Chapter 7

Management of High-Risk Obstetrical Patients with Morbidly Adherent Placenta in the Age of Resuscitative Endovascular Balloon Occlusion of the Aorta

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Abstract

Obstetric hemorrhage is the leading cause of maternal morbidity and mortality worldwide. At highest risk of massive obstetric hemorrhage, are women with morbidly adherent placenta (MAP). The complications associated with MAP are even more devastating in very high-risk obstetrical patients, where blood transfusion is not an option, either due to lack of resources or patient refusal, such as for Jehovah's Witnesses. Resuscitative endovascular balloon occlusion of the aorta (REBOA) is a minimally-invasive technique used in trauma surgery to control non-compressible hemorrhage. REBOA is emerging as useful tool for managing high-risk obstetric surgery for MAP. This review aims to provide a framework for use of REBOA in obstetric care in challenging circumstances.

Keywords: accreta, aortic balloon, balloon occlusion, Jehovah's Witness, morbidly adherent placenta, obstetric hemorrhage, percreta, REBOA

1. Introduction

Obstetric hemorrhage is the leading cause of maternal morbidity and mortality worldwide [1]. At highest risk of massive obstetric hemorrhage are women with a morbidly adherent placenta (MAP). MAP describes the penetration of placental chorionic villi into the uterus to varying degrees classified as—placenta accreta, increta, and percreta. The incidence of MAP is increasing.

In the United States alone, the rate doubled from 5.4 in 10,000 deliveries to 11.9 in 10,000 over a period of 6 years [2]. The most severe form, placenta percreta, in which chorionic villi penetrate through the uterine wall and into adjacent organs, has increased 50-fold in the last 50 years [3].

Women with multiple prior cesarean deliveries are at greatest risk for MAP. The risk of MAP in patients after one, two, or three prior cesarean deliveries increases 2.9, 4.6 and 12.6-fold, respectively [4]. Additional risk factors include prior surgical injury to the myometrium, including dilation and curettage, and advanced maternal age.

The potential consequences of obstetric hemorrhage are most dire in women who refuse, or cannot receive, blood products. For example, the maternal mortality ratio (MMR) due to major obstetric hemorrhage in Jehovah's Witnesses was 68 per 100,000 live births in one study; 130 times that of the general population [5]. Furthermore, in low resource settings, where blood products are not readily available, the MMR can be up to 645 per 100,000 live births [6]. Obstetric hemorrhage accounts for up to 42% of maternal deaths in low resource settings [7]. With this in mind, new strategies for obstetric hemorrhage control are essential for improving transfusion-free survival.

Resuscitative endovascular balloon occlusion of the aorta (REBOA) is an emerging, minimally-invasive technique to control non-compressible hemorrhage. Although initially developed for the management of traumatic hemorrhage, REBOA has been gaining popularity for the control of non-traumatic hemorrhage. Early reports of REBOA use in obstetric hemorrhage indicate that the approach reduces blood loss, improves maternal outcomes, and decreases rates of hysterectomy compared to traditional techniques, such as uterine balloon tamponade, and hypogastric or uterine artery occlusion [8–10]. This review describes the potential applications of REBOA for control of obstetric hemorrhage in high-risk obstetric surgery for MAP.

High-quality evidence to inform management of obstetric hemorrhage when transfusion is not an option is generally lacking. Small numbers of patients, clinical heterogeneity, and ethical principles preclude against randomized studies, so most data are drawn from case series and case reports, as well as from physiological principles and expert opinions. REBOA is a growing modality with novel applications, as well as technical and technological improvements that are continually evolving. The application of REBOA to obstetric hemorrhage is in its infancy, thus comparative data and long-term follow-up are lacking. While this may limit the strength of any generalizations that can be drawn from the literature, this review aims to provide a framework for use of REBOA in obstetric care in this challenging circumstance.

2. Demographics of high-risk patients

Approximately 60% of women with MAP will experience significant morbidity, including blood transfusion, urologic injury, infection, intensive care unit admission, and readmission. A 15% of obstetric hemorrhage requiring blood transfusion are due to MAP [11]. The majority of patients with MAP will undergo invasive procedures, have extensive blood loss and require massive blood transfusion [2, 11]. A 90% of patients with placenta percreta who undergo cesarean hysterectomy will require blood transfusion due to intraoperative blood losses greater than three liters, with median transfusion of 7 units of red blood cells [12, 13].

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The morbidity and mortality associated with MAP is even more devastating when blood transfusion is not an option, either from lack of resources or patient refusal. Patients decline blood transfusions for a variety of reasons, most commonly due to religious grounds, such as for Jehovah's Witnesses. For these patients, the risk of mortality due to obstetric hemorrhage is 130 times greater than in the normal population [5].

3. Traditional hemorrhage mitigation strategies

3.1. Preoperative optimization

During the first prenatal visit, willingness to accept blood products should be addressed and alternatives to transfusion discussed. For patients who indicate that they would not accept blood transfusion, providers should investigate which, if any, blood products or alternatives may be acceptable in the case of an emergency. In addition to establishing patient capacity, a thorough discussion of the potential risks and benefits of transfusion is necessary. This discussion with patients should be performed privately and confidentially. It must be free of coercion and judgment from outside parties [14, 15]. In circumstances of a religious basis for blood refusal, patients frequently consult with religious leaders, family and friends prior to making a decision, but the final decision must rest in the hands of the patient herself. These discussions must be clearly documented in the medical record.

Preoperative optimization of hemoglobin by treating underlying anemia is ideal. Many patients who do not accept blood will accept other methods to improve hemoglobin levels. Iron, vitamin B12, folate and recombinant erythropoietin can be used preoperatively [14, 15]. Intravenous iron is preferred over oral preparations because of faster and more reliable increases in hemoglobin. Recombinant erythropoietin can optimize hemoglobin both preoperatively and postoperatively. However, there are no clear guidelines on optimal dosing. While studies suggest erythropoietin is safe to use in pregnancy, it can increase the risk of venous thromboembolism (VTE), which may exacerbate an already hypercoagulable state [16]. Consultation and coordination with a hematologist should be considered.

As the pregnancy advances, careful monitoring of the placenta is imperative to understanding the extent of MAP. A plan for delivery in an appropriately-resourced setting is crucial. Advanced directives should be established, with legal counsel as necessary. A multidisciplinary effort should be assembled to discuss the optimal approach to planned and unplanned delivery. Ideally, this team should include members of the surgical obstetric team (which may include gynecologic oncology), maternal fetal medicine, neonatology, anesthesia, and in-house emergency surgery providers (such as trauma or vascular surgery) as indicated. Working with risk management, social services, and the ethics board may be necessary to optimize outcomes in these complex, high-risk situations.

3.2. Intraoperative adjuncts

Minimization of intraoperative blood loss and optimization of anemia tolerance improves outcomes. While the surgical team focuses on hemostatic techniques to decrease blood loss, the anesthesia team can also support this goal. Patient positioning and ventilation mode can alter venous congestion, venous preload, cardiac output and peripheral vascular resistance. Normothermia aids in hemostasis. Additionally, intentional hypotension after delivery of the fetus may help minimize blood loss. A more detailed description of the anesthetic management of patients with MAP is beyond the scope of this article and has been covered elsewhere [16].

Several other methods can improve physiologic tolerance of anemia. Intraoperative volume expansion can be achieved through acute normovolemic hemodilution (ANH). With ANH, venous blood is removed into citrated bags at the start of surgery. The blood remains in a closed circuit with the patient throughout surgery. Crystalloid is administered to increase blood volume until hemorrhage is controlled, at which point ANH blood is transfused [17, 18]. Survival after more than five liters of blood loss has been documented in Jehovah's Witness patients with placenta percreta using ANH and cell salvage [19].

There is variability in the products that Jehovah's Witnesses will and will not accept [15]. Generally, whole blood products are prohibited, but some patients will accept fractions, such as hemoglobin, albumin, cryoprecipitate, clotting factors and platelets. A study of Jehovah's Witness patients found that, although most would decline conventional blood products, 76% would accept other blood components [20]. Most will accept crystalloid, colloid, recombinant factor VIIa (rFVIIa), factor VIII (FVIII), fibrinogen, tranexamic acid (TXA), and artificial blood substitutes [14, 15], but use of individual blood components alone may have limitations. Cryoprecipitate, containing FVIII, factor XIII (FXIII), von Willebrand factor (vWF) and fibrinogen, can be used in a postpartum hemorrhage to reduce risk of coagulopathy due to hypofibrinogenemia. However, it is not a substitute for plasma due to the lack of other coagulation factors. There is limited evidence that rFVIIa is helpful in refractory postpartum hemorrhage [21]. Finally, TXA is an anti-fibrinolytic agent that can be an adjunct for hemorrhage management. A Cochrane review found that TXA decreases blood loss and hemorrhage in both vaginal and cesarean deliveries [22]. The WOMAN trial found that administering TXA for postpartum hemorrhage within 3 hours of delivery decreased the rate of death due to bleeding compared to placebo. The authors found no difference in adverse events, including VTE, organ failure, sepsis, and seizure. They also found no difference in the rates of hysterectomy in both groups [23].

Cell salvage has become an important component of operative hemorrhage management for high-risk patients. However, there are important limitations of the cell salvage to consider. Cell salvage can only utilize blood collected into the canister, must have a minimum of 500 ml of blood before the cells can be washed, and returns at most 50% of the washed blood volume back to the patient. Furthermore, this technique does not allow for easy collection of vaginal blood loss, and therefore has limited utility in many obstetric hemorrhage cases. Safe use of the cell-saver has been demonstrated in obstetric patients, particularly when no future pregnancy is planned [24].

3.3. Traditional invasive hemorrhage control techniques

Definitive management for MAP is to complete a cesarean hysterectomy. A more conservative approach is to leave the placenta and uterus in situ after cesarean delivery of the infant. Follow up plans include observation with or without methotrexate, delayed hysteroscopic resection or interval hysterectomy several weeks later [25, 26]. Although conservative management is successful in 78.4% of cases, this treatment carries an increased risk of postoperative sepsis and hemorrhage, which could necessitate emergent hysterectomy, further increasing the risk of more serious complications [25, 27]. In patients where the placenta is left in place, a risk of bleeding and infection exists for up to 5 months [28]. The risks of this approach may be prohibitively high in patients who cannot accept blood transfusion [25].

Traditional vascular methods of hemorrhage control during cesarean hysterectomy include intraoperative hypogastric artery ligation, uterine artery balloon occlusion with or without embolization, and temporary balloon occlusion of the hypogastric arteries. These methods have come under criticism after studies failed to demonstrate a significant reduction in blood loss or transfusion volumes compared to cesarean hysterectomy without these measures [29–31].

Ligation of the hypogastric arteries theoretically reduces pulse pressure to the uterus; however, it is successful in reducing operative blood loss in fewer than 50% of cases. Furthermore, ligation is estimated to be even less useful in MAP involving the bladder [32]. The literature regarding prophylactic intravascular hypogastric balloon occlusion during cesarean hysterectomy with MAP is mixed. Some studies suggest this technique reduces intraoperative blood loss and transfusion requirements [33], but others have found no difference in blood loss even in combination with uterine artery embolization, concluding that prophylactic intravascular balloon catheters yield no significant benefit [29–31]. These disparate findings are most likely explained by the persistent proximal collateral circulation to the uterus which contributes to venous hemorrhage during surgery [34, 35].

Aortic cross-clamping can aid in hemorrhage control when hypogastric artery occlusion is insufficient [36]. Once surgical hemostasis has been maximized, damage control techniques such as packing and temporary abdominal closure may be useful in cases of disseminated intravascular coagulation.

3.4. Management of postoperative anemia

Postoperative management centers around reducing further hemorrhage and providing supportive care for profound anemia. Intensive care monitoring may be required. Hematology consultation may provide guidance regarding hemoglobin optimization with use of high dose erythropoietin, intravenous iron, and other adjuncts [16]. Using pediatric blood collection tubes and avoiding unnecessary lab draws are helpful strategies. In extreme cases, measures to reduce oxygen demand and increase oxygen delivery, including intubation, sedation, and hyperbaric oxygen, may be beneficial [16, 37]. Finally, providers must weigh the risks and benefits of anticoagulation causing increased bleeding against the risk of VTE.

4. Novel hemorrhage mitigation strategies

4.1. Resuscitative endovascular balloon occlusion of the aorta (REBOA)

REBOA is a catheter-based alternative to aortic cross clamping that can be used proactively prior to hemodynamic collapse and even prior to anticipated hemorrhage. Endoluminal aortic

• Gain common femoral arterial access
• Position the balloon in the most distal location appropriate for providing adequate hemorrhage control
• Slowly deflate the occlusion balloon when hemodynamics permit
• Remove the catheter and sheath promptly, apply pressure to access site
• Monitor the patient post-operatively for ischemia–reperfusion injury and arterial access site complications

Table 1. Principles of REBOA.

occlusion to control non-compressible torso hemorrhage was first described in 1954 [38]. The technique was popularized decades later when advances in endovascular technology made catheter-based vascular control more commonplace for repair of aortic aneurysms. Recently, the REBOA catheter has been modified to be percutaneous, wireless, and fluoroscopy-free, leading to its wider adoption for non-compressible hemorrhage control [39].

Despite advancements in technology, the general principles of performing REBOA have remained largely unchanged (**Table 1**). Most published data about REBOA come from trauma literature, but its use in obstetric emergencies and high-risk surgeries is expanding [8–10, 40]. Our institution has successfully documented the use of REBOA in a Jehovah's Witness patient with placenta percreta [41]. This section will discuss the unique considerations for performing REBOA in the high-risk obstetric patient.

4.2. Benefits

REBOA is an alternative endovascular hemorrhage control technique, which significantly reduces obstetric blood loss compared to combined hypogastric and uterine artery occlusion [8–10]. Reports of prophylactic REBOA use during MAP procedures demonstrate improved maternal outcomes and decreased hysterectomy rates [9]. Compared to uterine or hypogastric artery occlusion techniques, REBOA requires less time for placement and only unilateral arterial puncture making it useful in emergent cases (**Table 2**) [8]. REBOA use has demonstrated lower transfusion volumes than other occlusion techniques [8]. Furthermore, new modifications in REBOA allow placement without fluoroscopy which leads to little to no fetal radiation exposure [8, 42–45].

Catheter measurements based on anatomic landmarks can serve as a basis for positioning of the balloon within the aorta [39, 46]. The effect of a gravid abdomen on the accuracy of

• Single arterial access site, concurrent arterial blood pressure monitoring
• Little to no fetal radiation exposure
• Can be inserted and adjusted in the operating room
• Improved hemostasis compared to hypogastric and/or uterine artery occlusion
• Can be inserted quickly in response to emergent hemorrhage

Table 2. Benefits of REBOA.

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using external landmarks for fluoroscopy-free REBOA positioning has not been established. However, alternative methods for positioning in obstetric patients include palpation of the balloon within the aorta during laparotomy or from measurements taken from a pre-operative MRI [42, 43]. Confirming catheter position with an x-ray limits radiation exposure to the fetus compared to the use of fluoroscopy. Any of these positioning methods can be performed in a standard operating room with a standard table. Additionally, the catheter can be inflated, deflated, and repositioned as needed throughout the case without the needing to move the patient or obtain additional imaging.

Previous cases of REBOA use in MAP procedures describe placement by an interventional radiologist, however fluoroscopy-free REBOAs in trauma patients are most commonly placed by surgeons or emergency medicine physicians (**Table 3**) [9, 10, 40, 42, 43, 47–50]. These providers are readily available in the hospital, allowing for expedient response times. REBOA insertion, positioning, and inflation can be completed in approximately 2–3 minutes by a

A

Author	Study design	Number of patients	Prophylactic or reactive	Device used	Image guidance
Zone 1 occlusion technique					
Russo1	CR	1	Prophylactic	7Fr (Prytime)	None
Zone 3 occlusion technique					
Bell-Thomas2	CR	1	Reactive	10Fr (BVM Medical)	None
Luo3	CS	4	Prophylactic	10Fr (Cook)	Fluoro
Masamoto4	CR	1	Prophylactic	5Fr (Sheft)	Fluoro
Paull5	CR	1	Prophylactic	8.5Fr (Cook)	Fluoro
Usman6	CR	1	Reactive	NR	None
Wei7	CS	3	Prophylactic	8Fr (Bard)	Fluoro
Duan8	CS	4	Prophylactic	8Fr (Bard)	Fluoro
Wu9	Cohort	88	Prophylactic	5Fr (Cook)	Fluoro

B

Author	Occlusion time (min)	Blood loss (L)	Blood transfused	Operative time (hours)	Length of stay (days)	Complications
Zone 1 Occlusion Technique						
Russo1	32	3	None	4.2	5	None
Zone 3 Occlusion Technique						
Bell-Thomas2	NR	Massive	>40 units	4	>60	Vesico-vaginal fistula
Luo3	NS	0.8	0.4 L	1.3	NR	Ureteral damage ×2
Masamoto4	80	3.2	1.2 L	NR	NR	None

B						
Author	**Occlusion time (min)**	**Blood loss (L)**	**Blood transfused**	**Operative time (hours)**	**Length of stay (days)**	**Complications**
Paull5	NR	1.4	None	NR	7	None
Usman6	NR	Massive	40 units	6.5	9	NR
Wei7	NS	3.33 (2–6)	3.7 (2–7)	NS	NS	NS
Duan8	22.4	0.6	0.4 L	1.1	5.5	None
Wu9	23.6	0.9	0.4 L	1.1	5.1	None

CR: case report; NR: not reported; CS: case series; NS: not specified (grouped in with other causes of hemorrhage).

Table 3. Previously reported obstetrical use of REBOA for MAP, 3A. Types of REBOA devices used, 3B. Surgical outcomes of REBOA use for MAP.

trained provider using the ER-REBOA catheter (Prytime Medical, Boerne, TX). In the future, REBOA can be used increasingly for both obstetric emergencies and complicated obstetric scenarios, such as a high-risk obstetric patient with MAP.

4.3. Risks and limitations

The risks and limitations of REBOA are still being described, and the relative incidence of each is not yet known. The majority of data published on this topic describes the application of REBOA in the trauma population that consists largely of male patients with concomitant hemorrhagic shock. Potential complications from REBOA include those related to arterial access, balloon positioning and inflation, and the physiologic changes that result from inflation and deflation of the device (**Table 4**). From the trauma literature, access site complications are similar to those encountered during other forms of arterial puncture, but may be severe, including limb ischemia requiring amputation [51, 52]. Balloon malposition into an aortic branch vessel or migration into a higher or lower position within the aorta has also been described, sometimes resulting in uncontrolled arterial rupture and death [45, 51]. In animal models, proximal hypertension resulting from aortic occlusion has led to acute heart failure, cerebral edema, and respiratory failure [53, 54]. Distal organ ischemia during occlusion can lead to renal failure, bowel ischemia, and paralysis [51, 52]. Finally, washout of toxic metabolites following balloon deflation can cause rebound hypotension with cardiac collapse [55].

The use of REBOA in obstetrics introduces a different patient population with other comorbidities and requires a different anatomic site of aortic occlusion. The ability to predict complications for this population from the available trauma literature is therefore limited. The potential for severe complications exists and providers performing the procedure should be aware of these risks to improve patient management and the informed consent process.

The optimal location and duration of aortic occlusion is controversial. The primary blood supply to the gravid uterus includes the uterine arteries and collaterals from other branches of the internal iliac artery. However, particularly in cases of abnormal placentation, robust collaterals from the external iliac, ovarian, and other systemic arteries exist [34, 35]. Most

• Access site complications, including limb ischemia requiring amputation	• Use low-profile (7Fr) sheath • Use ultrasound to obtain CFA access • Monitor ipsilateral DP/PT pulses while the sheath is in place • Consider heparin flushes • Post-procedure angiography prior to sheath removal
• Balloon malposition or migration	• Confirm balloon position with x-ray • Secure catheter while in place • Dedicated provider to maintain REBOA catheter/balloon control
• Proximal hypertension that may lead to acute heart failure, cerebral edema or ARDS	• Close communication with anesthesia • Concurrent administration of vasodilators while balloon inflated • Reposition from Zone 1 to Zone 3 when able • Minimize duration of occlusion
• Distal organ ischemia, that may cause renal failure, ischemic bowel, or paralysis	• Minimize duration of occlusion • Reposition from Zone 1 to Zone 3 when able • Institute partial or intermittent REBOA when able
• Washout of toxic metabolites, leading to rebound hypotension and cardiac instability	• Institute partial or intermittent REBOA when able • Slowly, gradually deflate balloon • Communicate with anesthesia • Time administration of fluids, calcium, and pressors ith balloon deflation

Table 4. Risks of REBOA and methods of mitigation.

reports of obstetric REBOA use describe occlusion in the infra-renal aorta (Zone 3). However, when Zone 3 occlusion is insufficient, supra-celiac (Zone 1) occlusion may further limit collateral circulation through visceral and lumbosacral vessels and reduce venous back-bleeding. Caution should be used as Zone 1 occlusion is associated with more ischemic complications than Zone 3 occlusion [41]. Extrapolating from trauma literature, Zone 1 occlusion is tolerated for minutes, not hours, and multisystem organ failure and death have been reported after long inflation times [46, 52, 56]. In a prophylactic setting, the lack of pre-existing shock may improve ischemia tolerance and reduce the anticipated risks. However, there may still be a significant risk of supra-physiologic aortic pressure leading to heart failure [55].

4.4. Risk reduction

Risks of REBOA use can be reduced with multidisciplinary expertise, proper training, and adherence to good techniques. Low-profile, 7Fr common femoral arterial sheaths placed with ultrasound guidance have fewer access site complications than larger 12Fr sheaths. Additionally, distal thrombosis is rare with 7Fr sheaths and limb ischemia requiring amputation has not been reported. REBOA requires a dedicated provider to secure against catheter migration, manage inflation and deflation, and faithfully monitor the ipsilateral lower extremity for ischemia.

During balloon inflation, the anesthesia team should work to off-set unwanted blood pressure augmentation and maintain normal physiologic pressures. The surgical teams should aim to achieve hemorrhage control rapidly to keep the duration of Zone 1 occlusion to a minimum. Other methods used to reduce ischemia include intermittent or partial balloon deflation and relocating the REBOA balloon to Zone 3 when able [55]. These techniques will allow some distal blood flow to perfuse ischemic tissues and prolong the overall duration of REBOA use. Providers should be aware that balloon deflation is associated with the rapid redistribution of circulating blood volume and the washout of ischemic metabolites, including a bolus of potassium, which can result in rebound hypotension and cardiac instability [55]. The combination of partial occlusion and relocation from Zone 1 to Zone 3, along with close communication with the anesthesia providers to time fluid and drug administration with inflation and deflation, can aid in maintaining hemodynamic stability throughout surgery.

There is a dearth of published information about management of intra-arterial balloons during high-risk obstetric procedures. Of all reported cases, there has been only one documented aortic rupture due to a smaller than expected aortic diameter [45]. Few cases describe flushing the sheath or catheters, although doing so is a well-established principle of vascular surgery. Whether the flush solution should contain heparin is additionally controversial when these catheters are used for hemorrhage control in patients that cannot receive blood. The authors' practice is to use 30 ml 2% heparin (2 units of heparin per 100 ml of crystalloid) through the sheath and another 30 ml through the central lumen of the REBOA catheter every 10 minutes, while monitoring thromboelastography to ensure the absence of systemic coagulopathy. Frequent monitoring of distal pulses in the ipsilateral extremity should be maintained throughout the case and for 24 hours after sheath removal. Continuous Doppler may be a helpful adjunct to aid in early detection of arterial access complications.

The risks and benefits of anticoagulation deserve special consideration in this patient population. Pregnancy itself confers a hypercoagulable state. These patients may be at even higher risk of clot formation due to the administration of TXA, erythropoietin, cryoprecipitate or other coagulation factors. Postoperatively, VTE risk remains high in the setting of immobility and/or symptomatic anemia. In the immediate postoperative period, the risk of death from hemorrhage may outweigh the risks from VTE. Within several days of surgery however, the probability of hemorrhage decreases, justifying prophylactic heparin administration to reduce the risk of VTE.

5. Future directions

REBOA is a novel, minimally-invasive method to control non-compressible hemorrhage. Much of the literature regarding techniques for placement and risks of use are derived male trauma patients. More research is needed to investigate the use of REBOA in a peripartum setting. Reports of prophylactic use of REBOA to minimize blood loss during high-risk obstetric operations, claim to reduce blood loss and improve rates of uterine salvage compared to other types of arterial occlusion techniques, such as hypogastric and uterine artery occlusion. Most of this evidence comes from retrospective case series out of Asia. Comparative data is needed to examine the risks and benefits of REBOA compared to other methods of hemorrhage control utilized in the West. Although case reports and case series have shown that REBOA can successfully provide temporary control of obstetric hemorrhage, up to three liters of blood loss has been reported in these cases despite aortic occlusion. Larger studies are needed to quantify the expected hemorrhage volume during aortic occlusion to help inform perioperative plans.

Furthermore, instructions on REBOA use and placement for the obstetric patient are extrapolated from the trauma literature. Whether external landmarks on the gravid abdomen can be used reliably for positioning of REBOA has yet to be determined. More research is needed to establish whether imaging is needed to verify balloon position prior to inflation, and to assess the associated risk of radiation exposure to the fetus. The optimal zone of REBOA inflation is not known for obstetric hemorrhage. More research should focus on defining collateral pathways for circulation to the gravid uterus, especially in the case of abnormal placentation. Additionally, the effect of proximal vs. distal occlusion on blood pressure support during various stages of hemorrhagic shock should be established to aid in defining the optimal level of occlusion for initial balloon inflation in prophylactic and reactive settings.

Finally, the risks of REBOA are also generated from its reactive placement in trauma patients experiencing hemorrhagic shock. Although it can be assumed that prophylactic use of REBOA during planned obstetric procedures will have decreased risk compared to trauma situations, more research is needed to investigate this use of REBOA. As the adoption of REBOA for obstetric hemorrhage becomes more prevalent, it is expected that increasing evidence will help delineate more definitive guidelines for this population.

6. Recommendations

For high-risk patients with MAP, thorough planning throughout the prenatal period is critical to successful management. Prenatal optimization of hemoglobin and preoperative involvement of a multidisciplinary team can improve maternal outcomes. If blood products are not readily available or are declined by the patient, alternative options should be discussed. Clearly eliciting if blood fractions, clotting factors, and TXA will be accepted by the patient can assist in surgical planning. Meticulous surgical techniques and clear communication with the anesthesia team can minimize intraoperative hemorrhage. Additional adjuncts such as ANH and cell salvage may ease the effects of blood loss. Consideration of REBOA use may decrease the volume of blood lost and the need for transfusion. Planning for REBOA use in a proactive and prophylactic setting may limit the risks of the procedure and improve morbidity and mortality.

Implementing REBOA in the obstetric patient requires careful multidisciplinary management and clear communication throughout the perioperative period. General principles of vascular access should be respected. Minimizing the risk of limb ischemia requires selecting the smallest sheath possible to accommodate the selected balloon catheter, frequent vascular checks of both lower extremities, consideration of post-procedural angiography, and prompt sheath removal. The duration of balloon inflation should be minimized, and intermittent or partial balloon deflation should be used as adjuncts to reduce ischemia when necessary. Anticipating

• Assemble multidisciplinary team including all perioperative stakeholders
• Optimize preoperative blood volume and hemoglobin
• Plan risks and benefits discussion comparing available hemorrhage control adjuncts available at the institution
• Consider REBOA as an adjunct to temporary hemorrhage control
• Expeditiously achieve definitive hemorrhage control
• Provide post-operative intensive care, anticipating fluid shifts and electrolyte abnormalities associated with severe anemia and ischemia–reperfusion

Table 5. Summary recommendations.

hemodynamic and metabolic changes associated with balloon inflation and deflation is paramount and requires frequent communication between the operating and anesthesia teams to time the administration of medications and fluids.

Finally, providing supportive care for profound anemia and limiting unnecessary lab draws can improve postoperative outcomes. Careful consideration must be given to the use and timing of anticoagulation in setting where further hemorrhage could be detrimental to patients. A summary of the recommendations can be found in **Table 5**.

7. Conclusions

In conclusion, women undergoing planned operations for MAP are among those at highest risk for catastrophic obstetric hemorrhage, especially those for whom blood products are not an option. A multidisciplinary approach to management is the key to patient survival. Goals include limiting blood loss, maintaining hemodynamic stability, and reducing postoperative morbidity. In addition to the obstetric and anesthesia teams, assistance by general, acute care, trauma, or vascular surgeons may be required for hemorrhage control. REBOA is an emerging hemorrhage-control technique with benefits for obstetric applications and represents a tool that should be in the armamentarium of obstetric/gynecologic surgeons.

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Conflict of interest

The authors report no conflict of interest.

Notes/thanks/other declarations

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Acronyms and abbreviations

ANH	acute normovolemic hemodilution
FVIII	Factor VIII
MMR	maternal mortality ratio
MAP	morbidly adherent placenta
rFVIIa	recombinant factor VIIa
REBOA	resuscitative endovascular balloon occlusion of the aorta
TXA	tranexamic acid
VTE	venous thromboembolism
vWF	Von Willebrand factor

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