False-Negative FAST Examination: Associations With Injury Characteristics and Patient Outcomes

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Study objective: Focused assessment with sonography in trauma (FAST) is widely used for evaluating patients with blunt abdominal trauma; however, it sometimes produces false-negative results. Presenting characteristics in the emergency department may help identify patients at risk for false-negative FAST result or help the physician predict injuries in patients with a negative FAST result who are unstable or deteriorate during observation. Alternatively, false-negative FAST may have no clinical significance. The objectives of this study are to estimate associations between false-negative FAST results and patient characteristics, specific abdominal organ injuries, and patient outcomes.

Methods: This was a retrospective cohort study including consecutive patients who presented to an urban Level I trauma center between July 2005 and December 2008 with blunt abdominal trauma, a documented FAST, and pathologic free fluid as determined by computed tomography, diagnostic peritoneal lavage, laparotomy, or autopsy. Physicians blinded to the study purpose used standardized abstraction methods to confirm FAST results and the presence of pathologic free fluid. Multivariable modeling was used to assess associations between potential predictors of a false-negative FAST result and false-negative FAST result and adverse outcomes.

Results: During the study period, 332 patients met inclusion criteria. Median age was 32 years (interquartile range 23 to 45 years), 67% were male patients, the median Injury Severity Score was 27 (interquartile range 17 to 41), and 162 (49%) had a false-negative FAST result. Head injury was positively associated with false-negative FAST result (odds ratio [OR] 4.9; 95% confidence interval [CI] 1.5 to 15.7), whereas severe abdominal injury was negatively associated (OR 0.3; 95% CI 0.1 to 0.5). Injuries to the spleen (OR 0.4; 95% CI 0.24 to 0.66), liver (OR 0.36; 95% CI 0.21 to 0.61), and abdominal vasculature (OR 0.17; 95% CI 0.07 to 0.38) were also negatively associated with false-negative FAST result. False-negative FAST result was not associated with mortality (OR 0.89; 95% CI 0.42 to 1.9), prolonged ICU length of stay (relative risk 0.88; 95% CI 0.69 to 1.12), or total hospital length of stay (relative risk 0.92; 95% CI 0.76 to 1.12). However, patients with false-negative FAST results were substantially less likely to require therapeutic laparotomy (OR 0.31; 95% CI 0.19 to 0.52).

Conclusion: Patients with severe head injuries and minor abdominal injuries were more likely to have a false-negative than true-positive FAST result. On the other hand, patients with spleen, liver, or abdominal vascular injuries are less likely to have false-negative FAST examination results. Adverse outcomes were not associated with false-negative FAST examination results, and in fact patients with false-negative FAST result were less likely to have a therapeutic laparotomy. Further studies are needed to assess the strength of these findings. [Ann Emerg Med. 2012;60:326-334.]

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INTRODUCTION
Background

Trauma accounts for approximately 41 million emergency department (ED) visits annually in the United States and results in significant morbidity and mortality.[1,2] Trauma also incurs substantial economic burden, with annual direct and indirect costs estimated at $80 and $406 billion, respectively.[3] Trauma patients frequently require laboratory testing and imaging, including a focused assessment with sonography in trauma (FAST) examination to evaluate for intraperitoneal hemorrhage.

Editor's Capsule Summary

What is already known on this topic

The focused assessment with sonography in trauma (FAST) examination for the evaluation of injured patients is not sensitive enough to exclude all intra-abdominal injuries.

What question this study addressed

The authors examined injury characteristics, specific intra-abdominal injuries, and patient outcomes associated with false-negative FAST examination results.

What this study adds to our knowledge

Among 332 with patients with pathologic free fluid because of trauma, 49% had a false-negative FAST result. Head injury was positively associated, whereas severe abdominal trauma and injuries to the spleen, liver, or abdominal vasculature were negatively associated with false-negative FAST examination results. A false-negative FAST result, however, was rarely associated with poor patient outcomes.

How this is relevant to clinical practice

False-negative FAST result is associated with certain injury patterns but is not associated with adverse outcomes.

This examination is a component of the initial evaluation of a patient who experiences blunt abdominal trauma and is also a core competency for emergency medicine and surgical residency training programs.[4,5]

Importance

Results of the FAST examination are used in decision algorithms for patients with blunt abdominal trauma.[6-10] It is also well known that the sensitivity of FAST is inadequate to rule out intra-abdominal injury.[8-17] Little is known, however, about injury patterns and physical examination findings associated with false-negative FAST examination results and the their consequences on patient outcomes.[18-23] Knowledge of which presenting patient characteristics are associated with false-negative FAST results may help clinicians identify patients at risk for pathologic intra-abdominal free fluid despite a negative FAST result. It would also be helpful to know which organ injuries predominate in those with false-negative FAST examination results. This knowledge could inform selection of patients who might benefit from further imaging or observation and which organ injuries might be missed with FAST alone.

It has been theorized that missed pathology associated with false-negative FAST results may place patients at risk for adverse

outcomes.[18,19,24] However, to our knowledge no study has been performed to assess the association of false-negative FAST results with therapeutic operative intervention, mortality, or length of hospital stay. If false-negative FAST result is highly associated with adverse events, clinicians might consider being more aggressive in the use of other imaging modalities or operative intervention. On the other hand, if there is little or no association with adverse outcomes, clinicians might opt to observe these patients.

Goals of This Investigation

The objectives of this study were to estimate associations between injury characteristics available during the initial ED evaluation and false-negative FAST result, specific abdominal organ injuries and false-negative FAST result, and false-negative FAST result and patient outcomes, including need for emergency operative intervention, length of hospital admission, duration of intensive care, and mortality.

MATERIALS AND METHODS

Study Design and Setting

This was a retrospective cohort study performed at Denver Health Medical Center in Denver, CO. The center is a 477-bed urban county hospital with approximately 50,000 annual adult ED visits. It is also a Level I trauma center for the city and county of Denver and a trauma referral center for the Rocky Mountain region. Approximately 16,000 trauma patients are evaluated and treated at the center annually, and approximately 2,000 meet criteria for enrollment in the trauma registry; approximately 650 are severely injured, as defined by an Injury Severity Score greater than 15. Blunt trauma mechanisms account for approximately 88% of all patient visits.

Emergency medicine or surgery residents, under the supervision of attending emergency physicians or surgeons, perform FAST examinations in the ED. Attending physicians have privileges for performing and interpreting FAST and have undergone training in accordance with the American College of Emergency Physicians ultrasonographic guidelines.[25,26] Emergency medicine residents have undergone a minimum of 16 hours of combined didactic and hands-on training related to the FAST examination. Surgical residents receive didactic training and then are required to have their initial 10 FAST examinations reviewed for quality before being able to perform an examination independently.

The FAST examination has been taught and used for identification of pathologic free fluid at Denver Health Medical Center since 1992 and has been part of a blunt abdominal trauma key clinical pathway since 1994.[27] As designated by the key clinical pathway, trauma patients with potential abdominal injury undergo FAST evaluation regardless of whether assessed by surgical or emergency medicine personnel on presentation to the ED. Patients with a negative examination result, alert sensorium, no significant abdominal tenderness, and a nonhigh risk mechanism of injury may undergo observation with serial FAST examinations. The trauma team, which includes

representation from emergency medicine and surgery, manages all patients who ultimately meet trauma registry criteria. Some trauma patients, however, are managed solely by emergency physicians and may not require trauma consultation if no significant injuries are identified.

This study was approved by our institutional review board and met criteria for exemption from informed consent.

Selection of Participants

Consecutive patients of all ages with abdominal or pelvic injury identified from the Denver Health Medical Center trauma registry, blunt mechanism of injury, pathologic free fluid, and a FAST examination performed in the ED were included from July 1, 2005, through December 31, 2008. Inclusion criteria for the trauma registry are all patients with blunt and penetrating trauma who are admitted to the hospital, remain in the hospital for greater than or equal to 12 hours (eg, ED observation), are transferred to Denver Health Medical Center from another hospital, or who die in the ED or while hospitalized.

Patients were excluded if they were directly admitted to the hospital or operating room without an ED encounter, had operative intervention performed at an outside facility before being transferred to Denver Health Medical Center, or had pathologic free fluid identified greater than 24 hours after the ED encounter (suggesting that free fluid in these patients may not have been present during the initial assessment).

Data Collection and Processing

Trained research assistants (2 resident physicians and 1 fourth-year medical student) blinded to the purpose of the study performed data collection, using a structured closed-response data collection instrument (Microsoft Excel 2007; Microsoft, Redmond, WA). Abstractor training involved demonstrating the standardized approach to chart abstraction, as defined a priori by the investigative team, and providing the research assistants with an article outlining this approach as a reference tool. Subsequently, the research assistants (J.B., T.D., S.M.) were tested on a training set of records (previously abstracted by the principal investigator [B.L.]). All discrepancies were reviewed and additional training sets were completed until agreement reached 100% with training data sets.

Patients were identified for inclusion in the trauma registry by a team of personnel specifically trained in the oversight of the trauma registry and the acquisition of data. The ED patient log was searched daily to find patients who met criteria for inclusion in the trauma registry. Once patients were identified, data were systematically abstracted from their medical records and entered into an electronic database (TraumaBase; Clinical Data Management, Conifer, CO). Approximately 20% of the trauma registry records were internally reviewed with an institutional protocol to maintain quality assurance. A member of the trauma registry staff who did not perform the initial abstraction completed each review. Discrepancies were brought to the trauma registry committee and a consensus process was used to make corrections.

Clinical data were recorded on a structured trauma nursing record during the initial evaluation and treatment of the patient. Treating emergency physicians verbally reported clinical information to a nurse assigned to complete documentation, and nurses were instructed to ask for items not verbally communicated during this process. Diagnoses and procedures were coded in the registry according to the *International Classification of Diseases, Ninth Revision* (*ICD-9*).

Each patient identified from the trauma registry as having abdominal pelvic injury (using an Abbreviated Injury Score of 1 to 6 for the abdominal region or *ICD-9* codes 808.x for pelvic fracture) had his or her medical records evaluated with standardized chart abstraction methodology.[28] The principal investigator arbitrated discrepancies or uncertainties about data collection. After data collection, a 10% random sample was reabstracted by the principal investigator (B.L.) and a κ was calculated for the primary endpoint (true-positive versus false-negative FAST result) to assess reliability.

Data obtained from the trauma registry included admission date; age; sex; Injury Severity Score; maximum Abbreviated Injury Score for the head, face, chest, abdomen, extremity, and external regions; pulse (per minute) and systolic blood pressure (mm Hg) (in the field and on arrival to the ED); Glasgow Coma Scale (GCS) score in the ED; fractures of the ribs, pelvis, or spine; initial hematocrit level in the ED; performance of laparotomy; mortality; and autopsy, if relevant. The following variables were manually abstracted for each patient: mechanism of injury (blunt or penetrating), FAST results (positive, negative, indeterminate), regions of the FAST examination that indicated pathologic intra-abdominal free fluid (right upper quadrant, left upper quadrant, and pelvic), and the presence of abdominal organ injuries (liver, spleen, bladder, kidney, abdominal vascular/mesenteric vascular, bowel, and pancreas). FAST results were extracted from the ultrasonographic documentation sheet, which is completed when the FAST examination is performed and is scanned into the electronic medical record. Corresponding ultrasonographic images are discarded after the ultrasonographic documentation sheet is completed.

Presence of pathologic free fluid was defined as intra-abdominal fluid noted on operative report, computed tomography (CT) interpreted by an attending radiologist, autopsy report, or a positive diagnostic peritoneal lavage result (≥10 mL of gross blood or >100,000 RBCs/mL). Blood, urine, bile, and bowel contents were considered pathologic, whereas ascites, physiologic fluid, organized hematomas, and retroperitoneal and preperitoneal fluid were not considered pathologic intra-abdominal free fluid.

Fluid type, volume, and specific organ injuries were identified from discharge summaries and reports of autopsies, operations, or CT. Autopsies and operative reports took precedence over imaging as criterion standards. Fluid type was

considered unknown if not clearly described in an operative report or autopsy, with one exception. Descriptions from CT scans were considered adequate for determining fluid type and specific organ injuries when documented as "probable" or "consistent with" a specific fluid type or injury as long as the clinical course supported this report. If a report noted indeterminate findings, however, such as "possible injury," and the patient's clinical course did not correlate with an injury to this structure (ie, no intervention occurred and no report of an injury was made on the discharge summary), then the injury was not recorded.

Although we initially intended to investigate the size of the fluid volume on the likelihood of a false-negative FAST result, we found during the course of the investigation that there was significant variability in the accuracy of fluid volume reporting. Additionally, nearly 50% of fluid volumes were of unknown size, thus significantly hampering the ability to come to any meaningful conclusions about the effects of fluid volume on false-negative FAST result.

Intra-abdominal organ injuries were defined by hematomas abutting a specific organ, as well as lacerations, evidence of rupture, or hemorrhage from or into the organ.

Laparotomy was considered therapeutic if surgical intervention was required to treat intra-abdominal injury, specifically consisting of tissue repair or resection, intra-peritoneal or pelvic packing, or hemorrhage control.[29,30] Extraperitoneal (pre- or retroperitoneal) pelvic packing or bladder repair was not considered therapeutic for intra-abdominal injury.

Primary Data Analysis

All data were entered into an electronic spreadsheet (Microsoft Excel), and all statistical analyses were performed with SAS (version 9.2; SAS Institute, Inc., Cary, NC).

Multivariable modeling was used for each of the 3 study objectives. First, we used multivariable logistic regression analysis to estimate associations between patient characteristics and false-negative FAST result. Independent variables included severe injuries (defined as an Abbreviated Injury Score $\geq$4) to the head, chest, abdomen, and extremities, each of which was included as a binary variable in the model; fractures of the ribs, spine, or pelvis; initial pulse; systolic blood pressure; GCS score; and hematocrit level.

Second, multivariable logistic regression analysis was used to estimate associations between specific organ injury patterns and false-negative FAST result. Independent variables in this model were injuries to the liver, spleen, mesenteric vasculature (abdominal vascular), intestine, pancreas, kidney, and bladder. Both models included patient age, sex, and Injury Severity Score as covariates to adjust for patient demographics and injury severity. All variables were identified for inclusion a priori and were included in the final model regardless of their statistical significance. As such, no specific variable selection methods were used.

Third, to estimate associations between false-negative FAST result and patient outcomes, we used either multivariable logistic regression or negative binomial regression analyses, depending on whether the outcome was binary or interval, respectively. Specifically, logistic regression was used to model mortality or need for therapeutic laparotomy as dependent variables. Negative binomial regression was used to model lengths of stay in the hospital and ICU as dependent variables. Again, patient age, sex, and Injury Severity Score were included in each model to adjust for patient demographics and injury severity. For modeling purposes, all indeterminate FAST examination results were classified as positive. Statistical significance was defined with 95% confidence intervals (CIs). No variable transformation was performed and effect modification was not assessed. κ Was used to assess the interrater reliability for endpoint abstraction.

Conventional multivariable modeling approaches use only those observations with complete data, which often introduces bias. In an effort to minimize bias and preserve study power, we used multiple imputation to handle missing data. Variables included in the multiple imputation model included false-negative FAST result; age; sex; Abbreviated Injury Scores of the head, chest, abdomen, and extremity; ED pulse; ED systolic blood pressure; ED GCS score; fractures of the rib, pelvis, and spine; hematocrit level; Injury Severity Score; injuries to the spleen, liver, bladder, kidney, abdominal vasculature, and pancreas; mortality; hospital and ICU length of stay; and whether the patient had a therapeutic laparotomy.

We powered the study for an estimated 10 outcomes (ie, false-negative FAST result) per independent variable in our multivariable model, with the principal goal of avoiding overfitting. In this study, we had 14 potential independent variables, which required a minimum of 140 total patients with false-negative FAST result.

RESULTS

During the study period, 6,851 patients were entered into the Trauma Registry and 1,479 (22%) had an injury to the abdomen or pelvis. Of the 1,479 patients, 354 (24%) had pathologic free fluid as a result of blunt trauma. Of the 354 patients, 332 (94%) had a FAST examination performed in the ED (Figure). Agreement on endpoint abstraction was 100% ($\kappa=1.0$) between the research assistants and principal investigator.

Of the 332 included patients, the median age was 32 years (interquartile range 23 to 45 years), the median Injury Severity Score was 27 (interquartile range 17 to 41), 67% were male patients, and 41 (12%) patients died. Most patients were injured in motor vehicle crashes (201 [61%]), with the second most common mechanism being automobile versus pedestrian (40 [12%]). Of the 332 patients, 170 (51%; 95% CI 46% to 57%) had a true-positive FAST examination result (including 7 indeterminate results classified as positive) and 162 (49%; 95% CI 43% to 54%) had a false-negative FAST examination result. ED vital signs, GCS score, and initial hematocrit level were
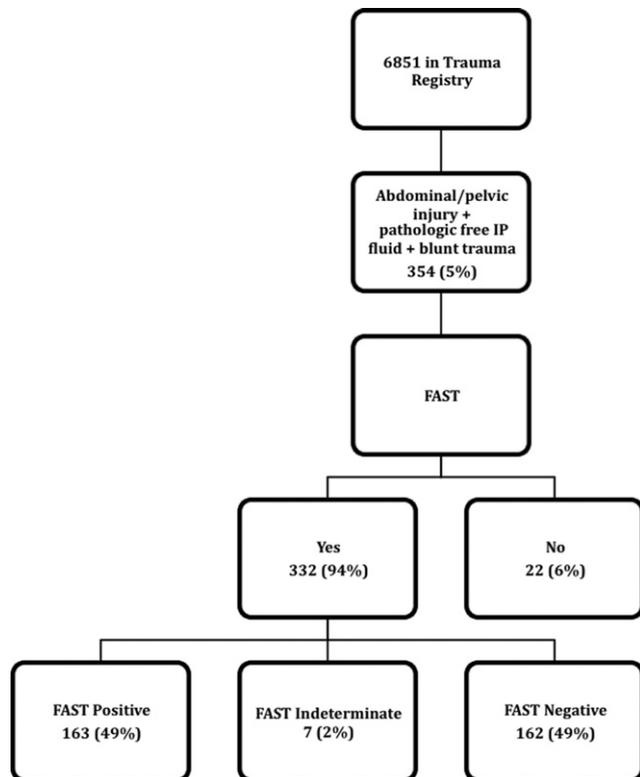
Figure. Flow diagram of patients included in this study. *IP,* Intraperitoneal.

Table 1. Patient characteristics stratified by FAST examination results.

Characteristic	FN FAST N (% or IQR)	TP FAST N (% or IQR)	Total N (% or IQR)
ED FAST*	162 (49)	170 (51)	332 (100)
Age (median), y	31 (22–44)	33 (24–46)	32 (23–45)
Male sex	109 (66)	117 (69)	226 (67)
ISS (median)	25 (14–36)	29 (18–42)	27 (17–41)
Hospital LOS (median)	6 (3–15)	10 (4–22)	8 (3–19)
ICU LOS (median)	3 (1–9)	5 (1–13)	4 (1–12)
Mechanism			
Motor vehicle	97 (60)	104 (61)	201 (61)
Auto versus pedestrian	19 (12)	21 (12)	40 (12)
Assault	10 (6)	11 (6)	21 (6)
Fall	19 (12)	15 (9)	34 (10)
Other	17 (10)	19 (10)	36 (11)
Out-of-hospital pulse (median)	100 (84–117)	100 (88–120)	100 (88–118)
Missing	20 (12)	15 (9)	35 (11)
ED pulse (median)	100 (86–119)	100 (83–120)	100 (84–120)
Missing	0 (0)	0 (0)	0 (0)
Out-of-hospital SBP (median)	118 (98–136)	110 (91–126)	110 (96–130)
Missing	20 (12)	28 (17)	48 (15)
ED SBP (median)	119 (103–130)	112 (90–130)	117 (96–130)
Missing	0 (0)	2 (1)	2 (1)
ED GCS score (median)	15 (11–15)	15 (4–15)	15 (8–15)
Missing	4 (3)	4 (2)	8 (2)
ED hematocrit (median)	41 (36–45)	40 (35–44)	41 (35–45)
Missing	10 (6)	20 (12)	30 (9)

FN, False negative; *TP,* true-positive; *IQR,* interquartile range; *ISS,* Injury Severity Score; *LOS,* length of stay; *SBP,* systolic blood pressure.
*True positive FAST includes 7 cases of indeterminate FAST.

similar between patients with false-negative and true-positive FAST examination results (Table 1). There were 233 CT scans performed, of which 222 results (95%) were positive. There were 13 diagnostic peritoneal lavages performed, of which 9 results (69%) were positive. There were 116 laparotomies performed, of which 103 results (89%) were therapeutic. GCS score was missing for 8 patients (2%), ED systolic blood pressure was missing for 2 patients (1%), and hematocrit was missing for 30 patients (9%). ED pulse, Injury Severity Score, Abbreviated Injury Score, age, sex, mortality, and length of stay were missing for no patients.

The right upper quadrant was the most common location of fluid identification in patients with a positive FAST result (n=132; 40%). The spleen was the most commonly injured abdominal organ (n=147; 44%) of the study population, followed by the liver (n=123; 37%).

When we modeled the associations between ED vital signs, GCS score, and hematocrit level, severe injury to various body regions, fractures of the ribs, pelvis, or spine, and false-negative FAST result, 2 variables were significantly associated with a false-negative FAST result. Severe head injury was positively associated with a false-negative FAST result (odds ratio [OR] 4.90; 95% CI 1.53 to 15.67), whereas severe abdominal injury was negatively associated (OR 0.27; 95% CI 0.13 to 0.55). Vital signs, GCS score, initial hematocrit level, and injuries to the ribs, spine, or pelvis were not associated with false-negative FAST result (Tables 2 and 3).

When we modeled the association between specific organ injuries and false-negative FAST result, injuries to the liver, spleen, and abdominal vascular structures were negatively associated: OR 0.36 (95% CI 0.21 to 0.61), 0.40 (95% CI 0.24 to 0.66), and 0.17 (95% CI 0.07 to 0.38), respectively. No other organ injuries or fractures were associated with a false-negative FAST result (Tables 2 and 4). When we modeled the associations between false-negative FAST result and hospital length of stay, ICU length of stay, or therapeutic laparotomy, the result was negatively associated with a therapeutic laparotomy (OR 0.31; 95% CI 0.19 to 0.52) but not increased hospital or ICU length of stay or mortality (Table 5).

When multiple imputation was performed to assess the effect of variable missingness on results of each of the models, there were no changes in magnitude, direction, or precision of any of the predictor variables with their respective outcomes (data not shown).

LIMITATIONS

Inclusion criteria required patient identification through the trauma registry, which may have resulted in systematic selection

Table 2. Injury characteristics stratified by FAST examination results.

Characteristic	FN FAST N (%)	TP FAST N (%)	Total N (%)
Total	162	170	332
Fracture			
Pelvic	66 (41)	59 (35)	125 (38)
Spine	64 (40)	70 (41)	134 (40)
Rib	90 (56)	93 (55)	183 (55)
Injury			
Spleen	63 (39)	84 (49)	147 (44)
Liver	46 (28)	77 (45)	123 (37)
Bladder	5 (3)	13 (8)	18 (5)
Kidney	24 (15)	21 (12)	45 (14)
Vascular	12 (7)	40 (24)	52 (16)
Intestinal	21 (13)	21 (12)	42 (13)
Pancreatic	4 (2)	6 (4)	10 (3)
AIS ≥4			
Head	36 (22)	27 (16)	63 (19)
Chest	42 (26)	62 (36)	104 (31)
Extremity	24 (49)	25 (51)	49 (15)
Abdomen	27 (17)	85 (50)	112 (34)

AIS, Abbreviated Injury Score.

Table 3. Multivariable logistic regression of patient characteristics, injury patterns, ED parameters, and false-negative FAST result.*

Variable	OR	95% CI
Age[†]	1.00	0.98–1.01
Male sex	0.91	0.51–1.62
ISS	0.98	0.94–1.02
Fractures		
Rib	1.88	1.01–3.52
Spine	0.88	0.48–1.60
Pelvis	1.61	0.82–3.14
Vital signs		
ED pulse[†]	0.97	0.88–1.08
ED SBP[†]	0.98	0.89–1.08
ED GCS score	1.06	0.98–1.15
ED hematocrit level[‡]	1.16	0.95–1.41
AIS ≥4		
Head	4.90	1.53–15.67
Chest	0.84	0.37–1.88
Extremity	1.86	0.69–5.05
Abdomen	0.27	0.13–0.55

*Hosmer-Lemeshow goodness of fit *P*=.30. Thirty-seven patients were not analyzed because of missing data.
[†]Per change of 10 points.
[‡]Per change of 5 points.

Table 4. Multivariable logistic regression of abdominal injuries and false-negative FAST result.*

Variable	OR*	95% CI
Injury		
Spleen	0.40	0.24–0.66
Liver	0.36	0.21–0.61
Bladder	0.33	0.10–1.07
Kidney	1.18	0.59–2.34
Vascular	0.17	0.07–0.38
Intestinal	1.65	0.72–3.78
Pancreas	1.41	0.32–6.14

*Hosmer-Lemeshow goodness of fit *P*=.12; 1 patient was excluded from analysis because of missing data.

Table 5. Associations of false-negative FAST examination results with outcomes.*

Outcome Variable	Predictors	Relative Risk (95% CI)
Hospital length of stay[†]	FN FAST	0.92 (0.76–1.12)
	Age	1.00 (1.00–1.01)
	ISS	1.04 (1.03–1.05)
	Male sex	0.91 (0.75–1.10)
ICU length of stay[†]	FN FAST	0.88 (0.69–1.12)
	Age	1.01 (1.01–1.02)
	ISS	1.06 (1.05–1.07)
	Male sex	0.87 (0.68–1.10)

Outcome Variable	Predictors	OR (95% CI)[‡]
Mortality[§]	FN FAST	0.89 (0.42–1.90)
	Age	1.04 (1.02–1.07)
	ISS	1.07 (1.05–1.10)
	Male sex	0.92 (0.43–1.99)
Therapeutic laparotomy[§]	FN FAST	0.31 (0.19–0.52)
	Age	1.01 (1.00–1.03)
	ISS	1.05 (1.03–1.06)
	Male sex	1.22 (0.71–2.10)

*Five patients were not analyzed because of missing data.
[†]Modeled with negative binomial regression.
[‡]Hosmer-Lemeshow goodness of fit statistic *P*=.39 (mortality) and *P*=.78 (therapeutic laparotomy), respectively.
[§]Modeled with logistic regression.

of patients with higher acuity. Trauma patients without significant injuries may have been discharged from the ED and not entered into the registry. It is unlikely, however, that patients with traumatic intra-abdominal free fluid (our study population) would have been asymptomatic and thus not identified while in the ED.

FAST sensitivity in our study is estimated to be near 50%, significantly lower than in previous studies.[9,12,13,15,31-33] Potential explanations include that (1) emergency residents

perform and interpret the majority of examinations; (2) FAST accuracy is greater among experienced sonographers[34-37]; (3) the most unstable trauma patients at our institution are rushed urgently to the operating room and may not have a FAST performed or recorded, and these patients are most likely to have true-positive findings; and (4) inclusion criteria required only pathologic intra-abdominal free fluid, including amounts too small for detection with ultrasonography.[8,16,17,38] CT is more common today compared with observation as a tool during trauma evaluations, possibly resulting in the identification of small amounts of free fluid that historically would have remained undetected. As such, it is also possible that the sensitivity estimate reported in our study more accurately reflects the sensitivity of FAST. Finally, Appendix E1 (available online at http://www.annemergmed.com) illustrates clinical vignettes demonstating various sonographer errors that contribute to FN FAST results.

The retrospective nature of the study allowed us to use only variables and patient data that were available in the trauma registry or medical record. It is unlikely that patients with clinically significant pathologic free fluid would have been discharged from the ED and thus not captured by the registry. In addition, the registry is systematically maintained and undergoes regular quality assurance evaluations to ensure its integrity.

The trauma registry included variables with missing data that were not available after chart abstraction. Even the largest number of missing variables represented less than 10% of the total number of observation. Despite this, exclusion of observations with missing data may have introduced bias. We attempted to assess this potential limitation by using multiple imputation as a method of sensitivity analysis. Multiple imputation is a rigorous and computationally sophisticated statistical method that provides unbiased estimates while incorporating observations with missing data. Imputed data are assumed to be missing randomly, and we cannot confirm or refute whether the missing information met this criterion. However, the results were not altered when multiple imputation was used to assess the effect of missing data, which does lend support to our findings.

Additionally, because data were abstracted from charts, there is the potential for misclassification bias. We attempted to minimize this effect by training research assistants, using a standard approach to chart abstraction, and assessing their reliability by reabstracting a subset of charts.

Last, the absolute number of deaths was small, which could lead to a type 2 error. The study was powered to assess for the association of initial clinical findings with false-negative FAST result and therefore was not powered to assess for the effect of false-negative FAST result on mortality. We believe that this information about the apparent lack of statistical association between false-negative FAST result and adverse consequences could be useful to the reader and may stimulate a study to directly assess the effects of false-negative FAST result on patient-centric outcomes.

DISCUSSION

To our knowledge, this is the largest study to date to evaluate potential predictors of false-negative FAST result with multivariable modeling. FAST examinations are performed to facilitate disposition decisions. Positive findings can aid in the decisionmaking for emergency operative intervention or further diagnostic studies, particularly in patients with unstable vital signs. Although negative results do not eliminate the need for further testing, we have attempted to aid physicians in identifying which patients may have undetected intraperitoneal hemorrhage or other pathologic fluid despite a negative FAST result. Our results suggest that false-negative FAST result seldom affects outcomes. This calls into question the significance of a false-negative FAST result. Perhaps there is a greater role for observation than immediate CT for patients with blunt abdominal trauma and a negative FAST result. In the era of nonoperative management for parenchymal injuries, an observational approach may not be harmful.

Patients who present with severe head trauma are more likely to have a false-negative FAST result. Patients with significant head trauma may distract the evaluating physician from performing a thorough ultrasonographic examination, and the patients themselves may be uncooperative, making an accurate diagnosis more challenging. Alternatively, severe head trauma may lead to liberal use of whole-body CT, which leads to the discovery of incidental or small amounts of free fluid. Whatever the cause, emergency physicians and trauma surgeons need to be aware of the potential pitfall of a false-negative FAST result in these patients. There was no association between false-negative FAST result and GCS score, probably because the Abbreviated Injury Score is much more specific to head injury than the GCS score, which is often confounded by other causes of altered mental status (eg, intoxication, sepsis, hypothermia).

On the other hand, patients who present with severe abdominal trauma are less likely to have a false-negative FAST result. It is possible that these patients accumulate blood more quickly, which is more easily detected. Additionally, clinically obvious signs of trauma (eg, abdominal distention, hematoma) may prompt the physician to perform a more careful examination.

A similar pattern can be proposed for patients with spleen, abdominal vascular, and liver injuries in whom rapid accumulation of large quantities of intraperitoneal blood is readily visible. Thus, it is sensible that these injuries were negatively associated with false-negative FAST examination results. Past studies have variable findings. One study reports no association between these injuries and false-negative FAST result,[22] whereas others identified these injuries in patients with false-negative FAST result but did not assess for association.[24,31,39-42] Additionally, a recent study in patients with solid organ injury found that false-negative FAST result occurs more often in patients with low-grade (I or II) versus high-grade (III to V) injuries.[23] Most of these studies do not use multivariable modeling to attempt to find independent associations of injury patterns or clinical characteristics with false-negative FAST result. Hoffman et al[22] attempted to overcome this. Unfortunately, they included far too many potential predictor variables for the number of outcomes, and thus their results may suffer from all of the possible consequences of model overfitting.

When patients' outcomes are evaluated, it appears that false-negative FAST result is negatively associated with therapeutic laparotomy. We believe that this is most likely because patients with false-negative FAST result had correspondingly smaller amounts of free fluid and thus had injuries that were less likely to need intervention. Further, we were concerned that missing even small amounts of pathologic free fluid may predispose patients to prolonged length of stay in the hospital or ICU and even potentially contribute to death. We found no such association.

Future studies that prospectively assess predictors of false-negative FAST result and the effects on outcomes may clarify the strength of our findings and help direct changes in management.

Patients with severe head injuries and minor abdominal injuries were more likely to have a false-negative FAST result than a true-positive one. On the other hand, patients with spleen, liver, or abdominal vascular injuries are less likely to have false-negative FAST examination results. Adverse outcomes were not associated with false-negative FAST examination results, and in fact, patients with such results were less likely to have a therapeutic laparotomy. Further studies are needed to assess the strength of these findings.

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APPENDIX E1

Case 1: FN FAST – "True" false negative

You are caring for a 45 year-old male victim of a high-speed, rollover motor vehicle collision. The patient was the restrained driver, airbags deployed, and he was ambulatory at the scene with only minor apparent injuries.

He is brought in by ambulance with normal vital signs and has an unremarkable physical examination aside from a few minor extremity bruises. You perform a FAST examination (Figure E1-E4), which is negative for evidence of intra-abdominal hemorrhage.

Given the high mechanism potential for injury, you admit this patient for observation. After six hours your patients' hematocrit has decreased by 10% and he has developed left-sided abdominal discomfort and mild tenderness. He otherwise feels and looks well. You obtain a computed tomography (CT) scan of the abdomen, which demonstrates a grade I-spleen laceration, small amounts free fluid in the left-upper quadrant and a sub-capsular splenic hematoma but no evidence of active hemorrhage.

Patient follow-up: Your patient is admitted to the trauma service and the hematocrit stabilizes without intervention. He has an unremarkable hospital course and is discharged two days later.

Teaching points: The FAST examination may fail to identify small amounts of pathologic free fluid, even when performed carefully and correctly by an experienced operator. This may be attributable to:

  a) inter-operator variability in the sensitivity of the FAST
  b) a minimal threshold of free fluid, below which, FAST is unlikely to be positive, even in the most experienced hands
  c) a delay in the accumulation of free fluid between the time of the initial FAST and the subsequent detection of free fluid

While this patients' hospital course did not appear to be negatively impacted by the FN FAST, you wonder if evidence supports such findings.

Case 2: FN FAST – Cursory examination fails to identify free fluid

A 21 year-old male is brought in by ambulance following a freeway speed motorcycle crash. A wet roadway caused the patient to slip and slide on his left side approximately 100 feet before colliding with the road median. He was helmeted, did not lose consciousness was not ambulatory at the scene. In the Emergency Department he complains of left leg pain and left-sized abdominal pain. Physical examination is notable for an obvious closed, left femur fracture and moderate abdominal tenderness to palpation in the left-upper quadrant. Your FAST examination is negative for free fluid but you suspect a solid-organ injury.

CT is notable for a grade II-spleen laceration and small amounts of intra-abdominal free fluid in the left-upper quadrant and near the tip of the liver.

Patient follow-up: The patient is admitted to the hospital, his femur fracture is repaired and his spleen laceration is managed non-operatively. The hospital course is unremarkable. He is discharged with restrictions from high-risk activities for three months, to avoid spleen re-injury.

Teaching points: The pitfall of the FAST imaging in this case was a cursory examination. A more careful examination would have revealed fluid near the tip of the liver (Figure E5) and in the sub-diaphragmatic region of the left-upper quadrant (Figure E6). Original views appear negative (Figure E7,E8).

Case 3: FN FAST – Indeterminate scan called "negative"

Your patient is a 55 year-old female pedestrian who was hit by a van travelling approximately 20 miles per hour. The victim was struck on the left side, thrown approximately 10 feet and was unconscious at the scene of the accident for which she was intubated.

In the ED she remains tachycardic but normotensive with adequate oxygenation. Physical examination is notable for a bleeding scalp laceration as well as multiple abrasions and hematomas of the left thorax, abdomen and extremities. She has an obvious deformity of the distal left lower extremity. You perform a FAST examination and have some difficulty discerning landmarks in the left-upper quadrant (Figure E9). You don't see any free fluid, so you interpret the study as "negative."

CT demonstrates a subarachnoid hemorrhage, multiple rib fractures, a grade III-spleen laceration, a sub-capsular spleen hematoma and small amounts of intra-abdominal free fluid in the left-upper quadrant.

Patient follow-up: The patient is admitted to the hospital and managed non-operatively. She is extubated but has a prolonged hospital course with gradually improving mental status. Ultimately she is discharged to a skilled nursing facility.

Teaching points: The FAST examination was misinterpreted as "negative." The proper interpretation should have been "indeterminate" due to inadequate visualization of anatomic landmarks. Figure E9 demonstrates a sub-optimal image with non-visualization of the spleen or diaphragm, excessive depth (wasted space beyond the kidney), and excessive gain (image appears very bright). You recognize the pitfall of your interpretation but hope to avoid FN FAST in the future. You wonder whether patient characteristics or injury patterns may predict those at high-risk for FN FAST examinations.

Figure E1. Coronal view of the right-upper quadrant, negative for free fluid.

Figure E2. Coronal view of the right-upper quadrant and the lateral, caudal border of the liver (arrow), negative for free fluid.

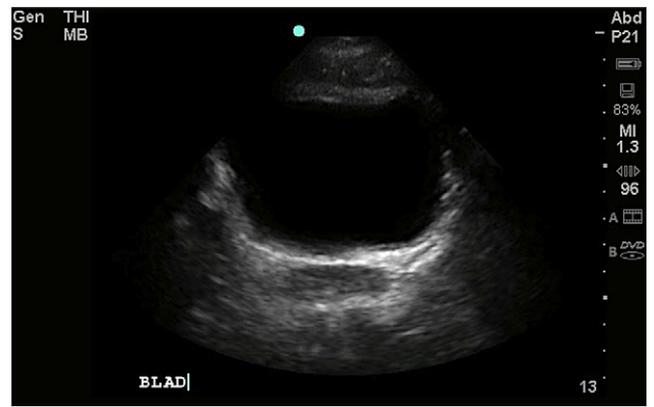**Figure E3.** Coronal view of the left-upper quadrant, negative for free fluid.

Figure E4. Axial view of the bladder, negative for free fluid. The prostate is demonstrated posterior to the bladder as a hypoechoic, oval strucure.
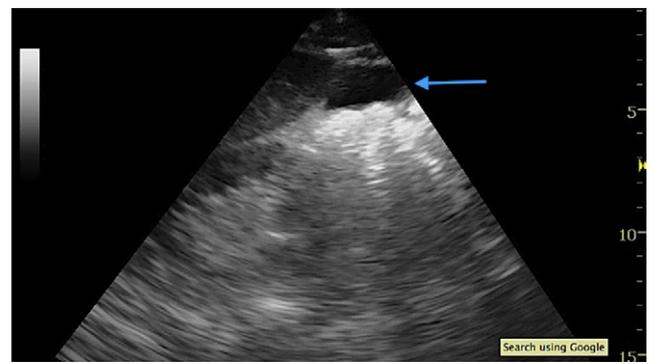

Figure E5. Coronal view of the right-upper quadrant demonstrating free fluid (arrow) near the lateral, caudal margin of the liver.

Figure E6. Coronal view of the left-upper quadrant demonstrating free fluid (arrow) near the lateral, sub-diaphragmatic region.
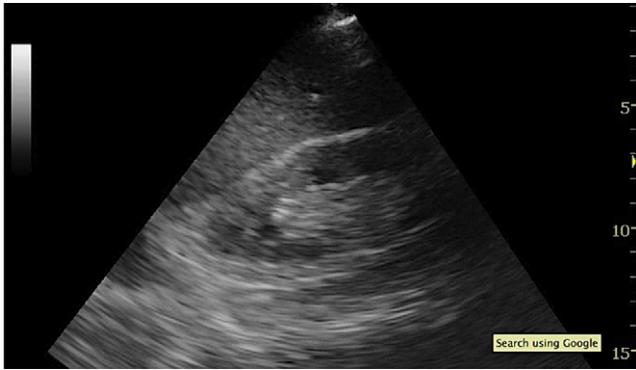
Figure E7. Coronal view of the right-upper quadrant appears negative.
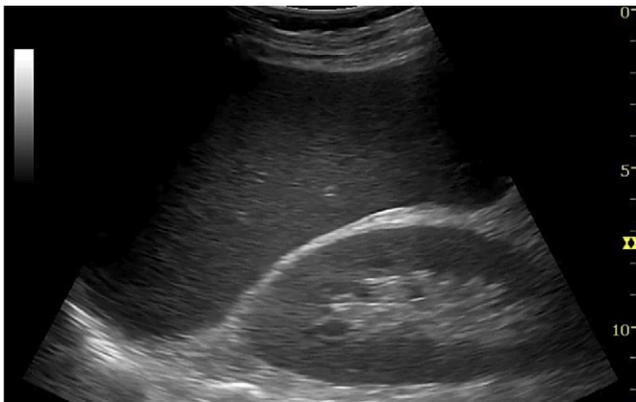

Figure E8. Coronal view of the left-upper quadrant appears negative.

Figure E9. Coronal view of the left-upper quadrant.