Anaesthesia 2016, 71, 1091–1100 doi:10.1111/anae.13525

Review Article

CPD available at http://www.learnataagbi.org

Focused echocardiography: a systematic review of diagnostic and clinical decision-making in anaesthesia and critical care

J. Heiberg,[1] D. El-Ansary,[2] D. J. Canty,[3] A. G. Royse[4] and C. F. Royse[5]

1 Post-doctoral Research Fellow, 3 Consultant, 5 Professor, Department of Anaesthesia and Pain Management, 2 Senior Lecturer, Department of Physiotherapy, 4 Consultant, Department of Surgery, Royal Melbourne Hospital, Melbourne, Victoria, Australia

Summary

Focused echocardiography is becoming a widely used tool to aid clinical assessment by anaesthetists and critical care physicians. At the present time, most physicians are not yet trained in focused echocardiography or believe that it may result in adverse outcomes by delaying, or otherwise interfering with, time-critical patient management. We performed a systematic review of electronic databases on the topic of focused echocardiography in anaesthesia and critical care. We found 18 full text articles, which consistently reported that focused echocardiography may be used to identify or exclude previously unrecognised or suspected cardiac abnormalities, resulting in frequent important changes to patient management. However, most of the articles were observational studies with inherent design flaws. Thirteen prospective studies, including two that measured patient outcome, were supportive of focused echocardiography, whereas five retrospective cohort studies, including three outcome studies, did not support focused echocardiography. There is an urgent requirement for randomised controlled trials.

Correspondence to: J. Heiberg
Email: johan.heiberg@clin.au.dk
Accepted: 19 April 2016
Keywords: anaesthetic management; diagnosis; echocardiography; ultrasonography

Introduction

Over the last decade, there has been a rapid uptake in the clinical use of focused echocardiography by emergency and critical care physicians and anaesthetists in order to guide decision-making in real time, or at the 'point-of-care' [1–6]. The important elements are that they are: performed by the treating physician at the time; performed in real time during clinical assessment at the bed side; and may be limited in scope, being confined to an assessment relevant to the clinical situation rather than a full or comprehensive examination as would be expected from a diagnostic laboratory. This has happened because of improved quality and availability of equipment; reduced cost of equipment; widespread training in clinical ultrasound being available; and also, importantly, the realisation that only a limited number of views are required to diagnose haemodynamic status and important cardiac pathology [7]. This enables the physician to confidently diagnose the likely cause of haemodynamic instability, such as hypovolaemia, left or right heart failure, vasodilatation, pericardial effusion and significant valve disease, and usually only takes a few minutes to perform at the bedside, or even during a cardiac arrest [8]. The diagnostic information aids the treating physician to make better-informed decisions. The time taken to perform

focused echocardiography is generally less than for alternative diagnostic modalities such as X-ray, CT scanning or ultrasound examinations in a cardiology or radiology setting, and does not require transporting the patient or exposing them to harmful radiation.

Most physicians are not yet trained to use focused echocardiography, or else believe it may lead to adverse outcomes by delaying or otherwise interfering with time-critical management. Furthermore, the cost of implementing focused echocardiography into clinical practice is significant (training, quality assurance, equipment) and therefore the clinical benefits should be cost effective.

The primary aim of this systematic review was to determine the effect of focused echocardiography on diagnosis and management of clinically important cardiac disease compared with conventional clinical assessment, in patients requiring non-cardiac surgery or admission to the critical care unit. A secondary aim was to examine the influence of focused echocardiography on patient outcome, including cardiovascular complications and death.

Methods

We performed a literature search based on the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) guidelines [9]. In December 2015, after confirming that a similar systematic review had not already been published, the principal researcher (JH) performed a detailed search of PubMed, MEDLINE and EMBASE electronic databases using the following search terms: ("Echocardiography" OR "Ultrasonography" OR "Heart Diseases/ultrasonography") AND ("Perioperative Care" OR "Intensive Care") AND "Humans". The search was restricted to peer-reviewed, original research, including prospective, retrospective cohort, case–control and cross-sectional studies; but excluded case reports, non-English language publications, studies published before 1 January 1995 or publications without the full text being available. Participants were humans aged at least 18 years. The intervention was focused echocardiography performed either before, during or after non-cardiac surgery or in a critical care setting. The outcomes included changes in clinical diagnosis, management, cardiac complications and death. For each individual publication, an outcome-level assessment of bias was performed that included the following parameters: patient selection, sonographer expertise, indication for surgery and indication for focused echocardiography. This bias assessment was considered in the synthesis of results but no scoring system was used and definitions of all criteria and endpoints were agreed by the researchers before performing the search (Appendix 1).

Results

A flow chart of the systematic review process is shown in Fig. 1. Our search identified 180 publications with a further 15 publications being found in the bibliographies, resulting in a total of 190 after duplicates had been removed. After reviewing the titles and abstracts of these publications for eligibility, 169 were excluded, leaving 21 publications that were checked for accuracy by two additional independent reviewers (DE and DC). One full-text publication was excluded as it was

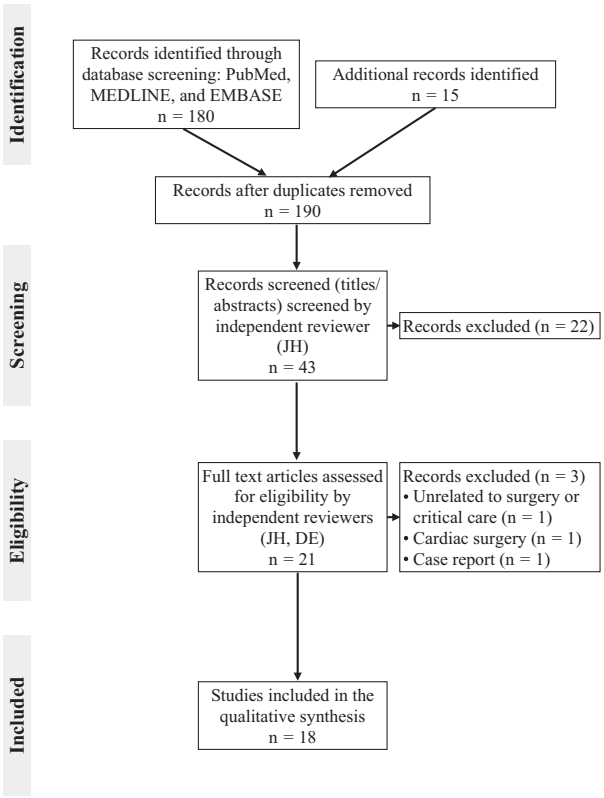

Figure 1 Flow diagram showing the systematic review process.

performed in a cardiac surgery setting, another was not in the peri-operative or critical care setting and another was a case series. A total of 18 full-text publications were therefore analysed. Data were extracted and stored in Microsoft Excel for Mac 2015 (Version 14.5.8; Microsoft Corporation, Redmond, WA, USA). An overview of the included full-text publications with primary and secondary outcome measures is shown in Table 1. Two-thirds (12) of the publications were in anaesthesia and one-third (6) were in critical care. There were no prospective randomised controlled trials. There were 13 prospective, interventional cohort studies of which two included a control group and there were five retrospective cohort studies of which three included a control group. There was considerable variability in the aims, patient populations and endpoints used. Six studies reported interpretability of imaging (which was between 86% and 100%) [12, 15, 18, 22, 24, 26], whereas this was unreported in 12 studies.

The impact of focused echocardiography on clinical diagnosis is listed in Table 2. In anaesthesia, the change in diagnosis due to detection of clinically significant cardiac pathology was reported in four studies and varied from 17% to 78% of cases [10, 11, 13, 14]. The diagnostic impact appeared greater in the three studies where focused echocardiography was performed in patients with a recognised indication for focused echocardiography (a change in diagnosis was made in between 51% and 67% of cases) compared with one study where focused echocardiography was used as a routine screening tool in which a diagnosis was changed in 17% of patients. In each of the four studies in the anaesthesia setting, focused echocardiography was performed before emergency surgery [10, 11, 13, 14]. In the critical care setting, there were three studies that reported the total change in diagnosis due to clinically significant cardiac pathology, where the change in diagnosis following focused echocardiography ranged from 33% to 37% [24, 25, 27] of cases. In both settings, the most common new diagnosis was left ventricular dysfunction (in between 0% and 23% of patients). There was also a significant number of patients with a new diagnosis of valve disease (1–48%), hypovolaemia (0–34%) or pulmonary hypertension (1–14%) in the anaesthesia setting and right ventricular dysfunction (14%) or hypervolaemia (9%) in the critical care setting. Six studies in anaesthesia and three studies in critical care did not report on changes in diagnosis.

Changes in patient management are summarised in Table 3. In the anaesthetic setting, changes in management were reported in four studies and ranged from 12% to 82% [10, 12, 14, 15]. The impact on management appeared greater in the studies where focused echocardiography was performed for a recognised indication (between 54% and 82%) compared with one study where focused echocardiography was used as a screening tool (12%). In the four anaesthesia studies, focused echocardiography was performed before surgery, one in the pre-operative clinic [12] and three before emergency surgery [10, 14, 15]. In the critical care setting, two studies reported changes in patient management that ranged from 41% to 51% [22, 27]. The most common changes were medical (in 4% to 52% of cases) and included altered anaesthetic technique (in between 2% and 12% of cases in the anaesthesia setting) and in choice of inotropes or vasopressors (in 8% to 25% of cases) and fluids (in 12% to 65% of cases) in the critical care setting. In anaesthesia, there was also a significant number of changes to surgical management (in between 7% and 46% of cases). In anaesthesia and critical care, six studies and one study, respectively, did not report changes in patient management. In anaesthesia, four studies reported on patient outcome compared with a control group [13, 17, 19, 21]. One of these was a prospective cohort study that supported the use of focused echocardiography. Canty et al. [13] demonstrated a 30-day mortality of 5% in an echocardiography group compared with 15% in a group receiving standard treatment with one-year mortality reduced to 17% in the intervention group compared with 33% in the control group. Three studies were retrospective cohort trials that did not support the use of focused echocardiography. Jettoo et al. [17] demonstrated 10% and 5% in-hospital mortality in an echocardiography group and standardised treatment group, respectively. O'hEireamhoin et al. [19] found 24% and 3% six–month mortality in an echocardiography and control group, respectively. Wijeysundera et al. [21] found increases in 30-day and one-year mortality in their echocardiography group

Table 1 Overview of publications reporting the impact of focused echocardiography on diagnosis, management and outcome compared with conventional clinical management in non-cardiac surgery and critical care.

	Authors	Year	Study design	Aim	Indication for focused echocardiography	Main findings
Anaesthesia						
1	Botker et al. [10]	2014	Prospective cohort	Determine the frequency of new findings with routine preoperative echo	Screening	17% diagnosis change, 12% management change
2	Canty et al. [11]	2009	Prospective cohort	Determine the frequency of changes in management due to echo before, during and after surgery	Suspected valve or cardiac dysfunction, or altered volume state	51% diagnosis change
3	Canty et al. [12]	2012	Prospective cohort	Determine the incidence of changes in management due to echo performed before surgery in the pre-operative clinic	Suspected valve or cardiac dysfunction (80%), or screening (20%)	54% management change
4	Canty et al. [13]	2012	Retrospective cohort	Determine if pre-operative echo is associated with reduced mortality after hip fracture surgery	Suspected valve or cardiac dysfunction	78% diagnosis change, 69% lower 30-day and 49% lower 1-year mortality
5	Canty et al. [14]	2012	Prospective cohort	Determine the frequency of changed diagnosis and management from echo performed before emergency surgery	Suspected valve or cardiac dysfunction, altered volume state (75%), or screening (25%)	67% diagnosis change, 44% management change
6	Cowie et al. [15]	2011	Prospective cohort	Determine the frequency of changed management from echo before surgery	Haemodynamic instability (22%), suspected valve (58%) or cardiac dysfunction (14%), or pericardial effusion (2%)	82% management change
7	Cowie et al. [16]	2012	Retrospective cohort	Determine the risk and predictive value of cardiac pathology detected on preoperative echo with adverse cardiac outcomes	Haemodynamic instability, suspected valve or cardiac dysfunction	Pulmonary hypertension, cardiac dysfunction, and valvular disease increase risk of adverse events
8	Jettoo et al. [17]	2011	Retrospective cohort	Determine the frequency of changed management from echo performed before hip fracture surgery	Haemodynamic instability (13%), suspected valve (81%) or cardiac dysfunction (6%)	100% higher in-hospital mortality
9	Loxdale et al. [18]	2012	Prospective cohort	Determine the prevalence and severity of aortic stenosis and left ventricular dysfunction with echo before hip fracture surgery	Suspected or known valve dysfunction (100%)	39% prevalence of aortic stenosis, 7% prevalence of heart failure
10	O'hEireamhoin et al. [19]	2011	Retrospective cohort	Determine the frequency of operative delay and postoperative complications in patients who received echo within 6 months before surgery	Unspecified	700% higher 6-month mortality, 1.8 days operative delay

(continued)

Table 1 (*continued*)

	Authors	Year	Study design	Aim	Indication for focused echocardiography	Main findings
11	Rohde et al. [20]	2001	Prospective cohort	Determine the risk and predictive value of cardiac pathology detected on pre-operative echo with adverse cardiac outcomes	Unspecified	Cardiac dysfunction, LV hypertrophy, and stenotic valvular disease increase the risk of adverse events
12	Wijeysundera et al. [21]	2011	Retrospective cohort	Determine if pre-operative echo is associated with reduced mortality and shorter hospital stay after elective surgery	Unspecified	14% higher 30-day and 7% higher 1-year mortality 0.3 days longer hospital stay
Critical care						
13	Joseph et al. [22]	2004	Prospective cohort	Determine whether echo can identify the cause of shock in critically ill patients with suspected cardiac shock	Haemodynamic instability	51% management change
14	Kanji et al. [23]	2014	Prospective cohort	Determine whether echo-based protocol for management is associated with changed fluid and inotrope therapy and improved survival compared with controls in patients with undifferentiated vasopressor-dependent shock	Screening	26% lower 30-day mortality
15	Manasia et al. [24]	2005	Prospective cohort	Determine the feasibility and frequency of changed management from hand-held echo	Haemodynamic instability (21%), or screening (79%)	37% diagnosis change
16	Marcelino et al. [25]	2009	Prospective cohort	Determine the prevalence of cardiac pathology detected with echo and their risk and predictive value for mortality and length of stay	Screening	33% diagnosis change
17	Orme et al. [26]	2009	Prospective cohort	Determine the frequency of changed management from echo	Haemodynamic instability (18%), suspected valve (3%) or cardiac dysfunction (57%), altered volume state (10%), pericardial effusion (8%) or not specified (4%)	38% management change
18	Stanko et al. [27]	2005	Prospective cohort	Determine the frequency of changed diagnosis and management from echo	Haemodynamic instability (59%) suspected valve (2%) or cardiac dysfunction (25%), altered volume state (9%), or pericardial effusion (5%)	29% diagnosis change, 41% management change

LV, left ventricle.

with relative risks of 14% and 7%, respectively. In the critical care setting, one prospective outcome study by Kanji et al. [23] found a 28-day mortality of 34% in their echocardiography group compared with 46% in their standardised treatment group. In terms of adverse events rather than mortality, Kanji et al. [23] found a reduced incidence of renal failure (68%) in their intervention group compared with 95% in a standardised

Table 2 Changes in diagnosis due to significant cardiac pathology after focused transthoracic echocardiography compared with conventional clinical assessment. Values are proportion.

Authors		Diagnoses, total	LV dysfunction	RV dysfunction	Valve disease	Hypovolaemia	Hypervolaemia	Pulmonary hypertension	Pleural effusion	Pericardial effusion
Anaesthesia										
1	Botker et al. [10]	17%	0%	0%	1%	0%	0%	–	14%	2%
2	Canty and Royse [11]	51%	14%	6%	22%	6%	–	1%	2%	4%
3	Canty et al. [12]	–	14%	1%	21%	1%	–	1%	–	–
4	Canty et al. [13]	78%	20%	–	14%	34%	–	11%	–	–
5	Canty et al.[14]	67%	23%	2%	19%	27%	–	14%	–	–
8	Jettoo et al. [17]	–	–	–	48%	–	–	–	–	–
Critical care										
15	Manasia et al. [24]	37%	28%	–	–	–	–	–	–	–
16	Marcelino et al. [25]	33%	22%	14%	2%	–	9%	–	–	3%
18	Stanko et al. [27]	29%	–	–	–	–	–	–	–	–

LV, left ventricule; RV, right ventricule.

Table 3 Changes in patient management following focused transthoracic echocardiography compared with conventional clinical assessment. Values are proportion.

Authors		Management total	Medical management	Surgical management	Anaesthetic technique	Anaesthetic drug therapy	Inotropes/ vasopressor	Fluids	Surgery	Postoperative disposition
Anaesthesia										
1	Botker et al. [10]	12%	4%	7%	3%	2%	0%	1%	3%	6%
2	Canty and Royse [11]	–	40%	–	–	–	–	–	16%	–
3	Canty et al. [12]	54%	36%	46%	13%	–	11%	–	12%	34%
4	Canty et al. [13]	–	52%	–	52%	–	–	–	–	–
5	Canty et al. [14]	44%	30%	14%	–	–	–	–	–	–
6	Cowie [15]	82%	51%	31%	37%	12%	9%	17%	4%	27%
7	Cowie [16]	–	–	–	–	–	–	–	3%	–
Critical care										
13	Joseph et al. [22]	51%	35%	16%	–	–	–	–	12%	–
14	Kanji et al. [23]	–	–	–	–	–	25%	65%	–	–
15	Manasia et al. [24]	–	37%	–	–	–	21%	24%	–	–
17	Orme et al. [26]	–	38%	–	–	19%	8%	12%	7%	5%
18	Stanko et al. [27]	41%	39%	7%	–	–	–	–	–	4%

treatment group. Five studies reported on adverse events and mortality without a comparator. In the anaesthetic and critical care setting, complication rates of between 8% and 18% were reported [16, 20], including myocardial infarction (3–11%) [16, 19, 20] and heart failure (7–33%) [13, 16, 18, 22]. Two studies reported relative risk assessments on echocardiographic findings. Cowie [16] demonstrated that the incidence of adverse cardiac events was high in patients with pulmonary hypertension, cardiac dysfunction and stenotic valvular disease, especially when these occurred in combination. Rohde et al. [20] reported that moderate to severe left ventricular hypertrophy, systolic dysfunction and peak aortic gradients above 40 mmHg correlated with major cardiac complications.

Discussion

The main purpose of this systematic review was to determine evidence for the influence of focused echocardiography on diagnosis and clinical management. The publications we included had a wide variety of study designs and there were no prospective randomised trials. Thirteen out of 18 studies were prospective and interventional in design and although only two were clinical outcome studies using controls for comparison, they were both supportive of focused echocardiography in terms of reducing mortality rates. Seven studies reported a significant diagnostic impact of focused echocardiography in both anaesthesia and critical care that led to frequent changes in patient management in six of the studies. It has been claimed that focused echocardiography is, potentially, a life-saving diagnostic tool in anaesthesia and critical care. This review therefore highlights the need for sufficiently powered and well-designed randomised controlled trials to determine whether focused echocardiography can improve clinical outcome, and whether this potential benefit justifies the not insignificant cost of equipment purchase and personnel training.

In eight publications, the most common indication for focused echocardiography was suspected valvular or ventricular dysfunction. By contrast, Botker et al. [10] performed focused echocardiography as a screening tool, which explains their lower impact on diagnoses compared with other studies. Two studies [13, 14] reported a high incidence of newly diagnosed hypovolaemia, which may reflect the differences in indications for focused echocardiography. These studies also included older patients. In the ICU setting, the most common new diagnosis was ventricular failure, reported in up 28% of patients, and was most likely to be due to sepsis. The changes in patient management varied widely but, with increasing demand for critical care beds [28–30], the fact that a focused echocardiography examination was often normal when the clinician had diagnosed abnormality, meant that a step down in the level of treatment was possible.

In the critical care unit, focused echocardiography is used to identify causes of haemodynamic instability, respiratory distress, volume status, response to therapy [25, 31] and causes of shock [22, 32]. In our review, one of the most frequently reported management changes was that related to intravenous fluids, which is not surprising because there are well-validated echocardiography applications to predict fluid responsiveness [33–35] that can be utilised when the patient is breathing spontaneously, rather than during mechanical ventilation of the lungs [36].

Adverse cardiac events are a leading cause of morbidity and mortality after major surgery [37–39]. In anaesthesia, the only prospective study found lower 30-day and one-year mortality rates in elderly hip fracture patients who had focused echocardiography. By contrast, three retrospective studies found similar or higher rates of mortality after pre-operative echocardiography [17, 19, 21]. However, these studies have design flaws as they were audits of every patient having pre-operative echocardiography. When comparing such cohorts with patients who did not undergo echocardiography before surgery, selection bias occurs. In the critical care setting, only two studies addressed this issue. Kanji et al. [23] demonstrated that echocardiography-based recommendations for intravenous fluids and inotropes improved 28-day survival in comparison with standard treatment in randomly selected patients. They also reported a reduction in the incidence of acute kidney injury in their echocardiography group compared with controls.

The studies included in this review had various study designs, and there are issues to consider. Firstly, the mean (SD) ages of included cohorts varied significantly, from 62 (21) years to 85 (8) years [10, 17] and

different age limits were applied in order to be included in a study. This is important because the prevalence of unexpected cardiac pathology is substantially greater in patients older than 65 years, and will inevitably result in more changes to patient management and a greater impact on outcome. Secondly, the indications for focused echocardiography differed between studies. In studies when consecutive screening was performed, one must expect less pathology and therefore less impact of focused echocardiography compared with studies when echocardiography was performed because of suspected valvular or ventricular dysfunction. Thirdly, in all the publications, except for two [10, 24], focused echocardiography was performed by sonographers, who were categorised as experts, with the imaging reported as interpretable in between 86% and 100% of examinations [10, 26].

In conclusion, focused echocardiography is an emerging element of clinical assessment in non-cardiac surgery and critical care. The published literature to support it is rapidly evolving, but at the moment the evidence base for its use remains mostly confined to uncontrolled or retrospective observational studies and no randomised trials have yet been conducted. From the studies published so far, impact on diagnosis and clinical decision-making is well described but there are few studies examining patient outcome. Two studies [13, 23] report lower complication rates and mortality after echocardiography-based guidance compared with standard patient management. Randomised trials, despite their cost and time constraints, are essential in order to determine whether the improved diagnostic capability of focused echocardiography can translate into improved patient outcome.

Acknowledgements

We thank the librarian T. Celeste for help with the literature search.

No external funding or competing interests declared.

References

1. Neskovic AN, Edvardsen T, Galderisi M, et al. Focus cardiac ultrasound: the European Association of Cardiovascular Imaging viewpoint. *European Heart Journal Cardiovascular Imaging* 2014; **15**: 956–60.
2. Spencer KT, Kimura BJ, Korcarz CE, Pellikka PA, Rahko PS, Siegel RJ. Focused cardiac ultrasound: recommendations from the American Society of Echocardiography. *Journal of the American Society of Echocardiography* 2013; **26**: 567–81.
3. Via G, Hussain A, Wells M, et al. International evidence-based recommendations for focused cardiac ultrasound. *Journal of the American Society of Echocardiography* 2014; **27**: 683, e1-e33.
4. Labovitz AJ, Noble VE, Bierig M, et al. Focused cardiac ultrasound in the emergent setting: a consensus statement of the American Society of Echocardiography and American College of Emergency Physicians. *Journal of the American Society of Echocardiography* 2010; **23**: 1225–30.
5. Moore CL, Copel JA. Point-of-care ultrasonography. *New England Journal of Medicine* 2011; **364**: 749–57.
6. Neskovic AN, Hagendorff A, Lancellotti P, et al. Emergency echocardiography: the European Association of Cardiovascular Imaging recommendations. *European Heart Journal Cardiovascular Imaging* 2013; **14**: 1–11.
7. Price S, Nicol E, Gibson DG, Evans TW. Echocardiography in the critically ill: current and potential roles. *Intensive Care Medicine* 2006; **32**: 48–59.
8. Royse CF. Ultrasound-guided haemodynamic state assessment. *Best Practice and Research Clinical Anaesthesiology* 2009; **23**: 273–83.
9. Moher D, Shamseer L, Clarke M, et al. Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. *Systematic Reviews* 2015; **4**: 1.
10. Bøtker MT, Vang ML, Grøfte T, Sloth E, Frederiksen CA. Routine pre-operative focused ultrasonography by anesthesiologists in patients undergoing urgent surgical procedures. *Acta Anaesthesiologica Scandinavica* 2014; **58**: 807–14.
11. Canty DJ, Royse CF. Audit of anaesthetist-performed echocardiography on perioperative management decisions for non-cardiac surgery. *British Journal of Anaesthesia* 2009; **103**: 352–8.
12. Canty DJ, Royse CF, Kilpatrick D, Bowman L, Royse AG. The impact of focused transthoracic echocardiography in the pre-operative clinic. *Anaesthesia* 2012; **67**: 618–25.
13. Canty DJ, Royse CF, Kilpatrick D, Bowyer A, Royse AG. The impact on cardiac diagnosis and mortality of focused transthoracic echocardiography in hip fracture surgery patients with increased risk of cardiac disease: a retrospective cohort study. *Anaesthesia* 2012; **67**: 1202–9.
14. Canty DJ, Royse CF, Kilpatrick D, Williams DL, Royse AG. The impact of pre-operative focused transthoracic echocardiography in emergency non-cardiac surgery patients with known or risk of cardiac disease. *Anaesthesia* 2012; **67**: 714–20.
15. Cowie B. Three years' experience of focused cardiovascular ultrasound in the peri-operative period. *Anaesthesia* 2011; **66**: 268–73.
16. Cowie B. Focused transthoracic echocardiography predicts perioperative cardiovascular morbidity. *Journal of Cardiothoracic and Vascular Anesthesia* 2012; **26**: 989–93.
17. Jettoo P, Kakwani R, Junejo S, Talkhani I, Dixon P. Pre-operative echocardiogram in hip fracture patients with cardiac murmur — an audit. *Journal of Orthopaedic Surgery and Research* 2011; **6**: 49.
18. Loxdale SJ, Sneyd JR, Donovan A, Werrett G, Viira DJ. The role of routine pre-operative bedside echocardiography in detecting aortic stenosis in patients with a hip fracture. *Anaesthesia* 2012; **67**: 51–4.
19. O'hEireamhoin S, Beyer T, Ahmed M, Mulhall KJ. The role of preoperative cardiac investigation in emergency hip surgery. *Journal of Trauma* 2011; **71**: 1345–7.

20. Rohde LE, Polanczyk CA, Goldman L, Cook EF, Lee RT, Lee TH. Usefulness of transthoracic echocardiography as a tool for risk stratification of patients undergoing major noncardiac surgery. *American Journal of Cardiology* 2001; **87**: 505–9.
21. Wijeysundera DN, Beattie WS, Karkouti K, Neuman MD, Austin PC, Laupacis A. Association of echocardiography before major elective non-cardiac surgery with postoperative survival and length of hospital stay: population based cohort study. *British Medical Journal* 2011; **342**: d3695.
22. Joseph MX, Disney PJ, Da Costa R, Hutchison SJ. Transthoracic echocardiography to identify or exclude cardiac cause of shock. *Chest* 2004; **126**: 1592–7.
23. Kanji HD, MCallum J, Sirounis D, MacRedmond R, Moss R, Boyd JH. Limited echocardiography-guided therapy in subacute shock is associated with change in management and improved outcomes. *Journal of Critical Care* 2014; **29**: 700–5.
24. Manasia AR, Nagaraj HM, Kodali RB, et al. Feasibility and potential clinical utility of goal-directed transthoracic echocardiography performed by noncardiologist intensivists using a small hand-carried device (SonoHeart) in critically ill patients. *Journal of Cardiothoracic and Vascular Anesthesia* 2005; **19**: 155–9.
25. Marcelino PA, Marum SM, Fernandes AP, Germano N, Lopes MG. Routine transthoracic echocardiography in a general Intensive Care Unit: an 18 month survey in 704 patients. *European Journal of Internal Medicine* 2009; **20**: e37–42.
26. Orme RM, Oram MP, McKinstry CE. Impact of echocardiography on patient management in the intensive care unit: an audit of district general hospital practice. *British Journal of Anaesthesia* 2009; **102**: 340–4.
27. Stanko LK, Jacobsohn E, Tam JW, De Wet CJ, Avidan M. Transthoracic echocardiography: impact on diagnosis and management in tertiary care intensive care units. *Anaesthesia and Intensive Care* 2005; **33**: 492–6.
28. Pearse RM, Moreno RP, Bauer P, et al. Mortality after surgery in Europe: a 7 day cohort study. *Lancet* 2012; **380**: 1059–65.
29. Wild C, Narath M. Evaluating and planning ICUs: methods and approaches to differentiate between need and demand. *Health Policy* 2005; **71**: 289–301.
30. Wunsch H, Angus DC, Harrison DA, et al. Variation in critical care services across North America and Western Europe. *Critical Care Medicine* 2008; **36**: 2787–93, e1–9.
31. Jensen MB, Sloth E, Larsen KM, Schmidt MB. Transthoracic echocardiography for cardiopulmonary monitoring in intensive care. *European Journal of Anaesthesiology* 2004; **21**: 700–7.
32. Jones AE, Tayal VS, Sullivan DM, Kline JA. Randomized, controlled trial of immediate versus delayed goal-directed ultrasound to identify the cause of nontraumatic hypotension in emergency department patients. *Critical Care Medicine* 2004; **32**: 1703–8.
33. Barbier C, Loubieres Y, Schmit C, et al. Respiratory changes in inferior vena cava diameter are helpful in predicting fluid responsiveness in ventilated septic patients. *Intensive Care Medicine* 2004; **30**: 1740–6.
34. Charron C, Caille V, Jardin F, Vieillard-Baron A. Echocardiographic measurement of fluid responsiveness. *Current Opinion in Critical Care* 2006; **12**: 249–54.
35. Feissel M, Michard F, Faller JP, Teboul JL. The respiratory variation in inferior vena cava diameter as a guide to fluid therapy. *Intensive Care Medicine* 2004; **30**: 1834–7.
36. Lamia B, Ochagavia A, Monnet X, Chemla D, Richard C, Teboul JL. Echocardiographic prediction of volume responsiveness in critically ill patients with spontaneously breathing activity. *Intensive Care Medicine* 2007; **33**: 1125–32.
37. Davenport DL, Ferraris VA, Hosokawa P, Henderson WG, Khuri SF, Mentzer RM Jr. Multivariable predictors of postoperative cardiac adverse events after general and vascular surgery: results from the patient safety in surgery study. *Journal of the American College of Surgeons* 2007; **204**: 1199–210.
38. Djokovic JL, Hedley-Whyte J. Prediction of outcome of surgery and anesthesia in patients over 80. *Journal of the American Medical Association* 1979; **242**: 2301–6.
39. Mangano DT. Perioperative cardiac morbidity. *Anesthesiology* 1990; **72**: 153–84.

Appendix 1
Definitions used during the search process.

Term	Definition
Changes in clinical diagnosis	
Diagnoses, total	Diagnoses accumulated
LV dysfunction	Change in grade of LV dysfunction (normal, subnormal, moderate, or severe)
RV dysfunction	Increased RV-size or decreased RV systolic function
Valve disease	New moderate or severe valve dysfunction
Hypovolaemia	Defined by each paper
Hypervolaemia	Defined by each paper
Pulmonary hypertension	New pulmonary arterial pressure above 25 mmHg
Pleural effusion	New demonstration of more than 2.5 cm equalling 500 ml
Pericardial effusion	New demonstration of more than 0.5 cm
Changes in clinical management	
Management, total	Medical + surgical management
Medical management	Anaesthetic technique + Anaesthetic drug therapy + Inotropes/vasopressors + Fluids (defined below)
Surgical management	Surgery + Postoperative disposition (defined below)

(continued)

Appendix 1 (*continued*)

Term	Definition
Anaesthetic technique	Change from general to regional anaesthesia or vice versa, or change in decision about invasive monitoring e.g. arterial or central venous catheter
Anaesthetic drug therapy	Change in anaesthetic drug type or dosage
Inotropes/vasopressors	Change in inotrope/vasopressor drug type or dosage
Fluids	Change in fluid type or amount
Surgery	Delayed, cancelled, or more/less invasive surgery performed
Postoperative disposition	Change in disposition between ICU, high dependency ward, and standard ward, or change in decision to refer e.g. TOE or cardiologist-performed echocardiography

LV, left ventricule; RV, right ventricule; TOE, transoesophageal echocardiography.