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ORIGINAL ARTICLE

CT-guided tractography is a safe and complementary diagnostic tool in the management of penetrating abdominal trauma

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KEYWORDS
Computed tomography guided tractography;
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Negative laparotomy

Summary *Background/Objective:* Despite extensive published research, the surgical approach to penetrating abdominal trauma patients is still under debate. Computed tomography-guided tractography (CTT) is an imaging modality in which water soluble iodinated contrast medium is administered into the site of the injury in the CT unit. The aim of this study was to determine the diagnostic accuracy of the CTT.
Methods: A retrospective evaluation was made of patients admitted to the Emergency Department with penetrating abdominal trauma and who underwent CTT. Contrast enhanced abdominal CT and CTT reports, surgical findings and clinical results were examined.
Results: Evaluation was made of a total of 101 patients comprising 89 males (88.1%) and 12 females (11.9%). CTT was determined to have 92.8% sensitivity, 93.6% specificity, 97% positive predictive value, and 85.5% negative predictive value. In 27 patients (26.7%) where the CTT indicated passage through the peritoneum, no parenchymal organ injury was present. Only one patient (2.9%) without peritoneal penetration on CTT had organ injury at exploration. No procedure-related morbidities developed.
Conclusion: CTT is a safe imaging modality for the evaluation of hemodynamically stable patients. Compared to other imaging modalities, there is clearer demonstration of whether or not the peritoneum is intact. However penetration on CTT does not exactly correlate with organ injury.

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1. Introduction

Penetrating anterior abdominal stab injury is an important type of trauma considering the increasing number of patients faced with civil urban violence. Management and intervention of penetrating injuries has changed in the past years from routine/mandatory laparotomy to a selective/conservative approach,[1–3] because unnecessary, negative laparotomy/non-therapeutic trauma laparotomy rates range from 23% to 53%, morbidity rates range from 2.5% to 41% and the mortality rate rises to 5%.[2–5] The mandatory laparotomy strategy was abandoned due to possible complications. Small bowel obstruction, pneumothorax, ileus, delirium, wound infection, myocardial infarction, visceral injury, hernia, wound dehiscence etc. and even death have been reported secondary to unnecessary laparotomy.[2,6] Non-therapeutic laparotomies extend the duration of the hospitalization and also increase hospital costs.

Selective, non-operative management of penetrating abdominal injuries has successfully minimized the number of non-therapeutic laparotomies for hemodynamically stable patients.[2] Careful, serial physical examinations are important in the follow-up of these patients. IV contrast-enhanced abdominopelvic Computed Tomography (CT) should be considered as a diagnostic tool to decide the management approach. Local wound exploration (LWE), diagnostic peritoneal lavage (DPL) and use of ultrasonography (US) are the diagnostic methods in the management of penetrating abdominal trauma.[1,2] Diagnostic laparoscopy is also considered in the evaluation of left-sided diaphragmatic injuries.[2,7]

Management of a penetrating abdominal injury depends on the early diagnosis of life-threating visceral injury and decreasing the incidence of unnecessary laparotomies. Detection of peritoneal violation is also an important key point. Bruckner et al. first described Computed tomography-guided tractography (CTT) techniques to delineate the entire path of a tangential bullet injury by filling the tract with water-soluble contrast before the CT scan.[8] Indeed CTT is not a first step diagnostic tool as it is a part of CT and can be only a complementary part for CT. Despite extensive published research that has focused on penetrating abdominal trauma and the presence of trauma guidelines, the surgical approach and management of penetrating abdominal trauma patients is still under debate.

The aim of this study was to determine the diagnostic accuracy of the CTT technique and its effect on the management of penetrating abdominal trauma.

2. Materials and methods

This retrospective study was performed at a training and research hospital of a University after obtaining the approval of the Ethics Committee. The data were collected between 2011 and 2016. Patients with indications for emergent laparotomy were excluded. The study included hemodynamically stable penetrating abdominal trauma patients with anterior stab wounds, who also underwent CTT during IV contrast enhanced abdominal CT scan. Data were retrieved from the patient files, including patient age, gender, trauma mechanism, physical examination findings, US and CT reports, operation findings and survival of the patients. Patients were excluded from the study if they were hemodynamically unstable (systolic blood pressure $<$90 mmHg, heart rate$>$100 beats per minute or patients who were accepted as unstable with clinical evaluation and underwent emergent laparotomy), were unconscious, if there was evisceration, acute hemorrhage, peritonitis, stab wounds with multiple tracts or data and images were not available, and as well as if CTT procedure was not applied.

2.1. The technical aspects of CTT

The routine technique which has been used for CTT in our hospital as follows: first of all the site of stab wound was disinfected with a disinfectant solution and local anesthesia was deeply applied around the stab wound. A Foley catheter (depends on the size of wound but usually with the size of 10—12 F) was inserted into the deepest place of the wound and a balloon was slowly inflated while the patient was lying in the supine position to prevent leakage of the contrast agent. Then, 50—100 ml of contrast agent was injected into the tract of the wound using the Foley catheter, iopromide (300 mg iodine per mL; iopromide, ultravist; Bayer schering pharma AG, Berlin, Germany) by a surgeon (Fig. 1). There was no obligation for using a total 50—100 ml of the contrast agent. If the patient complained of pain or resistance to the injection of contrast agent was felt, the injection was stopped at that point and no more contrast agent was injected. To prevent the contrast agent

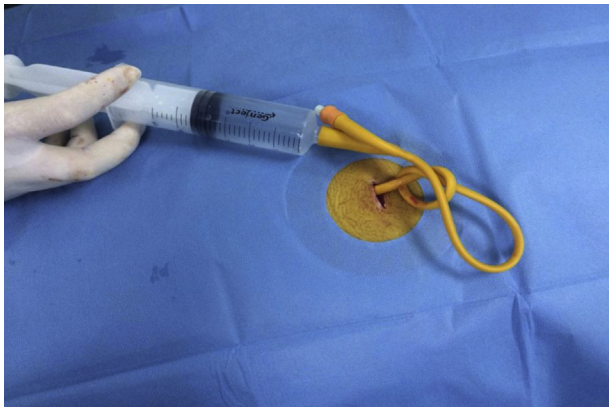

Figure 1 Preparation of a patient for CT tractography.

from leaking out of a large stab wound, the skin was clamped manually with needle holders if necessary. Imaging of the patients was performed using optima CT660, GE Healthcare with a slice thickness of 2.5 mm and 1.25 mm sagittal-coronal reformats. Then, approximately 80 cc IV non-ionic water-soluble 300 mg I/ml contrast medium was injected at 2.5 ml/s injection rate. Since CT scans are sufficient for CTT evaluation, there is no need for a separate imaging for this procedure. Thus, patients are not exposed to additional radiation dose during CTT procedure. Images were evaluated by a radiologist and a trauma surgeon (Figs. 2 and 3)

2.2. Terminology for laparotomy

In this study, 'Therapeutic trauma laparotomy (TTL) was defined as a laparotomy performed in a trauma setting after an injury had been identified by screening and a therapeutic maneuver had been applied.[6] A 'negative trauma laparotomy' (NTL) was defined as one in which the patient undergoing exploration appeared to have no abdominal injuries. A 'non-therapeutic trauma laparotomy' (NTTL) was a laparotomy during which only minor injuries that did not require any surgical treatment were found.[6,9]

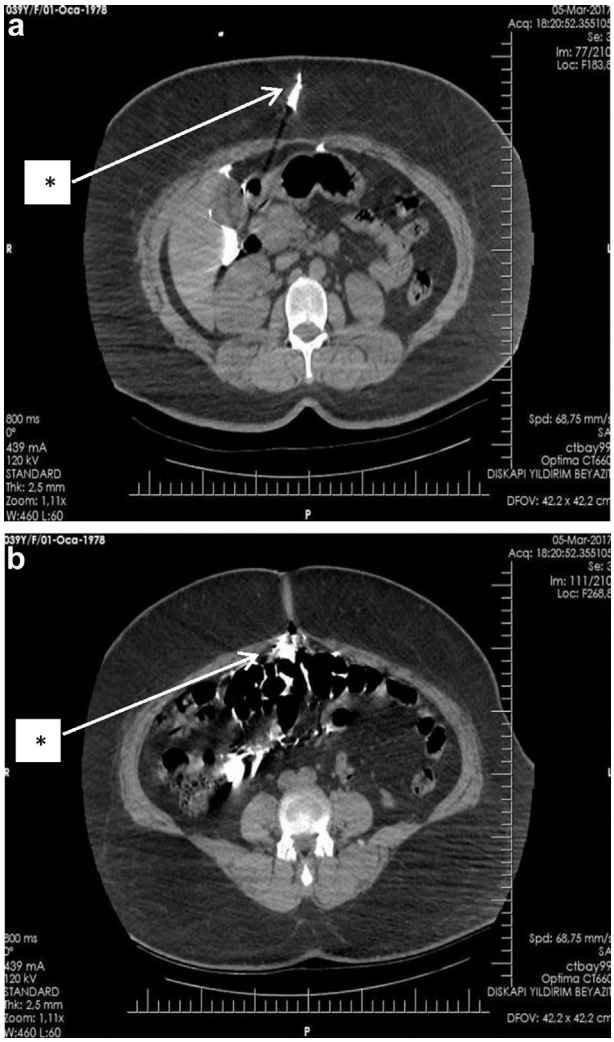

Figure 2 CTT images of a 39-year-old male patient which demonstrated peritoneal violation. Subcutaneous tractus (*) (a), and intra-abdominal passage of free contrast agent (*) (b) are indicated. The patient was treated with primary intestinal repair.

2.3. Statistical analysis

Statistical analysis was applied using IBM SPSS for Windows Version 22.0 software. Sensitivity, specificity, positive predictive value, and negative predictive value were calculated for CTT method to evaluate their power to predict the surgical results. Sensitivity is the probability that a test will indicate 'disease' among those with the disease. Specificity is the fraction of those without disease who will have a negative test result. Positive predictive value is the chance that a person with a positive test truly has the disease and negative predictive value is the chance that a person with a negative test truly has not got the disease.

3. Results

Evaluation was made of a total of 101 patients with a mean age of 32.6 $\pm$ 12.7 years, comprising 89 males (88.1%) and 12 females (11.9%). The demographic features of the patients are shown in Table 1.

CT combined with CTT were applied to all the 101 patients included in the study. The results were reported as normal in 60 (59.4%) patients in whom CT was applied. Of the total 101 patients with CTT, the contrast agent was seen to pass to the peritoneum (CTT positive) in 67 (66.3%) patients and not to pass to the peritoneum (CTT negative) in 34 (33.7%) patients (Table 2).

Forty (59.7%) of the 67 CTT positive patients had TTL due to organ injury, 25 (37.3%) of them had NTL & NTTL as they had peritoneal violation with no abdominal injuries or had only minor injuries that did not require any surgical treatment, and two (2.9%) of them also had NTL as they had no peritoneal violation at exploration laparotomy. Five (14.7%) of the 34 CTT negative patients underwent surgery because of symptoms suggesting peritonel irritation. Although all these five CTT negative patients had peritoneal violation on inspection during surgery, four of them (11.8%) had NTL (no organ injury) at exploration laparotomy. Only one of those CTT negative patients (2.9%) had TTL (organ injury) at exploration. Hollow viscus injury was diagnosed at exploration of this patient. Other 29 (85.3%) of the 34 CTT negative patients did not need surgery and was discharged after 24—48 h of follow up. Totally 27 (40%) of the 67 CTT positive and 4 (11.8%) of the 34 CTT negative patients had NTL & NTTL whereas 40 (59.7%) of the 67 CTT positive and 1 (2.9%) of the 34 CTT negative patients had TTL.

In 40 patients with organ injury underwent TTL, the injury was determined in a single organ in 34 (85%) patients and in 2 organs in 6 (15%) patients. Of the total 46 organ injuries, the most commonly injured organ was the small intestine in 18 (39.1%) cases, followed by the stomach in 10 (21.7%), the colon in 10 (21.7%), the liver in 6 (13%) and the diaphragm in 2 (4.3%) cases. Of the 6 (15%) patients with multiple organ injury, the injuries were of the small intestine and colon in 3 cases, the liver and stomach in 1, the

Figure 3 A 48 year-old-male patient without evidence of peritoneal violation.

Table 1 The demographic features of the patients.

Age (years)	Mean ± SD	Min – Max
Female	31,8 ± 8,8	18–51
Male	32,7 ± 13,2	17–90
Total	32,6 ± 12,7	17–90
Gender	n	%
Female	12	11.9
Male	89	88.1

liver and small intestine in 1, and the stomach and small intestine in 1.

CTT was calculated to have 92.8% sensitivity, 93.6% specificity, 97% positive predictive value, and 85.5% negative predictive value (Table 3). No CTT procedure related morbidities or surgical complications were observed in any patient.

4. Discussion

For hemodynamically unstable patients with organ injury because of penetrating abdominal trauma, the diagnostic and treatment strategies must be extremely well known.[8] With early diagnosis and appropriate treatment, morbidity and mortality in this patient group can be reduced. Nevertheless, a significant proportion of patients with penetrating abdominal trauma are hemodynamically stable and can be treated conservatively. There are studies in literature that have reported that patients with parenchymal organ injury can be followed up without surgery.[10]

Table 2 The diagnostic methods of the patients and surgical results of CT combined with CTT technique.

Methods	Findings	n	%
CT	Normal	60	59.4
	Intra-abdominal free fluid (+)/Parenchymal organ injury (+)	41	40.6
CTT	**Peritoneal Violation (PV): (CTT +)**	67	66.3
	Concordance between CTT + and Surgical Exploration (***n = 67***)		
	Organ injury	40	59.7
	PV but no organ injury	25	37.3
	No peritoneal violation	2	2.9
	No Peritoneal Violation (NPV): (CTT -)	34	33.7
	Concordance between CTT - and Surgical Exploration (***n = 34***)		
	No need for laparotomy	29	85.3
	PV but no organ injury	4	11.8
	Organ injury at laparotomy	1	2.9

PV: NPV: No Peritoneal Violation.

Table 3 Comparison of CTT with surgical exploration and diagnostic value of CTT for peritoneal penetration.

		Surgery, n			
		PV, OI (+)	PV, OI(−)	NPV	Total
CTT, n	PV	40 *True positive*	25 *True positive*	2 *False positive*	67
	NPV	1 *False negative*	4 *False negative*	29[a] *True negative*	34
	Total	41	29	31	101
	True positive	False positive	False negative	True negative	
n	65	2	5	29	101
Sensitivity	Specificity	Positive predictive value		Negative predictive value	
92.8%	93.6%	97%		85.5%	

PV: Peritoneal Violation, NPV: No Peritoneal Violation, OI: Organ Injury.
[a] No need for laparotomy, discharged without s.

Which method or methods should be used in making an early and correct diagnosis of hemodynamically stable patients with a penetrating abdominal trauma is of great importance. Furthermore, the cases with peritoneal violation with clinically and radiologically symptoms need more attention. Peritoneal irritation positive sypmtoms of physical examination and radiologically free fluids, free gas in abdominal cavity may lead to surgical intervention. Accordingly, the identification of peritoneal violation is of vital importance together with other factors in the decision for surgery. CTT is a rapid, simple and safe imaging method that can be applied immediately before or during CT in patients with penetrating abdominal trauma who are hemodynamically stable. If the peritoneum is seen to be intact on CTT, the patient is not operated on, is monitored for a short time and is then discharged from hospital.[11,12]

Although it is not a new technique, there are few studies in literature related to CTT. However, in recent years, the efforts of clinicians to reduce the rates of negative and non-therapeutic laparotomies have led to a search for new imaging methods and this has created an increase in the number of studies evaluating the guidelines. Similarly, several studies have started to investigate the efficacy of CTT in the Emergency Department (ED). Even LWE, which is widely used in the evaluation of peritoneal violation, is not recommended in the guidelines for the management of some penetrating abdominal injuries because of reported developments in imaging technology and high rates of negative laparotomy.[2,13]

To the best of our knowledge, the current study has the highest number of patients of studies in literature investigating the efficacy of CTT. In a study of 41 patients by Bansal et al, it was reported that the superiority of CTT over conventional imaging methods was not known but it was a safe and effective method in posterior abdomen and flank injuries.[11] Uzunosmanoglu et al examined 73 patients and reported that in the determination of peritoneal violation, the diagnostic performance of CTT was 100% specificity, 100% sensitivity, 100% positive predictive value (PPV), 100% negative predictive value (NPV) and 100% accuracy.[12] In a series of 20 patients, Ertan et al concluded that surgery was not necessary in patients where peritoneal penetration was not seen on CTT, and the need for surgery could be determined with 90% accuracy with the CTT technique.[14] However, it has also been reported in literature, that unlike the results of Uzunosmanoglu et al, there could be cases of false negative peritoneal violation because of technical problems.[14,15] We agree with Ertan et al and Uzunosmanoglu et al about that CTT has high PPV and NPV for peritoneal penetration but decision of surgical exploration must depend on multiple factors. Indeed when CTT is negative, follow up without surgery may be safe as we also found that only one of 34 CTT negative patients had organ injury. This patient was easily diagnosed during careful follow up. However CTT positive should not mean an absolute need for surgery, it only proves high possibility of peritoneal penetration. Over forty percent (27 of 67) combined rate of NTL and NTTL in CTT positive patients was a disappointment in our study which means that CTT should only be a complementary diagnostic tool.

According to the findings of the current study, there were 5 (4.9%) false negative patients with negative peritoneal violation on CTT and abdominal penetration at. Patients under the influence of alcohol or drugs constitute problems for the CTT technique. Establishing co-operation with these patients can be a problematic situation for clinicians.[15] Despite the application of local anesthetic in our clinical practice, there is an awareness that both the stab wounds and the CTT technique are painful for patients. Due to muscle rigidity caused by pain in some patients, the passage of the contrast agent may be prevented and this can lead to a false negative result.[15] Other factors which may cause a diagnostic dilemma include sharp objects such as a screwdriver, small stab wounds, a diagonal stab tract, a thin, long or laterally located tracts, constriction of the muscles, heavy musculature and increased body mass index.[15] These factors may prevent the contrast agent from passing through the stab wound during tractography and may also help to protect the abdominal wall during stabbing. In this study 5 (14.7%) CTT negative of 34 patients underwent surgery because of other factors. These five patients had peritoneal violation but only one of them (2.9%) had organ injury at exploration and underwent therapeutic laparotomy. Follow up for the CTT negative patient is safe when other diagnostic tools and physical examination is concordant with it.

According to the findings of the current study, there were 2 (1.9%) false positive patients with positive peritoneal violation on CTT and negative operation findings. Non-compliance of the patient may also cause inappropriate

delivery of the contrast agent, or spillage of the contrast agent over the body resulting in false positivity. Moreover, as reported in previous studies, there may be reasons such as artefacts or remnants of contrast agent. The use of diluted contrast agent in particular may lead to artefacts seen on the images and under emergency conditions, these can be evaluated as causing false positive results. In the 2 false positive patients of the current study, the image was determined to have originated from artefacts when the technique evaluation was later made by the radiologist. In contrast to the results of Uzunosmanoglu et al, the current study is the first in literature to have presented false negative and false positive results and evaluations.[12,14]

In the current study, NTL and NTTL was applied to 27 (27%) patients with positive peritoneal violation and no organ injury. Kevric et al reported a rate of 21% NTL and the rate of peritoneal violation was not absolutely equivalent to intra-abdominal visceral injuries.[16] When the results of the technique applied in the current study were evaluated, a finding requiring discussion is that no parenchymal injury was determined in the laparotomy applied in 27 (27%) patients with peritoneal passage of the contrast agent. This NTL rate is not actually a high value according to different algorithms applied in different centers. However, it is thought that the perception that determination of peritoneal violation on CTT increases the likelihood of parenchymal injury directs the decision of clinicians for the surgical approach to be taken. On the other hand laparoscopic exploration may be an alternative for stable patients with penetrating abdominal trauma and organ evisceration. Laparoscopic management is feasible, has a high accuracy in identifying intra-abdominal injuries, provides all benefits of minimal invasive surgery, and avoids NTTL.[17]

In accordance with reports in literature, no morbidity related to the technique applied or the passage of contrast agent to the peritoneum was observed in any of the patients in the current study. Furthermore high rates of sensitivity, specificity, PPV, and NPV were determined for CTT in the current study. These results show that CTT is a method which can be used safely in the clinic. The location

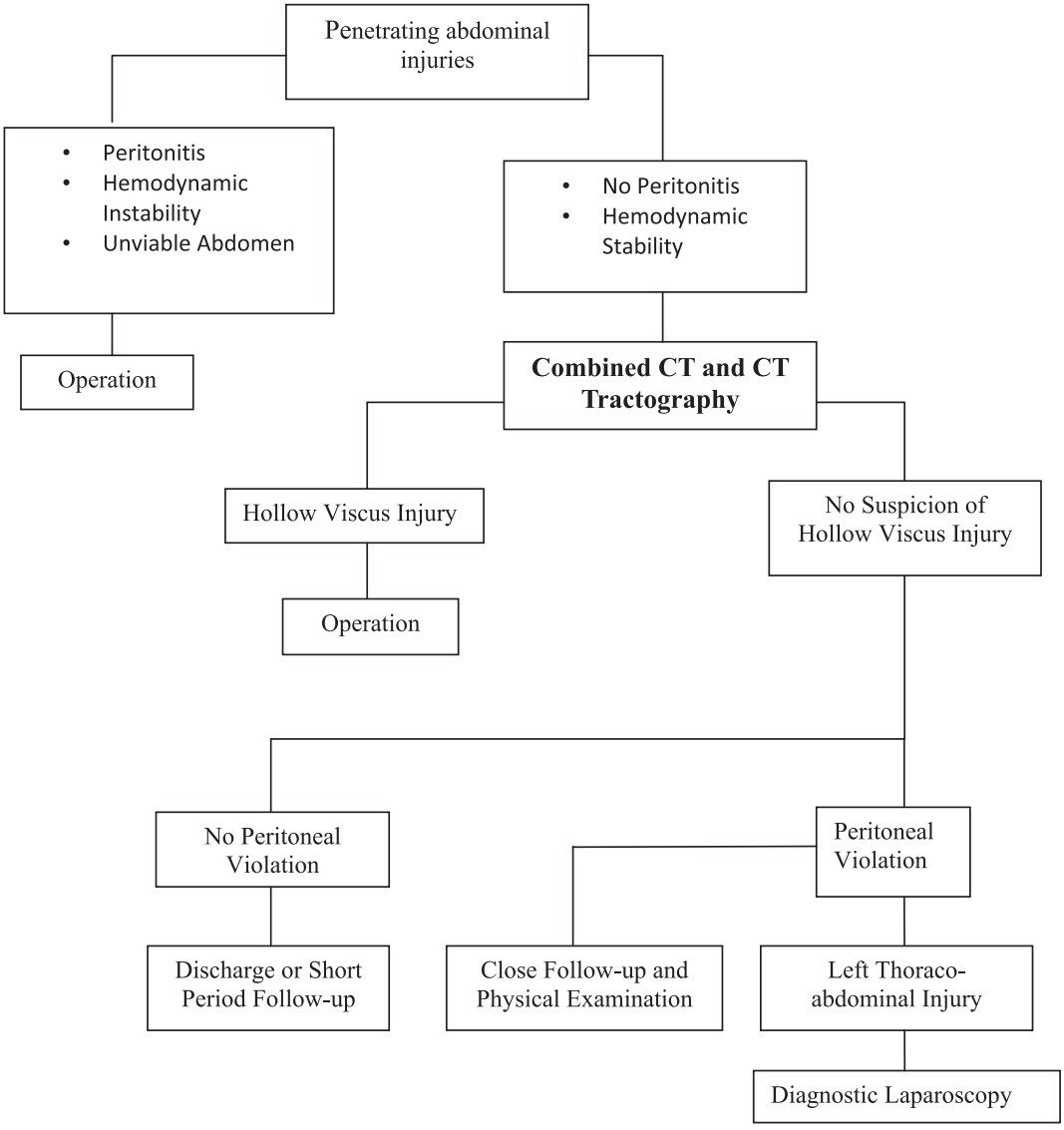

Figure 4 Proposed algorithm of penetrating abdominal trauma including the CTT.

of CTT in penetrating abdominal trauma patients is summarized in Fig. 4.

5. Conclusion

In patients with penetrating abdominal trauma, CTT is an extremely effective method in the determination of peritoneal violation. However penetration on CTT does not correlate with organ injury. Approximately forty percent combined rate of negative and NTTL in CTT patients demonstrate the importance of other factors. When supported with serial physical examinations and imaging methods, NTL rates could be reduced. On the other hand follow up for CTT negative patient may be a safe option when also combined with physical examination and other diagnostic tools.

Conflict of interest

The authors have no conflict of interests to declare. This study was presented in the oral presentation session at the Annual Scientific Meeting of the European Society of Emergency Radiology/British Society of Emergency Radiology Congress, London, UK, April 25—26, 2017.

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