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Systematic Review / Meta-analysis

FAST accuracy in major pelvic fractures for decision-making of abdominal exploration: Systematic review and meta-analysis

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ABSTRACT

Background: Major pelvic fractures are often associated with intra-abdominal organ injuries. Considering patients' hemodynamic status, Focused Assessment with Sonography for Trauma (FAST) can facilitate decision-making for abdominal exploration. Non-therapeutic exploratory laparotomy from pelvic fractures should be avoided. Aim of this study is to determine the accuracy of FAST in diagnosing significant intraabdominal hemorrhage that leads to determine whether or not to pursue therapeutic abdominal exploration in patients with major pelvic fractures.

Material and methods: We systematically reviewed the PubMed and SCOPUS databases from 2009 to 2019 and also using a retrospective review of patients admitted to the Acute Care Surgery service from 2016 to 2019. We performed a meta-analysis by using a random effects model.

Results: A total 677 patients were analyzed, 28 cases from our hospital. Mean patient age was 40.8 years. Leading mechanism of injury were motor vehicle collision (44.72%), fall from height (13.41%), and motorcycle collision (13.69%). Average injury severity score (ISS) was 32.5 (range: 24.1–50), and overall mortality rate was 11.65%. The pooled sensitivity, specificity, and accuracy of FAST to identify significant intra-abdominal hemorrhage was 79%,90%, and 93%, respectively (95% confidence interval: 89%–94%). Meta-regression revealed no significant correlation between injury severity score and the accuracy of FAST.

Conclusion: Our meta-analysis revealed that FAST in major pelvic fracture accurately detected significant intra-abdominal hemorrhage. Using FAST in the presence of unstable hemodynamics, we can decide to perform abdominal exploration with the expectation of finding significant intra-abdominal hemorrhage require surgically control.

1. Introduction

According to the Advanced Trauma Life Support (ATLS) protocols, the first step in a standard, rapid, reliable, and convenient diagnostic tool for early detection of intra-abdominal hemorrhage in severely injured patients is an abdominal ultrasound or Focused Assessment with Sonography for Trauma (FAST). Major pelvic fractures are bony unstable pelvic fractures that can result in massive exsanguinous hemorrhage from bony surfaces, pelvic venous plexuses, or pelvic arteries located mainly in the retroperitoneum. Mortality rates in patients with major pelvic fractures can reach 40%, and concomitant abdominal organ injury is reported in up to 30.7% of patients [1–3]. The most common associated injuries are the bladder and urethra (14.6%), liver (10.2%), small bowel (8.8%), and spleen (5.8%) [3]. In blunt abdominal trauma, FAST has high overall sensitivity, specificity, and accuracy to detect intra-abdominal free fluid, when used by well-trained surgeons, emergency physicians, and residents (80.43%, 75%, and 80%, respectively) [4]. FAST remains the most useful tool in hemodynamic unstable trauma patients. It allows the trauma surgeon to quickly exclude bleeding "cavities" and guides definite surgical care. In major pelvic fractures

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with retroperitoneal hematoma, blood sometimes enters the peritoneal cavity becoming free fluid detected by FAST. So, intra-abdominal hemorrhage can arise from the retroperitoneal hematoma or true intra-abdominal organ injuries. In this situation, FAST is unreliable for detecting significant intra-abdominal injury with a low sensitivity of 26% [5]. In patients with stable hemodynamics, we have time to investigate further, such as by performing whole-abdomen computed tomography (CT) scans to determine whether the blood originates from true intra-abdominal injuries, pelvic fractures, or from iliac vessels injury. Most of pelvic arterial hemorrhage can be managed by angiography and embolization. However, in hemodynamically unstable patients, trauma surgeons must decide whether to perform abdominal exploration or undergo an embolization of pelvic arteries in patients with free peritoneal fluid detected by FAST who cannot undergo abdominal CT for definitive diagnosis of intra-abdominal organ injury [6,7]. In some of these patients, we sometimes encounter a negative exploration with loss of pelvic tamponade leading to the need for emergency embolization or preperitoneal packing to control exsanguinous bleeding. The abdominal exploration eliminates the tamponade effect in the pelvic cavity, which sometimes leads to uncontrollable massive bleeding. Thus, abdominal exploration in patients with major pelvic fractures should be reserved for select cases. The aim of the study was to determine the accuracy of FAST in detecting significant intra-abdominal hemorrhage to determine whether to perform abdominal exploration in patients with major pelvic fractures.

2. Methods

We performed a systematic review and meta-analysis following the Preferred Reporting Items for Systematic reviews and Meta-analyses guidelines, as show in Fig. 1 [8].

2.1. Search strategies

We formulated the research question according to the Problem/Population, Intervention, Comparison, Outcome guidelines and performed a systematic review of studies listed in the PubMed and SCOPUS databases from 2009 to 2019. We used the following keywords as search terms: “pelvic injury” or “pelvic fracture” and “FAST” or “focused assessment with sonography for trauma” or “abdominal ultrasound” and

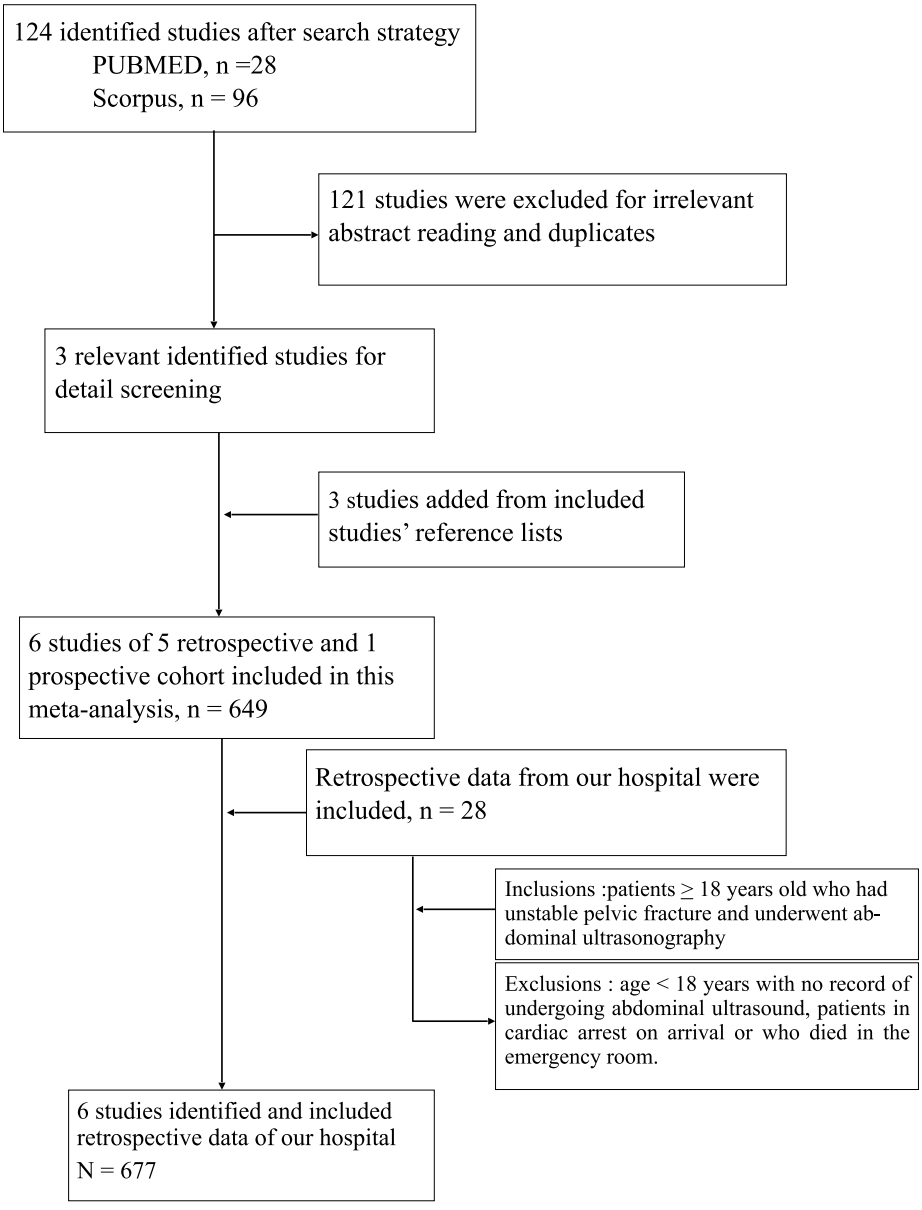

Fig. 1. Study flowchart according to the Preferred Reporting Items for Systematic reviews and Meta-analyses guidelines.

"abdominal bleeding" or "abdominal hemorrhage" or "abdominal hemorrhage". The 121 articles were excluded by screening for irrelevant abstracts reading and duplicated studies. Three relevant studies were included and 3 studies added from included studies' reference lists, so total 6 studies were included. A retrospective data collection from our hospital were included for meta-analysis(Fig. 1.).

2.2. Inclusions and exclusions criteria

According to a PICOS criteria for inclusion and exclusion of meta-analysis, the participants of all included studies were adults patients age $\geq$ 18 years old who had unstable pelvic fracture regardless of the sample size and underwent abdominal ultrasonography as a primary survey or as an adjunct to the primary survey, according to the ATLS guidelines. The studied has no control group. A primary outcome is accuracy of FAST in detection of significant intra-abdominal injury in unstable pelvic fracture and the secondary outcome is a decision making of abdominal exploration in clinical setting of unstable pelvic fracture with positive FAST results. All of treatment studies were included. Exclusion criteria were trauma patients <18 years of age with no record of undergoing FAST, and patients in cardiac arrest on arrival or who died in the emergency room.

2.3. Study registration

This study had registered at Thai Clinical Trails Registry(TCTR).

2.4. Study selection

We limited our search to studies originally published in English and involving only human patients. We also evaluated the demographic data and accuracy of FAST using a retrospective review of patients with unstable pelvic fractures admitted to the Trauma and Acute Care Surgery service from 1 January 2009 to 1 July 2019. We searched our patients database using the International Classification of Diseases-9 codes S-327 and S-328.

2.5. Definition

The definition of major pelvic fractures in our study was according to the Tile classification subtype B and C, and anteroposterior compression (APC) II, III, lateral compression(LC) II, III and vertical shear of unstable type in the Young–Burgess classification [9,10]. In our hospital, FAST was performed by second- and fourth-year general surgery residents who were required to complete the Advanced Trauma Life support (ATLS) course and adjudicated by attending trauma surgical staff in every cases. FAST positive was defined by any amount of intra-abdominal fluid detected by ultrasound.

We defined significant intra-abdominal injury as an injury requiring surgical control by abdominal exploration.

2.6. Outcome of interests

The primary outcome of interest is accuracy of FAST in detection of significant intra-abdominal injury in unstable pelvic fracture. The secondary outcome is a decision making of abdominal exploration in clinical setting of unstable pelvic fracture with positive FAST results.

2.7. Data extraction

Data extraction was performed by two independent authors, and disagreements were resolved by consensus. We collected the characteristics of the included studies and patients and created two-by-two contingency tables using the data.

2.8. Risk of bias assessments

We used the ROBINS-I tool to assess bias in seven domains, namely, confounding, participant selection, measurement of interventions, departures from intended interventions, missing data, measurement of outcomes, and selection of the reported result [11].

2.9. Statistical analysis

For each study, the number of true positives, false positives, true negatives, and false negatives was collected for the diagnostic test. These diagnostic data were then pooled across studies, and we performed a pooled meta-analysis to analyze the sensitivity, specificity, and accuracy combined with our institution's data. Heterogeneity was evaluated using Cochrane's Q test and the I^2 statistic. If heterogeneity was present, we used a random-effects model, and with no heterogeneity, we used a fixed-effects model. We also performed sensitivity analyses to identify the significant factors associated with the accuracy of FAST, using meta-regression. Publication bias was assessed using a Deek's funnel plot. If the plot was asymmetrical, the characteristic information described whether heterogeneity or publication bias was the cause of the asymmetry.

3. Results

From the data for patients with traumatic major pelvic fractures at our hospital from 1 January 2009 to 1 July 2019, we identified and included 28 cases of major pelvic fractures. Patients' average age was 45.10 years (range, 14–82 years); 21 patients were men (75%), and 7 patients were women (25%). Mean injury severity score (ISS) was 25.92. A revised trauma score was 6.64. Overall mortality was 10.71%, and the mechanisms of injury were motorcycle collision (46.43%), pedestrian vs. motor vehicle accident (25%), fall from height (21.43%), motor vehicle collision (3.57%), and crush injury (3.57%). Calculated sensitivity, specificity, and accuracy of FAST to identified intra-abdominal injuries was 57.14%, 90.47%, and 82.14%, respectively. Positive predictive value (PPV) and negative predictive value was 66.67% and 86.36%, respectively. The rate of nontherpeutic laparotomies in preoperative FAST-positive patients was 13.64%, which represented extension of retroperitoneal hematoma into the abdominal cavity. In therapeutic laparotomies, the injuries associated with the major pelvic fractures were intra-abdominal vascular injuries (42.86%), retroperitoneal hematoma (42.86%), injuries to the urinary bladder (28.57%), spleen (14.29%), liver (14.29%), small bowel and mesentery (14.29%), colorectum (14.29%), and kidney (14.29%) (Table 1). From Table 1, the 2 of 6 patients who had FAST positive were omitted to therapeutic laparotomies due to respond to fluid and blood components and whole-abdomen CT scan show liver injury and retroperitoneal hematoma which was candidated for non-operative management.

From our literature search, five retrospective studies and 1 prospective study, combined with our data involving 677 patients were included for analysis [5].(9–13) The summary of included study has shown in Table 2. The pooled characteristics data are summarized in Table 3. Among the 677 patients, 64.55% (n = 437) were men, and the mean age was 40.88 years (range, 36.8–45.1 years). The overall mortality rate was 11.65%. The mean ISS score was 32.50 (range, 24.1–50), and the mechanisms of injury were motor vehicle collision (44.72%), fall from height (13.41%), motorcycle collision (13.69%), pedestrian accident (8.33%), bicycle accident (13.50%), and assault (0.93%). The associated intra-abdominal injuries with major pelvic fracture were the spleen (6.94%), liver (4.58%), small bowel and mesentery (3.40%), bladder (1.92%), colorectum (1.33%), kidney (0.74%), and diaphragm (0.74%). The pooled sensitivity, specificity, and accuracy of FAST to identified intra-abdominal injuries were 79%, 90%, and 93%, respectively. A Forest plot for sensitivity, specificity, and accuracy showed heterogeneity, which was caused by differences in the definition of

Table 1
Demographic data for patients with traumatic major pelvic fracture in the Acute Care Surgery service at Ramathibodi Hospital 2016–2019.

N = 28		FAST results		Total
Characteristic		Positive	Negative	
Age (years, mean (SD)): (min, max)		35.66 (14.94): (17, 59)	47.68 (21.62): (14, 82)	45.10 (20.74): (14, 82)
Sex: n (%)	Male	4 (66.67)	17 (77.27)	21 (75)
	Female	2 (33.33)	5 (22.73)	7 (25)
Overall mortality: n (%)				3 (10.71)
ISS score (mean (SD)): (min, max)		33.33 (11.62): (20, 50)	23.90 (12.67): (8, 50)	25.92 (12.86): (8, 50)
Mechanism: n (%)	Motorcycle collision	3 (50)	10 (45.45)	11 (46.43)
	Pedestrian accident	1 (16.67)	6 (27.27)	7 (25)
	Fall from height	0	6 (24.27)	6 (21.43)
	Motor vehicle collision	1 (16.67)	0	1 (3.57)
	Crush injury	1 (16.67)	0	1 (3.57)
Abdominal exploration: n (%)	Positive findings	4 (66.67)	3 (13.64)	7 (25)
	Negative findings	0	1 (4.55)	1 (3.57)
	Not performed	2 (33.33)	18 (81.82)	20 (71.43)
Intra-abdominal injury confirmed by abdominal exploration: n (%)	Intra-abdominal vascular	1 (25)	2 (66.67)	3 (42.86)
	Retroperitoneal hematoma	2 (50)	1 (33.33)	3 (42.86)
	Bladder	2 (50)	0	2 (28.57)
	Spleen	1 (25)	0	1 (14.29)
	Liver	1 (25)	0	1 (14.29)
	Small bowel and mesentery	1 (25)	0	1 (14.29)
	Colon and rectum	0	1(33.33)	1 (14.29)
	Kidney	0	1(33.33)	1 (14.29)

significant intra-abdominal injury among the included articles (Figs. 2 and 3). The definition of significant intra-abdominal injury in each study was different and determined according to the confirmation test used in the study. Steffen et al. and our results were confirmed as FAST positive with significant intra-abdominal injury identified during abdominal exploration, but other studies used varies confirmation tests such as CT, diagnostic peritoneal lavage (DPL), and abdominal exploration. The Deek's funnel plot showed that there was no publication bias ($p = 0.62$) (Fig. 4), and there was no evidence of a risk of bias in the assessment using the ROBINS-I tool.

4. Discussion

Major pelvic fractures have concomitant intra-abdominal injuries and/or intrapelvic cavity organ injuries in 30.7% of patients, and more severe pelvic fractures are associated with higher rates of concomitant intra-abdominal organ injuries [3]. When injured patients have unstable hemodynamics, we have no time to identify the source of the bleeding to determine whether the source is concomitant intra-abdominal injuries or active bleeding from the pelvic bony fractures or pelvic arterial hemorrhage. The first option in the investigation of intra-abdominal injury in trauma patients is FAST, according to the ATLS guidelines, to detect intra-abdominal free fluid, which could indicate hemoperitoneum or uroperitoneum. FAST can detect free fluid but cannot identify the originating injury, which prevents surgeon from determining the accurate definitive treatment. However, presence of pelvic fractures is an important clinical risk factor limiting the accuracy of FAST because free fluid from a major pelvic fracture could be retroperitoneal hematoma entering the transperitoneal plane into the peritoneal space or intraperitoneal free fluid (hemoperitoneum or uroperitoneum) caused by significant intra-abdominal organ injury [5].

Currently, the investigation of choice in major pelvic fractures

Table 3
Pooled demographic data from the 6 studies and the Acute Care Surgery service at Ramathibodi Hospital.

N = 677		FAST positive
Age (years) Mean (SD): (min, max)		40.88 (3.60): (36.8, 45.1)
Sex: n (%)	Male	437 (64.55)
	Female	240 (35.45)
Overall mortality: n (%)		36 (11.65)
ISS score Mean (SD): (min, max)		32.50 (10.93): (24.1, 50)
Mechanism of injury: n (%)	Motor vehicle collision	267 (44.72)
	Fall from height	64 (13.41)
	Motorcycle collision	40 (13.69)
	Pedestrian	25 (8.33)
	Bicycle accident	25 (13.50)
	Assault	2 (0.93)
Intra-abdominal injury diagnosed using whole-abdomen computed tomography and abdominal exploration: n (%)	Spleen	47 (6.94)
	Liver	31 (4.58)
	Small bowel and mesentery	23 (3.40)
	Bladder	13 (1.92)
	Colon and rectum	9 (1.33)
	Kidney	5 (0.74)
	Diaphragm	5 (0.74)

Table 2
Summary of the included studies.

Publication (year)	Study design	Number of cases	Definition of major pelvic fracture	Mortality rate (%)	Confirmation test of significant intra-abdominal injury for positive FAST
Steffen Ruchholtz (2004) [13]	Prospective	80	-Type B, C of AO/SICO classification [19]	NA	-Abdominal exploration
Vivek S. Tayal (2006) [14]	Retrospective	87	-Type A2, B, C of Tile classification [9]	NA	-Diagnostic peritoneal lavage (DPL) -Whole-abdomen CT scan -Abdominal exploration
Randall S. Friese (2007) [5]	Retrospective	96	NA	4.85	-Whole-abdomen CT scan -Abdominal exploration
Jonathan Charbit (2012) [15]	Retrospective	185	-Type B, C of Tile classification [9]	5.82	-Abdominal exploration
Diederik O.F. Verbeek (2014) [16]	Retrospective	80	-AP II, III, LC III, vertical shear, combined of Young-Burgess classification [10]	NA	-Whole-abdomen CT scan -Abdominal exploration
Nicole Townsend Christian (2018) [17]	Retrospective	81	NA	NA	-Whole-abdomen CT scan -Abdominal exploration
Present data (2019)	Retrospective	28	-Type B, C of Tile classification [9] -AP II, III, LC II, III and vertical shear of Young-Burgess classification [10]	0.97	-Abdominal exploration

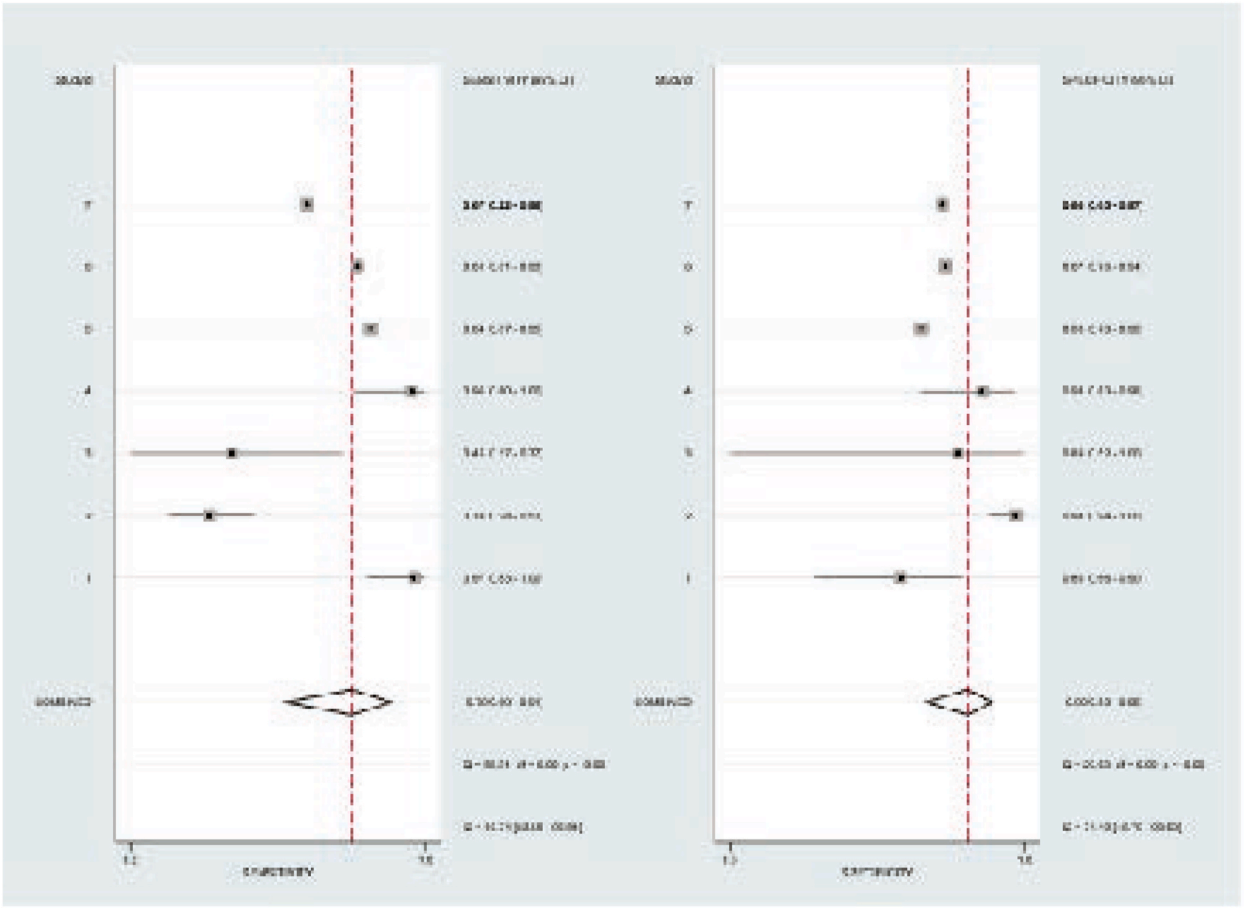

Fig. 2. Meta-analysis of pooled sensitivity and specificity of FAST performed in patients with traumatic major pelvic injury showing heterogeneity between studies because of the different definitions of significant intra-abdominal injury.

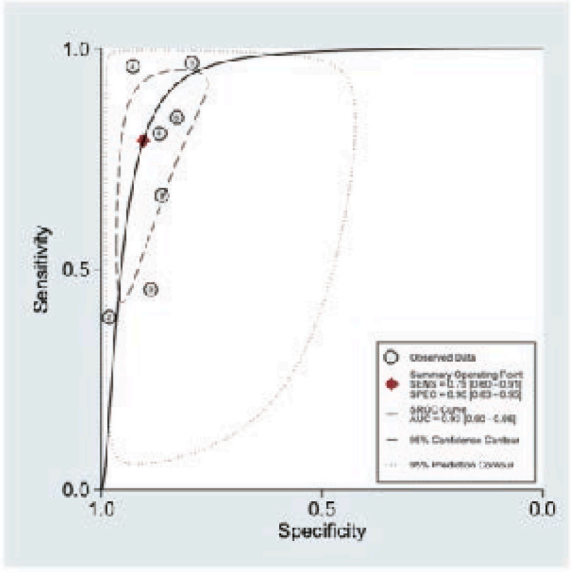

Fig. 3. A graph of the areas under the receiver operating characteristic curves for the pooled sensitivity, specificity, and accuracy of FAST performed in traumatic major pelvic injury showing pooled sensitivity, specificity, and accuracy of 79%, 90%, and 93%, respectively.

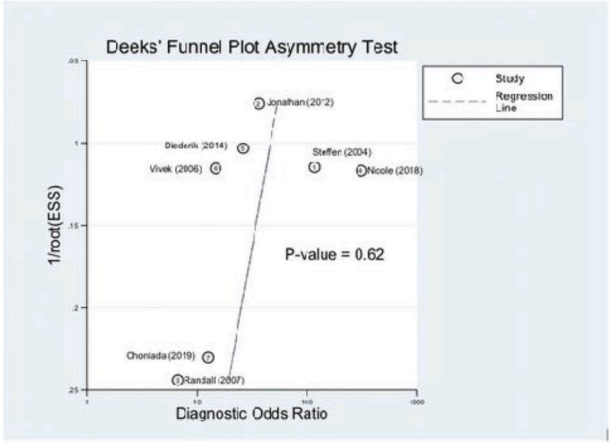

Fig. 4. A funnel plot showing no publication bias between the included studies.

patients with stable hemodynamics and suspected concomitant intra-abdominal injury is whole-abdominal computed tomography (CT) scan or whole-body CT scan to precisely identify the injured organ before determining the definitive treatment. However, CT is rarely possible in hemodynamically unstable patients, which creates a surgical dilemma for surgeons who must determine whether concomitant intra-abdominal injury is present using only FAST. Therefore, in this study, we performed a meta-analysis to determine the accuracy and reliability of FAST to detect significant intra-abdominal injury, defined as an injury

requiring abdominal exploration, with major pelvic fracture, especially in patients with unstable hemodynamics, to help surgeons make decision whether to perform abdominal exploration before proceeding to embolization in patients with suspected pelvic arterial hemorrhage.

In the event that the non-therapeutic laparotomies is performed, the exploration may lead to loss of pelvic tamponade and massive exsanguinous pelvic bleeding can occur; a double jeopardy. In patients with major pelvic fracture, no published studies have confirmed the idea of double jeopardy, but Berg et al. reported this concept in the management of thoraco-abdominal trauma in which open thoracotomy rarely identifies injuries; however, abdominal injury occurred more often and required exploration [12]. Missed sequenced exploration causes detrimental effects, but missed injury also leads to bad outcomes. In practical practice of this situation, many of surgeons decided to made an incision of abdominal exploration from upper abdomen down to only mid lower abdomen to avoid losing of pelvic tamponade. This approach should be always preferred exactly to avoid causing more harm. Also, hybrid angio-suites are currently available in many trauma centers, where laparotomy and angiography can be done simultaneously with better results.

From our Acute Care Surgery service data, overall mortality in patients with major pelvic fractures was low as 10.71% due to our hospital is a tertiary and referral centre. A list of concomitant injuries is shown in Table 1. The average ISS score was 25.92. In patients with major pelvic fractures and unstable hemodynamics, if FAST is positive for free peritoneal fluid, we immediately performed abdominal exploration with the expectation of finding intra-abdominal injuries requiring surgical control. We performed external fixation of pelvic fractures immediately prior to abdominal exploration. The accuracy of positive FAST results in detecting significant intra-abdominal organ injury was 82.14%, which might be considered high to reliable; PPV was 66.67%. This accuracy of FAST indicates a correlation between positive FAST results and the presence of significant intra-abdominal injury requiring surgical control. In our meta-analysis of five retrospective, one prospective study, and our data, the pooled overall mortality rate from major pelvic fractures was as 11.65% which similar to our results. The pooled accuracy was 93%, and PPV was 80% which is higher than our results and enough to reliably indicate that patients with major pelvic fracture and positive FAST results have significant intra-abdominal injury; therefore, abdominal exploration is required. We attempted to identify the significant factors associated with FAST accuracy, using meta-regression, which showed no significant effect of the ISS and mechanism of injury on FAST accuracy.

As shown in Fig. 2 and Fig. 3, there was heterogeneity in the results because of differences in the definition and confirmation test of "significant intra-abdominal injury" to confirm the accuracy of FAST, in the included articles. A summary of the different confirmation of significant intra-abdominal injury is shown in Table 2. Confirming FAST accuracy using DPL does not help surgeons decide whether to perform abdominal exploration because DPL cannot identify organ injuries that might be successfully treated nonsurgically. CT scan and abdominal exploration can identify which intra-abdominal injury need surgically control. Therefore, from our data, we used the findings in patients who underwent abdominal exploration to confirm FAST accuracy for detecting significant intra-abdominal injuries with the expectation of finding injuries requiring surgical control. Steffen et al. also defined significant intra-abdominal injury as injury requiring surgical control. The authors found that in patients with major pelvic fracture with positive FAST results who underwent abdominal exploration, injuries requiring surgical repair were present in up to 98% of patients, indicating a strong correlation between positive FAST results and significant intra-abdominal injury.(13) Regardless of patients' hemodynamics, this finding indicates that abdominal exploration is necessary in patients with major pelvic fracture with positive FAST results. Nicole et al. also reported the reliability of FAST to detect significant hemoperitoneum in patients with life-threatening pelvic fractures, to determine the role of resuscitative endovascular balloon occlusion of the aorta. (17) The authors reported a false negative result of only 2%. These results indicate that FAST is sufficiently accurate to require abdominal exploration in hemodynamically unstable patients with major pelvic fracture with free fluid identified on FAST. Vivek et al. compared FAST results with findings from CT, DPL, and surgical exploration and found a PPV of 72.4%, but the authors did not report the subgroup of surgical exploration results. (14).

Sixty percent of patients with initial FAST negative results still undergo abdominal exploration for injuries such as diaphragmatic injury or high suspicious of hallow viscus organ injury when no fluid is detected on FAST. This finding was reported by Ballard et al. who found that even with initial negative FAST results in major pelvic fractures, patients required further investigations, because 31% required abdominal exploration later [18]. These occult injuries were diagnosed by CT scan, and 4/13 were false negative patients who required abdominal exploration because of grade IV liver injuries, bladder perforations, and diaphragmatic ruptures. Randall et al. also supported this idea and proposed that in patients with stable hemodynamics and negative FAST results, further investigation should be performed because the false negative rate for FAST for hemoperitoneum was 19.3%, indicating failure of FAST accuracy to detect significant intra-abdominal injury [5]. Furthermore, the authors found a low sensitivity of FAST of 26% to detect significant intra-abdominal injury, and the sensitivity did not improve even after a subgroup analysis in patients with shock [5]. Therefore, in major pelvic fracture with initial FAST negative results, whole-abdomen CT still should be performed to detect occult injury, such as diaphragmatic injuries or hallow viscus organ injuries, which could be missed. The limitation of this study is most of the article included in meta-analysis are retrospective study. There is small number of cases from our institution. Further prospective study with larger number of cases should be perform.

5. Conclusion

Our meta-analysis revealed that FAST in major pelvic fracture accurately detected significant intra-abdominal hemorrhage. Using FAST in the presence of unstable hemodynamics, we can decide to perform abdominal exploration with the expectation of finding significant intra-abdominal hemorrhage require surgically control. In hemodynamically stable patients, further investigation such as whole-abdomen CT scan should be considered to identify occult injuries.

Declarations

Ethics approval and consent to participate.

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Conflict of interest

The authors declare that they do not have conflict of interest; **Ethic approval:** Ethic approval has permitted by the ethical committee of Mahidol University.

Abbreviations

ATLS	According to the Advanced Trauma Life Support
FAST	Focused Assessment with Sonography for Trauma
CT	computed tomography
APC	anteroposterior compression

LC	lateral compression
ISS	injury severity score
DPL	diagnostic peritoneal lavage

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.amsu.2020.10.018.

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