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Postnatal healing of cesarean scar: an ultrasound study

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Title page

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Condensation page

Tweetable statement (210 characters): Postnatal ultrasound frequently identifies suboptimally healed cesarean scars within the cervix after advanced labor cesarean delivery.

Short title: Postnatal healing of cesarean scar

AJOG at a glance (130 words):

Why was this study conducted? Postnatal assessment of cesarean scar is not routinely performed. We investigated how antenatal, intrapartum, intraoperative and postnatal factors influence the location, morphology and healing of labor cesarean scars using postnatal ultrasound.

What are the key findings?

- Cervical dilatation and fetal station independently predicted scar location.
- Cesarean deliveries performed in advanced labour were nearly eight times more likely to result in scars located in the cervix rather than the lower uterine segment, compared to those performed in early labor.
- Suboptimal scar healing was associated with advanced maternal age, advanced gestation, high BMI and increased second trimester uterine artery vascular resistance, locking sutures during surgery and cesarean scar location in the cervix.

What does this add to what is known? The study provides new insights into the factors influencing cesarean scar healing and location after cesarean surgery in labor.

Conflict of interest: The authors have no conflicts of interest to declare.

Abstract with keywords (500 words)

Background

Impaired healing of cesarean delivery scars results in long-term complications, including scar niche formation, which may adversely impact future pregnancies and lead to gynaecological symptoms such as postmenstrual spotting, dysmenorrhea and chronic pelvic pain. Moreover, there is increasing evidence that a cesarean delivery scar located close to or within the cervix is associated with an increased risk of subsequent spontaneous preterm birth. The factors influencing cesarean birth scar location and healing remain poorly understood.

Objective(s)

We explored the impact of antenatal, intrapartum, intraoperative and postnatal factors on cesarean scar sonographic healing, location and morphology after cesarean delivery in labor.

Study design

This prospective observational cohort study recruited women who underwent cesarean delivery during active labor (cervical dilation 4-10 cm) at University College London Hospital, UK (January 2021-October 2022). Transvaginal ultrasound was performed 4 to 12 months postpartum to evaluate cesarean delivery scar characteristics and location relative to the internal cervical os. Indicators of impaired scar healing were presence of a scar niche (depth ≥2mm) and/or a healing ratio (residual/adjacent myometrial or cervical thickness) of ≤0.5. Regression analysis assessed the associations between clinical variables and cesarean scar parameters.

87

88 **Results**

89 Cesarean delivery scars were identified in 96.8% of women recruited (90/93).
90 Advanced labor cesarean delivery (8-10 cm dilatation) was associated with an eight-
91 fold increased likelihood of a scar located at or caudal to the internal os (RR 7.77; 95%
92 CI 2.59, 23.39; p<0.001) compared to cesarean birth performed earlier in labor (4-7
93 cm dilatation). Cervical dilatation and fetal station at surgery significantly influenced
94 scar position relative to the internal cervical os (p<0.001). For each 1cm increase in
95 cervical dilatation during labor, the scar was positioned 0.88mm more caudally on the
96 uterus or cervix (95%CI 0.62, 1.14; p<0.001). Similarly, for each 1cm descent of the
97 fetal part within the maternal pelvis, the cesarean scar was located 1.5mm more
98 caudally on the uterus or cervix (95%CI 0.71, 2.33; p<0.001). The niche prevalence
99 was 37.8% (34/90), of which 67.6% (23/24) had a healing ratio ≤0.5. Risk factors for
100 suboptimal scar healing included BMI ≥ 25, increased uterine artery vascular Doppler
101 resistance, gestational age > 40 weeks, the use of locking sutures during surgery and
102 cesarean delivery scar location caudal to the internal os on postnatal ultrasound
103 (p<0.05). Uterine scars, situated cranial to the internal os, had significantly larger niche
104 dimensions compared to those located within the cervix, at or caudal to the internal os
105 (p<0.05).

106

107 **Conclusion(s)**

108 Advanced cervical dilatation and low fetal station at emergency cesarean delivery in
109 labor are independent predictors of cesarean scar location near or within the cervix,
110 and these cervical scars heal less well than scars located higher in the uterus. Even
111 women having a cesarean birth at 8-9cm have a high risk of the scar being close or

within the cervix, which is known to increase the risk of subsequent spontaneous preterm birth. Further research is needed into the impact of cesarean scar characteristics on gynaecologic symptoms and future pregnancy outcomes and to develop techniques to improve cesarean scar healing.

Keywords (1-7): cesarean scar, cervical dilation, fetal station, ultrasound, scar healing, cesarean niche, obstetric outcomes

Main text (3000 words)

Introduction

Cesarean delivery (CD) rates surpass the World Health Organisation's recommended thresholds.[1] Impaired CD uterine scar healing, as identified on ultrasound (US) by the formation of scar niches[2], can lead to gynaecological symptoms, known as cesarean scar disorder[3], secondary subfertility[4] and impact subsequent pregnancies by increasing the risks of cesarean scar pregnancy, abnormally invasive placenta and uterine rupture.[5]

CD scar niches have a multifactorial origin and their prevalence in non-pregnant cohorts varies depending on detection methods, definition criteria and study population selection.[6] Currently there is no consensus on the optimal treatment approach for CD scar niches, with proposed management strategies varying based on individual symptoms and reproductive goals.[7]

Moreover, advanced labor CD is linked to an increased risk of subsequent spontaneous preterm birth (sPTB)[8], likely related to iatrogenic surgical trauma to the cervix.[9,10] Postnatal studies have demonstrated that the location of the CD scar is an important determinant of niche development[11] and that advanced labor CD is associated with the cesarean scar being in the endocervical canal, however other factors influencing the CD scar characteristics have not been evaluated.[12] Understanding factors that influence cesarean scar healing and localisation is crucial to reduce the incidence of these complications and guide postnatal management of CD scar.

This study hypothesised that antenatal, intrapartum, intraoperative and postnatal factors would impact CD scar morphology and position relative to the internal cervical

os and we prospectively investigated this in a cohort of postnatal women using transvaginal US.

Materials and Methods:

This prospective observational cohort study recruited participants who underwent CD between January 2021 and October 2022 at University College London Hospitals NHS Foundation Trust, London UK. Ethical approval was obtained from the Research Ethics Committee (REC 20/SC/0113) and the Health Research Authority (IRAS 261256). The study included participants with a history of single CD performed during active labor (cervical dilatation ≥4), a singleton pregnancy and birth at ≥ 37 weeks' gestation. Participants with previous uterine surgery other than CD or multiple CD, were excluded from the study.

Cesarean scar ultrasound examination protocol

Although evidence remains limited,[13,14] the timing of postnatal cesarean scar assessment was selected based on expert Delphi consensus.[2] Postnatal transvaginal US assessments were conducted 4-12 months postpartum, using the Voluson E8 or E10 Expert ultrasound system (GE Healthcare, Austria) with a 4-9 MHz 3D transvaginal probe, without contrast enhancement. CD scar niche was defined as an indentation at the level of scar measuring ≥2 mm in depth.[2] The CD scar assessment protocol included parameters such as niche length, depth and width, scar distance to the internal cervical os, residual (RMT) and adjacent myometrial/cervical thickness (AMT).[15] The internal cervical os was identified using anatomical landmarks (such as endocervical mucosa, posterior vaginal fornix, uterovesical fold) as well as the intersection between the cervical and uterine axes[16], and further confirmed through

colour Doppler mapping of the uterine arteries at the level where the vessel angle changes after crossing the ureter.[17] The distance from the CD scar niche to the internal os was measured by positioning the callipers on the edge of the niche that was nearest the internal os and the internal os itself.[18] Indicators of impaired CD scar healing on US were presence of a scar niche and/or a ratio of RMT/AMT (healing ratio) of ≤0.5.[19] (Figure 1)

Outcome measures

The primary outcome of the study was the identification of the CD scar and the determinants of its location relative to the internal cervical os, with a specific focus on cervical dilatation and fetal station at birth. Secondary outcomes included CD scar healing parameters and their association with antenatal, intrapartum, surgical and postnatal factors, as well as scar morphology assessment stratified by scar location. During the US appointment participants answered a set of predefined questions about postpartum gynaecological features including menstrual cycles, contraception and lactation. Hospital medical records were reviewed to collect remaining factors potentially associated with CD scar healing.

Statistical analyses

Sample size calculation was informed by previous literature evidence,[12] with a significance level of 0.05, statistical power of 80% and adjustment for scar visibility yielded an estimated requirement of n_1=56 participants for advanced labor CD (cervical dilatation of 8-10cm) and n_2=36 participants for early labor CD (cervical dilatation of 4-7cm) to detect a categorical difference in the CD scar position - the proportion of scars located above versus at or below the internal os. A priori planned

analyses aimed to evaluate the impact of cervical dilatation and fetal station on scar location, including comparisons between early and advanced labor groups. Secondary analyses examined associations between scar healing parameters (niche presence, healing ratio ≤0.5) and clinical factors, including comparisons of scar morphology between uterine and cervical scars.

Statistical analysis was performed using IBM SPSS Statistics®. Descriptive statistics were employed to summarise the data. Normal distribution was assessed using Shapiro-Wilks test. A p value of <0.05 was set as the threshold for statistical significance. Independent sample t-tests were used to compare group means where assumptions were met, while the Wilcoxon test was employed for comparing differences in medians for non-normally distributed data. Categorical variables were compared using the Chi-square or Fisher's exact test when expected frequencies were < 5. Linear regression was used to assess the changes in scar position relative to the internal cervical os. Multivariable logistic regression was conducted to identify predictors of niche development; a similar analysis for healing ratio ≤ 0.5 was not performed due to the limited number of events. Post hoc bootstrapping with 1000 resamples was applied and a Bonferroni adjusted threshold was used in the interpretation of p-values.

Results

Out of 286 eligible participants approached in the study period, 93 (32.5%) agreed to participate. The median age of participants was 34 ± 4 years and the median BMI recorded in the first trimester of pregnancy was 23 ± 3 kg/m^2; 89.2% (83/93) were nulliparous (Table 1). The primary indications for CD were delayed labor progress (43%, 40/93), pathological intrapartum cardiotocograph trace monitoring (35.5%,

33/93) and chorioamnionitis (11.8%, 11/93). The median gestational age at birth was 40 ± 1 weeks. The median cervical dilatation at the time of CD was 9 cm, with 61.3% (57/93) occurring in advanced labor (8-10cm cervical dilatation). The median fetal station was -1 cm to maternal ischial spines with 97.8% (91/93) of the presentations being cephalic.

The mean interval between birth and US assessment was 7 ± 2 months (4, 12), with 48.9% (44/90) participants reporting lactational or contraception-induced amenorrhoea (Supplementary Figure 1). The CD scar was identified in 96.8%, 90/93 of cases, with 37.8% (34/90) having a niche present and 26.7% (24/90) showing a healing ratio ≤0.5. Scar locations were distributed as follows: 57.8% (52/90) cranial, 21.1% (19/90) at, and 21.1% (19/90) caudal to the internal cervical os. (Table 2) Advanced labor CD was associated with a sevenfold higher chance of a low fetal station (at or below the maternal ischial spines) compared to early labor CD, RR 7.3 (95%CI 1.8 - 29.3), p<0.001 and an eightfold risk of cervical scar location at or caudal to the internal os RR 7.8 (95%CI 2.6 - 23.4), p<0.001 compared early labor CD. (Table 3). CD scars from advanced labor were 3.7mm (95%CI 2.4, 4.9), p<0.001 more caudally located in the uterus or cervix than those from early labor CD.

Cervical dilatation and fetal station at the time of CD surgery significantly influenced scar position: for each centimetre increase in cervical dilatation at the time of CD, the scar was positioned 0.88 mm more caudally in the uterus or cervix (95%CI 0.62, 1.14; p<0.001) and for each centimetre fetal station descent within the maternal pelvis, the CD scar was located 1.5 mm more caudally in the uterus or cervix (95%CI 0.71, 2.33; p<0.001). (Figure 2) Cervical dilatation demonstrated stronger predictive power for low

CD scar position than fetal station: AUC 0.819 (95%CI 0.731, 0.907) and AUC 0.705, (95% CI 0.600, 0.810), respectively.

Univariate analysis linked suboptimal scar healing with advanced maternal age ≥40 (RR 3.0, 95%CI 1.6 - 5.6; p=0.01 for low healing ratio), raised BMI ≥25 (RR 1.8, 95%CI 1.1- 2.9; p=0.036 for niche development and RR 2.8, 95%CI 1.4 - 5.5; p=0.003 for low healing ratio), increased uterine vascular resistance i.e. combined uterine artery pulsatility index > 2.5 in the second trimester (RR 2.6, 95%CI 1.7 - 3.8; p=0.005 for niche development and RR 3.4, 95%CI 1.9 – 6.0; p=0.005 for low healing ratio) and gestational age at delivery ≥ 40 weeks (RR 2.2, 95%CI 1.1 - 4.3; p=0.013 for niche development), Double layer uterine closure, with a locked first layer and an unlocked second layer, showed a twofold increase in the risk of uterine niche development (RR 2.2, 95%CI 1.2 - 4.0; p=0.008) while locking of both uterine layers demonstrated a threefold increase in the risk of uterine niches (RR 3.3, 95%CI 1.8 - 6.1; p=0.009). The use of topical haemostatic agent (Fibrillar Surgicel®) correlated with a risk reduction for healing ratio ≤0.5 (RR 0.2, 95%CI 0.02-1.1; p=0.019). Fetal macrosomia, defined as birthweight > 4000g, significantly increased both the risk of niche formation and a suboptimal healing ratio (RR 1.8, 95%CI 1.1 - 3.0; p=0.047 and RR 2.6, 95%CI 1.4 - 4.9; p=0.013, respectively). Postnatal CD scars located at the level of the internal os or caudal to it, demonstrated an increased risk of niche development and suboptimal healing ratio (RR 1.7, 95%CI 1.0 - 3.0; p=0.041 and RR 2.7, 95%CI 1.3 - 5.7; p=0.005, respectively). (Supplementary Table 1)

Increased uterine vascular resistance (aOR 27.55, 95%CI 1.92-395.13; p=0.015) and the use of locked sutures for the first layer of uterine closure (aOR 7.77, 95%CI 1.92-31.37; p=0.004) were independently associated with niche development after

adjusting for maternal age, BMI and gestational age. These were the only two predictors that remained significant after post hoc bootstrap resampling and Bonferroni correction (adjusted α = 0.008), with corresponding p-values of 0.001 and 0.002, respectively. (Table 4)

There was a significantly higher proportion of suboptimally healed scars (CD niche and/or healing ratio ≤ 0.5) in women with scars located at or caudal to the internal os (cervical scars) compared to scars located cranial to the internal os (uterine scars): 50% vs 28.9%, p=0.041 and 42.1% vs 15.4%, p=0.005 (Figure 3). Cervical scars demonstrated significantly shorter niche length and niche width measurements compared to uterine scars: 3.8 mm (2.7- 5.1) vs 4.1 mm (3.7 - 5.7), p=0.023 and 4.1 mm (2.8 - 5.0) vs 4.6 mm (3.1 - 6.1), p=0.013, respectively. No significant difference was found in niche depth, which measured 3.2 mm (2.3 - 4.3) vs 3.1 mm (2.4 - 4.0), p=0.670. Supplementary Table 2 summarises maternal and neonatal outcomes.

Comment

Principal Findings

This study establishes that clinical antenatal, intrapartum and surgical factors significantly influence CD scar characteristics, which may affect future gynecological and reproductive outcomes. Advanced cervical dilatation and low fetal station during labor CD independently predict cesarean scar location near or within the cervix. Scars located at or caudal to the internal cervical os are at greater risk of suboptimal healing, such as niche formation or healing ratio ≤0.5 on postnatal US, despite demonstrating smaller niche dimensions, compared to scars within the uterus, cranial to the internal cervical os. Suboptimal CD scar healing is further associated with factors like increased second trimester uterine vascular resistance, the use of locked sutures for uterine closure and post-term pregnancy.

Results in the Context of What is Known

The scar visualisation rate in this study is consistent with previous studies in non-pregnant populations,[2,20] with niche formation rate comparable to non-selected cohorts with a history of CD (24%-70%).[6] Advanced labor CD significantly increases the likelihood of postnatal scars being located in the cervix, at or caudal to the internal os, providing insights into the mechanism linking full dilatation CD with an increased risk of sPTB in subsequent pregnancies. In women with advanced labor CD, the risk of sPTB in future pregnancies progressively increases with advancing cervical dilatation [8,21-25] In pregnancies following full dilatation CD, scars located within 5 mm of the internal os or within the cervix were associated with substantially higher sPTB risk (OR 6.9; 95% CI 1.3 – 58; p=0.035).[10] This study adds to our understanding of

how labor progression influences postnatal CD scar location and therefore its subsequent influence on sPTB risk in future pregnancies. Kamel et al reported a higher incidence of postnatal cervical scars in women undergoing advanced labor CB 97.7%, 42/43 compared to 65.4%, 35/54 observed in our study.[12] This difference may reflect variations in surgical techniques or ultrasound criteria for identifying cervical CD scar involvement.

The study found that lower fetal station at surgery also predicts a more caudal scar position, thereby augmenting the risk of cervical involvement. No other studies have specifically compared the impact of fetal station on scar location. Eriksson et al.[26] reported an association between the index CD with low fetal station in the maternal pelvis and a higher incidence of sPTB in subsequent pregnancies, regardless of cervical dilatation.

Regarding CD scar niche formation and stage of labor, existing evidence remains mixed. Several observational studies[27-30] have reported higher niche rates in pre-labor CD, while a secondary analysis of an RCT[31] and an observational study[32] have found higher rates in the labor group. Vikhareva et al.[11] described that low uterine incisions made at advanced labor stages were associated with a higher likelihood of a large scar defect, defined as RMT ≤ 2.5mm. Cervical scars can disrupt the local mucus formation process,[33] leading to suboptimal healing and higher niche rates compared to uterine scars. [34-37]

There is no uniform definition of what constitutes a large niche[6] and there is limited evidence regarding CD scar morphology according to the scar location. In this study, we found that niche dimensions were larger in uterine scars compared to cervical

scars, which may suggest that once a uterine niche forms, abnormal tension forces during healing lead to defects proportional in size to the amount of muscular tissue involved. This is supported by the myofiber disarray and elastosis observed in cases of uterine trauma.[38] However, smaller cervical scar niches may still have greater functional impact due to their relative size to the cervix and location.

Like other studies, we observed that advanced maternal age and raised BMI increase the likelihood of suboptimal cesarean scar healing.[30,39,40] There is mixed evidence regarding the recommended uterine closure techniques at CD. In the UK, the current National Institute for Clinical Excellence guidelines[41] suggest a choice between single or double layer uterine closure. Whilst four RCTs investigating the impact of locking sutures on uterine scar healing did not identify significant differences in niche rates,[31,42-44] one study reported larger niche area in the locked group (6.2mm^2, 95%CI 2.1-16.7 vs 3.8mm^2, 95%CI 1.9-8.2; p≤0.001).[44] Roberge et al.[45] reported that double layer continuous unlocked sutures was associated with better sonographic scar healing compared to single layer locked closure. However, a more recent multicentre RCT did not find any evidence demonstrating the superiority of double-layer closure over single-layer closure in reducing postmenstrual spotting after a first CD.[46] There is a suggestion that locking 'haemostatic' sutures may contribute to vascular occlusion,[47,48] potentially impairing the scar healing process, however, experimental studies supporting this theory are currently lacking. Other factors associated with CD in advanced labor – including increased intraoperative blood loss and use of additional haemostatic interventions may influence scar healing. In our cohort, uterine incision extensions were more frequent in women undergoing CD in advanced labor compared with early labor (30% vs 5.5%, p=0.007). While the implications of such extensions for long term scar healing remain uncertain, previous research has shown that the risk

of uterine extensions increases progressively with advancing cervical dilatation, rising from 6.2% at 0-5cm to 12.4% at 6-9cm and 16.8% at full dilatation ($p<0.001$).[49]

Increased uterine vascular resistance is a marker of impaired utero-placental perfusion, associated with pre-eclampsia and fetal growth restriction.[50] While transient hypoxia following an injury can trigger the wound healing process, maintaining adequate perfusion is essential, as prolonged hypoxia may lead to adverse outcomes.[51] Uterine artery impedance returns to non-pregnant levels within 12–14 weeks postpartum, but findings regarding early postnatal changes are inconsistent.[52] Additionally, it has been suggested that uterine artery undergoes regional hemodynamic adaptations in response to the menstrual cycle.[53] The complexity of uterine vascular dynamics and cesarean scar healing warrants further investigation, however, although uterine artery Doppler assessment is increasingly incorporated in UK antenatal care pathways[54], its routine use has not been universally adopted worldwide.

Clinical Implications

The National Health Service England recommends PTB surveillance for women with a history of full dilatation CD in subsequent pregnancies.[54] Although there is evidence suggesting an increased risk of PTB following advanced labour CD,[8,22,24] the cost effectiveness of broader screening is uncertain. Postnatal US can effectively assess CD scar location and aid in risk stratification, although its mapping to future pregnancy outcomes is yet to be studied.The literature has established associations between the presence of a cesarean scar niche and adverse obstetric and gynaecological outcomes. Long term conditions such as postmenstrual bleeding or pain appear to be linked to the presence of a niche[55] and more prevalent in women with a suboptimal

healing ratio,[19] posing significant impact on woman's quality of life.[56] Recent studies have also highlighted potential associations between cesarean scar niches and secondary subfertility[33,57] and that a large scar defect on US is a predisposing risk factor for recurrent scar pregnancy.[58] An increased risk of uterine dehiscence or rupture is associated with larger niches.[59, 60] Women with a pregnancy implanted within a scar niche face the risk of abnormally invasive placenta.[61] The effectiveness of surgical niche repair has been suggested for certain gynaecological symptoms but less investigated in relation with obstetric outcomes.[7,62,63]

Research implications

This study serves as a pilot for further investigations into the mechanisms of cesarean scar development and its impact on long-term maternal health. Given the uncertainty surrounding the optimal treatment for CD scar niches, further research is essential to identify modifiable risk factors and to standardise surgical techniques, which could enable targeted interventions for improved scar healing. In cases where prevention of these iatrogenic complications is not feasible, the development of predictive models based on postnatal ultrasound characteristics is crucial to guide triage and antenatal surveillance for women at increased risk of adverse outcomes in subsequent pregnancies.

Strengths and Limitations

A key strength of this study is its prospective design, which enabled the systematic collection of detailed clinical information and standardised US data across the cohort. Cesarean scars were assessed at a minimum of 4 months postpartum - while niche prevalence is unlikely to change beyond the early postpartum period,[14,55] longitudinal

changes in scar morphology may still occur due to ongoing scar remodelling. A small prospective study reported a significant reduction in the RMT/AMT ratio between 2 and 12 months postpartum (0.80 vs 0.54; p=0.002),[55] suggesting that the timing of assessment in our study may have influenced the observed healing ratios. Niche visualisation and morphological appearance may also be affected by cyclical endometrial changes related to the menstrual cycle,[2] potentially introducing variability in scar assessment. However, the high rate of amenorrhoea within our cohort likely minimised this source of bias.

Although there are multiple studies in the literature investigating the risk factors for CD scar defects, the lack of uniformity in the definition and method of assessment of scar niches makes it difficult to draw firm conclusions. The observational design limits causality inference and the relatively small sample size reduced statistical power. The generalisability of our findings may also be limited by the demographic profile of the cohort and unrecorded variations in surgical practice (e.g. incision placement, bladder flap creation, degree of emergency impacting on surgical steps, inclusion of decidual tissue during uterine closure suturing). Randomised controlled trials evaluating specific surgical interventions and including more diverse populations are required to validate these findings.

Conclusions

Cervical dilatation and fetal station independently predict cesarean scar location, with cervical dilatation being the stronger factor. Suboptimal CD scar healing is associated with BMI ≥ 25, increased second trimester uterine vascular resistance, gestational age > 40 weeks and cervical scars. Intraoperative factors, such as the use of locking sutures, also corelate with poor scar healing. The study highlights distinct outcomes

of CD scars based on their location and association with peripartum factors, laying the foundation for further research into the mechanisms of cesarean scar development and their long-term health implications.

Table Legends

Table 1 Characteristics of the study population

Table 2 Cesarean delivery scar ultrasound characteristics

Table 3 Cervical dilatation versus cesarean scar position

Table 4 Adjusted odd ratios for factors associated with niche development

Figure Legends

Figure 1 Measurements of cesarean scar niche

Figure 2 (a and b) Relationship between cervical dilatation and station of the fetal presenting part versus scar distance to the internal cervical os

Figure 3 Cesarean scar healing according to scar location

Supplementary Table Legends

Supplementary Table 1 (a, b, c and d) Antenatal, intrapartum, intraoperative and postnatal factors and cesarean scar healing

Supplementary Table 2 (a and b) Maternal and neonatal outcomes

Supplementary Figure Legends

Supplementary Figure 1 (a and b) Gynaecological features at postnatal cesarean scar assessment

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639 Table 1 Characteristics of the study population

Demographic characteristics, n=93	
Maternal age (years)	34 ± 4
<30	11 (11.8%)
30-39	73 (78.5%)
>40	9 (9.7%)
Ethnicity	
White	71 (76.3%)
Black	3 (3.2%)
South-East Asian	7 (7.5%)
East Asian	4 (4.3%)
Mixed/Other	8 (8.6%)
BMI 1st trimester of pregnancy (kg/m^2)	23.4 ± 3.5
<18.5	1 (1.1%)
18.5 – 24.9	60 (64.5%)
25.0 – 29.9	27 (29%)
>30	4 (4.3%)
Smoking status	
Never	80 (86%)
Ex-smoker	12 (12.9%)
Current smoker	1 (1.1%)
Pregnancy and labor characteristics, n=93	
Primiparous	83 (89.2%)
Gestational diabetes mellitus	7 (7.5%)
Hypertension/preeclampsia	3 (3.2%)
Spontaneous onset of labour	55 (59.1%)
Cephalic presentation	91 (97.8%)
Cervical dilatation	9
Fetal station	-1
Primary indication for CD	
Delayed progress in labour	40 (43.0%)
Suspected fetal compromise/pathological intrapartum CTG	33 (35.5%)
Chorioamnionitis	11 (11.8%)
Other*	9 (9.7%)
Uterine extensions	18 (19.3%)
Gestational age at birth (weeks)	40 ± 1 (37, 42)
37 - 40	63 (67.7%)
≥ 40	30 (32.3%)
Birthweight (g)	3.5 ± 0.4 (2.5, 4.6)
2 500 - 4 000	76 (81.7%)
≥ 4 000	17 (18.3%)
Postpartum haemorrhage ≥ 1000 mL	15 (16.1%)
Timing of postnatal ultrasound (months)	7 ± 2 (4, 12)

640 Data presented as median ± interquartile range for continuous variables and as
641 number of cases (percentage) for categorical variables. BMI, body mass index. CD,
642 cesarean delivery. CTG, cardiotocograph. Other*: breech presentation, placental
643 abruption, cord prolapse or maternal request.

644 Table 2 Cesarean birth scar ultrasound characteristics
645

CD scar characteristic	n=93
Cesarean scar visualisation	90/93 (96.8%)
Scar niche present	34/90 (37.8%)
Healing ratio ≤ 0.5	24/90 (26.7%)
Niche and healing ratio ≤ 0.5	23/34 (67.6%)
Niche classification	
Simple niche	32/34 (94.1%)
Niche with one branch	2/34 (5.9%)
Complex niche	0/34 (0%)
Cesarean scar position	
Cranial to the internal os	52/90 (57.8%)
At the internal os	19/90 (21.1%)
Caudal to the internal os	19/90 (21.1%)
Scar distance to the internal os (mm)	
Scars located cranial to the internal os	3.79 ± 2.05 (1.5, 12.9)
Scars located at the internal os	0 ± 0 (0, 0)
Scars located caudal to the internal os*	-3.36 ± 1.35 (-1.4, -6.7)
Niche measurements (mm)	
Niche length	3.95 ± 1.75 (1.8, 10.3)
Niche depth	3.15 ± 1.46 (1.5, 7.8)
Niche width	4.15 ± 2.32 (2.2, 14.6)
Residual myometrial/cervical thickness (mm)	6.80 ± 2.35 (1.8, 12.7)
Adjacent myometrial/cervical thickness (mm)	9.40 ± 1.97 (5.2, 15.4)

646 Data presented as median ± standard deviation (range) for continuous variables and
647 as number of cases (percentage) for categorical variables. CD, cesarean delivery.
648 *Mathematically positive value indicates that the CD scar is located cranial to the
649 internal os, negative value indicates that the CD scar is located caudal to the internal
650 os.
651
652

653 Table 3 Cervical dilatation versus cesarean scar position
654

Cervical dilatation	Number of cases			
	Cervical scar	**Uterine scar**	Total	
Advanced labour CD (8-10 cm)	35 (64.5%, 35/54)	19 (35.2%, 19/54)	54	**RR 7.77** (95% CI 2.586 - 23.391; p<0.001)
Early labour CD (4-7 cm)	3 (8.3%, 3/36)	33 (91.7%, 33/36)	36	
Total	38 (42.2%, 38/90)	52 (57.8%, 52/90)	90	

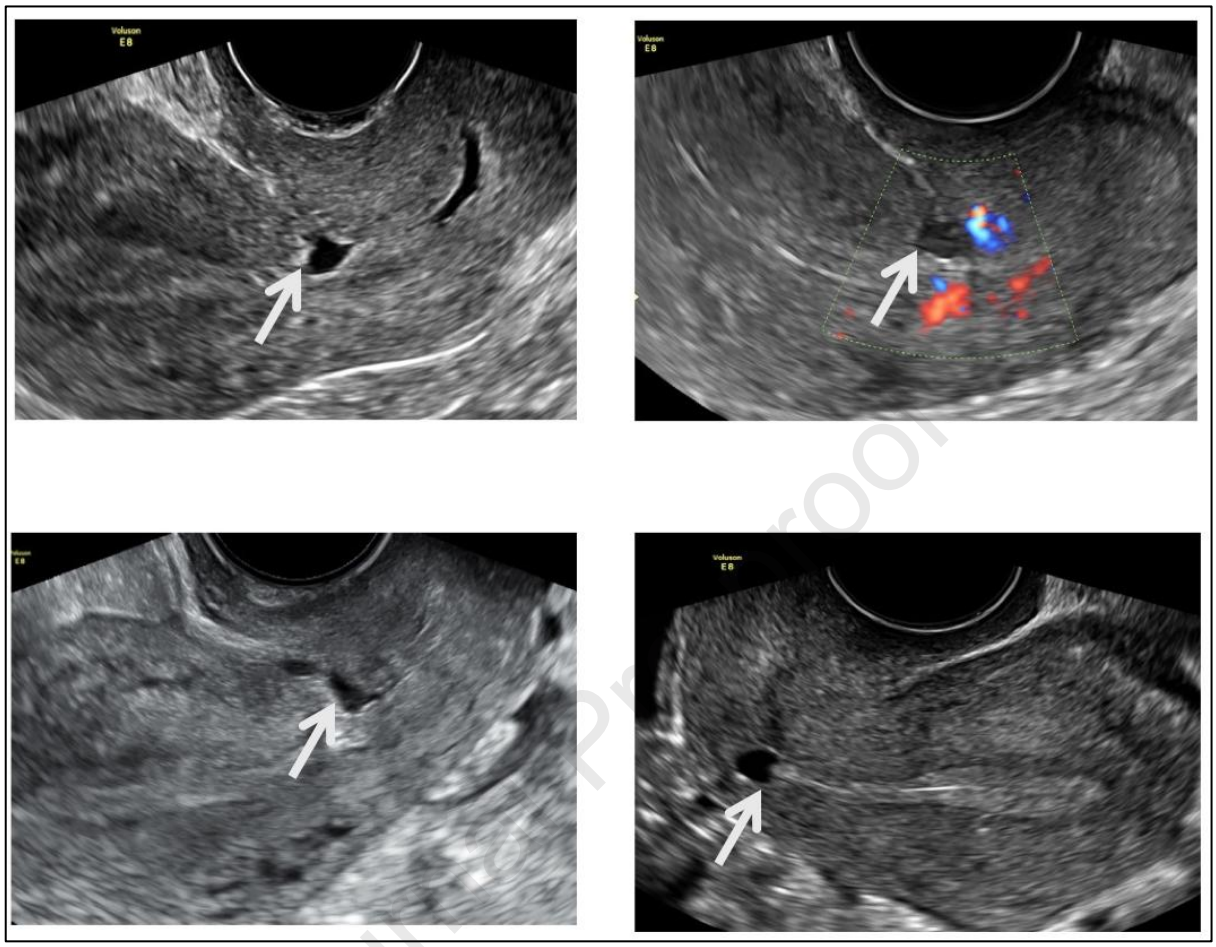
655 Cervical scar position includes CD scars at the level of the internal os or caudal to it.

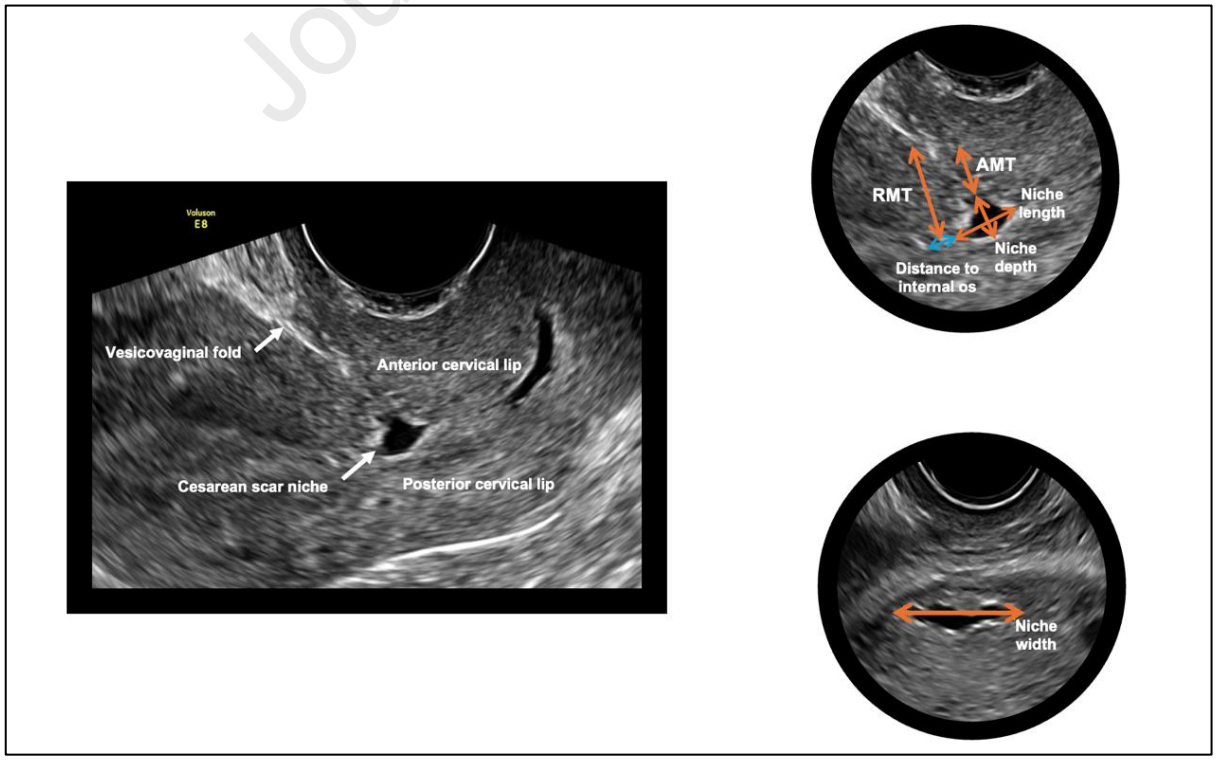
Table 4 Adjusted odd ratios for factors associated with niche development

	Cesarean scar niche		
	aOR (95%CI)	**p-value**	**Bootstrap p-value**
Age (years)	1.13 (0.96-1.32)	0.145	0.228
BMI (kg/m^2)	1.24 (0.99-1.56)	0.062	0.046
Gestational age at birth (weeks)	1.62 (0.87-3.05)	0.131	0.185
Raised uterine vascular resistance	27.55 (1.92-395.13)	0.015	0.001*****
Locked sutures 1st layer uterine closure	7.77 (1.92-31.37)	0.004	0.002*****
Cesarean scar located in the cervix	3.81 (1.01-14.51)	0.050	0.053

Multivariate logistic regression. Bootstrapping (n=1000). *Statistically significant after Bonferroni correction (adjusted α = 0.008). aOR, adjusted odds ratio. BMI, body mass index. Raised uterine vascular resistance defined as combined uterine arteries pulsatility index > 2.5 in the second trimester of pregnancy. Cesarean scar located in the cervix defined as scar situated at/caudally to the internal os on transvaginal ultrasound assessment.

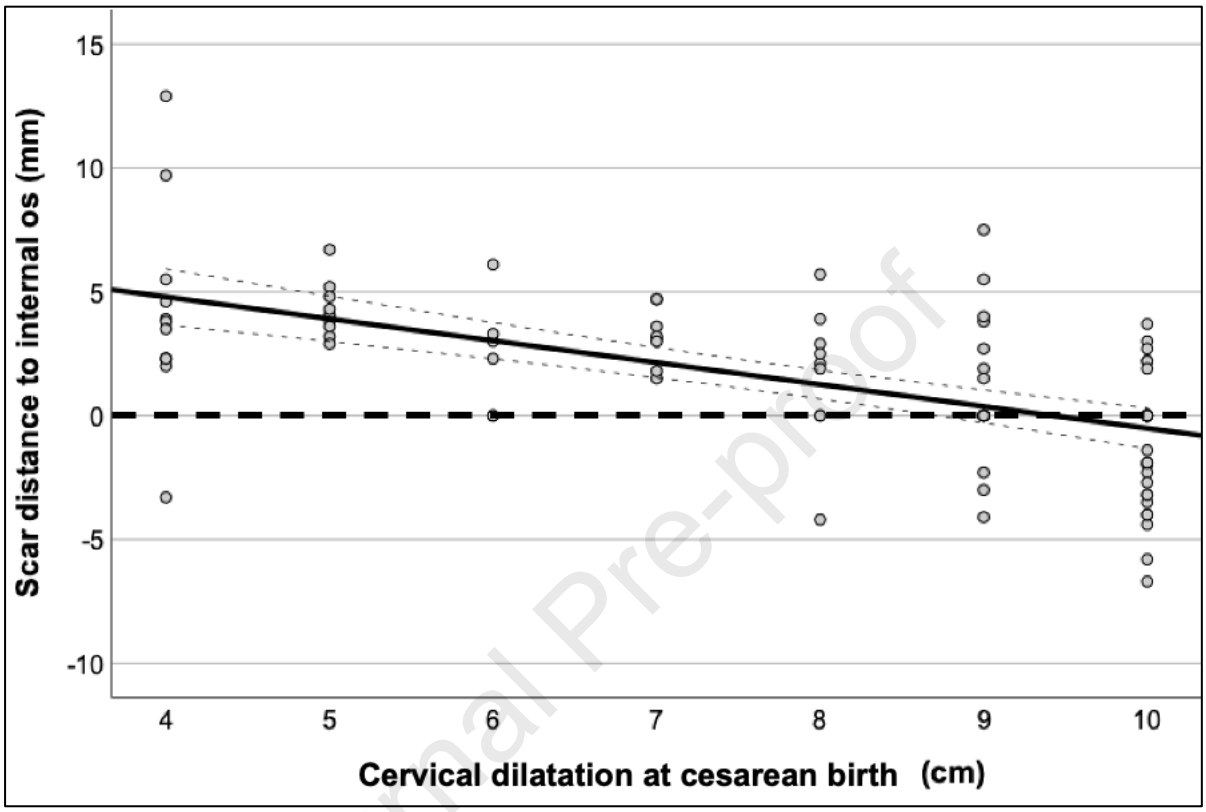
Figure 1 Measurements of cesarean scar niche



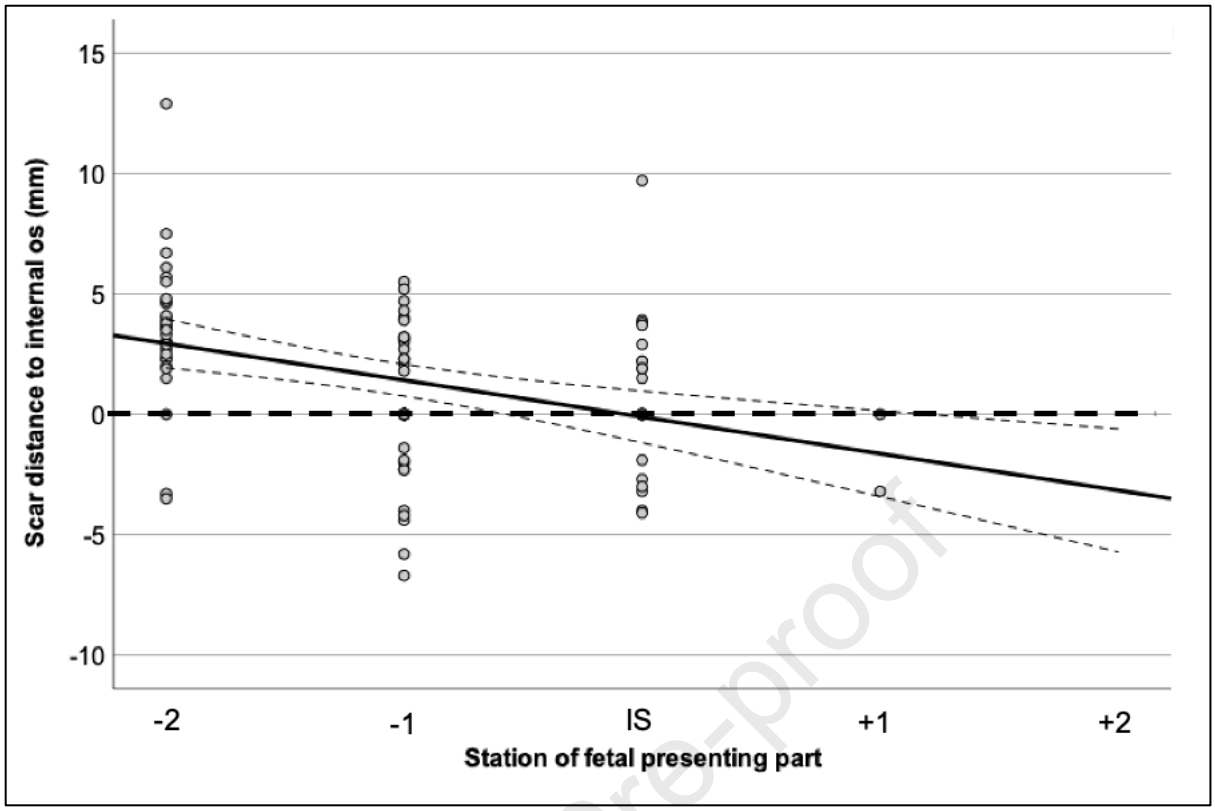


Grayscale transvaginal ultrasound image of the uterus and cervix showing cesarean scar niche measurements - sagittal plane (top right): Niche length and depth; Distance to internal os; RMT, residual myometrial thickness; AMT, adjacent myometrial thickness; coronal plane (bottom right) – Niche width.

Figure 2 (a and b) Relationship between cervical dilatation (top) and station of the fetal presenting part (bottom) versus scar distance to the internal cervical os

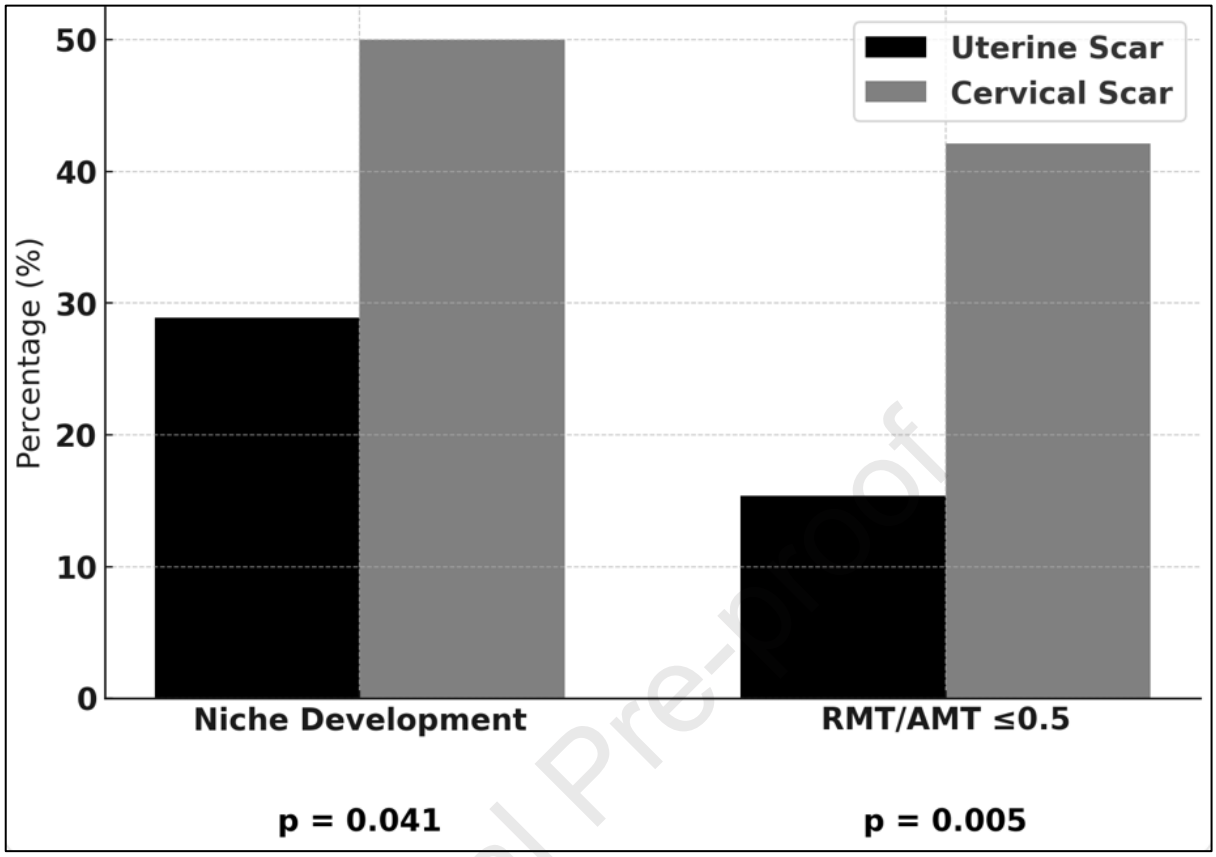


Continuous line - negative regression line. Fine interrupted line - 95% confidence interval of the mean. Horizontal bold interrupted line - level of the internal os. Linear regression analysis.



IS, maternal ischial spines. Continuous line - negative regression line. Fine interrupted line - 95% confidence interval of the mean. Horizontal bold interrupted line - level of the internal os = 0mm.

Figure 3 Cesarean scar healing according to scar location



	Early labour CD (4-7cm) n=36	Advanced labour CD (8-10cm) n=54	p value	Uterine scar n=52	Cervical scar n=38	p value
Niche development			0.478			**0.041**
Niche present	12 (33.3%)	22 (40.8%)		15 (28.9%)	19 (50%)	
Niche absent	24 (66.7%)	32 (59.2%)		37 (71.1%)	19 (50%)	
Healing ratio			0.846			**0.005**
RMT/AMT ≤0.5	10 (27.8%)	14 (26%)		8 (15.4%)	16 (42.1%)	
RMT/AMT >0.5	26 (72.2%)	40 (74%)		44 (84.6%)	22 (57.9%)	

Data presented as absolute value (n) and percentage calculated within the group of interest. Chi-square test to establish significance. Uterine scar - scar located cranial to the internal os. Cervical scar - scar located at/caudal to the internal os. CD, cesarean delivery. RMT, residual myometrial thickness. AMT, adjacent myometrial thickness.