Trauma Radiology

Yukichi Tanahashi, M.D., Masayuki Matsuo, M.D.
From the Department of Radiology, Gifu University School of Medicine, Japan

Introduction

The vital statistics by Japanese Ministry of Health, Labour and Welfare demonstrates that the mortality rate for unintentional injuries has not decreased in the last decades (33.2 per 0.1 million) [1]. In worldwide, the overall trauma-related mortality has increased by 24% from 1990 to 2010 [2]. A previous report showed that an increase in the age of trauma patients, motor vehicle collisions, and falls likely contributed to the global rise in trauma mortality [3]. On the other hand, Oyeniyi et al reported the significant reduction of trauma mortality was seen at an urban level 1 trauma center, attributable to decreased hemorrhagic death [4]. This report indicates that the efforts focused on hemorrhage control intervention may result in the reduction of trauma mortality.

Trunkey first described the tri-model pattern of trauma deaths over 30 years ago [5]. The half of trauma deaths were occurred in the 1st period within an hour (immediate death). The 30% of trauma deaths were occurred in 2nd period (few hours after injury). The trauma deaths in 2nd periods were mainly due to intracranial bleeds and exsanguination. And the rest of trauma deaths were occurred in the 3rd period (days to weeks) due to infection, multiple organ failure, or both. However, a recent research has shown that this pattern of distribution no longer exists. Demetriades et al reported that there are two distinct peaks of deaths: the first peak (50.2% of trauma deaths) within the first hour of injury and the second peak (18.3% of trauma deaths) from 1 to 6 hours after admission [6]. Oyeniyi et al showed that the distribution of trauma deaths showed unimodal distribution with 26% of deaths occurring within the first hour. They also reported that 81% of hemorrhage related deaths occurring in the first 24 hours and the median time to death was 1.7 hours [4]. This implies that efforts in controlling the hemorrhage would contribute to the decrease of trauma mortality.

The development of endovascular interventions and surgical treatments have changed the treatment strategy for trauma that is a paradigm shift from operative to non-operative management, including embolization for hemodynamically stable and some of hemodynamically unstable blunt trauma patients [7-10]. The embolization and surgical treatments are not competitive and are complementary treatments with each other. Recently, the efficacy of hybrid treatment combining embolization and surgery was reported [11, 12]. Another endovascular intervention for trauma is the resuscitative endovascular balloon occlusion of the aorta (REBOA) for temporal control of abdomino pelvic hemorrhage.

To provide best trauma care, the multidisciplinary team organization, comprising an emergency physician, general surgeon, anesthesiologist, orthopedic trauma surgeon, radiologist, IR physician, and paramedics, is mandatory. Because the availability of IR and surgery is different among the institutions, it is imperative to develop own treatment strategy and team at each institution.

Trauma induced coagulopathy and embolic material choice

Severely injured patients easily lapse into coagulopathy. Trauma induced coagulopathy is called DIC with the fibrinolytic phenotype, which is characterized by the activation of coagulation, consumption coagulopathy, insufficient control of coagulation, and increased fibrinolysis [13]. This type of coagulopathy induces oozing-type non-surgical bleeding and significantly affects the patients' prognosis [13]. The acidosis, hypothermia, and hemodilution by fluid or transfusion are the factors which modify the coagulopathic condition.

It is imperative for IR physicians to evaluate the coagulability because the embolic material should be changed based on patient's coagulopathic condition. The embolic materials frequently used for embolization in trauma care are gelatin sponge particle, metal coils, and n-butyl-Cyanoacrylate (NBCA). Gelatin sponge particle is basically the first choice of embolic material. Metallic coil is mainly used for the treatment of pseudoaneurysm or avulsed artery. Since these embolic materials are depend on patients' coagulability, these are effective in the patient who does not have coagulopathy. On the other hand, n-butyl-Cyanoacrylate (NBCA) polymerizes rapidly once it contacts with blood and embolizes immediately, so that it is effective even in the patients with coagulopathy. Therefore, in the severely injured patients, the embolization using NBCA should be considered.

Blunt abdominal trauma

The embolization is life-saving procedure in abdominopelvic hemorrhage, reducing relevant mortality rates and contribute to the increase of non-operative management (NOM) success rate.

The spleen is the most frequently affected organ, followed by the liver, kidney, pancreas and a hollow viscus. The management of splenic injury is a big issue for trauma care, because it causes massive intraperitoneal hemorrhage. Although splenectomy remains the gold standard for the most of patients with splenic injuries who are hemodynamically unstable, NOM has become common treatment option in patients who are hemodynamically stable and even in some of hemodynamically unstable patients. Because of the future risk for overwhelming post-splenectomy infections (OPSI), NOM should be chosen as far as possible.

The splenic artery embolization (SAE) could be proximal (splenic artery) and distal (selective) or combined. Ierardi et al reported that proximal embolization was

performed significantly more often than distal embolization (601 patients vs 144 patients; 64% vs 15.33%) [9]. A combination of both technique was applied in 30 patients (3.19%) [9]. They also reported that the most common embolic materials were coils or gelatin sponge particles, followed by vascular plug and coils or PVA particle [9]. There are limited evidences which embolization method would be better. Previous reports which compare the proximal and distal embolization revealed that there is no significant difference between two techniques regarding clinical failure and major complications [14, 15]. The minor complications occurred significantly more often after distal embolizaition than proximal [14].

Since it is difficult to perform re-intervention after proximal embolization for re-bleeding or delayed hemorrhage due to traumatic pseudoaneurysm, distal embolization is preferred in Japan **(figure1)**. In addition, proximal embolization may cause pancreatic ischemia. Although the risk of splenic infarction is higher with distal embolization, the infarctions caused by distal embolization is limited, which rarely results in a splenectomy.

The liver is the second most frequent affected organ **(figure2)**. The majority of patients with blunt hepatic trauma can be successfully managed by NOM. Embolization is indicated for patients who showed extravasation of contrast media on contrast enhanced CT or angiography. Ierardi et al reported that the embolic materials used were coils, gelatin sponge, and PVA. The mean clinical success rate was 79.8% [9]. When the hepatic vein, inferior vena cava, or portal vein injury are suspected, surgical repair should be considered.

Pelvic trauma

Blunt pelvic trauma is a severe condition that often results in massive hemorrhage and has high mortality and morbidity. Pelvic radiographic imaging is a useful screening tool to rapidly determine the need for immediate intervention. In the patients who are hemodynamically stable, contrast enhanced CT is the standard imaging modality to assess the pelvic fractures, retroperitoneal hematomas, and active bleeding. Immediate and appropriate multimodality therapies including external pelvic stabilization, embolization, and extra-peritoneal pelvic packing, REBOA are effective. Embolization for pelvic trauma is considered in the following situation; hemodynamically unstable, extravasation of contrast media on contrast enhanced CT, and elderly (>60 years old) **(figure3)**. The embolization for pelvic fracture can be proximal (internal iliac artery), distal (selective), or combined. The embolic materials must be chosen based on patients' condition. In the review, gelatin sponge and coils are the most commonly used materials. Coils and vascular Amplatzer plugs are frequently used for targeted embolization of distal vessels. NBCA may be considered for very distal vessels and can be used in case of re-bleeding [10]. In hemodynamically stable patients, selective embolization with GS can control the bleeding. On the contrary, bilateral internal iliac

artery embolization with GS or NBCA may be required in hemodynamically unstable patients. Treatment success in the form of non-requirement for subsequent intervention has reported rates up to 95% [9, 10].

Embolization in Damage Control Strategy

The concept of "damage control surgery" was first developed in the early 1980s in an attempt to reduce mortality in severely injured patients. It is now well known that trauma patients are more likely to lapse into the metabolic failures, such as coagulopathy, hypothermia and metabolic acidosis, resulting in the increase of hemorrhage. These metabolic failures are called "lethal triad". Trauma patients with these metabolic failures cannot go through the complex operations such as formal hepatic resection or pancreaticoduodenectomy. Damage control surgery is a multi-step strategy focused on restoring hemodynamics and prevent the metabolic failures, rather than complete fixation of injury. Once metabolic failures are corrected, the definitive surgical procedure can be carried out as necessary.

Because embolization has become applied to the treatment of some of hemodynamically unstable patients [16], the concept of "damage control" should be applied to endovascular treatment too. Embolization for the hemodynamically unstable patients should focus on the stabilization of patients' hemodynamics, so that the proximal and extensive embolization are permissible to shorten procedure time. On the other hand, in hemodynamically stable patients, the embolization should focus on complete, selective, and less-invasive procedure. IR physicians have to evaluate the adequate procedure time and embolization method based on patients' hemodynamic status, metabolic condition, and coagulability.

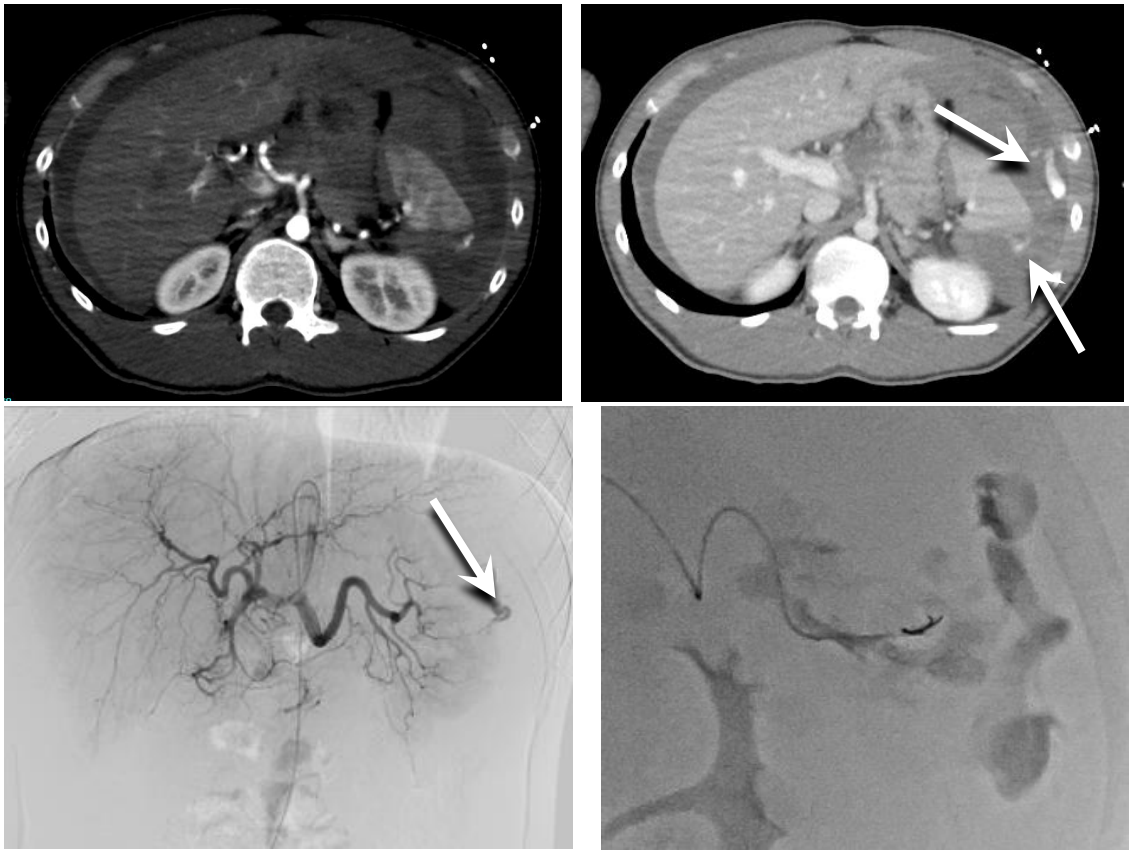
Equipment preparation and team organization

Because the availability of IR physicians, equipment, and surgeons differ among the institutions, it is difficult to make the guideline for treatment strategy and team organization. It is important to make efforts to provide better trauma care at each institution, including 24-7 IR physician on-call system, early activation of IR team [17], and the precompose packing of IR equipment required to standard procedure.

Summary

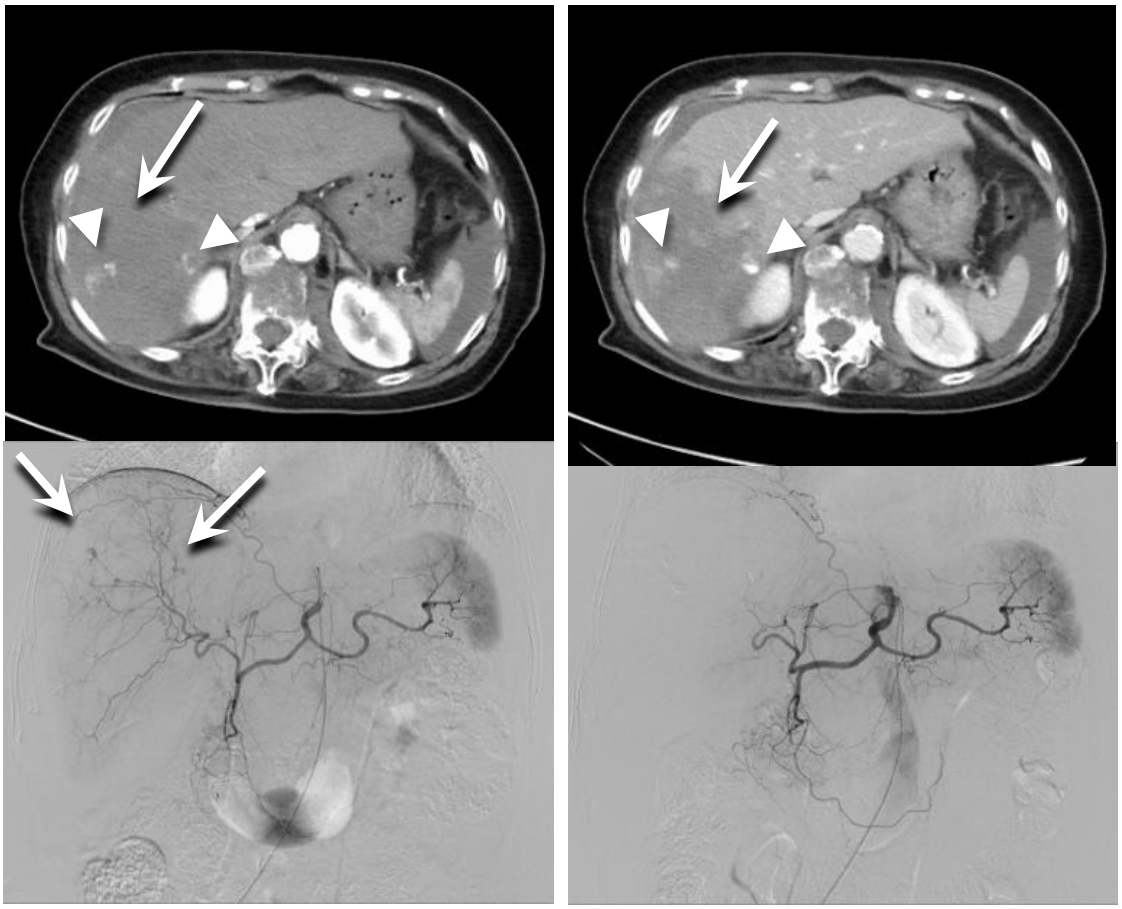
Endovascular treatment has become the essential intervention for trauma patients, including some of hemodynamically unstable patients. The trauma patients easily collapsed into consumptive coagulopathy, resulted in the increase of hemorrhage. The embolic material and the range of embolization should be decided on site based on patients' hemodynamics, coagulability, and injury grade. To provide good trauma care, the multidisciplinary team organization is crucial. This lecture focuses on expanding the

knowledge of these strategies and the demonstration of representative cases for understanding the time-conscious procedures of emergent embolization in trauma care.



a | b
c | d

Fig1. A 22-year-old man with grade IIIa splenic injury from fall during snowboard.
(a, b) Dynamic contrast enhanced CT images showed the extravasation of contrast media (arrows) adjacent to the spleen.
(c) Celiac arteriogram showed a extravasation corresponding to the CT finding (arrow).
(d) The splenic branch was embolized by GS and metal coils.



a	b
c	d

Fig2. A 83-year-old woman with grade IIIb hepatic injury from a fall.
(a, b) Dynamic contrast Enhanced CT images showed a massive deep injury (arrow) with extravasations (arrowheads).
(c) Celiac arteriogram showed a extravasations in the right upper liver parenchyma (arrows).
(e) Celiac arteriogram obtained after embolization with gelatin sponge particle showed the disappearance of pseudoaneurysm.

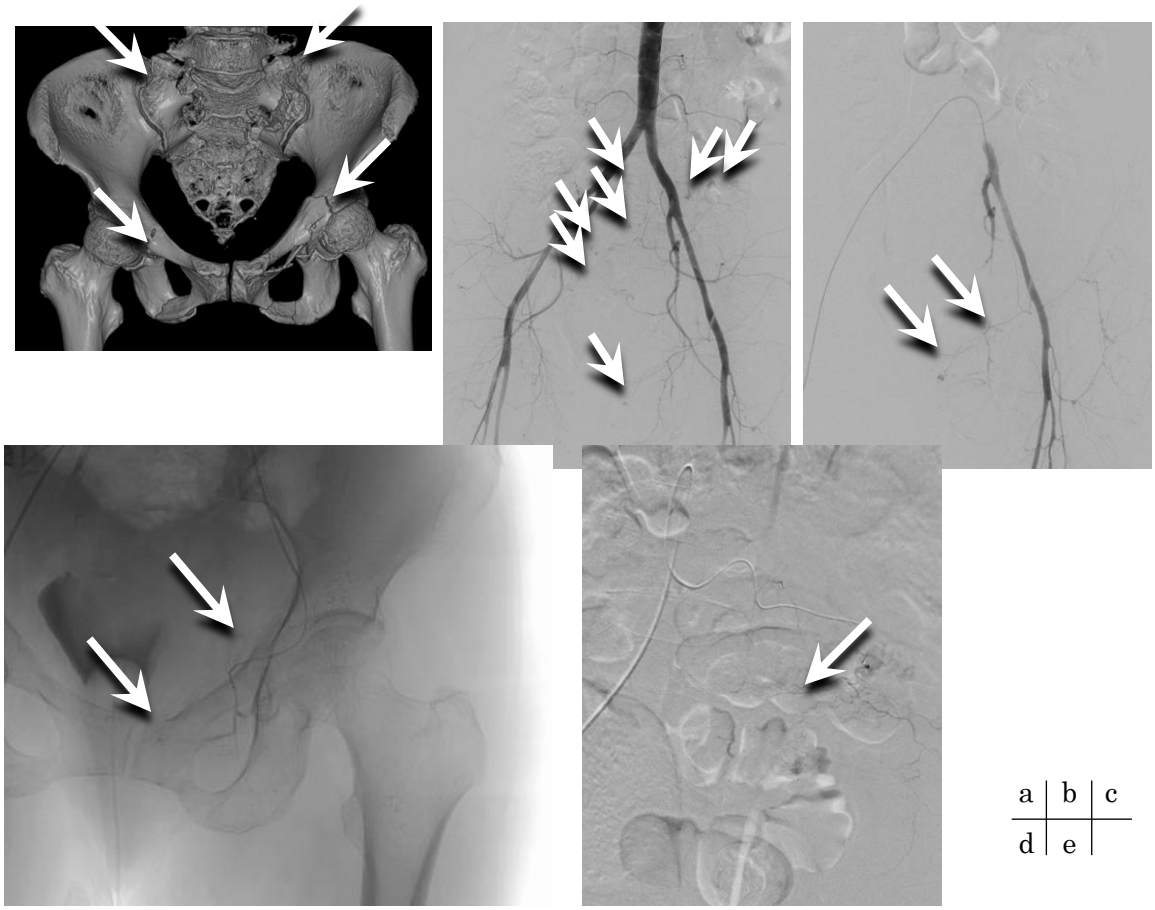


Fig3. A 71-year-old woman with grade III pelvic injury from a traffic accident.

(a) Pelvic X ray showed pelvic fractures in sacrum and pubis bilaterally (arrows).

(b) Pelvic arteriogram showed multiple extravasations (arrows).

(c) Left common iliac arteriogram obtained after the embolization of internal iliac arteriogram showed the extravsation adjacent to left pubis fracture via corona mortis (arrows).

(d) The corona mortis (arrows) was selectively embolized with gelatin sponge.

(e) Left lumbar arteriogram at the level of L5 showed the extravasation (arrows) and enbolized with gelatin sponge.

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