Comparison of the use of lung ultrasound and chest radiography in the diagnosis of rib fractures: a systematic review

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Received 20 December 2017
Revised 30 September 2018
Accepted 13 November 2018
Published Online First 23 November 2018

To cite: Battle C, Hayward S, Eggert S, *et al*. *Emerg Med J* 2019;**36**:185–190.

ABSTRACT

Introduction It is well-recognised that the detection of rib fractures is unreliable using chest radiograph. The aim of this systematic review was to investigate whether the use of lung ultrasound is superior in accuracy to chest radiography, in the diagnosis of rib fractures following blunt chest wall trauma.

Methods The search filter was used for international online electronic databases including MEDLINE, EMBASE, Cochrane and ScienceDirect, with no imposed time or language limitations. Grey literature was searched. Two review authors completed study selection, data extraction and data synthesis/analysis process. Quality assessment using the Quality Assessment of Diagnostic Accuracy Studies Tool (QUADAS-2) was completed.

Results 13 studies were included. Overall, study results demonstrated that the use of lung ultrasound in the diagnosis of rib fractures in blunt chest wall trauma patients appears superior compared with chest radiograph. All studies were small, single centre and considered to be at risk of bias on quality assessment. Meta-analysis was not possible due to high levels of heterogeneity, lack of appropriate reference standard and poor study quality.

Discussion The results demonstrate that lung ultrasound may be superior to chest radiography, but the low quality of the studies means that no definitive statement can be made.

INTRODUCTION

Blunt chest wall trauma is present in over 15% of all trauma admissions to EDs worldwide[1] and most commonly occurs due to a motor vehicle collision, a high or low velocity fall or a direct blow to the chest wall.[2–4] Rates of reported mortality in blunt chest wall trauma increase with age and levels of frailty and can vary between 4% and 60%.[5 6] Rib fractures represent the most frequent blunt chest trauma and can be associated with complications such as pneumothorax or lung contusion.[7] Delayed onset of pulmonary complications following blunt chest wall trauma is common and as a result, prediction of outcome and decisions regarding appropriate management on presentation to the ED, can be difficult.

Prognostication is further complicated by the fact that 33%–50% of rib fractures are missed on chest radiograph.[8 9] Despite this well-recognised questionable sensitivity, the chest radiograph remains the primary diagnostic modality for blunt chest wall trauma and is widely performed to investigate suspected rib fractures.[10] The American College of Radiology has recently revised its appropriateness criteria and now recommends that it is unnecessary to perform chest radiography for diagnosis of rib fractures in adults sustaining minor trauma.[11]

More recently, the use of lung ultrasound (LUS) has been investigated for diagnostic accuracy in the identification of rib fractures following blunt chest wall trauma. When compared with standard radiography, LUS has been considered superior in the diagnosis of pneumothorax, pneumonia, pleural effusion and alveolar diseases and has similar performance characteristics to CT scan.[12 13] Evidence is more controversial however regarding the use of LUS in the management of rib fractures.[11]

To identify rib fractures using LUS, the transducer is aligned in the transverse position, parallel to the long axis of the rib. Fracture of the rib will be viewed as discontinuity of the cortical margin, a linear acoustic edge shadow arising from the margin of the broken rib, a reverberation artefact and a local haematoma.[7] A number of studies have been conducted examining the use of LUS compared with chest radiography in the diagnosis of rib fractures following blunt chest wall trauma. The aim of this systematic review is to investigate whether the use of LUS is superior in accuracy to chest radiography, in the diagnosis of rib fractures following blunt chest wall trauma.

METHODS

This study was registered on the PROSPERO database, University of York (CRD:42017067908).[14]

Search strategy

This systematic review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines.[15] A broad search strategy was used to ensure all relevant articles were captured. The search filter was used for international online electronic databases including MEDLINE, EMBASE, Cochrane and ScienceDirect, with no imposed time or language limitations. Reference lists of eligible studies and review articles were hand-searched. *Annals of Emergency Medicine*, *Emergency Medicine Journal*, *Injury and the Journal of Trauma and Acute Care Surgery* were also hand-searched from their introduction until the end of May 2017 for relevant studies.

All available worldwide Emergency Medicine Conference abstracts were searched. In addition, OpenSIGLE (System for Information on Grey

Table 1 Keyword combinations used in literature search

Chest	AND	Blunt chest trauma	AND	Lung ultrasound
Thora*		Rib fractures		Sonography
Lung		Pneumothorax		Ultrasonograph*
		Haemothorax/hemothorax		
		Effusion		
		Contusion		

*Indicates where the truncated version of the search term was used.

Literature in Europe) which provides access to grey literature produced in Europe from 1980 until 2005, the National Technical Information Service and Health Management Information Consortium databases which include unpublished papers were searched. The website ClinicalTrials.gov was also searched for any ongoing trials. The authors of the studies selected for inclusion in this review were contacted in order to provide expert opinion on further studies for inclusion and a deadline for response was set at 6 weeks.

The search term combinations were Medical Subject Heading terms, text words and word variants for the chest. These were combined with relevant terms for rib fractures and with terms for lung ultrasound. The search terms are illustrated in table 1.

Table 2 highlights the inclusion and exclusion criteria used for study selection. Studies not investigating diagnostic accuracy of LUS compared with chest radiography were excluded from the review.

Study selection

Titles and/or abstracts of studies retrieved using the search strategy and those from additional sources were screened independently by two review authors (CB and SH) according to the inclusion/exclusion criteria. The full text of these potentially eligible studies were retrieved and independently assessed for eligibility by the same two reviewers. Any disagreements were resolved through discussion with a third reviewer (PE).

Data extraction and management

A standardised, prepiloted form was used to extract data from the included studies for assessment of study quality and evidence synthesis. Extracted information included: study setting; study population and participant demographics and baseline characteristics; details of the lung ultrasound intervention and control (chest radiography) conditions; study methodology; recruitment and study completion rates; outcomes and times of measurement; information for assessment of the risk of bias. Two review authors extracted data independently (CB and SH), discrepancies were identified and resolved through discussion, with third author (PE) where necessary.

Quality assessment

Two review authors (CB and SH) independently assessed the risk of bias and quality of the included studies using the QUADAS-2 Tool for Quality Assessment of Diagnostic Accuracy Studies.[16] The tool comprises four domains: patient selection, index test, reference standard and flow and timing. Each domain will be assessed in terms of risk of bias, and the first three domains were assessed in terms of concerns regarding applicability. Disagreements between the review authors over the risk of bias in particular studies were resolved by discussion, with involvement of a third review author (PE) where necessary. Each item was scored low, high or unclear. Studies which scored 'low' on all four domains were considered to have an overall 'low risk of bias and low concern regarding applicability'. If a study was judged 'high' or 'unclear' on one or more domains, then they were considered 'at risk of bias or concerns regarding applicability'. No studies were excluded due to poor quality or lack of reference standard, rather all quality issues were considered when interpreting the results of each study.

Data analysis and synthesis

As suggested in the Centre for Reviews and Dissemination (CRD) guidelines for systematic reviews,[17] due to the high degree of heterogeneity, limited study quality and lack of appropriate reference standard used in the included studies, it was not possible to conduct a meta-analysis. A descriptive summary and explanation of the characteristics and findings of the included studies was presented. Using the framework outlined in the CRD guidelines, the following elements were considered for the data analysis and synthesis: development of a theory as to whether LUS is accurate, why and for whom; development of a preliminary synthesis of findings of included studies; exploration of relationships within and between studies and assessment of the robustness of the synthesis.[17]

RESULTS

Study selection

A total of 4317 citations were identified using the described search strategy. Following screening of the titles and abstracts using the two-step process, 4292 articles were excluded. Of the 25 full articles that were retrieved and critically appraised, a total of 13 were included in the review. Three non-English language studies were identified and translated. One study was North American,[18] six studies were Asian[19–25] and five European.[7 26–29] A prospective diagnostic test accuracy study design was used in all but one of the included studies, with Martino *et al*[29] using a case series design.[29]

In terms of the use of the reference standard, one study used CT scan and chest radiograph,[19] two used bone scintigraphy,[20 26] one used chest radiograph[22] and three used a repeat LUS[21 23 25]

Table 2 Inclusion and exclusion criteria for study selection

	Inclusion	Exclusion
1) Population	a. Adults aged 16 years or more b. Patients with blunt chest wall trauma (blunt chest injury resulting in chest wall contusion or rib fractures, with or without underlying lung injury) c. Undergoing both radiological and ultrasound investigation	a. Patients with penetrating trauma only b. Patients with multitrauma only and no reference to chest trauma c. Patients with intrathoracic injuries only and no chest wall trauma d. Children (aged under 16 years)
2) Interventions/exposures	Lung ultrasound	No lung ultrasound included
3) Comparators	Chest radiograph	No chest radiograph included
4) Study design	Observational studies	Review articles, letters/editorials, case studies, case-control series

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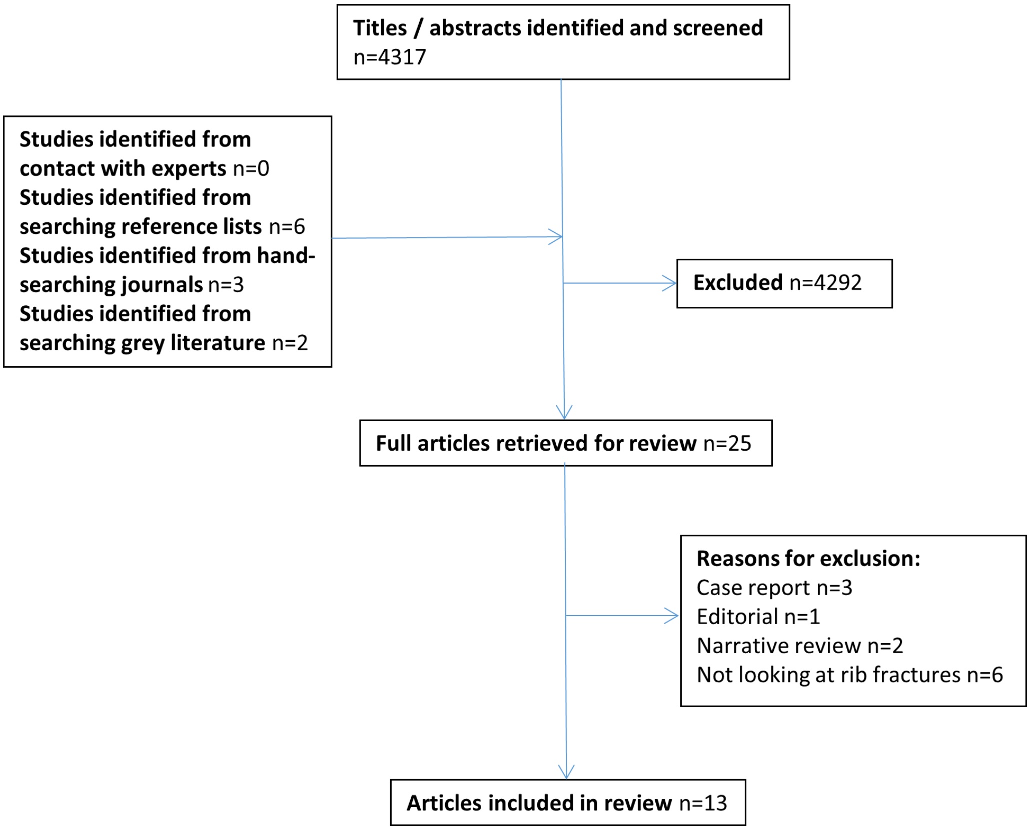

Figure 1 Flow diagram of study selection process.

at a later time point. Six of the studies failed to use a reference test at all.[7,18,24,26,28,29] In addition, the methods used in the studies differed, with six studies investigating rib fracture diagnosis using LUS in patients with no evidence of rib fracture on chest radiograph[19,22–25,29] and six studies[7,18,19,25,26,28] investigating rib fracture diagnosis using both LUS and chest radiograph in patients with clinical suspicion of rib fractures.

There was a marked difference in the period of time between presentation and completion of the LUS. Some completed the LUS immediately following the chest radiograph while others waited a number of weeks for the LUS to be performed. The LUS operator was reported to be a radiologist in four studies[7,19,21,23] an emergency physician in one study[17] and not stated in eight studies.[20,22,24–29] Not all studies used a blinded approach in which the operator was unaware of the chest radiograph results, compared with other studies in which two radiologists were used blinded to other radiological investigations. The position of the patient in the LUS also varied, from sitting in a number of studies, to a lateral decubitus position in others. The probe used in the studies to complete the LUS varied between a 3.5, 5, 7.5, 9 and 12.5 MHz linear probe. The chest radiograph used in the studies also varied between a plain posteroanterior view to an oblique, targeted view.

No further studies were identified through contact with the included studies' authors. Figure 1 outlines the study selection process and reasons for exclusions.

Study characteristics

A total of 13 studies were included in the review. All studies were single centre, with a variable number of patients in each study (range 5–201). The characteristics and main results of each study are included in table 3.

Quality assessment

The quality assessment using the QUADAS-2 checklist showed a variable risk of bias and applicability concerns across the studies. Table 4 shows the quality assessment results of each study. All included studies were considered at risk of bias or concerns regarding applicability.

Patient characteristics

The patient population investigated in the included studies was trauma patients presenting to the ED. Most studies stated that they had included patients with isolated, minor or mild blunt chest trauma, or excluded patients with any concurrent major injury.[7,19,21–25] Only one study stated that they specifically included a small number of polytrauma patients.[26] LUS was also reported to be superior in the identification of costal cartilage fractures in isolated blunt chest trauma patients.[19,25] One study identified patients for inclusion, by presence of high-uptake rib lesions on bone scintigraphy (including those with a history of trauma).[20]

Diagnostic accuracy of lung ultrasound

Only one study reported sensitivity and specificity values for both LUS, chest radiograph and clinical acumen, with LUS having a higher sensitivity, but lower specificity than both chest radiograph and clinical acumen.[21] All other studies reported proportions (numbers or percentages) of rib fractures identified on diagnostic tests.[7,18–20,22–29] LUS was reported to identify a higher proportion of patients with rib fractures than chest radiograph in 11 of the included studies.[7,19,20,22–29] Furthermore, the use of LUS in the diagnosis of patients with rib fractures was reported superior to targeted, oblique rib radiographs in two studies[7,28]

Table 3 Extracted data illustrating the studies' characteristics and main finding

Study	N	Age (years)	Index test	Reference standard	Transducer/ operator	Sampling	Primary outcome	Results
Lalande *et al*[18]	96	Median: 54 (IQR: 38–69)	LUS CXR	None	Transducer: NS Emergency physician	Consecutive	Feasibility of PoCUS for rib # diagnosis using VAS score	32% pts had a # on either modality. 29% pts had # on LUS not seen on CXR. 12% pts had # on CXR not seen on LUS.
Lee *et al*[19]	93	Mean: 51 (17–78)	LUS	CXR, MDCT	7.5 MHz linear Two radiologists	Consecutive	Presence of costal cartilage fracture	69% pts had a chrondral # on LUS, not seen on CXR or MDCT.
Paik *et al*[20]	58	Mean: 61 (22–88)	LUS, CXR	Bone scan	5–12 MHz linear Operator NS	Consecutive	Presence of rib lesion (fracture or metastasis)	97% pts with rib # identified on LUS (cf bone scan). 43% pts with rib # identified on CXR (cf bone scan).
Rainer *et al*[21]	88	Mean: 51 (SD: 19)	LUS, CXR, Clinical acumen	LUS at 3 weeks	5–9 MHz linear Radiologist	Consecutive	Presence of rib fracture	Sensitivity: LUS: 80.3 (69.5–88.5) CXR: 23.7 (14.7–34.8) CA: 26.0 (15.8–36.3) Specificity: LUS: 83.3 (51.6–97.4) CXR: 91.7 (61.5–98.6) CA: 91.7 (61.5–98.6).
Kara *et al*[22]	37	Mean: 42 (16–85)	LUS	CXR	7.5 MHz linear Operator NS	Consecutive	Presence of rib fracture	40.5% pts had rib # on LUS not seen on CXR. 59.5% pts had no # on LUS (as interpreted on CXR).
Turk *et al*[23]	20	Mean: 47 (25–68)	LUS, CXR	LUS at 7–12 days	12.5 MHz linear Radiologist	Consecutive	Presence of rib fracture	90% pts had rib #s on LUS not seen on CXR. This confirmed at follow-up LUS.
Hurley *et al*[7]	14	Mean: 31 (16–55)	LUS, CXR standard and oblique views)	None	12.5 MHz linear Radiologist	Consecutive	Presence of rib fracture	n=14 rib #s seen on LUS. n=11 rib #s seen on PA CXR. n=13 rib #s seen on oblique CXR.
Hwang and Lee[24]	201	Mean: 48 (3–91)	LUS, CXR	None	12 MHz Operator NS	Consecutive	Presence of rib fracture	70% pts had rib # on LUS not seen on CXR. 48% pts had additional rib # on LUS to number identified on CXR.
Griffith *et al*[25]	50	Mean: 50 (24–89)	LUS, CXR	LUS at 3 weeks	9/12 MHz linear Operator NS	Case series	Presence of rib fracture	n=83 rib #s in 39 (78%) of pts on LUS. n=8 rib #s in 6 (12%) of pts on CXR. n=12 additional rib #s in 9 pts (4 of whom who had no # on initial LUS) on 3-week follow-up LUS.
Wüstner *et al*[26]	100	NS	LUS, CXR	None	3.5–7.5 MHz linear. Operator NS	Consecutive	Presence of rib fracture	65% pts had rib #s on LUS compared with 36% pts on CXR.
Wischhofer *et al*[27]	21	NS	LUS, CXR	Bone scan	5 MHz linear. Operator NS	Case series	Presence of rib fracture	76% (n=16) pts had rib #s not seen on CXR. 11 of these 16 had signs of rib # on bone scan.
Bitschnau *et al*[28]	103	Mean: 54.3 Range NS	LUS, CXR	None	7 Mhz linear, 3.5–5 MHz linear rarely. Operator NS	Consecutive	Presence of rib fracture	58% of pts had rib #s on LUS. 0% of pts had rib # on PA CXR. 30% of pts had rib #s on targeted CXR.
Martino *et al*[29]	5	Mean: NS (34–63)	LUS, CXR	None	7.5 MHz linear, Operator NS	Case series	Presence of rib fracture	90% of pts had rib #s on LUS. 0% of pts had rib #s on CXR.

#, fracture.
#, fracture; CA, clinical acumen; LUS, lung ultrasound; MDCT, multidirectional CT scan; NS, not stated; pts, patients; PoCUS, point-of-care ultrasound scan; VAS, visual analogue scale.

Table 4 Results of the QUADAS-2 quality assessment process

	Risk of bias				Applicability concerns		
Study	**Patient selection**	**Index test**	**Reference standard**	**Flow and timing**	**Patient selection**	**Index test**	**Reference standard**
Lalande *et al*[18]	High	Unclear	High	Unclear	Low	Unclear	Low
Lee *et al*[18]	Low	Unclear	Unclear	Unclear	Low	Unclear	Low
Paik *et al*[20]	Low	Unclear	Low	Unclear	Low	Low	Low
Rainer *et al*[21]	Low	Low	Unclear	Unclear	Low	Low	Low
Kara *et al*[21]	Low	Unclear	High	Low	Low	Unclear	Low
Turk *et al*[23]	High	Unclear	Unclear	Low	Low	Low	Low
Hurley *et al*[7]	Low	Low	Unclear	Low	Low	Low	Low
Hwang and Lee[24]	High	Unclear	High	High	Unclear	Unclear	Unclear
Griffith *et al*[25]	Unclear	Unclear	Unclear	Unclear	Low	Low	Low
Wüstner *et al*[26]	Low	Low	High	High	Low	Low	Unclear
Wischhofer *et al*[27]	Low	Unclear	Unclear	High	Low	Low	Unclear
Bitschnau *et al*[28]	Low	Low	High	Unclear	Low	Low	Unclear
Martino *et al*[29]	High	Unclear	High	Unclear	Low	Low	Unclear

and MDCT (in detection of costal cartilage fractures) in another study.[19] The actual number of rib fractures identified by LUS compared with chest radiograph was also reported to be higher in four of the studies.[24–27] In contrast, two studies reported that a certain number of fractures were evident on chest radiograph, but missed on LUS.[18 26]

No study reported whether there had been any assessment of LUS reliability. In terms of LUS interobserver agreement, this was not measured in any of the studies. The type of LUS operator varied between studies (radiologist and emergency physician) and was not actually specified in a number of the studies, as outlined in table 3. As a result, no conclusions can be made regarding the reliability of LUS from the included studies.

LUS strengths and weakness

LUS was also reported to be superior to chest radiograph and other radiographic modalities due to a number of clinical factors including; it is unaffected by respiratory motion, it leads to a reduction in the use of expensive CT and MRI scan and in radiation exposure, immediate interpretation and availability of results is possible, LUS is portable permitting use in prehospital environment and finally, it can be used by non-radiologists.[19 21–23 25 28] Three key disadvantages of LUS in the diagnosis of rib fractures were proposed in a number of the studies including; LUS is time-consuming, it can be painful for the patient and that the retroscapular and infraclavicular portions of the first rib were inaccessible.[7 19 24 25] Furthermore, large breasts and obesity were also reported to be limitations of LUS.[18 19 24]

Relationship within and between studies

Meta-analysis of study results was not possible due to the poor quality and high levels of heterogeneity between the studies. Differences between the studies included the use/choice of reference standard, time period between injury and completion of the LUS, choice of probe, LUS operator and patient position used for the LUS.

DISCUSSION

The results of this review demonstrate that LUS may be superior to chest radiography, but the low quality of the studies means that no definitive statement can be made. Although two of the included studies also reported a small number of rib fractures evident on chest radiograph that were not picked up by LUS, the overall results of the review suggests that LUS is the superior of the two modalities. High levels of heterogeneity between the studies precluded meta-analysis and the drawing of any definitive conclusions. Results of the review should be interpreted with caution due to general poor study quality, risk of bias and lack of appropriate reference standard.

A number of advantages and disadvantages of LUS were also discussed in the included studies. One advantage of LUS over chest radiograph reported in the studies included the ability to diagnose damage to the lung, underlying the rib fractures. This is not always evident on early chest radiograph and may improve prognostication and clinical decision making earlier postinjury. Time taken to undertake the scan, pain and difficulty scanning obese patients were some of the disadvantages of LUS when compared with chest radiograph, described in the included studies.

One of the key issues of research investigating the use of LUS in the diagnosis of rib fractures is the broad spectrum of injury that this will encompass. Such injuries will include simple bruising to the chest wall, through to major chest trauma including underlying vascular or organ involvement. It is unlikely that the clinical utility and accuracy of LUS will be consistent across this spectrum of injury. Minimal information regarding severity of patients' injuries was described in the included papers, so conclusions regarding LUS in rib fracture diagnosis are limited. Further research across the full spectrum of the rib fracture injury is needed.

The LUS operator varied between the included studies with a number of the studies failing to discuss who had carried out the LUS. In only one included study was the operator reported to be an emergency physician. The influence of the operator should be considered, as it is possible that in small single-centre studies, the operator is an enthusiast who has developed a high degree of skill in LUS. As a result, it may be difficult to generalise the results of this review to routine care of rib fracture patients in the ED.

In order to fully assess the accuracy of LUS in the diagnosis of rib fractures, further research is needed. As CT scan is generally agreed to be the gold standard test in the diagnosis of rib fractures, studies directly comparing LUS with CT scan should be completed. Such research would assist clinicians in the management of blunt chest trauma patients, where a CT scan is not warranted. It is not currently possible to recommend an immediate change in clinical practice based on the results of this review, due to the low quality of the studies, the lack of a reference standard and the variability in methods used within each study.

There are a number of limitations of this review. The main limitation was that an accurate assessment of LUS inter-rater or intrarater observer agreement was not completed in any of the included studies using a Cohen's κ statistic. A κ statistic would have allowed for assessment of LUS reliability, without using a gold standard reference test. This could be considered in future studies. Furthermore, the studies do not include sufficient detail to draw any conclusions regarding the LUS operator characteristics and this should also be considered in future work.

As discussed, the included studies lacked an appropriate reference standard and were at risk of bias, which precluded any meta-analysis. Applicability of the review findings is limited, as a number of the included studies were not completed within the ED setting. Publication bias is also an inherent potential risk in any systematic review, which may have influenced the results of this study. An attempt to overcome this source of bias was made, through searching grey literature and ongoing studies.

In conclusion, the included studies appear to suggest that LUS may be superior to chest radiograph in the diagnosis of rib fractures, although poor study quality and risk of bias precludes definitive conclusions at this time.

Acknowledgements The authors would like to thank the Library and Information Service, Staff Library at Morriston Hospital, ABMU Health Board for their assistance with the literature search and retrieval of articles.

Contributors All authors contributed to the conception and design of the study. CB, SH and PAE completed the data acquisition, analysis and interpretation. SE interpreted the foreign language papers. CB drafted the work and SH, PAE and SE revised it critically for important intellectual content. All authors have approved the version to be published and agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Funding The authors have not declared a specific grant for this research from any funding agency in the public, commercial or not-for-profit sectors.

Competing interests None declared.

Patient consent Not required.

Provenance and peer review Not commissioned; externally peer reviewed.

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