ACCURACY OF CONVENTIONAL IMAGING OF PENETRATING TORSO INJURIES IN THE TRAUMA RESUSCITATION ROOM

Running head: IMAGING IN PENETRATING TRAUMA

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ABSTRACT

Objectives: Chest X-ray (CXR), abdominal ultrasound, cardiac ultrasound and abdominal X-ray are the most frequently used imaging modalities for radiological evaluation of patients with penetrating torso trauma. The aim of this study was to evaluate the accuracy of these imaging modalities.

Methods: From January 2001 until January 2005, all consecutive patients with penetrating torso injuries presenting at the Emergency Department of a level 1 trauma center were included. Imaging modalities (chest/abdominal X-ray and abdominal/cardiac ultrasound), were compared retrospectively with a "gold standard" (i.e., CT or surgery within 2 hours after arrival) or outcome of conservative treatment. The accuracy of the imaging modalities was calculated.

Results: 318 patients were included. Based upon 299 CXRs, the sensitivity for diagnosing pneumothorax, hemothorax and subcutaneous emphysema was 71%, 63% and 61%, respectively. The sensitivity of abdominal ultrasound (n=229) to detect free abdominal fluid and/or intra-abdominal injury was 65%. The specificity, positive predictive value (PPV), negative predictive value (NPV), and accuracy of the two imaging modalities to detect any of the diagnoses mentioned were ≥ 87%. Cardiac ultrasound (n=31) did not show any false positive or false negative results for detecting cardiac effusion. Pneumoperitoneum was not seen on abdominal X-ray in 8 of 11 patients with perforation of a hollow organ.

Conclusions: Despite high specificity, PPV and NPV, a considerable number of lesions remain undetected following CXR and abdominal ultrasound due to moderate to inadequate sensitivity. Abdominal X-ray hardly provides additional information. Careful clinical monitoring of patients is mandatory, particularly when CT-scan or operative treatment is not indicated.

Key words: penetrating torso injury,diagnostic imaging, ultrasound, Chest X-ray, accuracy

INTRODUCTION

Although the numbers of gunshot wounds (GSW) and stab wounds (SW) in the Netherlands are not as high as those in many other nations, the incidence of patients with penetrating injury presenting to the Emergency Departments (ED) in the Netherlands is considerable and is rising steadily [1]. In general, all patients with penetrating trauma are directly presented to the ED by (helicopter) emergency services ((H)EMS). As a result of the implementation of Prehospital Trauma Life Support protocols (PHTLS®) and the scoop-and-run principles, prehospital times are very short for these patients, and increasing numbers of severely injured patients reach the hospital alive [2]. During trauma evaluation, different imaging modalities can be used. Clinical management strategies will be determined depending upon the imaging results. Insight into the accuracy of the imaging modalities that are used is therefore crucial.

The Advanced Trauma Life Support (ATLS®) course provides a guideline for systematic and structured acute evaluation of trauma patients in the ED. Imaging modalities as adjuncts during the initial assessment of patients with penetrating trauma include: Chest X-Ray (CXR), Ultrasound, Abdominal X-Ray (AXR), and Diagnostic Peritoneal Lavage (DPL) [3]. In this study hospital DPL has been replaced by Focused Abdominal Sonography for Trauma (FAST).

A perfect imaging modality shows signs and symptoms with 100% accuracy. Due to this perfect accuracy, the sensitivity, specificity, negative predictive value (NPV), and positive predictive value (PPV) will be 100%. Any deviation in accuracy may potentially lead to missed or incorrect diagnoses. A negative outcome of the abdominal ultrasound (no intraperitoneal fluid), for example, does not exclude other intra-abdominal injury, such as a diaphragm rupture or a perforation of a hollow organ [1,4]. For peritoneal violation the CT scan has a sensitivity of 97%, a specificity of 98% and an accuracy of 98% in patients with penetrating torso injury [5]. Due to this high accuracy, CT-scan is used in this study as one of the 'golden standards'.

Most studies evaluating the use of imaging modalities in trauma patients (mainly ultrasound) have investigated patients who sustained *blunt* trauma or combined patient populations that sustained either *blunt or penetrating* trauma [6-14]. Less is known about the accuracy of imaging means in patients with *penetrating* trauma only.

Doctors often fully rely on the conventional images made during the first assessment of a trauma patient with penetrating injury. Any missed diagnosis could be potentially lead to inadequate treatment. It is unclear to what extent diagnoses such as rib fractures or pneumothorax, which are easily seen on CT-scans, are missed when evaluating chest X-rays.
Therefore the aim of this study was to evaluate the reliability of the most commonly used conventional imaging modalities (CXR, AXR, abdominal/cardiac ultrasound) in the initial assessment of patients with *penetrating* torso injury, by determining their sensitivity, specificity, positive predictive value, negative predictive value, and accuracy for specific diagnoses.

METHODS

Study Design

A retrospective chart review of patients presented to the Emergency Department (ED) with penetrating torso injury during 4 consecutive years was performed, in order to evaluate the imaging modalities used during the primary survey. This study received approval of the Local Medical Ethics Committee of the Erasmus MC, Rotterdam, the Netherlands.

Study Setting and Population

This study was conducted at the ED of a 1.200+ bed level I trauma center, the Erasmus MC, located in Rotterdam, in the South Western part of the Netherlands, and serving a population of 4.9 million inhabitants. Annually, over 23,000 patients visit the ED. From January 2001 until December 2004, all consecutive trauma patients aged over 14 years who presented to the ED with penetrating injury to the torso were included. The penetrating injuries were caused by stab- or gunshot wounds. The torso was defined as the region between the clavicles above and the inferior gluteal crease below. Patients who died immediately in the ED without any imaging performed, or who were transferred to or from another hospital were excluded.

Study Protocol

CXR, AXR and ultrasound (as part of the FAST exam) were performed on indication during initial assessment to determine the degree of severity of the injuries of these patients and to determine if there was an indication for intervention or admission. CXR was performed with the patient in supine position. All patients with stab wounds underwent CXR and ultrasound according to the ATLS® guidelines [3]. Patients with gunshot wounds additionally got an AXR to detect and localise the bullet(s). Cardiac ultrasound was performed on indication, for example in patients with a penetrating wound in the left chest with signs or suspicion of a cardiac tamponade.

The patient’s vital data and imaging results were extracted from the Rotterdam Trauma Registry and the Hospital Medical Files. The first CXR, (abdominal and cardiac) ultrasound, and AXR, obtained directly upon presentation to the ED, were compared with one of the two entities with high diagnostic accuracy (laparotomy/ thoracotomy or CT-scan), within two hours after arrival at the ED, or, if none of these were performed, with the final outcome of conservative treatment. The CT protocol used consisted of a blanco scan without contrast, and a venous and arterial phase scan after administration of i.v. contrast. Oral and/or rectal contrast was given when vascular injury did not seem to be first priority, and when suspicion of enteral injury arose. During trauma assessment the images were evaluated by the resident of Radiology, Surgery and Emergency Medicine. At a later stage, all reports were approved, and possibly improved, by a radiologist prior to incorporation into the patient file. The final, approved, reports were used for the current study.

Measurements

Reliability of CXR was evaluated for the signs of pneumothorax, pneumomediastinum, pneumoperitoneum, hemothorax, subcutaneous emphysema, enlarged mediastinum, rib fractures, lung damage (atelectasis, laceration, contusion, hematoma) and diaphragm rupture. Abdominal and cardiac ultrasounds were evaluated for detection of free abdominal fluid/ intra-abdominal injury and cardiac effusion, respectively. For AXR the accuracy to detect pneumoperitoneum and corpus alienum was determined.

The first endpoint is the diagnosis of a specific injury, based on conventional imaging modalities. The second endpoints are the findings based on laparotomy/thoracotomy or CT-scan. Parameters calculated for these findings are sensitivity, specificity, positive predictive value, negative predictive value, and accuracy for the conventional imaging modalities used in penetrating trauma. Results also include the consequences of missed-diagnoses for the patient, like thoracic drainage after a pneumothorax diagnosed on CT-scan after it was initially on chest X-ray.

Definitions/ Data Analysis

Table 1 illustrates and defines the calculation of sensitivity, specificity, PPV, NPV, and accuracy from numbers of TP, TN, FP, and FN. Findings that were present or absent on both the primary imaging modality and the CT-scan or upon surgical exploration were regarded as true positive (TP) or true negative (TN), respectively. Findings that were present on the primary imaging modality but absent in the control entity or were not present during clinical follow up, were regarded as false positive (FP). Absent signs on imaging that were present on a control entity or became clear during follow up (within 2 hours) were documented as false negative (FN). Accuracy was defined as the overall percentage of true positive and true negative findings. Adequate calculation of the sensitivity and PPV of a specific sign or diagnoses could be done if the number of TPs was ≥25. Likewise, the number of TNs had to be ≥25 to accurately assess specificity and NPV.

RESULTS

During the study period, 353 patients presented to the ED with penetrating torso injuries. 318 patients (mean age 33 years, standard deviation of 12) were included into this study; 33 female and 285 male; 253 patients with stab wounds and 65 with gunshot wounds. Thirty-five patients were excluded; 15 patients had at closer inspection injuries outside the torso region, 3 patients were under the age of 15, one patient was transferred to another hospital, and for 16 patients no results of the imaging investigations could be retrieved.

In total, 299 CXRs, 229 FASTs, 31 cardiac ultrasounds, and 36 AXRs were performed. Table 2 shows the results of the imaging investigations and summarizes the TPs, FPs, TNs, and FNs for each sign or diagnosis, with the calculated sensitivity, specificity, PPV, NPV, and accuracy.

Only pneumothorax, hemothorax, and subcutaneous emphysema on CXR and intra-abdominal fluid on abdominal ultrasound revealed sufficient TP values (≥25) to further determine sensitivity, specificity, PPV, NPV, and accuracy. Due to limited TP rates, sensitivity, specificity, PPV, NPV, and accuracy could not be calculated for the other signs and diagnoses on CXR, for pericardial effusion on cardiac ultrasound and for pneumoperitoneum and corpus alienum on abdominal X-ray.

The sensitivity for CXR to diagnose pneumothorax, hemothorax and subcutaneous emphysema was 71%, 63% and 61%, respectively. The specificity, PPV, NPV, and accuracy was ≥88%. Of the false negative CXR for pneumothorax, 59% of the patients (13/22) needed thoracic drainage. Of the false negative CXR for hemothorax, 31% (9/29) needed an intervention (7 chest tube thoracostomies and 2 thoracotomies). False negative result for subcutaneous emphysema and rib fractures alone had no consequences for the patients. Diaphragm ruptures were missed on the CXR in 10 out of 10 patients, of which 8 needed surgical repair. In 97% of the patients (28/29) with surgery for a perforation of a hollow organ, pneumoperitoneum was not seen at the initial CXR. In the 2 false positive CXR for pneumothorax this diagnosis was excluded by other CXR or CT, so the patients did not undergo thoracic drainage.

The sensitivity of abdominal ultrasound to detect intra-abdominal fluid was 65%, with a specificity, a PPV, a NPV and an accuracy of ≥87% (Table 2). In 63% (15/24) of the false negative abdominal ultrasounds, the patient needed surgical intervention for intra-abdominal injury (mainly liver laceration and/or bowel perforation). The four false positive ultrasounds had no surgical consequences for the patients. In these patients intra-abdominal fluid was excluded by a subsequent CT-scan.

Cardiac ultrasound to detect pericardial effusion showed no false negatives or false positives.

Pneumoperitoneum was not seen on abdominal X-ray in 8 of 11 patients with a perforation of a hollow organ diagnosed during surgery. A corpus alienum was detected in 8 of 9 patients who actually had a bullet in situ. The single false negative and false positive results for corpus alienum on the abdominal X-ray did not lead to surgical interventions. In the patients with false negative results for pneumoperitoneum in abdominal X-ray (8/11, 73%) all needed surgery for perforation of a hollow organ in the abdomen.

DISCUSSION

The treatment of penetrating truncal trauma has been mostly operative, but negative laparotomy rates of up to 30% have been reported [1,15,16]. In order to minimize negative laparotomy rates observational and non-operative approaches are used more frequently. Serial physical examination is an accepted strategy, cost effective, and returns to the basic clinical skill of ‘laying ones hands’ on the patient [17]. However, the physical examination can be inaccurate, especially in the presence of distracting injuries, altered levels of consciousness, non-specific signs and symptoms, and differences in an individual’s reaction to injury [3]. Thus imaging tests must be selected to reliably discriminate between patients who require therapeutic interventions or further studies from those who do not [17].

The aim of the current study was to investigate the accuracy of CXR, abdominal and cardiac ultrasound and abdominal X-ray, using the CT-scan as a control.

Current data show a sensitivity of the CXR for detecting pneumothorax of 71%, which means that in up to 30% of cases the pneumothoraces were missed at the initial CXR. Several studies have revealed that in trauma patients 40-50% of all pneumothoraces are missed on an initial CXR [18-20]. The current study shows a smaller percentage of missed pneumothoraces compared to the literature, this can be due to the different inclusion criteria for the patients, since the current study only included patients with penetrating trauma. Other studies looked at all trauma patients or only at blunt trauma patients.

Administration of anesthesia and mechanical ventilation may produce enlargement of a sub-clinical pneumothorax and may produce clinical deterioration [19]. In 59% of the missed pneumothoraces in the current study a chest tube was inserted. This is comparable with the percentages found in the literature: 43-67% [18,19]. Other signs and symptoms which can be missed on the initial CXR described in the literature are: rib fractures, sternal fracture, diaphragmatic tear, hemothorax, and lung contusion [18,21-24]. Table 2 shows that also in the current study those diagnoses were missed in some patients. Caution must therefore be taken in interpreting these films in the trauma resuscitation room. Studies are done to compare conventional radiographic work-up with CT-scan. They show that in 65-74% of severely injured patients after blunt force trauma, a CT-scan detects major chest traumas that have been missed on CXR: lung contusion, pneumothorax, hemothorax, and diaphragmatic rupture [25,26].

In the trauma setting, especially in penetrating trauma, a stab wound can cause a small perforation of a hollow organ and small amounts of free air, which are not visible on plain X-ray. In the current study a CXR was made during trauma assessment in 29 patients with a perforation of a hollow viscus seen during surgery. Free air was seen in the CXR in only one of these patients. Abdominal X-ray was made in 11 patients with a perforation of a hollow organ seen on CT or during surgery, 3 showed signs of this diagnosis on abdominal X-ray; 2 showed pneumoperitoneum and in one patient the contrast given before the abdominal X-ray indicated a stomach perforation. The abdominal X-rays did not add much additional information to the CXR and ultrasound. Most initial chest/abdominal X-rays done for trauma are supine, which is not the most sensitive study to detect free air; however upright CXR is only slightly better. Udobi et al showed that in 11 patients with a perforated gastrointestinal viscus caused by penetrating trauma with a CXR, only two were positive for free air [27]. Stapakis et al compared the sensitivity of CT with upright chest radiography on trauma patients who had introduction of intraperitoneal air from diagnostic peritoneal lavage (DPL) [28]. All patients demonstrated free air on abdominal CT-scan. Only 5 of 13 patients demonstrated free air on plain radiography.

Ultrasound is a imaging modality that is used for the evaluation of abdominal trauma in the vast majority of trauma centers. It is rapidly performed, non-invasive, inexpensive, portable, and easily repeated [4,15]. Ultrasound has been used worldwide for blunt abdominal trauma and sensitivity has been shown to be 84-94%, with a specificity of 95-100% (Table 3). However, less is known about the use of ultrasound in penetrating trauma. Limited numbers of studies have been performed to investigate the role of ultrasound in penetrating torso injury. Herein, the sensitivity to detect intra-abdominal injury ranged from 46% to 67% (Table 3) [4,15,27]. Ultrasound in penetrating abdominal trauma is not as reliable as in blunt trauma to detect intra-abdominal injury, possibly since penetrating injuries are more focal and the presence or absence of blood is not a reliable parameter in determining inury [27]. The ultrasound examination, no matter who performs it, may miss injuries that are not associated with a significant amount of free intraperitoneal fluid, such as hollow viscus, mesenteric, intraparenchymal solid, or retroperitoneal injuries [17]. This is often the type of injury seen in penetrating trauma. Branney et al. showed that about 600 ml of fluid is detected with ultrasound by most examiners [29]. In his study the minimum amount of fluid detected was 225 ml. They showed that 10% of the ultrasonographers were able to detect fluid volumes of 400 ml or less. The volume at which 85% of the sonographers had detected fluid was 850 ml [29]. This illustrates that in penetrating trauma an ultrasound can easily be false negative since the amount of free fluid often remains below the threshold of detection.

The current study showed a sensitivity of 65%, a specificity of 98%, a PPV of 92%, a NPV of 87%, and an accuracy of 88% for detecting intra-abdominal injury. Like the studies mentioned above [4,15,17,27] current results support the statement that ultrasound can be a useful initial imaging study after penetrating abdominal trauma. A positive ultrasound is a strong predictor of injury, and patients should proceed directly to laparotomy. If negative, additional imaging studies should be performed to rule out occult injuries, including timely serial ultrasound exams and/or CT-scan.

Although the current study did not calculate sensitivity, specificity, PPV, NPV, and accuracy of cardiac ultrasound to detect pericardial effusion because of the low numbers, it has higher true negative en true positive rates compared with abdominal ultrasound. Rozycki et al showed a sensitivity of 100% and specificity of 97% of ultrasound in patients with possible penetrating cardiac wounds [30].

In summary, the current study shows that many signs and diagnoses still are missed on conventional imaging work-up (CXR, cardiac and abdominal ultrasound, abdominal X-ray), the rates of missed diagnoses being comparable to what has been described in the literature.

LIMITATIONS

A limitation of retrospective collection of data, i.e. after the trauma evaluation, is that patient charts and radiology reports did not always state the specifically excluded diagnosis. Since the clinicians had not been instructed on forehand to specifically look for the signs or diagnoses investigated, it cannot be ruled out that some information might have been missed by the researchers. This may result in an underestimation of the sensitivity, specificity, PPV, NPV and accuracy. Nevertheless the sensitivity of CXR for pneumothorax and of ultrasound for intra-abdominal injury are in the same range and even at the upper limit as published in the literature (Table 3).

Calculation of the accuracy in the current study was based upon approved radiology reports. During the trauma assessment the images were read by the residents of Radiology, Surgery and Emergency Medicine. Physicians have acted based on these reports. Due to the retrospective nature of this study, it cannot be determined to what extent the radiologists have made corrections to the initial reports. For that, a prospective study would be needed.

Another limitation is that trauma management is a dynamic process, and that the condition of the patient can change at any time. It is recognized that initial negative ultrasound examinations may become positive due to the accumulation of intraperitoneal fluid from either ongoing bleeding, leaking from a hollow viscus, or from third spacing after resuscitation [17]. Similar to Kirkpatrick et al. we speculate that this might have been the cause of the false negative examinations. For example, when ultrasound was negative for intra-abdominal fluid and a CT-scan was made which showed intra-abdominal fluid, the ultrasound was scored as false negative. This result might have been different if ultrasound and CT-scan had been performed within a limited time frame. In order to limit this bias, the time lack between the imaging and the gold standard was set at 2 hours.

CONCLUSION

The results of this study show a high specificity, PPV, and NPV for CXR detecting pneumothorax, hemothorax and subcutaneous emphysema, and for ultrasound detecting intra-abdominal injury. A considerable number of lesions remained undetected on CXR and abdominal ultrasound, possibly due to the insufficient sensitivity of the tests. Cardiac ultrasound has higher true positive en true negative rates compared with abdominal ultrasound. Abdominal X-ray is not recommended for penetrating trauma, since it does not provide much additional information in the evaluation of a trauma patient other than the localisation of a corpus alienum such as a bullet. When CT-scan or operative treatment is not indicated based upon CXR and ultrasound, careful monitoring of these patients is mandatory, and patients should be admitted for observation. A negative CT-scan will not replace serial clinical examinations. It does however lower the index of suspicion, and a non-operative policy as long as clinical findings do not contradict, can be followed.

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Table 1: Definition and calculation of sensitivity, specificity, PPV, NPV, and accuracy

Sensitivity	TP/(TP+FN)	Proportion of diagnostic test results positive for a specific finding when this finding is actually present in the patient
Specificity	TN/(TN+FP)	Proportion of diagnostic test results negative for a specific finding when this finding is actually absent in the patient
Positive predictive value	TP/(TP+FP)	Proportion of patients positive for a specific finding who actually have a positive diagnostic test result for this finding
Negative predictive value	TN/(TN+FN)	Proportion of patients negative for a specific finding who actually have a negative diagnostic test result for this finding
Accuracy	TP+TN/(TP+FP+FN+TN)	Proportion of positive results in the population

TP, true positive; TN, true negative; FP, false positive; FN, false negative.

Table 2: Overview of the number of TP, FP, TN, and FN diagnoses for each diagnosis with their sensitivity, specificity, PPV, NPV, and accuracy in percentages

Imaging modality: signs and symptoms	**TP**	**TN**	**FP**	**FN**	**Sens (%)**	**Spec (%)**	**PPV (%)**	**NPV (%)**	**Accuracy (%)**
Chest X-ray (N=299)									
Pneumothorax	56	219	2	22	**71**	**99**	**97**	**91**	**92**
Pneumomediastinum	2	294	1	2	ND	ND	ND	ND	ND
Pneumoperitoneum	1	270	0	28	ND	ND	ND	ND	ND
Hemothorax *	49	220	0	29	**63**	**100**	**100**	**88**	**90**
Subcutaneous emphysema	25	258	0	16	**61**	**100**	**100**	**94**	**95**
Enlarged mediastinum	2	296	1	0	ND	ND	ND	ND	ND
Rib fracture	4	288	1	6	ND	ND	ND	ND	ND
Lung damage	13	252	0	34	ND	ND	ND	ND	ND
Diaphragm rupture	0	289	0	10	ND	ND	ND	ND	ND
Abdominal ultrasound (N=229)									
Intra-abdominal fluid	44	157	4	24	**65**	**98**	**92**	**87**	**88**
Cardiac ultrasound (N=31)									
Pericardial effusion *	12	18	0	0	ND	ND	ND	ND	ND
Abdominal X-ray (N=36)									
Pneumoperitoneum *	3	24	0	8	ND	ND	ND	ND	ND
Corpus alienum	8	26	1	1	ND	ND	ND	ND	ND

ND, not determined; * interpretation not possible in one patient; TP, True Positive, TN, True Negative; FP, False Positive; FN, False Negative; Sens, Sensitivity; Spec, Specificitly; PPV, Positive Predictive Value; NPV, Negative Predictive Value.

Table 3: Overview of literature on accuracy of ultrasound used in trauma

Abdominal ultrasound

Trauma	Study	No. patients	Sens (%)	Spec (%)	PPV (%)	NPV (%)	Accuracy (%)
Blunt	Bode et al. 1993 [14]	353	92.8	100	100	99.4	99.4
	Lingawi et al. 2000 [12]	1090	94	98	78	100	95
	Brown et al. 2001 [13]	2693	84	96	61	99	96
	Nural et al. 2005 [10]	454	86.5	95.4	62.7	98.7	94.7
	Salera et al. 2005 [6]	864	91.5	97.5	ND	ND	ND
Blunt & Penetrating	Rozycki et al. 1993 [8]	476	79	95.6	ND	ND	ND
	Rozycki et al. 1995 [7]	371	81.5	99.7	ND	ND	ND
	Rozycki et al. 1998 [9]	1540	83.3	99.7	ND	ND	ND
	Nunes et al. 2001 [11]	147	69	100	100	95	95
Penetrating	Udobi et al. 2001 [27]	75	46	94	90	60	ND
	Boulanger et al. 2001 [4]	72	67	98	92	89	ND
	Soffer et al. 2004 [15]	177	48	98	ND	ND	85
	Varin et al. 2008	229	65	98	92	87	88

Cardiac Ultrasound

Trauma	Study	No. patients	Sens (%)	Spec (%)	PPV (%)	NPV (%)	Accuracy (%)
Penetrating	Rozycki et al. 1998 [9]	313	100	99.3	ND	ND	ND
	Rozycki et al. 1999 [30]	261	100	96.9	ND	ND	97.3

ND, not determined
Sens, Sensitivity; Spec, Specificitly; PPV, Positive Predictive Value; NPV, Negative Predictive Value.