INTERVENTIONAL RADIOLOGY
Official journal of the Japanese Society of Interventional Radiology and Asia Pacific Society of Cardiovascular and Interventional Radiology

REVIEW

Transcatheter Arterial Embolization for Hemorrhagic Pelvic Fracture: Review Article

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Abstract:
Pelvic fractures are severe trauma that can cause hemorrhagic shock. The mortality rate is high when patients fall into shock. Therefore, prompt diagnosis and treatment are necessary. Hemostasis for hemorrhage associated with pelvic fractures is achieved through the mechanical stabilization of the fracture site, preperitoneal pelvic packing, and transcatheter arterial embolization. These techniques are frequently employed in hemodynamically unstable patients presenting with pelvic fractures. Among them, transcatheter arterial embolization is often considered the first-line choice: it is a particularly effective hemostatic method for arterial hemorrhage caused by pelvic fracture. An embolization technique and embolic agents should be considered comprehensively while considering the patient's hemodynamics, angiographic findings, and the urgency of the situation. This article describes the indications, techniques, results, and complications of transcatheter arterial embolization for pelvic fractures.

Keywords:
embolization, pelvic fracture, hemorrhage, hemostasis, hemodynamics

Interventional Radiology 2024; 9(3): 156-163
https://doi.org/10.22575/interventionalradiology.2023-0015
https://ir-journal.jp/

Introduction

Pelvic fractures are often caused by high-energy trauma such as a traffic accident or fall from height. Pelvic fractures cause massive retroperitoneal hemorrhage. They can easily lead to hemorrhagic shock. The mortality rate for pelvic fracture patients associated with shock is as high as 40%-50% [1-4]. More than 50% of patients with pelvic fractures have other site injuries [5, 6]. Moreover, more than 40% have associated thoracic and abdominal organ injuries, which can be sources of life-threatening hemorrhage [7]. Therefore, prompt diagnosis and treatment are necessary.

The sources of bleeding in cases of pelvic fracture are bones, veins, and arteries. Eighty percent of the bleeding originates in veins and bones, and 20% in arteries [8, 9]. However, 44%-67% of pelvic fractures with shock reportedly result from arterial bleeding [10]. Mechanical stabilization with external pelvic fixation or temporary external fixation devices is often used for bleeding from the fracture site. Preperitoneal pelvic packing is often used for venous bleeding. Transcatheter artery embolization (TAE) is often used for arterial bleeding. For patients with unstable pelvic fractures, it is common to use these techniques in combination. In fact, the success rate of TAE for pelvic fractures is high: 74%-100% [11]. Moreover, some reports have described improved survival rates with early TAE [3, 12]. TAE plays a fundamentally important role in hemostasis for pelvic fractures. In this article, we specifically describe TAE for pelvic fractures.

Vascular Anatomy

It is crucially important to elucidate the arterial anatomy of the pelvic region when performing TAE. The abdominal aorta divides into the left and right common iliac arteries at the level of the fourth lumbar vertebra. The common iliac artery divides at the lower edge of the fifth lumbar vertebra into the internal iliac artery (IIA), running posteriorly medial, and the external iliac artery, running anterolaterally. In addition, the median sacral artery branches from the dorsal side just above the aortic bifurcation. The IIA is divided into two major branches: the visceral branch, which is distributed to the pelvic organs, and the parietal branch, which is distributed to the body wall. The visceral branches include the

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Received: February 27, 2023, Accepted: August 5, 2023, Advance Publication by J-STAGE: February 8, 2024

inferior vesical artery, middle rectal artery, and uterine artery. The parietal branches include the iliolumbar artery, lateral sacral artery, superior gluteal artery, inferior gluteal artery, obturator artery, and internal pudendal artery. However, the branches of the external iliac artery include the inferior epigastric artery and deep circumflex iliac artery.

The blood vessels in the pelvis are abundant in collateral circulation (**Fig. 1**). For example, the iliolumbar artery forms an anastomosis with the lumbar artery and deep circumflex iliac artery; the obturator artery, with the inferior epigastric artery and medial circumflex femoral artery; the median sacral artery, with the lateral sacral artery; and the inferior gluteal artery, with the lateral circumflex femoral artery.

The artery responsible for bleeding in pelvic fractures is often the IIA and its branches [11, 13-16]. By contrast, the branches of the external iliac artery and common femoral artery are also involved in bleeding [17, 18]. As described above, the pelvic vessels are rich in collateral circulation. They require careful attention. Furthermore, corona mortis and persistent sciatic arteries are often overlooked. Although the definition of corona mortis varies in literature, it is usually defined as the anastomosis between the pubic branch of the obturator artery and inferior epigastric artery. Each artery and each vein are regarded as having a corona mortis, with 17% of arteries and 41.7% of veins having a corona mortis [19]. The persistent sciatic artery is a vascular anomaly in which the sciatic artery, the main feeding artery of the lower extremities during the embryonic period, is left behind without disappearing during development. The incidence of persistent sciatic artery is 0.03%-0.06%. Approximately one-third of persistent sciatic artery cases are bilateral [20].

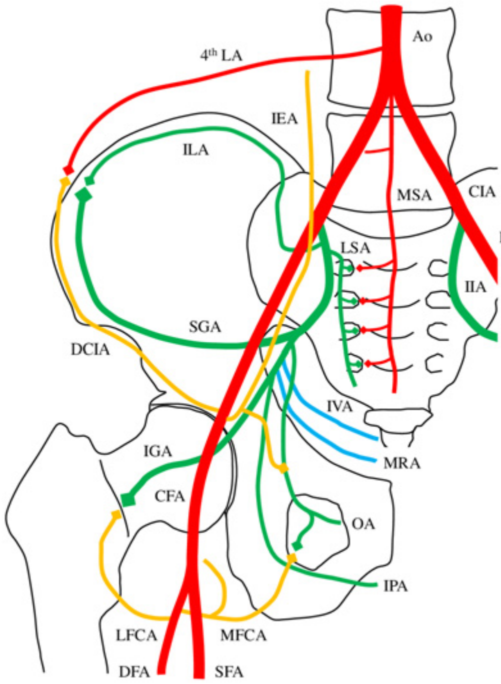

Figure 1. Arteries and collateral circulation in the pelvic region. Ao, aorta; CFA, common femoral artery; CIA, common iliac artery; DCIA, deep circumflex iliac artery; DFA, deep femoral artery; EIA, external iliac artery; 4th LA, fourth lumbar artery; IEA, inferior epigastric artery; IGA, inferior gluteal artery; IIA, internal iliac artery; ILA, iliolumbar artery; IPA, internal pudendal artery; IVA, inferior vesical artery; LFCA, lateral circumflex femoral artery; LSA, lateral sacral artery; MFCA, medial circumflex femoral artery; MRA, middle rectal artery; MSA, median sacral artery; OA, obturator artery; SFA, superficial femoral artery; SGA, superior gluteal artery

Classification

A classification of pelvic fractures used widely around the world is the Young-Burgess classification (**Table 1**) [21]. The Young-Burgess classification system divides pelvic fractures by the direction of the external force: anteroposterior compression, lateral compression, vertical shear, and combined mechanism. Each type of fracture is also graded by severity. Multiple proposed management algorithms for pelvic fractures might vary among institutions. For example, The World Society of Emergency Surgery (WSES) has proposed a classification (**Table 2**) and management algorithm (**Fig. 2**) that combines the Young-Burgess classification with the patient's hemodynamics [22].

Predicting the injured vessels from the fracture pattern is possible. Anteroposterior compression fractures are often associated with vascular injuries in the posterior pelvic region, whereas lateral compression fractures are associated with vascular injuries in the anterior pelvic region [23]. Predicting the injured arteries from the fracture site is also possible to some degree.

In addition, predicting the damaged blood vessels from the fracture site is possible to a certain extent. For example, in the case of pubic bone or ischium fracture, the internal pudendal artery or obturator artery might be injured. In the case of ilium fracture, the iliofemoral artery or superior rectal artery might be injured. In the case of anterior superior iliac spine fracture, the external iliac artery or middle sacral artery might be injured.

Angiography and Embolization

Indication

TAE is a common hemostasis for arterial bleeding resulting from pelvic fractures [14, 24, 25]. In cases of pelvic fractures with unstable hemodynamics, where the pelvis is considered the primary source of bleeding, it might be necessary to perform TAE without obtaining a computed tomography (CT) image. In such cases, it is common to use adjuncts such as external pelvic fixation, preperitoneal pelvic packing, and resuscitative endovascular balloon occlusion of the aorta (REBOA) in combination with TAE.

If contrast-enhanced CT is performed and extravasation is observed, then TAE should be considered irrespective of the patient's hemodynamics [26-28]. Actually, TAE should also be considered in the presence of pseudoaneurysm, avulsion, or massive pelvic hematoma [28-30]. A large amount of retroperitoneal hematoma (>500 mL) on CT suggests a high

Table 1. Young–Burgess Classification for Pelvic Fractures.

Anteroposterior Compression
I. Symphysis diastasis < 2.5 cm
II. Symphysis diastasis > 2.5 cm, sacrospinous and anterior SI ligament disruption, results in rotational instability
III. Symphysis diastasis > 2.5 cm, with complete disruption of the anterior and posterior SI ligament, results in complete rotational and vertical instability
Lateral Compression
I. Sacral crush injury on the ipsilateral side
II. Sacral crush injury with disruption of posterior SI ligaments; iliac ring fracture may be present (crescent fracture); rotationally unstable
III. Severe internal rotation of ipsilateral hemipelvis with external rotation of contralateral side ("windswept" pelvis), rotationally unstable
Vertical Shear
Vertical displacement of symphysis and sacroiliac joints resulting in complete rotational and vertical instability
Combined Mechanism
Any combination of the above mechanisms

SI: sacroiliac

Table 2. World Society of Emergency Surgery Pelvic Injury Classification.

	WSES grade	Young–Burgess classification	Hemodynamic	Mechanic	CT-scan	First-line Treatment
Minor	Grade I	APC I–LC I	Stable	Stable	Yes	NOM
Moderate	Grade II	LC II/III–APC II/III	Stable	Unstable	Yes	Pelvic Binder in the field ± Angioembolization (if blush at CT-scan) OM–Anterior External Fixation*
	Grade III	VS–CM	Stable	Unstable	Yes	Pelvic Binder in the field ± Angioembolization (if blush at CT-scan) OM–C-Clamp*
Severe	Grade IV	Any	Unstable	Any	No	Pelvic Binder in the field Preperitoneal Pelvic Packing ± Mechanical fixation ± REBOA ± Angioembolization

*: Patients hemodynamically stable and mechanically unstable with no other lesions requiring treatment and with a negative CT-scan can proceed directly to definitive mechanical stabilization. WSES, World Society of Emergency Surgery; LC, lateral compression; APC, anteroposterior compression; VS, vertical shear; CM, combined mechanism; NOM, nonoperative management; OM, operative management; REBOA, resuscitative endovascular balloon occlusion of the aorta

probability of arterial injury [31]. However, the absence of these findings does not rule out arterial injury [27, 32-34].

In addition to imaging findings, age, patient's coagulation cascade, medication history, past medical history, and patient hemodynamics are examined when making a comprehensive decision on the indication for TAE. Elderly patients have fragile muscles and soft tissues, which are less effective in compression hemostasis [35]. Moreover, they are more likely to take anticoagulants and/or antiplatelet drugs, which can cause massive hemorrhage without spontaneous hemostasis. Patients older than 60 years with major pelvic fractures, such as an open book, butterfly segment, and vertical shear, should be considered for TAE irrespective of the patient's hemodynamics [28, 36]. However, in young patients without a predisposition to hemorrhage, although they can be followed up closely, TAE can be considered if anemia progression or hemodynamic instability is observed.

Angiography and Embolization Technique

Access

In conditions of severe shock, systemic vascular spasms can make securing an arterial sheath difficult. If shock or transition to shock is expected, then do not hesitate to secure an arterial sheath, which can quickly initiate the procedure when TAE is needed or can provide an access route for REBOA [37-40]. In severe shock cases, TAE might be performed while occluding the aorta by inserting a REBOA catheter through one sheath. If the injury site can be determined to be solely pelvic bone fracture, then it is acceptable to occlude at zone III (in the infrarenal abdominal aorta). However, in many cases, there might be concurrent intra-abdominal visceral injuries such as liver and spleen injuries. In addition, because of the often incomplete understanding of the injury site, occlusion at zone I (in the descending thoracic aorta distal to the left subclavian artery) is typically used as the primary strategy.

Failure to secure an arterial sheath must be overcome

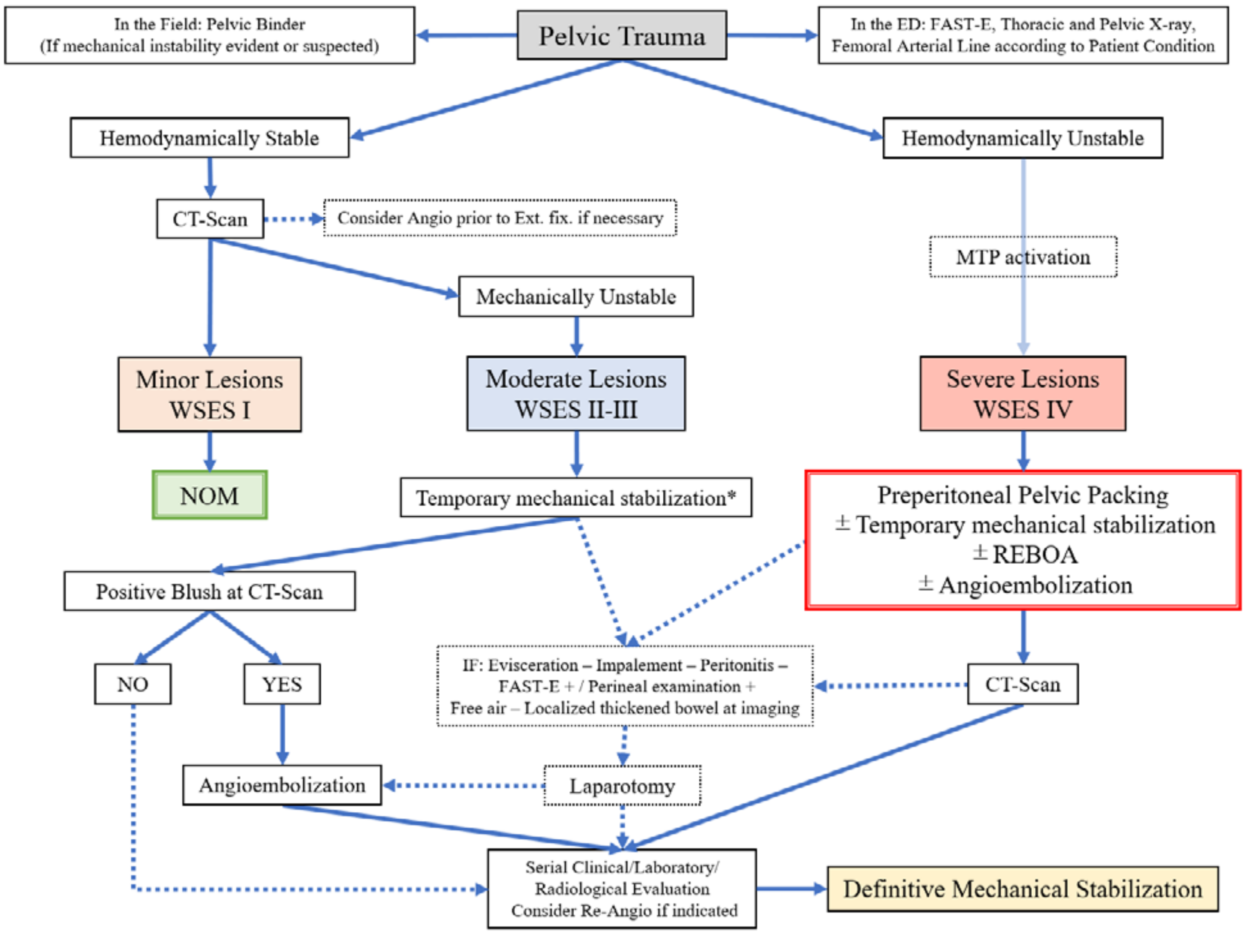

Figure 2. Pelvic trauma management algorithm.
*: Patients hemodynamically stable and mechanically unstable with no other lesions requiring treatment and with a negative CT-scan, can proceed directly to definitive mechanical stabilization. MTP, massive transfusion protocol; FAST-E, eco-FAST extended; ED, emergency department; CT, computed tomography; NOM, nonoperative management; REBOA, resuscitative endovascular balloon occlusion of the aorta. HEMODYNAMIC STABILITY is the condition in which the patient achieves a constant or amelioration of blood pressure after fluids with a blood pressure > 90 mmHg and heart rate < 100 bpm. HEMODYNAMIC INSTABILITY is the condition in which the patient has an admission systolic blood pressure < 90 mmHg or > 90 mmHg but requiring bolus infusions/transfusions and/or vasopressor drugs, admission base deficit (BD) >6 mmol/L, shock index > 1, or transfusion requirement of at least 4–6 units of packed red blood cells within the first 24 h.

quickly and reliably because failure to do so might not only engender more blood loss but also delay subsequent interventions or lead to the loss of endovascular treatment options such as TAE or REBOA. Three techniques can be used to secure the sheath: the blind/landmark technique, ultrasound-guided technique, and surgical cut-down technique [41-45]. Historically, the blind technique has been the mainstay of the puncture method, but it is unreliable. Moreover, complications such as hematoma and arteriovenous fistula (AVF) formation are common. The ultrasound-guided technique is recommended to secure a sheath accurately [42, 44].

Angiography and embolization technique

In cases with hemodynamic instability or when contrast-enhanced CT is performed before TAE, pelvic arteriography for mapping might be omitted. Especially in cases where a contrast-enhanced CT was taken before TAE, it is important to predetermine the location and branching angle of the IIA origin, identify potential vessels of injury, and plan the approach to an injured artery to avoid unnecessary imaging or contrast agent use.

Pelvic fractures often bleed from IIA branches [11, 13, 14]. First, the IIA on the affected side should be selected. If extravasation, pseudoaneurysm, avulsion, or AVF is observed, then embolization should be considered [29, 30]. Extravasation is a finding that is suggestive of active bleeding, but it is noteworthy that extravasation might not be apparent if the patient is in shock and the vessels are spastic. In addition, the presence or absence of persistent sciatic artery should be noted. In particular, the nonselective embolization of the IIA in the complete type, in which the persistent sciatic artery remains continuous with the popliteal artery, can cause lower extremity ischemia.

The decision for selective or nonselective embolization is based on a comprehensive evaluation of the patient's hemodynamics, angiographic findings, and level of urgency. In cases with hemodynamic instability, bilateral IIA embolization is the standard embolization technique [28, 46]. Even when multiple extravasations are present, when treatment of other sites is planned, or when a risk of coagulopathy exists, bilateral IIA embolization is the basic technique because of the need to complete the procedure quickly. However, arteries branching from proximal the IIA, such as the iliolumbar artery and lateral sacral artery, might not be sufficiently embolized from the main trunk of the IIA. They might require additional selective embolization.

In cases with hemodynamic stability, selective embolization might be attempted if time permits. In the case of pseudoaneurysm and AVF, selective embolization is the basic approach. However, the time to hemostasis should not be delayed by adhering to selective embolization. When selective embolization is performed, especially for the visceral branches and parietal branches distributed in the medial pelvis, anastomosis with the contralateral IIA should be considered. Additional contralateral embolization should be performed if necessary. However, when selective embolization is performed on parietal branches distributed in the lateral pelvis such as the superior and inferior gluteal arteries, unilateral embolization might be sufficient but attention must be devoted to anastomosis with the branches of the external iliac artery and lumbar artery.

After embolization, pelvic arteriography is performed. At this time, the imaging range includes the level of the third lumbar vertebra on the cranial side and the level of the bifurcation of the superficial femoral artery and the deep femoral artery on the caudal side. The effect of embolization should be confirmed. Additional embolization should be performed if necessary.

The sheath should be left in place in case postoperative rebleeding should occur [28, 47]. TAE is also useful for rebleeding. It is therefore necessary to be prepared and willing to redo TAE.

Embolic Agents

Common embolic agents include gelatin sponge (GS), metallic coils, and n-butyl-2-cyanoacrylate (NBCA).

GS is a temporary embolic agent that dissolves. The vessel reopens within 1-3 weeks. The hemostatic efficacy of GS is dependent on the patient's coagulation cascade. Actually, GS has the ability to expedite embolization procedures. Moreover, it is beneficial for the management of multiple bleeding sites. GS is used in small fragments created through either pumping or cutting methods. Under circumstances where the pumping method is employed, the size of GS fragments can vary considerably [48], potentially resulting in peripheral or proximal embolization. When cutting, GS fragments can be tailored to the appropriate size for the specific vessel requiring hemostasis.

Metallic coils serve as a permanent embolic agent. Hemostatic efficacy is contingent upon the patient's coagulation cascade. Meticulous utilization of metallic coils is prevalent in pseudoaneurysms, AVF, and avulsions [49].

NBCA is a liquid embolic agent that is used frequently in coagulopathy cases because it operates independently of the patient's coagulation cascade [50-52]. During radiographic fluoroscopy, NBCA is not visible, and it is often mixed with a contrast agent, such as Lipiodol, to improve visibility. The mixing ratio of NBCA and Lipiodol should be adjusted based on the type of occlusion being treated. For short-segment occlusions, the amount of Lipiodol mixed with NBCA should be decreased, whereas for long-segment occlusions, the amount of Lipiodol should be increased. This adjustment ensures that the mixture is optimal for the specific occlusion being treated and improves the accuracy and effectiveness of the treatment. Therefore, it is crucial to consider the appropriate mixing ratio of NBCA and Lipiodol when performing embolization procedures to achieve optimal outcomes. The potential for catheter adherence within the vessel or overflow with subsequent embolization outside the target vessel exists, and proficiency in its utilization necessitates appropriate training and experience [30].

When performing TAE for pelvic fractures, GS is frequently considered the primary embolic agent. However, in severe coagulopathy, GS tends to induce recanalization, even following injection. GS is often used to provide additional embolization for recanalization. Metallic coils and NBCA might also be used. In the case of pelvic fractures with hemodynamic instability, embolization with NBCA from the main trunk of the IIA might be unavoidable because of marked coagulopathy [53]. However, the usefulness and safety of this approach have not been well established.

Effectiveness

The technical success rate of TAE for pelvic fractures is 90%-100% [24, 49, 54-56]. The clinical success rate in terms of improving vital signs and reducing transfusion demand is 84%-100% [15, 49, 55]. The repeat angiography rate for rebleeding is 0%-23% [47, 55, 57, 58]. The repeat embolization rate is 11.3%-40% [57-60]. The mortality rate for patients undergoing TAE is 4%-56% [5].

A crucially important determinant of patient outcomes in cases of pelvic fractures is the interval between hospital admission and initiation of angiography and embolization. Mortality rates are reportedly 16% when the time from arrival to angiography is less than 60 min, and 64% when the time is 60 min or more [61]. Furthermore, every one-hour delay in time to embolization is estimated to increase in-hospital mortality by 1.79 times [62]. On the basis of those findings, expeditious hemostasis is of paramount importance. It is imperative to activate the interventional radiology team as early as possible and to initiate and complete TAE as soon as feasible [63]. Coordination and cooperation among multidisciplinary teams, including not only interventional radiologists but also trauma surgeons, orthopedic surgeons, anesthesiologists, emergency physicians, nurses, and radiological technologists, are indispensable for the management of severe pelvic fractures.

Complications

The complications associated with TAE for pelvic fractures include gluteal ischemia and necrosis, erectile dysfunction, and neuropathy, in addition to the common complications of endovascular treatment such as hypersensitivity reactions to the contrast agent and hematoma formation at the puncture site.

The prevalence of gluteal necrosis following TAE for pelvic fractures has been reported as 3.3%-9.4% from various studies [30, 64, 65]. Furthermore, the mortality rate in cases of gluteal necrosis is reported as a staggering 60%, with fatal outcomes [66]. The results of several studies have suggested that TAE significantly increases the incidence of gluteal necrosis [67-69]. In particular, the use of metallic coils as an embolic agent has been noted as increasing the risk of gluteal necrosis [64]. GS is often the preferred embolic agent. However, when prepared using the pumping method, the fragment sizes are not uniform [48], which might engender peripheral embolization, thus increasing the risk of gluteal necrosis. The risk of gluteal necrosis can be mitigated by adjusting the GS size to a uniform size using the cutting method and by embolizing from the bilateral IIA main trunks [66, 70]. Some reports have suggested that gluteal necrosis might not be related directly to TAE [71] but rather to the direct external force to the gluteal region as a result of trauma, prolonged shock, and the use of vasopressors [66, 70]. Erectile dysfunction is frequently observed following bilateral embolization [72], but it is believed to be a consequence of the underlying trauma rather than the embolization procedure itself [73-75]. Similarly, neuropathic symptoms such as lower extremity paresthesia and paresis do not differ significantly according to the use of embolization and nonembolization techniques [6, 73].

Conclusion

TAE is an efficacious method for achieving hemostasis in cases of arterial hemorrhage resulting from pelvic fracture. The selection of the embolization technique and embolic agents should be made in a comprehensive manner, considering the patient's hemodynamics, angiographic findings, and the urgency of the situation.

Acknowledgement: No grant or other assistance was received for this article.
Conflict of Interest: None
Author Contribution: All authors (R.U. and H.K.) meet the International Committee of Medical Journal Editors (ICMJE) criteria for authorship and take responsibility for the content of the article.
Disclaimer: Hiroshi Kondo is one of the Editorial Board members of Interventional Radiology. This author was not involved in the peer-review or decision-making process for this paper.

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