49

Embolization and Balloon Catheter Placement

K. Choji and T. Shimizu

INTRODUCTION: OVERVIEW

Embolization is a technique in which a plastic catheter is inserted into the target artery through which small particles or other embolic materials are infused to occlude the artery. The objective of embolization is to stop active hemorrhage. Embolization is valid in both primary (i.e. within 24 hours of delivery) and secondary (i.e. after 24 hours from delivery) postpartum hemorrhage (PPH). When embolization is successful, the patient recovers without undergoing additional surgery. Embolization saves not only the life of the patient and provides quick recovery, but also the uterus and adnexal organs, thus ensuring future fertility, if this be desired.

The report of successful embolization to treat PPH published by Heaston *et al.* in 1979[1] was followed by others in the 1980s[2–10]. By the 1990s the technique was used in maternity units around the world[11–25]. In an extensive review of the literature by Vedantham and colleagues in 1997[19], cessation of hemorrhage was reported in 100% of 49 cases after vaginal delivery and 89% of 18 cases after cesarean section. More recent reports include 70–79%[26–28], 83–89%[24,29], 91–97%[25,30–33] and 100%[7,11,34–36] cessation of hemorrhage rates. The clinical success is believed not to be related to mode of delivery, cause of PPH, transfusion requirements or time from delivery to embolization[28]. Rather, success depends on reducing the perfusion pressure of the source arteries of hemorrhage to allow coagulation and healing of the injured arteries. The degree of pressure reduction necessary varies according to the coagulation status of the patient. If complete occlusion of an artery with embolic material is achieved, it will result in null perfusion pressure, which will be followed by coagulation and healing of the artery. In practice, not all the source arteries can be identified. As a result, there is frequently a degree of arbitrariness in the amount of embolic material infused and the site of infusion. This could lead to insufficient infusion (underembolization) or excessive embolization (overembolization)[28]. The former indicates unsuccessful hemostasis, while the latter increases the risk of ischemic complications. Prior hysterectomy makes the embolization more difficult and, if possible, this should be avoided[28,37].

Virtually no contraindications to embolization are thought to exist. In contrast to surgery, even severe coagulopathy does not present a contraindication. Coagulopathy is frequently encountered in PPH due to a number of factors, including disseminated intravascular coagulation (DIC), depletion of clotting factors (‘wash-out phenomenon’) and dilution of clotting factors with crystalloid fluid that is administered as part of the resuscitation process as well as the lack of clotting factors in stored blood[7,38,39]. The likely mechanism of rapid recovery following embolization is as follows. If emboli successfully occlude the breached arterial branches, the acute and continuous washout effect ceases. This is followed by the reinforcement of depleted coagulation factors produced by the patient’s body or through transfusion. The result is rapid recovery from both blood loss and coagulation abnormality. Embolization can lead to hemostasis in cases with known coagulopathy[31]. In addition, hemostasis and correction of acquired coagulopathy has also been reported[25].

Complications occur but only in a relatively small proportion of cases[1–3,7,11,17,24–29,31,32,35,36,40–43], and, in view of the data obtained from cases where radiation doses were measured, it appears unlikely that the patients suffer from significant radiation effects[24,33,36,40,44].

In hospitals where embolization is available, it should be the procedure of choice for PPH that fails to respond to initial intraoperative maneuvers including B-Lynch sutures and following conventional medical treatment, leaving hysterectomy as the last resort. In obstetric units where an in-house radiology team is unavailable to undertake appropriate interventions, reliable access to such a team should be sought. Once established, the means by which this collaboration can be activated must be widely available to staff and posted prominently in nursing and clerical stations.

In some cases, particularly with placental abnormalities, higher risk of PPH is foreseen prior to planned surgery[45–51]. Prophylactic intra-arterial balloon catheter placement for cases with high risk of PPH such as placental abnormalities has been proposed[14,20,24,27,33,40–42,52,53] and is discussed in other chapters.

VASCULAR ANATOMY ON IMAGING

General anatomy

The internal iliac artery is the first major branch of the common iliac artery, which descends from the bifurcation of the aorta and proceeds into the pelvis. There may be some variation in the distance between the aortic and the iliac bifurcations. Normally, there should be little difficulty in identification of the internal iliac artery because of its substantial size and its inward (inferomedial) direction compared with the external iliac artery which courses laterally after the bifurcation of the common iliac trunk. The proximal bifurcation of the internal iliac artery produces two trunks that are officially termed the anterior and posterior branches. The posterior branch supplies the gluteal region, whilst the anterior branch supplies the remainder of the pelvis. In the majority of instances, the branches of this anterior trunk include the uterine, vaginal, superior cystic, middle rectal, obturator, internal pudendal and inferior gluteal arteries (Figure 1a). In fact, a number of variations in the distribution of the branches of the internal iliac artery are possible[54,55]. In 30% of patients, however, some of these arteries have more proximal origins at the level of the bifurcation of the anterior and posterior branches (Figure 1b). This is especially true in the case of the obturator and uterine arteries. In addition, the internal pudendal artery may arise from the posterior branch. A recent article from Kenya has shown that the actual anatomy differs from that seen in classical descriptions in as many as 20% of cases[56]. To avoid confusion as a result of such anatomical variation, we advise referring to the anterior and posterior branches as the inferior and superior gluteal trunks, respectively. This nomenclature becomes more appropriate when performing angiography.

On an angiographic image, the inferior gluteal artery is seen as descending relatively laterally and extending lower than the bony pelvis. The importance of this artery is to give off the sciatic branch which supplies the sciatic nerve. Therefore, the accidental embolization of the inferior gluteal artery could result in transient or long-term injury to the sciatic nerve. Furthermore, heavy embolization of the branches of the superior gluteal trunk (posterior branch) could result in ischemia of the nerves and gluteal muscles, which could cause pain in the gluteal region.

The uterine artery is identified from the distribution in the enlarged prenatal or immediately postnatal uterus. Note that the characteristic coiling appearance of the intramural branches of the uterine artery in the normal sized uterus have disappeared in the enlarged near natal uterus. Identifying the origin of the uterine artery on the usual frontal projection in fluoroscopy

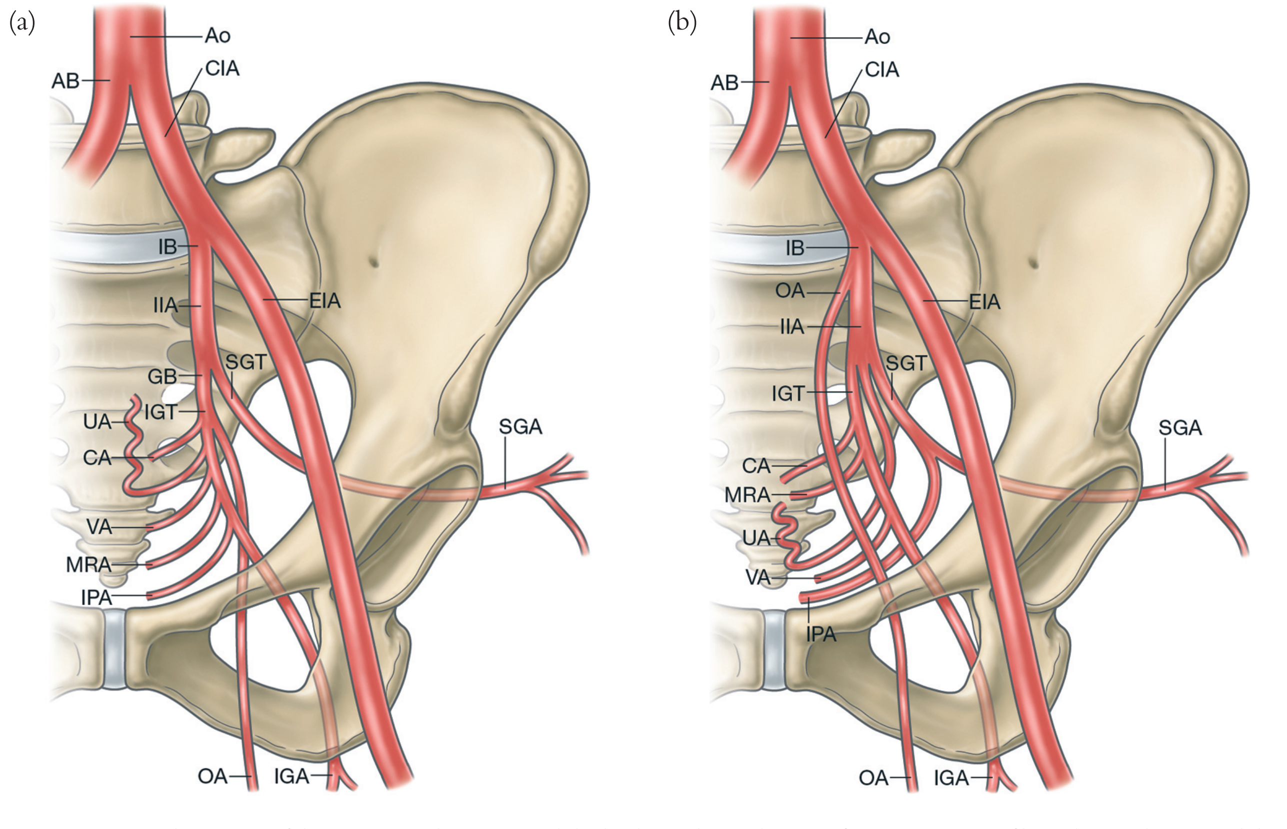

Figure 1 Branch patterns of the arteries to the uterus and the birth canal. (a) The most frequent pattern of branching. The internal iliac artery (IIA) is initially divided into the posterior and anterior divisions, which are hereafter termed as superior and inferior gluteal trunks (SGT and IGT, respectively). The point of division is termed the gluteal bifurcation (GB). The uterine, vaginal and internal pudendal arteries (UA, VA and IPA, respectively) are the branches of the IGT together with the obturator and cystic arteries (OA and CA, respectively). (b) Less common patterns include the uterine artery (UA) arising at the gluteal bifurcation (GB), the obturator artery (OA) arising directly from the internal iliac artery (IIA) proximal to the gluteal bifurcation (GB), the internal pudendal artery (IPA) arising from the superior gluteal trunk (SGT). Ao, aorta; AB, aortic bifurcation; IB, iliac bifurcation; CIA, common iliac artery; EIA, external iliac artery; MRA, middle rectal artery; SGA, superior gluteal artery; IGA, inferior gluteal artery

can be difficult. This is because it lacks any characteristic appearance and the image of the artery is often overlapped by other branches of the internal iliac artery on the usual frontal projection in fluoroscopy. As a result, oblique views of the inferior gluteal trunk (anterior branch) are frequently required to clarify the origin of the uterine artery.

The superior cystic artery can be identified by superselective catheterization and manual contrast injection; these techniques demonstrate the distal network of the artery in the bladder wall and occasionally the cystic artery on the opposite side. The pudendal artery, usually a branch from the inferior gluteal trunk (anterior branch), is harder to confirm, and often requires some guesswork. Further difficulties may arise from the presence of a hematoma which can alter the appearance and distribution of all these arteries.

The middle and inferior rectal arteries originate from the inferior gluteal and the internal pudendal arteries, respectively. These supply the middle and lower portions of the rectum, anal canal and the perianal skin. *Theoretically*, superselective embolization of the middle or inferior rectal artery may result in necrosis of these areas. However, such complications have not been reported thus far, presumably due to the prominent collateral network of other arteries.

The vaginal artery may originate from either the uterine artery at the level of the cervix or the inferior gluteal trunk (anterior branch). In addition, the vagina is also supplied by branches of the internal pudendal artery. These arteries are important and often not thought of when it is necessary to reduce blood flow to the pelvis.

Collateral pathways

Abundant collateral networks of blood vessels exist throughout the pelvis. This is of particular importance when performing embolization or related radiological interventional procedures. Stated another way, embolization of the uterine artery exclusively may not be sufficient to achieve satisfactory cessation in major life-threatening hemorrhage because of the existence of collaterals. The major potential collateral arteries to the uterus include the ovarian arteries, which directly branch off from the abdominal aorta, as well as the vaginal and pudendal arteries. There are reported cases where it was necessary to perform embolization of such small arteries with superselective catheterization into the ovarian artery[30], vaginal artery[25,30] and pudendal artery[30]. In addition, lower lumbar arteries can occasionally be the main feeding artery for the retractable intrapelvic hemorrhage[2], as well as branches of the external iliac artery and femoral arteries, particularly medial circumflex femoral artery[1,2], but such circumstances are not common.

EMBOLIC MATERIALS

Table 1 summarizes embolic materials, including particles (including pledgets), coils and liquids. Figure 2 illustrates the theoretical mechanism and arterial positions for each embolic material, and also for temporary balloon occlusion.

Among the potential particles (Figure 2a), gelatin sponge is the material of first choice. The main reason why gelatin sponge is deemed most appropriate for PPH is that it dissolves within approximately 3 weeks, thus preserving the peripheral microarterial circulation[11]. In contrast, particles of permanent embolic materials, including polyvinyl alcohol (PVA) particles, tend to remain in the blood vessels and soft tissue[57]. On embolization, peripheral tissue survives when crucial collateral circulation is spared or new collaterals are developed. The common wisdom is that using gelatin sponge lowers the risk of serious ischemic complications. Nevertheless, such complications are not as rare as previously described, suggesting that the benefit of using gelatin sponge particles compared with truly permanent particles is a higher probability, but not a certainty, of avoiding ischemic complications.

In practice, gelatin sponge is supplied in the plate form which is normally used in the operating theater as hemostatic material. The gelatin sponge plate must be either cut into small pieces such as pledgets or grated into particles. The majority of authors reporting embolization for PPH used pledgets of gelatin sponge, which were handcut during the emergency treatment. The typical sizes of gelatin sponge particles and pledgets appear to be between 1 mm × 1 mm × 1 mm and 1 mm × 1 mm × 10 mm, they are usually cut using fine scissors or razor. However, making gelatin sponge pledgets is a time-consuming and tedious process. The authors' choice is grated gelatin sponge particles; a sterilized stainless steel grater is used for grating (Figure 3). This has the advantage of short preparation time, in addition to the inherent advantages of gelatin sponge including availability, effect, safety and cost. We recommend grated gelatin sponge as the first choice of embolic material.

Although the sizes of the grated particles vary in each case, the principle is that the size of the grated particles depends on the force exerted on grating; the greater the grating force exerted, the larger the particles and vice versa. The authors tend to use grated particles approximately 5 mm in diameter. When they are mixed with fluid such as saline or radiological contrast, the particles become softer and easily pass through 4 and 5 Fr catheters. Slightly smaller (2–3 mm) particles are more appropriate for 3 Fr catheters. However, it should be noted that there are reports warning about the risk of using small sized particles[7]. Where calibrated gelatin sponge particles are commercially available, some authors have recommended avoiding the usage of those smaller than 1 mm × 1 mm × 10 mm[58].

Although the use of gelatin sponge is popular in practice and is recommended by authors, no evidence is available to contraindicate the use of permanent embolic materials, such as polyvinyl alcohol (PVA) particles, except for the warning of the risk using small particles as mentioned above. Successful use of

Table 1 Embolic materials

Materials	*Duration of effect*	*Approximate size*	*Mechanism of effect*	*Advantages*	*Disadvantages*
Particles					
Gelatin sponge (cut)	Temporary	1–5 mm	Blockage of blood vessel, inflammatory occlusion (partly)	Economic, safe	Cutting is time-consuming
Gelatin sponge (grated)	Temporary	0.3–5 mm	Blockage of blood vessel, inflammatory occlusion (partly)	Economic, safe, easy to make	Smaller particles (<1 mm) cannot be prevented, proximal embolization could occur
Polyvinyl alcohol (PVA)	Permanent	100–700 μm	Blockage of blood vessel, inflammatory occlusion (partly)	Readily available	Could be expensive, proximal embolization could occur
Autologous blood clot	Temporary	1–5 mm	Blockage of blood vessel, inflammatory occlusion (partly)	Available by adding thrombin *in vitro*	Duration of effect is unreliable
Autologous blood clot (degenerate)	Permanent	<1–5 mm	Blockage of blood vessel, inflammatory occlusion (partly)	Available by heating or exposing to alcohol or its derivatives	Usually not readily available, smaller particles cannot be prevented
Liquid					
Alcohol	Permanent		Destruction of blood vessel by ablating the intima, producing degenerate thrombi	Economic and ultrapotent	Painful, hazardous as unwanted vessels could be affected
Ethanolamine oleate	Permanent		Similar to alcohol but milder effect	Similar to alcohol but milder effect, the effect could be stabilized when combined with gelatin sponge	Similar to alcohol but milder effect
Glues such as cyanoacrylate and tris-acryl gelatin ('Biosphere', Merit Medical)	Permanent		Blockage of blood vessel	Readily available, stable	Requires expertise in the use of materials, adherence of the delivery catheter could occur
Coils such as Granturco coils	Permanent	From microsize to large ones	Mechanical blockage with or without thrombosis limited at the deployed site	No ischemic complications on their own. Protects distal portions in non-targeted particle embolization	Weak embolization effect if not accompanied by particles

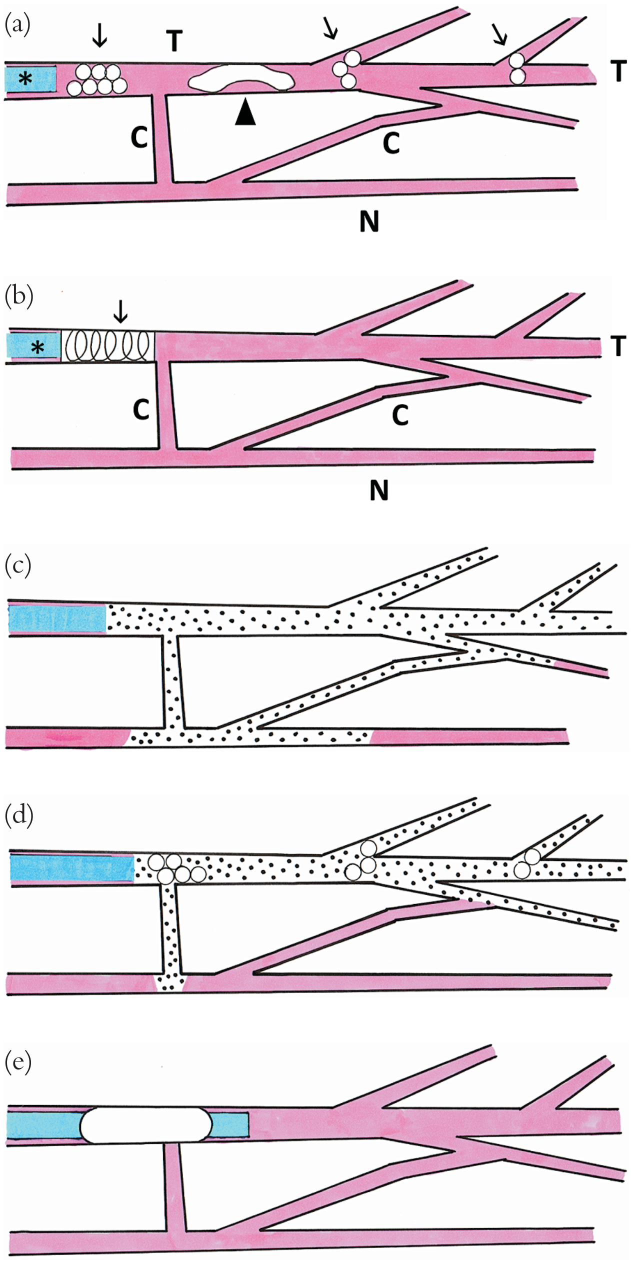

Figure 2 Mechanism of each embolic material. (a) Particles. Particles (arrows) including pledgets (arrowhead) are infused through the delivery catheter (*) and flow to more peripheral sites. Good obstruction including that of the peripheral circulation can be achieved. Gelatin sponge particles/pledgets are degradable within 2–3 weeks after delivery, although a substantial proportion of blood vessels will be occluded with inflammation. Peripheral tissue will survive when crucial collateral circulation is spared or new collaterals are developed. (b) Coils. Coils (or microcoils if a 3 Fr gauge microcatheter is used) are deployed at the tip of the delivery catheter, when it is pushed out with guidewire. Coils (arrow) occlude the artery at the point of deployment; peripheral circulation is preserved. Coils are generally used as an adjunct to other embolic materials (mainly particles) to increase the embolization effect. Similar to ligation, coils, once deployed, cannot be moved and preclude further intervention at the periphery of the deployment site. Because of this, coils can be placed to prevent particles from reaching the periphery to the coils in order to preserve peripheral arteries supplying the nerves. Other indications for coils include sites of vascular injury. (c) Liquids. Alcohol (stippled zones), when it replaces blood in the vessels, causes intimal damage and formation of permanent embolic material from degenerated blood cells. Glues occlude the vessels by filling the lumina with a hard cast of the glue material/products. Liquid of low viscosity (e.g. alcohol) tends to go through collaterals even to larger blood vessels beyond the collaterals, potentially resulting in extensive occlusion and vascular injury. (d) EGGS. Ethanolamine oleate containing grated gelatin sponge particles (EGGS) is a mixture of 5% ethanolamine oleate solution (stippled zones) and gelatin sponge particles (circles) to the consistency of soft paste. This is more potent than simple particles, as it acts as a half liquid material, while the gelatin sponge prevents washout. Only a small amount (e.g. 0.5 ml) can be infused into a targeted artery which is profusely hemorrhagic. (e) Balloon. When inflated, a temporary balloon (white area) occludes the proximal portion only, usually at a single site on each side. The effects may be similar to ligation or coil deployment, although the balloon will be deflated subsequently and removed; intervention beyond the balloon is also a possibility. Balloons must not be continuously inflated prior to delivery or fetal distress could occur. T, target artery of embolization; C, collaterals; N, nearby artery which is not the target of embolization

PVA[15,24,25,42,53,59] and cyanoacrylate[25], mainly as an adjunct to gelatin sponge, has been described in several reports. The size of commercially available synthetic particles varies from 20 μm to larger than 1 mm. For intrapelvic use, particles smaller than 300 μm (i.e. 0.3 mm) should not be used; 500–900 μm (0.5–0.9 mm) particles are safer and effective in producing good obstruction including in the peripheral circulation. Larger particles tend to clog the small caliber catheters. When PVA particles are used, caution is needed as they tend to gather together and stay in the proximal sites more than would be expected (proximal embolization). Among the commercially available permanent embolic particles, tris-acryl collagen-coated microspheres appear to have a reduced effect of proximal embolization.

Larger embolic materials such as coils occlude or reduce the blood flow significantly at the point of

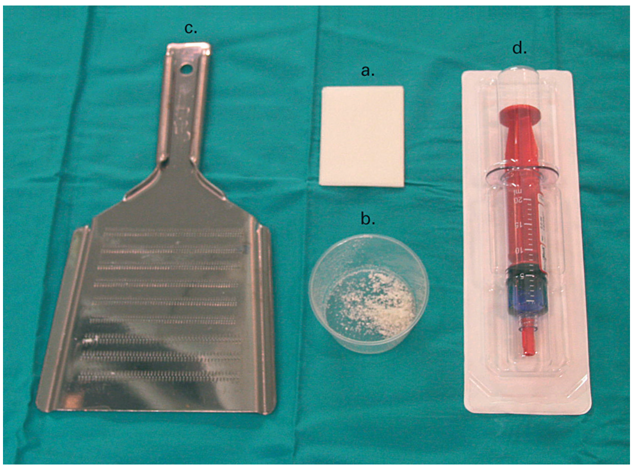

Figure 3 Typical embolization particles. (a) Gelatin sponge; (b) grater for gelatin sponge; (c) grated gelatin sponge particles; and (d) polyvinyl alcohol (PVA) particles in a bottled syringe

deployment (Figure 2b). Coils act by proximal obstruction; peripheral circulation will be preserved. Because of this, ischemic complications rarely occur with coil deployment only; on the other hand, the hemostatic effect is often suboptimal, although a report exists of successful hemostasis following the deployment of several coils in the bilateral inferior gluteal trunks (anterior divisions) in a case with a large arteriovenous shunt[60]. As the peripheral networks of collateral small arteries are not occluded, the effect of coil deployment is similar to that of ligation. After the deployment, radiological intervention using catheters and guidewire cannot be achieved in the peripheral part of the artery beyond the coil. Owing to these limitations, coils should be used as an adjunct to the primary embolic materials such as gelatin sponge: the role of the coils is to reduce perfusion pressure and flow within the target artery so that the embolization effect of the particles will be increased. Other roles of coils include preservation of the peripheral branches of the superior gluteal trunk (posterior branch) and inferior gluteal trunk (anterior branch). Following the deployment of coil(s) in the branches of either (or both) of the superior and inferior gluteal arteries, the peripheral branches of each artery will be guarded from any further embolization; infusion of embolic particles to the proximal portion to the coil is unlikely to compromise the flow in these arteries, thus avoiding ischemic complications to the nerves and muscles[7,58] (Figure 4). When there is injury to relatively large vessels, deployment of the coil at the injury site is also effective (Figure 5), where the physical size and immobility of the coils are advantageous factors.

Liquid materials (Figure 2c) are divided into alcohols and glues. Alcohol damages the arterial wall, particularly the intima, resulting in stenosis and occlusion.

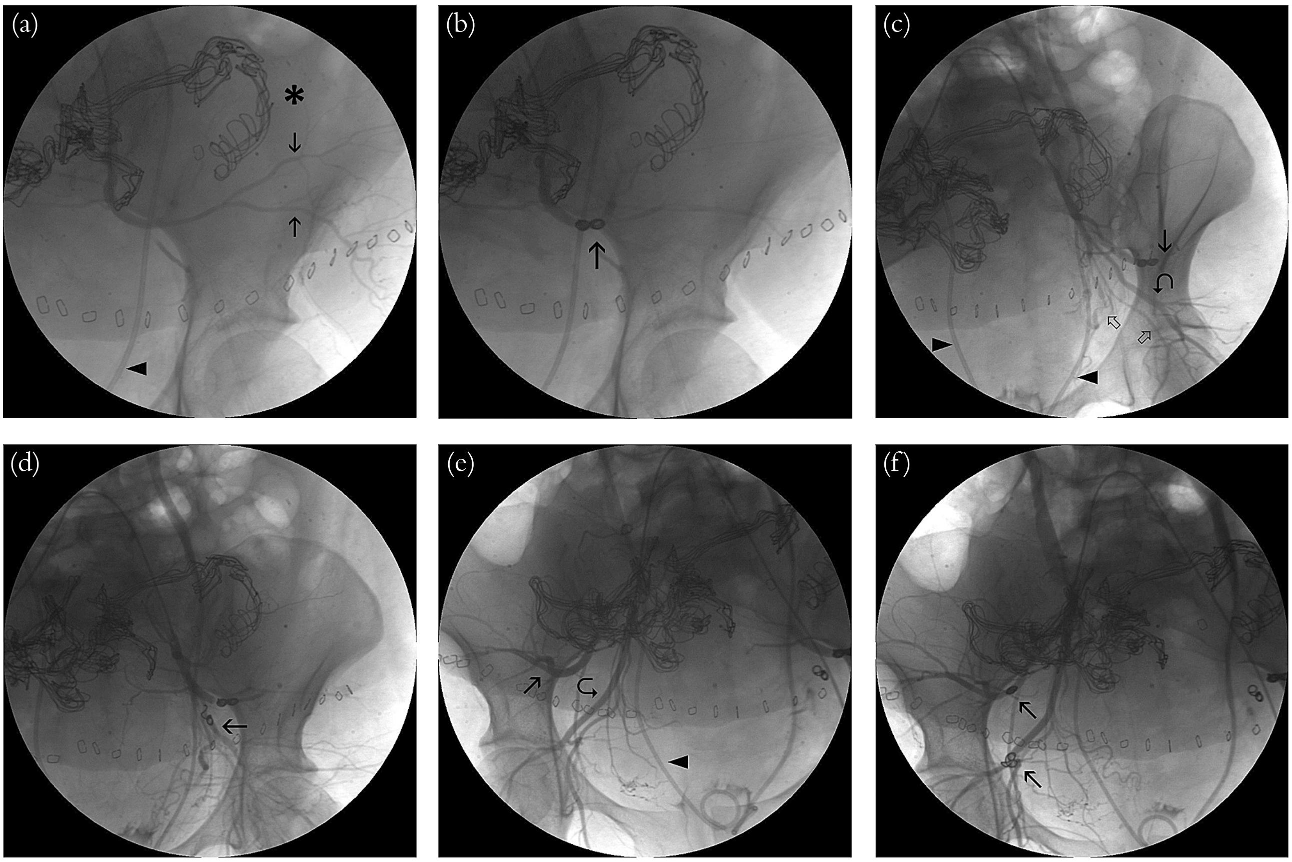

Figure 4 Coil deployment to avoid nerve injury in the superior and inferior gluteal trunks prior to non-targeted embolization. The patient was a 31-year-old Caucasian with prenatally diagnosed placenta increta/percreta at the lower anterior myometrium. The patient had previously undergone four cesarean sections. Primary PPH occurred on the 5th cesarean section. Despite hysterectomy, hemorrhage persisted, resulting in disseminated intravascular coagulation. Nephrocystic stents to reduce hydronephrosis had been placed. (a) Superselective arteriogram of the left superior gluteal trunk (posterior division). Its peripheral branches (arrows) were shown. Packed gauze (*), surgical staples of lower abdominal wound and the left sided nephrocystic stent (arrowhead) were noted. (b) A coil (Azur, Terumo) was placed in the superior gluteal trunk (arrow). Immediate reduction of the flow distal to the coil was observed. (c) Left internal iliac arteriogram following coil placement in the superior gluteal trunk. Arrowheads indicate nephrocystic stents. The practically occluded superior gluteal trunk at the coil (arrow), patent inferior gluteal trunk (curved arrow) and its branches were demonstrated. Bilateral nephrocystic stents (arrowheads) were *in situ*. (d) A coil (Azur) was deployed (arrow) in the inferior gluteal trunk. Non-targeted embolization of the internal iliac artery using grated gelatin sponge particles was then performed. (e) Right internal iliac arteriogram. Superior gluteal (arrow) and inferior gluteal (curved arrow) trunks were shown. Nephrocystic stent (arrowhead) was present. (f) Deployed coils (Azur) in the superior and inferior gluteal trunks (arrows). The flow in the distal portions to the coils was reduced greatly several minutes later, when non-targeted embolization of the internal iliac artery was undertaken. Grated gelatin sponge particles were used. The hemodynamics soon stabilized without the signs of ischemic complications; the patient recovered fully

This is coupled by degeneration of blood cells acting as permanent embolic particles, which are formed when the blood cells are exposed to alcohol. Glue fills in the arterial lumina; cyanoacrylate incorporates blood as it polymerizes with water, while other glues, such as Onyx®, replace the blood within the lumen and hardens. Most liquid materials are not viscous. Liquids, especially alcohol, carry the risk of damaging the arteries of adjacent organs by reversely traversing collaterals, when infused in sufficient amount to ablate the target artery. Glues can solidify within the blood vessels earlier than expected. This may result in fixation of the catheter. Because of these risks, liquids should be used as adjuncts to gelatin sponge, and only in cases where hemostasis is not achieved with gelatin sponge only.

Ethanolamine oleate, a type of alcohol, can be absorbed in gelatin sponge materials. Grated gelatin sponge can be soaked in 5% ethanolamine oleate to form a soft paste consistency. This combined material (ethanolamine in grated gelatin sponge (EGGS)) is a very potent embolic material, as gelatin sponge particles will hold ethanolamine oleate to prevent early wash-out. At the same time, the viscosity due to the addition of gelatin sponge particles reduces the risk of significant penetration through the collaterals to the adjacent organ arteries (Figure 2d). EGGS should be used only in small amounts, e.g. up to 0.5 ml into the uterine artery with overt extravasation, or, in extremely severe cases 1–1.5 ml (Figure 6). Deep insertion of the catheter tip into the target artery before injecting EGGS would be safer to prevent injury to organs adjacent to the uterus.

Racker and Braithwaite reported the fine arterial communication between the uterine artery and arteries to the lower ureters[61]. This is one of the examples explaining why particles which are too small or liquid materials are theoretically more hazardous as embolic materials than larger sized particles. It is, therefore, strongly recommended to use non-microscopic sized gelatin sponge. Liquid materials including EGGS are to be considered only when it is highly suspected that it may be difficult to achieve hemostasis using larger sized gelatin sponge. The amount of liquid material should be limited to as little as possible to prevent complications.

Catheters with an inflatable balloon achieve temporary occlusion at relatively proximal sites, from the internal iliac to uterine arteries (Figure 2e). They are used mainly in the prophylaxis of PPH in cases with adhesive or invasive placenta as described below and in Chapters 25–29. The advantages of balloon catheter placement are: (1) it can be planned during normal working hours, changing possible emergency cases to elective ones; (2) the balloon is removable, resuming normal flow when hemostasis is confirmed; (3) peripheral circulation is untouched, and ischemic complications do not occur; and (4) if used prophylactically, quick conversion to embolotherapy is possible, in case balloon placement is of suboptimal effect. The disadvantage of balloon placement is that the preservation of the peripheral circulation also means that the collateral circulation is untouched, and therefore, persisting hemorrhage via collaterals is still a possibility. In fact, there is no consensus that balloon occlusion of the internal iliac arteries and their branches only effectively reduces PPH. From a technical perspective, balloons are of two types, occlusion or dilation. The former is softer and shorter in length, whereas the latter has a stronger structure with variable length (e.g. 4–26 cm). Either type can be used for the prophylaxis of PPH. Appropriate balloon diameters are 10–11 mm

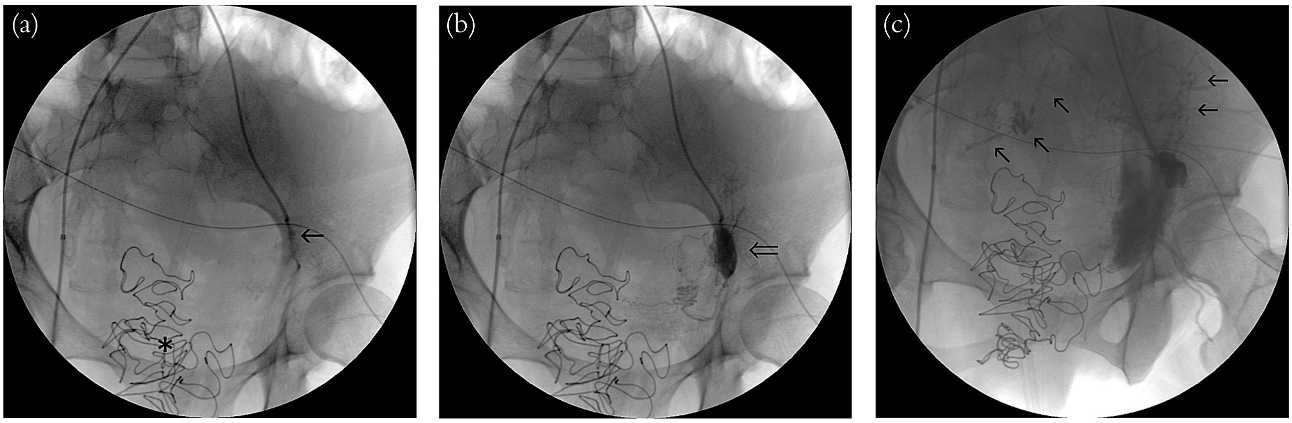

Figure 5 Non-targeted embolization of the internal iliac artery with repair of injured artery in primary PPH on a 39-year-old patient of a Chinese origin. Despite hysterectomy, the patient suffered from persistent per vaginal hemorrhage. (a) Contralateral cannulation to the left inferior gluteal trunk (anterior division). The catheter tip is shown with an arrow. Gauze pack in the vagina noted (*). (b) Extravasation (open arrow) was encountered immediately on test injection. Non-targeted embolization using grated gelatin sponge particles was performed, followed by the deployment of a 5 mm × 5 cm Gianturco coil (Cook, UK). (c) A more gentle test injection of a small amount of radiological contrast, after shifting the catheter tip to a slightly more proximal location, resulted in another immediate extravasation. Thus proving that with the fragile arterial wall, surgical repair and ligation would have been difficult. Demonstration of several branches of the inferior gluteal trunk (arrows), including branches of intrauterine arteries. A further focus of extravasation occurred in the more proximal portion in the internal iliac artery. These sites of arterial injury were again treated with the deployment of Gianturco coils of the same size. Hemostasis was successfully achieved following embolization

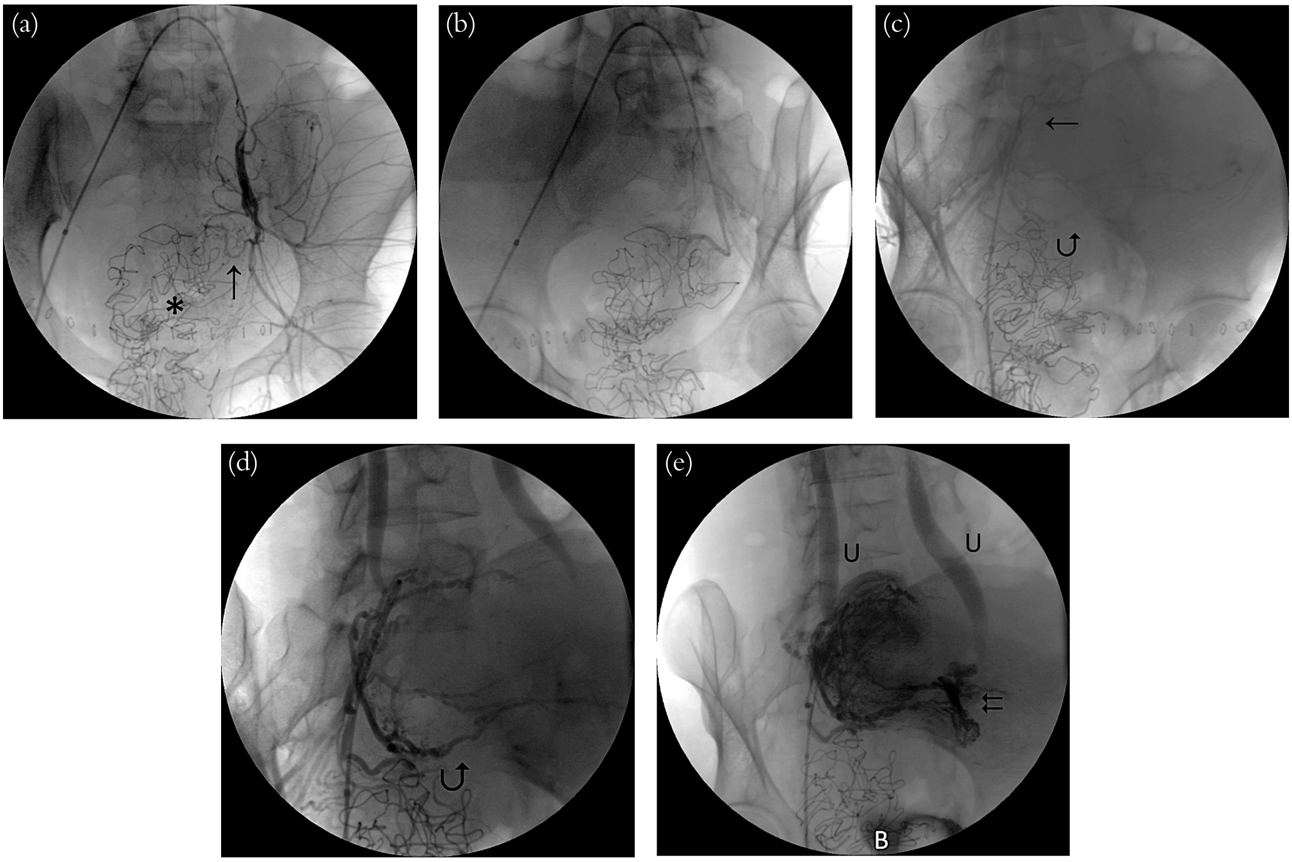

Figure 6 Uterine artery embolization in primary PPH on a 28-year old of Arabic origin with postvaginal delivery and uterine atony. (a) Contralateral cannulation to the left internal iliac artery and selective arteriogram was obtained (frontal views). The uterine artery (arrow) was detected. Gauze pack in the vagina shown (*). (b) The uterine artery was cannulated and superselective arteriograms were obtained. No extravasation was disclosed. This artery was embolized using grated gelatin sponge particles only. (c) Ipsilateral cannulation. The catheter tip (arrow) was in the right internal iliac artery. The uterine artery (curved arrow) was detected without the signs of extravasation. Arteriograms on this side were obtained in the right anterior oblique position. (d) Superselective cannulation to the uterine artery and arteriogram in the early phase. The uterine artery (curved arrow) was clearly identified. (e) The late phase of the uterine arteriogram. Extravasation appeared (arrows). The uterine artery was embolized using a small amount of EGGS (5% ethanolamine oleate containing grated gelatin sponge particles) in addition to simple grated gelatin sponge particles. Hemorrhage stopped and the patient recovered. Ureters (U) and bladder (B) containing balloon catheter

for internal iliac artery, 6–9 mm for inferior gluteal trunk and 5–7 mm for uterine artery. The amount of fluid to fill the balloon differs with the site of placement and balloon size. For example, it will be 2–3 ml, if a 10 mm × 6 cm balloon is inflated at the boundary between the internal iliac artery and inferior gluteal trunk. However, this quantity must be tested and confirmed under fluoroscopy when the catheter is inserted. It is preferable to use a pressure meter when the balloon is inflated. The necessary pressure to temporally occlude the artery is 1 atm or less, which is far smaller than the pressure required in balloon angioplasty of the iliac arteries which is at least 6 atm, typically between 10 and 12 atm. The length of the balloon and its placement position need to be decided by the radiologist on a case by case basis: there is no clear consensus on these issues. It is of note that the catheter/balloon must be deflated when the balloon is removed or repositioned, which is a procedure to prevent damaging the intima of the artery possibly resulting in subsequent stenosis or occlusion where the balloon is placed.

TECHNICAL ASPECTS

Preparation

Unless working in an absolute emergency, it is worthwhile to obtain a coagulation panel including platelet count and prothrombin time (international normalized ratio (INR)). Although dysfunctional coagulation does not contraindicate embolization[3,39,44], its correction may help in preparation for postprocedural hemostasis and the prevention of complications relating to it. Because embolization is an invasive procedure, obtaining informed consent from the patient is essential, provided the patient retains her consciousness. This process must include a full explanation of the procedure and a discussion of the possible complications, effect on future fertility and potential effects of the radiation. In cases where the patient has lost consciousness, however, such as in a shock or semi-shock status, consent is not practical. In such situations, explanations must be provided to the direct family, if present, particularly regarding possible complications.

Ideally the patient is kept nil by mouth for an appropriate duration prior to procedure, in order to avoid complications from vomiting. Bladder catheterization is not essential, although it is helpful in preventing the bladder from filling with contrast, containing urine that could obscure angiographic findings during the procedure.

Cross-sectional imaging

Antenatal diagnosis of placenta abnormalities

Ultrasonography is the principal means used to assess conditions of placental abnormality including placenta accreta, increta and percreta[45,62,63]. However, results are inconclusive in some cases and magnetic resonance imaging (MRI) has been proposed for detailed analysis of adjacent deep organs[46–51]. Placenta accreta, increta and percreta are demonstratable when bulging of the uterine boundary towards the adjacent organs such as bladder is present on both modalities, hypervascularity of the placenta is detected in the suspected areas, normal myometrial appearances are absent, and dark intraplacental bands are present on MRI. In cases where such abnormalities are present and which are regarded as high risk for hemorrhage, the placement of a balloon catheter in the internal iliac or uterine arteries can and should be considered.

Estimation of hematoma size

Localization and measurement of the size of the hematoma prior to arteriography and embolization is extremely useful, although not essential, and, in some cases, impractical. Confirming whether the hematoma is within or outside the uterus and its relationship to pelvic structures dictates the course of the embolization procedure[64] (Figure 7). Plain MRI is a useful method to examine the pelvis, as it requires a small number of examinations with different radiofrequency signal maneuvers (sequences) to demonstrate the objective images in the sagittal, coronal and axial (transverse) cross-sections. On the other hand, high speed arterial phase computer tomography (CT) is advantageous in the detection of active hemorrhagic sites[65].

Premedication

The interventional radiologist needs to decide the type and quantity of agents used for premedication, unless the patient is under anesthetic control as would be the case for those in shock status. If no interacting drugs have been administered, the authors recommend a combination of opiate and sedative antihistamines such as pethidine 50–100 mg i.m. (in two divided doses, if more than 50 mg is given) and promethazine hydrochloride 25–50 mg i.m.

Location for embolization and arterial puncture

The ideal location for embolization is the interventional radiology suite where vascular procedures routinely take place. In reality, however, interventional radiologists may be requested to perform procedures in surgical theaters in emergency situations. The obvious advantage in performing the embolization or related procedures in theaters is that the patient requiring the hemostatic procedure is already under anesthesia. The disadvantages are that the imaging system is usually suboptimal in image quality and functions, and the range of available devices and consumables including catheters may be limited. As described below, there is usually sufficient time for the patient to be transferred to the interventional radiology suite without undergoing extremely urgent procedures in the vast majority of cases, and the authors strongly recommend this if at all possible.

Targets of embolization

The prime target of embolization is the arterial source of the bleeding. Commonly, this is the uterine artery, when the source of hemorrhage is in the myometrium, cervix or endometrium (Figure 6). On the other hand, if the hemorrhage is as a result of a laceration of the birth canal below the level of the uterus, the source is likely to be a smaller vessel such as the vaginal or internal pudendal artery. If branches other than the uterine artery are the source of hemorrhage, superselective catheterization and arteriogram of each branch are required to assess the extent of extravasation (Figure 7). Fortunately, the availability of smaller diameter catheters and hydrophilic coated guidewires makes such superselective catheterization less challenging. Extravasation is unlikely to be demonstrated on non-superselective angiograms such as the global pelvic arteriogram and internal iliac arteriogram.

When extravasation is confirmed, embolic material is infused to occlude the artery. If extravasation is not proven, embolization of each of the branches supplying the suspected area of hemorrhage may be performed; alternatively, non-targeted embolization of slightly proximal arteries (or the internal iliac artery in extreme cases) can be performed. In such cases, protection of the distal branches of the inferior gluteal trunk and the superior gluteal trunk with coils is a safe option (Figure 4).

The most accurate demonstration of the flow distribution of transcatheterally infused material is obtained with combined arteriographs, using a combination of dedicated angiography table and CT equipment. Unfortunately, such complex equipment is available only in highly specialized institutions. More often than not, the interventional radiologist judges the vascular anatomy and the distribution of the embolic material on the basis of simple two-dimensional arteriograms in the frontal or oblique projections.

The order of arteriogram and catheter maneuvers

All procedures should be performed using aseptic technique. Unilateral or bilateral groin puncture(s) is

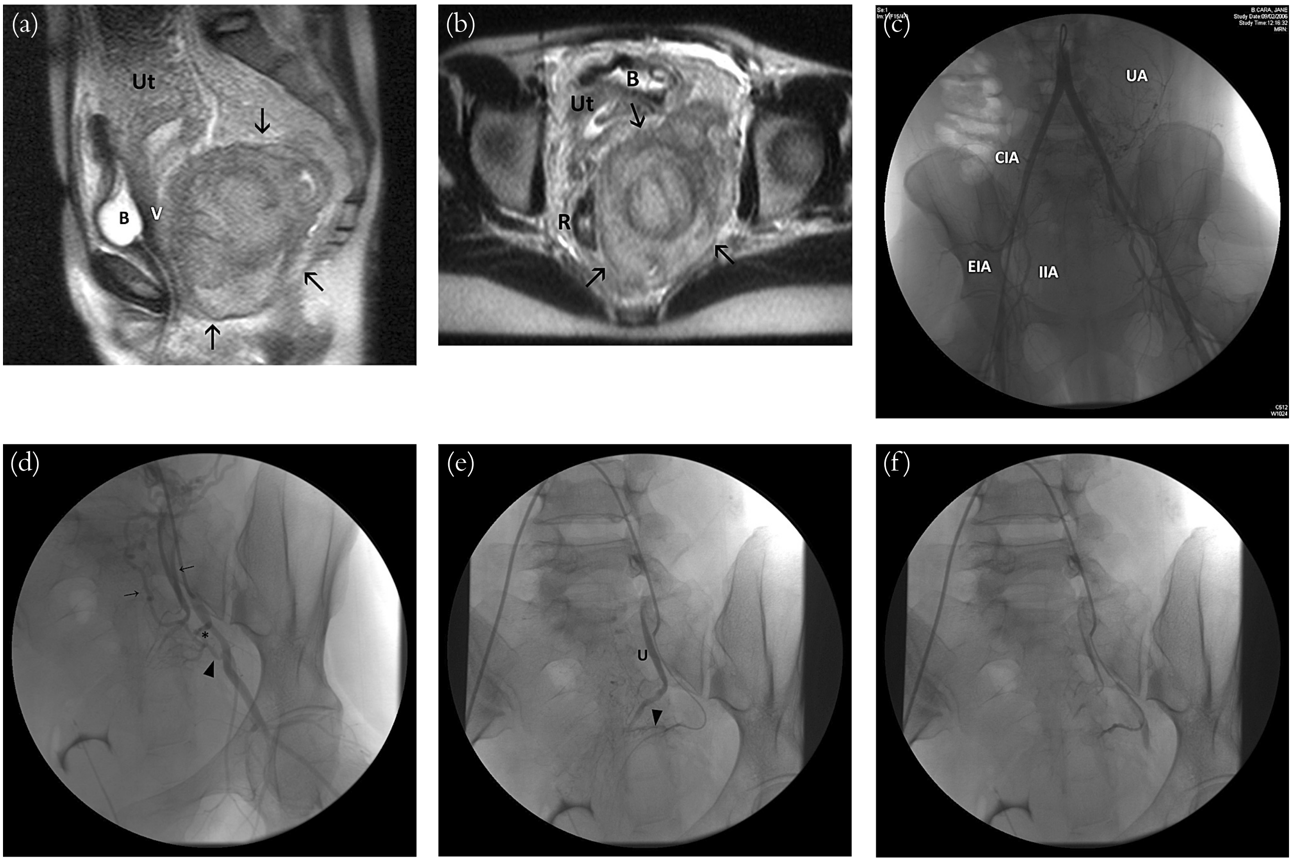

Figure 7 Extrauterine artery embolization in primary PPH from the birth canal on a 23-year-old Caucasian after vaginal delivery. The patient had a double uterus, double vagina and previous removal of the right uterus. Hemorrhage per vagina was only of a moderate degree. (a) and (b) T2-weighted magnetic resonance images (MRI) in the sagittal and axial (horizontal) cross-sections, respectively. A 9 cm hematoma (arrows) was demonstrated inferior to the uterus (Ut), left lateral to the rectum (R), posterior to the bladder (B) and vaginal zone (V). From these views and the information of the anatomical variation, it was anticipated that left-sided embolization only would achieve hemostasis. (c) Whole pelvic arteriography. The right common femoral artery was punctured and a 5 Fr gauge modified hook catheter was inserted into the distal aorta where radiological contrast was infused. The outline of the common, internal and external iliac arteries (CIA, IIA and EIA, respectively) and their major branches were shown. The intramural branches of the uterine artery (UA) distributed both above and within the pelvis. On this distant arteriogram, general vascular anatomy of the pelvis was demonstrated, although the suspected hemorrhagic lesion was not detected. (d) Left internal iliac arteriography in the left anterior oblique position. Both uterine artery (arrows) and vaginal artery (arrowhead) were identified. The superior gluteal trunk (*) was superimposed by the inferior gluteal trunk. This falls into the category of vascular anatomy shown in Figure 1b. A 5 Fr gauge cobra-shaped catheter was used. (e) Left vaginal arteriography. Tiny extravasation was confirmed (arrowhead) on hand injection of radiological contrast through the 3 Fr gauge microcatheter (arrow). Embolization was performed using particles of grated gelatin sponge particles until the extravasation was barely detectable. U, ureter. (f) Left vaginal arteriography postembolization. Compared with the image prior to embolization (e), the disappearance of small arterial branches around the extravasation was evident. Following embolization, the hemoglobin level increased to 11 g/dl on the next day and 12 g/dl on the following day. The patient was discharged 2 days after embolization without undergoing any other intervention. Her outpatient follow-up was uneventful

performed. An introducer sheath is used to stabilize the arterial entrance at the puncture site(s) in the groin(s). The standard diameter of the sheath is 5 Fr gauge; a 6 Fr gauge (or larger) sheath is usually necessary for 8–11 mm diameter balloon occlusion.

Hook shaped catheters are the first choice to enter the contralateral iliac arteries from either the aorta or the common iliacs on either side. We recently modified our technique with bilateral groin punctures, changing from a 5 Fr hook catheter to a 4 Fr soft J-curved catheter. Although the 5 Fr catheter works for relatively larger arteries such as the internal iliac, proximal portions of the inferior and superior gluteal trunks (anterior and posterior branches), and for superselective catherization of the uterine arteries, a 4 Fr appears to be a better size. The 3 Fr microgauge catheters may be required to go into smaller branches, which then can be inserted through the aforementioned 4 or 5 Fr catheters. For the catheter maneuvers, hydrophilic coated guidewires with angled tips are used. In principle, the performing interventional radiologist should choose the combination of catheters, with which the radiologist feels comfortable and familiar. Catheters made of soft polyurethane appear to be less irritating to the arterial wall. Once the arterial wall is irritated, spasm may supervene, resulting in a difficult maneuver and increasing the risk of arterial wall damage. Spasm can be prevented and treated by the intra-arterial infusion of nitrate vasodilators, such as isosorbide dinitrate 0.05–0.25 mg per branch. A

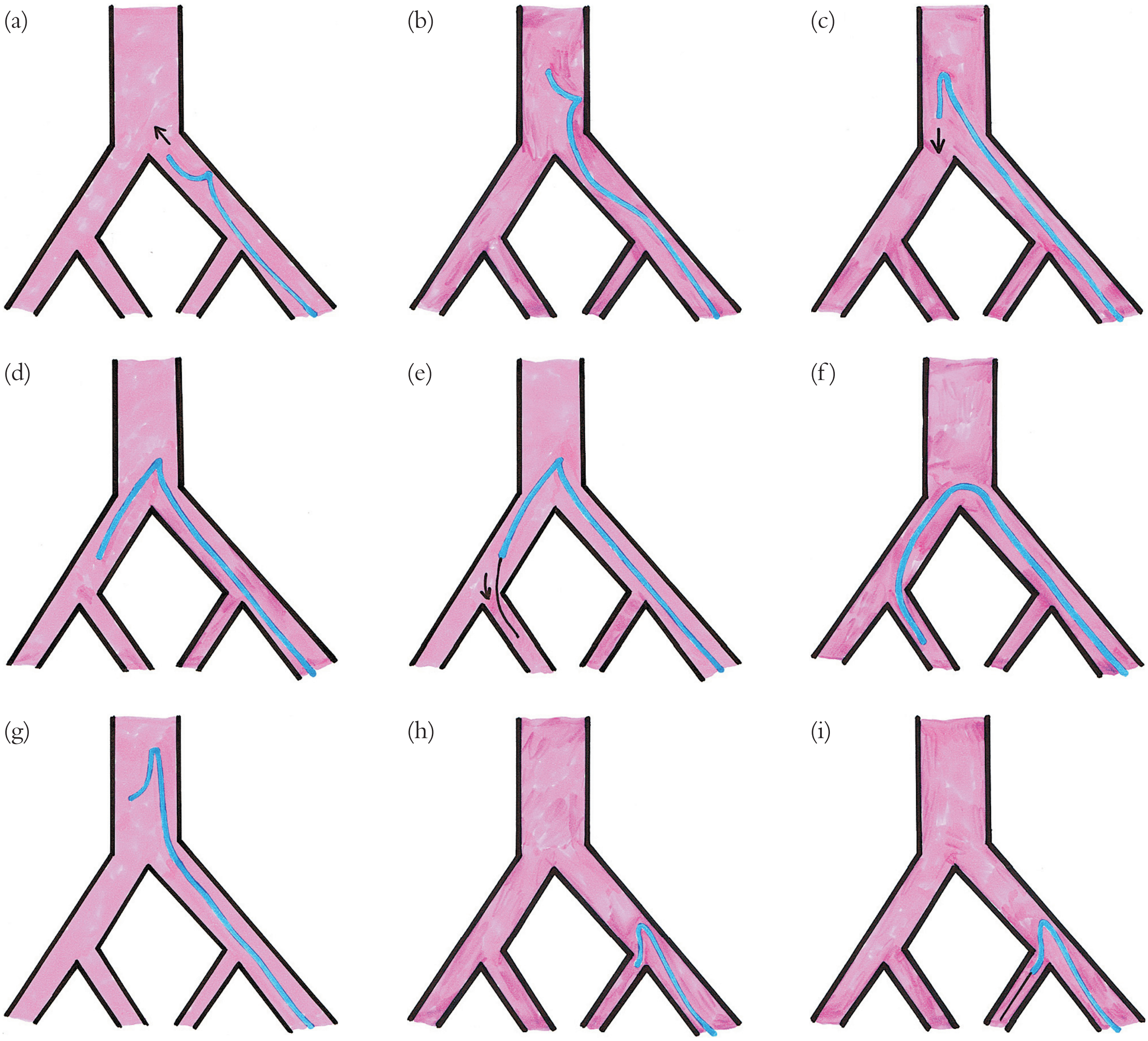

Figure 8 Routes of catheterization. (a) Cannulation to the contralateral internal iliac artery with a hook type catheter. The first step is to insert the catheter into the common iliac artery on the ipsilateral side. (b) The catheter is advanced to the lower aorta. (c) The catheter tip is turned downwards. Then the catheter is pulled down. (d) The catheter tip is inserted into the contralateral common iliac artery. Guidewire is often necessary. (e) Angled tip guidewire with hydrophilic coating is inserted into the internal iliac artery. (f) The catheter is pushed into the internal iliac artery lumen over the guidewire. If the catheter is a soft 4 Fr one, it will enter distal branches of the internal iliac arteryby gently maneuvering the hydrophilic coated wire. (g) Cannulation into the ipsilateral internal iliac artery with the same hook type catheter. The hook shape of the catheter head is formed within the aorta. (h) The catheter is pulled down to the ipsilateral common iliac artery. The catheter is further pulled down, keeping the catheter tip facing inferiorly and medially, so that the tip enters the internal iliac artery. (i) Using hydrophilic coated guidewire, the catheter can be advanced to distal portions of the internal iliac artery. If the catheter is unlikely to go deeper into the internal iliac artery, the catheter should be then be replaced by a softer one at this point over guidewire

hydrophilic coated guidewire with a small J-shape tip is often useful to advance the catheter in tortuous and branching arteries.

The first arteriogram to be obtained should be an image of the pelvis from the aortic bifurcation to the groins; this provides a global view of the pelvic arteries. In reality, either common or internal iliac arteriograms often provide this view. Following this, the catheter should be advanced to the areas closer to the target of embolization. Frontal views are the basic projection; oblique views aid in the demonstration of the origins of the target areas and facilitate catheterization.

BALLOON CATHETER PLACEMENT AND EMBOLIZATION IN ADHESIVE AND ADHERENT PLACENTATION

Among the placental abnormalities, the adhesive and invasive forms, namely placenta accreta, increta and percreta, represent the second largest cause of PPH after atony. High success rates for embolization techniques have been reported in cases with these abnormalities in terms of cessation of bleeding[14,27,29,31,36,41,42,53]. At the same time, difficulties in obtaining hemostasis after embolization or cases with hemorrhagic complications following initial

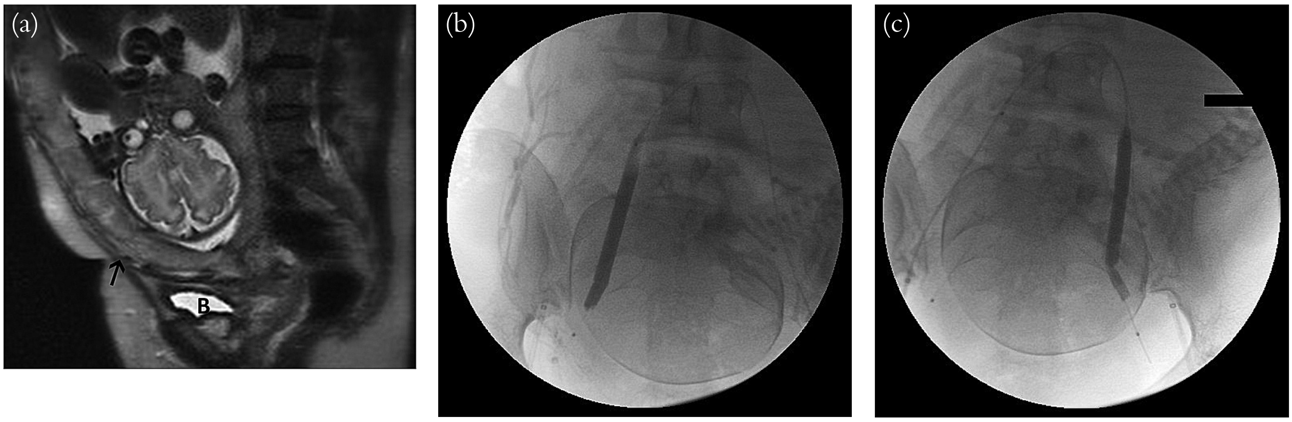

Figure 9 Prophylactic placement of balloon catheters in a case with antenatally diagnosed placenta increta. (a) A sagittal cross-section of antenatal MRI (T2-weighted). Cephalic presentation of the fetus, placenta previa, thin and disrupted lower anterior myometrium with placental invasion (arrow) were detected, consistent with placent increta. The bladder (B) was preserved. (b) Contralateral cannulation of a 9 mm × 10 cm dilation balloon catheter to the right internal iliac artery and its inferior gluteal trunk (anterior division). Test inflation of the balloon proved satisfactory filling within the artery as shown on this image, which was immediately deflated so that no distress of the fetus would occur. (c) Likewise, the same type of catheter was inserted into the left boundary area between the internal iliac artery and the inferior gluteal trunk. Test inflation of the balloon was repeated

hemostasis by embolization also have been reported[29,42,53]. One report noted that coils were necessary in addition to standard gelatin sponges in more than 80% of placenta accreta cases[41].

In cases where such placental abnormalities are suspected or confirmed on prenatal imaging, prophylactic catheterization can be achieved by the placement of catheters in the internal iliac, inferior gluteal trunk (anterior branch) or uterine arteries[20,27,40,42,44,52] (Figure 9). The choice of balloon catheters and advantages of the method using balloon catheters are described in the section on 'embolic materials' of this chapter. This process is neither complicated nor time consuming. The best timing for catheter placement is immediately prior to the delivery. However, for logistical reasons, we tend to place the catheters one day prior to planned delivery by section. Caution is necessary to prevent thrombosis mainly of the femoral artery, if catheters and sheaths are placed for more than several hours. As only one balloon can be placed on each side in practice, balloon catheters are inserted from both groins via the common femoral arteries on both sides through sheaths. The sheaths inserted and catheters placed can inflict irritation and intimal injury at the sites of placement. The authors flush the catheters and sheath slowly and continuously using four infusion pumps independently to prevent such injuries. An example regimen would be for each sheath to be infused with 1 liter of normal saline containing heparin 100 IU at an infusion rate of 40 ml/h, and for each catheter to be infused with 1 liter only of normal saline at an infusion rate of 40 ml/h.

Some reported series state that balloon inflation only was not useful in reducing hemorrhage during cesarean delivery[40,44], whereas others reported successful outcomes. In view of the mechanism of hemostasis depicted in Figure 2e, it is understandable that hemostasis is not achievable with balloon occlusion of the proximal arteries only as a result of the presence of well-developed peripheral collateral arteries such as the ovarian, femoral circumflex and lumbar arteries. Regardless, prophylactic catheter placement in cases of placental abnormality has the distinct advantage of prompt commencement of embolization, if hemostasis is difficult to achieve[42].

Figure 10 shows a reasonable protocol involving prophylactic balloon placement and therapeutic embolization in cases with suspected or diagnosed placenta accreta, increta or percreta. Several authors have reported no major complications in their series[11,14,24,30,33,34].

COMPLICATIONS

Numerous complications have been described[1–3,7,11,17,24–29,31,32,35,36,39–42] and major complications range from 0%[14,24,30,33,34] up to 18%[27,32]. It is rare, however, that these complications contribute directly to the death of a patient.

The causes of complications include:

(1) *Technical errors* These are rather uncommon, including hematoma at the puncture site[12,28], pseudoaneurysm formation[35] and vascular injury[7,28,29,31].

(2) *Systemic reactions* Pulmonary edema[1,26,29,40] and allergy to iodine[29] have been reported.

(3) *Pre-existing hypovolemia related complications* Cardiac ischemia[26], renal impairment[2,25,26] and retroperitoneal hemorrhage[28,29,65] have been described, as has necrosis of small bowel loops[7,31], which are more likely due to prolonged hypervolemia than embolization. Serious complications as a result of prolonged hemorrhage and hypervolemia occurred in four cases including death from brain hypoxia[28], panpituitary necrosis resulting in diabetes insipidus owing to prolonged hypoxia[28] and

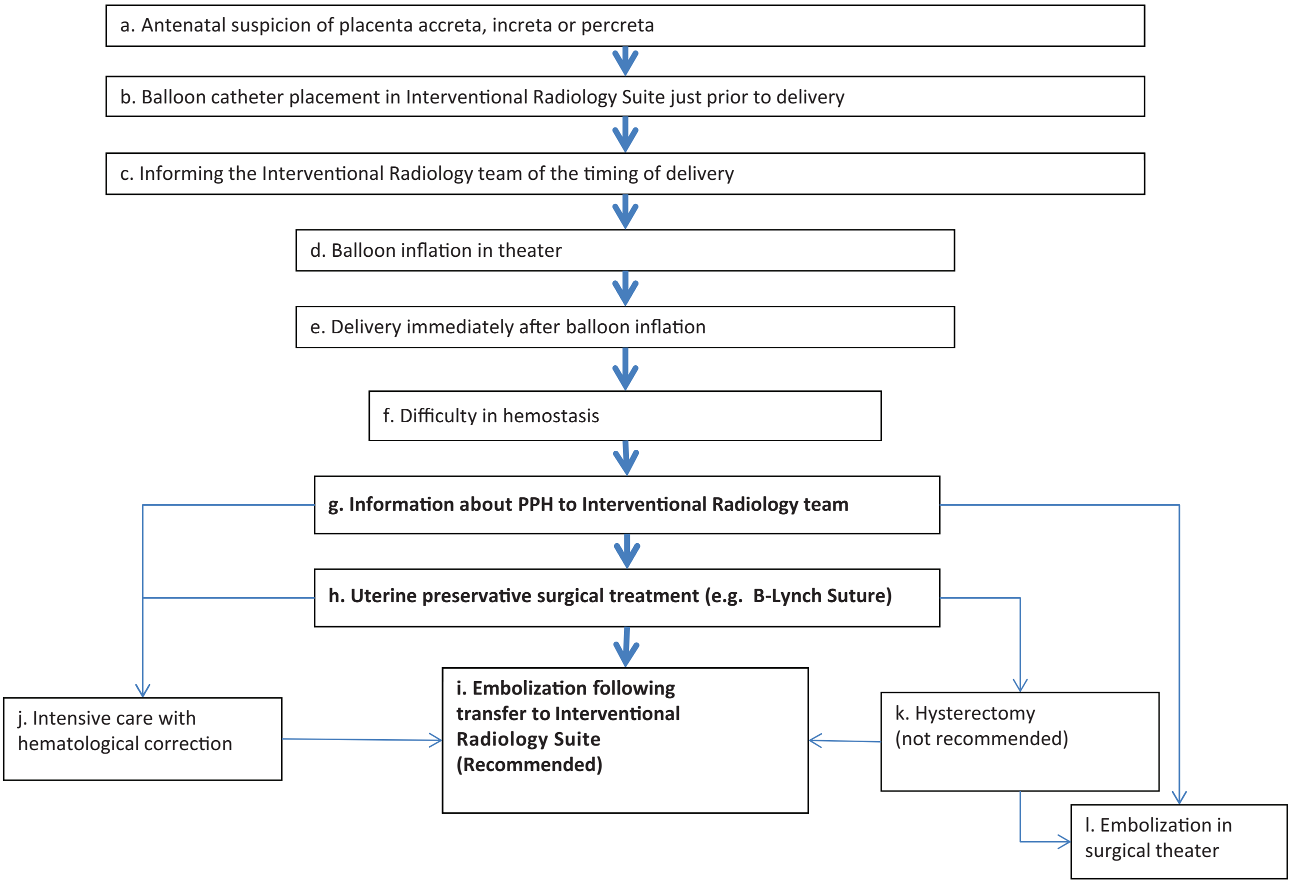

Figure 10 Recommended protocol in cases with antenatal diagnosis of placenta accreta, increta or percreta

deaths from brain hemorrhage despite successful genital hemostasis[25,26]. It should be noted that these factors which are not direct consequences of embolization could pose a serious threat to patient prognosis.

(4) *Postembolic ischemia* Necrosis of the uterus has been reported sporadically[27,28,31,42,43,57]. Adjacent organs such as vagina[27], bladder[43] and ureters[40] are also prone to ischemic necrosis. Fistula formation following necrosis between the bladder and vagina has been described[32], as has atrophy of the endometrium, adhesion of the uterus and scarring within the uterus[42].

(5) *Sciatica and nerve injury* Symptoms owing to ischemia of the lumbar nerve plexus have been described[3,7,26,27,31,34–36].

(6) *Infection* Intrapelvic abscess formation[10,13] and endometrial infection[28,36] have been reported.

(7) *Acute thromboembolism of the lower limb arteries* This has been reported in a small number of cases[25,27,31,32] and has been attributed to overflow of gelatin sponge products from the internal iliac artery to the external iliac circulation. Surgical intervention of leg arteries may become necessary.

(8) *Deep venous thrombosis* This is a rather uncommon complication. Only one case with deep ipsilateral femoral vein thrombosis without any particular cause was reported in a series of 36 cases[35].

(9) *Other abdominal or systemic symptoms* Pyrexia is commonly encountered and is usually of a self-limiting nature, unless an abscess results[1,11,17,24,34,41]. Abdominal pain is also common[11] and ileus has been reported[2,28].

(10) *Multiple organ damage* This report followed embolization of a wide range of arteries within the pelvis for PPH from a ruptured uterus[2] in which renal failure, ileus, surgical wound abscess, perforated sigmoid colon resulting in fistula to skin surface, subphrenic abscess, pneumonia and ulcer of the flank occurred.

(11) *Radiation* The biological effect of radiation only has been measured in two studies[33,36]. Doses to the ovaries measured in six cases averaged 586 mGy ranging between 204 and 729 mGy[36], whereas the skin dose averaged 34 mGy, ranging from 11 to 80 mGy[33]. These figures are consistent with measured absorption doses of skin and estimated doses to the ovaries in a series of 20 cases of uterine artery embolization[66]. In this latter study, fluoroscopy was performed for a maximum of 52.5 min with the mean value of 21.9 min, resulting in a maximum skin dose of 304 cGy (mean 162 cGy); the estimated maximum ovarian dose was 65 cGy (mean 22.3 cGy). These figures were

greater than the doses of other image examinations of the pelvis such as hysterosalpingography (0.04–0.55 cGy), recanalization of the Fallopian tube (0.2–2.75 cGy), or CT of the body trunk (0.1–1.9 cGy); on the other hand, they were smaller than the dose in radiotherapy for intrapelvic Hodgkin's lymphoma (263–3500 cGy). On the basis of the known risks of pelvic irradiation administered for Hodgkin's disease, the dose associated with uterine artery embolization is unlikely to result in acute or long-term radiation injury to the patient or to a measurable increase in the genetic risk to the patient's future children. In embolization cases for PPH, there may be instances where longer fluoroscopy time is required than in uterine artery embolization for fibroids. Nevertheless, it would still be similar to that of uterine artery embolization, and, therefore, injury from irradiation is unlikely. In cases where catheter insertion to the intrapelvic arteries was undertaken, radiation doses to the fetus have been estimated in at least three studies. These estimates were 100–160 mGy[24], 40–200 mGy (median 6 mGy)[40] and 32 mGy[44]. Although it is commonly held that there exists no threshold dose below which no excess risk to the fetus arises, the doses to the fetus are supposed to be unlikely to cause injury based on available data[67,68].

(12) *Menstruation* Recovery of menstruation occurred in the vast majority of patients who underwent follow-up, excluding those undergoing hysterectomy, having natural menopause or who developed malignancy and received chemotherapy[14,17,29–31,33,42]. In a study of a subgroup consisting of 23 patients, 91% resumed regular menstruation, whereas 8.7% suffered from dysmenorrhea[35].

(13) *Fertility* All series assessing fertility following embolotherapy of the intrapelvic arteries for PPH conclude that fertility and pregnancy do not appear affected by embolotherapy[21,30,31,33,35,36,69]. In these reports, the majority of the patients who wished to conceive were successful; most delivered a healthy child. In one series, the authors noted a high frequency of PPH (100% four cases) as a result of adhesive placenta in patients who had previously undergone embolization for PPH in the preceding delivery[70]. This issue requires further examination.

In summary, the complications of embolotherapy for PPH have occurred in a relatively small proportion of patients undergoing the procedure. The vast majority of these were owing to ischemic damage to the uterus and nearby organs. It is important to view the complications against the backdrop of the circumstances wherein the operations are performed on seriously and sometimes critically ill patients, some of whom are literally and figuratively at 'death's door'. Under such circumstances, those who perform embolization on patients with serious PPH need to seek the best point of compromise between embolization effect and prevention of tissue ischemia. At the same time, there is no evidence that embolotherapy in PPH patients or prophylactic catheter placement in patients with antenatally diagnosed placental abnormalities will result in significant radiation injury to the patients or fetus. The majority of the patients who undergo embolization and preservation of the uterus retain menstruation and fertility potential.

LOGISTICS

In order to provide embolotherapy for PPH in an efficient manner, it is essential to establish a network that allows reliable access to an interventional radiology team; it is neither realistic nor necessary for all sites providing obstetric care to have such a team. This is because cases of PPH that require embolization are relatively uncommon and generally there is a relatively long time interval between the onset of PPH and the need for radiological interventions.

In a 54-month study in Jerusalem[37], the authors encountered 636 cases of PPH among 20,255 births (3.1%). Among these, only nine required embolization (1.4% of the PPH cases, but 0.045% of the entire cohort).

In the majority of instances, a relatively long time interval ensued during which obstetricians performed the first lines of treatment including transfusion and when the preparation by the interventional radiology team took place simultaneously. Indeed, extremely urgent (e.g. in less than 60 min) radiological intervention is rarely requested. The time interval between delivery and intervention averages 263 min, ranging from 90 to 750 min[29] or a mean of 11 h and median of 6 h[28]. This fact, while somewhat reassuring, must be considered in light of knowledge that delays in performing embolization can result in death or necrosis of critical organs. Such events follow prolonged organ ischemia, hypoxia or depletion of coagulation materials[25,26,28].

In view of this, it is logical to set up a system whereby an early warning and request is issued to the interventional radiology team. A recommended protocol involving embolotherapy is shown in Figure 11.

Similarly, prophylactic balloon catheter placement should be considered in cases where placenta accreta, increta or percreta is suspected or diagnosed on prenatal imaging such as ultrasonography or MRI. Although such procedures increase the number of irradiated cases among pregnant women and their fetuses, the radiation dose is not high and the procedure is not time consuming. Implementation of such a system would reduce the level of urgency to a semielective procedure, from otherwise possible emergency situations; thus further reducing the number of truly emergency cases. A recommended protocol involving prophylactic placement of balloon catheters is shown in Figure 10 as previously described in this chapter.

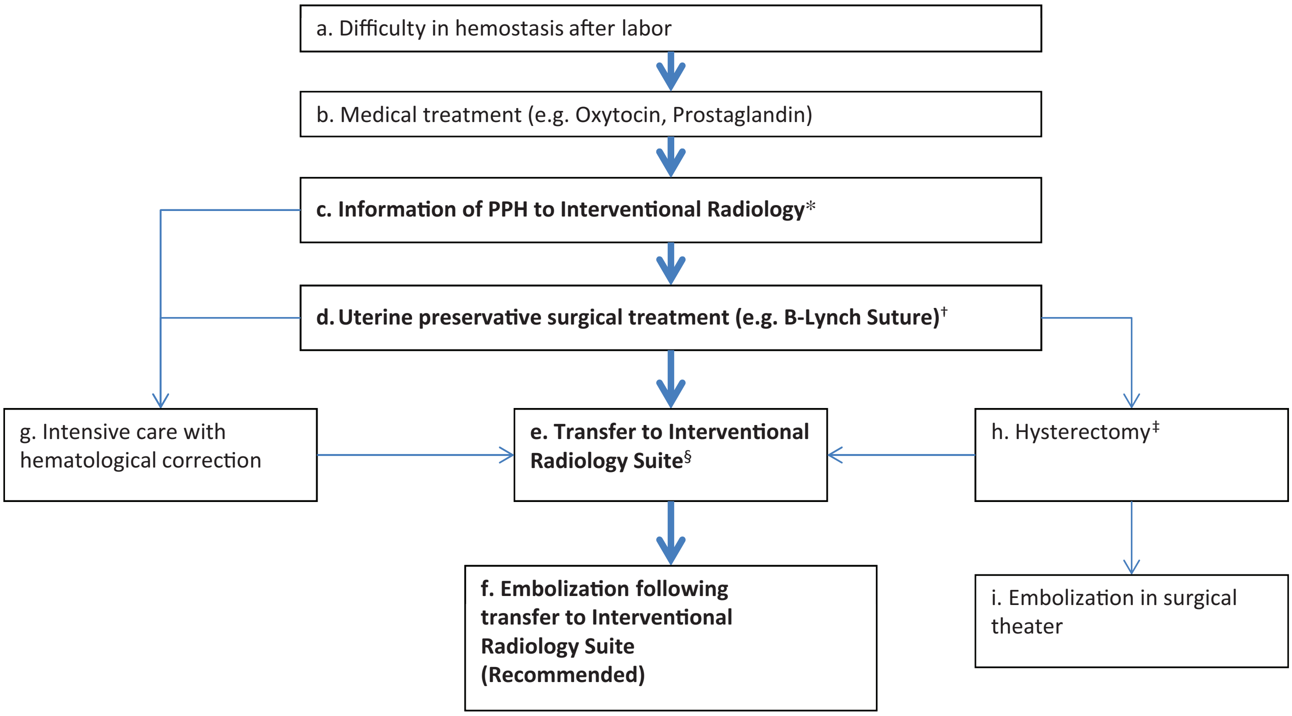

Figure 11 Recommended protocol in unexpected primary and secondary PPH. *Including the interventional radiology team of a nearby center, if embolization is to take place in that center. If this is the case, the team involved in the patient's transfer needs to be informed. †Only valid in primary PPH; in cases with secondary PPH, go straight to either (e) or (g). ‡Preferably avoid hysterectomy and extensive ligation of the arteries including the uterine arteries. §Including the interventional radiology suite of nearby center, if embolization is not available in the original hospital

EMBOLIZATION FOR ECTOPIC PREGNANCIES

In addition to PPH, ectopic pregnancies, especially cervical pregnancies, also can result in fatal hemorrhage. Using prenatal ultrasonography, these abnormal pregnancies can be readily diagnosed. Bilateral uterine artery embolization has been reported to be effective for hemostasis in cases with life-threatening hemorrhage after the evacuation of ectopic pregnancies[58,71–74], other forms of abortion[14,33,75] and hemorrhage after abortion due to retained placenta increta[76]. Either gelatin sponge or polyvinyl alcohol particles have been used successfully.

CONCLUSION

Embolization of the hemorrhagic source arteries in cases with intractable PPH is a highly feasible, decisive, relatively safe and beneficial procedure, which can preclude laparotomy and hysterectomy. The majority of the patients will retain fertility following the procedure.

Embolization should be implemented in the treatment strategy for PPH. It is indicated when conventional medical and surgical (non-hysterectomy) treatments fail in hemostasis. In principle, it should be performed prior to hysterectomy. Prophylactic balloon catheter placement is an option in cases where placenta accreta, increta or percreta is diagnosed or suspected antenatally.

ACKNOWLEDGMENT

The authors are grateful to Professor Louis G. Keith for a thorough review of this chapter, to Dr K. Envar, T. Choji and H. Choji for correction, and to Mrs S. Monsen-Fry for typing the manuscript.

References

1. Heaston DK, Mineau DE, Brown BJ, Miller FJ Jr. Transcatheter arterial embolization for control of persistent massive puerperal hemorrhage after bilateral surgical hypogastric artery ligation. Am J Roentgenol 1979;133:152–4
2. Pais SO, Glickman M, Schwartz P, Pingoude E, Berkowitz R. Embolization of pelvic arteries for control of postpartum hemorrhage. Obstet Gynecol 1980;55:754–8
3. Heffner LJ, Mennuti, MT, Rudoff JC, McLean GK. Primary management of postpartum vulvovaginal hematomas by angiographic embolization. Am J Perinatol 1985;2:204–7
4. Rosenthal DM, Colapinto R. Angiographic arterial embolization in the management of postoperative vaginal hemorrhage. Am J Obstet Gynecol 1985;151:227–31
5. Itol M, Matsui K, Mabe K, Katabuchi H, Fujisaki S. Transcatheter embolization of pelvic arteries as the safest method for postpartum hemorrhage. Int J Gynaecol Obstet 1986;24: 373–8
6. Minck RN, Palestrant A, Chemey WB. Successful management of postpartum vaginal hemorrhage by angiographic embolization. Ariz Med 1984;41:537–8
7. Greenwood LH, Glickman MG, Schwartz PE, Morse SS, Denny DF. Obstetric and nonmalignant gynecologic bleeding: treatment with angiographic embolization. Radiology 1987;164:155–9.
8. Feinberg BB, Resnik E, Hurt WG, Bump RC, Kubota R, Cho SR. Angiographic embolization in the management of

late postpartum hemorrhage. A case report. J Reprod Med 1987;32:929–31
9. Shweni PM, Bishop BB, Hansen JN, Subrayen KT. Severe secondary postpartum haemorrhage after Caesarean section. S Afr Med J 1987;72:617–9
10. Chin HG, Scott DR, Resnick R, Davis GB, Lurie AL. Angiographic embolization of intractable puerperal hematomas. Am J Obstet Gynecol 1989;160:434–8
11. Yamashita Y, Takahashi M, Ito M, Okamura H. Transcatheter arterial embolization in the management of postpartum hemorrhage due to genital tract injury. Obstet Gynecol 1991;77:160–3
12. Bakri YN, Linjawi T. Angiographic embolization for control of pelvic genital tract hemorrhage. Report of 14 cases. Acta Obstet Gynecol Scand 1992;71:17–21
13. Gilbert WM, More TR, Resnick R, Doemeny J, Chin H, Brookstein JJ. Angiographic embolization in the management of hemorrhagic complications of pregnancy. Am J Obstet Gynecol 1992;166:493–7
14. Mitty HA, Sterling KM, Alvarez M, Gendler R. Obstetric hemorrhage: prophylactic and emergency arterial catheterization and embolotherapy. Radiology 1993;188: 183–7
15. Abbas FM, Currie JL, Mitchell S, Osterman F, Rosenshein NB, Horowitz IR. Selective vascular embolization in benign gynecologic conditions. J Reprod Med 1994;39:492–6
16. Joseph JF, Mernoff D, Donovan J, Metz SA. Percutaneous angiographic arterial embolization for gynecologic and obstetric pelvic hemorrhage. A report of three cases. J Reprod Med 1994;39:915–20
17. Yamashita Y, Harada M, Yamamoto H, et al. Transcatheter arterial embolization of obstetric and gynecological bleeding: efficacy and clinical outcome. Br J Radiol 1994;67:530–4
18. Merland JJ, Houdart E, Herbreteaux D, et al. Place of emergency arterial embolization in obstetrics hemorrhage about 16 personal cases. Eur J Obstet Gynecol Reprod Biol 1996;65:141–3
19. Vedantham S, Goodwin SC, McLucas B, Mohr G. Uterine artery embolization: an underused method of controlling pelvic hemorrhage. Am J Obstet Gynecol 1997;176:938–48
20. Dubois J, Garel, Grignon A, Lemay M, Leduc L. Placenta percreta: balloon occlusion and embolization of the internal iliac arteries to reduce intraoperative blood losses. Am J Obstet Gynecol 1996;176:723–6
21. Stancato-Pasik A, Mitty HA, Richard HM, Eshkar N. Obstetrics embolotherapy: effect on menses and pregnancy. Radiology 1997;204:791–3
22. Hsu YR, Wan YL. Successful management of intractable puerperal hematoma and severe postpartum hemorrhage with DIC through transcatheter arterial embolization – two cases. Acta Obstet Gynecol Scand 1998;77:129–31
23. Pelage JP, Le Dref O, Mateo J, et al. Life-threatening primary postpartum hemorrhage: treatment with emergency selective arterial embolization. Radiology 1998;208:359–62
24. Hansch E, Chitkara U, McAlpine J, El-Sayed Y, Dake MD, Razavi MK. Pelvic arterial embolization for control of obstetric hemorrhage: a five-year experience. Am J Obstet Gynecol 1999;180:1454–60
25. Pelage JP, Soyer P, Repiquet D, et al. Secondary postpartum hemorrhage: treatment with selective arterial embolization. Radiology 1999;212:385–9
26. Touboul C, Badiou W, Saada J, et al. Efficacy of selective arterial embolisation for the treatment of life-threatening post-partum haemorrhage in a large population. PLoS ONE 2008;3:e3819
27. Ojala K, Perälä J, Kariniemi J, Ranta P, Raudaskoski T, Tekay A. Arterial embolization and prophylactic catheterization for the treatment for severe obstetric hemorrhage. Acta Obstet Gynecol Scand 2005;84:1075–80
28. Kirby JM, Kachura JR, Rajan DK, et al. Arterial embolization for primary postpartum hemorrhage. J Vasc. Interv Radiol 2009;20:1036–45
29. Chauleur C, Fanget C, Tourne G, Levy R, Larchez C, Seffert P. Serious primary post-partum hemorrhage, arterial embolization and future fertility: a retrospective study of 46 cases. Hum Reprod 2008;23:1553–9
30. Deux JF, Bazot M, Le Blanche AF, et al. Is elective embolization of uterine arteries a safe alternative to hysterectomy in patient's with postpartum hemorrhage? Am J Roentgenol 2001;177:145–9
31. Ornan D, White R, Pollak J, Tal M. Pelvic embolization for intractable postpartum hemorrhage: long-term follow-up and implications for fertility. Obstet Gynecol 2003;102:904–10
32. Maassen MS, Lambers MDA, Tutein Nolthenius RP, van der Valk PHM, Elgrsma OE. Complications and failure of uterine artery embolization for intractable postpartum hemorrhage. Br J Obstet Gynaecol 2009;116:55–61
33. Uchiyama D, Koganemaru M, Abe T, Hori D, Hayaduchi N. Arterial catheterization and embolization for management of emergent or anticipated massive obstetrical hemorrhage. Radiat Med 2008;26:188–97
34. Tsuang ML, Wong WC, Kun KY, et al. Arterial embolisation in intractable primary post-partum haemorrhage: case series. Hong Kong Med J 2004;10:301–6
35. Boulleret C, Chahid T, Gallot D, et al. Hypogastric arterial selective and superselective embolization for severe postpartum hemorrhage: a retrospective review of 36 cases. Cardiovasc Intervent Radiol 2004;27:344–8
36. Eriksson LG, Mulic-Lutvica A, Jangland L, Nyman R. Massive Postpartum hemorrrhage treated with transcatheter arterial embolization: technical aspects and long-term effects on fertility and menstrual cycle. Acta Radiol 2007;48:635–42
37. Bloom AI, Verstandig A, Gielchinsky Y, Nadjari M, Elchalal U. Arterial embolisation for persistent primary post-partum haemorrhage: before or after hysterectomy? Br J Obstet Gynaecol 2004;111:880–4
38. Mukherjee S, Arulkumaran S. Post-partum haemorrhage. Obstet Gynaecol Reproductive Med 2009;19:121–6
39. Porteous AOR, Appleton DS, Hoveyda F, Lees CC. Acquired haemophilia and post-partum haemorrhage treated with internal pudendal embolisation. Br J Obstet Gynaecol 2005;112:678–9
40. Levine AB, Kuhlman K, Bonn J. Placenta acreta: comparison of cases managed with and without pelvic artery balloon catheters. J Matern Fetal Med 1999;8:173–6
41. Chou MM, Hwang JI, Tseng JJ, Ho ESC. Internal iliac artery embolization before hysterectomy for placenta accreta. J Vasc Interv Radiol 2003;14:1195–9
42. Diop AN, Chabrot P, Bertrand A, et al. Placenta acreta: management with uterine artery embolization in 17 cases. J Vasc Interv Radiol 2010;21:644–8
43. Porcu G, Roger V, Jacquier A, et al. Uterus and bladder necrosis after uterine artery embolisation for post-partum haemorrhage. Br J Obstet Gynaecol 2005;112:122–3
44. Bodner LJ, Nosher JL, Gribbin C, Siegel RL, Beale S, Scorza W. Balloon-assisted occlusion of the internal iliac arteries in patients with placenta accrete/percreta. Cardiovasc Intevent Radiol 2006;29:354–61
45. Finberg HJ, Williams JW. Placenta acreta: prospective sonographic diagnosis in patients with placenta previa and prior cesarean section. J Ultrasound Med 1992;11:333–43
46. Levine D, Hulka CA, Ludmir J, Li W, Edelman RR. Placenta acreta: evaluation with color Doppler US, power Doppler US, and MR imaging. Radiology 1997;205:773–6
47. Kirkinen P, Helin-Martikainen HL, Vanninen R, Partanen K. Placenta acreta: imaging by gray-scale and contrast-enhanced color Doppler sonography and magnetic resonance imaging. J Clin Ultrasound 1998;26:90–4
48. Maldjian C, Adam R, Pelosi M, Pelosi M III, Rubellis R, Maldjian J. MRI appearance of placenta percreta and placenta acreta. Magn Reson Imaging 1999;17:965–71
49. Lam G, Kuller J, McMahon M. Use of magnetic resonance imaging and ultrasound in the antenatal diagnosis of placenta acreta. J Soc Gynecol Investig 2002;9:37–40

50. Palacios Jaraquemada JM, Bruno CH. Magnetic resonance imaging in 300 cases of placenta acreta: surgical correlation of new findings. Acta Obstet Gynecol Scand 2005;84:716–24
51. Dwyer BK, Belogolovkin V, Tran L, et al. Prenatal diagnosis of placenta acreta: sonography or magnetic resonance imaging? J Ultrasound Med 2008;27:1275–81
52. Kidney DD, Nguyen AM, Ahdoot D, Bickmore D, Deutsch LS, Majors C. Prophylatic perioperative hypogastric artery balloon occlusion in abnormal placentation. Am J Roentgenol 2001;176:1521–4
53. Soyer P, Morel O, Fargeaudou Y, et al. Value of pelvic embolization in the management of severe postpartum hemorrhage due to placenta accreta, increta or percreta. Eur J Radiol 2010;doi:10.1016/j.ejrad.2010.07.018
54. Ito T. The Pelvis. In: Kaibougaku kougi Lectures in Anatomy, (in Japanese) 1st edn. Tokyo: Nanzando, 1983:475–84
55. Lippert H, Pabst R. Arterial Variations in Man: Classification and Frequency, 1st edn. Munich: Bergmann, 1985
56. Obimbo MM, Ogeng'o JA, Saidi H. Variant anatomy of the uterine artery in a Kenyan population. International J Gynecol Obstet 2010;111:49–52
57. Cottier JP, Fignon A, Tranquart F, Herbreteau D. Uterine necrosis after arterial embolization for postpartum hemorrhage. Obstet Gynecol 2002;100:1074–7
58. Hare WSC, Holland CJ. Paresis following internal iliac artery embolization. Radiology 1983;146:47–51
59. Has R, Balci NC, Ìblahimoğlu L, Rozanas Ì, Topuz S. Uterine artery embolization in a 10-week cervical pregnancy with coexisting fibroids. Int J Gynecol Obstet 2001;72:253–8
60. Kumar S, Souza JD, Indrajit IK, Mohindra V. Internal iliac artery embolization in post LSCS haemorrhage. Med J Armed Forces India 2006;62:198–9
61. Racker DC, Braithwaite JL. The blood supply to the lower end of the ureter and its relation to Wertheim's hysterectomy. J Obstet Gynaecol 1951;58:608–13
62. Chou MM, Ho ESC, Lee YH. Prenatal diagnosis of placenta previa accreta by transabdominal color Doppler ultrasound. Ultrasound Obstet Gynecol 2000;15:28–35
63. Comestock CH, Love JJ Jr, Bronsteen RA, et al. Sonographic detection of placenta accreta in the second and third trimesters of pregnancy. Am J Obstet Gynecol 2004;190:1135–40
64. Boulton H, Choji K, Pandit M. Embolization as first-line treatment in the management of puerperal haematoma in a case of congenital urogenital anomaly. Congenit Anom 2008; 48:48–50
65. Lee NK, Kim S, Kim CW, Lee JW, Jeon UB, Suh DS. Identification of bleeding sites in patients with postpartum hemorrhage: MDCT compared with angiography. Am J Roentgenol 2010;194:383–90
66. Nikolic B, Spies JB, Lundsten MJ, Abbara S. Patient radiation dose associated with uterine artery embolization. Radiology 2000;214:121–5
67. Wagner LK, Lester RG, Saldana LR. Exposure of the pregnant patient to diagnostic radiations: a guide to medical management, 2nd edn. Madison, WI: Medical Physics Publishing, 1997:88
68. Hunda W, Stone R. Review of Radiation Physics. Baltimore, MD: Williams & Williams, 1995:85
69. Descargues G, Mauger Tinlot F, Douvrin F, Clavier E, Lemoine JP, Marpeau L. Menses, fertility and pregnancy after arterial embolization for the control of postpartum haemorrhage. Human Reproduction 2004;19:339–43
70. Salomon LJ, de Tayrac R, Castaigne-Meary V, et al. Fertility and pregnancy outcome following pelvic arterial embolization for severe post-partum haemorrhage. A cohort study. Hum Reprod 2003;18:849–52
71. Lobel SM, Meyerovitz MF, Benson CC, Goff D, Bengtson JMB. Preoperative angiographic uterine artery embolization in the management of cervical pregnancy. Obstet Gynecol 1990;76:938–41
72. Simon P, Donner C, Delcour C, Kirkpatrick C, Rodesch F. Selective uterine artery embolization in the treatment of cervical pregnancy: two case reports. Eur J Obstet Gynecol 1991;40:159–61
73. Ryu KY, Kim SR, Cho SH, Song SY. Preoperative uterine artery embolization and evacuation in the management of cervical pregnancy: report of two cases. J Korean Med Sci 2001;16:801–4
74. Ratnam LA, Gibson M, Sandhu C, Torrie P, Chandraharan E, Belli AM. Transcatheter pelvic arterial embolisation for control of obstetric and gynaecological haemorrhage. J Obstet Gynaecol 2008;28:573–9
75. Takeda A, Koyama K, Imoto S, Mori M, Nakano T, Nakamura H. Conservative management of placenta increta after first trimester abortion by transcatheter chemoembolization: a case report and review of the literature. Arch Gynecol Obstet 2010;281:381–6
76. Soleymani Majd H, Srikantha M, Majumdar S, B-Lynch C, Choji K, Canthaboo M, Ismail L. Successful use of uterine artery embolization to treat placenta increta in the first trimester. Arch Gynecol Obstet 2009;279:713–5