British Journal of Anaesthesia **103** (BJA/PGA Supplement): i47–i56 (2009)
doi:10.1093/bja/aep303

BJA

OBSTETRICS

Maternal haemorrhage

M. Walfish*, A. Neuman and D. Wlody

SUNY Downstate Medical Center, 450 Clarkson Ave., Box 6, Brooklyn, NY 11203, USA
**Corresponding author. E-mail: menachem.walfish@downstate.edu*

Maternal haemorrhage is the leading cause of preventable maternal death worldwide and encompasses antepartum, intrapartum, and postpartum bleeding. This review highlights factors that predispose to severe bleeding, its management, and the most recent treatment and guidelines. Advances in obstetric care have provided physicians with the diagnostic tools to detect, anticipate, and prevent severe life-threatening maternal haemorrhage in most patients who have had prenatal care. In an optimal setting, patients at high risk for haemorrhage are referred to tertiary care centres where multidisciplinary teams are prepared to care for and deal with known potential complications. However, even with the best prenatal care, unexpected haemorrhage occurs. The first step in management is stabilization of haemodynamic status, which involves securing large bore i.v. access, invasive monitoring, and aggressive fluid management and transfusion therapy. Care for the patient with maternal bleeding should follow an algorithm that goes through a rapid and successive sequence of medical and surgical approaches to stem bleeding and decrease morbidity and mortality. With the addition of potent uterotonic agents and the advent of minimally invasive interventional radiological techniques such as angiographic embolization and arterial ligation, definitive yet conservative management is now possible in an attempt to avoid hysterectomy in patients with severe peripartum bleeding. If these interventions are inadequate to control the bleeding, the decision to proceed to hysterectomy must be made expeditiously. Recombinant factor VIIa is a relatively new treatment that could prove useful for severe coagulopathy and intractable bleeding.

Br J Anaesth 2009; **103** (Suppl. 1): i47–i56

Keywords: anaesthesia, obstetric; anaesthetic techniques; complications, haemorrhage; uterus, blood flow

Obstetric haemorrhage is the single most significant cause of maternal mortality worldwide accounting for 25–30% of all maternal deaths.[54 55] From 1991 to 1999, 17% of pregnancy-related deaths in the USA were due to haemorrhage.[13] The most recent report of the Confidential Enquiries into Maternal Deaths in the UK showed that 17 of 132 direct deaths were due to haemorrhage.[15] Life-threatening postpartum haemorrhage (PPH) occurs in ~1:1000 deliveries in the developed world.[22] Serious morbidity resulting from haemorrhage includes adult respiratory distress syndrome, coagulopathy, shock, loss of fertility, and pituitary necrosis.[2] Although the risk of dying from pregnancy decreased dramatically during the last century, 60–90% of deaths from PPH are potentially preventable with better medical care.[5 15] This review covers the aetiology, evaluation, and management of maternal haemorrhage.

Definition

A variety of definitions for PPH have been proposed, yet no single satisfactory definition exists.[2] The World Health Organization defines PPH as blood loss >500 ml in the first 24 h after delivery.[56] However, there is evidence that 500 ml is actually normal blood loss after vaginal delivery and 1000 ml after Caesarean section with little clinical relevance. Practitioners are poorly trained in estimating blood loss leading to an inaccurate and often underestimated value.[19] Another popular definition of haemorrhage is a 10% decrease in either the haemoglobin or the haematocrit, but determinations of these values are often delayed and might not reflect the patient's current haemodynamic status.[14] Commonly, PPH is diagnosed when the amount of bleeding exceeds the practitioner's estimates of 'normal'.[58] Clinical signs and symptoms of blood loss including weakness, sweating, and tachycardia might not

Table 1 Stages of hypovolaemic shock

	Stage			
	I Compensated	**II Mild**	**III Moderate**	**IV Severe**
Blood loss	<15%; 750–1000 ml	15–30%; 1000–1500 ml	30–40%; 1500–2000 ml	>40%; ≥2000 ml
Heart rate (beats min^{-1})	<100	>100	>120	>140
Arterial pressure	Normal; vasoconstriction redistributes blood flow, slight increase in diastolic pressure	Orthostatic changes in arterial pressure, vasoconstriction intensifies in non-critical organs (skin, muscle, gut)	Markedly decreased (systolic arterial pressure <90 mm Hg); vasoconstriction decreases perfusion to abdominal organs	Profoundly decreased (systolic arterial pressure <80 mm Hg); decreased perfusion to vital organs (brain, heart)
Respiration	Normal	Mild increase	Moderate tachypnoea	Marked tachypnoea—respiratory failure
Mental status	Normal, slightly anxious	Mildly anxious, agitated	Confused, agitated	Obtunded
Urine output (ml h^{-1})	>30	20–30	<20	None (anuria)
Capillary refill	Normal (<2 s)	>2 s; clammy skin	Usually >3 s; cool, pale skin	>3 s; cold, mottled skin

occur until 15–25% of total blood volume is lost with haemodynamic collapse occurring only at losses between 35% and 45%.[6] Given the wide range of definitions applied to maternal haemorrhage and their limitations, it is important to combine the clinical presentation and objective data, while keeping in mind the probability of concealed bleeding within the uterus, peritoneal cavity, and retroperitoneal space, and the relative masking of haemodynamic signs of haemorrhagic shock (Table 1) due to the physiological adaptations of pregnancy.[9]

Antepartum haemorrhage

Antepartum haemorrhage is defined as bleeding from the genital tract after 24 weeks of gestation and has an incidence of 2–5% of all pregnancies beyond 24 weeks.[11] The causes of antepartum haemorrhage range from cervicitis to placental abnormalities, most commonly placental praevia or placental abruption.[35] A proactive approach should be used for patients at high risk for haemorrhage since preoperative preparedness can improve outcome.[17] Complications of antepartum haemorrhage include maternal shock, a greater risk of premature delivery, fetal hypoxia, and sudden fetal death, making antepartum haemorrhage an even greater risk to the fetus than to the mother.[11]

Placental abruption

Haemorrhage arising from premature separation of a normally situated placenta is known as placental abruption (Table 2).[11] Abruption complicates about 1% of pregnancies and is the leading cause of vaginal bleeding in the latter half of pregnancy. The classic presentation consists of vaginal bleeding, uterine tenderness, and increased uterine activity.[43] Known risk factors include: hypertension, pre-eclampsia, advanced maternal age, multiparity, maternal/paternal tobacco use, cocaine use, trauma, premature rupture of membranes, chorioamnionitis, and prior abruption.[35] The diagnosis of abruption is made clinically with ultrasound confirmation in certain cases.[11] The maternal effect of abruption depends primarily on its severity, but its effect on the fetus is determined by both its severity and the gestational age at which it occurs.[43] In cases of concealed abruption, vaginal bleeding can be absent, and an underestimation of maternal hypovolaemia can occur.[35] The management of placental abruption, including the timing and route of delivery, depends on the degree of maternal and fetal compromise, presentation, and gestational age.[43] The major complications of abruption include haemorrhagic shock, acute renal failure, coagulopathy, and fetal demise.[35] Abruption is the most common cause of disseminated intravascular coagulation in pregnancy.[43] Epidural analgesia can be offered to a patient with partial abruption as long as coagulation and volume status are considered.[35] Most urgent cases of placental abruption, with a non-reassuring fetal heart rate, are performed under general anaesthesia. After delivery, the patient should be monitored closely due to the risk of persistent haemorrhage from uterine atony or coagulopathy.[43]

Table 2 Placental abruption

Signs and symptoms	Vaginal bleeding (although about 20% of cases have no bleeding)
	Uterine tenderness
	Rapid contractions
	Abdominal pain
	Fetal heart rate abnormalities
Causes	Specific cause, often unknown
	Trauma or injury to abdomen
	Rarely, short umbilical cord or rapid loss of amniotic fluid
Risk factors	Multiparity, hypertension, polyhydramnios, abdominal trauma, substance abuse, prior abruption
Diagnosis	Clinical signs/symptoms
	Ultrasound
Treatment	Assess fetal well-being
	Assure adequate i.v. access
	Type and cross-match blood
	Vaginal delivery *vs* Caesarean section

Uterine rupture

Uterine rupture is tearing of the uterine wall during pregnancy or delivery.[51] It remains one of the most life-threatening emergencies in obstetrics, as it is associated with high maternal and perinatal morbidity and mortality.[36] Although most cases result from rupture of a previous Caesarean scar and are diagnosed within a hospital setting, the primigravid uterus is not immune to spontaneous rupture and it must be considered in all women, regardless of parity.[52] Other risk factors include prior uterine surgery, trauma, uterine anomalies, dystocia, use of uterotonic drugs, and abnormal placentation. Clinical presentation can vary from subtle findings, such as uterine tenderness and non-reassuring fetal heart patterns, to severe localized abdominal pain and a rapid onset of maternal hypovolaemic shock.[36] Prompt recognition of uterine rupture leading to surgical intervention is critical in influencing perinatal and maternal morbidity and mortality.[51]

Placenta praevia

Placenta praevia occurs when the placenta is totally or partially inserted in the lower uterine segment (Fig. 1). Conditions associated with placenta praevia have a common element of prior uterine trauma and include multiparity, advanced maternal age, previous C-section or other uterine surgery, and prior praevia.[35] The classic sign of placenta praevia is painless vaginal bleeding during the second or third trimester. The initial bleed is often mild. Diagnosis is usually made by ultrasound, followed by planned management by the obstetric service based on severity and fetal maturity.[11] Ultimately, Caesarean section is the recommended mode of delivery. Patients with placenta praevia are at a significantly increased risk for high intraoperative blood loss due to the possibility of the obstetrician incising through the placenta and the increased risk for placenta accreta.[49] In addition, the uterine site of abnormal implantation does not contract as effectively as a normal uterine segment.[4] Although there is no consensus on the use of general *vs* regional anaesthesia in patients with placenta praevia, and each case can be decided only after a complete evaluation, Bonner and colleagues[7] determined that most obstetric anaesthesiologists preferred neuraxial anaesthesia over general anaesthesia in both elective and emergency situations.

Postpartum haemorrhage

PPH can be categorized as an abnormality of one or more of the following: uterine tone (uterine atony), retained tissue (placental tissue or blood clots), trauma (genital tract lacerations), or coagulation (coagulopathy).[17] Primary PPH occurs during the first 24 h and is more likely to result in maternal morbidity and mortality while secondary haemorrhage refers to haemorrhage 24 h to 6 weeks after delivery.[35] Prevention of PPH relies on active management, at the time of delivery, including administration of prophylactic uterotonic agents, early cord clamping, and controlled cord traction of the umbilical cord at placental delivery.[18] Although many risk factors have been associated with PPH, it often occurs without warning. A management protocol for the diagnosis and treatment of PPH should be available at every delivery unit.[10] A notable example of this implementation is the interdisciplinary protocol developed by New York State Department of Health in conjunction with American College of Obstetricians and Gynecologists (ACOG).[39]

Risk factors for PPH

Uterine atony

Uterine atony, defined as the lack of efficient uterine contractility after placental separation, is the most common cause of PPH and complicates ~1 in 20 deliveries.[10] Risk factors for uterine atony include conditions in which the uterus is overdistended (polyhydramnios, multiple gestation, and macrosomia), fatigued (prolonged labour, chorioamnionitis), or unable to contract due to tocolytics or general anaesthesia.[18] Risk factors for the development of uterine atony were quantitated in a study by Rouse and colleagues[46] who examined more than 23 000 deliveries in 13 university centres. The overall incidence of atony was 6%. Multiple gestation [odds ratio (OR) 2.40], Hispanic ethnicity (OR 2.21), labour induction >18 h (OR 2.23), and birth weight >4500 g (OR 2.05) were all significant predictors of atony. However, two-thirds of the women studied had no risk factors, yet they accounted for more than half of the cases of uterine atony. In the author's words: 'vigilance and preparation for this potential emergency are necessary in all women undergoing Cesarean delivery'.[46] The most common physical findings in patients with uterine atony are a soft, boggy uterus and vaginal bleeding. An engorged atonic uterus can contain more than 1 litre of blood and unrecognized intrauterine bleeding can manifest as haemodynamic instability secondary to hypovolaemia.[35] Initial treatment of uterine atony entails discontinuation of those agents, for example, inhalation anaesthetics, which often contribute to atony, emptying of the bladder, bimanual compression, uterine massage, and uterotonic agents. These procedures can diminish bleeding, expel blood and clots, and allow time for further pharmacological or surgical measures to be implemented.[2]

Abnormal placentation

Abnormal placentation refers to abnormal attachment of the placenta to the uterine wall and includes accreta, increta, and percreta, depending on the extent of uterine invasion.[4] Abnormal placentation can result in massive haemorrhage and along with uterine atony is the most common cause of postpartum hysterectomy.[24] Important risk factors are the presence of placenta praevia and a

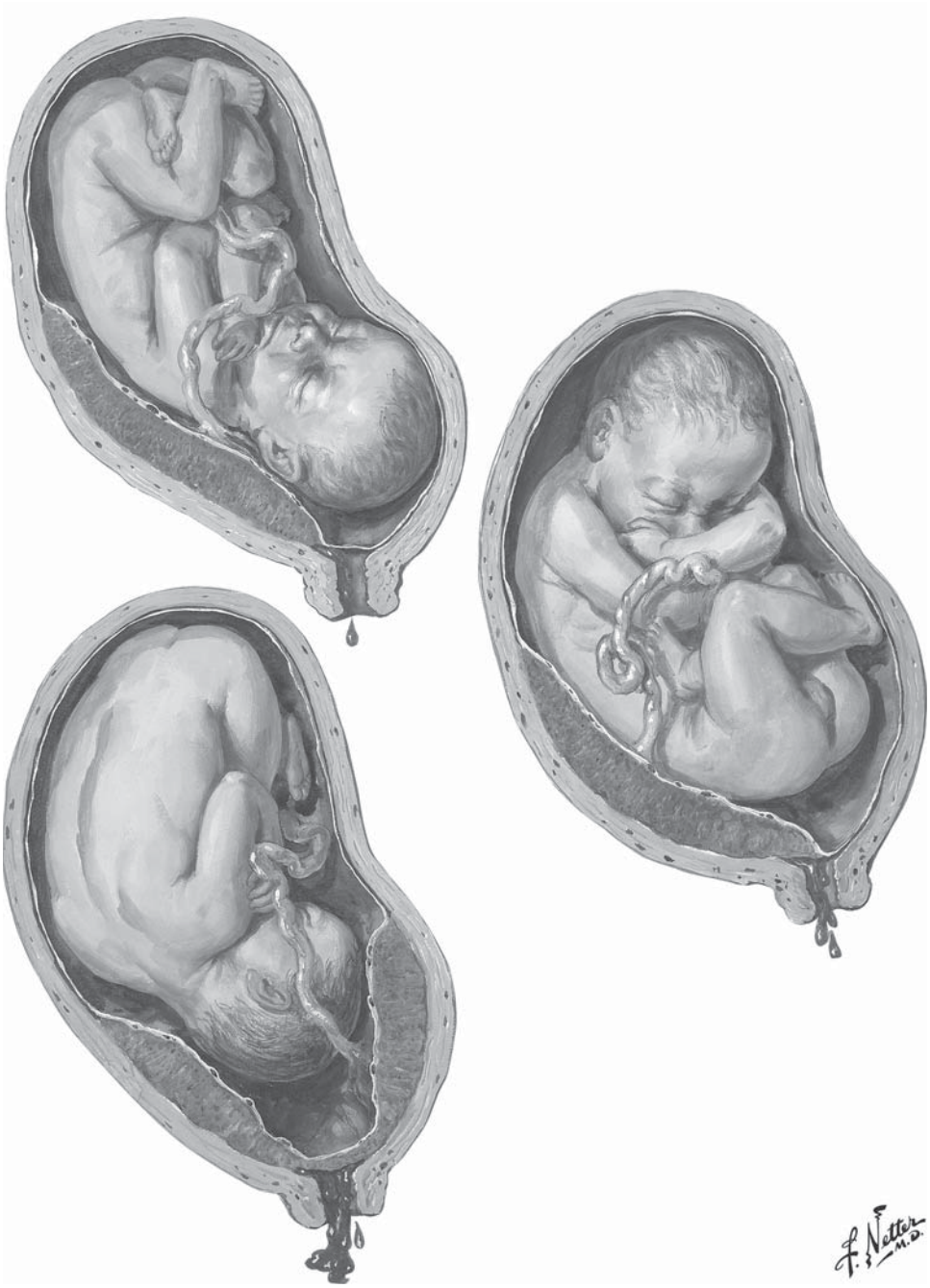

Fig 1 Types of placenta praevia. Top, marginal placenta praevia; Middle, partial placental praevia; Bottom, complete placental praevia. From netterimages.com. Used with permission of Elsevier. All rights reserved.

history of prior Caesarean deliveries.[10] A markedly increased risk of placenta accreta is associated with an increasing number of prior Caesarean deliveries (Table 3), with and without placenta praevia.[49] Antenatal diagnosis of placenta accreta can be made by ultrasound or MRI and facilitates effective planning.[35] If the diagnosis or a strong suspicion is formed before delivery, ACOG suggests a number of preparatory measures including patient counselling regarding the likelihood of hysterectomy and

Table 3 Risk of placenta accreta after previous Caesarean section[51]

Number of previous Caesareans	Risk of placenta accreta (%)
0	1.9
1	15.6
2	23.5
3	29.4
4	33.3
5	50

transfusion, availability of adequate personnel, blood products, cell salvage, and prior multidisciplinary assessment.[2] Although the extent of surgical management depends on the extent of the abnormal attachment, attempts to separate the placenta can result in massive haemorrhage, and a prompt decision to proceed to hysterectomy without delay enhances the likelihood of an optimal outcome.[34]

Obstetric trauma

The most common injuries at delivery are lacerations and haematomas of the perineum, vagina, and cervix. A majority of the cases are minor, but some injuries are associated with significant, immediate, or delayed haemorrhage.[35] Risk factors for injuring the pelvic vasculature and haematoma formation include null parity, episiotomy, advanced maternal age, operative delivery, breech presentation, multiple gestation, and high birth weight.[36] Although common presenting signs and symptoms are based on the location of the injury and include a rectal or vaginal mass, discoloration, and perineal pain or pressure, the clinical manifestations of the injuries are primarily the result of blood loss which can be significant before the development of signs and symptoms of hypovolaemia.[58] This can be especially true with respect to retroperitoneal bleeding. Most retroperitoneal haematomata present within 24 h of delivery and can be accompanied by fever, ileus, thigh pain, and leg oedema.[58] Conservative management involving observation, ice, pressure, and analgesics should be limited to those patients with small pelvic haematomata that are stable in size, with no evidence of haemodynamic compromise.[33] Otherwise, surgical exploration, evacuation, and ligation of vessels should be performed in a controlled setting in order to avoid the known severe complications of infection, septicaemia, pressure necrosis, profuse haemorrhage, and death.[58] The choice of anaesthetic technique depends on the affected area, surgical requirements, physical status of the patient, and urgency of the procedure.[35]

Coagulopathy

Although the majority of cases of PPH are related to the primary obstetric pathology and the cause can be easily identified, the possibility of an inherited bleeding disorder should be considered in situations of unexplained and recurrent haemorrhage.[31] PPH can be the first indication of von Willebrand's disease (VWD) and should be considered.[30] VWD is a result of a deficiency in, or a dysfunction of, a multimeric protein named von Willebrand factor (VWF). VWF plays an important role in haemostasis by facilitating platelet adhesion and acting as a carrier protein for coagulation factor VIII, thereby increasing the procoagulant activity of factor VIII.[30] Other, less common, bleeding disorders associated with PPH include deficiencies in prothrombin, fibrinogen, and factors V, VII, X, and XI.[31] Screening women with a history of menorrhagia is an important strategy in identifying patients with these disorders, thereby reducing PPH and maternal mortality.[29] Patients in the third trimester should be treated in consultation with a haematologist to ensure an optimized haemostatic profile before delivery. Therapy for patients with bleeding disorders consists of haemostatic agents such as tranexamic acid and desmopressin (DDAVP) followed by coagulation factor replacement in severe cases or disorders refractory to antifibrinolytic treatment.[30] The tendency to bleed and the risk of PPH in haemophiliacs and patients with VWD correlate with the plasma levels of their clotting factors, with the most significant haemorrhage occurring at factor levels <50 IU dl^{-1} and no prophylactic treatment for labour.[31] A consensus conference of obstetricians, gynaecologists, and haematologists recommended a multidisciplinary team approach, active management of the third stage of labour, the administration of VWF concentrate and tranexamic acid, and the use of extreme caution with DDAVP due to risk of hyponatraemia. The experts also considered epidural analgesia/anaesthesia safe in patients with third trimester VWF levels of 50 IU dl^{-1} or above.[30] It is important to note that the risk of PPH persists for as long as 1 month after delivery.[30]

Management

General principles

Although specific interventions will be required depending on the underlying cause of the haemorrhage, several basic steps are essential in the initial and continued management of any patient with obstetric haemorrhage.[17] Bonnar[6] describes a five-step management plan for massive obstetric haemorrhage: (i) organization of the multidisciplinary team; (ii) restoration of blood volume via large bore access using fluid and blood; (iii) correction of defective coagulation with blood products and factors; (iv) evaluation of response to treatment by haemodynamic and laboratory assessment; and (v) remedying of the underlying cause of the bleeding. Another therapeutic goal in the treatment of severe PPH is avoidance of myocardial ischaemia by increasing the myocardial supply–demand ratio. A significant percentage of parturients with haemorrhagic shock experienced electrocardiographic signs of ischaemia and decreased contractility that correlated with the severity of haemorrhage.[32] Given that most maternal morbidity and mortality is due to underestimation of blood loss, inadequate volume replacement, and delay in intervention, a management protocol for treatment of obstetric haemorrhage should be available at every delivery unit that initiates a sequence of conservative and operative interventions. Success of each treatment should be rapidly assessed with the swift institution of the next intervention if it has failed.[10] Prompt communication between anaesthesiology, obstetric–gynaecology, nursing, laboratory, and blood bank is essential for effective evaluation and management of excessive blood loss.[2]

Table 4 Pharmacological treatment of uterine atony

Drug	Dosage
Oxytocin	Bolus 0.5–1 unit, infusion 20–160 units litre^{-1}
Methergine	0.1–0.2 mg i.m.
15-methyl PGF_{2a} (Hemabate®)	250 μg i.m. every 15 min, maximum 2 mg
Misoprostol (Cytotec®)	1000 μg rectally
Misoprostol (prophylactic)	200 μg inserted in buccal space
Prostaglandin E_2 (Prostin E2®)	20 mg rectally

Conservative treatment of maternal haemorrhage

Oxytocin is routinely used to maintain uterine tone during Caesarean section (Table 4). Typical concentrations are 20–40 units litre^{-1}, administered at 500–1000 ml h^{-1}. At least one study suggested that a concentration of 160 units litre^{-1} administered at 1000 ml h^{-1} significantly decreased the need for further uterotonics, with no increase in the incidence of hypotension.[37] The use of bolus doses of oxytocin is controversial; Svanström and colleagues[50] demonstrated that a 10 unit bolus during Caesarean section led to significant hypotension and electrocardiographic evidence of myocardial ischaemia. However, Carvalho and colleagues[12] calculated the ED_{90} for bolus oxytocin to be 0.35 units, with a calculated response rate of 100% when 1 unit was administered as a bolus, with no hypotension at this dose.

Ergot alkaloids such as ergometrine or its derivative methylergonovine (methylergometrine, Methergine®) are commonly used when the response to oxytocin is insufficient. The action of these agents is mediated through alpha-adrenergic receptors, and as such, their use is associated with hypertension, especially when phenylephrine has been administered previously. Coronary artery vasospasm leading to myocardial ischaemia or even myocardial infarction has been reported.[38 57] Nausea and vomiting are common.

There is increasing recognition of the usefulness of prostaglandins for the treatment of uterine atony. 15-Methyl PGF_{2a} (Hemabate®) can be administered i.m. or directly into the uterus, in 250 μg doses every 15 min, up to a maximum of 2 mg. Hypertension and diarrhoea are not uncommon. Increases in bronchial tone are also common, and can be life-threatening, especially in patients with reactive airway disease.[28]

Misoprostol (Cytotec®), a PGE_1 analogue originally marketed as a gastric cytoprotective agent for patients receiving non-steroidal anti-inflammatory drug therapy, and more recently as an abortifacient, has also shown great promise as a uterotonic agent. In 14 women with uncontrollable obstetric haemorrhage, rectal administration of 1000 μg led to sustained uterine contraction and control of haemorrhage within 3 min.[40] The buccal administration of misoprostol before elective Caesarean section has been described; while blood loss was unchanged, a 200 μg dose inserted in the buccal space immediately before Caesarean section reduced the need for additional uterotonic agents by almost 40%.[26]

Invasive treatment of maternal haemorrhage

Regardless of the cause of obstetric haemorrhage, conservative measures might fail to control bleeding. In these cases, invasive procedures must be performed promptly to avoid severe morbidity and mortality. Options with their respective success rates include intrauterine balloon tamponade (84%), uterine compression sutures (92%), angiographic arterial embolization (91%), arterial ligation (85%), and hysterectomy.[35 48] It is recommended that obstetricians consider all available interventions in order to stop the haemorrhage and that all hospitals with delivery units should aim to provide an emergency interventional radiology service, as these procedures have the potential to save the lives of patients with catastrophic PPH.[20] There are no randomized controlled studies on the various treatment methods and the success rate of one method has not been shown to be better than another in the management of severe PPH.[20]

Balloon tamponade

Uterine packing procedures have been used for many years in order to control PPH. Roller gauze packs were originally used, but due to their potential traumatic placement and concern for concealed ongoing haemorrhage, the use of balloon tamponade has been favoured more recently.[35] Although a variety of balloon devices have proven successful, the Sengstaken–Blakemore oesophageal catheter is the most frequently reported. The device can be deployed quickly, requires minimal analgesia for both insertion and removal, and it preserves fertility. It can be used to perform a 'tamponade test' which arrests the bleeding in most women and allows the obstetrician to identify which patients will require surgical intervention.[20] The catheter is inserted in the uterine cavity and the balloon is filled with warm sterile water or saline until the uterus is firm on abdominal palpation and until the bleeding is arrested. If little or no bleeding is observed via the cervix or through the lumen of the catheter, the tamponade test is considered positive and laparotomy is avoided. Ongoing bleeding would require surgical exploration.[21] Although intrauterine balloon tamponade has not been proven superior to other methods of controlling postpartum bleeding, it is the least invasive, most rapid, and lacks significant complications, thus making it a logical first step in PPH management.[35]

Uterine compression sutures

Uterine compression sutures function in a manner similar to manual compression. They have been used as an

adjunctive intervention aimed at maintaining uterine contractility through tamponade.[4] They are most useful in cases of refractory uterine atony but have also been used in cases of retained placenta and coagulopathy.[35] Advantages include a high success rate, ease of placement at the time of laparotomy, and fertility preservation. Disadvantages include the need for laparotomy and usually hysterotomy and reported complications including uterine wall erosion, uterine necrosis, and pyometria.[20] Modifications of uterine compression sutures such as the U-sutures have evolved leading to a reduction in these complications.[25] Uterine compression sutures are more likely to successfully arrest bleeding, if bimanual compression of the uterus achieves homeostasis.[22] The specific placement of compression sutures and their location requires operator judgement. If profuse bleeding is noted from the placental attachment site, placental bed sutures can be used to ligate vessels.[25]

Angiographic arterial embolization

The uterine arteries, which are branches of the anterior trunk of the internal iliac arteries, provide the primary blood supply of the uterus. The ovarian arteries also contribute significantly to uterine blood flow during pregnancy.[35] Arterial embolization of these vessels is of significant value in treating obstetric haemorrhage.[41] Embolization requires fluoroscopic guidance and the expertise of an interventional radiologist.[20] Using angiography, the radiologist can identify the vessels responsible for the bleeding and embolize them.[35] The patient must be stable enough for transfer to a radiological suite and should be monitored at all times with the ability to proceed to surgical intervention should the patient become unstable.[4] Angiographic occlusion balloon catheters can be placed to occlude the hypogastric or common iliac arteries as a temporizing measure.[33] Prophylactic placement of arterial catheters for cases with high risk of haemorrhage such as placenta praevia and accreta can allow rapid occlusion of these vessels if necessary.[27] Several studies have noted that clotting disorders improve rapidly after embolization possibly due to the facilitation of uterine contraction that leads to a secondary liberation of procoagulant factors into circulation.[16] Success rates for embolization are reported as high as 85−95%.[35] Reported complications of this procedure include fever, vascular perforation, lower extremity ischaemia, bladder, and rectal wall necrosis. Flow through the vessels return over time, preserving both the uterus and fertility.[48] Embolization therapy is unlikely to be successful after arterial ligation.[27]

Arterial ligation

Surgical ligation of the uterine, ovarian, and internal iliac arteries can be useful when other methods to control maternal haemorrhage have failed. Ligation results in a decrease in pulse pressure distal to the ligature,[35] thereby more readily achieving haemostasis through clot formation.[48] Bilateral ligation of the uterine vessels is a more attractive option than internal iliac artery ligation because the uterine arteries are easily accessible, the procedure is more successful, and the field of dissection generally is not near the ureters and the iliac veins.[42] Stepwise uterine devascularization has been described whereby uterine, tubal branches of the ovarian, and finally internal iliac arteries are ligated.[1] In a study of 103 patients, uterine devascularization was 100% effective and hysterectomy was not needed in any case.[1] But ligation techniques are technically challenging and time-consuming requiring both surgical expertise and a haemodynamically stable patient. Risks include lower extremity ischaemia, neuropathy, intestinal occlusion, and peripheral nerve ischaemia.[20] When it is successful, surgical ligation permits preservation of fertility.[35.]

Hysterectomy

Hysterectomy is often the definitive treatment for PPH with the most common indications being uterine atony and placenta accreta.[35] Peripartum hysterectomy is estimated to occur ∼0.8 per 1000 deliveries.[24] If alternative interventions fail, hysterectomy should not be delayed in patients who continue to bleed. Prompt control of uterine haemorrhage is vital to decrease morbidity and prevent death, as continued blood loss can lead to disseminated intravascular coagulation. The operative technique and preparation for hysterectomy depend on the timing and indication of the procedure.[48] Peripartum hysterectomy can be a technically challenging operation due to the enlarged uterus, engorged vessels, and oedematous tissues.[35] Preoperative preparation, including standardized protocols, availability of trained staff, and immediate access to equipment, is essential to minimizing morbidity.[48] Complications of hysterectomy include operative site infection, bladder and ureteral injuries, further intra-abdominal haemorrhage, and injury to other organs.[48]

Transfusion therapy

In healthy young women, adequate oxygen delivery can be maintained at haemoglobin levels as low as 6−7 g dl^{-1}.[3] Nevertheless, in the setting of haemodynamic instability, coexisting cardiopulmonary disease, or coagulopathy, administration of blood products is usually necessary. Optimal therapy will be guided by laboratory determinations of haemoglobin concentration, platelet count, and coagulation function. In life-threatening situations, however, empiric treatment with packed red blood cells (RBCs), platelets, fresh-frozen plasma, or cryoprecipitate might be necessary. There is no current uniform consensus on the optimal ratio of blood products to transfuse into severely bleeding patients and prior recommendations for fresh-frozen plasma:RBC and platelets:RBC transfusion ratios range from 1:10 to 2:3 and 6:10 to 12:10, respectively.[44] Studies in patients with severe

haemorrhage from combat-related trauma requiring massive transfusion have found that a high 1:1.4 plasma:RBC ratio is independently associated with significantly improved survival by decreasing death from haemorrhage.[8] On the basis of these studies, it is now recommended by the US Army Surgeon General to transfuse plasma and RBCs in a 1:1 ratio in patients with significant trauma. Considering the similarities between maternal haemorrhage and major haemorrhage due to trauma with regard to the accompanying hypothermia, acidosis, and coagulopathy, it might be appropriate to extend these recommendations to massive PPH, although definitive data are not available.[44]

There is considerable interest in the use of intraoperative blood salvage during significant maternal haemorrhage. One obstacle to the use of cell salvage has been the concern that reinfusion of the as yet undetermined causative agent of amniotic fluid embolism syndrome might precipitate that life-threatening complication. Although at least one study of 139 women undergoing cell salvage and reinfusion during Caesarean section suggests that this modality can be used with minimal risk,[45] others have suggested that the number of patients studied to date is insufficient to provide a blanket endorsement of the safety of this practice.[47] If cell salvage is to be utilized, it is recommended that collection should be initiated only after the surgical field has been irrigated and gross contamination with amniotic fluid has been eliminated. The use of a leucocyte depletion filter during reinfusion of processed blood might enhance the margin of safety.

Recombinant activated factor VII

Recombinant activated factor VII (rFVIIa) (Novoseven) is a synthetic vitamin K-dependent glycoprotein that has been administered for haemorrhage unresponsive to conventional blood product resuscitation. FVIIa works via activation of the extrinsic pathway of the coagulation cascade leading to an enhanced generation of thrombin and a stable fibrin plug at the site of injury. It was originally developed for the treatment of bleeding in patients with haemophilia A or B with inhibitors to factor VIII or IX.[53] rFVII has also been successfully used to prevent or control bleeding in several other conditions including thrombocytopenia, platelet function disorders, impaired liver function, and extensive surgery and severe trauma with massive bleeding.[10] Although no randomized controlled studies have been published on the use of FVIIa in PPH, case reports have suggested great efficacy in helping to control massive obstetric bleeding.[23] Consideration for the use of rFVII in PPH must take into account efficacy, side-effects including increased risk of thromboembolism, and costs of rFVII *vs* other treatment.[53] The American Society of Anesthesiologists recommends consideration of rFVIIa when 'traditional well tested options for treating microvascular bleeding have been exhausted'.[3] After failure of all medical and surgical treatments and after multiple transfusions of RBCs and fresh-frozen plasma but before hysterectomy, Welsh and colleagues[53] suggest an rFVIIa dose of 90 μg kg^{-1} followed by a second identical dose if no response is seen after 20 min.

Table 5 Managing maternal haemorrhage algorithm.[39] *Most commonly used dose for haemorrhage

Vital signs
Normal vitals do not always assure patient stability
Control the airway
Maintain oxygenation and ventilation
Support the circulation
Pallor, delayed capillary refill, and decreased urine output can indicate compromised blood volume without change in arterial pressure or heart rate
Decreased urine output, hypotension, and tachycardia may be late signs of compromise
Infusions
Start second large bore (16 G or larger)
Salt solutions replace blood loss at 3:1
Volume expanders replace blood loss at 1:1 (albumin, hetastarch, dextran)
Packed RBCs
Coagulation factors
Warm blood products and infusions to prevent hypothermia, coagulopathy, and arrhythmias
Medications for uterine atony
Oxytocin
10–40 units in l litre saline i.v. rapid infusion
*30–40 units $litre^{-1}$ is the most commonly used dose for haemorrhage
Methylegonovine (Methergine)
0.2 mg i.m. every 2–4 h up to 5 doses (avoid with hypertension)
Prostaglandin F_2 Alpha (Hemabate)
250 μg i.m. or intramyometrial, repeat every 20–90 min maximum 8 doses (avoid with asthma or hypertension)
Prostaglandin E_2 suppositories (Dinoprostone, Prostin E_2)
20 mg per rectum every 2 h (avoid with hypotension)
Misoprostol (Cytotec)
1000 μg per rectum or sublingual (10 100 μg tabs or 5 200 μg tabs)
Surgical interventions
May be life-saving measure and should not be delayed

Conclusion

Anaesthesiologists play a vital role in the care and management of patients with peripartum haemorrhage. As members of the multidisciplinary team, anaesthesiologists should utilize their expertise in fluid management, transfusion therapy, and critical care to prevent and treat the catastrophic events that accompany severe bleeding. Table 5 is an example of an algorithm that can serve as a guide to the management and treatment of peripartum haemorrhage. Although guides and protocols such as this one are useful, they cannot take the place of experienced and trained physicians in assessing and managing maternal haemorrhage. With the recent advent of minimally invasive treatments and drugs to temporize bleeding, physicians now have more options at their disposal. Therefore, vigilance and an aggressive approach (Table 5) are keys in reducing morbidity and mortality and ensuring the best possible outcome for patients with maternal haemorrhage.

Funding

Preparation of this manuscript has been supported by the Department of Anesthesiology, SUNY Downstate Medical Center, Brooklyn, NY, USA.

References

1 AbdRabbo SA. Stepwise uterine devascularization: a novel technique for management of uncontrollable postpartum haemorrhage with preservation of the uterus. *Am J Obstet Gynecol* 1994; **171**: 694–700
2 American College of Obstetricians and Gynecologists. Postpartum, haemorrhage. Practice Bulletin No. 76. *Obstet Gynecol* 2006; **108**: 1039–47
3 American Society of Anesthesiologists Task Force on Perioperative Blood Transfusion and Adjuvant Therapies. Practice guidelines for perioperative blood transfusion and adjuvant therapies. *Anesthesiology* 2006; **105**: 198–208
4 Bauer ST, Bonanno C. Abnormal placentation. *Semin Perinatol* 2009; **33**: 88–95
5 Berg CJ, Harper MA, Atkinson SM, *et al*. Preventability of pregnancy-related deaths. Results of a state-wide review. *Obstet Gynecol* 2005; **106**: 1228–34
6 Bonnar J. Massive obstetric haemorrhage. *Baillieres Clin Obstet Gynaecol* 2000; **14**: 1–18
7 Bonner SM, Haynes SR, Ryall D. The anaesthetic management of caesarean section for placenta praevia: a questionnaire survey. *Anaesthesia* 1995; **50**: 992–4
8 Borgman MA, Spinella PC, Perkins JG, *et al*. The ratio of blood products transfused affects mortality in patients receiving massive transfusions at a combat support hospital. *J Trauma* 2007; **63**: 805–13
9 Bose P, Regan F, Paterson-Brown S. Improving the accuracy of estimated blood loss at obstetric haemorrhage using clinical reconstructions. *BJOG* 2006; **113**: 919–24
10 Bouwmeester FW, Bolte AC, van Geijn HP. Pharmacologic and surgical therapy for primary postpartum haemorrhage. *Curr Pharm Des* 2005; **11**: 759–73
11 Calleja-Agius J, Custo R, Brincat M, *et al*. Placental abruption and placenta praevia. *Eur Clin Obstet Gynaecol* 2006; **2**: 121–7
12 Carvalho JC, Balki M, Kingdom J, Windrim R. Oxytocin requirements at elective cesarean delivery: a dose-finding study. *Obstet Gynecol* 2004; **104**: 1005–10
13 Chang J, Elam-Evans LD, Berg CJ, *et al*. Pregnancy-related mortality surveillance-United States, 1991–1999. *Morb Mortal Weekly Rep* **52**: 1–8
14 Combs CA, Murphy EL, Laros RK, Jr. Factors associated with postpartum haemorrhage with vaginal birth. *Obstet Gynecol* 1991; **77**: 69–76
15 Confidential Enquiries into Maternal Deaths in the United Kingdom, 2003–2005. Available from http://www.cemach.org.uk. Accessed August 28, 2009
16 Deux JF, Bazot M, Leblanche AF, *et al*. Is selective embolisation of uterine arteries a safe alternative to hysterectomy in patients with postpartum haemorrhage? *Am J Roentgenol* 2001; **177**: 145–9
17 Devine PC. Obstetric haemorrhage. *Semin Perinatol* 2009; **33**: 76–80
18 Dildy GA. Postpartum haemorrhage: new management options. *Clin Obstet Gynecol* 2002; **45**: 330–44
19 Dildy GA, III, Paine AR, George NC, *et al*. Estimating blood loss: can teaching significantly improve visual estimation? *Obstet Gynecol* 2004; **104**: 601–6
20 Doumouchtsis SK, Papageoghiou AT, Arulkumaran S. Systematic review of conservative management of postpartum haemorrhage: what to do when medical treatment fails. *Obstet Gynecol Surv* 2007; **62**: 540–7
21 Doumouchtsis SK, Papageoghiou AT, Vernier C. Management of postpartum haemorrhage by uterine balloon tamponade: prospective evaluation of effectiveness. *Acta Obstet Gynecol* 2008; **87**: 849–55
22 Drife J. Management of primary postpartum haemorrhage. *Br J Obstet Gynaecol* 1997; **104**: 275–7
23 Gallos G, Redai I, Smiley R. The role of the anesthesiologist in management of obstetric hemorrhage. *Semin Perinatol* 2009; **33**: 116–23
24 Glaze S, Ekwalanga P, Roberts G, *et al*. Peripartum hysterectomy: 1999 to 2006. *Obstet Gynecol* 2008; **111**: 732–8
25 Hackethal A, Brueggmann D, Oehke F, Tinneberg HR, Zygmunt MT, Muenstedt K. Uterine compression U-sutures in primary postpartum haemorrhage after Cesarean section: fertility preservation with a simple and effective technique. *Hum Reprod* 2008; **23**: 74–9
26 Hamm J, Russell Z, Botha T, *et al*. Buccal misoprostol to prevent haemorrhage at cesarean delivery: a randomized study. *Am J Obstet Gynecol* 2005; **192**: 1404–6
27 Hansch E, Chitkara U, McaAlpine J, *et al*. Pelvic arterial embolisation for control obstetric haemorrhage: a five year experience. *Am J Obstet Gynecol* 1999; **180**: 1454–60
28 Harber CR, Levy DM, Chidambaram S, Macpherson MB. Life-threatening bronchospasm after intramuscular carboprost for postpartum haemorrhage. *BJOG* 2007; **114**: 366–8
29 James AH, Jamison MG. Bleeding events and other complications during pregnancy and childbirth in women with von Willebrand disease. *J Thromb Haemost* 2007; **106**: 509–16
30 James AH, Kouides PA, Abdul-Kadir R, *et al*. Von Willebrand disease and other bleeding disorders in women: consensus on diagnosis and management from an international expert panel. *Am J Obstet Gynecol* 2009; **201**: 12e1–8
31 Kadir RA, Aledort LM. Obstetrical and gynaecological bleeding: a common presenting symptom. *Clin Lab Haematol* 2000; **22**: 12–6
32 Karpati PC, Rossignol M, Pirot M, *et al*. High incidence of myocardial ischemia during postpartum haemorrhage. *Anesthesiology* 2004; **100**: 30–6
33 Kim D, Baer SD. Up to date: interventional radiology in management of obstetrical and gynecological disorders. 2008. Available from uptodate.com. Accessed August 12
34 Knight M, UKOSS. Peripartum hysterectomy in the UK: management and outcomes of the associated haemorrhage. *Br J Obstet Gynaecol* 2007; **114**: 1380–7
35 Mayer DC, Smith KA. *Chestnut's Obstetric Anaesthesia Principles and Practice*, 4th Edn. Missouri: Elsevier Mosby, 2009; 825–30
36 Mirza FD, Gaddipaty S. Obstetric emergencies. *Semin Perinatol* 2009; **33**: 97–103
37 Munn MB, Owen J, Vincent R, *et al*. Comparison of two oxytocin regimens to prevent uterine atony at cesarean delivery: a randomized controlled trial. *Obstet Gynecol* 2001; **98**: 386–90
38 Nall KS, Feldman B. Postpartum myocardial infarction induced by methergine. *Am J Emerg Med* 1998; **16**: 502–4
39 New York State Department of Health. *Managing Haemorrhage Poster. NYS Safe Motherhood Initiative*. Available from www.acog.org. Accessed August 26, 2009
40 O'Brien P, El-Refaey H, Gordon A, *et al*. Rectally administered misoprostol for the treatment of postpartum haemorrhage unresponsive to oxytocin and ergometrine: a descriptive study. *Obstet Gynecol* 1998; **92**: 212–4

41 Ojala K, Perala J, Kariniemi J. Arterial embolisation and prophylactic catheterization for the treatment for severe obstetric haemorrhage. *Acta Obstet Gynecol Scand* 2005; **84**: 1075–80

42 Oleary JA. Uterine artery ligation in the control of postcesarean haemorrhage. *J Reprod Med* 1995; **40**: 189

43 Oyelese Y, Ananth CV. Placental abruption. *Obstet Gynecol* 2006; **108**: 1005–16

44 Padmanabhan A, Schwartz J, Spitalnik SL. Transfusion therapy in postpartum haemorrhage. *Semin Perinatol* 2009; **33**: 124–7

45 Rebarber A, Lonser R, Jackson S, *et al*. The safety of intraoperative autologous blood collection and autotransfusion during cesarian section. *Am J Obstet Gynecol* 1998; **179**: 715–20

46 Rouse DJ, Leindecker S, Landon M, *et al*. The MFMU Cesarean Registry: uterine atony after primary cesarean delivery. *Am J Obstet Gynecol* 2005; **193**: 1056–60

47 Santrach PJ. Is cell salvage a safe technique for the obstetric patient? *Con Soc Obstet Anaesth Perinatol Newsletter,* Fall 2005; 7–9

48 Shah M, Wright JD. Surgical intervention in the management of postpartum haemorrhage. *Semin Perinatol* 2009; **33**: 109–14

49 Silver RM, Landon MB, Rouse DJ, *et al*. Maternal morbidity associated with multiple repeat cesarean deliveries. *Obstet Gynecol* 2006; **107**: 1226–32

50 Svanström MC, Biber B, Hanes M, *et al*. Signs of myocardial ischaemia after injection of oxytocin: a randomized double-blind comparison of oxytocin and methylergometrine during Caesarean section. *Br J Anaesth* 2008; **100**: 683–9

51 Usta IM, Hobeika EM, Musa AA, *et al*. *Am J Obstet Gynecol* 2005; **193**: 1045–9

52 Walsh CA, Baxi LV. Rupture of the primigravid uterus: a review of the literature. *Obstet Gynecol Surv* 2007; **62**: 327–34

53 Welsh A, McLintock C, Gatt S, *et al*. Guidelines for the use of recombinant activated factor VII in massive obstetric haemorrhage. *Aust N Z J Obstet Gynaecol* 2008; **48**: 12–6

54 World Health Organization. *Maternal Mortality in 2000: Estimates Developed by WHO, UNICEF, and UNFPA*. Geneva: World Health Organization, 2004

55 World Health Organization. *The World Health Report 2005: Make Every Mother and Child Count*. Geneva, Switzerland: WHO Press, 2005; 62

56 World Health Organization. The prevention and management of postpartum haemorrhage. *WHO Report of Technical Working Group*. Geneva: World Health Organization, 1990

57 Yaegashi N, Miura M, Okamura K. Acute myocardial infarction associated with postpartum ergot alkaloid administration. *Int J Gynaecol Obstet* 1999; **64**: 67–8

58 You WB, Zahn CM. Postpartum haemorrhage: abnormally adherent placenta, uterine inversion, and puerperal hematomas. *Clin Obstet Gynecol* 2006; **49**: 184–97