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Change in uterine artery blood flow with intrauterine balloon tamponade

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The purpose of this study was to investigate the change in uterine artery blood flow in cases of intrauterine balloon tamponade (IBT). This was a retrospective cross-sectional study of 132 patients who underwent singleton cesarean section. IBT was performed in 35 of the 132 patients. There were 21 cases of placental mediated pregnancy complications (PMPC), which were not included in the IBT group. Placental positional abnormalities were significantly more common in the IBT group than in the control group (89% vs. 9%, $P < 0.001$). Multivariate analysis identified PMPC as a factor affecting the immediate preoperative uterine artery pulsatility index (UtA-PI). Finally, PMPC was excluded and we assessed 35 and 76 patients assigned to the IBT and control groups, respectively. We compared changes in uterine artery blood flow with and without IBT and by balloon volume. In the IBT group, the immediate pre- and postoperative UtA-PIs were significantly lower (0.56 ± 0.18 vs. 0.63 ± 0.15, $P = 0.011$, statistical power = 0.577) and higher (1.37 ± 0.66 vs. 0.96 ± 0.28, $P < 0.001$, statistical power = 0.986), respectively, than those in the control group. The immediate postoperative UtA-PIs depending on balloon expansion volume were 1.13 ± 0.60, 1.24 ± 0.57, and 1.71 ± 0.75, with balloon volumes of 100--199 mL, 200--299 mL, and 300--399 mL, respectively. In summary, IBT during cesarean section increases the immediate postoperative UtA-PI, and tends to increase with increase in balloon volume.

Keywords

Balloon tamponade; Uterine artery; Doppler ultrasound; Cesarean section; Placenta previa

1. Introduction

In Japan, postpartum hemorrhage (PPH) remains the main cause of maternal deaths, and is responsible for 23% of maternal deaths from direct obstetric causes [1]. Intrauterine balloon tamponade (IBT) is one of the leading methods for managing PPH [2, 3]. The use of IBT can reportedly reduce intra- and postoperative blood loss from placenta previa [4–8]. Moreover, the use of IBT reduces the need for more invasive procedures, such as radiological uterine artery embolization, compression sutures, and peripartal hysterectomy [9, 10].

Various reports describe bleeding control by filling the balloons, which is called the tamponade test [11, 12]. This test is advantageous in that it is volume-independent and achieves a clinical end-point of hemostasis. IBT produces a tamponade effect by pressure exertion on the myometrial wall, which results in mechanical stimulation of myometrial contraction. Until recently, it has been considered that IBT stops continuous bleeding when the internal myometrial pressure is higher than the systemic arterial blood pressure [13].

The over-inflation of the balloon in the uterus to prevent migration may cause other problems [14]. First, uterine distention is very painful; therefore, hemostasis should be achieved with the minimal volume of uterine distension. Second, there is concern about uterine rupture or uterocervical injury due to excessive expansion. The optimal expansion volume is considered the minimum volume for which the IBT is effective.

Doppler assessment of uterine artery blood flow is frequently used during pregnancy to evaluate placental perfusion. Uterine artery blood flow changes during pregnancy to supply the required blood for fetal development. Past study reported changes in UtA-PI associated with postpartum uterine reconstruction. It was shown that UtA-PI increases progressively during the first eight weeks, regardless of the number of deliveries [15]. UtA-PI increases with postpartum uterine recovery and may be an indicator of poor recovery.

If the hemostatic mechanism of IBT is mechanical compression of the uterine artery, it can be hypothesized that the aforementioned hemostatic effect is objectively quantified by changes in UtA-PI. If this hypothesis is correct, it will not only clarify the mechanism of IBT, but also pose a challenge to the effective management of PPH. The purpose of this study was to examine the utility of IBT as seen from the change in uterine artery blood flow. We believe that our findings would facilitate the understanding of the mechanism of action of IBT.

2. Materials and methods

We conducted a retrospective cross-sectional study of 132 consecutive singleton pregnant women who underwent cesarean delivery at a tertiary medical center from October 2016 to July 2020. Fig. 1 shows the flow diagram of the study. We recruited patients who had undergone elective cesarean sec-

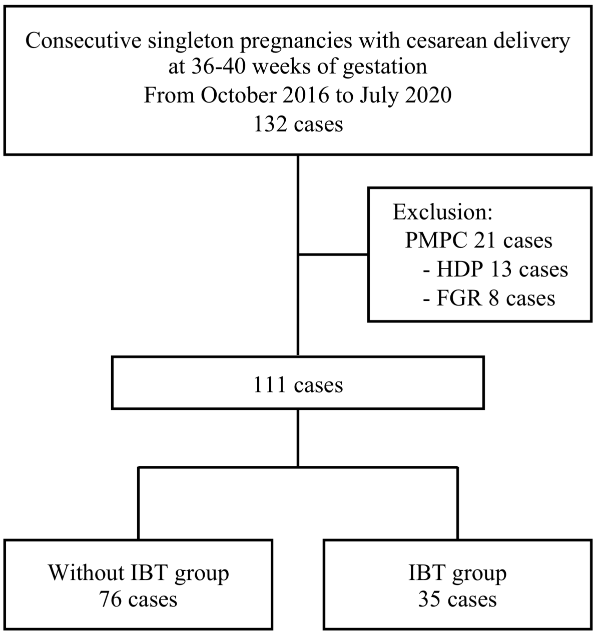

Fig. 1. Study participants and inclusion criteria. PMPC, placenta-mediated pregnancy complications; HDP, hypertensive disorders of pregnancy; FGR, fetal growth restriction; IBT, intrauterine balloon tamponade.

tion prior to labor onset. We collected data on clinical characteristics, ultrasound and laboratory findings, and perinatal outcomes from the medical records.

IBT was performed when the intraoperative blood loss exceeded 1000 mL, and the bleeding could not be controlled even after administering uterotonic agents and ligating the bleeding point. Before closing the myometrium incision, we counted the amount of suction bleeding containing amniotic fluid and used to determine IBT indication. Since the final blood loss included suction bleeding during abdominal closure and gauze bleeding count, there were cases in which the total blood loss exceeded 1000 mL even in control group. In all cases, intrauterine balloons were inserted transabdominally during surgery, and removed within 12 hours post-insertion [16]. Following the tamponade test procedure, the balloon was initially expanded with at least 100 mL of distilled water, which was serially increased by 50 mL until bleeding from the drainage tube disappeared. The blood flow (pulsatility index [PI], peak systolic velocity [PSV], and velocity time integral [VTI]) of the ascending branches of the left and right uterine arteries was measured using bedside transvaginal ultrasound. Ultrasound measurements were performed in four stages: immediate preoperative, immediate postoperative (under IBT insertion), 24 h postoperative (after IBT removal), and 5 days postoperative stages. Immediate preoperative UtA-PI was measured within 2 hours before cesarean section. Immediate postoperative UtA-PI was measured in the hospital room after surgery and within an hour after IBT insertion. Oxytocin was administered to all patients in the immediate postoperative period; however, no oxytocin was administered at 24 h post-surgery. In order to eliminate the effects of uterine contraction, all ultrasound assessments were performed in the absence of uterine contractions [17]. After cesareans section, uterine contractions as so-called post labor pains are observed intermittently, so immediate post-operative uterine artery blood flow was measured without uterine contractions. That is, the ultrasound measurement was performed by continuously observing the Doppler waveform for several tens of seconds and confirming that there was no change in the waveform due to uterine contraction.

Doppler measurements were performed transvaginally before and after surgery, using a Prosound α6 (Hitachi-Aloka Medical, Tokyo, Japan). The uterine artery was identified at the uterocervical junction with the help of color Doppler. After obtaining a clear view of the uterine artery, the Doppler sample gate was placed at the center of the vessel of the ascending uterine artery (sample size, 2 mm). The angle of insonation was corrected to obtain a measurement line parallel to the arterial wall.

Factors affecting the immediate preoperative UtA-PI were revealed by multivariate analysis. We compared the uterine artery blood flow at each measurement stage with and without IBT. Thereafter, changes in uterine artery blood flow were compared among the three groups-with balloon volumes 100–199 mL, 200–200 mL, and 300–399 mL.

Statistical analyses were performed using EZR [18], which is a graphical user interface for R (The R Foundation for Statistical Computing, Vienna, Austria). Data were expressed as means and standard deviations. Logistic regression analysis was used for multivariate analysis of factors affecting immediate postoperative UtA-PI. The Kolmogorov-Smirnov test was used to test the normality of the distribution. For comparison between two groups, we used the Student's *t*-test (for normal distributions) and Mann-Whitney U test (for non-normal distributions). The Kruskal-Wallis test with Bonferroni correction was used to compare the three groups. Statistical significance was set at $P < 0.05$.

3. Results

We performed 528 ultrasound scans for 132 women. IBT was performed during surgery in 35 of 132 cases. The balloon volume was less than 200 mL, less than 300 mL, and more than 300 mL in 6, 19, and 10 cases, respectively. Uterine artery embolization was required in one patient in IBT group and two patients in non-IBT group. There were no cases requiring hysterectomy. In this study, no cases required additional analgesics or removal of the balloon due to pain associated with IBT. No uterine rupture or cervical laceration due to IBT was observed.

The background characteristics of the 132 cases are shown in Table 1. Placental positional abnormalities were significantly more common in the IBT than the control group (89% vs. 9%, $P < 0.001$). No placenta-mediated pregnancy complications (PMPC), including hypertensive disorders of pregnancy and fetal growth restriction, were found in the IBT group.

Table 1. Comparison of background characteristics and indications for cesarean section with and without intrauterine balloon tamponade in all cases.

	without IBT (n = 97)	IBT (n = 35)	*P*
primiparity	39 (40%)	16 (46%)	0.690
Placental positional abnormalities	9 (9%)	31 (89%)	< 0.001
Placenta mediated pregnancy complications	21 (22%)	0 (0%)	0.001
Hypertensive disorder of pregnancy	13 (13%)	0 (0%)	0.020
Fetal growth restriction	8 (8%)	0 (0%)	0.109
Mother age (years)	34 ± 5	35 ± 6	0.526
Gestational age at delivery	37w4d ± 13d	37w2d ± 7d	0.281
Indications for cesarean section			
Placental positional abnormalities	9 (9%)	31 (89%)	< 0.001
Arrest of labor	10 (10%)	2 (6%)	0.515
Repeat cesarean section	37 (38%)	1 (3%)	< 0.001
Breech presentation	13 (13%)	1 (3%)	0.112
Non-reassuring fetal status	5 (5%)	0 (0%)	
Maternal underlying conditions	23 (24%)	0 (0%)	

Number of cases (%)/mean ± SD.

Maternal underlying conditions include severe hypertensive disorders of pregnancy, severe mental illness, and birth canal obstruction (due to uterine fibroids, ovarian tumors).

Table 2. Multivariate regression analysis for immediate preoperative uterine artery pulsatility index.

	Regression estimate	95% CI lower	95% CI upper	*P*
primiparity	-0.053	-0.134	0.026	0.185
Placental positional abnormalities	-0.078	-0.168	0.012	0.088
Placenta mediated pregnancy complications	0.248	0.126	0.371	< 0.001
Mother age	-0.001	-0.009	0.007	0.813
Gestational age at delivery	-0.023	-0.051	0.004	0.097

CI, confidence interval.

Table 3. Comparison of perinatal prognosis with and without intrauterine balloon tamponade in analyzed cases.

	without IBT (n = 76)	IBT (n = 35)	*P*	Power
Gestational Age	38w0d ± 10d	37w2d ± 7d	< 0.001	0.783
Birth weight (g)	2987 ± 389	2756 ± 342	0.003	0.830
Umbilical blood pH	7.302 ± 0.041	7.289 ± 0.057	0.400	
Placental weight (g)	617 ± 122	575 ± 77	0.119	
Blood loss (mL)	1058 ± 600	1663 ± 859	< 0.001	0.978
Pre-surgery Hb (g/dL)	11.0 ± 1.1	11.2 ± 1.0	0.465	
Post-surgery Hb (g/dL)	10.1 ± 1.2	9.2 ± 1.5	0.003	0.871

Mean ± SD.

Table 2 shows multivariate analysis for immediate preoperative UtA-PI. PMPC was revealed as a relevant factor for UtA-PI. PMPC was excluded to avoid the effect on uterine artery blood flow assessment. Finally, we analyzed 35 and 76 cases in the IBT and control groups, respectively.

Table 3 shows the perinatal outcomes for each group. Compared to the control group, patients in the IBT group had significantly lower gestational age at delivery (37w2d ± 7d vs. 38w0d ± 7d, $P < 0.001$, statistical power = 0.783), lower birth weight (2756 g ± 342 g vs. 2987 g ± 389 g, P = 0.003, statistical power = 0.830), higher blood loss (1663 mL ± 859 mL vs. 1058 mL ± 600 mL, $P < 0.001$, statistical power = 0.978), and lower postpartum hemoglobin (9.2 g/dL ± 1.5 g/dL vs. 10.1 g/dL ± 1.2 g/dL, P = 0.003, statistical power = 0.871). IBT failed to manage bleeding in one case, which was managed using radiological uterine artery embolization. In the control group, two patients required uterine artery embolization. None of the cases required re-laparotomy or peripartal hysterectomy.

Table 4 shows the changes in uterine artery blood flow with and without IBT. In the IBT group, the immediate pre- and postoperative UtA-PIs were significantly lower (0.56 ± 0.18 vs. 0.63 ± 0.15, P = 0.011, statistical power = 0.577) and higher (1.37 ± 0.66 vs. 0.96 ± 0.28, $P < 0.001$, statistical power = 0.986), respectively, than those in the control group. The change rate of UtA-PI was significantly higher in the IBT than in the control group (2.61 ± 1.34 vs. 1.59 ± 0.50, $P < 0.001$, statistical power = 0.999). The change rates of PSV (0.85 ± 0.50 vs. 1.08 ± 0.56, P = 0.045, statistical power = 0.524) and VTI (1.00 ± 0.73 vs. 1.29 ± 0.72, P = 0.039, statistical power = 0.500) were significantly lower in the IBT than in the control group. There was no difference in UtA-PI, PSV, and VTI 24 h postoperatively, after the intrauterine balloon removal.

Table 4. Comparison of changes in uterine artery blood flow with and without intrauterine balloon tamponade in analyzed cases.

	without IBT (n = 76)	IBT (n = 35)	*P*	Power
Immediately pre-surgery				
UtA-PI	0.63 ± 0.15	0.56 ± 0.18	0.011	0.577
UtA-PSV	110.6 ± 39.1	117.0 ± 36.8	0.393	
UtA-VTI	59.3 ± 27.2	62.0 ± 25.6	0.55	
Immediately post-surgery				
UtA-PI	0.96 ± 0.28	1.37 ± 0.66	< 0.001	0.986
UtA-PSV	106.3 ± 40.5	92.9 ± 47.4	0.12	
UtA-VTI	66.8 ± 26.9	54.5 ± 33.8	0.046	0.526
Change ratio (immediately post-surgery/immediately pre-surgery)				
UtA-PI	1.59 ± 0.50	2.61 ± 1.34	< 0.001	0.999
UtA-PSV	1.08 ± 0.56	0.85 ± 0.50	0.045	0.524
UtA-VTI	1.29 ± 0.72	1.00 ± 0.73	0.039	0.500
24 hours post-surgery				
UtA-PI	1.05 ± 0.33	0.93 ± 0.22	0.073	
UtA-PSV	89.9 ± 36.6	101.9 ± 42.5	0.112	
UtA-VTI	54.5 ± 26.8	64.4 ± 29.3	0.029	
Change ratio (24 hours post-surgery/immediately post-surgery)				
UtA-PI	1.13 ± 0.28	0.78 ± 0.29	< 0.001	0.999
UtA-PSV	0.93 ± 0.46	1.52 ± 1.40	0.015	0.869
UtA-VTI	0.93 ± 0.76	1.97 ± 2.28	< 0.001	0.912
5 days post-surgery				
UtA-PI	1.28 ± 0.42	1.10 ± 0.42	0.047	0.608
UtA-PSV	87.0 ± 25.1	95.0 ± 38.7	0.405	
UtA-VTI	47.9 ± 18.1	57.3 ± 27.4	0.099	
Change ratio (5 days post-surgery/24 hours post-surgery)				
UtA-PI	1.31 ± 0.43	1.27 ± 0.40	0.837	
UtA-PSV	1.05 ± 0.48	1.01 ± 0.53	0.508	
UtA-VTI	0.98 ± 0.54	1.02 ± 0.76	0.658	

UtA, uterine artery; PI, pulsatility index; PSV, peak systolic velocity; VTI, velocity time integral.

The immediate postoperative UtA-PIs depending on the balloon expansion volume were 1.13 ± 0.60, 1.24 ± 0.57, and 1.71 ± 0.75, with balloon volumes of 100–199 mL, 200–299 mL, and 300–399 mL, respectively; the UtA-PSVs were 107.5 ± 56.8, 94.7 ± 53.5, and 82.1 ± 28.5, respectively; and the UtA-VTIs were 66.4 ± 36.8, 56.5 ± 38.4, and 44.8 ± 21.1, respectively. None of the aforementioned uterine artery blood flows was significantly changed by balloon volume.

4. Discussion

In this study, when IBT was performed, the immediate postoperative UtA-PI significantly increased. In addition, UtA-PI decreased to the same level as prior to IBT, after the balloon removal. Uterine artery blood flow velocity was also reduced when IBT was performed.

There are various reports on factors that affect UtA-PI [15, 19]. In our study, multivariate analysis revealed PMPC as a factor affecting immediate preoperative UtA-PI. By excluding PMPC, we closely evaluated the effect of IBT on uterine artery blood flow. Immediate preoperative UtA-PI was significantly lower in IBT group. We speculated this was because there were many cases of placental positional abnormalities in IBT group. As shown in Table 2, using multivariate analysis for preoperative UtA-PI, placental positional abnormalities was extracted as a factor that independently affects UtA-PI. In cases of placental positional abnormalities, it is speculated that development of blood flow in placental bed around the lower uterine segment, which is close to the main trunk of uterine artery, reduces uterine artery vascular resistance. Immediate postoperative UtA-PI increased significantly with IBT. On the other hand, 24 h postoperative UtA-PI tended to be lower in IBT group, although there was no significant, and 5 days postoperative UtA-PI was significantly lower in IBT group. From the above, we think UtA-PI is originally lowered in case of placental positional abnormalities, and it is emphasized UtA-PI is increased by IBT performed.

A previous study reported that intrauterine pressure does not change even when the expansion volume of IBT exceeds 100 mL [20], and it is better to avoid unnecessary balloon inflation if the bleeding is reduced [21]. In our study, increased UtA-PI was observed even with relatively small expansion volumes (100–199 mL). Although there was no statistically significant change, UtA-PI and flow velocity tended to increase and decrease, respectively, as the balloon volume increased. It is speculated that the direct compression effect on the uterine artery increases depending on the expansion volume, even if the intrauterine pressure does not increase. In clinical practice, hemostasis is often achieved with a small balloon volume (volume < 100 mL) in case of PPH. Therefore, it is considered that IBT with small balloon volume acts by directly compressing the bleeding point, whereas IBT with large balloon volume additionally acts by increasing vascular resistance, thereby interrupting blood flow.

In cases of placental positional abnormalities, which made up the majority of IBT group, bleeding from the placental bed increased significantly. in these cases, hemostasis is likely to be achieved by direct compression of the bleeding point by IBT. In cases without placental positional abnormalities, intraoperative uterine atony was the main cause of increased bleeding. It is considered that direct compression of the uterine artery by IBT was effective in achieving hemostasis even in these situations. One patient in IBT group who required uterine artery embolization was not associated with placenta positional abnormalities. Due to the marked uterine atony and manifestation of abnormal coagulation, we stepped up the hemostasis treatment. Two patients underwent UAE in control group. One case was PMPC (severe preeclampsia), and sudden massive bleeding was observed 3 hours after surgery. In this case, UAE was selected over IBT because of concerns about the manifestation of abnormal coagulation. The other case was PPH on 3 days after surgery, which pointed out a vascular image suggesting pseudoaneurysm and intermittent extravasation at the bottom of uterus. In all cases, UAE showed good hemostasis and no hysterectomy was required.

This retrospective study was limited by the fact that the IBT group contained many placental positional abnormalities, and there was only a small number of cases of IBT. Moreover, in this study, it is difficult to show that the higher UtA-PI, the smaller the amount of bleeding; therefore, future studies will need to assess the aforementioned relationship with and without IBT. However, it is clear that IBT reduces postoperative blood loss in patients with placental positional abnormality, and the changes in uterine artery blood flow are consistent with the IBT performed. We recommended performing UtA-PI measurement in prospective, extensive studies to determine the effect of IBT and the volume of balloon expansion in more detail.

5. Conclusions

IBT during cesarean section increases UtA-PI. And UtA-PI tends to increase as the balloon volume increases. We believe that our study findings will help to clarify the effect of IBT on uterine blood flow.

Author contributions

RS designed and analyzed the data. RS, TS, and KM performed the operation and collected the data. All authors approved the final version. KM supervised the study.

Ethics approval and consent to participate

The study was conducted in accordance with the Declaration of Helsinki, and the protocol for this study was approved by the ethics committee of Gifu University Hospital, Gifu, Japan (approval number: 2019-165).

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Conflict of interest

The authors declare no conflict of interest.

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