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Interventions of Postpartum Hemorrhage

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Abstract: Postpartum hemorrhage is a common and potentially life-threatening obstetric complication, with successful management relying heavily on early identification of hemorrhage and prompt intervention. This article will review the management of postpartum hemorrhage, including initial steps, exam-specific interventions, medical therapy, minimally invasive, and surgical interventions.

Key words: postpartum hemorrhage, postpartum complications, uterotonics, surgical management

Introduction

Postpartum hemorrhage is the leading cause of maternal mortality worldwide.[1,2] Successful management relies heavily on early identification of hemorrhage and prompt intervention.

Physiological adaptations during pregnancy allow for blood loss at the time of delivery, and the most contemporary definition of postpartum hemorrhage is an estimated blood loss of > 1000 mL by any mode of delivery.[1,2] Maternal cardiovascular adaptions begin as early as 6 weeks of gestation and peak in the third trimester near term. These include a 45% increase in blood volume, a 20% to 30% increase in red blood cell (RBC) mass, and a 15 to 20 bpm increase in heart rate.[3–5] Cardiac output increases by 43% at term, 50% during labor, and an additional 60% to 80% immediately postpartum due to autotransfusion from contractions and mobilization of extravascular fluid postpartum.[6,7] It is not until 1 hour after delivery that cardiac indices return to prelabor values.[6] These physiological changes can make prompt identification of hemorrhage difficult, as reliance on vital sign changes may not accurately describe the severity of hemorrhage. Classes of hypovolemic shock and early vital sign changes have been described in the nonpregnant literature (Table 1); however, it is important to understand that maternal cardiovascular changes of pregnancy may delay recognition of the traditional classes of hemorrhagic shock.[5,8]

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The authors declare that they have nothing to disclose.

TABLE 1. Classes of Hemorrhagic Shock

	Class I	Class II	Class III	Class IV
Classes of hemorrhagic shock in the nonpregnant population and their expected signs*				
Blood loss (%)	< 15	15-30	30-40	> 40
Blood loss (mL)	< 750	750-1500	1500-2000	> 2000
Pulse rate (BPM)	< 100	100-120	120-140	> 140
Blood pressure	Normal	Normal	Decreased	Significantly decreased
Pulse pressure	Normal/increased	Decreased	Decreased	Decreased
Urine output (mL/h)	> 30	20-30	5-15	Minimal
Expected values postpartum†				
Blood loss (ml)	900	1200-1500	1800-2100	2400

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Immediate Management

INITIAL STEPS

Once a postpartum hemorrhage is recognized, an institutional protocol should be activated with a multidisciplinary response team inclusive of nursing staff, obstetric providers, anesthesia, surgical services, and blood bank. Frequent hemodynamic assessments, laboratory collection, and placement of additional vascular access should be performed. A urinary Foley catheter should also be placed to monitor urine output for response to resuscitation and decompress the bladder.[1] Estimated and quantitative blood loss and vital sign assessments can be used to guide initial therapy while laboratory values are pending. After a thorough examination, this may include massive transfusion, medication therapy, or surgical therapy. The shock index (ratio of pulse to systolic blood pressure) can be utilized to assess the immediate severity of hemorrhage.[9] Several studies have found threshold values of > 0.9 to better predict poor maternal outcomes from severe obstetric hemorrhage when compared with any 1 vital sign alone.[5,9–11]

FLUID RESUSCITATION

Begin immediate fluid resuscitation with a warmed isotonic crystalloid solution. There is limited data in the obstetric literature to guide the optimal ratio of fluid volume replacement to the amount of blood lost. Current obstetric guidelines have been extrapolated from trauma literature and suggest volume replacement of 3:1.[1] However, caution should be given to massive crystalloid infusion, as it may precipitate endothelial injury, leading to fluid leak from the intravascular compartment and electrolyte abnormalities.[3] A small randomized control trial compared a standard (1.5 to 2:1) fluid volume-to-blood loss ratio with a restrictive ratio (0.75 to 1:1) in patients with obstetric hemorrhage and found no difference in the outcomes of the need for transfusion or control of hemorrhage.[12] This suggests that volume repletion can be guided by vital parameters to avoid the complications of fluid overload.[3] Although goal vital sign parameters for fluid resuscitation have not been defined, Karpati et al[13] identified a threshold of systolic blood pressure <88 mm Hg, diastolic blood pressure <50, and heart rate > 115 to be predictive of myocardial ischemia in individuals with obstetric hemorrhage.

ANESTHETIC CONSIDERATIONS

The multidisciplinary response to postpartum hemorrhage includes anesthesia

specialists who can assist with airway management, treatment of pain, and transfusion of blood products. Oxygenation should be maintained >95% during the initial assessment to optimize the oxygen-carrying capacity.[1] The decision for intubation and general anesthesia should be made early in a decompensating patient due to the risk of rapid airway edema with massive transfusion.[3] Pain should be assessed, and in a stable patient that has inadequate or no regional anesthesia, sedation with ketamine or fentanyl can be considered.[3] Should adjunctive medications for uterine relaxation be indicated based on examination findings, nitroglycerin, terbutaline, or inhaled general anesthesia can also be considered. There should be a low threshold to move to the operating room should there be inadequate equipment, lighting, or a need for general anesthesia.[3] If time permits, and there is the availability of perfusion specialists, consideration can be given to an autotransfusion device (cell saver).[14] This device collects blood from the operative field via an anticoagulated suction device, which is then filtered and reinfused into the patient's bloodstream.[14] Cell saver was previously thought to be contraindicated due to the theoretical risk for amniotic fluid embolism; however, available data have demonstrated no increased risk of complication.[15]

MONITORING LABORATORY VALUES

The initial response to a postpartum hemorrhage should include prompt laboratory assessment. Awaiting laboratory results can be timely depending on available hospital facility services, and this should not delay indicated treatment. Transfusion can begin before laboratory results based on estimated blood loss and vital sign parameters. A feasible test that does not require laboratory services is bedside clotting time. Blood can be collected in a tube without additives, and if the clotting time is noted to be >8 minutes, this is an indication that the fibrinogen stores are inadequate, and transfusion should be started.[16] Additional laboratory assessments should include blood type and crossmatch, complete blood cell count, coagulation panel (including fibrinogen), and basic electrolytes. Ionized calcium and potassium concentrations are altered in the setting of massive transfusion and should be monitored serially.[17,18] A patient with severe hemorrhage is at risk for acidemia and hypothermia, which can exacerbate coagulopathy. These can be managed by warming solutions before infusion, applying external heat, and instilling bicarbonate if pH <7.1.[19,20]

There is an increasing interest in coagulation tests that are able to provide a global assessment of hemostasis within whole blood at the bedside. Thromboelastography and rotational thromboelastometry can provide immediate information about platelet function, fibrinogen, coagulation factors, and rates of fibrinolysis and can be used for immediate guidance of transfusion products.[21] Although promising, more data are needed before this strategy can be implemented into everyday practice. Afshari et al[22] conducted a Cochrane systematic review that included 9 randomized control trials comparing the use of thromboelastography/rotational thromboelastometry to usual care and found no difference in morbidity and mortality. A systematic review within the obstetric population has found similar results.[23]

TRANSFUSION OF BLOOD PRODUCTS

Blood product transfusion will be discussed in detail in a following section but will be briefly reviewed here for completeness. When massive transfusion is undertaken, the optimal ratio of blood products is not well defined within the obstetric literature. Current guidelines are extrapolated from trauma literature and recommend a ratio of 1:1:1 (plasma,

platelets, and RBCs).[2] These guidelines exist despite the limited evidence of efficacy. Holcomb et al[24] performed a large randomized control trial of 680 trauma patients comparing blood product ratios of 1:1:1 versus 1:1:2 and found no difference in 30-day all-cause mortality despite the decreased rate of exsanguination in 24 hours. Similarly, a 2018 systematic review including 16 randomized control trials comparing the same ratios found no difference in morbidity and mortality.[25] Until further trials can be performed, specifically within the obstetric population, ratio-specific transfusions should be determined by institutional protocols and product availability.

The use of fibrinogen levels at the time of obstetric hemorrhage is promising; however, fibrinogen is altered in pregnancy and makes careful interpretation important. Fibrinogen increases with gestational age, with reference ranges between 350 and 650 mg/dL at term.[26–28] Multiple studies have identified fibrinogen as a good predictive parameter of obstetric hemorrhage severity, indicating a threshold of <200 mg/dL to denote an increased risk for maternal complications.[29–32] Fibrinogen replacement should be considered at this threshold; however, the efficacy of fibrinogen replacement in an obstetric hemorrhage remains mixed.[33,34] Further study is needed to determine the optimal blood product replacement strategy in the obstetric population.

Finally, coagulation factors such as FVIIa and prothrombin concentrate have been proposed for the treatment of postpartum hemorrhage; however, recombinant human FVIIa has demonstrated mixed success and may be associated with an increased rate of thrombotic event,[35–37] whereas prothrombin concentrate has not been validated.[38]

TABLE 2. Etiologies of Postpartum Hemorrhage

Uterine abnormality	Atony rupture inversion
Lacerations	Perineal
	Vulvar
	Vaginal
	Cervical
	Broad ligament
	Urinary tract
	Rectal
Hematoma	Vulvar
	Vaginal
	Broad ligament
	Retroperitoneal
Placenta abnormality	Placenta accreta spectrum
	Retained placenta
	Placental site subinvolution
Coagulopathy	Infection
	Consumptive (Disseminated intravascular coagulation)
	Amniotic fluid embolism
	Acute fatty liver of pregnancy

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Examination-Specific Interventions

Although uterine atony is the most common cause of postpartum hemorrhage, a thorough examination is required to assess for alternative etiologies that would be amenable to specific medical and surgical treatment (Table 2). Peripartum lacerations are successfully treated with primary closure once identified. Perineal, vulvar, and lower vaginal lacerations can be readily identified and repaired in the delivery room.[39] However, lacerations to the upper vagina, cervix, uterus, broad ligament, urinary tract, or rectum may be more difficult to identify, and a high index of suspicion is necessary.[40]

In a patient with minimal vaginal bleeding but signs of acute postpartum hemorrhage, an abdominal sonogram may be useful to identify the presence of intra-abdominal bleeding, which can result from concealed uterine or solid organ

rupture.[41] An abdominal sonogram can also be used to assess the uterine cavity and identify cases of retained placenta.[42] If necessary, the examination should be performed in the operating room to ensure appropriate equipment, lighting, and anesthesia, with the ability to proceed with surgical intervention if indicated.

PUERPERAL HEMATOMA

Puerperal hematomas may result from a concealed laceration or a spontaneous rupture of a vessel in association with an arteriovenous malformation or pseudoaneurysm. If a hematoma is identified on examination, it should be determined whether it is rapidly expanding. Stable hematomas can be expectantly managed with minimal complications.[43] Expanding hematomas are a cause of severe postpartum hemorrhage and should be managed promptly with a multidisciplinary response and resuscitation while definitive therapy can be planned. There is a paucity of data on the most effective method to treat expanding hematomas, and no studies that have directly compared different strategies. Successful management strategies include direct surgical exploration with the placement of tamponade balloons or surgical drains[44–46] and selective artery embolization.[47] Selective artery embolization may be beneficial as first-line therapy due to its ability to pinpoint small branches of arteries or pseudoaneurysms that may not be identifiable during the surgical treatment.[47–49]

PLACENTAL ABNORMALITY

Examination during a postpartum hemorrhage should include an assessment of the placenta. If the placenta is unable to be removed, this suggests either placenta accreta spectrum or entrapped placenta. Placenta accreta spectrum will be discussed in detail in a following section. Treatment of an entrapped placenta can be initially managed with gentle cord traction, administration of nitroglycerin for lower uterine segment and cervical relaxation, and manual extraction.[50–52] In cases of refractory retained placenta, ultrasound-guided instrumental removal and suction curettage are effective management strategies.[53,54]

UTERINE INVERSION

Uterine inversion is a rare cause of postpartum hemorrhage. Initial management includes maintaining the placental attachment and discontinuing uterotonic agents. The mainstay of treatment is the administration of uterine relaxants and the replacement of the uterine fundus.[1] Uterine relaxants include nitroglycerin, terbutaline, magnesium sulfate, and inhaled anesthetics.[1,55] The replacement of the uterus can be achieved with gentle manual pressure on the uterine fundus to return it to the abdominal cavity.[1] Less common techniques include an infusion of warm saline into the vagina to create hydrostatic pressure and laparoscopic reduction.[56–58] However, the treatment of refractory cases includes exploratory laparotomy with the replacement of the uterus via the Huntington procedure, described as serial clamping of the uterus with upward traction,[59] or the Haultain procedure, described as a posterior vertical incision of the cervix with repositioning of the uterine fundus once the restriction is released.[60] A less invasive laparotomy technique was recently described by Antonelli et al[61] wherein a vacuum suction cup is placed on the serosal surface of the uterine fundus and brought through the restriction with superior traction.

Medical Therapy

In the event of postpartum hemorrhage due to uterine atony, the use of uterotonic medications is the first-line treatment.[2] Before placental delivery, uterotonic agents produce contractions, which provide shearing forces to promote the

separation of the placenta.[62] After placental delivery, uterotonic agents cause the contraction of myometrial fibers around the spiral arterioles, acting as a torniquet to control uterine bleeding.[1] The American College of Obstetrics & Gynecology notes that multiple uterotonic agents are often used and recommends the use of uterotonic agents in rapid succession in the event of inadequate response with ongoing hemorrhage (Table 3).[2]

OXYTOCIN

Oxytocin is widely accepted as the first-line uterotonic for both the prevention and treatment of postpartum hemorrhage during all births.[2,63,64] A synthetic peptide, oxytocin binds to myometrial receptors to increase myofibril sodium permeability, stimulating uterine smooth muscle contractions.[63] Oxytocin can be administered either intravenously (IV) or intramuscularly (IM) and is rapid acting, with a half-life of 2 to 4 minutes.[62] Notably, high volumes of oxytocin can result in an antidiuretic effect, causing hyponatremia, headache, vomiting, drowsiness, and convulsions.[62] A large systematic review, including 24 trials with 10,000 patients, found that compared with no uterotonics or placebo, prophylactic oxytocin reduced the rates of estimated blood loss (EBL) >500 mL and >1000 mL by 40% to 50% and reduced the need for additional uterotonics by 46%.[62] The World Health Organization recommends the use of oxytocin for postpartum hemorrhage prevention for all births and is the uterotonic agent of choice in settings where multiple uterotonic options are available.[63]

In the third stage of labor, prophylactic oxytocin infusion of 10 to 40 units (U) in a 500- or 1000-mL solution is recommended.[64] In the event of hemorrhage, rapid infusion of this solution at a rate of >500 mL/h is recommended, and the further titration is indicated based on initial hemorrhage response.[64] A 2021 systematic review and meta-analysis compared IV oxytocin dosing regimens for the prevention of postpartum hemorrhage after cesarean delivery and found that compared with bolus-only regimens, bolus plus infusion regimens led to minor reductions in mean blood loss.[65] Furthermore, bolus-only regimens of 10 U decreased the need for additional uterotonics compared with 5 U.[65] In regard to administration route, a meta-analysis found that compared with IV oxytocin, IM oxytocin was associated with higher rates of postpartum hemorrhage, blood transfusion, and need for manual extraction of the placenta.[66] Thus, if IV access is already established at the time of delivery, IV administration is preferable.

In studying patterns of uterotonic use, Bateman et al[67] determined that a second uterotonic agent is required in 3% to 25% of postpartum hemorrhages. Studies to date have been unsuccessful in identifying the most effective second-line uterotonic agent.[68] Thus, obstetric guidelines recommend that choice of second-line uterotonic be guided by side effect profile and contraindications.[2]

METHYLERGONOVINE

Methylergonovine (methergine) is an ergot alkaloid, available in IM, IV, and per os (PO) formulations, which binds adrenergic myometrial receptors to cause a sustained uterine contraction.[62] A benefit of methylergonovine use is its rapid bioavailability and long half-life.[1] A 2018 metanalysis including 140 randomized trials with 89,000 patients found that an ergot alkaloid combined with oxytocin was 20% to 30% more effective at preventing postpartum hemorrhage with >500 mL and >1000 mL EBL when compared with oxytocin alone.[69] One propensity score-matched analysis found that compared with carboprost, methylergonovine is associated with a reduced risk of hemorrhage-related morbidity,

TABLE 3. Postpartum Hemorrhage Medications and Doses

Agent	Dose	Route	Interval	Response time (min)	Side effects	Contraindications
Oxytocin (Pitocin)	10-40 U in crystalloid infusion	IV, IM, IU	Continuous	1-5	Nausea, emesis, hypotension, water intoxication	None
Misoprostol (Cytotec)	200-1000 μg	SL, PO, PR	Single dose	30-60	Nausea, emesis, diarrhea, fever, chills	None
Methylergonovine (Methergine)	200 μg	IM, IU, PO	Every 2-4 h	2-5	Hypertension, hypotension, nausea, emesis	Hypertension, scleroderma, migraine, Raynaud
Prostaglandin $F_{2\alpha}$ (Hemabate)	250 μg	IM, IU	Every 15-90 min (maximum of 8 doses)	15-30	Nausea, emesis, diarrhea, flushing, chills	Active cardiac, pulmonary, renal, or hepatic disease
Prostaglandin E_2 (Dinoprostone)	20 mg	PR	Every 2 h	10	Nausea, emesis, diarrhea, fever, chills, headache	Hypotension

IM indicates intramuscular; IU, intrauterine; IV, intravenous; PO, per os; PR, per rectum; SL, sublingual.

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defined as blood transfusion or need for additional surgical intervention, during cesarean delivery.[70] Because of its adrenergic effect, an important relative contraindication to methylergonovine use is hypertension and preeclampsia disorders.[1] Although the most common side effects of methylergonovine are nausea and vomiting, rare case reports of chest pain, arterial spasm, and myocardial infarction have been published.[64] However, a large retrospective cohort study did not find a significantly increased risk of acute coronary syndrome or acute myocardial infarction after receiving methylergonovine.[71]

MISOPROSTOL

Misoprostol is a synthetic prostaglandin E1 analog, which is safe and inexpensive.[1] It is absorbed 9 to 15 minutes after use and has the fastest onset if administered sublingual or PO, but more prolonged activity and higher bioavailability if administered per rectum or vagina.[63] Notably, misoprostol is cheap, stable at room temperature, and does not require any additional supplies for administration, making it a good option in resource-limited settings.[63] However, compared with oxytocin, misoprostol is associated with more side effects such as nausea, vomiting, fever, and chills.[63] Evidence to guide the use of misoprostol for the management of postpartum hemorrhage is mixed. A 2012 systematic review found that compared with placebo, PO or sublingual misoprostol reduced the rates of postpartum hemorrhage by 34% and blood transfusion by 69%.[72] However, when compared with oxytocin, a 2014 systematic review found that misoprostol was associated with higher rates of EBL >1000 mL, blood transfusion, and overall mean blood loss.[73] The same review found that adjunctive use of misoprostol with simultaneous administration of additional uterotonics did not show a statistically significant reduction in serious maternal morbidity, maternal mortality, ICU admission, or hysterectomy.[73] Conversely, a 2018 systematic review found that compared with oxytocin alone, the combination of misoprostol plus oxytocin reduced the use of additional uterotonics and blood transfusion by 40% to 50%, but not the rates of postpartum hemorrhage >1000 mL EBL.[69] Moreover, those who received misoprostol had higher rates of nausea, vomiting, and fever.[69]

CARBOPROST

Carboprost (hemabate) is a prostaglandin F2a analog, which can be administered either IM or intrauterine (IU). Peak plasma drug levels are reached about 30 minutes after IM administration, and additional doses can be administered in 15- to 90-minute intervals.[64] Because of its bronchoconstrictive properties, asthma is a strong contraindication to the use of carboprost.[1] Other contraindications include active hepatic or cardiovascular disease, and common side effects include nausea, vomiting, diarrhea, and fever.[64] One study found that carboprost administration was successful in controlling hemorrhage in 88% of postpartum hemorrhages.[74] A 2012 systematic review showed that IM prostaglandins resulted in less blood loss and a shorter duration of the third stage of labor, but that side effects, such as vomiting, abdominal pain, and diarrhea, were more common.[72] Notably, although acceptable for postpartum hemorrhage treatment in conjunction with other medications, carboprost is not recommended for prophylaxis due to its significant side effect profile and high unit cost.[63]

PROSTAGLANDN E2

There are limited recent studies on prostaglandin E2 as a uterotonic as its use is often precluded by its unfavorable side effect profile, which includes fever, chills, nausea, emesis, and diarrhea.[1] A 1991 randomized control trial showed that

compared with saline, prostaglandin E2 used in the third stage of labor was associated with a 35% reduction in postpartum blood loss and was comparable to oxytocin.[75] A 2011 French study showed that 83% of women who received prostaglandin E2 for hemorrhage due to atony did not require any additional procedures to control bleeding.[76]

TRANEXAMIC ACID

At the time of placental delivery, there is a rapid degradation of both fibrinogen and fibrin, as well as an increase in the activation of both plasminogen activators and fibrin degradation products.[77] Tranexamic acid (TXA) blocks the binding site of plasminogen to fibrin to prevent fibrinolysis and maintain blood clotting.[77] TXA is commonly used in a wide range of surgical specialties to prevent fibrinolysis and thus reduce blood loss. Reported adverse effects include nausea, vomiting, and diarrhea, with additional reports of rare complications including thrombosis, renal cortical necrosis, and retinal artery obstruction.[73]

Ducloy-Bouthers et al[78] published the first randomized control trial on TXA use to treat primary postpartum hemorrhage and found a significant reduction in blood loss, bleeding duration, and blood transfusion in the TXA group. The WOMAN trial[79] was an international, double-blind randomized control trial comparing TXA to placebo during postpartum hemorrhage. Although the trial demonstrated no reduction in the composite primary endpoints of hysterectomy or death from all causes, there was a 20% reduction in death due to bleeding in women who received TXA.[79] In terms of postpartum hemorrhage prevention, a large 2015 systematic review found that prophylactic TXA use decreased the rate of EBL >400 to 500 mL in all modes of delivery and >1000 mL in women who underwent cesarean section, with no difference in thromboembolic episodes.[77] An additional 2018 systematic review showed that compared with placebo or standard care alone, IV TXA reduced the risk of maternal death due to bleeding.[80] Given the current paucity of data on prophylactic TXA, American College of Obstetrics & Gynecology does not recommend its use as prophylaxis outside of the context of research; however, does recommend consideration of its use in the setting of obstetric hemorrhage when initial medical therapy fails.[2]

Minimally Invasive Interventions

UTERINE TAMPONADE

In cases of refractory hemorrhage after medical interventions and examination-specific treatments, tamponade devices have been successful. Uterine tamponade is particularly successful in those with a diagnosis of uterine atony.[81] Uterine tamponade can be achieved with gauze packing, IU balloon placement (Bakri or Foley), or suction devices.[82] A 2020 meta-analysis that included 4700 patients with postpartum hemorrhage, demonstrated an 86% success rate of controlling the hemorrhage with uterine balloon tamponade.[81] Before the popularization of the Bakri balloon, tamponade was commonly achieved with IU packing.[83] Trials comparing the efficacy and safety of gauze packing to balloon tamponade in the setting of postpartum hemorrhage have been mixed but overall demonstrate good efficacy.[84–86] Disadvantages of these methods include duration of use, with a typical required indwelling time of 12 to 24 hours during which prolonged monitoring is needed, as well as the potential for concealed bleeding.[87]

Newer methods of uterine tamponade include the XSTAT, a device currently in clinical testing, which contains minisponges compressed within a tubular applicator for

transcervical insertion. Originally designed for use in combat, the sponges conform to the uterine cavity shape and expand with blood absorption to apply direct pressure to bleeding sites. In 9 cases of postpartum hemorrhage, this device resolved bleeding within 1 minute, with sponges left in place for 1 hour on average.[88]

The Jada system, another novel device that recently became available for commercial use, creates uterine tamponade with IU suction (Fig. 1).[87] The device consists of an IU loop lined with vacuum pores, a cervical seal, and tubing, which is connected to a vacuum source (typically wall suction or other regulated vacuum source).[87] Compared with uterine balloon tamponade, which expands the uterine walls to apply direct pressure to the uterine vasculature, the IU vacuum created by this device simultaneously evacuates the uterus of pooled blood and expedites uterine contraction, constricting myometrial vessels to control bleeding.[87] Initial studies report a hemorrhage control rate of 94% within 2 to 5 minutes after placement and no increased significant adverse events.[89] More study is needed to decipher the optimal time to use this device during a postpartum hemorrhage.

Another vacuum system under investigation is a modified Bakri balloon system. The IU Bakri balloon is inflated with only 50 to 100 mL of saline, and the balloon catheter is subsequently attached to a vacuum device.[90] A single-center observational cohort study found this method was associated with a success rate of 86% in cases of postpartum hemorrhage due to uterine atony.[90]

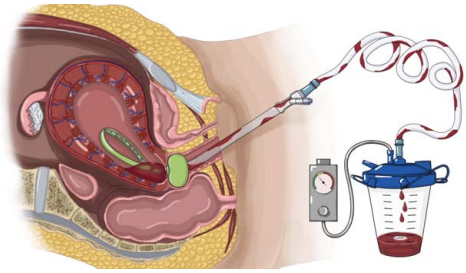

FIGURE 1. The Jada system. From Jada Medical Illustrations. full color online

UTERINE ARTERY EMBOLIZATION

In a stable patient and with interventional radiology services readily available, uterine artery embolization is an option for refractory bleeding. The procedure involves the injection of gelatin or polyvinyl alcohol particles into the uterine artery or anterior division of the internal iliac arteries to occlude the pelvic vasculature and decrease pelvic blood flow.[91] The reported rates of hemorrhage control range from 75% to 100% after this procedure.[39,92,93] Lower success rates are reported in those with disseminated intravascular coagulopathy, higher estimated blood loss (>1500 mL), and having received >5 U of RBC transfusion.[94–96] Fertility after uterine artery embolization has been of concern; however, a systematic review by Doumouchtsis et al[97] reported 91% menstrual regularity and 78% fertility after this procedure. However, pregnancy outcomes remain of concern, as this population is at higher risk of placenta accreta spectrum in a subsequent pregnancy.[98,99]

AORTIC COMPRESSION

Techniques that reduce blood flow to the lower abdominal and pelvic vasculature may be used as a bridge to the definitive treatment of postpartum hemorrhage. Resuscitative endovascular balloon occlusion of the aorta (REBOA) is a percutaneous balloon that is placed under ultrasound guidance and inflated proximal to the bifurcation of the iliac arteries that has demonstrated survival benefits.[100,101] REBOA has been used successfully in the obstetric population for severe postpartum hemorrhage as a bridge to definitive therapy[102] and as an adjunct in placenta accreta spectrum surgeries.[103,104]

External or internal aortic compression can also be applied if REBOA is unavailable and can significantly decrease lower pelvic and extremity blood flow and blood pressure.[105]

Surgical Interventions

Exploratory laparotomy is indicated if minimally invasive techniques fail to control the postpartum hemorrhage. The initial goal of the surgical techniques is to reduce blood flow to the pelvis, uterus, and lower genital tract and ultimately remove the bleeding organ if these attempts are unsuccessful.

ARTERY LIGATION

Uterine artery ligation, as described by O'Leary in 1966, involves grasping the anterior and posterior aspects of the broad ligament at the lateral lower uterine segment and identifying the ascending branches of the uterine artery as they enter the myometrium at the cervical-uterine junction. Bilateral suture ligation of the uterine artery is then performed, incorporating the lower uterine segment myometrium to ensure the inclusion of the deep myometrial uterine artery branches (Fig. 2).[106,107] If this technique fails to control the hemorrhage, vessel ligation can continue in a stepwise manner to occlude mid-level uterine branches and utero-ovarian pedicle vessels.[39] This stepwise technique was used in 103 individuals with intractable postpartum hemorrhage and was found to be 100% successful in preventing hysterectomy.[108] Internal iliac artery ligation is also reported; however, this technique requires extensive retroperitoneal dissection and only has 40% to 60% success rate.[109,110]

UTERINE COMPRESSION

Uterine tourniquet is a surgical technique that can decrease uterine bleeding while coordinating definitive surgical management. There are limited reports of its use during postpartum hemorrhage; however, Breen[111] reported on its successful use in 13 patients with postpartum hemorrhage. The described technique creates a tourniquet from a Foley catheter by tying it circumferentially around the lower uterine segment without incising the broad ligament. Definitive hysterectomy was then carried out successfully in all patients >24 hours later after stabilization.[111]

Uterine compression sutures, first described by Lynch et al[112] in 1997, can compress the uterus and treat uterine atony. An absorbable suture is placed anteriorly in the lower uterine segment and wrapped around the uterine fundus to the posterior aspect. In tying the suture, the uterine fundus is compressed toward the lower uterine segment (Fig. 3).[112] Alternative compression sutures that attach the anterior and posterior endometrium have been described with similar success.[113–115] A review of the differing techniques shows comparable efficacy[116,117]; however, there are also reported cases of associated ischemic necrosis.[118,119]

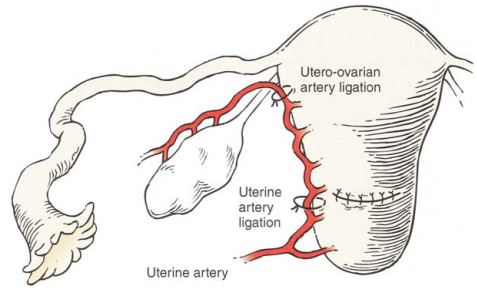

FIGURE 2. Uterine artery ligation. From Francois et al.[1] full color online

HYSTERECTOMY

Definitive management of a postpartum hemorrhage refractory to all other techniques is hysterectomy. One large systematic review published in 2010 assessed 981 cases of emergency hysterectomy for postpartum hemorrhage.[120] The reported mortality rate was 2.6%; common indications

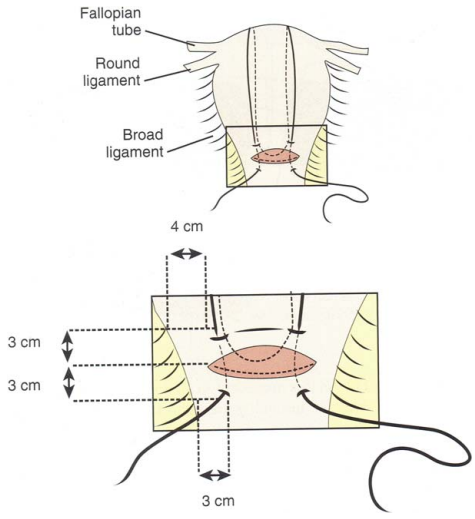

FIGURE 3. B-Lynch compression suture. From Francois et al.[1] full color online

for hysterectomy were placenta accreta spectrum (38%) and uterine atony (29%), and subtotal hysterectomy was performed in 48% of the cases.[120] Because total hysterectomies are thought to add to operative time and can be difficult when the cervix is dilated, experts recommend subtotal hysterectomy unless bleeding cannot be controlled without removing the cervix. Studies comparing total to subtotal hysterectomy are mixed. Although total hysterectomies may have more surgical complications and urinary tract injuries, subtotal hysterectomies were found to have higher rates of reoperation and perioperative death.[121,122] Ultimately, the choice of hysterectomy type should be at the discretion of the surgical team, taking into consideration the patient's stability and source of hemorrhage.

PELVIC PACKING

Pelvic packing can provide additional hemostasis after hysterectomy. A technique first described by Logothetopulos[123] in 1926 has many names (mushroom, parachute, umbrella, or logothetopulos pack) and may provide additional hemostasis over traditional abdominal packing.[123,124] A mushroom-shaped pack can be created from a sterile plastic bag and surgical gauze, brought out through the vagina, and placed under traction to compress the pelvic floor fascia against the bony pelvis.[124] There have been several case reports of this technique to control posthysterectomy hemorrhage, which can be used as a final strategy to control bleeding.[124,125]

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