39 weeks' gestation; these women were excluded from development of the prediction model.

Table 1 Indications for emergency Cesarean section (CS) in 47 women with visible CS scar and one previous CS, who attempted vaginal birth after Cesarean section

Indication	n *(%)*
Confirmed scar rupture	2 (4.3)
Antepartum hemorrhage	2 (4.3)
Placenta previa	2 (4.3)
Breech presentation	3 (6.4)
Fetal distress	14 (29.8)
Fetal distress secondary to placental abruption	1 (2.1)
Failure to progress	20 (42.6)
PET/GDM/PROM	2 (4.3)
Placental abruption	1 (2.1)

GDM, gestational diabetes mellitus; PET, pre-eclamptic toxemia; PROM, premature rupture of membranes.

Women with a history of one previous CS and visible scar ($n = 131$) were offered a trial of VBAC. Ten women were subsequently excluded because they underwent CS prior to labor due to various causes. Of the remaining 121 cases, successful VBAC was achieved in 74 (61%), while 47 cases had failed trials of labor that resulted in an intrapartum emergency CS. The indications for CS in the failed VBAC group are shown in Table 1. Around 80% were for fetal distress, failure to progress or possible scar rupture.

The average birth weight was 3170 g in the cases of failed VBAC and 3410 g in the successful VBAC group. The mean gestational age at delivery was 38 + 5 (median, 39) weeks in the failed VBAC group and 40 + 1 (median, 40) weeks in the successful VBAC group. A total of 30/47 (64%) cases in the failed and 57/74 (77%) cases in the successful VBAC group went into spontaneous labor, with labor induced in the remaining women. No differences between these groups were seen in the use of prostaglandins, although more women with a failed trial of VBAC received Syntocinon. Descriptive statistics for other variables according to success or failure of VBAC are described in Table 2. The median RMT in the second trimester was higher for patients who subsequently underwent a successful VBAC than it was for patients with a failed VBAC (4.2 *vs* 2.8 mm) and the median difference in RMT from the first to the second trimester (i.e. ΔRMT) was lower for women with a successful VBAC than it was for women with failed trial of labor (0.8 *vs* 2.8 mm).

In a logistic regression model including age, BMI, second-trimester RMT, ΔRMT and previous VBAC, BMI had a small, but statistically non-significant, positive effect on the chance of successful vaginal delivery (odds ratio (OR) = 1.08, $P = 0.23$). This effect is contrary to findings in the literature[2] and BMI was excluded from the prediction model to enhance generalizability.

The fitted logistic regression model suggests that the chance of a successful VBAC increases with larger second-trimester RMT (OR = 6.26 per mm, $P = 0.0009$). In addition, the greater the decrease in RMT from the first to the second trimester (ΔRMT), the lower the probability of a successful VBAC (OR = 0.25 per mm, $P < 0.0001$). Although not statistically significant, the effect of maternal

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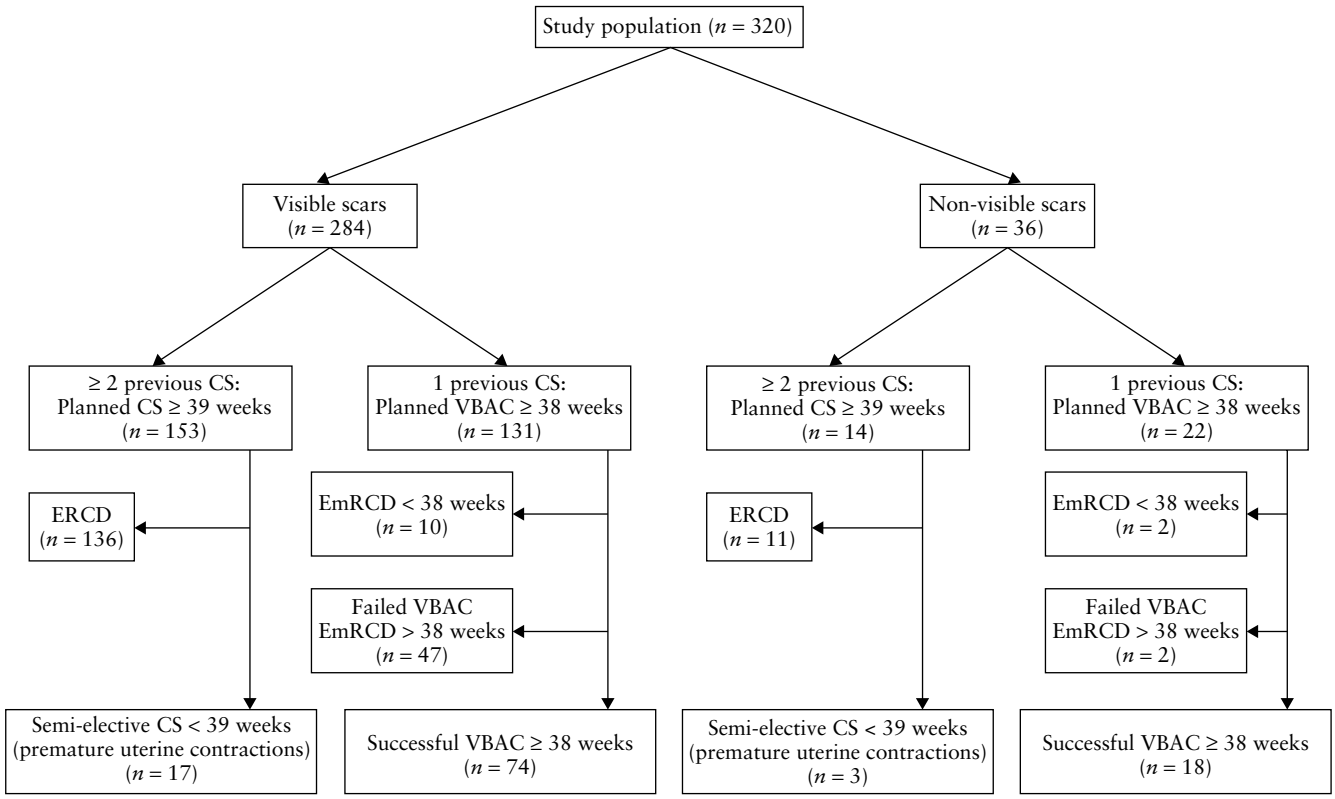

Figure 2 Flow chart summarizing the study group, showing mode of delivery according to Cesarean section (CS) scar visibility. EmRCD, emergency repeat Cesarean delivery; ERCD, elective repeat Cesarean delivery; VBAC, vaginal birth after Cesarean section.

Table 2 Descriptive statistics of patient, scar, labor and birth weight characteristics according to mode of delivery in 121 women with visible Cesarean section (CS) scar and one previous CS

Parameter	*Failed VBAC* (n = *47*)	*Successful VBAC* (n = *74*)
Age (years)	33 (20, 28, 35, 43)	32 (21.0, 29.0, 34.0, 39.0)
Body mass index (kg/m^2)	25 (19, 23, 29, 40)	27 (18.0, 24.0, 30.0, 41.0)
Previous VBAC	3 (6.4)	25 (33.8)
RMT (mm)		
First trimester	5.5 (3.0, 4.8, 6.4, 9.1)	5.9 (2.8, 3.5, 5.9, 7.6)
Second trimester	2.8 (0.5, 2.6, 3.1, 4.2)	4.2 (2.6, 3.0, 4.6, 6.3)
Third trimester	2.5 (0.5, 2.4, 2.6, 3.8)	3.6 (3.2, 2.6, 3.9, 5.9)
ΔRMT: first trimester − second trimester (mm)	2.8 (0.1, 2.1, 3.4, 6.2)	0.8 (0.1, 0.4, 1.2, 4.7)
GA at delivery (weeks)	39 (31, 38, 40, 42)	40 (38, 40, 41, 42)
Birth weight (g)	3170 (1495, 2926, 3600, 4756)	3488 (2420, 3125, 3700, 4540)
Spontaneous onset of labor	30 (63.8)	57 (77.0)
Use of Syntocinon	12 (25.5)	2 (2.7)
Use of prostaglandin	9 (19.1)	8 (10.8)

Data given as median (minimum, 1st quartile, 3rd quartile, maximum) or *n* (%). GA, gestational age; RMT, residual myometrial thickness; VBAC, vaginal birth after Cesarean section.

age was negative while the effect of previous VBAC was positive (OR = 0.70, $P = 0.30$ and OR = 3.28, $P = 0.22$, respectively). The penalized effect estimates are given in Table 3 alongside the non-penalized estimates; the former are preferred for making predictions in new patients (an example is given in the Discussion).

At a cut-off probability of 0.7, the model had values for validated sensitivity and specificity of 90% (Table 4). The training set AUC for the model was 0.96 (95% CI, 0.90–0.98) and the internally validated AUC was 0.94 (95% CI, 0.89–0.96). In comparison, a reduced model excluding the scar features had a training set AUC of 0.66 (95% CI, 0.55–0.77) and an internally validated AUC of 0.62 (95% CI, 0.51–0.73).

A calibration plot showed the estimated probabilities for successful VBAC given by the model to be accurate (Figure 3). There was some underestimation of the probability (by 0.1 or less) for predicted probabilities 0.2 and 0.7, but the majority of women have predicted probabilities outside this range.

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Table 3 Estimated effects of patient and scar characteristics in fitted logistic regression model to predict success of trial of vaginal birth after Cesarean section

Effect	$\beta_{penalized}$	$\beta_{non\text{-}penalized}$	$OR_{non\text{-}penalized}$ *(95% CI)*	P
Intercept	−0.77	−1.34	—	0.6256
Age (per 5 year increase)	−0.29	−0.36	0.70 (0.35–1.37)	0.2957
RMT (per mm increase)	1.44	1.83	6.26 (2.12–18.52)	0.0009
ΔRMT (per mm decrease)	−1.22	−1.39	0.25 (0.13–0.48)	< 0.0001
Previous VBAC (yes/no)	1.09	1.19	3.28 (0.50–21.47)	0.2157

OR, odds ratio; RMT, second trimester residual myometrial thickness; ΔRMT, change in RMT from first to the second trimester; VBAC, vaginal birth after Cesarean section.

Table 4 Sensitivity and specificity for success of trial of vaginal birth after Cesarean section using the prediction model at specified cut-off values for predicted probability

Cut-off for probability	*Sensitivity*	*Specificity*
0.3	97 (97)	74 (74)
0.5	95 (94)	83 (81)
0.7	90 (90)	91 (90)
0.9	59 (59)	98 (96)

Sensitivity and specificity are given as percentages. Values validated by a bootstrap procedure are shown in parentheses.

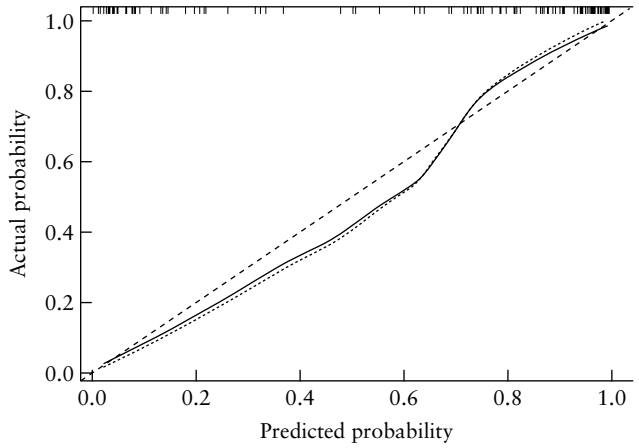

Figure 3 Calibration plot for model to predict success of vaginal birth after Cesarean section (VBAC), based on patient age, previous history of VBAC, residual myometrial thickness (RMT) and change in RMT from first to second trimester, in 121 women with visible Cesarean section (CS) scar and one previous CS: apparent (·····), validated (——) and ideal (- - - -) calibration. Vertical lines at top represent individual data points.

Clinical usefulness

The decision curve for our prediction model is shown in Figure 4. The validated net benefit, based only on cut-offs of 0.3, 0.5, 0.7 and 0.9, are also shown. The model clearly shows greater net benefit across the range of probability thresholds considered, compared with the default strategies. At the cut-off probability of 0.7, the validated net benefit of the model was 0.45 higher than was that of giving none of the women a trial of VBAC. The interpretation of this value is that the benefit of using the model with scar characteristics in addition to patient characteristics is equivalent to identifying 45 additional

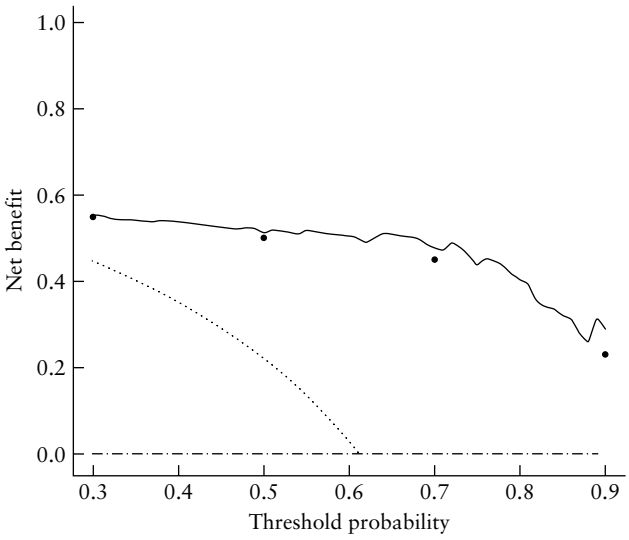

Figure 4 Decision curves for three strategies in the management of delivery in women with visible Cesarean section (CS) scar and one previous CS: using prediction model for success of vaginal birth after Cesarean section (VBAC) (——), giving all women a trial of VBAC (·····) and giving no woman a trial of VBAC (–·–·–). Validated net benefit, based on probability cut-offs of 0.3, 0.5, 0.7 and 0.9, is also shown (•).

successful VBACs per 100 patients at the same rate of emergency CS. The model also has clinical utility compared to the default strategy of giving all women a trial of VBAC. This was even the case at a cut-off of 0.3, at which the validated net benefit of the model was 0.11 higher. This is equivalent to 26 (= 0.11 × 100/(0.30/0.70)) fewer emergency CS deliveries per 100 patients with no increase in the number of unnecessary elective CS deliveries.

DISCUSSION

We have shown that when sonographic measurements of CS scars during pregnancy, namely RMT in the second trimester and change in RMT from the first to the second trimester, are incorporated into prediction models, the success of a trial of labor can be predicted with a high level of accuracy. Previously published models have focused on single RMT measurements made in the late third trimester. In contrast, our study suggests that if an assessment of the scar is made relatively early in pregnancy then decisions regarding the mode of delivery can be made well in advance of any potential delivery date, hence our decision

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to examine changes in RMT from the first to the second trimester rather than from the second to the third.

We found that women who underwent successful trials of labor had significantly greater RMT measurements in the second trimester in comparison with women who had a failed VBAC. Furthermore, women with a successful VBAC showed minimal changes in RMT from the first to the second trimester. It is interesting that it is the RMT that seems predictive of outcome rather than the size of the hypoechoic part of the scar (the so-called niche or 'defect'). We have previously suggested that, even in the presence of a large hypoechoic segment, the scar is not necessarily defective as long as the RMT is sufficiently thick and remains so during the pregnancy[15]. Moreover, the outcome when the scar could not be visualized perhaps supports this, as when a trial of VBAC was attempted in these women, 82% of cases resulted in a successful vaginal delivery. We think that an inability to visualize a scar (providing the assumed location of the CS scar can be located anatomically) probably reflects good scar healing, with no hypoechoic segment on ultrasound. This issue is important, as anecdotally we have noticed a trend for clinicians to request assessments of CS scars using ultrasound to determine whether they are 'deficient'. Our findings suggest that the observation of a large hypoechoic part of the scar may not indicate that scar integrity is compromised, providing that the RMT is adequate.

There have been several reports describing prediction models to help clinicians counsel women regarding the mode of delivery after previous CS. However, to our knowledge, the use of a combination of CS scar measurements with clinical variables to predict the success or failure of a trial of VBAC has not been described previously. Studies published to date have focused on either single RMT measurements at 36 weeks' gestation[22–24] or solely on demographic and clinical factors[2]. Eden *et al.*[2] carried out a systematic review to evaluate VBAC prediction models and concluded that none consistently identified women at risk of a failed trial of labor. We have introduced the change in RMT over time as a predictive variable. As the uterus changes in size so rapidly during the course of a pregnancy, we felt it likely that the speed of change in scar dimensions may reflect scar integrity. Our data suggest that this may indeed be the case.

The studies included in the review by Eden *et al.*[2] were mainly retrospective cohort and case–control studies. Whilst previously reported models contain both antepartum and intrapartum variables, none has included information relating to the appearance of the CS scar. Including scar measurements in our model enabled us to predict success of VBAC based on a small number of relatively easily obtained variables. For example, at a 0.7 cut-off, the sensitivity of the reduced model (patient characteristics only) was 33%, but this improved to 90% when CS scar features were added (full model); this could limit the need to include an exhaustive list of clinical variables.

A strength of our model is that it provides both patient and clinician with a calibrated probability for the likely success of a trial of VBAC. We can illustrate this by giving two relatively extreme examples. The formula for the probability of success (based on the coefficients provided in Table 2) is $P = 1/(1 + \exp(-z))$, where 'exp' refers to the exponential function and $z = -0.77 - 0.29 \times \text{age}/5 + 1.44 \times \text{RMT} - 1.22 \times \Delta\text{RMT} + 1.09 \times (1 \text{ if previous VBAC})$. If we consider a woman aged 32, without a previous VBAC, with an RMT on her second-trimester scan of 2.7 mm and a decrease in RMT of 1.5 mm from the first to the second trimester, then, by entering the specified values, the estimated chance of successful vaginal delivery for this patient is 36%. In contrast, if the same woman had an RMT of 4.1 mm at the second-trimester ultrasound scan and a decrease in RMT of 0.9 mm from the first to the second trimester, she would have an estimated 90% chance of a successful vaginal delivery. There were two cases of confirmed uterine rupture in the group selected for a trial of VBAC in our study population. If we apply the model in these cases, the estimated chance of their achieving a successful VBAC would be 0.00005% and 0.00009%, respectively. Had the model been applied prospectively, both women would have been strongly advised against a trial of VBAC and so would have avoided the morbidity associated with uterine rupture.

The AUC for our model is perhaps surprisingly high. This may reflect the relatively small number of women in the study. However, even if interpreted with caution, the findings suggest that the scar is a major factor in the function of the uterus during a trial of labor. The main indications for repeat CS in the failed VBAC group were fetal distress and failure to progress. It is entirely plausible that both these factors could be exacerbated by poor scar healing. Furthermore, a poorly healed scar may impact on decidualization and subsequent placentation and be associated with a greater likelihood of fetal distress in labor.

A key issue for any test is reproducibility. We have shown previously that the interobserver variability for measurement of CS scars is low in the first trimester and moderate in the second and third trimesters[14]. It is therefore reasonable to suggest that these measurements will be of value if used more widely. It is important to highlight that whilst this model and approach show promise, external validation in different units and populations is needed before introduction into clinical practice.

CS rates have increased globally over recent years and, as a result, the number of women approaching their second pregnancy with a scar on the uterus is also increasing. Consequently, establishing reliable ways in which to advise this group of women on the likelihood of their succeeding in a future trial of labor is of increasing importance. We have shown that the inclusion of sonographic RMT measurements in a prediction model can give an accurate quantitative assessment of the likelihood of successful vaginal delivery after a previous

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CS. If the observed test performance is retained on external validation, this 'scar-based' approach to advising women contemplating a trial of VBAC could allow them to make well-informed decisions regarding their options for delivery relatively early in the course of pregnancy.

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