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Fetal and Neonatal Outcomes Following Maternal Aortic Balloon Occlusion for Hemorrhage in Pregnancy: A Review of the Literature

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Abstract

Background: Hemorrhage is a leading cause of maternal death worldwide, with increased risk in women with abnormal placentation. Aortic balloon occlusion (ABO), including resuscitative endovascular balloon occlusion (REBOA), has been used for obstetrical hemorrhage for 20 years, and is associated with decreased operative blood loss, fewer transfusions, and lower rates of hysterectomy. However, the effect of aortic occlusion on fetal/neonatal outcomes is not well known.

Methods: A literature review on ABO for obstetrical or traumatic hemorrhage was performed. Cases were included if fetal/neonatal outcomes were reported. Data was collected on timing of balloon inflation (pre or post-delivery), fetal/neonatal mortality, and Apgar scores. Secondary maternal outcomes included blood loss, need for hysterectomy, ABO-related complications, and mortality.

Results: Twenty-one reports of aortic balloon occlusion in 825 cases of obstetrical hemorrhage were reviewed (nine case reports/series and twelve comparative studies). 13.5% (111/825) had aortic occlusion prior to delivery of the fetus. Comparative cohorts included 448 patients who underwent iliac artery balloon occlusion (n=219) or no vascular balloon occlusion (n=229).

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The most common neonatal outcome reported was Apgar scores, with no difference in fetal/neonatal outcomes between ABO and non-ABO patients in any study. One neonatal mortality occurred in the sole reported case of ABO use in a pregnant trauma patient at 24 weeks gestation. One maternal mortality occurred due to aortic dissection. Five comparative studies reported significantly decreased blood loss in ABO patients compared to non-ABO patients and four studies reported significantly lower rates of hysterectomy in ABO patients. ABO-related complications were reported in 1.6% of patients (13/825).

Conclusion: Obstetrical hemorrhage is a devastating complication, and aortic balloon occlusion may potentially decrease blood loss and reduce the hysterectomy rate without compromising fetal and neonatal outcomes. Further research is needed to determine the safety of pre-delivery aortic occlusion as this occurred in 14% of cases.

Level of Evidence: IV

Keywords

Aortic occlusion; maternal hemorrhage; REBOA; resuscitative endovascular balloon occlusion of the aorta; neonatal outcomes

Background

Hemorrhage accounts for 27% of maternal deaths worldwide [1]. Abnormal placentation is a known risk factor for peripartum hemorrhage, occurring in 1 in every 272 births [2], and is responsible for the majority of maternal deaths due to hemorrhage [1]. At delivery, up to 90% of patients with abnormal placentation can require transfusion and 39% require massive transfusion, defined as ≥10 units of red blood cells within 24 hours [3]. These patients also have high rates of hysterectomy for hemorrhage control [4]. Outside of obstetrical hemorrhage, trauma is the most frequent cause of maternal deaths [5], and most trauma in pregnancy occurs in the third trimester [6,7]. Placental abruption complicates half of all cases of trauma during pregnancy[8], and uterine rupture occurs in 1% of pregnant trauma patients [9,10]. These populations represent a large area for potential intervention to prevent maternal morbidity and mortality.

When faced with massive obstetrical hemorrhage, there are several endovascular hemorrhage control methods available, such as bilateral internal iliac artery balloon occlusion [11] and pelvic or uterine artery angioembolization [12]. However, due to the extensive collateral blood supply of the gravid uterus, endovascular occlusion of the internal iliac arteries may not be as effective as abdominal aorta occlusion in cases of life-threatening hemorrhage [13]. Recently, resuscitative endovascular balloon occlusion of the aorta (REBOA) has emerged as an additional option for this devastating complication [14]. REBOA is a balloon catheter device that can be placed at the bedside. Although most frequently used in trauma, there is growing evidence supporting REBOA use in non-traumatic hemorrhage including gastrointestinal bleeding [15], ruptured visceral aneurysms [15], and obstetrical bleeding [16]. The first published case of aortic balloon occlusion for obstetrical hemorrhage was in 1995 in a patient with placenta percreta [17]. Since then, there have been over one thousand reported cases of aortic balloon occlusion for peripartum hemorrhage. Although in

cases of traumatic hemorrhagic shock, it is advantageous to place and inflate the REBOA catheter early in the patient's course [18], in the pregnant trauma patient or the patient at risk of exsanguination from obstetrical hemorrhage, the presence of the fetus complicates the decision, due to concern regarding the effects of diminished placental blood supply from REBOA inflation. However, the effects of aortic balloon occlusion on the fetus and neonate are not well known.

We provide a review of the existing literature on aortic balloon occlusion (ABO) in cases of peripartum hemorrhage, focusing on fetal and neonatal outcomes.

Methods

Literature Search

A search of PubMed and Google Scholar was performed for English-language articles using the following terms in combinations: 'REBOA,' 'aortic occlusion,' 'prophylactic,' 'placenta percreta,' 'placenta increta,' 'placenta accreta,' 'morbidly adherent placenta,' 'balloon occlusion,' 'pregnancy AND trauma,' 'uterine rupture.' Inclusion criteria were studies of any design (case report, case series, retrospective or prospective cohort, randomized trial) reporting on aortic balloon occlusion for hemorrhage during pregnancy or delivery (placenta increta, placenta percreta, placenta accreta, placenta previa, uterine rupture, traumatic hemorrhage), which reported fetal or neonatal outcomes. Articles were excluded if patients did not undergo endovascular aortic balloon occlusion, or if fetal or neonatal outcomes were not described.

Data Extraction and Analysis

Data was collected from each article on indications for ABO, details of aortic balloon catheter placement, operative findings, neonatal and maternal outcomes, and complications. Descriptive statistics were performed.

Results

A total of 21 papers were identified for inclusion in this review: five case reports, four case series, and twelve comparative studies. These included a total of 1273 women, of which 825 underwent ABO and 448 were in control groups, either without any vascular balloon occlusion (n = 229) or undergoing iliac artery balloon occlusion (n = 219).

Case Reports and Case Series Describing ABO for Non-Traumatic Obstetrical Hemorrhage

Eight case reports and case series were identified describing aortic balloon occlusion for obstetrical hemorrhage in 142 patients (Table 1). Five described prophylactic placement of aortic balloon occlusion catheters and five described emergent placement. Most papers reported on cases involving placenta accreta, increta, or percreta. One case report involved a case of placenta accreta with uterine rupture [19].

Femoral Access—Fourteen studies reported on femoral access method. Most commonly, femoral access was obtained percutaneously. All but one study reported the femoral sheath size, most commonly 8 French (2 studies, 51 patients), followed by 12 French (1 study, 42

patients). Single patient case reports most commonly used 7 French sheaths [19-21]. One case series reported a range of sheath sizes from 5 to 8 French [22], and two case reports did not include sheath size [23].

Aortic Occlusion Details—Occlusion time was reported in 6 studies, ranging 18-80 minutes. One case series reported 15 minutes of intermittent aortic occlusion [24]. In the majority of patients, the balloon was inflated only after delivery of the fetus. In one case of uterine rupture and maternal hemodynamic instability, a REBOA balloon was inflated in Zone 3 four minutes prior to fetal delivery [19]. Additionally, in one case series of 42 women, the aortic balloon was inflated prior to uterine incision in 15 patients at the obstetrician's request [25].

Operative Details—The estimated blood loss (EBL) was reported in 7 studies, ranging from 586 milliliters (ml) [26] to over 20 liters [21]. Red blood cell transfusion volumes were reported in all studies, ranging from a mean of 1.7 units of blood [22] to massive transfusion [23]. Twenty-three patients out of 142 underwent hysterectomy (16.2%).

Complications—All studies reported whether complications occurred due to aortic occlusion. Only four complications were reported for 142 total patients (2.8%). The complications were deep vein thrombosis [23] access vessel thrombosis [22], femoral nerve ischemia [22], and a groin hematoma [25].

Neonatal Outcomes—Quantitative neonatal outcomes were reported in eight studies (Table 2) in the form of Apgar scores [19-22,25-28]; one study reported "good" Apgar scores for the baby but did not specify further. Initial Apgar scores at 1 minute ranged from 1 to >7, with one infant having a 1-minute Apgar of 1 which improved to an Apgar of 5 at five minutes [25]. The remainder of the 5-minute Apgar scores were all greater than 6 in studies reporting these values [20,21,26,27]. The gestational age of the neonates ranged from 32 weeks 5 days to 37 weeks 2 days in studies reporting this information. In studies not reporting individual gestational ages, averages were provided, ranging from a median of 35.3 weeks to 37.1 weeks. One study reported the rate of neonatal intensive care unit (NICU) admissions at 11.9% [25]. There were no reported neonatal mortalities.

Specifically looking at cases in which the ABO was inflated prior to fetal delivery, in one case report, the Apgar scores were 1 and 5 at one minute and five minutes, respectively, for a neonate born at 35 weeks gestation following four minutes of ABO. The neonate's umbilical artery blood gas indicated neonatal acidemia with a pH < 6.981 [19]. However, this patient survived to hospital discharge at day of life 23 after a reportedly uneventful hospitalization. The other paper reporting on patients undergoing ABO prior to uterine incision did not report neonatal outcomes separately from patients undergoing ABO after fetal delivery [25].

Comparative Studies Describing ABO for Non-Traumatic Obstetrical Hemorrhage

Twelve comparative studies were identified for inclusion (Table 3). In all but one paper [29], the intervention was done in a planned, non-emergent manner. Most commonly, ABO was compared no ABO [30-36], or to internal iliac artery occlusion [13,37,38]. One study compared ABO alone to ABO with Bakri balloon tamponade [39]. One study compared ABO before

and after uterine incision [29]. In one study comparing ABO to IIA balloons, the occlusive balloons were inflated before delivery in both groups [13]. Seven studies included patients followed in a prospective manner, with the mothers electing which group to enroll in, while five studies reported retrospective data from the two comparison groups. No randomized controlled trials were found.

Femoral Access—Femoral access was obtained percutaneously; one study did not specify the method of access. Sheath sizes were primarily 8 Fr (6 studies, 438 patients), with 12 Fr sheaths used in 3 studies (101 patients), and 3 studies did not state sheath size.

Aortic Occlusion Details—The mean aortic occlusion time ranged from 6.6 minutes to 60 minutes in studies reporting this information. In two papers, intermittent ABO was employed, with a one-minute deflation every five minutes in one case [37], and routine balloon deflation every 10 minute to assess for bleeding in another case [32]. A total of 94 patients underwent aortic occlusion prior to delivery of the fetus [13,29].

Operative Details—In the eight studies comparing ABO to no ABO, EBL was significantly lower in the ABO group in five studies, and not significantly different in three studies. When comparing ABO to no EBO, transfusion volumes were significantly lower in the ABO group in four studies, and not significantly different in four groups. Hysterectomy rates were significantly lower in the ABO group in four studies, not significantly different in three studies, and not reported in one study among papers comparing ABO to no ABO. In the three papers comparing ABO to bilateral IIA occlusion, both EBL and transfusion volumes were significantly lower in the ABO group in the one paper reporting this outcome; hysterectomy rates did not differ. There was one study which compared ABO before and after fetal delivery in women with placenta previa. This study reported significantly lower EBL in pre-delivery cohort, and a significantly lower rate of requiring transfusion (31% pre-delivery vs. 88.9% post-delivery, $p < 0.0001$), but did not report transfusion volumes.

Complications—The presence or absence of complications was reported in all studies. In four studies, there were no complications (198 patients). The remainder of studies reported 1-2 complications each. The most common complication was thrombus, occurring in four patients, followed by DVT (2 patients) and hematoma (2 patients). There was one maternal death from aortic dissection, resulting in a retroperitoneal hematoma, occurring on the first post-operative day, reported by Zhu *et al*; no further details were provided.

Neonatal Outcomes—Neonatal outcomes were reported in all studies (Table 4). There were no statistically significant differences in Apgar Scores at 1 or 5 minutes between ABO groups and control groups in any study. The lowest reported 1-minute Apgar scores in the ABO group was one patient below 7 in one study of 38 neonates [32], and a median score of 7.6 in a study of 48 neonates [39]. Five-minute Apgar scores were mostly > 7, although one patient in a control group had an Apgar of < 7 at five minutes [32]. Two studies additionally reported on length of hospitalization for the neonates, which did not differ between ABO group and control groups (mean 4.6 days ABO vs. 5.3 days control, $p = 0.475$ in Cui *et al* [32]; median 10 days vs. 10 days, $p = 0.78$ in Blumenthal *et al* [35]). Three studies reported on rates of NICU admission, with no difference between ABO and control groups (17.2% vs. 17.5%,

p = 1 in Xie *et al* [33]; 16.7% vs. 15.8%, p = 1 in Zeng *et al* [39]; and 100% vs. 93.8%, p = 0.3 in Blumenthal *et al* [35]). No neonatal mortalities were reported.

Case Report Describing ABO in Pregnant Trauma Patients

The use of ABO in pregnant trauma patients has rarely been reported. We identified one case report describing the use of ABO in a pregnant 20-year-old polytrauma patient injured in a motor vehicle collision [28]. The gestational age was approximately 24 weeks. Due to hemodynamic instability and concern for uterine rupture, the patient underwent placement of a Zone 3 REBOA through a 7 French sheath. The uterus was found to be intact, but blood-filled, and the peri-viable fetus was delivered. A hysterectomy was avoided. The REBOA had been inflated for nine minutes prior to fetal delivery. The patient survived without any reported REBOA-related complications; however, the neonate succumbed to complications of prematurity at 3 weeks old.

Discussion

Aortic balloon occlusion is a minimally invasive method of temporary hemorrhage control with the potential to save two lives in the case of obstetric hemorrhage. We reviewed the literature on aortic balloon occlusion for obstetrical hemorrhage aiming to summarize fetal and neonatal outcomes in cases for which ABO was utilized. All but one case involved obstetrical hemorrhage due to conditions including morbidly adherent placenta or uterine rupture. Importantly, a total of 111 patients underwent aortic occlusion prior to delivery of the fetus (111/825 total ABO cases, 13.5%). The majority of reported neonatal outcomes were in the form of Apgar scores, the majority of which were greater than 6 by five minutes of life. Rates of NICU admission, when reported, were around 10-20% of neonates, but one study reported a 100% NICU admission rate. Other potentially relevant outcomes, including fetal arterial blood gas, umbilical artery blood gas, and neonatal neurologic status were rarely reported. Details of fetal hemodynamics and resuscitation were not discussed. Importantly, in studies comparing ABO to control groups without ABO, there were no statistically significant differences in neonatal Apgar scores, hospitalization lengths, or NICU admission rates. The only reported neonatal mortality was in the single case of ABO in a pregnant trauma patient, with the cause of neonatal death being complications of prematurity. Importantly, multiple studies reported significantly lower maternal blood loss in cases of ABO, and significantly lower hysterectomy rates. The one study comparing ABO before and after fetal delivery found significantly lower EBL and transfusion rate in the pre-delivery ABO cohort. ABO-related complications were rare, occurring in 13 of 825 women undergoing ABO (1.6%), primarily access-site complications. Notably, one maternal death occurred due to aortic dissection. Overall, ABO for obstetrical hemorrhage appears safe, and is not associated with worsened fetal outcomes than patients not undergoing ABO. However, there are no available randomized trials on the use of ABO in this population, and these findings may be due to inherent biases in study design and patient selection.

The benefits of aortic balloon occlusion in obstetrical hemorrhage include decreased operative blood loss, lower volumes of blood transfusion, and lower rates of hysterectomy. Thus, in addition to the reducing hemorrhage, aortic balloon occlusion may also allow

for fertility preservation by lowering hysterectomy rates. Multidisciplinary collaboration with acute care and trauma surgeons in the placement of REBOA in exsanguinating obstetrical patient has been reported [40], however there are no published algorithms to guide surgeons in the care of these patients. Although in many cases, catastrophic hemorrhage and maternal mortality may be prevented by meticulous surgical technique, REBOA represents an additional tool in the armamentarium of the surgeon caring for these high-risk patients, and multi-disciplinary collaboration should be employed in cases requiring REBOA.

The decision of which patients may require aortic balloon occlusion is a complicated one, and early multidisciplinary discussion of each case should be done whenever possible to determine a plan of action. As femoral access is the rate-limiting step in REBOA use [18], consideration should be given to REBOA placement prior to abdominal incision in cases of known ongoing maternal hemorrhage. Small-bore introducer sheaths, no larger than 7 French, should be used to decrease the risk of vascular complications [41]. In the case of life-threatening hemorrhage, vasoconstriction and vascular spasm may complicate attempts to cannulate the femoral artery, and in cases at high risk for intraoperative hemorrhage, a femoral introducer sheath, with or without an uninflated aortic balloon, can be placed pre-operatively. If needed, the balloon catheter can then be inserted through the sheath, or if in place already, inflated when hemorrhage is encountered [8]. Femoral access can be obtained in under three minutes [42], and inflation of the REBOA balloon can be performed rapidly following that step. In cases of maternal trauma resulting in peri-arrest or arrest physiology, REBOA may be considered as an adjunct to improve proximal perfusion while facilitating Cesarean section, if indicated.

Further work is needed to determine the appropriate timing of balloon inflation for cases of obstetrical hemorrhage. Due to the concern for occluding fetal blood supply with pre-delivery balloon inflation, nearly all reports describe balloon inflation after fetal delivery. One study reported on a subset of 15 cases where the aortic balloon was inflated prior to uterine incision due to concern for hemorrhage; all Apgar scores were > 7 except for one neonate with asphyxia who went on to have a 5-minute Apgar score of 8 [25]. It was not stated whether this neonate was part of the 15 who underwent pre-delivery balloon inflation. To our knowledge, there is only one study comparing aortic balloon inflation prior to uterine incision to aortic balloon inflation following delivery of the fetus. This was a retrospective study of women with placenta previa, comparing 42 patients with pre-incision aortic balloon inflation to 37 patients with post-delivery aortic balloon inflation [29]. The EBL of the pre-incision group was lower (413 ml vs. 810 ml, $p < 0.001$). Apgar scores did not differ significantly (5-minute score 8.9 vs. 9.3, $p=0.5$). The time between uterine incision and delivery of the fetus was <2 minutes in all cases, and they concluded that this short aortic occlusion did not have a significant effect on neonatal outcomes. Animal work has additionally provided evidence of fetal tolerance of partial maternal aortic occlusion down to placental mean arterial pressures of 40 mmHg [43]. More work is needed in this area to determine the safety and efficacy of aortic occlusion prior to fetal delivery. In cases of life-threatening hemorrhage, with concern for imminent maternal demise due to cardiovascular collapse, we recommend early inflation of the balloon while the obstetrical team rapidly delivers the fetus.

To inform conversations regarding management of these patients, additional data is needed. Translational animal models may be used to study the differing effects of complete vs. partial REBOA on fetal and neonatal outcomes, focusing particularly on neurologic outcomes. Available animal data is limited to non-survival studies, focusing on fetal hemodynamics, and neuroimaging, finding a tolerance of relatively low levels of placental perfusion without evidence of brain ischemia on imaging following maternal partial REBOA [43,44]. Long-term data is lacking and is critical to know the potential risks of this intervention. Additionally, we recommend that publications describing the use of REBOA in cases of maternal hemorrhage report on a robust array of fetal and neonatal outcomes, including fetal hemodynamics, neonatal resuscitation required, potential neurologic sequelae including neurologic dysfunction or abnormalities on neuroimaging, and when possible, long-term functional outcomes. Critically, identifying the patients at highest risk of peripartum hemorrhage who may potentially benefit from REBOA use is an area that requires further research.

Optimal management of these patients requires multidisciplinary collaboration between multiple sectors of the healthcare team, including obstetricians, maternal fetal medicine specialists, trauma, acute care, and/or vascular surgeons, interventional radiology, anesthesiology, and nursing staff. The authors recommend establishing a multidisciplinary working group of providers with expertise in these areas to develop institutional protocols for management and to regularly review upcoming cases with potential ABO use, such as women with known abnormal placentation or pregnancies at high risk for peripartum hemorrhage. Mothers should be counseled on the potential use of REBOA, including its risks and potential benefits. Early and frequent collaboration with vascular or trauma surgeons facile with endovascular interventions should be encouraged to optimize technical outcomes. Appropriately equipped REBOA kits should be obtained and readily available in Labor & Delivery and the main OR, and the logistical steps of implementing a REBOA at an institution may follow guidance published in the trauma literature [45,46].

Once the decision has been made to pursue potential ABO in the elective setting, the patient should undergo pre-operative work-up and preparation in anticipation of potential hemorrhage, including appropriate laboratory evaluations and type and cross for blood products. Femoral arterial access may be obtained by a 5-7 French catheter placed under ultrasound guidance, and the REBOA catheter may be placed in Zone 3 of the aorta (infrarenal) prior to incision. A variety of methods are available for confirming REBOA placement within the appropriate zone of the aorta, including abdominal radiograph or fluoroscopy. To confirm arterial placement, an arterial waveform can be transduced or an arterial blood gas can be sent. Although trauma and acute care surgery are most commonly in-house and available for emergency consultations, vascular surgery or interventional radiology may also be involved in these cases depending on institutional resources and availability. Each institution should evaluate which department is best able to provide this type of emergent endovascular support to its obstetric group. The ABO balloon may be inflated after the umbilical cord has been clamped, if needed, to facilitate completion of the Cesarean section and any additional interventions that may be indicated based on the degree of abnormal placentation. However, in cases of life-threatening hemorrhage, the authors recommend inflation of the ABO early to avoid maternal exsanguination. In cases of

emergency ABO use for unanticipated obstetrical hemorrhage, or hemorrhage in a pregnant trauma patient, several key steps differ from those listed above. Most importantly, as femoral access is the rate-limiting step in REBOA use [18], a femoral cut-down may be employed rather than percutaneous catheterization.

Post-operatively, these patients will generally be admitted to the surgical intensive care unit to monitor hemodynamics and vascular exam, except in cases of minimal intraoperative blood loss and a hemodynamically stable patient. In these cases not requiring intensive care admission, patients may be monitored in the PACU for vascular checks. We recommend lower extremity vascular exams every 15 minutes for the first hour, every 30 minutes for the next two hours, and every hour until 6 hours of monitoring have been completed. Early vascular surgery consultation is recommended for any concern of post-REBOA complications including thrombosis, dissection, or limb ischemia. Vascular imaging should be obtained based on the clinical course and institutional protocols. Early prophylactic anticoagulation should be started when possible. Multidisciplinary review of all obstetrical REBOA cases should be performed routinely to identify opportunities for improvement.

Conclusion

REBOA represents a readily available and minimally invasive intervention with the potential to save two lives in the case of peripartum hemorrhage. Fetal and neonatal outcomes in women undergoing ABO appear similar to outcomes in women not undergoing ABO. Additionally, ABO was associated with greatly reduced blood loss, blood transfusion, and hysterectomy rates. Complication and mortality rates were low. Whenever possible, patients at high-risk for obstetrical hemorrhage should be discussed in a multi-disciplinary setting and the use of aortic balloon occlusion should be considered to avoid any delay in hemorrhage control. More research is needed to inform optimal timing of REBOA inflation in these cases

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Table 1:

Case reports and Series of Maternal-Fetal Aortic Balloon Occlusion: Maternal Outcomes

Study	Design	Pts	PPX	Indication	Sheath	Access	AO time (min)	EBL (ml)	Transfusion (RBC)	Hyst?	Cx
Masamoto [20]	CR	1	P	Previa and percreta	7 Fr	Perc	80	3200	1200 ml autologous blood	Y	None
Parra [23]	CR	1	E	Previa and percreta	NS	NS	NS	NS	MTP	Y	DVT
Okada [19]	CR	1	E	Accreta and uterine rupture	7 Fr	Perc	54	6900	20 units	Y	None
Duan [26]	CS	42	P	Accreta	8 Fr	Perc	22.4 (mean)	586	422 ml	1/42	None
Wei [22]	CS	45	P	Accreta, increta, or percreta	5-8 Fr	Perc	NS	835	1.7 units	4/45	1 thrombus 1 nerve ischemia
Luo [25]	CS	42	P	Previa or accreta	12 Fr	Perc	20 (median)	500	400 ml	5/42	1 hematoma
Peng [24]	CS	9	P	Previa	8 Fr	Perc	NS	1200	2 units	9/9	None
Ji [21]	CR	1	E	Previa and percreta	7 Fr	NS	75 (intermittent, partial)	>20,000	36	Y	None

#Pts: Number of patients; EBL: estimated blood loss; RBC: red blood cells; ml: milliliters; min: minutes[19,22]; Hyst: Hysterectomy; Cx: Complications; MTP: massive transfusion protocol; CR: case report; CS: case series; PPX: Prophylactic vs Emergent placement of balloon catheter; P: prophylactic placement of balloon catheter pre-operatively; E: emergency placement of balloon catheter intra-operatively; Fr: French; Perc: percutaneous; AO: Aortic occlusion.

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Table 2:

Neonatal Outcomes in Maternal-Fetal Aortic Balloon Occlusion Case Reports and Series

Study	# of patients	Apgar scores	Additional information
Masamoto [20]	1	1 minute: 4 5 minutes: 7	
Parra [23]	1	Reported to be good	
Okada [19]	1	1 minute: 1 5 minutes: 5	
Duan [26]	42	1 minute: NS 5 minutes: > 8 for all	
Wei [22]	45	1 minute: > 7 for all 5 minutes: NS	Umbilical artery blood gas results: pH < 6.98, base deficit −15.6 mmol/L.
Luo [25]	42	1 minute: > 7* for all but one infant 5 minutes: NS	5 newborns were admitted to the NICU.
Peng [24]	9	1 minute: NS 5 minutes: median score 9; all infants > 6	
Ji [21]	1	1 minute: 7 5 minutes: 8, healthy	

*Luo: One infant had an Apgar score < 7 at 1 minute due to asphyxia, but the 5-minute Apgar score was 8. NS: Not stated. NICU: Neonatal Intensive Care Unit.

Table 3:

Comparison Studies of Maternal-Fetal Aortic Balloon Occlusion

Study	# Patients		Ctrl group	PPX	Indication	Sheath	Access	AO time (min)		EBL (ml)		Transfusion (RBC)		Hyst?		Cx
	ABO	Ctrl						ABO	Ctrl	ABO	Ctrl	ABO	Ctrl	ABO	Ctrl	
Panici [30]	15	18	No ABO	P	Accreta, increta	8 Fr	Perc	NS	NA	950 *	3375	0 units *	4 units	2/13 *	9/18	None
Wu [31]	230	38	No ABO	P	Previa with accreta	8 Fr	Perc	**23.6**	NA	920 *	2800	422 ml *	1580 ml	0/230 *	3/38	2 (DVT)
Cui [32]	38	31	No ABO	P	Previa with accreta	8 Fr	Perc	**NS**	NA	1560	2145	3.6 units	4.4 units	2/38	3/31	1 thrombus
Xie [33]	30	41	No ABO	P	Accreta	12 Fr	Perc	**24.5**	NA	961 *	1560	400 ml	400 ml	5/30	10/41	1 hematoma
Zeng [39]	48	38	No ABO	P	Increta, percreta	NS	Perc	**NS**	NA	1467 *	2218	5.4 units *	9.3 units	2/48 *	9/38	1 thrombus
Li [34]	24	32	No ABO	P	Previa with accreta	8 Fr	Perc	**23.8**	NA	1600	2032	5.8 units	7.4 units	2/24 *	16/32	1 thrombus
Blumenthal [35]	16	19	No ABO	P	Accreta, increta, percreta	NS	Perc	**60**	NA	2007	2112	2 units	2 units	NS	NS	1 hematoma
Sun [36]	19	12	No ABO	P	Accreta	12 Fr	Perc	**18**	NA	1200 *	3150	800 ml *	1950 ml	4/19	6/12	1 thrombus
Mei [37]	74	100	IIA balloon	P	Accreta	8 Fr	Perc	**NS**	NS	600	600	NS	NS	0/74	0/100	None
Wang [38]	57	48	IIA balloon	P	Accreta	8 Fr	NS	22.1	23.8	450 *	619 *	481 *	615 *	2/57	0/48	None
Wei [13]	52	71	IIA balloon	P	Previa with accreta	12 Fr	Perc	**6.6**	6.7	NS	NS	NS	NS	5/52	5/71	None
Zhu [29]	42 (pre)	37 (post)	ABO pre/ post fetal delivery	Both	Previa	NS	Perc	NS	NS	413 *	810	NS	NS	0/42	2/37	1 maternal death from aortic dissection

ABO: Aortic balloon occlusion; PPX: Prophylactic; P: Prophylactic placement of balloon catheter pre-operatively; AO: Aortic Occlusion time; min: minutes; EBL: estimated blood loss; Ctrl: control; RBC: red blood cells; ml: milliliters; MTP: massive transfusion protocol; Fr: French; Perc: percutaneous; NS: not stated.

*denotes statistical significant at $p < 0.05$.

Table 4:

Neonatal Outcomes in Maternal-Fetal Aortic Balloon Occlusion Comparison Studies

Study	Apgar score – ABO (mean score unless otherwise stated)			Apgar score – Control (mean score unless otherwise stated)		
	# Pts	1 minute	5 minutes	# Pts	1 minute	5 minutes
Panici [30]	15	NS	> 8 in all	18	NS	> 8 in all
Wu [31]	230	8.8	9.7	38	8.4	9.6
Cui [32]	38	>7 in 37/38 patients	>7 in all	31	>7 in 27/31 patients	>7 in 30/31 patients
Xie [33]	30	NS	>4 in all	41	NS	>4 in all
Zeng [39]	48	7.6	9.4	38	7.8	9.3
Li [34]	24	8.4	9.5	32	8.5	9.4
Blumenthal [35]	16	7[a]	9[a]	19	8[a]	9[a]
Sun [36]	19	10 in all	10 in all	12	10 in all	10 in all
Mei [37]	74	NS	NS	100	NS	NS
Wang [38]	57	10.3	NS	48	10.1	NS
Wei [13]	52	NS	>7 in 51/52 patients	71	NS	>7 in 61/71 patients
Zhu [29]	42	8.5	8.9	37	9.4	9.3

ABO: Aortic Balloon Occlusion; NS: Not specified. Pts: Patients.

[a]Data presented as median values.