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Selective Computed Tomography and Angioembolization Provide Benefits in the Management of Patients with Concomitant Unstable Hemodynamics and Negative Sonography Results

Chih-Yuan Fu · Chi-Hsun Hsieh · Chun-Han Shih · Yu-Chun Wang · Ray-Jade Chen · Hung-Chang Huang · Jui-Chien Huang · Shih-Chi Wu · Hsun-Chung Tsuo · Hsiu-Jung Tung

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Abstract
Background The FAST (focused assessment of sonography for trauma) examination can rapidly identify free fluid in the abdominal or thoracic cavity, which is indicative of hemorrhage requiring emergency surgery in multiple-trauma patients. In patients with negative FAST examination results, it is difficult to identify the site of the hemorrhage and to plan treatment accordingly. We attempted to delineate the role of selective computed tomography (CT) and transarterial angioembolization (TAE) in the management of such unstable patients.
Methods From January 2005 to April 2011 patients with concomitant unstable hemodynamics and negative FAST examination results were identified. Their demographic and time to start of embolization were recorded. The initial systolic blood pressure (SBP) in emergency department patients was compared with the SBP after TAE.
Results A total of 33 patients were enrolled, and 85% required TAE. SBP improved significantly after TAE. There were 18 patients who received TAE without CT scan because the site of hemorrhage was obvious. Fifteen patients received a CT scan during the time required for angiography preparation. Ten of them received subsequent TAE based on the CT scan findings, and the treatment plan was changed in the other five patients. There was no significant difference between patients with or without a CT scan with respect to the time interval between arrival and starting embolization.
Conclusions Transarterial angioembolization is suggested in the management of patients with concomitant unstable hemodynamics and negative FAST examination results. During the time interval required for angiography preparation, a CT scan can be performed. This approach provides

C.-Y. Fu · C.-H. Shih · R.-J. Chen
Department of Trauma and Emergency Surgery,
Taipei Medical University-Wan Fang Hospital, Taipei, Taiwan
e-mail: drfu5564@yahoo.com.tw

C.-H. Shih
e-mail: 99183@wanfang.gov.tw

R.-J. Chen
e-mail: rayjchen@tmu.edu.tw

C.-H. Hsieh · Y.-C. Wang (✉) · H.-C. Huang · J.-C. Huang · S.-C. Wu
Trauma and Emergency Center, China Medical University Hospital, Yue Der Road No. 2, Taichung, Taiwan
e-mail: traumawang@yahoo.com.tw

C.-H. Hsieh
e-mail: hsiehchihsun@yahoo.com.tw

H.-C. Huang
e-mail: adam0936287309@yahoo.com.tw

J.-C. Huang
e-mail: gary.kmt@msa.hinet.net

S.-C. Wu
e-mail: rw114@www.cmuh.org.tw

C.-H. Hsieh · Y.-C. Wang · S.-C. Wu
School of Medicine, China Medical University,
Taichung, Taiwan

H.-C. Tsuo · H.-J. Tung
School of Medicine, Taipei Medical University,
Taipei, Taiwan
e-mail: b101095067@tmu.edu.tw

H.-J. Tung
e-mail: thjami@gmail.com

valuable information for further decision making without delaying definitive treatment.

Introduction

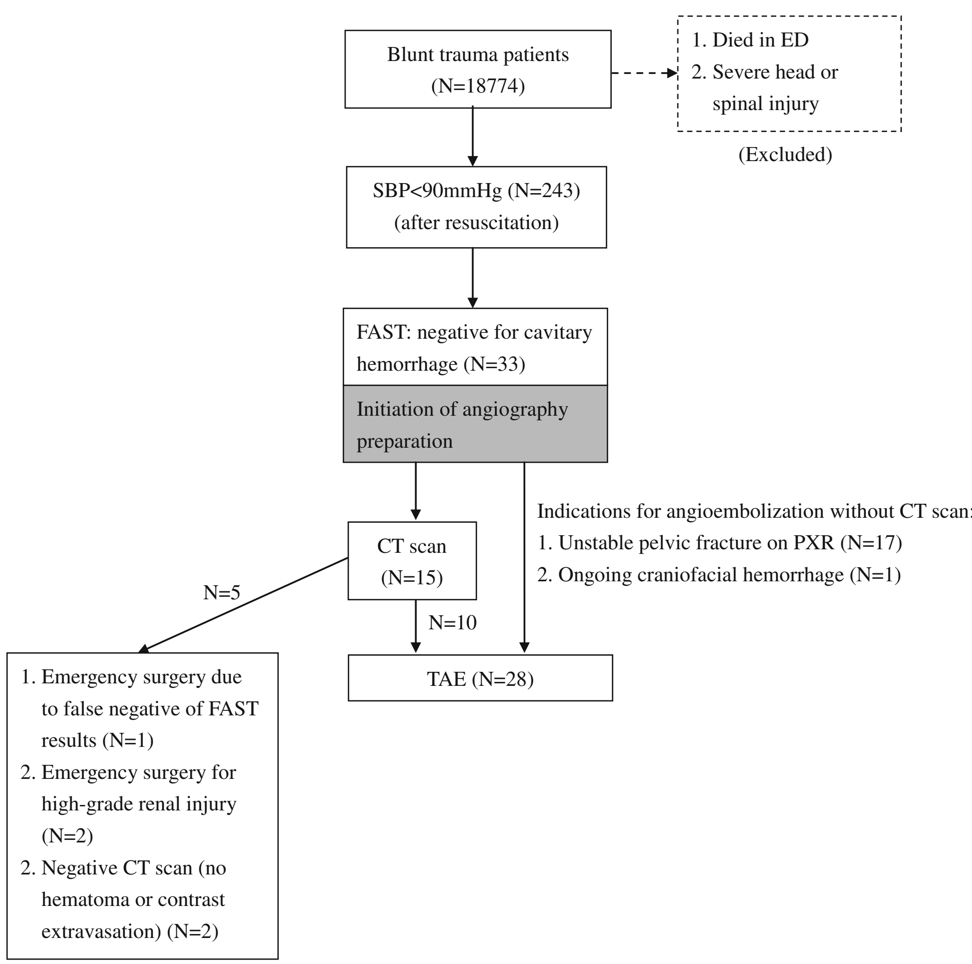
Trauma remains one of the leading causes of morbidity and mortality worldwide [1–3]. Regardless of the mechanism of injury, most deaths that occur within the first hour following a traumatic event are the result of injury-induced hemorrhage. Such instances cause 30–50% of injury-associated deaths within the first 24 h of trauma care [4–9]. Moreover, hemorrhage-induced hypotension in trauma patients is predictive of mortality. Therefore, in addition to aggressive resuscitation, it is important to identify the source of the hemorrhage and achieve adequate hemostasis rapidly in trauma patients suffering from hemorrhagic shock.

In the primary survey of trauma patients with unstable hemodynamics, the focused assessment of sonography for trauma (FAST) examination was applied to identify cavitary hemorrhages, which present as free fluid in the abdominal or thoracic cavity and mandate emergency operation without any further imaging studies [10, 11]. However, for some patients, the source of hemorrhage will remain unclear after history taking, physical examination, and FAST examination. A computed tomography (CT) scan can be used to identify the source of hemorrhage. For hemodynamically unstable patients, however, CT scanning is considered traditionally to be a time-consuming procedure that might delay definitive treatment. Therefore, physicians face a dilemma in the management of unstable patients with negative FAST examination results.

In the hemostasis procedure for such patients, the role of exploratory surgery was considered insignificant; furthermore, non-therapeutic surgery may delay definitive treatment. In contrast, transarterial angioembolization (TAE) can be used to achieve hemostasis in the case of hemorrhage that cannot be detected by FAST examination [12, 13].

To our knowledge, reports on trauma patients with concomitant unstable hemodynamics and negative FAST examination results have been scarce to date. Thus, the purpose of the present study was to delineate the further

Fig. 1 The established algorithm and patient distribution



management of such patients in the acute setting, and to evaluate the role and efficacy of selective CT scanning and TAE in such situations.

Materials and methods

We retrospectively reviewed the trauma registry and medical records of trauma patients at the China Medical University Hospital (CMUH) and Wan Fang Hospital (WFH) from January 2005 to April 2011. Both of these institutions are major trauma referral centers. There were no discrepancies in surgical techniques or technical skill levels between CMUH and WFH.

During the 76-month investigational period, the blunt trauma patients were identified and treated according to an established algorithm (Fig. 1). In the present study, hemodynamic instability was defined as systolic blood pressure (SBP) less than 90 mmHg after an initial fluid bolus of 2,000 ml of lactated Ringer's solution or normal saline solution over 15–20 min. The trigger of blood transfusion (packed red blood cells or whole blood) in the resuscitation is considered in patients who are either non-responders or transient responders with an estimated acute blood loss of >30% blood volume [10].

The trauma series plain films (chest X-ray: CXR; pelvic X-ray: PXR) and FAST examination were performed routinely as an adjunct to the primary survey [10]. Patients who died in the emergency department (ED) without other evaluation or who had severe head/spinal injury, which may have contributed to unstable hemodynamics and hemorrhage, were not enrolled in the study. Patients who underwent emergency surgery (thoracotomy, laparotomy, or both) due to cavitary hemorrhage noted on the FAST examination were also excluded.

Patients with concomitant unstable hemodynamics and negative FAST examination results were the focus of this study. Angiography preparation was initiated while these patients' unstable hemodynamics and negative FAST examination results were analyzed in the ED. Patients with unstable pelvic fractures observed on PXR and those with ongoing craniofacial hemorrhage were sent directly to the angiography room for embolization without undergoing other imaging studies. For the embolization of these patients, the external carotid artery was examined for craniofacial hemorrhage, and the internal iliac artery (IIA) was examined for possible retroperitoneal hemorrhage related to pelvic fracture. The other patients without obvious foci of TAE received CT scans during the time required for angiography preparation. In patients who underwent CT scanning, subsequent TAE was focused on the sites with contrast extravasation or hematoma formation. Other patients did not receive angiogram or TAE after the CT scan.

At both institutions, the resuscitation room, ED operating room, and CT and angiography suite were integrated in the same area. Patients could be transferred between the resuscitation room and the imaging study suite in a notably short time with continuous resuscitation. Besides, the FAST was performed by experienced attending ED physicians or trauma surgeons, who provided reliable examinations. Furthermore, there were in-house trauma surgeons available 24 h a day who assisted in femoral arterial puncture, arterial line placement, or cut-down with arteriotomy in difficult puncture cases. The TAE procedure was performed by experienced radiologists who used absorbable gelatin-sponge pledgets (Gelfoam), stainless-steel coils, or both. The protocol was abandoned for any patient who became profoundly hypotensive (SBP 60 mmHg or lower) before or during angiography [14]. These patients were managed with additional resuscitation (continued fluid administration and/or vasopressor administration) [15].

In the present study, we investigated the characteristics of patients with concomitant unstable hemodynamics and negative FAST examination results in the ED according to the medical records and trauma registration data bank. The demographic characteristics, injury severity scores (ISS), injury mechanisms, time to start of embolization (with or without CT scan), and outcomes in these patients were recorded and analyzed. The initial SBP in the ED was compared with the SBP after TAE. The efficacy of selective CT scanning and TAE was also examined. The cases of patients who received CT scans but not TAE were analyzed.

All data are presented as percentages of patients or means with standard deviations. The Wilcoxon two-sample exact test was used for the comparison of numerical data, and the chi-square test was used in the comparison of nominal data. All statistical analyses were performed with the SPSS computer software package (version 13.0, Chicago, IL). A value of $p < 0.05$ was considered significant.

Results

During the 76-month study period, 18,774 blunt trauma patients admitted to the CMUH or the WFH were studied. The patient distribution is presented in Fig. 1. After excluding severe head or spinal injury patients and patients who died in the ED, there were 243 patients with SBP < 90 mmHg after fluid resuscitation with 2,000 ml of lactated Ringer's solution or normal saline. Thirty-three of these 243 patients had negative FAST examination results and were subsequently enrolled in the study. The mean age of the 33 patients with concomitant unstable

Table 1 Demographics of the 28 patients with concomitant unstable hemodynamics and negative FAST (focused assessment of sonography for trauma) examination results who received TAE (transarterial angioembolization)

Variables	Patients underwent CT scanning followed by TAE ($n = 10$)	Patients received TAE directly without CT scanning ($n = 18$)	p Value
Age, years	38.4 ± 13.8	39.2 ± 17.4	0.744[a]
Gender, n (%)			0.809[b]
Male	6 (60%)	13 (72%)	
Female	4 (40%)	5 (28%)	
ISS	31.4 ± 21.2	28.1 ± 15.5	0.112[a]
Injury mechanism, n (%)			–
Traffic crash	8 (80.0%)	16 (89%)	
Fall (>3 m)	2 (20.0%)	2 (11%)	
SBP in ED, mmHg	69.4 ± 22.6	63.1 ± .27.5	–
SBP after TAE, mmHg	118.0 ± 23.1	95.3 ± 12.2	
p Value	<0.001[a]	<0.001[a]	
Time to start of embolization, min[a]	39.7 ± 11.3 (CT scan)	31.4 ± 18.1 (no CT scan)	0.178[a]
Mortality, n (%)	2 (20%)	2 (11%)	–

Variables are expressed as mean ± SD

There was no significant difference in the time interval from arrival to TAE between patients who did or did not undergo computed tomography (CT) scanning

ISS injury severity score; *SBP* systolic blood pressure, *ED* emergency department

[a] Wilcoxon two-sample exact test

[b] Chi-square test

hemodynamics and negative FAST examination results was 40.2 ± 9.9 years. Of these patients, 24 were male (73%) and nine were female (27%).

There were 18 patients who received TAE after the primary survey without CT scan because the site of injury or source of hemorrhage was obvious (unstable pelvic fracture on PXR; 17 had ongoing craniofacial hemorrhage: During the preparation for angiography, a CT scan was performed on the 15 patients without obvious injury sites or sources of hemorrhage. Based on the CT scan findings, 10 (67%) of these 15 patients received further TAE, and 5 (33%) of them received other treatment instead of TAE.

Comparisons of the patients who received TAE with and without undergoing CT scanning are presented in Table 1. There was no significant difference between these two groups of patients in terms of age, sex, ISS, and outcome. The time between arrival and starting embolization was not significantly longer in patients who underwent CT scanning compared with those patients who did not undergo CT scanning ($p = 0.178$). Furthermore, the SBP after TAE was higher than SBP in the ED patient and in patients either who did (69.4 ± 22.6 versus 118.0 ± 23.1 mmHg; $p < 0.001$) or did not (63.1 ± .27.5 versus 95.3 ± 12.2 mmHg; $p < 0.001$) undergo CT scanning.

Table 2 presents the 15 patients without obvious foci for TAE during the primary survey who then underwent CT scanning during the time required for angiography preparation. The CT scan was followed by TAE in 10 patients because of specific findings on the CT scan. Most of these 10 patients (9/10, 90%) had pelvic fracture-related hemorrhages (contrast extravasation: 7, retroperitoneal hematoma: 2), although the PXR revealed normal or stable pelvic fractures. Five patients did not undergo angiogram or TAE after CT scanning. Their demographic characteristics, injury mechanisms, CT scan findings, and subsequent treatment are listed in Table 3. Computed tomography scans revealed hemoperitoneum in one patient, and this result indicated that the FAST examination findings were false negative. This patient was sent for an

Table 2 The patients without obvious focus of TAE during the primary survey received CT scans during the time required for angiography preparation

	CT scan findings		Subsequent treatment	Hemostasis results and outcome
TAE (+) ($n = 10$)	Pelvic fracture with contrast extravasation	7 (47%)	Followed with TAE according to CT scan findings	Success (5/7); failure/death (2/7)
	Pelvic fracture with retroperitoneal hematoma[a]	2 (13%)		Success (2/2)
	Lumbar artery contrast extravasation	1 (7%)		Success (1/1)
TAE (–) ($n = 5$)	High-grade renal injury	2 (13%)	Emergency surgery (2/2)	Survived (1/2); died (1/2)
	Mesentery hemorrhage with hemoperitoneum[b]	1 (7%)	Emergency surgery	Survived (1/1)
	Negative finding	2 (13%)	Maintain resuscitation	Died (2/2)

[a] Contrast extravasation on CT scan indicates active hemorrhaging and the need for TAE. Although there were two patients without contrast extravasation, they were sent for TAE because of retroperitoneal hematoma and possible hemorrhaging

[b] One patient had false-negative FAST examination results and underwent emergency surgery after hemoperitoneum was seen on the CT scan

Table 3 Characteristics of patients who received CT scans but not TAE

Patient No.	Age	Gender	ISS	Injury mechanism	Initial SBP (mmHg)	CT scan finding	Subsequent treatment	Outcome	Appendix
1	58	M	34	Traffic crash	66	Hemo-peritoneum, mesentery CE	Emergency laparotomy	Dead	False negative findings on FAST
2	80	M	41	Traffic crash	84	High-grade renal injury with CE	Emergency laparotomy	Dead	CT to surgery: < 10 min
3	20	M	41	Traffic crash	79	High-grade renal injury with CE	Emergency laparotomy	Alive	The time required for surgical preparation was shorter than that required for TAE preparation[#]
4	37	M	20	Traffic crash	62	Negative finding	Maintain resuscitation	Dead	The resuscitation ultimately failed
5	41	M	16	Fall (9 m)	71	Negative finding	Maintain resuscitation	Dead	

Patients 2 and 3 underwent immediate emergency surgery instead of TAE despite the presence of contrast CE, as seen on the CT scan

CE contrast extravasation

emergency laparotomy. Two patients had high-grade renal injuries with retroperitoneal contrast extravasation; they underwent immediate nephrectomies. The operating room can be prepared within 10 min at our institution, which is less time than is required for angiography preparation. The CT scans of the other two patients were negative; the resuscitation ultimately failed.

Discussion

In the primary survey of trauma patients with unstable hemodynamics, the FAST examination can rapidly identify free fluid in the abdominal or thoracic cavity, which is indicative of hemorrhage [10]. However, it is difficult to identify the source of a hemorrhage and to plan the treatment of patients with concomitant unstable hemodynamics and negative FAST examination results. In the present study, a high percentage (85%, 28/33) of such patients required TAE for hemostasis. One of them had an active craniofacial hemorrhage that presented as persistent nasal bleeding; the other 27 patients (96%) had retroperitoneal hemorrhages that could not be detected by FAST. Representing an important alternative to surgery, TAE plays an important role in the hemostasis of patients with retroperitoneal or craniofacial hemorrhages [12, 13, 16]. In the present study, the overall success rate of hemostasis was 86% (24/28). The SBP after TAE was significantly higher than SBP on arrival (Table 1). Therefore, in the management of patients with concomitant unstable hemodynamics and negative FAST examination results, retroperitoneal and craniofacial hemorrhage should be considered, and early TAE may be advisable.

When the source of hemorrhage is obvious, the emergency hemostatic procedure (either surgery or embolization) should be performed without performing unnecessary imaging studies. In the present study, 18 patients received TAE without undergoing further imaging studies after the primary survey because of the identification of an unstable pelvic fracture on PXR ($n = 17$) or an active external craniofacial hemorrhage ($n = 1$). The reported rate of hemorrhage in unstable pelvic fractures ranges from 18% to 62.5%; the internal iliac artery (IIA) is the most common source of hemorrhage [17–20]. Hence, the embolization could be focused on the injury sites (e.g., bilateral IIAs for pelvic fracture). The decision to proceed with TAE for such patients would not be changed even if additional imaging studies were performed.

However, there were 15 unstable patients in whom the site of injury or source of hemorrhage was not obvious during the primary survey (Table 2). For these patients, TAE without imaging did not seem feasible and was considered as risky without knowledge of the hemorrhage site. However, in contrast to thoracotomy and laparotomy, which allow the surgeon to examine the entire thoraco-abdominal cavity, interventional radiologists usually need more information to know where the source of hemorrhage is and to perform precise embolization. For practical reasons, the possibility of retroperitoneal hemorrhage and the necessity of TAE could not be excluded in these patients. Angiography preparation was initiated during the initial evaluation and resuscitation. Notably, the development of multi-detector CT reduced the scanning time necessary for whole-body CT scans [21]. Therefore, in addition to continuous resuscitation, a CT scan could be completed during the time lag required for angiography preparation. There was no significant difference in the time from arrival to starting embolization between patients who did or did not undergo CT scanning (39.7 ± 11.3 versus 31.4 ± 18.1; $p = 0.178$) (Table 1). Thus, the CT scan did not delay definitive treatment or resuscitation during this period.

Physicians (ED physicians, trauma surgeons, and interventional radiologists) are able to obtain important information from a CT scan that would improve the quality of critical care decisions. In the present study, 15 patients underwent CT scans during the time required for angiography preparation. Subsequent TAE was performed after CT scans in 10 of those patients (67%). Most (9/10) patients were found to have retroperitoneal hemorrhages related to pelvic fractures, even though PXR revealed normal or just stable pelvic fractures (Table 2). This high proportion of retroperitoneal hemorrhages could be explained by the reported retroperitoneal hemorrhage rate for stable pelvic fractures of 7–10% [18, 19]. Angiography can be focused on the hemorrhage sites, and radiologists can perform precise embolization informed by the CT scan findings.

However, the treatment plan changed from TAE to another management approach after the CT scan in 5 patients (Table 3). A CT scan plays a role in such situations, providing details that inform subsequent treatment and may prevent unnecessary angiography. Thus CT scans improve the quality of critical decisions about the patient's treatment during the time required for angiography preparation.

Patients with concomitant unstable hemodynamics and negative FAST examination results are relatively rare, making it difficult to collect a large number of cases for study. We recognize the limitations of the present study, including its retrospective nature and the small number of cases examined. A possible selection bias may limit our conclusions. However, the results show the benefit of selective CT scanning and TAE for patients with concomitant unstable hemodynamics and negative FAST examination results. Further studies with larger sample sizes and prospective designs are needed to establish algorithms for prompt diagnoses and precise treatment plans in the ED.

Conclusions

The use of TAE is suggested in the management of patients with concomitant unstable hemodynamics and negative FAST examination results. During the time required for angiography preparation, a CT scan can be performed. This approach provides valuable information for further decision making without delaying definitive treatment. Selective CT scanning and TAE provide substantial benefits in such patients.

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