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MATERNAL-FETAL MEDICINE

Cesarean section scar in 3 T magnetic resonance imaging and ultrasound: image characteristics and comparison of the methods

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Abstract

Purpose Uterine rupture during labor is a rare but life-threatening complication after previous cesarean section (CS). Prenatal risk is assessed using ultrasound thickness measurement of the lower uterine segment (LUS). Due to inhomogeneous study results, however, clinical obstetrics still lacks for standard protocols and reliable reference values. As 3 T magnetic resonance imaging (MRI) has not yet been sufficiently studied regarding LUS diagnostics after previous CS, we sought to evaluate its feasibility focusing on thickness measurements and typical characteristics of the CS-scar region in comparison to ultrasound and the intraoperative status.

Methods In this prospective study, 25 asymptomatic patients with one previous CS and inconspicuous ultrasound findings were included. An additional 3 T MRI with either a T2-weighted Turbo-Spin-Echo or a Half Fourier-Acquired-Single-shot-Turbo-spin-Echo sequence in a sagittal orientation was performed. We analyzed categorical image quality, inter- and intra-rater reliability as well as anatomy, morphology and thickness of the LUS. Results were compared to ultrasound and intraoperative findings.

Results MRI provided good to excellent image quality in all patients. The imaged structures presented with a high variability in anatomy and morphology. Image characteristics indicating the uterine scar were only found in 11/25 (44%) patients. LUS thickness measurements with MRI showed good inter- and intra-rater reliability but poor agreement with ultrasound.

Conclusions MRI is appropriate for additional LUS diagnostics in patients with previous CS. The strong individual variability of LUS-anatomy and morphology might explain the difficulties in establishing uniform diagnostic standards after CS.

Keywords Cesarean section · Prenatal diagnosis · Magnetic resonance imaging · Ultrasonography · Uterine rupture

Introduction

One of the main concerns in birth planning after previous cesarean section (CS) is the risk for the rare (0.4–0.9%) but life-threatening complication of scar rupture during birth [1]. Due to vaginal birth rates after cesarean section (VBAC) of up to 87% women are usually encouraged for a trial of labor (TOL) but have to be carefully selected balancing the individual benefits and risks [2–4]. Since introduced into clinical routine in 1996, the role of lower uterine segment (LUS) thickness measurement for preselection has been evaluated in numerous studies over the last 20 years [5–9]. Today, there is consensus about an inverse proportionality of the LUS thickness and the risk for uterine rupture. However, inhomogeneous study results reflect limited reliability of ultrasound for LUS diagnostics. Transvaginal (TVS) and transabdominal ultrasound (TAS) or the combination of both is inconsistently used with 2D or 3D techniques. Furthermore, LUS thickness is measured including parts of the urinary bladder wall (full LUS thickness) in some studies and only the mere myometrial layer (myometrial LUS thickness) in other studies. As a result, cut-off values for the thin LUS show wide ranges of 3.1–5.1 mm for the full and 2.1–4.0 mm for the myometrial thickness [6–12]. The clinical use is also limited because the hysterotomy scar cannot directly be

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visualized in later pregnancy in most cases. Choosing the point of measurement at the thinnest LUS area instead is highly subjective and results in a high observer dependency. Moreover, the known ultrasound limitations, particularly by the small field of view, varying insonation angles and patient constitution additionally restrict the capability of ultrasound LUS diagnostics.

MRI is a safe imaging modality during pregnancy that provides accurate tissue differentiation without the need of contrast agents and independent of patient constitution or other ultrasound limitations [13]. As recently published by our group, MRI can be useful for additional LUS diagnostics during pregnancy after previous CS but its potential is still insufficiently investigated [14–16]. Until today, anatomy and morphology of the LUS and the hysterotomy scar have never been evaluated with 3 T MRI. Therefore, we sought to assess feasibility and reliability of LUS and scar imaging with 3 T MRI in a low-risk group of pregnant women after previous CS with inconspicuous ultrasound findings. Using fast T2-weighted sequences, we describe the typical anatomy and morphology of the LUS as well as characteristics of the uterine scar and performed LUS thickness measurements. MRI findings were compared to ultrasound and intraoperative findings.

Materials and methods

This study was approved by the local ethics committee (AZ 024/14ff) and was performed in accordance with the ethical standards of the Declaration of Helsinki and its later amendments. Informed consent was obtained from all individual participants included in the study. None of the authors received funding.

We prospectively studied 25 consecutive patients with one previous CS and singleton pregnancy in the third trimester of pregnancy. In our level 1 perinatal care center, regular selection and birth planning were performed [17]. According to our in-house guidelines, all women underwent an additional transabdominal LUS thickness measurement. Only low-risk patients with an inconspicuous medical history, absent clinical symptoms and normal ultrasound LUS findings were included into the study. These patients underwent an additional 3 T MRI examination within the following week. Exclusion criteria were multiple pregnancies, multiple CS, suspected abnormal invasion of the placenta, a suspected LUS dehiscence and common MRI contraindications such as ferromagnetic implants or claustrophobia.

Ultrasound was performed once by an experienced investigator (J.H.) on a Voluson E8 Expert system using a 3–8-MHz abdominal probe for TAS and a transvaginal probe for TVS. Since previously analyzed in numerous studies with large patient numbers we did not evaluate inter-rater and intra-rater reliability of the ultrasound measurements. For better contrast patients were asked to have a full-filled urinary bladder. Description of the LUS and thickness measurements were performed in sagittal slices as previously described (Fig. 1) [11]. In a first suprasymphysary scan from the left to the right, we assessed LUS continuity. The full LUS and the myometrial LUS thickness were measured where the LUS was thinnest. LUS was considered thinned out if the full LUS thickness was < 2.5 mm or the myometrial LUS thickness < 2.0 mm. A LUS thickness < 1.0 mm was interpreted as dehiscence and patients were not included (Table 1).

MRI was performed on a 3 T MRI system (MAGNETOM Trio, Siemens Healthineers, Erlangen, Germany) with a two-channel body matrix coil. Patients were scanned in a supine position. The urinary bladder was requested to be full. For LUS diagnostics and measurements, a standard T2-weighted Turbo Spin Echo (T2-TSE) and a Half Fourier Acquired Single-shot Turbo spin Echo (T2-HASTE) sequence were acquired in a sagittal orientation, adjusted to the cervical channel in each patient. The detailed sequence parameters are given in Table 2. An additional axial T2-HASTE sequence was used to improve orientation.

MRI was analyzed by two experienced investigators (J.H. and M.E.). Image quality was evaluated using the following Likert scoring system: category 1-excellent quality/no artifacts, 2-acceptable quality/artifacts but diagnostic quality, 3-non diagnostic quality/strong artifacts. The filling level of the urinary bladder was categorized as sufficient (full-filled) or non-sufficient (partially filled).

The LUS was defined as the thin layer between the myometrium of the uterine front wall above and the cervix below it. After assessing continuity of the LUS, we described its anatomy (position in relation to the urinary bladder wall, extension, distance to the internal uterine orifice) and morphology (MRI signal intensity in comparison to the myometrium of the uterine front wall: hyperintense/hypointense/isointense; tissue homogeneity: homogeneous/heterogeneous; regularity of the outline borders: regular/irregular). Signal alterations indicating the hysterotomy scar were assessed and described.

According to ultrasound, we performed LUS thickness measurements directly at the scar if visible or alternatively where the LUS was thinnest. If possible to define we measured the myometrial LUS layer and if not only the full LUS thickness as demonstrated in Fig. 2. For analysis, we used the thinnest LUS thickness. An LUS thickness < 2.0 mm was considered to be thinned out and < 1.0 mm dehiscent.

Birth planning and medical decisions were not influenced by MRI findings. A repeated CS was planned with 38^0–39^0 weeks if the LUS was thinned out (full LUS thickness > 1<2.5 mm) and with 39^0–40^0 weeks if the LUS thickness was ≥ 2.5 mm. Patients with planned TOL

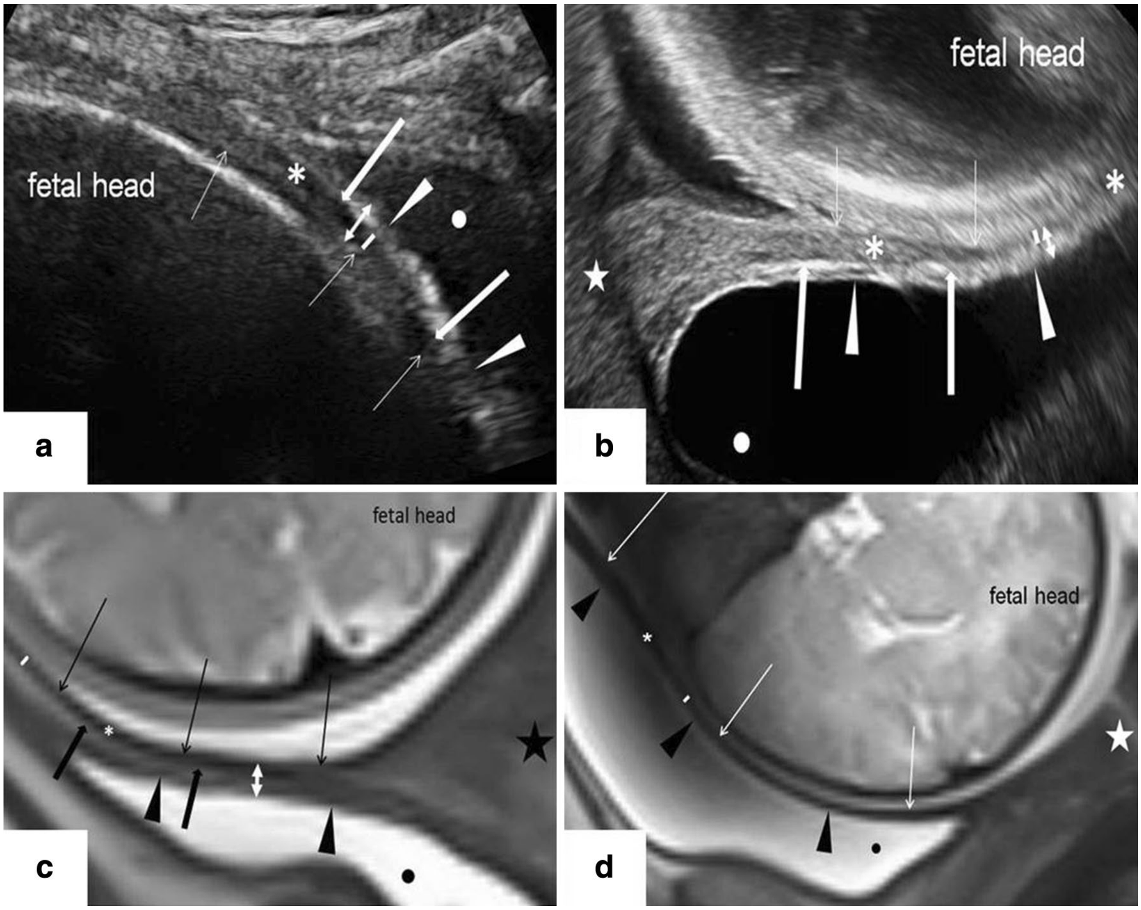

Fig. 1 Thickness measurements of the lower uterine segment (LUS) using transabdominal (**a**) and transvaginal (**b**) ultrasound and MRI (**c**, **d**), determined at the thinnest point. *Thin arrows* interface decidua/amniotic fluid, *bold arrows* interface LUS/urinary bladder wall, *arrow heads* interface urinary bladder wall/urine, *asterisk* LUS, *point* urinary bladder, *star* cervix. Full LUS thickness (double arrow) and LUS myometrial thickness (line) were measured analog in ultrasound (**a**, **b**) and MRI (**c**). If the interface LUS/urinary bladder was not to define at the thinnest point (**d**), full LUS thickness (line) was measured

were managed observantly until 41^3 weeks. In patients who delivered by repeated CS, integrity of the LUS was intraoperatively classified according to the Qureshi system: grade I—LUS well developed, grade II—LUS thin but intact/uterine contents not visible, grade III—scar dehiscence/uterine contents visible, grade VI—uterine rupture (Fig. 2) [18]. Primary fetal outcome was evaluated by the classical parameter gestational age at birth, fetal birth weight, umbilical artery pH and APGAR value.

For statistical analyses, non-parametric tests were used due to the small sample size. Descriptive statistical analyses were performed. Inter- and intra-rater reliabilities of LUS thickness measurements were calculated using intra-class correlations (ICC) with a two-way mixed model. Agreements were considered fair to good if ICC was 0.45–0.75, good if ICC was 0.75–0.90 and excellent if ≥ 0.90 [19, 20]. Bland–Altman plots were used to represent the results graphically. *p* values of 0.05 were considered statistically significant. The 95% confidence intervals are given. IBM SPSS Statistics 22 was used for all statistical analyses.

Results

Patient characteristics are given in Table 1.

T2-TSE and T2-HASTE sequences provided an excellent anatomic overview of the uterus in total, the LUS and surrounding structures. Diagnostic image quality was achieved in all patients and was even excellent in 22 (88%) patients (Table 3). None of the women requested interruption of the examination. Due to short acquisition times, fetal movement artifacts only occasionally limited image quality and sequences could quickly and easily be repeated, if necessary. In our patient group, T2-TSE sequences had to be repeated in two patients. Due to its shorter acquisition time, the T2-HASTE sequence was less vulnerable to fetal movement artifacts than the T2-TSE sequence. On the other

Table 1 Patient characteristics

	Patient group ($n=25$)
Maternal age at examination (years)	35 (IQR 7.5)
Gestational age (weeks)	
At sonography	37 (IQR 3)
At MRI	37 (IQR 5)
Days between sonography and MRI	6 (IQR 6.5)
Gravidity (*n*)	3 (IQR 1)
Parity (*n*)	1 (IQR 1)
Patients with prior vaginal delivery (*n*)	9 (36%)
Patients with prior VBAC (*n*)	5 (20%)
Prior cesarean section was	
Elective	8 (32%)
Emergency, during 1st stage	12 (48%)
Emergency, during 2nd stage	5 (20%)
Maternal body mass index	23.2 (IQR 7)
Maternal diseases (*n*)	9 (36%)

Parameters are given as median [interquartile range (IQR)] or total amount (%)

VBAC vaginal birth after cesarean section)

hand, in case of absent fetal movement T2-TSE sequences provided more detailed tissue contrasts.

With MRI the LUS was diagnosed to be intact in all patients, which was confirmed by intraoperative findings. As demonstrated in Fig. 3, anatomy of the LUS differed strongly. Because mostly thinned, the LUS was generally well definable from the uterine front wall and the cervical myometrium. The longitudinal LUS extension differed strongly within the patient group (48 mm, 20–88 mm), (Fig. 3a–d). Due to individual anatomy, its main part (> 50%) was mostly [20/25 (80%)] but not always located behind the urinary bladder wall (Fig. 3a–c). In 5/25 (20%) patients, it was detected even above the urinary fold (Fig. 3d). Besides anatomy, also morphologic criteria of the LUS differed individually. Compared to the adjacent myometrium of the uterine front wall and the cervix, the signal intensity of the LUS was frequently hypointense [19/25 (76%)]. However, since 6/25 (24%) patients showed an isointense MRI signal, this was not a specific finding. The inner and outer boundaries of the LUS appeared regularly in 14/25 (56%) (Fig. 4a) and irregularly in 11/25 (44%) patients (Fig. 4d).

Circumscribed blurred or irregular LUS borders, inhomogeneous tissue signal characteristics and prompt changes in diameter as demonstrated in Fig. 4 were interpreted as signs of the hysterotomy scar and were visible in 11/25 (44%) patients. If typical scar signs were not apparent, we assumed the scar at the thinnest LUS dimension. We found strong variations of the distance between the scar and the internal cervical orifice (42 mm; 11–83 mm), reflecting strong variations in location of the hysterotomy scar, which even was not always located within the LUS. Since mostly located behind the urinary bladder wall (21/25 (84%), it was determined above the urinary fold in 3/25 (12%) patients and within the cervical myometrium in 4/25 (16%) patients (Fig. 4). Our study group showed a significant relation between the time of the previous cesarean section and the anatomical location, related to the cervix. The uterine scar of patients with a cesarean section during the second stage of delivery was detected significantly closer to the internal uterine orifice than those of patients with an elective CS or a CS during the first stage of delivery ($p=0.022$, Fig. 5).

Although requested to be full, MRI showed optimal urinary bladder filling in only 14/25 (56%) patients. LUS thickness did not differ in patients with sufficient and insufficient bladder filling level ($p = 0.852$, $p = 0.893$, $p = 0.851$).

T2-HASTE and T2-TSE images were appropriate for full LUS thickness measurements in all patients but the myometrial layer was definable in only 18/25 (72%) patients. Results from LUS thickness measurements are given in Table 3, comparing MRI and ultrasound.

Intra class correlations (ICC) and differences of the means with their standard deviations are given in Table 4. As shown there, TVS agreed better with both T2-weighted MRI sequences than with TAS but overall agreement between ultrasound and MRI measurements was at most moderate. Contrarily, agreements and also inter- and intra-rater reliability between the T2-weighted MRI sequences were good to excellent. As demonstrated by the corresponding Bland–Altman plots the differences of the means were largely in the submillimeter range and therefore within clinically acceptable limits (Table 4, Fig. 6).

Table 2 MRI protocol parameters

Sequence	Slice thickness (mm)	TR (ms)	TE (ms)	Matrix	Inplane resolution (mm)	Orientation
T2-HASTE	5	800	89	320 × 320	0.9 × 1.2	Axial
T2-HASTE	4	1500	95	320 × 320	0.9 × 1.2	Sagittal
T2-TSE	3	4110	126	192 × 192	1.2 × 1.3	Sagittal

T2-HASTE T2-weighted Half Fourier-Acquired Single shot Turbo spin Echo sequence, *T2-TSE* T2-weighted Turbo-Spin-Echo sequence, *TR* time to repeat, *TE* time to echo

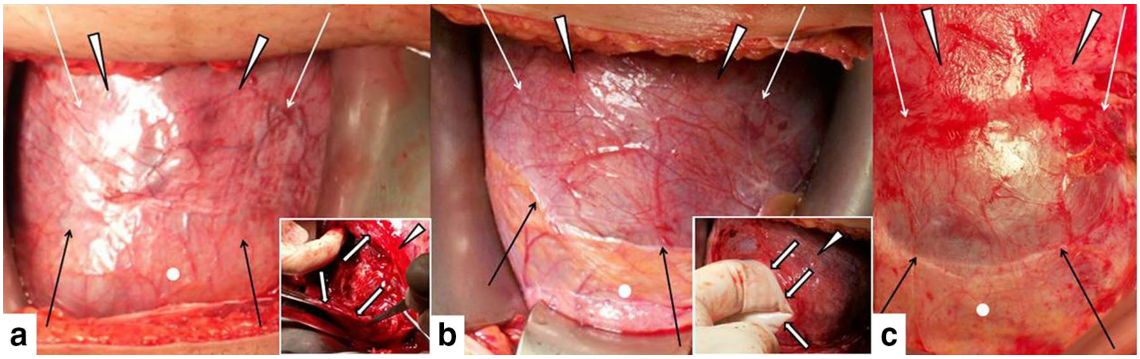

Fig. 2 Intraoperative classifications using the Qureshi scoring system. **a** Grade I—lower uterine segment (LUS) well developed. **b** Grade II—LUS thin but intact/uterine contents not visible, **c** Grade III—scar dehiscence/uterine contents visible. A grade IV finding of a uterine rupture describing a connection between uterine and abdominal cavity is not shown. A grade II finding can foremost be defined after incision (**b**, small pictures) but is sometimes difficult to differentiate against a grade I finding (**a**, small picture). In grade I and grade II findings, uterine and urinary structures are more difficult to differentiate than in grade III findings (**c**). In **c**, the LUS appears more transparent, so that amniotic fluid and the fetal head shimmer through the LUS wall. *Thin white arrows* upper boarder of the LUS, in **a** and **b** only to estimate, *thin black arrows* upper boarder of the urinary bladder, in **a** and **b** only to estimate, *arrow heads* myometrium of the lower uterine front wall, *bold arrows* LUS myometrium after incision, *point* urinary bladder

Table 3 Comparison of image quality

	Ultrasound ($n=25$)		MRI ($n=25$)	
	TAS	TVS	T2-TSE	T2-HASTE
Image quality				
Excellent	22 (88%)	24 (96%)	10 (40%)	19 (76%)
Acceptable	3 (12%)	1 (4%)	15 (60%)	6 (24%)
Non diagnostic	0	0	0	0
LUS thickness (mm)				
Myometrial layer	2.5 (IQR 1.5)	2.1 (IQR 1.3)	2.1 (IQR 0.9)	1.9 (IQR 1.1)
Full LUS	5.0 (IQR 1.6)	4.8 (IQR 1.8)	4.9 (IQR 2.7)	4.5 (IQR 1.8)
Thinnest measurement			2.2 (IQR 0.7)	2.1 (IQR 0.7)
LUS integrity in MRI (*n*)				
Normal	25	19	20	16
Thinned out	0	6	5	9
Dehiscent	0	0	0	0
Complete rupture	0	0	0	0

Quality is demonstrated with the Likert scale system with category 1-3. LUS-thickness is given as median [interquartile range (IQR)], LUS-integrity as absolute numbers

TAS transabdominal ultrasound scan, *TVS* transvaginal ultrasound scan, *T2-TSE* T2-weighted Turbo-Spin-Echo sequence, *T2-HASTE* T2-weighted Half Fourier-Acquired Single shot Turbo spin Echo sequence, *LUS* lower uterine segment thickness and integrity in ultrasound and MRI

Transvaginal and transabdominal ultrasound provided diagnostic image quality in all patients and the LUS structures could be imaged highly resolved in most patients (Table 3). Nevertheless, signs of the hysterotomy scar, such as changes in diameter, blurred contours or inhomogeneous echogenicity were only seen in 3/25 (12%) patients. Table 3 shows results of ultrasound LUS thickness measurements. As presented in Table 4, LUS thickness agreed better between TVS and TAS if the full myometrial thickness was determined. Agreements between ultrasound and MRI measurements were fair.

A repeated CS was indicated in 15/25 (60%) patients because of mother's request (4/15, 26.6%), additional breech presentation (2/15, 13.3%), fetomaternal disproportion (1/15, 6.7%), a thin LUS in ultrasound (4/15, 26.6%), a pathologic CTG related to intrauterine fetal growth restriction (1/15, 6.7%), failed induction of labor (1/15, 6.7%) and obstructed labor during the dilation (1/15, 6.7%) or expulsion phase (1/15, 6.7%).

Intraoperative findings confirmed the non-invasive prenatal diagnosis of an intact LUS in all patients. An LUS thinning was intraoperatively found in six patients (Table 5)

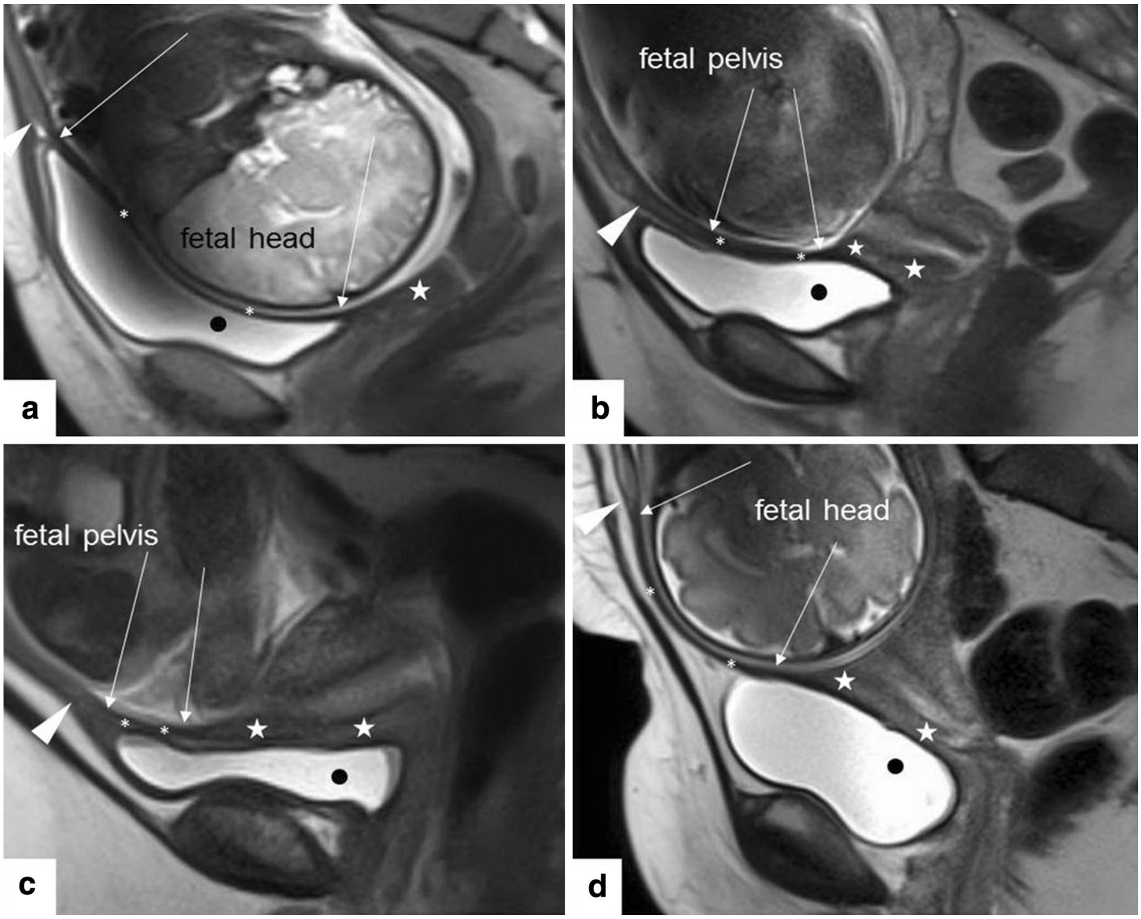

Fig. 3 Variability of the anatomy and morphology of the lower uterine segment (LUS). The LUS (asterisk, area between the thin arrows) is clearly identifiable by a significant thinning between the lower anterior uterine wall (arrow heads) and the cervix (stars). The MRI signal of the LUS is frequently hypointense. Proportions of the uterine front wall, the LUS and the cervix behind the urinary bladder as well as the LUS extension differed individually strongly. The LUS was mostly (**a**–**c**) but not always located behind the urinary bladder (**d**). Differentiation between the LUS and the posterior bladder wall was mostly (**b**, **c**) not always possible (**a**)

but only confirmed the MRI finding in three cases. In one case, intraoperative thinning was prenatally diagnosed with ultrasound but not with MRI and in two cases neither with ultrasound nor with MRI. An intraoperative grade I finding was prenatally diagnosed as LUS thinning with MRI and ultrasound in two patients and only with MRI in another patient.

The fetal and maternal outcome was appropriate in all patients and did not differ between the vaginal and the cesarean delivery group (Table 5).

Discussion

Our data show that 3 T MRI is a valuable complementary imaging modality to ultrasound in LUS diagnostics. With the use of fast T2-weighted sequences short acquisition times can be achieved resulting in reduction of movement artifacts. If necessary, MRI scans can be easily and quickly repeated, so that good to excellent image quality can routinely be obtained with a great comfort for advanced pregnant women and therefore high patient acceptance. Patient comfort can also be increased neglecting the condition of the urinary bladder filling level, particularly because it does not seem to influence the LUS thickness and cannot be standardized, anyway.

Our results emphasize challenges in current ultrasound LUS diagnostics primarily resulting from a high variability in anatomy and morphology. High spatial and temporal resolution is a clear strength of ultrasound but the advantage of higher flexibility by real-time adjustments is accompanied by a higher observer dependency. The well-known ultrasound limitations additionally challenge LUS diagnostics in clinical routine [10, 11]. Accordingly to the current literature, we found the best image quality for TVS which is less affected by patient constitution than TAS [15, 16]. For

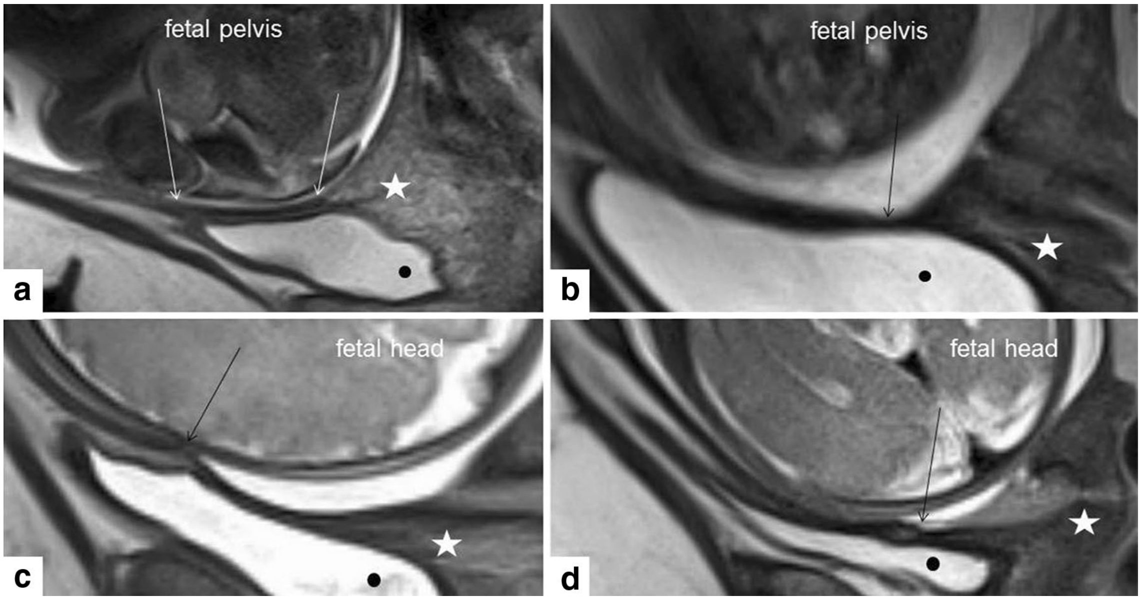

Fig. 4 Typical findings of the scarred lower uterine segment (LUS). A thick and intact, hypointense LUS (tissue between the thin white arrows) was common and might reflect an optimal uterine scar healing (**a**). Signs of the uterine scar such as a circumscribed thinning with abrupt change of LUS diameter (thin black arrows, **b** and **c**), irregular/diffuse wall borders (**c** and **d**) and inhomogeneous signal intensity in T2 sequences (**c** and **d**) in this area were observed in only a few patients

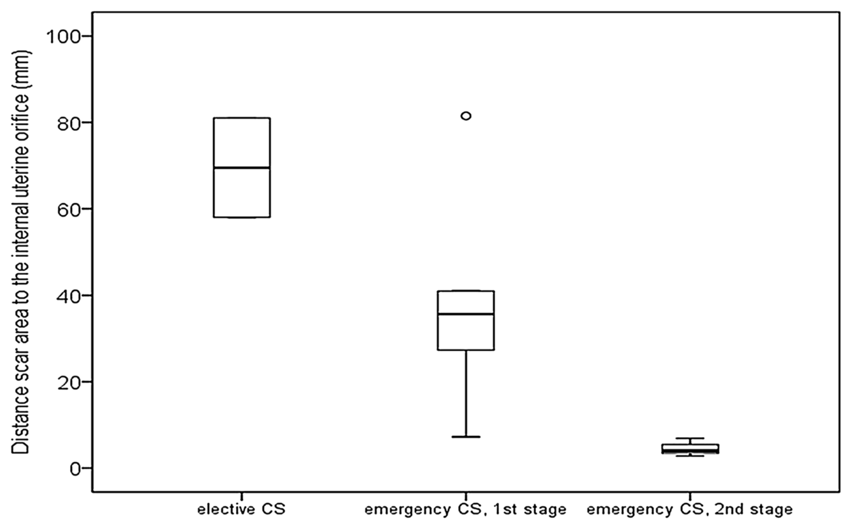

Fig. 5 Relation between time of the previous cesarean section (CS) and location of the uterine scar. Elective CS: cervix closed, Emergency CS, first stage: cervical dilation ≤ 7 cm, Emergency CS, second stage: cervical dilation > 7 cm

LUS diagnostic, however, image quality is less important than finding the area of risk. TVS is appropriate for imaging of the cervix and the lower to the middle LUS parts. With TVS also the upper LUS parts can frequently be imaged. Conversely, TAS rather images the upper to the middle and only rarely the lower LUS parts or the cervix. As we could show that particularly patients with a previous cesarean section during later stages of delivery are at risk for lower uterine scar locations TAS might miss detection and therefore measurement at the correct level. A low uterine incision has also been depicted as a pitfall of LUS diagnostic in other studies [21]. Because the restriction of their specific fields of view can hamper each ultrasound modality, we support the recommendation of a consequent simultaneous use of TVS and TAS [8].

As we could show, MRI provides reliable imaging and an excellent anatomical overview, notwithstanding ultrasound limitations. One clear benefit of MRI is that all parts of the cervix, the LUS and the whole anterior uterine wall can simultaneously be visualized. Therefore, defining the point of measurement at the suspected scar area, either by tissue alterations or the strongest LUS thinning, is more reliable with MRI than with ultrasound and results in a lower observer dependency and better measurement agreements.

Table 4 Intraclass correlation coefficient/mean of difference (mm) [standard deviation (mm)] between LUS measurements in MRI and ultrasound; inter-rater and intra-rater reliability for MRI sequences

	Full LUS	LUS myometrium	Thinnest measurement
T2-HASTE to			
TAS	0.393/– 1.622 (1.549)**	– 0.230/– 0.842 (0.992)*	
TVS	0.632/– 1.384 (1.279)**	0.561/– 0.466 (0.778)*	0.821/– 0.294 (0.659)*
T2-TSE	0.835/0.300 (0.863)	0.954/– 0.042 (0.213)	
T2-TSE to			
TAS	0.629/– 1.923 (1.264)**	– 0.631/– 0.933 (1.442)	
TVS	0.590/– 1.685 (1.279)**	0.700/– 0.117 (0.584)	
TAS to TVS	0.743/0.242 (1.158)	0.408/0.639 (1.012)*	
Inter-rater reliability			
T2-HASTE	0.875/0.395 (0.564)*	0.572/0.129 (0.573)	0.684/– 0.236 (0.554)*
T2-TSE	0.884/0.184 (0.915)	0.942/0.067 (0.207)	0.800/0.448 (0.653)*
Intra-rater reliability			
T2-HASTE	0.840/0.297 (0.820)	0.769/– 0.027 (0.384)	0.712/– 0.108 (0.617)
T2-TSE	0.863/– 0.320 (0.755)*	0.707/1.350 (0.652)**	0.821/– 0.344 (0.504)*

T2-HASTE T2-weighted Half Fourier-Acquired Single shot Turbo spin Echo sequence, *TAS* transabdominal ultrasound scan, *TVS* transvaginal ultrasound scan, *LUS* lower uterine segment, *TAS* transabdominal ultrasound scan, *TVS* transvaginal ultrasound scan, *T2-TSE* T2-weighted Turbo-Spin-Echo sequence, *LUS* lower uterine segment

Significant differences from 0 are marked *$p < 0.005$, **$p < 0.001$

Contrarily to our results, there are current studies that found better accuracy for ultrasound than for MRI. However, one of these studies suffers from severe methodological deficits [22]: First, the authors used an MRI orientation perpendicular to the uterine scar, which by our and also other authors experience can image the scar only in very few patients with previous CS [12]. Because the hysterotomy scar does not always express specific tissue alterations, we recommend the use of an orientation in adjustment to the cervix. Second, the given figures in this study suggest that different anatomical structures were measured with MRI and ultrasound. Furthermore, the LUS in the third trimester of pregnancy appears unusually thick, particularly considering the high amount of scar defects. Also the calculated accuracy of imaging and intraoperative findings appears mismatching [16, 23]. In another study, diagnostic accuracy and agreement of the methods were not tested with adequate statistic methods [16].

Besides visualization, also the current standard measurement techniques of LUS thickness must be emphasized as a potential source of a systemic error in current ultrasound studies [11]. They are based on the assumption that the LUS or the scar area is located somewhere behind the urinary bladder wall. Furthermore, the full LUS thickness measurement includes parts of the urinary bladder wall. MRI, however, showed that the scar region was mostly behind the urinary bladder but in some patients also beyond the LUS, above the bladder or as discussed above, within the cervix [21]. Also differentiation between myometrial layer and bladder wall is not always given. Consequently, LUS measurements with standard ultrasound techniques would not be appropriate in these cases. This might be a further reason for study inhomogeneity and also for the poor agreement of ultrasound and MRI measurements in our and previous studies [15, 16, 22]. It is likely that LUS thickness was measured at different locations with MRI and ultrasound but this should not be misinterpreted as an inferiority of MRI [16, 22].

Because of the small sample size, our study could not evaluate significant influencing factors on LUS measurement, and moreover, could not provide reference values for LUS thickness after previous CS. However, our observations underline difficulties finding such values. Since LUS thickness and uterine rupture have shown to be related, we do not question the usefulness of prenatal LUS imaging but suggest that future studies should carefully revise current LUS diagnostic and prenatal selection before TOL after previous CS [7–9, 24, 25]. We think that an algorithm which is adjustable to the individual patient condition could provide a better reliability. Both imaging modalities, ultrasound and MRI have their specific strengths and limitations, summarized in Table 6. Because of its high availability, low costs, good operability and its high temporal and spatial resolution, we think that ultrasound is the most suitable first-line imaging modality for LUS diagnostic after CS in clinical routine. We support recent recommendations of a detailed ultrasound examination by a trained investigator using both, TAS and TVS in combination [8, 24]. TAS should include a detailed scan also of the lower uterine front wall. If ultrasound conditions are limited or for suspected anomalies, we consider enhanced diagnostic with MRI to be useful as second-line imaging

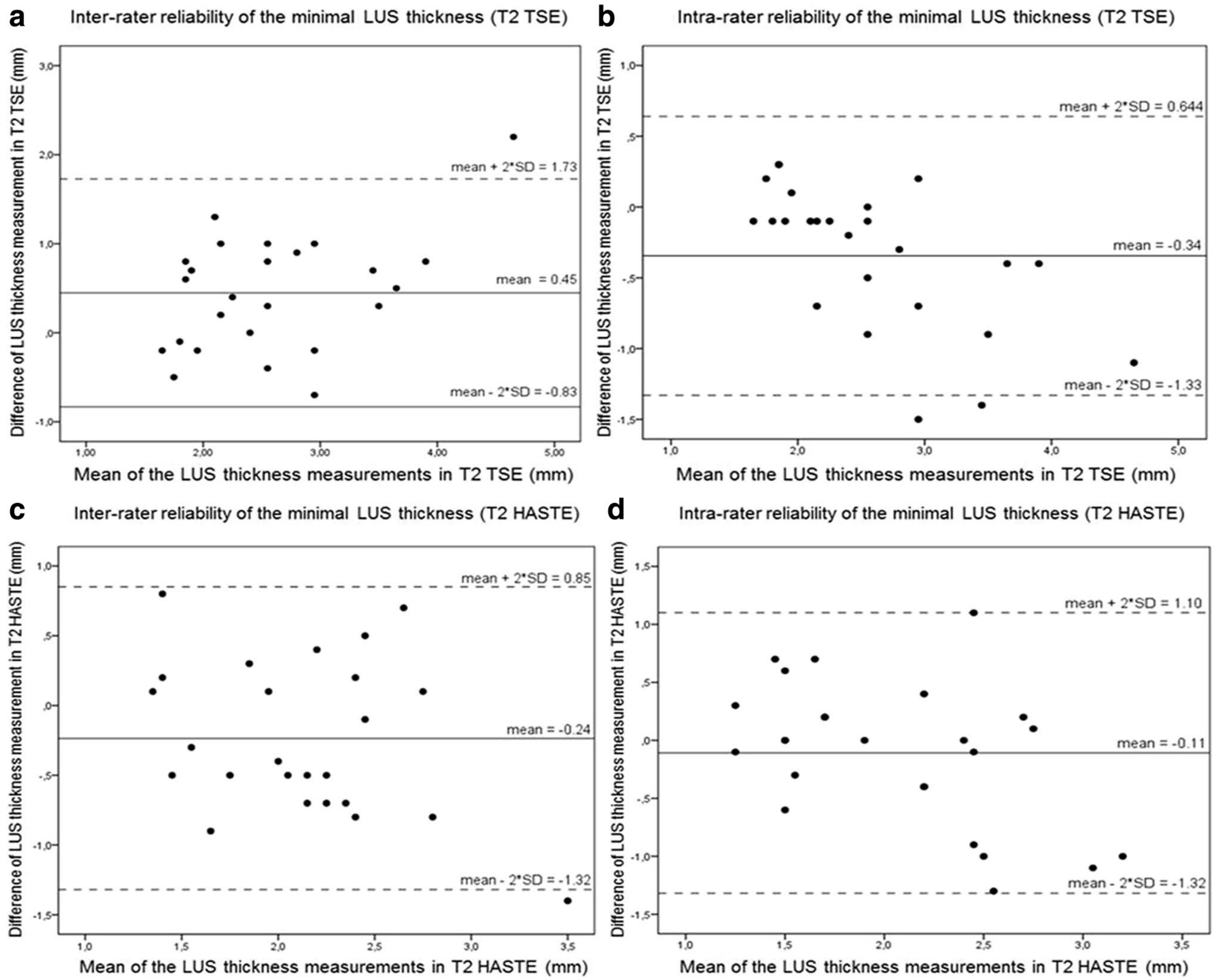

Fig. 6 Bland–Altman plots demonstrate inter- and intra-rater reliabilities of the lower uterine segment (LUS) thickness in the T2-TSE (**a** and **b**) and T2-HASTE (**c** and **d**) sequence. The minimal LUS thickness was analyzed. *T2-TSE* T2-weighted Turbo-Spin-Echo, *T2-HASTE* T2-weighted Half Fourier-Acquired Single shot Turbo spin Echo

tool. Because mainly independent from location of the LUS or the scar, the minimal LUS thickness should be measured. This means to determine the mere myometrial LUS thickness if to define and alternatively the full LUS thickness if not to define.

We demonstrated a strong individual variability of LUS morphology and thickness. There is a variety of reasons, such as perioperative conditions or individual wound healing that might explain these. An association to uterine defects could not be revealed from our data. Because of the low incidence of uterine defects and the high morphologic variability even in our small patient group, we doubt the usefulness of morphological criteria for risk-assessment as previously described [26]. T1- and T2-intensities are affected by numerous factors such as field homogeneity, patient position or the used MRI scanner. Therefore, we did not calculate T1 or T2 signal intensity ratios for evaluation of scar integrity.

It has also to be emphasized that the LUS is a dynamic muscular tissue. Differing thickness could be caused by temporary uterine contractions or by the factors influencing intrauterine pressure (e.g., by gestational age, fetal weight or the leading fetal part) so that differences in measurement even at the very same level might be inevitable [27–29]. Due to this, not even intraoperative caliper measurements could be evaluated as a reliable gold standard [29]. Maybe this and the subjectivity of intraoperative LUS classification are reasons for poor agreement of the prenatal diagnosis of LUS thinning with intraoperative findings. Contrarily, the prenatally diagnosed LUS integrity was reliably confirmed by operation in all patients with repeated CS. Consequently, definition of an intact LUS in distinction to a

Table 5 Maternal and neonatal outcomes

	Patient group ($n = 25$)
Gestational age at delivery (weeks)	39 (IQR 1)
Delivery route	
Vaginal	10 (40%)
Repeated cesarean section	15 (60%)
Elective	13 (92%)
Emergency	2 (8%)
Intraoperative findings (Qureshi system [18])	
Grade I	9 (60%)
Grade II	6 (40%)
Grade III	0
Grade IV	0
Neonatal outcome	
APGAR value	10 (IQR 1)
Umbilical artery pH	7.3 (IQR 0.08)
Fetal weight (g)	3310 (IQR 530)

Parameters are given as median [interquartile range (IQR)] or total amount (%)

Table 6 Comparison of strengths (+) and limitations (−) of ultrasound and MRI for LUS (= lower uterine segment) diagnostic

	Ultrasound		MRI	
	TAS	TVS	T2-TSE	T2-HASTE
Investigator dependency	−	−	+++	+++
Reproducibility	−	−	+++	+++
Resolution				
Temporal	+++	+++	+	++
Spatial	+++	+++	++	+
Covered structures				
Cervix	−	+++	+++	+++
Lower LUS parts	±	+++	+++	+++
Middle LUS parts	++	++	+++	+++
Upper LUS parts	+++	±	+++	+++
Uterine front wall	+++	−	+++	+++
Vulnerability to artifacts				
Patient constitution	−	−	+++	+++
Altered anatomy or morphology	++	++	+++	+++
Adjustability to anatomy	++	++	+++	+++
Movements	+++	+++	±	±
Time exposure	+++	+++	++	++
Availability	+++	+++	±	±
Costs	+++	+++	−	−

TAS transabdominal ultrasound scan, *TVS* transvaginal ultrasound scan, *T2-TSE* T2-weighted Turbo-Spin-Echo sequence, *T2-HASTE* T2-weighted Half Fourier-Acquired Single shot Turbo spin Echo sequence

uterine dehiscence or uterine rupture might be more useful in prenatal diagnostics.

The main limitation of this study is its small sample size due to its pilot character. The poor study knowledge about MRI in pregnancy after previous CS demands further research with larger study groups. It would be interesting to include advanced MRI techniques such as diffusion tensor imaging (DTI) that might enable fiber detection and direct cesarean scar visualization also in pregnant women [30, 31].

Nevertheless, this is the first prospective study that demonstrates feasibility of LUS diagnostics with 3 T-MRI and shows typical findings after previous CS.

Conclusions

Our results provide new impulses that might be helpful to improve current diagnostic algorithms for prenatal management after previous CS. The usefulness of a protocol with a first-line TAS and TVS in combination and an additional MRI as second-line examination should be evaluated in a large prospective outcome study. A qualitative assessment of the uterine scar integrity might be superior to the currently used quantitative LUS thickness measurement.

Author contributions JH: design/methods/administration of the study, data acquisition: MRI, ultrasound and clinical data, measurements, analyzing and interpreting data, writing the manuscript; ME: administration, acquiring MRI data, MRI measurements; KB: data acquisition: MRI, MRI measurements; MG: supervision, support in writing the manuscript; PS: concept/methods, administration, data acquisition: MRI, writing the manuscript; SS-P: data acquisition: ultrasound, analyzing data/interpretations; HS: design/concept, analyzing data/interpretations, ;supervision, writing the manuscript.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflicts of interest.

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