

Advantages of early intervention with arterial embolization for intra-abdominal solid organ injuries in children

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PURPOSE

Active bleeding due to abdominal trauma is an important cause of mortality in childhood. The aim of this study is to demonstrate the advantages of early percutaneous transcatheter arterial embolization (PTAE) procedures in children with intra-abdominal hemorrhage due to blunt trauma.

METHODS

Children with blunt abdominal trauma were retrospectively included. Two groups were identified for inclusion: patients with early embolization (EE group, n=10) and patients with late embolization (LE group, n=11). Both groups were investigated retrospectively and statistically analyzed with regard to lengths of stay in the intensive care unit and in the hospital, first enteral feeding after trauma, blood transfusion requirements, and cost.

RESULTS

The duration of stay in the intensive care unit was greater in the LE group than in the EE group (4 days vs. 2 days, respectively). The duration of hospital stay was greater in the LE group than in the EE group (14 days vs. 6 days, respectively). Blood transfusion requirements (15 cc/kg of RBC packs) were greater in the LE group than in the EE group (3 vs. 1, respectively). The total hospital cost was higher in the LE group than in the EE group (4502 USD vs. 1371.5 USD, respectively). The time before starting enteral feeding after first admission was higher in the LE group than in the EE group (4 days vs. 1 day, respectively).

CONCLUSION

Early embolization with PTAE results in shorter intensive care and hospitalization stays, earlier enteral feeding, and lower hospital costs for pediatric patients with intra-abdominal hemorrhage due to blunt trauma.

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Every year, 20 million children worldwide are exposed to unintentional trauma (1). In this population abdominal trauma is the third most common cause of death in children older than 1 year, after head and thoracic injuries (1). For these patients, active bleeding due to solid organ injury accounts for the majority of traumatic deaths (2). These traumas are usually from blunt force, with solid organ injuries occurring in 8% of patients (3). While nonoperative management is the standard approach in treatment of hemodynamically stable children (4), percutaneous transcatheter arterial embolization (PTAE) has been used effectively in hemodynamically unstable pediatric patients (5). Serial hematocrit, heart rate, arterial blood pressure, and urinary output should be monitored to determine whether the patient is hemodynamically unstable (5). A blood transfusion is often required during the nonoperative follow-up period (5).

The current standard approach in solid organ injury due to blunt abdominal trauma in pediatric patients is nonoperative management, when there is no ongoing bleeding (6). If there is ongoing bleeding, laparotomy or PTAE may be performed. The hemodynamic status of the patient is essential in the intervention decision (6). However, it is not always clear which of these two interventions is more appropriate (6).

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The treatment approach differs slightly according to the intra-abdominal organs damaged (6). Laparoscopy and laparotomy are recommended for severe pancreatic, aortic, diaphragmatic and intestinal injuries (6). In severe liver and spleen injuries, PTAE or laparotomy is recommended (6). PTAE is recommended if hemobilia is present (6). In severe renal injuries, internal or external drainage is recommended as well as PTAE or renal salvage surgery (6).

The aim of this study is to demonstrate the importance of early PTAE procedure in children with intra-abdominal hemorrhage due to blunt trauma, and show that embolization of damaged arteries detected during this procedure is very effective.

Methods

Patient inclusion criteria and classification

This retrospective study received the approval of the Ethics Committee of Scientific Research and Publications of our institute (2018/14-10). The records of all pediatric patients treated for blunt abdominal trauma between January 2015 and May 2018 were examined (Fig. 1). The inclusion criteria were: *i*) Grade IV and V solid organ injury; *ii*) PTAE due to blunt abdominal trauma; *iii*) ≤ 17 years of age; and *iv*) imaging examinations and all other relevant information available for review (5, 7).

Our study population included 21 patients with a mean age of 12. There were 13 boys (mean age, 9.6 ± 5.8 years; range, 1–17 years) and 8 girls (mean age, 11.2 ± 3.8 years; range, 5–16 years). The hospital records indicated that the same primary survey of trauma protocol was applied to each patient.

Main points

- Children with intra-abdominal hemorrhage due to solid organ injury from blunt trauma are shown to require intervention 3 hours after the first application to emergency room.
- In such cases, earlier intervention with PTAE produces improved results for the patient.
- We found that in patients with intra-abdominal hemorrhage, blood transfusion should be performed only if necessary; it does not need to be an obligatory intervention in every case.
- If PTAE is considered, it should be performed when a damaged artery is detected (even without extravasation).

Computed tomography

After vital signs were stabilized, the patients underwent abdominal computed tomography (CT) examination performed with a 256-slice CT scanner by Somatom Definition Flash® (Siemens Healthineers) with the following parameters: 35 mA, 100 kV; field of view, 277 mm; original slice thickness, 5 mm; reconstructed slice thickness, 1.25 mm. Ultravist® (iopromide, Bayer) 1–2 mL/kg was given intravenously before scanning. Any solid organ injury detected in the CT examination was graded according to the American Association of Trauma Surgery's organ injury score (Table 1) (8). CT examination was performed by two different radiologists with 16 and 11 years of experience in pediatric radiology, respectively.

Patient classification

Patients without active bleeding reported by clinical, laboratory, and radiologic evaluation were treated nonoperatively, even if they had a solid organ injury. The volume of intravenous fluid administered was monitored to control urine output at 1–2 mL/kg per hour. During follow-up, 15 mL/kg of erythrocyte suspension (RBC packs) was given intravenously over the course of 3 hours for patients with hematocrit values $\leq 24\%$. Patients with abdominal tenderness on physical examination, hemorrhage detected by laboratory findings, solid organ injury in the abdominal CT of grade 4 and above,

and/or those requiring a total transfusion rate of 40 mL/kg were considered as being in a hemodynamically unstable condition. CT angiogram was not performed in hemodynamically unstable patients. Until February 2017, our standard procedure involved a wait-and-see approach in which the blood transfusion requirement of the patient was observed. If an average of 40 mL/kg blood transfusion was needed, and clinical, radiologic, and laboratory findings indicated bleeding, PTAE was performed.

Massive bleeding was suspected in two patients 3 hours after arrival to the emergency room, in February 2017. Primary survey protocol was applied, and the intervention decision was made. A kidney and a liver injury with damaged vascular structures were detected by angiographic examination after 3 hours. However, there were no active extravasations of the vessels. For that reason, the procedure was terminated without embolization. Later, these patients were subjected to angiography again, 12 hours after the first, due to suspected intra-abdominal hemorrhage. Active bleeding was detected from vascular structures that had previously been damaged but not extravasated. The vascular structures in the active extravasation site were embolized. Those patients were thought to have had no extravasations due to low blood pressure (5–10 mmHg lower than normal), and extravasations became active once their

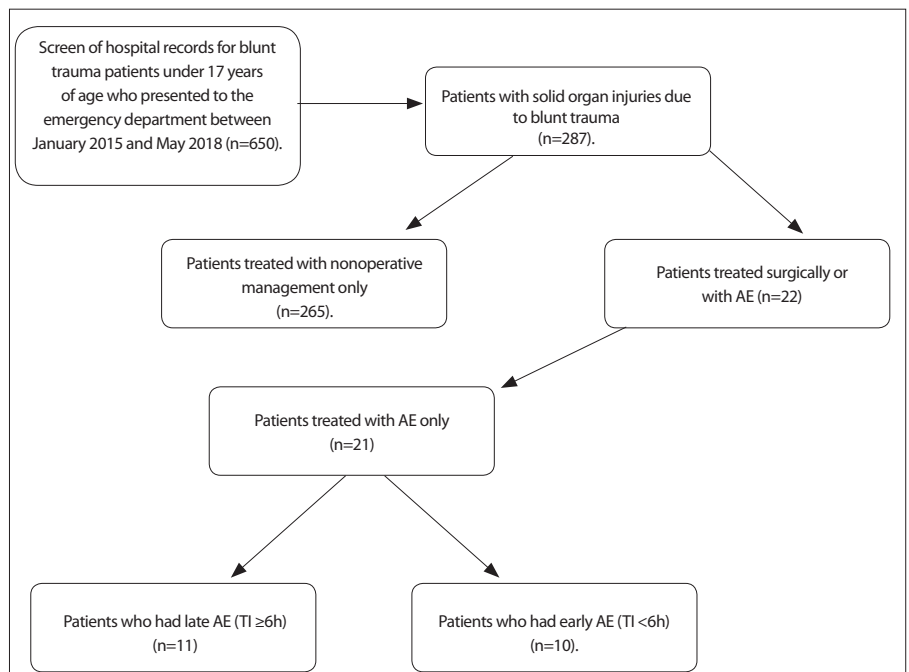


Figure 1. Flow chart of the retrospective review of the study. AE, arterial embolization; TI, time of intervention.

Table 1. Spleen, liver, and kidney injury scale according to CT imaging criteria

Grade	Spleen	Liver	Kidney
I	Subcapsular hematoma <10% surface area, parenchymal laceration <1 cm depth, capsular tear	Subcapsular hematoma <10% surface area, parenchymal laceration <1 cm depth	Subcapsular hematoma and/or parenchymal contusion without laceration
II	Subcapsular hematoma 10%–50% surface area; intraparenchymal hematoma <5 cm, parenchymal laceration 1–3 cm	Subcapsular hematoma 10%–50% surface area; intraparenchymal hematoma <10 cm in diameter, laceration 1–3 cm depth and ≤10 cm width	Perirenal hematoma confined to Gerota fascia, renal parenchymal laceration ≤1 cm depth without urinary extravasation
III	Subcapsular hematoma >50% surface area; ruptured subcapsular or intraparenchymal hematoma ≥5 cm, parenchymal laceration >3 cm	Subcapsular hematoma >50% surface area; ruptured subcapsular or parenchymal hematoma, intraparenchymal hematoma >10 cm, parenchymal laceration >3 cm depth, any injury in the presence of a liver vascular injury or active bleeding contained within liver parenchyma	Renal parenchymal laceration >1 cm depth without collecting system rupture or urinary extravasation, any injury in the presence of a kidney vascular injury or active bleeding contained within Gerota fascia
IV	Any injury in the presence of a splenic vascular injury or active bleeding confined within splenic capsule, parenchymal laceration involving segmental or hilar vessels producing >25% devascularization	Parenchymal disruption involving 25%–75% of a hepatic lobe, active bleeding extending beyond the liver parenchyma in to the peritoneum	Parenchymal laceration extending into urinary collecting system with urinary extravasation, renal pelvis laceration and/or complete ureteropelvic disruption, active bleeding beyond Gerota fascia into the retroperitoneum or peritoneum, segmental or complete kidney infarction(s) due to vessel thrombosis without active bleeding
V	Any injury in the presence of a splenic vascular injury with active bleeding extending beyond the spleen into the peritoneum, shattered spleen	Parenchymal disruption >75% of a hepatic lobe, juxtahepatic venous injury to include retrohepatic vena cava inferior and central major hepatic veins	Main renal artery or vein laceration or avulsion of hilum, devascularized kidney with active bleeding, shattered kidney with loss of identifiable parenchymal renal anatomy

blood pressure returned to normal after resuscitation. These two patients on whom the standard approach was applied were included in the late embolization group.

Thereafter, patients considered for the present study were those with these findings: hematocrit ≤29%, abdominal tenderness on physical examination, solid organ injury ≥ grade 4 on abdominal CT, clinical tachycardia (pulse rate over 139 bpm in 4-year-olds; over 119 bpm in 6-year-olds; 99 bpm in 7–17 year-olds) (9) and hypotension (minimum acceptable systolic blood pressure readings based on age: 70 mmHg + (2 × age in years) in children 1 to 10 years of age; 90 mmHg in children 10 years of age or older) (1), blunt trauma, and hemodynamic instability. The blood transfusion requirement was not used as a hemodynamic evaluation criterion in patients with blunt trauma. The intervention decision was based on clinical, laboratory, and radiologic findings indicating active bleeding. Embolization was performed when damaged vascular structures were detected, even if there were no extravasations.

Thus, two groups of patients were defined, according to when they underwent PTAE due to blunt intra-abdominal trauma.

Patient groups

Late embolization (LE) group included patients who were followed with the standard bleeding protocol and were subjected to intervention as a consequence (Fig. 2). Since the standard bleeding protocol was completed in 6 hours, this was used in the determination of the groups (10). Patients who underwent PTAE at least 6 hours after admission were in the LE group (Fig. 2). The PTAE procedure was applied to the LE group after primary survey, which included adequate blood and fluid resuscitation.

Early embolization (EE) group included patients who were treated with PTAE within the first 6 hours after admission (Fig. 2). Patients in the EE group suffered a grade 4 or higher solid organ injury and were considered hemodynamically unstable within 2 hours of admission (Fig. 2). The need for blood transfusion in these patients was not considered a hemodynamic evaluation criterion (Fig. 2). All patients included in the EE group had been administered fluid resuscitation for 2–3 hours before the PTAE procedure. There was no hypotension before PTAE in these patients,

although blood pressure values taken before the procedure were 5–10 mmHg below normal (11).

Application of PTAE

The LE and EE groups were initially subjected to the same procedure. The PTAE procedure was performed on the LE and EE groups with the same device (Siemens Artis Zee, Siemens Healthcare). Under sedation or general anesthesia in the radiology unit, the patient's body outside the abdominal area (head, neck, thoracic region, upper extremities and below the knees of the lower extremities) were covered with lead shields. The body of the specialist (head, thorax, abdomen, genital area and above the knees of the lower extremities) was covered with lead aprons. All patients underwent arterial entry from the right femoral artery for the PTAE procedure and ultrasonography. In all patients, the DAP (dose area product) range was between 11.25 Gy·cm² and 27.92 Gy·cm². First, a diagnostic arteriogram was taken with a suitable catheter. Embolization was performed in the LE group if extravasation or a pseudoaneurysm was detected. Embolization was performed in the EE

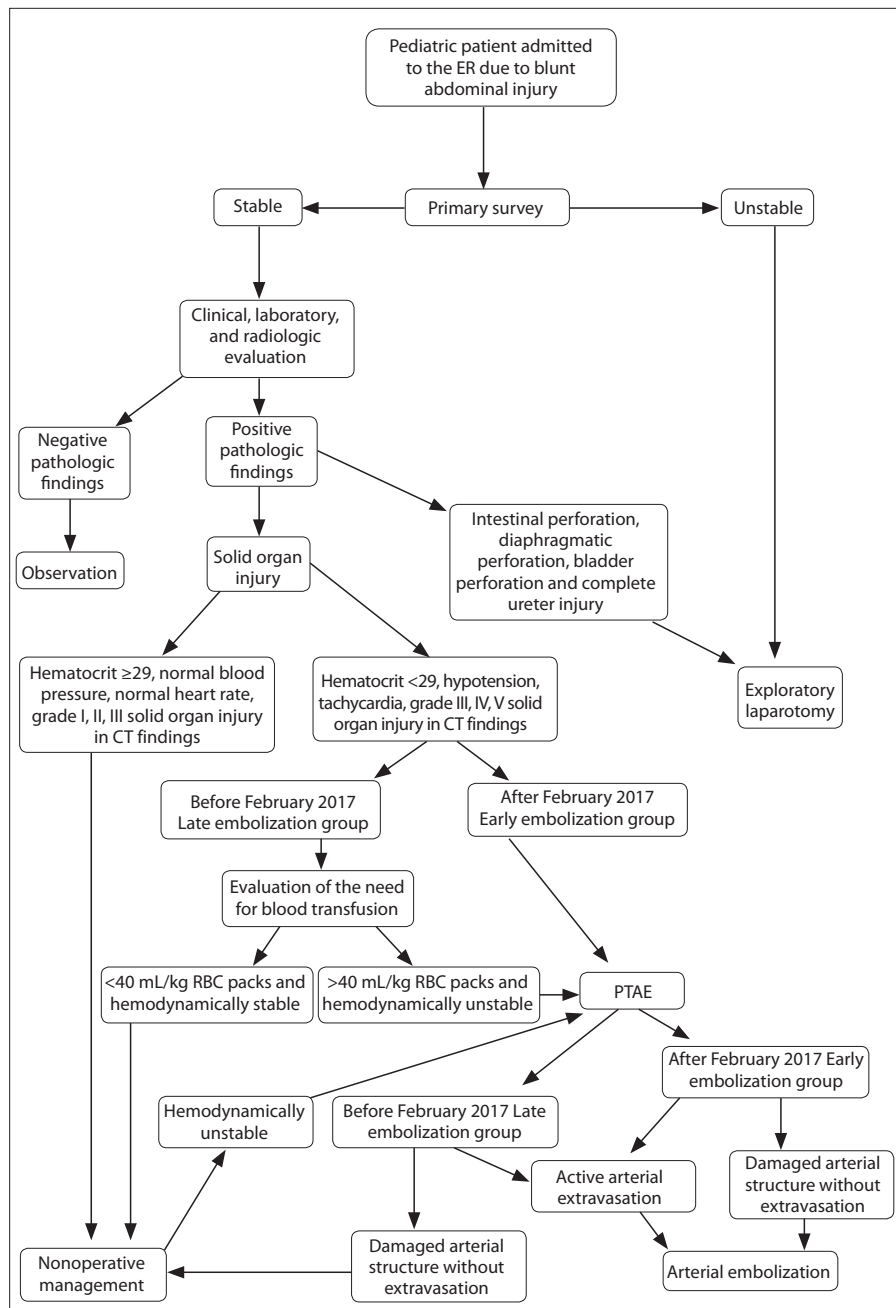


Figure 2. Algorithm for the management of pediatric patients admitted to the emergency department due to blunt abdominal trauma.

group if there was a damaged large vessel and there was no distal perfusion, even if there was no extravasation. A special catheter (Codman Prowler Select LP 2.3 F, Johnson&Johnson Medical) suitable for this procedure was used. The injured vessel was detected.

Blood flow in the artery was embolized using microparticles (Bead Block Pre-filled syringe 300–500 μm 1Unit Box, Biocompatibles) and metal coils (ev3 Bare Platinum Axiom Detachable Coil System, Micro Therapeutics). In

some cases, embolic agents (microparticles and metal coils) were used in combination to provide maximum hemostasis. Microparticles alone were used in the hemostasis of very small bleeding foci. Only the distal part of the damaged artery was embolized to optimize perfusion to the injured organ.

Follow-up

Both groups were investigated retrospectively and statistically analyzed with regard to mean intensive care unit and hospital

stays, first enteral feeding after trauma, RBC pack transfusion requirements, and costs.

The follow-up of patients after embolization was the same in both groups. Close monitoring of complete blood count, hourly blood pressure measurements, continuous pulse and blood oxygen saturation monitoring, close clinical examination, hourly urine output measurements were done. Hematocrit values were measured at intervals of 6 hours (6). If there were no clinical or laboratory findings related to bleeding 4–18 hours after PTAE procedure was performed, enteral feeding was begun (6). The patients were discharged, on average, 1 week after their vital laboratory findings were stable. Patients with kidney, liver, and spleen injuries were advised to follow restricted movement for 6 weeks after discharge (12). For patients with liver and spleen injury, no routine radiologic follow-up was performed after discharge (12). In the event a patient presented with abdominal complaints, he or she was evaluated by dynamic abdominal CT (12). The complete recovery time of grade III, IV, and V kidney injuries was considered as 4–6 months (12). During this time, these patients were monitored monthly with abdominal CT, dimercaptosuccinic acid (DMSA) scintigraphy, and/or abdominal ultrasound (12). During follow-up, daily blood pressure monitoring and weekly blood urea nitrogen (BUN) levels were measured (12).

Statistical analysis

Normality of data was evaluated by Shapiro-Wilk test. Normally distributed data was summarized by mean \pm standard deviation. Comparison of the groups within measurement time and time-group interaction was tested by repeated measures under general linear model and Bonferroni adjusted pairwise comparison was used. Non-normal data was expressed by median, minimum, and maximum values. Comparison of groups for these data was performed by Kruskal-Wallis test and Conover pairwise comparison method. Fisher's exact test was used for comparison of sex distribution within the groups. In all analyses significance level was considered as 0.05. For comparison of three groups at 95% confidence level ($\alpha=0.05$) and at 80% power ($\beta=0.20$), when the effect size was considered to be 1.06, the minimum sample size per group was calculated as 5.

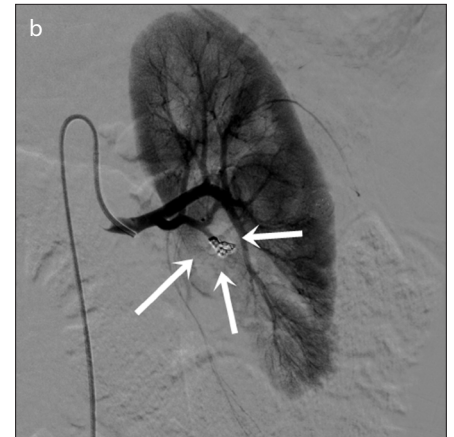
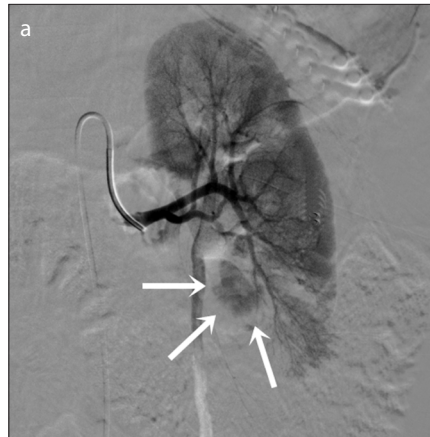
Table 2. Age and sex distribution of patients in late embolization and early embolization groups and the degree of injury of embolized organs

Patient	Late embolization group			Early embolization group		
	Grade of injured organs	Embolized organ	Age/ Gender	Grade of injured organs	Embolized organ	Age/ Gender
1	Grade IV spleen	Spleen IV	15/M	Grade IV spleen	Spleen IV	14/M
2	Grade IV left kidney	Kidney IV	15/M	Grade IV left kidney	Kidney IV	13/F
3	Grade IV right kidney	Kidney IV	16/F	Grade IV spleen	Spleen IV	14/M
4	Grade IV right kidney	Kidney IV	11/M	Kidney III+ Pelvic fracture	The posterior branch of the internal iliac artery	14/F
5	Grade IV spleen	Spleen IV	12/F	Grade IV spleen	Spleen IV	14/M
6	Grade IV liver +Pelvic fracture	Left lateral sacral artery	17/M	Grade IV left kidney	Kidney IV	6/F
7	Grade IV liver, right lung contusion	Liver IV	10/M	Grade IV left kidney	Kidney IV	11/F
8	Grade IV left kidney	Kidney IV	13/F	Grade IV spleen	Spleen IV	2/M
9	Grade IV right kidney	Kidney IV	1/M	Grade IV spleen	Spleen IV	5/F
10	Grade IV spleen, grade I liver	Spleen IV	5/M	Grade V left kidney	Kidney V	2/M
11	Grade V left kidney	Kidney V	5/M			
Mean injury grade: 4±0.30				Mean injury grade: 4±0.47		

M, male; F, female.

Table 3. Demographic data of nonoperative management patients

Nonoperative management patients	n=265
Age (years)	9.01±4.21
Male/Female	172/93
Injured solid organ	
Spleen	147
Liver	96
Kidney	22
Multiple solid organ injuries	22
Mean injury grade	2±0.75

**Figure 3. a, b.** Angiographic image (a, arrows) from a 14-year-old male patient with contrast agent extravasation as a result of left kidney damage due to falls from the late embolization group. Post-embolization image (b) shows no active extravasation from the damaged arterial structure of the kidney.

Results

The angiographic images of the patients from LE and EE groups are shown in Figs. 3 and 4. The CT image of the patient from the EE group with nonperfused spleen area distal to the damaged arteries is shown in Fig. 4c. The mean degree of organ injury was 4 in both groups (Table 2) and no significant difference was found between the two groups in terms of age or gender. Demographic data of the patients undergoing

nonoperative management and the results of the parameters evaluated in this study are shown in Table 3.

Mean length of stay in the intensive care unit and in the hospital, blood transfusion requirement, total hospital cost, and first feeding after trauma were found significantly different between the two groups (Table 4).

The durations of intensive care unit and hospital stays were longer in the LE group than in the EE group (Table 4).

The need for blood transfusion (15 mL/kg, RBC suspension packs) and total hospital costs were higher in the LE group than in the EE group (Table 4).

The interval between the first application and the first enteral feeding was longer in the LE group than in the EE group in a ratio of 4 (2–5) to 1 (0–2) days. Intervals between first application and embolization showed a mean of 16 hours in the LE group (15–22 hours) and a mean of 3 hours (2–5 hours) in the EE group (Table 4).



Figure 4. a–c. Angiograph (a) of a 14-year-old patient from the early embolization group shows Grade 4 splenic injuries. Contrast extravasation from damaged artery has not yet occurred (*arrows*). However, there is no blood supply in the distal region of the damaged artery. It is thought that extravasation may be caused by this damaged artery. Post-embolization image (b) shows damaged arteries embolized with metal coil (*arrows*). Computed tomography image (c) before embolization shows nonperfused spleen area (*arrows*) distal to the damaged arteries.

Table 4. Comparison of post-trauma intervention time and other variables in all groups

	LE (n=11)	EE (n=10)	Non-E (n=265)	P
Length of intensive care unit stay (days)	4 [3-15] ₁ ^a	2 [2-3] ₂ ^b	2 [1-6] ^b	<0.001
Length of hospital stay (days)	14 [8-28] ₁ ^a	6 [5-7] ₂ ^b	5 [2-7] ^c	<0.001
Blood transfusion (15 cc/kg RBC)	3 [2-5] ₁ ^a	1 [0-1] ₂ ^a	0 [0-1] ^b	<0.001
Total hospital cost (USD)	4502 [2627-7658] ₁ ^a	1371.5 [1038-3455] ₂ ^a	758 [244-1200] ^b	<0.001
Time of first feeding after trauma (days)	4 [2-5] ₁ ^a	1 [0-2] ₂ ^b	1 [0-3] ^b	<0.001

LE, late embolization; EE, early embolization; Non-E, nonoperative management; RBC, red blood cells; USD, US dollars.

The statistical analysis of the three groups is shown in superscript letters. The difference between the groups with different superscript letters found to be statistically significant. The LE and EE Group statistical analysis is indicated by lower subscript numbers. The difference between the groups with different lower subscript numbers found to be statistically significant. The rightmost P value applies to both different lower subscript numbers and superscript letters.

Table 5. Heart rate, systolic blood pressure, hematocrit value, and thrombocyte counts at admission

Admission variables Mean±SD	LE Group (n=11)	EE Group (n=10)	Non-E Group (n=265)	P
Hematocrit	[31.87±3.30] ^a	[28.10±1.80] ^b	[36.52±4.04] ^c	<0.001
Thrombocyte	[248.27±66.08] ^a	[213.20±56.63] ^a	[296.32±80.64] ^b	<0.001
Heart rate	[107.7±13.2]	[109.1±13.09]	[105.09±8.48]	>0.05
Systolic blood pressure	[86.9±5.8] ^a	[84.8±6.7] ^a	[104.93±7.44] ^b	<0.001

SD, standard deviation; LE, late embolization; EE, early embolization; Non-E, nonoperative management.

The statistical analysis of the three groups is shown in superscript letters.

The difference between the groups with different superscript letters found to be statistically significant.

The rightmost P value applies only to different superscript letters.

The mean hematocrit level in the LE group was higher at the first admission than in the EE group (Table 5). There were no differences in platelet count, heart rate, and systolic blood pressure between the two groups at first admission (Table 5). The mean hematocrit and platelet counts before the PTAE procedure were higher in the EE group than in the LE group. No differenc-

es in hematocrit or platelet count were detected in either group after PTAE. The mean platelet count and hematocrit 72 hours post-PTAE were higher in the EE group than in the LE group. The mean hematocrit at discharge was higher in the EE group than in the LE group. The mean platelet count at discharge did not differ between the two groups. The changes in hematocrit and

platelet counts for both groups are shown in Figs. 5, 6 and Tables 5–7.

None of the patients developed complications during the PTAE procedure, although mechanical ventilation was required in three patients in the LE group who needed massive blood transfusions. In those patients, pleural effusion developed, so thoracic catheters were inserted for drainage; the catheters were removed after an average of 3 days. Two patients in the EE group received antihistamine treatment due to allergic reactions after fresh frozen plasma was received. Renal hypertension developed 5 months after discharge in a patient from the LE group with grade 5 kidney injury. The hypertension was controlled by medical therapy. One patient from the EE group developed a renal abscess 1 month after the procedure and recovered completely after percutaneous drainage and medical treatment. The patients in both groups were discharged upon recovery.

Because of these positive effects, we have been applying early embolization proce-

Table 6. Comparison of hematocrit and platelet count in LE and EE groups over time

		Admission Mean±SD	Pre-PTAE mean±SD	Post-PTAE mean±SD	72 h Post-PTAE mean±SD	Discharge mean±SD	P
Hematocrit	LE (n=11)	31.87±3.30	25.45±2.86	29.30±3.33	29.05±3.36	31.07±2.29	Time <0.001
	EE (n=10)	28.10±1.80	28.13±1.86	30.89±2.44	32.67±2.39	35.26±2.69	Time*Group <0.001
Platelet	LE (n=11)	248.27±66.08	135.69±49.57	194.30±82.67	209.36±99.60	319.45±149.99	Time <0.001
	EE (n=10)	213.20±56.63	209.55±38.62	244.75±61.20	325.20±70.77	382.80±120.51	Time*Group <0.001

SD, standard deviation; LE, late embolization; EE, early embolization.

Table 7. Hematocrit and platelet count of LE and EE groups over time

	Hematocrit	Platelet count
Admission	LE [31.87±3.30] > EE [28.10±1.8]	LE [248.27±66.08] = EE [213.2±56.63]
Pre-PTAE	LE [25.45±2.86] < EE [28.13±1.86]	LE [135.69±49.57] < EE [209.55±38.62]
Post-PTAE	LE [29.30±3.33] = EE [30.89±2.44]	LE [194.30±82.67] = EE [244.75±61.20]
72 h Post-PTAE	LE [29.05±3.36] < EE [32.67±2.39]	LE [209.36±99.60] < EE [325.20±70.77]
Discharge	LE [31.07±2.29] < EE [35.26±2.69]	LE [319.45±149.99] = EE [382.80±120]

LE, late embolization; EE, early embolization; PTAE, percutaneous transcatheter arterial embolization.

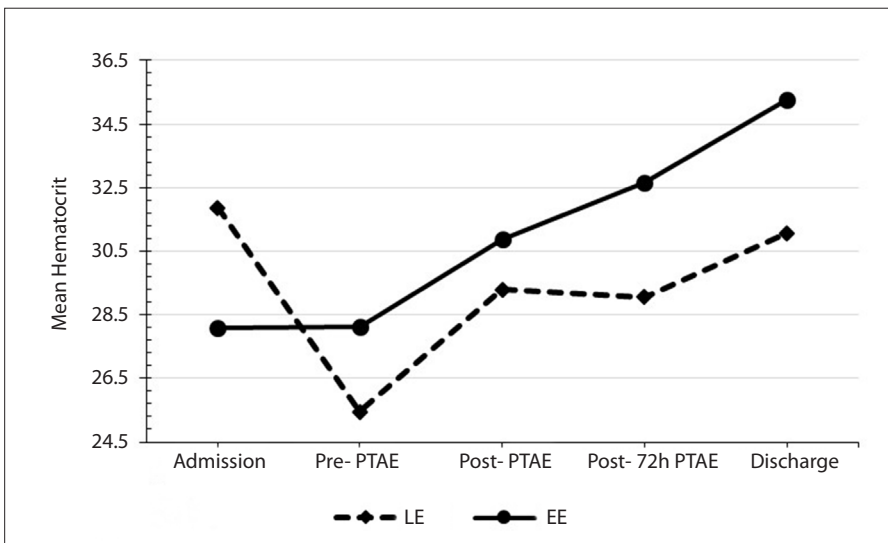


Figure 5. Diagram shows change in hematocrit counts of both groups. Mean hematocrit counts does not fall too much in the early embolization group.

dures to our patients who are suitable since February 2017.

Nonoperative management refers to the nonembolization (Non-E) group. Demographic information and other parameter values of the Non-E group are shown in Table 3.

In order to evaluate how the variables used in this study may have been affected by the severity of the trauma and the higher degree of solid organ injury, we analyzed

the data from all three groups, namely the Non-E group, LE group, and EE group. We did not set out to evaluate the efficacy of nonoperative management.

When all parameter values of the LE and EE groups were analyzed statistically in comparison with parameter values of the Non-E group, the group with the most advantageous treatment results was found to be the Non-E group (Tables 4, 8). It should

be noted that patients in the Non-E group were exposed to less severe trauma and a lower degree of intra-abdominal solid organ damage than the other groups. Moreover, nonoperative management could not have been applied to the LE or the EE group patients due to ongoing intra-abdominal bleeding.

The change of the hematocrit and platelet values of the LE group, EE group and the Non-E group over time is shown in Figs. 7 and 8.

Discussion

Management of pediatric trauma patients is a vital issue for research (7). The superiority of nonoperative management is widely accepted for pediatric patients with injuries due to blunt abdominal trauma (4, 6, 13). These patients constitute 95% of children with abdominal trauma (6, 13). However, it is absolutely necessary to intervene in the other 5% of pediatric patients with blunt abdominal trauma (14, 15), because these patients will likely die if left untreated (6). The first important issue in a trauma patient who needs intervention is to determine the time of intervention. Although there are many parameters that determine that time (12, 16), they are not standardized in many trauma centers (7). In current studies, the need for blood transfusion is among these parameters (7). Avanoğlu et al. (17) determined that these patients require transfusions of a mean of 39.5 mL/kg RBC packs. In other words, the variable that determines the waiting time for a patient before undergoing surgical intervention is the volume of RBC packs to be transfused. However, calculating the need for blood transfusion before intervention in a pediatric patient causes a significant loss of time and an increase in the amount of blood transfused, leading to more frequent complications related to blood transfusion (18).

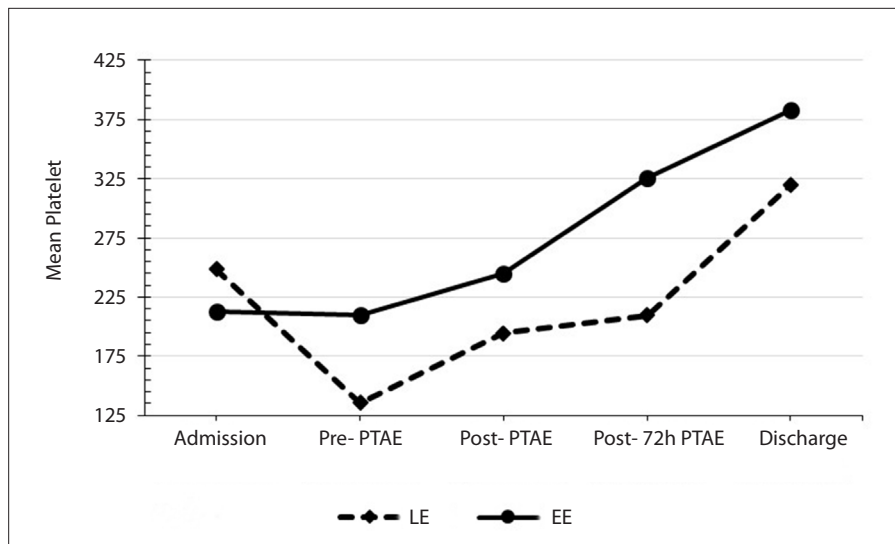


Figure 6. Diagram shows change in platelet counts of both groups. Mean platelet counts does not fall too much in the early embolization group.

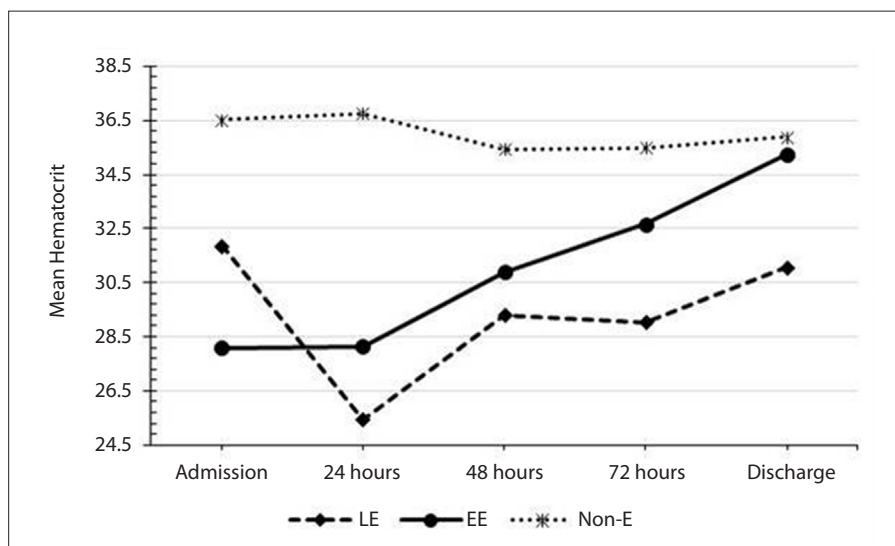


Figure 7. Diagram shows change in hematocrit counts of all groups.

Complications of blood transfusion can be significant and include metabolic acidosis, coagulopathy, hypothermia, electrolyte anomalies, lung injury and cardiac arrest due to hyperkalemia (18–23).

We support the delivery of blood to trauma patients if needed. It can save the patient's life by recovering tissue oxygen delivery (19, 24). In determining such intervention for pediatric trauma patients, we do not believe it advisable to calculate the amount of blood needed, because this calculation increases the lapsed time. The longer a hemorrhagic pediatric patient is held without intervention the greater the need for transfusion and its complications. In order to evaluate intra-abdominal hem-

orrhages due to trauma, different parameters can be examined besides the need for blood transfusion, such as hematocrit values (25) at the time of admission, and CT findings (26).

In this study, clinical, radiologic, and laboratory findings suggest that if a child develops intra-abdominal hemorrhage due to trauma, intervention can be decided in a short time. It was speculated that CT findings (\geq grade 4 injury), laboratory parameters, and clinical findings (tachycardia, hypotension [systolic blood pressure defined as $<70 \text{ mm/Hg} + 2 \times \text{age in years}$] (1), urine output $<1 \text{ mL/kg/h}$, and a sensitive physical examination) may suffice as indications for intervention in a trauma

patient. The hematocrit level of all patients with intra-abdominal injuries on whom we intervened was $<29\%$ before embolization (Fig. 5), and the CT organ injury grade was ≥ 4 (Table 2).

In a solid organ damaged by blunt abdominal trauma, it is important to distinguish the vasospasm from the damaged artery. This distinction is best performed by CT images (27). CT images will show non-perfusion in a certain area when the related artery is damaged (26). When there is a vasospasm in the artery of a solid organ, the distal region of this artery is seen as a hypoperfusion area in CT images (28). In this study, a nonperfused area was seen in CT images of the embolized organ in the EE group before the PTAE (Fig. 4c).

Renal traumas present a special issue due to the rate of intervention being higher than in other blunt intra-abdominal solid organ traumas (29).

Haqiwara et al. (30) divided adult patients into 4 groups according to the angiography findings. They classified Type A as heterogeneity in contrast agent involvement, Type B as disruption in renal artery branches, Type C as moderate contrast agent extravasation, and Type D as complete obstruction in the renal artery. They performed transarterial embolization to Type C and D, and conservative management to Type A and B. Of 21 patients, 12 had conservative management, 8 had transarterial embolization, and 1 patient had a nephrectomy. They performed PTAE after a mean duration of 12 hours of fluid resuscitation to 8 patients. They reported that 2 patients were operated after PTAE for ongoing bleeding and subsequently died due to coagulopathy.

In the literature, PTAE experience is very limited in renal injury caused by blunt abdominal trauma in children (29, 31, 32).

Lin et al. (29) reported that they performed renal angiography on 6 pediatric patients with blunt abdominal trauma, 4 of whom underwent arterial embolization and the other 2, who did not bleed, only angiography. Three of the 6 were given blood. All patients were discharged from the hospital after a mean hospital stay of 11 days.

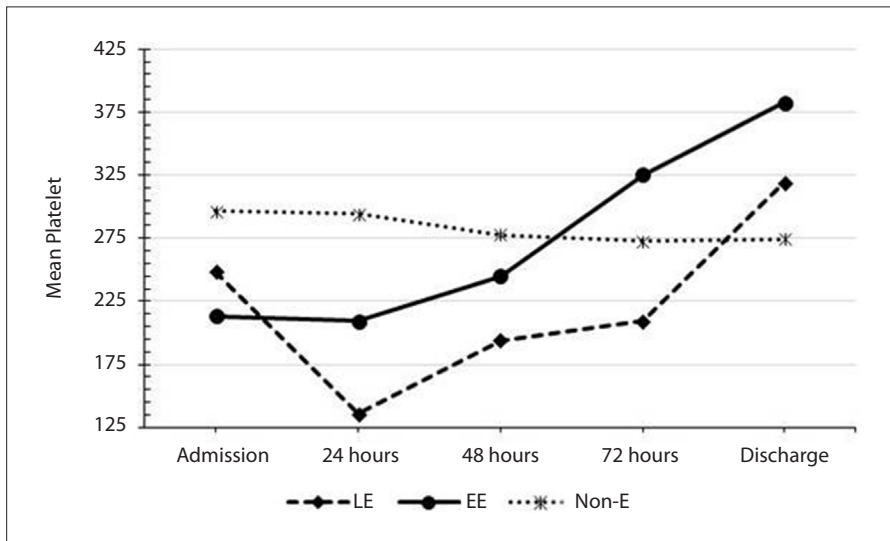
Eassa et al. (31) treated 18 patients with renal blunt trauma. Two had PTAE, 7 had surgery, and 9 had nonoperative management.

Vo et al. (32) reported on 97 patients who underwent angiography due to acute abdominal or pelvic trauma, 54 of whom required embolization. Targets of embolization included the pelvis ($n=39$), liver ($n=8$),

Table 8. Comparison of hematocrit and platelet count in LE, EE and Non-E groups over time

		Admission mean±SD	First 24 h mean±SD	First 48 h mean±SD	First 72 h mean±SD	Discharge mean±SD	P
Hematocrit	LE (n=11)	31.87±3.30	25.73±2.64	29.85±3.42	29.64±3.45	31.07±2.29	Time <0.001
	EE (n=10)	28.10±1.80	28.34±1.74	30.98±2.34	32.85±2.41	35.26±2.69	Time*Group <0.001
	Non-E (n=265)	36.52±4.04	36.75±3.53	35.45±3.40	35.50±3.55	35.89±3.75	
Platelet	LE (n=11)	248.27±66.08	127.55±51.23	196.32±85.74	211.23±100.24	319.45±149.99	Time <0.001
	EE (n=10)	213.20±56.63	215.325±42.54	248.825±65.33	327.12±82.36	382.80±120.51	Time*Group <0.001
	Non-E (n=265)	296.32±80.64	294.14±70.58	277.62±71.81	273.03±67.25	274.34±68.48	

SD, standard deviation; LE, late embolization; EE, early embolization; Non-E, nonoperative management.

**Figure 8.** Diagram shows change in platelet counts of all groups.

kidney (n=7), spleen (n=6), and retroperitoneum (n=2). Bleeding control was achieved in 47 patients; 12 died due to complications; and bleeding control failed in 7 patients. A total of 13 patients were diagnosed with renal trauma, of whom 7 had PTAE. Improvement was seen in patients with renal trauma without complications.

In our study we found that patients with kidney injuries due to blunt abdominal trauma were mostly treated with nonoperative management. There were a total of 33 patients with kidney injury due to blunt abdominal trauma, none of whom died. Among these, 11 underwent PTAE: 6 in the LE group and 5 in the EE group. The other 22 were treated with nonoperative management. No surgical intervention was performed on any patient with kidney injuries. Therefore in cases of kidney injury caused by blunt trauma in children, we advise against an aggressive approach.

Many studies have asserted that PTAE is the most advantageous option to be performed in case of intervention due to intra-abdominal hemorrhage from blunt trauma in pediatric patients (32, 33).

On the other hand, PTAE procedures may have a few disadvantages that may lead to some complications. The patients included in this study had no complications during the PTAE procedure, but complications associated with PTAE have been reported in the literature (34–39). During standard PTAE procedure, vascular structures of injured solid organs are evaluated, and embolization is performed on vascular structures with active contrast agent extravasation (5). However, this study revealed that even if no active extravasation in the damaged vascular structure is detected during the PTAE procedure, active hemorrhage can develop later in this damaged vascular structure. In this study, damaged vascular structures

were detected in two patients of the LE group undergoing PTAE procedure due to intra-abdominal hemorrhage, but the procedure was terminated without embolization as there was no active extravasation. In these two patients, 12–14 hours after the first PTAE procedure, unfortunately a second PTAE procedure had to be performed due to intra-abdominal hemorrhage and active extravasation detected from the damaged vascular structures that had not been previously extravasated. It might be that those patients had a low systolic blood pressure during the first PTAE procedure. After the necessary fluid resuscitation, when systolic blood pressure increased, the hemorrhage from damaged vascular structures may have begun. Because these damaged vascular structures do not contribute to the bloodstream of the organ in which they are present, their embolization may prevent the patient from being administered a second PTAE procedure and additional blood transfusion. In patients in the EE group, when vascular structure damage during the PTAE procedure was detected, embolization was performed even without extravasation. Patients in the EE group did not need the PTAE procedure repeated.

The decision to intervene in a patient with blunt abdominal trauma is made by evaluating clinical, laboratory, and CT findings. This decision may take almost 3 hours, but the delay can be shortened if determining the need for blood transfusion is not a criterion for intervention. Blood should be given if necessary, but determining the need for a blood transfusion at that time may lead to time loss and more complications. As a result of this study, PTAE can be recommended as soon as possible after the decision to intervene. When damaged vasculature is detected during angiography, PTAE may be

recommended even if there is no active extravasation, because these damaged arteries may start bleeding actively when the blood pressure returns to normal. Our experience showed that blood pressure in these patients was typically 5–10 mmHg below normal (11) before angiography due to bleeding, and lower blood pressure caused the bleeding to stop temporarily. If damaged arteries that have temporarily stopped bleeding are not embolized during the first angiography, the blood pressure rises again with the fluid resuscitation and the arteries start bleeding again. Performing anesthesia and angiography procedures for a second time on a patient with solid organ injury, and the time that passes until rebleeding is detected, may cause the collapse of critical systems (respiratory, urinary, immune, and coagulation systems) that are already running at the limit.

Our work has some limitations: First of all it is a retrospective study, this may have resulted in patient selection bias. Also, the number of patients in the groups is limited. In addition, the age ranges (from 1 yr.-old to 16 yrs.-old) of the patients examined in the study are very wide. Moreover the type of organ injuries of the patients was not similar and some of patients had multiple organ injuries.

In conclusion, early embolization with PTAE provides the patient shorter intensive care and hospital stay, earlier enteral feeding, less blood transfusion requirements, and lower hospital costs. On the other hand, because of the limited number of patients in our study, we cannot draw definitive conclusions. We believe that further studies should follow to prove the accuracy of the results this study has suggested.

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Conflict of interest disclosure

The authors declared no conflicts of interest.

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