Comparison of Ultrasonography and Radiography in Detection of Thoracic Bone Fractures; a Systematic Review and Meta-Analysis

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Received: June 2015; Accepted: August 2015

Abstract

Introduction: The potential benefit of ultrasonography for detection of thoracic bone fractures has been proven in various surveys but no comprehensive conclusion has been drawn yet; therefore, the present study aimed to conduct a thorough meta-analytic systematic review on this subject. Methods: Two reviewers independently carried out a comprehensive systematic search in Medline, EMBASE, ISI Web of Knowledge, Scopus, Cochrane Library, and ProQuest databases. Data were summarized as true positive, false positive, true negative and false negative and were analyzed via STATA 11.0 software using a mixed-effects binary regression model. Sources of heterogeneity were further assessed through subgroup analysis. Results: Data on 1667 patients (807 subjects with and 860 cases without thoracic fractures), whose age ranged from 0 to 92 years, were extracted from 17 surveys. Pooled sensitivity and specificity of ultrasonography in detection of thoracic bone fractures were 0.97 (95% CI: 0.90-0.99; I²= 88.88, p<0.001) and 0.94 (95% CI: 0.86-0.97; I²= 71.97, p<0.001), respectively. The same measures for chest radiography were found to be 0.77 (95% CI: 0.56-0.90; I²= 97.76, p<0.001) and 1.0 (95% CI: 0.91-1.00; I²= 97.24, p<0.001), respectively. The sensitivity of ultrasonography was higher in detection of rib fractures, compared to fractures of sternum or clavicle (97% vs. 91%). Moreover, the sensitivity was found to be higher when the procedure was carried out by a radiologist in comparison to an emergency medicine specialist (96% vs. 90%). Conclusion: Base on the findings of the present meta-analysis, screening performance characteristic of ultrasonography in detection of thoracic bone fractures was found to be higher than radiography. However, these characteristics were more prominent in detection of rib fractures and in cases where was performed by a radiologist. Key words: Thoracic fractures; ultrasonography; radiography; diagnostic tests, routine

Cite this article as: Yousefifard M, Baikpour M, Ghelichkhani P, et al. Comparison of ultrasonography and radiography in detection of thoracic bone fractures; a systematic review and meta-analysis. Emergency. 2016; 4(2):55-64.

Introduction:

Early diagnosis of rib fractures can rapidly indicate the source of thoracic pain and be helpful in pain management of trauma patients. Other than pain, rib fractures have been reported to be associated with morbidity and mortality in elderly patients (3-5). In most emergency departments, ultrasonography is considered as one of the most useful screening tools for rapid evaluation of trauma patients (6). Application of ultrasonography for assessment of chest wall injuries has been reported from 1980s (7). Since then the technology of ultrasound devices has significantly improved so that images with higher resolutions are obtained. In light of these improvements, the diagnostic value of this modality has been considerably enhanced (9). In this regard, studies have illustrated a considerably high diagnostic value of ultrasonography in detection of thoracic fractures, even higher than that of chest radiography (8, 10-12). For instance in his narrative review, Chan referred to ultrasonography as a reliable diagnostic tool.
for detection of thoracic bone fractures (13). Nevertheless, still no comprehensive review has been carried out comparing the diagnostic values of chest ultrasonography and radiography in detection of thoracic fractures. One solution is to perform a meta-analysis on the available evidence (15, 16). Accordingly, the present systematic review and meta-analysis aimed to determine the diagnostic values of chest ultrasonography and radiography in detection of thoracic bone fractures.

**Methods:**

*Search strategy and selection criteria*

The study protocol was established based on the guidelines of Meta-analysis of Observational Studies in Epidemiology statement (MOOSE) (19). After selection of keywords from Medical Subject Heading (MeSH) terms and EMTREE, two reviewers (M.Y, P.G) independently carried out an extended systematic search in databases of Medline (via PubMed), EMBASE (via OvidSP), ISI Web of Knowledge, Scopus, Cochrane Library, and ProQuest without any time or language limitations. The keywords included “Ultrasonography” OR “Sonography” OR “Ultrasound” OR “Radiography” OR “Chest Film” OR “Chest Radiograph” combined with “Rib Fractures” OR “Chest Wall Fracture” OR “Sternum Fracture” OR “Sternal Fracture” OR “Clavicle Fracture” OR “Scapula Fracture”. Additionally, the bibliographies of original and review articles as well as Google Scholar were also searched. All the studies evaluating the diagnostic accuracy of ultrasonography or chest radiography in detection of chest wall fractures were assessed. Review and editorial articles, case reports and studies with sample populations of less than 10 patients were excluded.

*Data extraction*

Two reviewers (M.Y, P.G) independently worked on summarizing the data regarding assessing quality of studies, baseline characteristics of patients (age, gender, the number of patients with and without hemothorax, the etiology of hemothorax), the characteristics of ultrasonography device (transducer, frequency), physicians in charge of imaging interpretation, blinding status, sampling method (consecutive, convenience), study design.
| Study          | No. of patient (+ / -) | Age (years) | Male (%) | Reference / Operator | Transducer / Operator | Sampling / Fracture | Weaknesses                      |
|---------------|------------------------|-------------|----------|----------------------|-----------------------|----------------------|---------------------------------|
| Hendrich 1995 (1) | 15 / 30                | 45 (29-61)  | 57.8     | CXR / US              | 7.5 MHz / Radiologist | Convenience / sternum | Low sample size                  |
| Engin 2000 (2)   | 18 / 5                 | 35.4 (18-75)| 82.6     | CXR / US              | 7.5 MHz / Radiologist | Convenience / sternum | Retrospective design            |
| Hurley 2004 (8)  | 15 / 5                 | 31 (16-55)  | 78.6     | CT / US, CXR          | 12.5 MHz / Radiologist| Consecutive / Rib       | Low sample size                  |
| Rainer 2004 (11) | 76 / 12                | 51 ± 19     | 59       | CT / US, CXR          | 5- to 10-MHz / Radiologist | Consecutive / Rib | Low sample size                  |
| Jin 2006 (10)    | 23 / 16                | 45.2 (15-82)| 52       | CT / US, CXR          | 5- to 9-MHz / Radiologist | Consecutive / Rib | Low sample size                  |
| Traub 2007 (14)  | 68 / 73                | 47.2 (18-89)| 75       | CT / CXR              | NA / Radiologist      | Consecutive / Rib       | Low sample size                  |
| Wootton-Gorges 2008 (17) | 131 / 94            | 0.2 (0.1-0.5) | 41.7     | CT / CXR              | NA / Radiologist      | Consecutive / Rib       | Low sample size                  |
| Cross 2010 (18)  | 43 / 57                | 10.7 (1-17) | 87.3     | CXR / US              | 7.5 to 15-MHz / EP   | Consecutive / Rib       | Possibility of selection bias   |
| Weinberg 2010 (20) | 25 / 187              | 13 (3-23)   | NR       | CT / US               | 7.5 to 10-MHz / EP   | Consecutive / Rib       | Possibility of selection bias   |
| You 2010 (21)    | 24 / 12                | 43 (8-73)   | 52.8     | CT / US               | 7- to 12-MHz / Radiologist | Consecutive / Rib | Low sample size                  |
| Szucs-Farkas 2011 (22) | 39 / 24              | 64.4 ± 14.7 | 73       | CT / CXR              | NA / Radiologist      | Consecutive / Rib       | Retrospective design            |
| Yazkan 2012 (23)  | 83 / 83                | 40.8 (16-92)| 73.5     | CT / CXR              | NA / Radiologist      | Consecutive / Rib       | Retrospective design            |
| Blasińska 2013 (24) | 34 / 26              | NR         | NR       | CT / CXR              | NA / Radiologist      | Consecutive / Rib       | Retrospective design            |
| Chardoli 2013 (25) | 51 / 149              | 37.9 (16-90) | 84       | CT / CXR              | NA / EP               | Consecutive / Rib       | The interpretation of the CXR   |
| Hoffstetter 2014 (26) | 92 / 8               | 28 (15-40)  | 73       | CT / US, CXR          | NA / Radiologist      | Consecutive / Rib       | and CT were not in blind fashion|
| Park 2015 (27)    | 15 / 24                | 61 (24-87)  | 60.7     | CT / CXR              | NA / Radiologist      | Consecutive / Rib       | Possible selection bias          |
|                 | 55 / 55                | 56.2 (16.9) | 57.4     | CT / CXR              | NA / Radiologist      | Consecutive / Rib       | Possibility of reporting bias    |

1. (+ / -): number of patient with fracture / number of patient without fracture; 2. Number are presented as mean ± standard deviation or (range). CT: Computed tomography; CXR: Chest radiography; EP: Emergency physician; NA: Not applicable; NR: Not Reported; US: Ultrasonography.
(retrospective, prospective). Finally the number of true positive (TP), true negative (TN), false positive (FP), and false negative (FN) cases were extracted. Disagreements were discussed with the third reviewer (M.H) and a solution was proposed. In cases of data inaccessibility, the corresponding authors of the articles were contacted. Data presented as charts were extracted via the method proposed by Sistrom and Mergo (28). In cases where only the sensitivity and specificity were presented, reliable web-based programs were used to calculate the number of TP, TN, FP, and FN cases.

**Quality assessment**

Quality of the studies were assessed based on the guidelines of 14-Item Quality Assessment of Diagnostic Accuracy Studies (QUADAS2) tool (29). The quality assessment were performed based on following items: acceptable reference tests, accounting for indeterminate results, avoiding differential verification bias, disease progression bias, incorporation bias and verification bias, blind index test interpretation, blind interpretation of reference test, explained withdrawal, relevant clinical data available, and representative spectrum. A total grading of poor, fair, and good was attributed to each survey and only the fair and good studies were included in the meta-analysis.

**Statistical analysis**

Analysis was performed using STATA 11.0 statistical software via MIDAS module. To evaluate the screening performance characteristics of ultrasonography and radiography in detection of chest wall fractures, summary receiver operative curves (SROCs) were drawn and pooled sensitivity, specificity, positive likelihood ratio and negative likelihood ratio with 95% confidence interval (95% CI) were calculated. Due to the high heterogeneity between the included studies, mixed-effects binary regression model was used. Heterogeneity was evaluated through calculations of I2 and χ2 tests and a P value of less than 0.05 was considered as statistically significant.

**Results:**

**Study characteristics**

17 out of 3894 studies found in the comprehensive search were included in the systematic review and meta-analysis (1, 2, 8, 10-12, 14, 17, 18, 20-27). 5 studies had assessed the diagnostic accuracy of ultrasonography in detection of thoracic bone fractures (1, 2, 18, 20, 21), 8 diagnostic value of chest radiography (14, 17, 22-27), and 4 diagnostic values of ultrasonography and radiography simultaneously (8, 10-12). 1667 cases (807 with and 860 without fractures) were extracted from the 17 mentioned articles, whose age ranged from 0 to 92 years old. Figure 1 shows the inclusion process of articles and table 1 summarizes the characteristics of included studies. No publication bias was observed (Figure 2).

**Meta-analysis**

The results of the analyses are presented as SROCs and Funnel plots in Figures 3 to 5. The area under the curve of SROC for ultrasonography and radiography in detection of chest wall fractures were found to be 0.99 (95% CI: 0.97-0.99) and 0.97 (95% CI: 0.96-0.99), respectively (Figure 3). Pooled sensitivity and specificity of ultrasonography in detection of thoracic bone fractures were 0.97 (95% CI: 0.90-0.99; I2 = 88.88, p<0.001) and 0.94 (95% CI: 0.86-0.97; I2 = 71.97, p<0.001), respectively (Figure 4-A). These characteristics for radiography were found to be 0.77 (95% CI: 0.56-0.90; I2 = 97.76, p<0.001) and 1.0 (95% CI: 0.91-1.00; I2 = 97.24, p<0.001), respectively (Figure 5-A). In addition, pooled positive and negative likelihood ratios of ultrasonography were 16.26 (95% CI: 6.26-38.87; I2 = 59.14, p<0.001) and 0.03 (95% CI: 0.01-0.11; I2 = 86.76, p<0.001), respectively (Figure 4-B), while these measures for radiography were reported to be 774.63 (95% CI: 7.0-8573.0; I2 = 96.62, p<0.001) and 0.23 (95% CI: 0.11-0.48; I2 = 96.94, p<0.001), respectively (Figure 5-B).

**Subgroup Analysis**

There were significant heterogeneity between the articles (Figure 4 and 5). Subgroup analysis was performed to remove its effects and find its probable sources. Table 2 presents the results of this analysis. Specificity of ultrasonography in detection of thoracic bone fractures was directly correlated with frequency of transducer (90% vs. 95%). The sensitivity of this modality was found to be higher in detection of rib fractures rather than fractures of clavicle or sternum (97% vs. 91%). Moreover it was found that the sensitivity would be higher if the procedure is performed by a radiologist (96%) compared to an emergency medicine specialist (90%). Sample size was another source of heterogeneity. Studies with sample sizes of greater than 100 patients reported higher diagnostic accuracies for ultrasonography in detection of thoracic bone fractures (97% vs. 91%).

As can be seen in Table 2, the most important factor affecting sensitivity of chest radiography is the interpreting physician. The sensitivity was found to be 66% when the radiogram was interpreted by an emergency medicine specialist while it was 80% when interpreted by a radiologist. Furthermore, consecutive sampling method compared with convenience (80% vs. 73%) and sample size of more than 100 patients (82% vs. 73%) were also found to be sources of heterogeneity.

**Discussion:**

Base on the results of the present meta-analysis sensitivity of chest ultrasonography in detection of thoracic...
**Table 2**: Subgroup analysis of diagnostic accuracy for chest radiography and ultrasonography in detection of thoracic bone fractures

|                          | No. of studies | Sensitivity (95% CI) | P  | Specificity (95% CI) | p  | heterogeneity, I² | P*   |
|--------------------------|---------------|----------------------|----|----------------------|----|------------------|------|
| **Ultrasonography**      |               |                      |    |                      |    |                  |      |
| **Patient enrollment**   |               |                      |    |                      |    |                  |      |
| Consecutive              | 3             | 0.98 (0.95-1.00)     | 0.01| 0.90 (0.77-1.00)     | 0.55| 43.0%            | 0.18 |
| Convenience              | 6             | 0.95 (0.90-0.99)     | 0.91| 0.86 (0.86-0.96)     | 0.01|                  |      |
| **Operator**             |               |                      |    |                      |    |                  |      |
| Emergency physician      | 3             | 0.90 (0.81-0.98)     | <0.001| 0.90 (0.83-0.97)     | 0.09| 21.0%            | 0.28 |
| Other physician          | 6             | 0.96 (0.93-0.99)     | 0.91| 0.84 (0.84-0.98)     | 0.01|                  |      |
| **Sample size**          |               |                      |    |                      |    |                  |      |
| < 100                    | 6             | 0.91 (0.84-0.97)     | 0.01| 0.90 (0.83-0.97)     | 0.04| 12.0%            | 0.32 |
| ≥ 100                    | 3             | 0.97 (0.94-1.00)     | 0.93| 0.87 (0.87-0.98)     | 0.01|                  |      |
| **Frequency of transducer** |         |                      |    |                      |    |                  |      |
| 5-10 MHz                 | 6             | 0.94 (0.89-0.99)     | 0.62| 0.90 (0.85-0.95)     | 0.03| 0.0%             | 0.51 |
| 10-15 MHz                | 3             | 0.95 (0.88-1.00)     | 0.95| 0.89 (0.89-1.00)     | 0.01|                  |      |
| **Type of fracture**     |               |                      |    |                      |    |                  |      |
| Rib                      | 4             | 0.97 (0.93-1.00)     | 0.01| 0.89 (0.83-0.96)     | 0.01| 45.0%            | 0.16 |
| Sternum / Clavicle       | 5             | 0.91 (0.84-0.97)     | 0.93| 0.94 (0.94-0.98)     | 0.01|                  |      |
| **Radiography**          |               |                      |    |                      |    |                  |      |
| **Patient enrollment**   |               |                      |    |                      |    |                  |      |
| Consecutive              | 7             | 0.80 (0.59 - 1.00)   | 0.70| 1.00 (1.00 - 1.00)   | 0.99| 0.0%             | 0.70 |
| Convenience              | 5             | 0.73 (0.45 - 1.00)   | 1.00| 0.98 (1.00 - 1.00)   | 0.99| 0.0%             | 0.78 |
| **Operator**             |               |                      |    |                      |    |                  |      |
| Emergency physician      | 3             | 0.66 (0.27 - 1.00)   | 0.53| 1.00 (1.00 - 1.00)   | 0.99| 0.0%             | 0.78 |
| Other physician          | 9             | 0.80 (0.63 - 0.98)   | 1.00| 1.00 (1.00 - 1.00)   | 0.99| 0.0%             | 0.78 |
| **Sample size**          |               |                      |    |                      |    |                  |      |
| < 100                    | 7             | 0.73 (0.49 - 0.97)   | 0.44| 1.00 (1.00 - 1.00)   | 0.99| 0.0%             | 0.57 |
| ≥ 100                    | 5             | 0.82 (0.61 - 1.00)   | 1.00| 1.00 (1.00 - 1.00)   | 0.99| 0.0%             | 0.57 |
| **Type of fracture**     |               |                      |    |                      |    |                  |      |
| Rib                      | 8             | 0.77 (0.57 - 0.97)   | 0.56| 1.00 (1.00 - 1.00)   | 0.99| 0.0%             | 0.98 |
| Sternum / Clavicle       | 4             | 0.77 (0.48 - 1.00)   | 1.00| 1.00 (1.00 - 1.00)   | 0.99| 0.0%             | 0.98 |

* P value < 0.1 was considered as significant for heterogeneity; CI: Confidence interval.
bone fractures following trauma was prominently higher than radiography (97% vs. 77%). Yet, the specificity of radiography was found to be significantly higher than ultrasonography in this regard (100% vs. 94%). On this basis and according to calculated likelihood ratios, a negative result of ultrasonography in detection of thoracic fracture is more reliable than radiography (negative likelihood ratio=0.03), while a positive result of chest radiography is more reliable than ultrasonography (positive likelihood ratio=774.63).

Ultrasoundography had a higher sensitivity in diagnosis of rib fractures rather than other chest wall bones, while the type of fracture had no effect on diagnostic value of radiography. This finding can be ascribed to the higher attention that physicians pay to rib fractures rather than other chest wall bones such as scapula and sternum.

Fractures are diagnosed via ultrasonography based on observation of cortical bone disruption. In cases of small fractures, detection of this sign in sonogram and distinguishing it from other findings is highly dependent on the skills of the operator. The role of operator’s skills in detection of injuries via ultrasonography was verified in the present study as well (31-34). Ultrasonography by a radiologist has a higher sensitivity compared to emergency medicine specialist. The present study found that the specificity of this modality increased with frequencies of higher than 10MHz which might be due to the higher resolution obtained with higher frequencies (35), making it easier to detect the signs of fracture.

Some narrative review articles and qualitative systematic reviews are indicative of the potential benefit of ultrasonography in detection of chest wall fractures. In this regard, Chan, in his systematic review conducted on studies indexed in Medline, declares that ultrasonography has a higher sensitivity in detection of thoracic bone fractures compared to radiography (13). Finding the diagnostic accuracy of ultrasonography to be two times the ability of radiography in fracture diagnosis, Dietrich et al. also referred to ultrasonography as a useful diagnostic tool for detection of rib fractures (36). The results of the present meta-analysis were congruent with these findings.

Presence of considerable heterogeneity between the included articles and simultaneous inclusion of retrospective and prospective studies in the meta-analysis were major limitations of this study. Subgroup analysis was performed to overcome the heterogeneity problem.

Conclusion:

Base on the findings of the present meta-analysis, screening performance characteristic of ultrasonography in detection of thoracic bone fractures was found to be higher than radiography. However, these characteristics were more prominent in detection of rib fractures and in cases where was performed by a radiologist.

Acknowledgments:
None

Conflict of interest:
None

Funding support:
This research has been supported by Tehran University of Medical Sciences & health Services grant number: 93-02-38-25618.

Authors’ contributions:
All authors passed four criteria for authorship contribution based on recommendations of the International Committee of Medical Journal Editors.

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Figure 2: Deeks’ funnel plot asymmetry test for assessment of publication bias. P values < 0.05 was considered as significant. Ultrasonography (A); Radiography (B). ESS: Effective sample sizes.

Figure 3: Summary receiver operative curves (SROC) for ultrasound (A) and chest radiography (B) in detection of thoracic bone fractures. AUC: Area under the curve; SENS: Sensitivity; SPEC: Specificity.
Figure 4: Forest plot of screening performance characteristics of chest ultrasonography in detection of thoracic bone fractures. Sensitivity and specificity (A); Diagnostic likelihood ratio (DLR) (B). CI: Confidence interval.
Figure 5: Forest plot of screening performance characteristics of chest radiography in detection of thoracic bone fractures. Sensitivity and specificity (A); Diagnostic likelihood ratio (DLR) (B). CI: Confidence interval.