Accuracy of Focused Assessment with Sonography for Trauma (FAST) in Disaster Settings: A Meta-Analysis and Systematic Review

Christine Lee, MD; Daniel Balk, MD; Jesse Schafer, MD; Jeremy Welwarth, DO, MPH; John Hardin, MD; Shaked Yarza, BSc; Victor Novack, MD, PhD; Beatrice Hoffmann, MD, PhD

ABSTRACT

Focused assessment with sonography for trauma (FAST) has been incorporated into the initial evaluation of trauma for decades. It is an important screening tool in the detection of intra-abdominal fluid. The objective of this study was to perform a systematic review of the use and accuracy of FAST as an imaging tool for blunt abdominal trauma in disaster/mass casualty settings. A systematic review of literature was conducted using key words and search terms. Two independent reviewers screened abstracts to determine inclusion using the Quality Assessment of Diagnostic Accuracy Studies (QUADAS). For studies passing QUADAS, a meta-analysis was performed calculating sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV). FAST results were compared with the gold standard, which was a combination of CT scan results, operative findings, and medical records of the clinical course. Initial database screening resulted in 133 articles, of which 21 were selected for QUADAS evaluation. Five studies passed QUADAS and were selected in the final meta-analysis, with a total of 4263 patients. The sensitivity of FAST was 92.1% (87.8–95.6), specificity 98.7% (96.0–99.9), PPV 90.7% (70.0–98.0), and NPV 98.8% (98.1–99.5) for the detection of intra-abdominal injury. In our meta-analysis, FAST was both sensitive and specific in the evaluation of trauma in the disaster setting.

Key Words: ultrasonography, disaster medicine, earthquakes, mass casualty incidents, focused assessment with sonography for trauma

Focused assessment with sonography for trauma (FAST) has been incorporated into the initial evaluation of trauma patients for many decades. It is an important screening tool in the detection of intra-abdominal fluid with expanded applications to chest trauma. Previous studies have demonstrated screening the utility of FAST with sensitivities ranging from 46%–78% and high specificity ranging from 95%–100% in the evaluation of blunt abdominal trauma at 2 separate trauma centers,[1,2] whereas another meta-analysis yielded sensitivities ranging from 28%–92% and 96%–100% specificities for the detection of free fluid.[3] The scope of ultrasound as a diagnostic and screening tool continues to grow within the emergency department (ED) as well as beyond the ED. Because ultrasound is generally readily available internationally and reasonably portable, battery operated with a quick startup time, it can be a fundamental tool in disaster settings when circumstances overwhelm the health system with sudden increases in patients and instability to infrastructure, including power outages. The objective of this study was to perform a systematic review of the use of ultrasound as a screening tool for blunt abdominal trauma in disaster/mass casualty settings.

METHODS

Search Strategy

We extracted search key words using Medical Subject Headings (MeSH) results relevant to ultrasound and disaster/mass casualty incidents. Search terms included "ultrasonography," "emergency medical services," "disaster medicine," "mass casualty incidents," and "earthquakes." Using the aforementioned search strategy and key words, a systemic review of relevant literature was performed on PubMed, Web of Science, and Embase. An exhaustive search of these databases was performed using appropriate key words; no literature was excluded from this initial search.

Study Selection

Two reviewers independently evaluated the cumulative selection of titles and abstracts for study relevance. We used an evidence-based algorithmic approach, the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA).[4] In the event that there was disagreement between reviewers, a third reviewer was invoked for a consensus. All literature deemed relevant through PRISMA, full articles were collected and evaluated according to the guidelines put forth by the 14-item Quality Assessment of Diagnostic Accuracy Studies (QUADAS) tool.[5] Based on QUADAS criteria, all relevant studies were screened for presence of bias and relevance to the study question by 2 reviewers. A third reviewer was invoked to assess any literature for which the initial QUADAS results required a consensus.

Our inclusion criteria were articles addressing the use of ultrasound in disaster or mass casualty settings. Those studies that met the inclusion criteria were then evaluated with the QUADAS tool and using additional exclusion criteria to determine inclusion into the final meta-analysis. Two independent reviewers screened the abstracts to determine eligibility. A third reviewer was used for any conflicts in agreement. Exclusion criteria were set as descriptive studies, studies that did not involve the use of FAST, studies with a small sample size ($n < 10$).

Data Extraction

For each study included, based on QUADAS, relevant data were extracted from the literature, including sample size, patient age range, operator, reference standard, clinical setting, and the type of disaster event. These numbers were collected by article raw data when available and by sensitivity/specificity calculations when raw data were not available.

Data Analysis

Sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were determined by extracting data, and a meta-analysis was performed. Ultrasound results were compared with the gold standard, which varied between studies but included computed tomography (CT) scan results, surgical operative findings, and medical records of the clinical course. We used the Freeman–Tukey transformation (arcsine square root transformation)[4] to calculate the weighted summary proportion under the random effects model.[5] Heterogeneity was assessed by graphic examination of forest plots and by calculating I^2[6] and Cochran's Q test. Possible publication bias was assessed by the funnel plot and Egger's regression intercept. We used MedCalc statistical software version 17.2[7] and Comprehensive Meta Analysis, version 3.3.070.[8] A 2-tailed P-value < 0.05 was considered statistically significant.

RESULTS

Initial database screening resulted in 133 potentially eligible studies, of which 21 were selected for QUADAS evaluation with good inter-rater agreement between the 2 investigators and a kappa unweighted coefficient of 0.51.[9] Two sets of duplicates were found during an evaluation of the full articles. Out of the 19 unique studies, 7 were excluded due to being more descriptive or observational studies, which did not yield results that could be compared with a gold standard for statistical analysis.[10,11] Three studies were excluded due to their being based on ultrasounds other than the FAST, including peripheral nerve evaluation[12] and various renal and soft tissue ultrasounds to evaluate patients with rhabdomyolysis and other genitourinary injury in the setting of earthquakes,[13,14] One study was excluded based on having a low sample size ($n < 10$).[15] One study was excluded due to the study population being performed at a trauma hospital but not during a disaster event/period.[16] A final study was excluded due to the lack of information regarding further clinical course, any confirmatory imaging to assess accuracy of the ultrasound to determine true/false negatives and positives.[17]

Five studies were selected in the final meta-analysis with a total of 4263 patients (Figure 1, Table 1). Among ultrasounds performed on the 4263 patients, 400 yielded positive and 3863 yielded negative FASTs. The age of the patients ranged from 2 days to 103 years. Four of the studies were performed during earthquakes,[18,19] and the fifth study took place during a war.[20] The pooled sensitivity was 92.1%, 95% CI 87.8–95.6%, $I^2 = 49\%$. P for I^2 was nonsignificant at 0.10. The pooled specificity was 98.7%, 95% CI 96.0–99.9%, $I^2 = 96\%$. P value for I^2 was significant at < 0.001. The pooled PPV 90.7%, 95% CI 70.0–98.0%, $I^2 = 97\%$. P for $I^2 < 0.001$, which was significant. The pooled NPV was 98.9%, 95% CI 98.1–99.5%, $I^2 = 71\%$. P for $I^2 = 0.01$, which was significant (Figure 2, Table 2).

Heterogeneity was assessed by a graphic examination of forest plots and by calculating I^2[21] and Cochran's Q test, and showed that there was high heterogeneity across studies. All I^2 were statistically significant with the exception of the analysis for sensitivity.

Possible publication bias was assessed by a funnel plot and Egger's regression intercept and showed that, with the exception of PPV, there did not appear to be significant bias in the studies.

DISCUSSION

Previous studies using FAST in the general trauma population applied in hospital settings have demonstrated that it is a highly specific but less sensitive tool for hemoperitoneum. This systematic review demonstrated that FAST was found to be both highly sensitive and specific in detecting hemoperitoneum when applied in disaster settings.

The first study, which was included in our meta-analysis performed by Sarkisian et al., used ultrasound for screening of abdominal and renal injuries.[23] Ultrasounds were performed by physician sonographers and were performed in the hospital. The machines used in this study were Acuson-128 (Acuson Corp, Mountain View, CA), SSD 256 (Aloka Co., Ltd., Tokyo, Japan), ADR-2002 (ATL, Inc., Bothell, WA), and Minivisor-2000 (Ausonics, Australia). Remarkably, intra-abdominal fluid was found in 35% of the cases. This study

FIGURE 1

PRISMA Flowchart of Study.

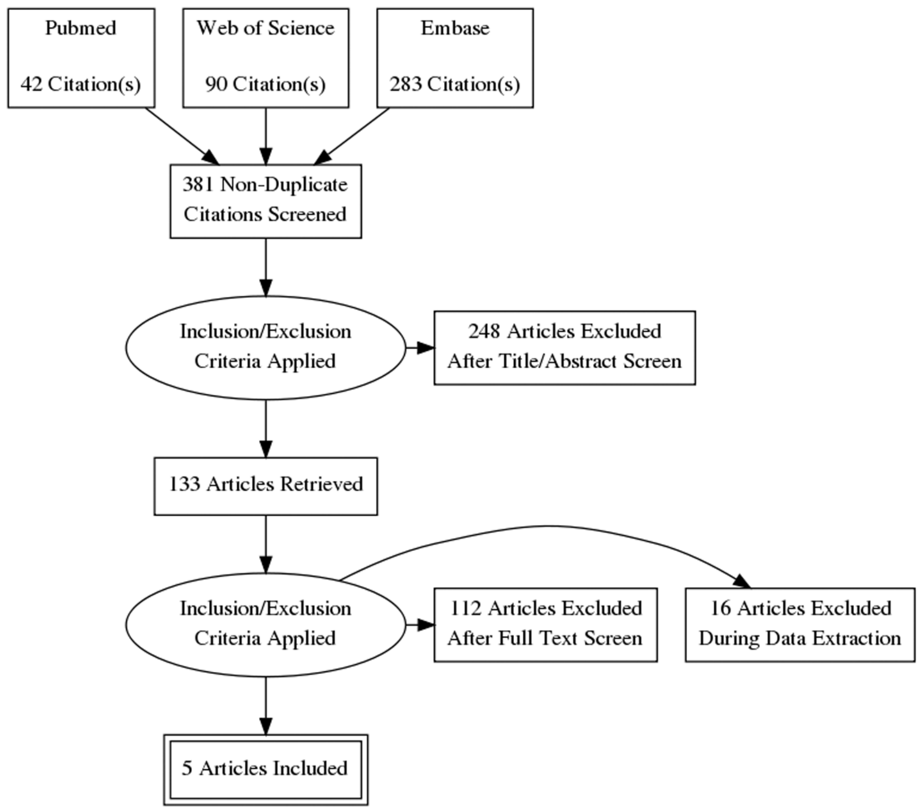

TABLE 1

Studies Included in Meta-Analysis and Characteristics

Study	No. of Patients	Age	Operator	Disaster Type	Weaknesses/Comments
Sarkisian 1991	400		Physician sonographers	Earthquake	
Zhou 2012	2204	7-103 months	Resident sonographers read by surgeons	Earthquake	Multi-center study
Dan 2010	1207	2-102 days		Earthquake	U/S performed mostly in field
Kakei 2013	350		ER, surgery, radiology physicians/residents	Earthquake	
Engel/Razi 2007	102	6–85 years	Radiology	War	Includes all trauma both penetrating and blunt

ER = emergency room; US = ultrasound.

represents one of the first studies showing the value of ultrasound in a mass casualty setting. Not all patients in this study received confirmatory imaging; however, all patients were followed retrospectively via medical records, and the authors reported only 1% false negatives and no false positives in their analysis.

Zhou et al. reviewed earthquake-related injuries at 701 hospitals during the Wenchuan earthquake.[25] Ultrasounds were reviewed by both an experienced surgeon and resident sonographer and compared against all subsequent imaging modalities, surgical findings, autopsy reports, and/or clinical course. All ultrasounds were performed within 24 hours to evaluate patients with suspected blunt abdominal trauma and were performed in the hospital. Because this was a multi-center study, they did not provide the machine types used in each of the settings. Also, they did not specify which

https://doi.org/10.1017/dmp.2019.23 Published online by Cambridge University Press

FIGURE 2

Forest Plots for Meta-Analysis.

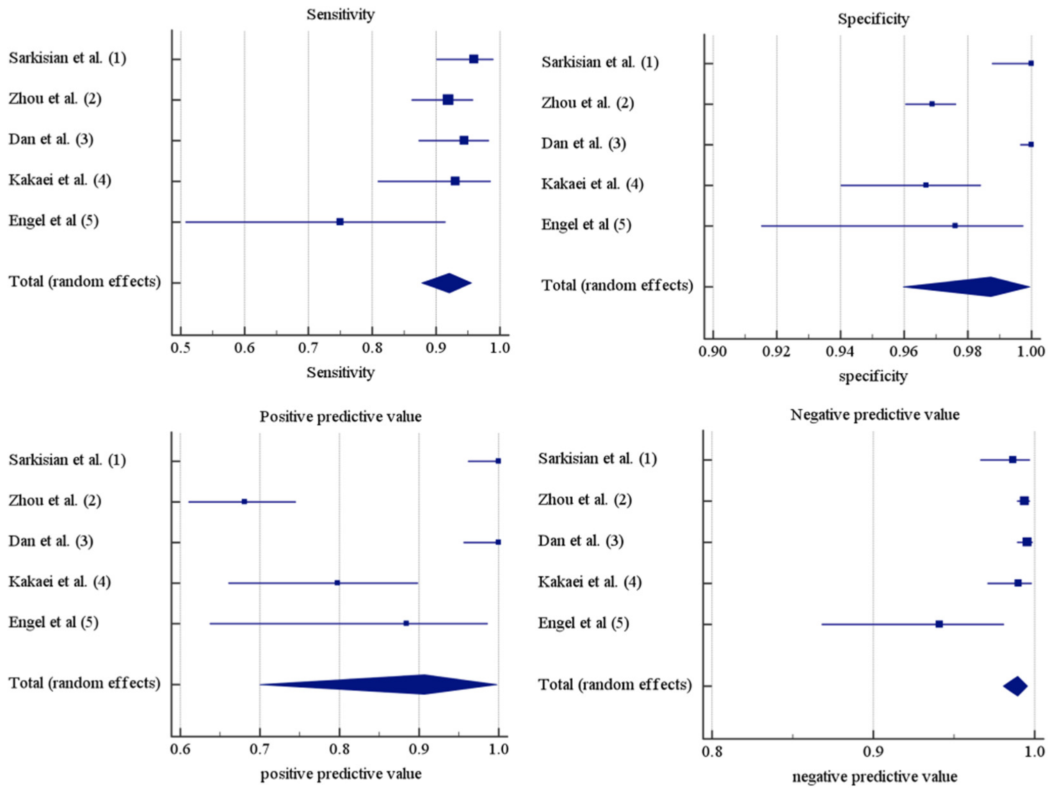

TABLE 2

Individual Study and Pooled Meta-Analysis Results

Study	Sensitivity	Specificity	PPV	NPV
Sarkisian et al.	96.0%	100%	100%	98.7%
Zhou et al.	91.9%	96.9%	68.1%	99.4%
Dan et al.	94.4%	100%	100%	99.6%
Kakaei et al.	93.0%	96.7%	79.8%	99.0%
Engel/Razi et al.	75.0%	97.6%	88.4%	94.1%
Total	92.1%	98.7%	90.7%	98.9%
I^2, *P*-value	47.79%	95.71%	96.6%	70.51%
	$P = 0.10$	$P < 0.0001$	$P < 0.0001$	$P = 0.01$

NPV = negative predictive value; PPV = positive predictive value.

department specialists were performing the FAST (radiology vs. surgery vs. emergency), but they do comment in their discussion that typically ultrasound studies are performed by radiologists or ultrasound technologists; however, during the earthquake, several major hospitals, including the hospital that published the study, rescue teams composed of both surgeons and emergency physicians, were performing FAST themselves during triage and all had had previous training in performing FAST. This study provided the most comprehensive data discussing results and their referred reference gold standard, which included CT, exploratory laparotomies, repeat ultrasounds, diagnostic peritoneal lavage (DPL), and observation.

Dan et al. was a single hospital study, examining patients injured during the Wenchuan earthquake.[24] The unique aspect of this study was that most of the ultrasounds were performed in the field, outdoors, presumably by physicians, but it is not specified what kind of providers performed the ultrasounds. They used portable Logic book color ultrasound (GE Co. Ltd, Spokane Valley, WA) or SonoSiteMMX color ultrasound (SonoSite, Inc., Bothell, WA).

Kakaei et al. examined the use of FAST in the 2012 Iranian earthquake.[26] Emergency physicians and surgery residents performed FAST, and nearly all of these ultrasounds were repeated by radiology residents and then subsequently were followed by CT results, clinical course, DPL, and surgical findings. These studies were all performed in the hospital. The authors note that there were 3 initial false-negative FAST patients who went on to have continued abdominal pain on serial exams and subsequently had positive DPL. These patients went on to have exploratory laparotomy revealing hollow viscous perforations, and all were reported to have

https://doi.org/10.1017/dmp.2019.23 Published online by Cambridge University Press

expired due to prolonged sepsis and peritonitis. This was 1 study in which false-negative findings resulted in adverse outcomes. However, it is unclear whether the initial FAST was indeed false negative and hampered by free intra-abdominal air from the hollow viscous perforation making the sonographic discovery of free fluid more difficult, or whether free fluid developed over time and was not present during the initial FAST exam. In all other studies, although there were false negatives, none resulted in a death. This is the only study that compares performance of ultrasounds performed by radiology residents with surgery or emergency residents or attendings, and they comment that there did not appear to be any changes in sensitivity by the operator but that specificity appeared to increase when the ultrasound was performed by radiology residents.

Finally, in Engel's study,[27] FAST was used for assessment during the Second Lebanon War. Although Engel's study was found during our literature search, we referred to another article published by the authors to obtain their data regarding FAST results.[29] In this study, ultrasounds were performed by radiology residents, and senior radiologists performed the exams within the ED. The machines used in this study were SSD-1400 (Aloka Co., Ltd., Tokyo, Japan), HDI 5000 (Philips Medical Systems, Bothell, WA), and MicroMaxx (SonoSite Inc., Bothell, WA). All examinations performed by radiology residents were subsequently reviewed by senior radiologists. One caveat to this study is that it evaluated patients with both blunt and penetrating abdominal injury and thus we were unable to extract data for only those who sustained blunt injuries.

There was some variation in where the ultrasound was performed (in the field vs. at hospital arrival) and by whom (ie, specialist in radiology, emergency, or surgery) in the studies included in this investigation. However, the high sensitivity and specificity of our meta-analysis demonstrate its potential value for expanded use in mass casualty settings. Based on the results of our meta-analysis, almost all of the I^2 were significant, indicating that there was high heterogeneity among the studies. Egger's regression analysis indicated that with the exception of PPV, there did not appear to be significant publication bias in our studies; however, the low number of studies in our analysis makes it difficult to make a definitive statement regarding publication bias.

Our recommendation is also supported by prior publications assessing use of imaging in a disaster setting. In their report of radiology imaging use during the Christchurch Earthquake of 2011, Gregan et al. reported that portable ultrasound equipment became the primary imaging method for all initial triage assessments.[30] Use of CT, X-ray, and even the larger, less portable ultrasound equipment failed due to complete power outage, including backup generator failure. Providers reported a preference for the smaller, portable, and quick startup battery operated point-of-care ultrasound equipment, because it allowed providers to quickly move from patient to patient without delay, and provided sufficient initial imaging information.[30] This study supports our recommendation that FAST and point-of-care ultrasound should be incorporated into disaster preparedness plans and protocols for hospitals and prehospital disaster response teams as in some scenarios due to the practical challenges that disasters present (ie, power outages, aftershocks, structural damage), ultrasound may sometimes be the most accessible imaging tool and, potentially in certain moments, the only available imaging tool. As FAST is already incorporated into training of surgery and emergency medicine, we suggest that disaster planning be focused on ensuring that portable, battery enabled/chargeable ultrasounds be readily available for use, whether it be for use in the field or for use at the bedside.

Limitations

One potential limitation of this study is that not all subjects with negative FAST received immediate confirmatory imaging, However, all patients were followed clinically, and those who had changes in clinical course received repeat imaging. Although there is a possibility that due to a lack of confirmatory testing in the FAST negative group, there may be more false negatives, it does not appear that these false negatives were clinically significant because they did not go on to have any adverse outcomes during the observations/study period in which the studies were performed, which generally follows the course of patients who present with trauma to the hospital setting in otherwise "normal" circumstances.

Another potential weakness of this study is that 2 of the included studies involve the same earthquake, the Wenchuan earthquake. Zhou et al.[25] retrospectively reviewed medical records from 701 hospitals, making it possible that some of the data included in his study were included in Dan et. al's[24] study. Therefore we cannot absolutely exclude that the current sample of the meta-analysis may include some duplicate patients.

Future directions include analyzing the success of ultrasound-guided procedures, such as nerve blocks, in the field in disaster settings, as well as other expanded applications of ultrasound. Many of the studies remarked on the importance of ultrasound in rapid triage to direct limited resources and determine which patients would need immediate transfer/transport to the operating room or further monitoring. In addition, many other articles in the search examine expanded uses of ultrasound in disaster settings, including the use of ultrasound guidance for multiple interventions, which would be of great benefit to patients being treated in the field.

CONCLUSION

FAST is both a sensitive and specific imaging modality in the evaluation of trauma in the disaster setting. FAST is a

https://doi.org/10.1017/dmp.2019.23 Published online by Cambridge University Press

relatively quick, noninvasive exam. Considering ultrasound's availability and portability, it stands as an important tool in disaster settings when circumstances overwhelm the existing resources and capacities of the health system.

About the Authors

Beth Israel Deaconess Medical Center, Emergency Medicine, Boston, Massachusetts (Lee, Balk, Schafer, Welwarth, Hardin, Hoffmann); Soroka University Medical Center, Beer-Sheva, Israel (Yarza, Novack); Faculty of Health Sciences, Ben-Gurion University of the Negev, Beer-Sheva, Israel (Yarza)

Correspondence and reprint requests to Christine E. Lee, 333 Harrison Street, Apt. 346, San Francisco, CA 94105 (e-mail: christine.e.lee@kp.org).

Conflict of Interest

The authors have no conflicts of interest to declare.

REFERENCES

1. Fleming S, Birth R, Ratnasingham K, et al. Accuracy of FAST scan in blunt abdominal trauma in a major London trauma centre. *Int J Surg*. 2012;10(9):470-474.
2. Hsu J, Joseph A, Tarlinton L, et al. The accuracy of focused assessment with sonography in trauma (FAST) in blunt trauma patients: experience of an Australian major trauma service. *Injury*. 2007;38(1):71-75.
3. Stengel D, Bauwens K, Sehouil J, et al. Systematic review and meta-analysis of emergency ultrasonography for blunt abdominal trauma. *Br J Surg*. 2001;88(7):901-912.
4. Freeman MF, Tukey JW. Transformations related to the angular and the square root. *Ann Math Stat*. 1950;21(4):607-611.
5. DerSimonian R, Laird N. Meta-analysis in clinical trials. *Control Clin Trials*. 1986;7(3):177-188.
6. Higgins JP, Thompson SG, Deeks JJ, Altman DG. Measuring inconsistency in meta-analyses. *Br Med J*. 2003;327(7414):557-560.
7. MedCalc Software, Version 17.2. Ostend, Belgium. 2017. https://www.medcalc.org/.
8. Biostat. Comprehensive Meta-Analysis version 3.3.070. Engelwood, NJ, USA. 2017. https://www.meta-analysis.com/pages/full_download.php. Accessed August 16, 2016.
9. Lowry R. VassarStats: statistical website for statistical computation. http://vassarstats.net/kappa.html. Accessed August 16, 2016.
10. Shah S, Dalal A, Smith R, et al. Impact of portable ultrasound in trauma care after the Haitian earthquake of 2010. *Am J Emerg Med*. 2010;28:970-971.
11. Shorter M, Macis D. Portable handheld ultrasound in austere environments: use in the Haiti disaster. *Prehosp Disaster Med*. 2012;27(2):172-177.
12. Zhang S, Zhu D, Wan Z, Cao Y. Utility of point-of-care ultrasound in acute management triage of earthquake injury. *Am J Emerg Med*. 2014;32(1):92-95.
13. Dean AJ, Ku BS, Zeseron EM. The utility of handheld ultrasound in an austere medical setting in Guatemala after a natural disaster. *Am J Disaster Med*. 2007;2(5):249-256.
14. Hasan M, Firoozabadi D, Abedinzadeh M, et al. Genitourinary system trauma after 2003 Bam earthquake in Kerman, Iran. *Ther Clin Risk Manag*. 2011;7:49-52.
15. Kimberly H, Stone MB. Clinician-performed ultrasonography during the Boston marathon mass casualty incident. *Ann Emerg Med*. 2013;62(2):199-200.
16. Lippert SC, Nagdev A, Stone MB, et al. Pain control in disaster settings: a role for ultrasound-guided nerve blocks. *Ann Emerg Med*. 2013;61(6):690-696.
17. Tang P, Wang Y, Zhang L, et al. Sonographic evaluation of peripheral nerve injuries following the Wenchuan earthquake. *J Clin Ultrasound*. 2012;40(1):7-13.
18. Keven K, Ates K, Yagmurlu B, et al. Renal Doppler ultrasonographic findings in earthquake victims with crush injury. *J Ultrasound Med*. 20(6):675-679.
19. Su BH, Qui L, Fu P, et al. Ultrasonographic appearance of rhabdomyolysis in patients with crush injury in the Wenchuan earthquake. *Chin Med J Engl*. 122(16):1872-1876.
20. Mazur SM, Rippey J. Transport and use of point-of-care ultrasound by a disaster medical assistance team. *Prehosp Disaster Med*. 2009;24(2):140-144.
21. Sztajnkrycer M, Baez A, Luke A. FAST ultrasound as an adjunct to triage using the START mass casualty triage system: a preliminary descriptive study. *Prehosp Emerg Care*. 2006;10(1):96-102.
22. Hu H, He Y, Zhang S, Cao Y. Streamlined focused assessment with sonography for mass casualty prehospital triage of blunt torso trauma patients. *Am J Emerg Med*. 2014;32(7):803-806.
23. Sarkisian AE, Khondkarian RA, Amirbekian NM, et al. Sonographic screening of mass casualties for abdominal and renal injuries following the 1988 Armenian earthquake. *J Trauma*. 1991;31(2):247-250.
24. Dan D, Mingsong L, Jie T, et al. Ultrasonographic applications after mass casualty incident caused by Wenchuan earthquake. *J Trauma*. 2010;68:1417-1420.
25. Zhou J, Huang J, Wu H, et al. Screening ultrasonography of 2,204 patients with blunt abdominal trauma in the Wenchuan earthquake. *J Trauma Acute Care Surg*. 2011;73(4):890-894.
26. Kakaei F, Zarrintan S, Rikhtegar R, Yaghoubi AR. Iranian 2012 earthquake: the importance of Focused Assessment with Sonography for Trauma (FAST) in assessing a huge mass of injured people. *Emerg Radiol*. 2013;20:307-308.
27. Engel A, Soudack M, Ofer A, et al. Coping with war mass casualties in a hospital under fire: the radiology experience. *Am J Roentgenol*. 2009;193(5):1212-1221.
28. Higgins JP, Thompson SG, Deeks JJ, Altman DG. Measuring inconsistency in meta-analyses. *Br Med J*. 2003;327(7414):557-560.
29. Beck-Razi N, Fischer D, Michaelson M, et al. The utility of focused assessment with sonography for trauma as a triage tool in multiple-casualty incidents during the second Lebanon war. *J Ultrasound Med*. 2007;26:1149-1156.
30. Gregan J, Balasingam A, Butler A. Radiology in the Christchurch earthquake of 22 February 2011: challenges, interim processes and clinical priorities. *J Med Imaging Radiat Oncol*. 2016;60(2):172-181.