Review article

Audiovisual feedback device use by health care professionals during CPR: A systematic review and meta-analysis of randomised and non-randomised trials

Shelley Kirkbright [a,*], Judith Finn [a,b,c], Hideo Tohira [b], Alexandra Bremner [a], Ian Jacobs [a,b], Antonio Celenza [a]

[a] University of Western Australia, Australia
[b] Curtin University, Perth, Australia
[c] Monash University, Melbourne, Australia

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ABSTRACT

Objectives: A systematic appraisal of the literature to determine if audiovisual feedback devices can improve CPR quality delivered by health care practitioners (HCPs) and/or survival outcomes following cardiac arrest.

Methods: We searched the Cochrane Central Register of Controlled Studies (CENTRAL) on The Cochrane Library, MEDLINE, EMBASE, CIHAHL and AUSTHEALTH in May 2013 for experimental and observational (human or manikin) studies examining the effect of the use of audiovisual feedback devices by HCPs in simulated and actual cardiac arrest. The primary outcome for human studies was survival to hospital discharge with good neurologic outcome. Secondary outcomes were other survival data and quality of CPR performance; the latter was also reported for manikin studies.

Results: Three human interventional studies ($n = 2100$) and 17 manikin studies met the inclusion criteria. Overall quality of included studies was poor, with significant clinical heterogeneity. All three human studies reported no significant change to any survival outcomes despite improvement in chest compression (CC) depth by 2.5 mm (95% CI 0.9–4.3), CC rate 6 min^{-1} closer to 100 (95% CI 2.4–10.7) and a reduction in no-flow fraction by 1.9% on meta-analysis. Manikin studies showed similar improvements in CC parameters.

Conclusion: In both manikin and human studies, feedback during resuscitation can result in rescuers providing CC parameters closer to recommendations. There is no evidence that this translates into improved patient outcomes. The reason for this is not yet evident and further patient centered research is warranted.

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* Corresponding author.
  E-mail addresses: shelley.kirkbright@uwa.edu.au, shelleykirkbright@gmail.com (S. Kirkbright).

1. Introduction

Out-of-hospital cardiac arrest (OHCA) is a major public health problem with over 90% case fatality.[1] Global incidence of adult OHCA is estimated at 95.9 per 100,000 person-years.[2] Survival to hospital discharge is poor, although it has been shown to vary widely between different emergency systems in the US.[3]

The 2010 International Liaison Committee on Resuscitation (ILCOR) consensus guidelines[4] reiterate the importance of optimising all links in the 'Chain of Survival'[5] to maximise neurologically intact survival after cardiac arrest. This includes the delivery of high quality CPR. Specifically rescuers should: push hard to a depth of at least 5 cm at a rate of at least 100 compressions per minute, allow full recoil of the chest in between compressions and minimise interruptions in chest compressions (CCs) with a compression to ventilation ratio of 30:2.[6] Relatively brief interruptions to CC of even 4 s duration, lead to reduced myocardial perfusion[7] and survival.[8] Furthermore, the success of defibrillation decreases in patients during prolonged periods without CC.[9] CC depth and fraction (the proportion of time CCs are administered in CPR) are directly related to survival from OHCA. Every 1 mm increase in depth (up to 50 mm) increases the adjusted odds of survival by 5% (OR 1.05, 95% CI 1.01–1.09).[10] High CC fractions (>60%) are associated with higher rates of return of spontaneous circulation (ROSC) (79% vs. 58%) and survival to discharge (25% vs. 12%) when compared with the lowest fraction group (<20%).[11]

Although it is known that good quality CPR leads to improved patient outcomes, health care practitioners commonly perform sub-optimal CPR[10,12–15] with as little as 28% of CC in the target depth range, effective compression rates as low as 64 per minute and a hands off fraction of 0.48.[12] Real-time feedback may enable rescuers to perform better CPR, which may translate into improved patient outcomes. The only systematic review of the impact of real-time feedback during CPR[13] was completed in 2009 and focused on feedback as a training device rather than an adjunct to real-life cardiac arrests. The authors concluded that there was good evidence supporting the use of feedback devices in CPR training to improve skill acquisition and retention.[13] However, a beneficial effect on patient outcomes has yet to be established. As several individual studies[16–23] have been published since the original review, it is time to review the evidence with a focus on the effect of the use of real-time feedback to improve the quality of CPR in the 'real' cardiac arrest episode.

Objectives: Our systematic review of interventional and observational studies seeks to address the questions "Does the use of feedback devices improve the quality of CPR performed by health care professionals when training on manikins compared to no device? Does the use of feedback devices improve patient outcomes (ROSC, survival to hospital discharge and neurologically intact survival) and quality of CPR parameters in cardiac arrests compared to no device?"

2. Methods

Protocol registration: PROSPERO registration number CRD42012003064.[24]

2.1. Eligibility criteria

Participants: CPR providers must be health care practitioners (HCPs) or HCP students, defined as people whose primary role is the provision of health care. Subjects may be manikins to address the outcome of CPR quality (hitherto referred to as the 'manikin studies') or humans experiencing a cardiac arrest to address both outcomes of CPR quality and survival (hitherto referred to as the 'human studies'). The cardiac arrest may occur in the in-hospital or out-of-hospital setting.

Interventions: Any study measuring CPR quality using a monitor that detects chest wall movement and, as a minimum, can quantify rate or depth of CCs was considered for inclusion. As the primary objective of our review was to determine if the use of feedback devices is able to improve actual CPR performance and/or outcome from cardiac arrest, rather than a teaching tool to improve skill acquisition, it was decided that the feedback device must be in use at the time of cardiac arrest or arrest simulation. Manikin studies that investigated the effect of feedback during training only, but not at the time of simulated resuscitation testing, and human studies that provided delayed feedback in the form of debriefing or performance evaluation were both excluded. Studies investigating the use of timing devices and metronomes that did not change or give feedback depending on the quality of CPR detected were also excluded.

Comparison: The intervention (real-time use of CPR feedback device) was compared to the comparison group of CPR performed without the use of the device.

Outcomes: The primary outcome for human studies was patient survival to hospital discharge with good neurological outcome. Secondary outcomes in human studies included other patient survival data (ROSC, alive (spontaneous circulation) on arrival to emergency department, survival to hospital discharge). For human and manikin studies, markers of improved CPR were abstracted: CC rate, CC depth, and proportion of time without CPR (no-flow fraction). We also collected data on adverse effects and user satisfaction with the devices.

Types of studies: Published original research articles on randomised and non-randomised interventional studies, as well as observational studies with a comparator group were included. No

publication date or language restrictions were imposed. Animal studies, case studies, reviews and opinion pieces were excluded.

2.2. Information sources

Electronic searches:

- Cochrane Central Register of Controlled Studies (CENTRAL) on *The Cochrane Library (Issue 2012)*
- MEDLINE using Ovid platform (1946 to 16/05/2013)
- EMBASE (1980 to 16/05/2013)
- CINAHL (1998 to 16/05/2013)
- AUSTHEALTH (1997 to 16/05/2013)

The Medline search strategy is in Appendix 1.

Searching other resources: The reference lists from included studies and review articles were searched for additional papers. Experts in the field and representatives from Laerdal, manufacturer of CPR quality and feedback monitoring device Q-CPR, were contacted for knowledge of published studies on the topic.

2.3. Study selection

Authors used pre-defined inclusion criteria to decide on the status of each citation. Two authors (SK and JF) screened citations in an independent, hierarchical fashion by title, abstract and then full article for relevance. At each stage of review citations were classified as "include", "exclude" or "indeterminate". Titles and abstracts with clearly unrelated content were discarded. Citations marked as "include" or "indeterminate" by either of the reviewers were included in the next level of review. Disagreements at the full article stage were resolved though consensus with the assistance of a third reviewer (IJ). Agreement between authors at each stage was quantified using a kappa statistic. A record was kept of all studies excluded at the full text stage, along with the reason.

2.4. Data collection process

One reviewer (SK) extracted the following data from included studies and the second author (JF) checked the extracted data, and discrepancies were resolved through consensus.

2.5. Data items

Information was extracted from each included trial on: (1) characteristics of trial participants (including age, sex); (2) arrest or simulated arrest details (OHCA/in-hospital-cardiac-arrest (IHCA), manikin, 2 person/1 person resuscitation, resuscitation guidelines in place); (3) study design including inclusion and exclusion criteria; (4) type of feedback device used; and (5) type of outcome measure (ROSC, survival outcomes, CPR quality measures, user satisfaction and adverse outcomes).

2.6. Assessment of risk of bias in individual studies

One author (SK) evaluated each included study for risk of bias. As recommended by the STROBE statement[25] and The Cochrane Handbook for Systematic Reviews of Interventions v5.1.0,[26] the randomised trials were evaluated for selection bias, performance bias, attrition bias and detection bias.

Quality of non-randomised trials was assessed using the Newcastle-Ottawa Scale (NOS),[27] a 'star based' scoring system which judges studies on three broad perspectives: the selection of the study groups, the comparability of the groups, and the ascertainment of either the exposure or outcome of interest for case–control or cohort studies respectively. Missing data were documented as part of study quality assessment.

2.6.1. Summary measures

Survival to hospital discharge with good neurologic outcome was the primary measure of treatment effect for the human studies. The meta-analyses were performed by computing odds-ratios (ORs) and 95% confidence intervals (CIs) using random-effects models for each survival outcome. Secondary outcomes were CC depth, CC rate and no-flow fraction (NFF), and meta-analyses of these outcomes were performed by computing mean differences and 95% CIs using random-effects models. P-values <0.05 were considered significant.

2.7. Planned methods of analyses

Inconsistency (the percentage of total variation across studies due to heterogeneity) of effects across feedback devices was measured using the Breslow–Day test performed by Review Manager RevMan Version 5.2.[28] The advantages of this measure of inconsistency (termed I^2) are that it does not inherently depend on the number of studies and can be interpreted similarly irrespective of the type of outcome data (dichotomous or continuous).[29] Meta-analysis was not performed when $I^2 > 75\%$.[30]

The heterogeneity between studies was explored qualitatively with thorough scrutiny of included studies for clinically relevant differences. A priori subgroup analysis was planned to address clinical heterogeneity. Subgroups identified included human/manikin studies, adult/paediatric studies, OHCA/IHCA studies and device used (CPREzy, QCPR, ZOLL, VAM, Heartstart 4000SP). We planned to conduct sensitivity analyses that included removal of data from studies assessed to be at moderate or high risk of bias during quality review.

For randomised cross-over (manikin) trials, only first stage data were used in meta-analyses to minimise bias introduced from a learning effect. For example, when a group randomised to perform CPR with the aid of a device in stage 1 and without the device in stage 2 was compared to a group that performed CPR without the device in stage 1 and with it in stage 2, only first stage data were included.

2.8. Risk of bias across studies

We assessed publication bias by evaluating funnel plots of the study. We acknowledge that asymmetry may also be produced by factors such as differences in study quality and heterogeneity.[29]

2.9. Unit of analysis issues

CC depths reported in inches were converted to centimeters. No-flow times, CC fraction and CC times were converted into NFF using the overall CPR time period. For example, NFF was calculated from one minus CC fraction, one minus CC time divided by total CPR time or no-flow time divided by total CPR time.

3. Results

3.1. Study selection

The comprehensive search identified 2959 citations (Medline 1697, EMBASE 670, AUSTHealth 8, CINAHL Plus 517, Cochrane CENTRAL 64, hand search of included papers and review article references 3). SK reviewed 2959 citations by title; 97 of these were categorised as "include" or "indeterminate" and were selected for review by abstract. Two authors (SK and JF) independently
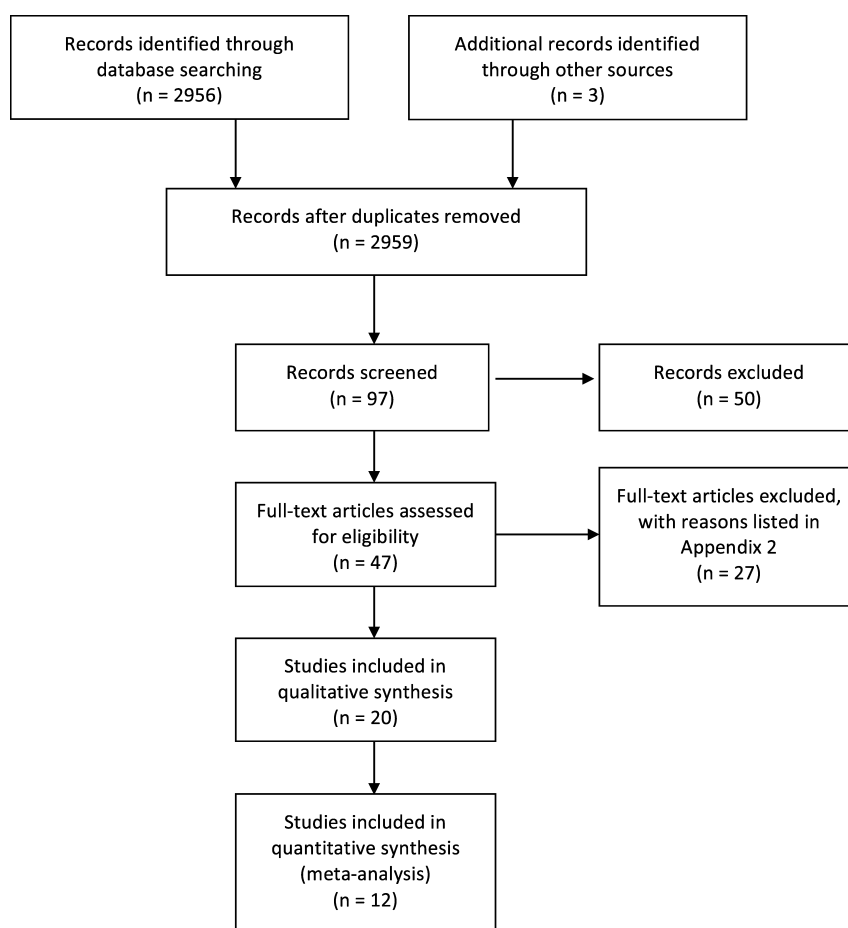
Fig. 1. PRISMA flow diagram.

reviewed these abstracts and identified 48 potentially relevant citations to be reviewed by full article of which 20 met all inclusion criteria and were included in this review. There was very good agreement for abstracts (kappa 0.915) and full agreement (kappa 1.0) at full article stage. Twenty-seven citations reviewed by full article were excluded. One study[17] that had been presented at a conference could not be included, as we could not get the full article despite several attempts to contact the authors. The process is detailed in a PRISMA flow diagram (Fig. 1).

3.2. Excluded studies

Common reasons for exclusions were: (1) that the article described an experiment involving the use of feedback mechanism either before or after the CPR event, for example, post event debriefing, rather than any real-time feedback whilst performing CPR, (2) that the study population performing CPR was mainly or entirely a layperson population, and (3) that the main study outcomes were not CPR quality variables or patient outcomes. Full details are in Appendix 2.

3.3. Characteristics of included studies

All included studies were published in English between 1995 and 2012. Most studies were conducted in Europe (60%) and North America (35%). Of the three studies in humans, all were conducted on adults, two included only OHCA[10,16] and one only IHCA.[31] There are no relevant published individually randomised controlled trials on humans however there were one cluster randomised trial[16] and two studies with retrospective controls in humans.[10,31]

Seventeen manikin studies were included. All included studies are summarised in Table 1.

Human studies: The mean age of included patients ranged from 62.3 to 68.0 years and the proportion of male subjects ranged from 49.5% to 75%. No ethnicity data were reported. The OHCA was emergency medical services (EMS) witnessed in 7–11% cases and received bystander CPR in 42–52% cases. Mean duration of arrest prior to EMS arrival ranged from 5.5 to 8 min. Rhythm was VF/VT in 26–40% OHCA cases. All three studies on humans used the Laerdal Q-CPR feedback device or a prototype of the same device.

Manikin studies: Seventeen manikin studies involving HCPs or student HCPs were included. Various feedback devices were investigated; CPREzy (Medteq Innovations Pty Ltd., Brisbane, Australia),[18,32–36] QCPR (Laerdal Medical, Stavanger, Norway),[18,22,37] Zoll CPR-plus,[38] ZOLL Pocket CPR (Zoll Medical Corporation, Chelmsford, USA),[19–21] voice assist manikin (VAM) (Laerdal Medical, Stavanger, Norway)[39–41] Heartstart 4000SP(Philips Medical System, Andover, MA, USA))[42] and an experimental pressure sensing monitor.[43] One study compared several types of feedback device to control (no device).[18] The devices are described in detail in the respective studies.

3.4. Risk of bias within studies

Evaluation of bias within the randomised studies is documented in Table 2. Due to the nature of the intervention, all of the included studies had some degree of performance bias as none of the personnel could be blinded. In the studies involving patients, all patients were unconscious at the time of the intervention. None of the studies had blinding of the outcome assessors, so all were at risk

Table 1
Summary of characteristics of included studies.

Study	Country	Sample size	Type	Device	CPR providers	Design	Outcomes
Abella 2007[31]	USA	Intervention $n=101$ Control $n=55$	IHCA Adult patients Exclusions – OT/ED IHCA, subsequent cardiac arrests in same admission	Laerdal QCPR	Hospital resuscitation team	Observational case–control study	Primary – CC rate, CC depth, NFF, ventilation rate. Secondary – ROSC, survival to discharge
Beckers 2007[32]	Germany	Intervention $n=111$ Control $n=91$	Manikin study Single rescuer 5 min	CPREzy	Medical students – nil BLS experience	Randomised controlled trial	% CC rate 90–110 min^{-1}, % CC depth 40–50 mm, rate of incomplete release of CC, incorrect hand position
Boyle 2002[33]	Australia	$n=34$	Manikin study Two rescuers 4 min	CPREzy	BLS trained hospital workers (nurses, physicians and technicians)	Observational cross-over trial	% CC correct position, % effective CC, divergence from CC rate of 100 min^{-1}
Dine 2008[37]	USA	Intervention $n=31$ Control $n=34$	Manikin study Single rescuer 2 min	Laerdal QCPR	Nurses	Randomised controlled trial	% CC depth 38–21 mm, % CC rate 90–100 min^{-1}, % correct CC, % incomplete release, CC proportion duty cycle, CC rate variability
Elding 1998[38]	UK	$n=40$	Manikin study Two rescuers 150 CC in 5:1 CC to ventilations ratio	CPRPlus	Nurses	Randomised cross-over trial	Correct CC per 150, incorrect CC pressure incomplete release, incorrect hand position
Fischer 2011[19]	USA	Intervention $n=34$ Control $n=34$	Manikin study Two rescuers 12 min	Zoll Pocket CPR	BLS trained flight attendants	Randomised controlled trial	Mean CC rate, mean CC depth, no-flow time, % effective CC, % correct hand position, ventilation rate
Handley 2003[39]	UK	Intervention $n=18$ Control $n=18$	Manikin study Single rescuer 3 min	VAM	Nurses	Randomised controlled trial	% CC rate 90–120 min^{-1}, % CC <38 mm, % CC >51 mm, % incomplete release, CC proportion of duty cycle, % ventilations 700–1000 ml
Havel 2010[23]	Austria	$n=24$	Manikin study in moving ambulance/helicopter Continuous CC 8 min	Philips Modified Heartstart 4000SP	Pre-hospital health care providers	Randomised cross-over trial	% CC depth 38–21 mm, % CC rate 90–110 min^{-1}, % CC correct release, median no-flow time
Hostler 2005[40]	USA	$n=114$	Manikin study Single rescuer 3 min	VAM	Pre-hospital health care providers	Randomised cross-over trial	% CC correct – rate 100 min^{-1} and depth 38–21 mm, mean CC depth. Data collected in 15 second intervals and assessed for decay over time
Hostler 2011[16]	USA	Intervention $n=815$ Control $n=771$	OHCA Adult patients Exclusions – trauma, pregnant, "do not resuscitate" order	Laerdal QCPR	Pre-hospital health care providers	Cluster-randomised controlled trial	Primary – ROSC Secondary – survival to discharge, neurological status (awake) at discharge, CC rate, CC depth, CC fraction, % CC with incomplete release, ventilation rate
Kramer-Johansen 2006[10]	Norway, Sweden and UK	Intervention $n=117$ Control $n=241$	OHCA Adult patients	Laerdal QCPR (prototype)	Pre-hospital health care providers	Observational case–control study	Primary – CC rate, CC depth, NFF, % CC incomplete release, CC proportion of duty cycle. Secondary – rate of hospital admission with ROSC, survival to hospital discharge
Lyengaraa 2012[20]	Denmark	Intervention $n=26$ Control $n=28$	Manikin study Single rescuer 2 min	ZOLL AED plus	CPR conference attendees	Randomised controlled trial	% CC at target depth (50–60 mm), % CC at target rate (100–120 min^{-1})
Noordergraaf 2006[34]	Netherlands	Intervention $n=112$ Control $n=111$	Manikin study Two-rescuers 4 min	CPREzy	BLS trained hospital workers (nurses, physicians and technicians)	Randomised controlled trial	% CC ineffective (depth <40 mm, incomplete release, incorrect duty cycle, rate <100 min^{-1}), % leaning, % incorrect hand position, mean CC depth (mm), mean CC rate (min^{-1})
Perkins 2005[35]	UK	$n=20$	Manikin study Continuous CC 3 min	CPREzy	Medical students – BLS trained	Randomised cross-over trial	CC rate, depth, duty cycle and correct hand position

Table 1 (Continued)

Study	Country	Sample size	Type	Device	CPR providers	Design	Outcomes
Pozner 2011[21]	USA	Intervention n = 12 Control n = 13	Manikin study Two-rescuers 6 min	Zoll pocket CPR	Nurses	Randomised controlled trial	CC rate and depth, user fatigue
Skorning 2010[22]	Germany	n = 93	Manikin study One rescuer 2 min	Laerdal QCPR	Health care professionals (technicians, paramedics and physicians)	Randomised cross-over trial	Mean CC rate and depth (38–51 mm), % CC correct depth (38–51 mm), % correct CC rate (90–120 min^{-1}), % incomplete release, % effective CC
Skorning 2011[36]	Germany	n = 81	Manikin study Continuous CC 3 min	CPREzy	Health care professionals (technicians, nurses, physicians)	Randomised cross-over trial	% CC correct mean rate (90–110 min^{-1}), % correct mean CC depth (40–50 mm), % incomplete release >20%, % incorrect hand position >20%
Thomas 1995[43]	USA	n = 10	Manikin study Single rescuer 2 min	Experimental pressure monitor device	Nurses	Observational cross-over trial	% CC correct (correct position and correct depth 38–51 mm)
Wik 2001[41]	Norway	n = 24	Manikin study Single rescuer 3 min	VAM	Paramedic students – BLS trained	Randomised cross-over trial	% CC correct depth (38–51 mm), % CC correct rate (90–120 min^{-1}), % correct duty cycle, % incomplete release, % incorrect hand position, % correct ventilation
Yeung 2011[18]	UK	Control n = 25 CPREzy n = 25 QCPR n = 26 Metronome n = 25	Manikin study Continuous CC 2 min	CPREzy, QCPR, metronome (not included in this review)	Health care professionals (technicians, nurses, physicians)	Randomised controlled trial	Mean CC depth, mean CC rate, % inadequate depth, % incomplete release, user satisfaction score

of detection bias. However, as the data items were all objective and many were measured by a computer (for example, CC depth and rate) the bias attributable to lack of blinding was assessed to be minimal. The four non-randomised studies were evaluated for quality and bias using the NOS (Table 3). The two non-randomised studies[10,31] involving humans rather than manikins used cohorts from sequential time periods. One study[10] described high attrition rates due to poor data quality. Abella et al.[31] did not report their attrition rate.

An early study[43] (1995) enrolled ten participants of unde-scribed demography who trialled a new feedback device. The device was not capable of providing feedback on CC rate and data on CC rate was not collected in another way. To avoid misleading results of CC depth improvement, this study was not included in meta-analyses.

3.5. Data analysis issues

There was a lack of consistency in how data were presented across the studies. Eight studies[22,23,32,33,36,37,39,41] presented CC data as percentage correct, meaning the proportion of CC that fell within the resuscitation guideline range. These proportions may differ if the same data are analysed for a time period with different guidelines. Six studies[23,32,36,37,39,41] presented data separately for CC depth and rate. One study[33] presented data combined as percentage correct CC, meaning at the correct depth and rate. Means and SDs could not be derived from these data, which are reported in Table 4, and therefore they could not be included in the meta-analyses. Skorning[22] presented mean CC depth and rate as well as percentage CC in correct range, therefore the data could be included in meta-analyses.

Two studies[20,40] reported the mean CC rate and depth for several discrete time intervals to investigate deterioration in CPR performance over time. These data were used to calculate an overall mean and SD for the resuscitation period to enable quantitative comparison with other studies.

3.6. Effects of interventions

1. Patient outcomes: Only one study[16] (a cluster RCT) reported on the primary outcome of this review. There was no difference in neurologically intact survival to hospital discharge between the groups with and without real-time CPR feedback using a definition of being discharged awake. Three studies (one cluster RCT[16] and two observational case control studies[10,31]) reported on ROSC (Fig. 2.1) and survival to hospital discharge (Fig. 2.2). All reported no significant difference.

Hostler et al.[16] performed a retrospective analysis which showed that survival and ROSC were related to time period and that early clusters were likely to do better with "feedback off" (cluster adjusted mean difference in % survival 5.5, 95% CI 9.6–1.3 lower in early clusters). However the difference was not significant for later clusters. The authors suggested this could be due to a learning curve when using the device.

2. CPR quality: Data are represented in Fig. 3. Three studies using human subjects,[10,16,31] and nine manikin studies[18–22,34,35,39,40] that presented data on CC quality were used in the meta-analyses. All three human studies[10,16,31] presented data on CC depth, rate and NFF. Eight manikin studies compared CC depth,[18–22,34,35,40] seven compared CC rate,[18–22,34,39] and one reported data on NFF.[19] Six studies[23,32,36,37,39,41] presented data as percentage of CC that fell within the correct range for depth and/or rate. These data are presented separately.

2.1 Human studies: Meta-analysis of CPR data quality revealed mean CC depth increased by more than 2.5 mm (95% CI 0.9–4.3)

Table 2
Risk of bias in included randomised controlled trials.

	Selection bias		Attrition bias	Reporting bias
	Randomisation	Allocation concealment		
Hostler 2011	Low risk – cluster randomised trial	Low risk – randomised externally to conceal	High risk. CPR data unavailable in 26%. Potentially biases due to differences in arrest data from group without CPR data	Low risk – report positive and neutral outcomes
Dine 2008	Low risk – randomised	Unclear risk – not stated	Missing data for 19% participants. Not included in analysis. Not reported which group.	Low risk Report positive and neutral outcomes
Skorning 2010	Low risk – randomly assigned to intervention or control first	Unclear risk – not stated	Unclear – not reported	Unclear – not reported
Yeung 2011	Low risk – randomised to control or intervention	Unclear risk – not stated	Low risk – attrition rate 2%	Low risk – report negative and positive findings
Beckers 2007	Low risk – randomised	Unclear risk – not stated	Unclear risk – excluded an undisclosed number of participants who failed to attend for the second test resulting in unequal group size.	Low risk – report positive and negative findings
Noordergraaf 2006	Low risk – randomised	Unclear – not stated	Low risk – no missing data. Included data even if full task not completed (3%)	Low risk – report positive neutral data
Perkins 2005	Low risk – randomised	Unclear risk – not stated	Unclear risk. Nil missing data but 3/20 participants replaced with height/age/sex matched participants for second stage	Low risk – report positive and neutral data
Skorning 2011	Low risk – randomised	Unclear risk – not stated	Unclear risk – not reported	Not reported
Elding 1998	Low risk – randomised cross over	Unclear risk – not stated	Unclear risk – not reported	Low risk – all data reported
Fischer 2011	Low risk – randomised	Unclear risk -allocation generated by 3rd party	Low risk – attrition rate 3% intervention, 6% control group	Low risk – report positive and negative outcomes
Lyengaraa 2012	Low risk – randomised	Low risk. Concealed in envelope.	Unclear risk. Data missing from feedback group 13% and non-feedback group 7%.	Low risk. No positive outcomes reported
Pozner 2011	Low risk – randomised	Unclear – not stated	Unclear risk – not reported	Unclear risk – not reported
Handley 2003	Low risk – randomised	Low risk – concealed	Low risk – no missing data	Low risk – report positive and negative data
Hostler 2005	Low risk – randomised	Unclear risk – not stated	Unclear risk – not reported	Low risk – report both positive and negative data
Wik 2001	Low risk randomised cross over	Low risk – concealed	Unclear risk – not reported	Low risk – report positive and negative findings
Havel 2010	Low risk – randomised cross-over	Low risk – concealed until start	Unclear risk – not reported	Low risk – report positive and neutral findings

(Fig. 3.1), mean CC rate decreased by more than 6 per minute (95% CI 2.4–10.7) (Fig. 3.2) and NFF decreased by 1.9% (95% CI 1.8–2.0) (Fig. 3.3) when participants used the feedback devices.

2.2 Manikin studies: Analysis of the CC depth data from manikin studies revealed significant heterogeneity precluding meta-analysis ($I^2 = 87\%$). When the manikin studies were analysed by device type, a significant increase in CC depth was only seen with the CPREzy device (6.2 mm, 95% CI 3.88–8.48). For all other devices studies were too heterogeneous to combine even in sub-groups (Fig. 3.1).

Table 3
Quality assessment of included non-randomised trials using Newcastle Ottawa Scale[27].

Study	Selection of study group Maximum 4 stars	Comparability of study group Maximum 2 stars	Assessment of outcome Maximum 3 stars
Abella 2007	★★★★ Represented target population well. Control and intervention groups from same hospital.	★ Cohorts collected over consecutive time periods. No significant difference in demographics/arrest details between two groups.	★★ Outcome assessment not blind but objective. Follow-up until discharge. Lost to follow-up data not presented.
Kramer-Johansen 2006	★★★★ Represented target population well. Control and intervention groups from same centres.	★ Cohorts collected over consecutive time periods. No significant difference in demographics/arrest details between two groups.	★ Outcome assessment not blind but objective. Follow-up until discharge. 27% of control and 8% of intervention group not included due to poor data quality.
Boyle 2002	★★★★ Participants represented the population of hospital workers who would perform CPR well.	★★ Same participants for both control and intervention (24 h rest between).	★★ Assessment of outcome was not blind but was objective. Follow up was long enough (4 min). The study does not report an attrition rate.
Thomas 1995	★★ Only ten participants limiting generalisability.	★ Same participants for both control and intervention (no record of rest period).	★ Assessment of outcome was not blind but was objective. Do not record CC rate.

Table 4
Effect of intervention on CPR quality. For studies presenting data as percentage within correct range.

Device type and study	% CC correct depth range		% CC correct rate range	
	Control	Feedback	Control	Feedback
1.5 Dine 2008[37] QCPR	19%	58% p = 0.002	45%	45% p = 1.0
2.1 Beckers 2007[32] CPREzy	19.8%	93.7% p < 0.001	34.1%	71.2% p < 0.01
2.5 Skorning 2011[36] CPREzy	51.2%	87.8% p < 0.001	12.2%	82.9% p < 0.001
5.1 Handley 2003[39] VAM	11.4%	56.0% p < 0.001		
5.4 Wik 2001[41] VAM	32%	92% p = 0.002		
6.1 Havel 2010[23] Heartstart 4000SP	93%	97% p = 0.03	44%	90% p < 0.001

A decrease in CC rate of almost 10 per minute (95% CI 5.4–13.9) was seen when participants used feedback devices when data from all manikin studies were combined (Fig. 3.2.2). When sub-grouped by device type (Fig. 3.2) significant heterogeneity precluded meta-analysis for all aside from the Laerdal QCPR device which showed a decrease in CC rate of 7 per minute (95% CI 3.28–10.96) when using the feedback device.

The only manikin study that reported NFF[19] found a non-significant decrease with the use of the feedback device.

Data from the six studies[23,32,36,37,39,41] that reported percent of CC within correct depth range or correct rate range are presented in Table 4. All six studies reported a significant increase in the proportion of CC within the correct depth range when using a feedback device. Four of the studies[23,32,36,37] reported on CC rate; three of these[24,30,35] reported a significant increase in the proportion of CC within the correct rate range when using feedback devices. A further two studies[38,43] only presented data on correct CC pressure and did not state how this correlated to CC depth and so could not be included in the meta-analyses. Both studies stated that the mean proportion of correct CC significantly increased ($p < 0.05$) when participants used the feedback device.

CPR quality data presented by the included studies but not included in this systematic review are documented in Table 1.

3. Adverse events and HCP satisfaction data: Occurrence of adverse events was not consistently reported. Of the three studies involving human patients, only one[16] mentioned adverse patient events, stating that there were none reported, and none reported data on user satisfaction.

Eight manikin studies[18,21,22,32,35–38] reported user satisfaction and/or adverse event data. There were no reports of major adverse events to the HCP. One study[35] reported a minor soft tissue injury to the BLS provider resulting from the hand being caught between the device and the manikin during compressions. The reported rate of user satisfaction was highly variable between studies. The CPREzy was reported to be uncomfortable to use by 16%[36] of HCPs in one study and 95% in another.[35] Similarly opinions about usefulness of the CPREzy device varied between 48%[35] and 75.5%.[32] The QCPR device was rated as "helpful" by 85% and 87% of participants in two studies.[22,37] One study[18] compared user satisfaction between control, QCPR and CPREzy and found users scored QCPR higher in terms of comfort, ease of use, distraction and confidence in the device. Another study[38] reporting on user satisfaction of CPRPlus found 25% complained of at least one of the following: increased effort to perform CPR, user pain and/or the device's slippery surface. One study[21] found 85% of participants reported the ZOLL Pocket CPR device was

Fig. 2. Patient outcomes – comparison of feedback vs. control. (2.1) ROSC. (2.2) Survival to hospital discharge.

3.1

	Feedback ON			Control				Mean Difference	Mean Difference
Study or Subgroup	Mean [mm]	SD [mm]	Total	Mean [mm]	SD [mm]	Total	Weight	IV, Random, 95% CI [mm]	IV, Random, 95% CI [mm]
1.4.1 Patient studies									
Abella 2007	44	10	101	42	12	55	7.3%	2.00 [-1.72, 5.72]	
Hostler 2011	39.6	0.4	815	37.8	0.4	771	12.7%	1.80 [1.76, 1.84]	
Kramer-Johansen 2006	38	6	117	34	9	241	11.2%	4.00 [2.43, 5.57]	
Subtotal (95% CI)			1033			1067	31.1%	2.60 [0.90, 4.31]	
Heterogeneity: Tau² = 1.51; Chi² = 7.52, df = 2 (P = 0.02); I² = 73%									
Test for overall effect: Z = 2.99 (P = 0.003)									
1.4.3 Manikin QCPR									
Skorning 2010	48.9	4.3	93	47.7	8.8	93	10.5%	1.20 [-0.79, 3.19]	
Yeung 2011	33.2	4.9	26	37.4	8.9	25	6.9%	-4.20 [-8.16, -0.24]	
1.4.4 Manikin CPREzy									
Noordergraaf 2006	45	4	112	40	9	111	10.7%	5.00 [3.17, 6.83]	
Perkins 2005	42.9	4.4	20	34.2	7.6	20	7.1%	8.70 [4.85, 12.55]	
Yeung 2011	43.6	8.8	25	37.2	10	25	5.1%	6.40 [1.18, 11.62]	
Subtotal (95% CI)			157			156	22.9%	6.18 [3.88, 8.48]	
Heterogeneity: Tau² = 1.50; Chi² = 2.96, df = 2 (P = 0.23); I² = 32%									
Test for overall effect: Z = 5.26 (P < 0.00001)									
1.4.5 Manikin ZOLL									
Fischer 2011	39	6	32	44	7	34	8.3%	-5.00 [-8.14, -1.86]	
Lyngeraa 2012	59.1	8.1	26	59	7.7	28	6.5%	0.10 [-4.12, 4.32]	
Pozner 2011	51	9	13	39	9	12	3.4%	12.00 [4.94, 19.06]	
1.4.6 Manikin VAM									
Hostler 2005	41.6	5.3	114	40.6	9.6	114	10.4%	1.00 [-1.01, 3.01]	

-20   -10   0   10   20
Favours [control] Favours [feedback ON]

3.2

	Feedback ON			Control				Mean Difference	Mean Difference
Study or Subgroup	Mean [min⁻¹]	SD [min⁻¹]	Total	Mean [min⁻¹]	SD [min⁻¹]	Total	Weight	IV, Random, 95% CI [min⁻¹]	IV, Random, 95% CI [min⁻¹]
1.5.1 Patient studies									
Abella 2007	100	13	101	104	18	55	10.3%	-4.00 [-9.39, 1.39]	
Hostler 2011	103.1	0.5	815	108	0.7	771	16.9%	-4.90 [-4.96, -4.84]	
Kramer-Johansen 2006	109	12	117	121	18	55	10.5%	-12.00 [-17.23, -6.77]	
Subtotal (95% CI)			1033			881	37.7%	-6.57 [-10.71, -2.43]	
Heterogeneity: Tau² = 9.51; Chi² = 7.18, df = 2 (P = 0.03); I² = 72%									
Test for overall effect: Z = 3.11 (P = 0.002)									
1.5.2 Manikin studies - QCPR									
Skorning 2010	107	9.9	93	113.9	17.3	93	12.4%	-6.90 [-10.95, -2.85]	
Yeung 2011	102.9	21	26	112	23	25	4.0%	-9.10 [-21.20, 3.00]	
Subtotal (95% CI)			119			118	16.3%	-7.12 [-10.96, -3.28]	
Heterogeneity: Tau² = 0.00; Chi² = 0.11, df = 1 (P = 0.74); I² = 0%									
Test for overall effect: Z = 3.63 (P = 0.0003)									
1.5.3 Manikin studies CPREzy									
Noordergraaf 2006	102	10	112	106	21	111	11.9%	-4.00 [-8.32, 0.32]	
Yeung 2011	98.8	12.4	25	114.7	19.7	25	5.9%	-15.90 [-25.02, -6.78]	
1.5.4 Manikin studies - ZOLL									
Fischer 2011	101	6	32	109	15	34	10.2%	-8.00 [-13.45, -2.55]	
Lyngeraa 2012	103	9.5	26	108.3	11.7	28	9.9%	-5.30 [-10.97, 0.37]	
Pozner 2011	101	9.7	13	127	13.8	12	5.7%	-26.00 [-35.42, -16.58]	
1.5.5 Manikin studies - VAM									
Handley 2003	99.3	18.9	18	110.3	29.9	18	2.4%	-11.00 [-27.34, 5.34]	

-20   -10   0   10   20
Favours [feedback ON] Favours [control]

3.2.2

	Feedback ON			Control				Mean Difference	Mean Difference
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight	IV, Random, 95% CI	IV, Random, 95% CI
Fischer 2011	101	6	32	109	15	34	15.7%	-8.00 [-13.45, -2.55]	
Handley 2003	99.3	18.9	18	110.3	29.9	18	5.1%	-11.00 [-27.34, 5.34]	
Lyngeraa 2012	103	9.5	26	108.3	11.7	28	15.4%	-5.30 [-10.97, 0.37]	
Noordergraaf 2006	102	10	112	106	21	111	17.3%	-4.00 [-8.32, 0.32]	
Pozner 2011	101	9.7	13	127	13.8	12	10.3%	-26.00 [-35.42, -16.58]	
Skorning 2010	107	9.9	93	113.9	17.3	93	17.7%	-6.90 [-10.95, -2.85]	
Yeung 2011 *	102.9	21	26	112	23	25	7.8%	-9.10 [-21.20, 3.00]	
Yeung 2011 **	98.8	12.4	25	114.7	19.7	25	10.7%	-15.90 [-25.02, -6.78]	
Total (95% CI)			345			346	100.0%	-9.64 [-13.87, -5.40]	
Heterogeneity: Tau² = 22.05; Chi² = 21.46, df = 7 (P = 0.003); I² = 67%									
Test for overall effect: Z = 4.46 (P < 0.00001)									

-20   -10   0   10   20
Favours [experimental] Favours [control]

Yeung 2011* CPREzy
Yeung 2011** QCPR

3.3

	Feedback ON			Control				Mean Difference	Mean Difference
Study or Subgroup	Mean [%]	SD [%]	Total	Mean [%]	SD [%]	Total	Weight	IV, Random, 95% CI [%]	IV, Random, 95% CI [%]
1.6.1 Patient studies									
Abella 2007	20	13	101	23	20	55	0.0%	-3.00 [-8.86, 2.86]	
Hostler 2011	34.1	1	815	36	1	771	99.5%	-1.90 [-2.00, -1.80]	
Kramer-Johansen 2006	44	17	117	48	18	241	0.1%	-4.00 [-7.83, -0.17]	
Subtotal (95% CI)			1033			1067	99.6%	-1.90 [-2.00, -1.80]	
Heterogeneity: Tau² = 0.00; Chi² = 1.29, df = 2 (P = 0.52); I² = 0%									
Test for overall effect: Z = 37.87 (P < 0.00001)									
1.6.2 Manikin studies									
Fischer 2011	31.1	3.6	32	32.6	2.9	34	0.4%	-1.50 [-3.08, 0.08]	

-20   -10   0   10   20
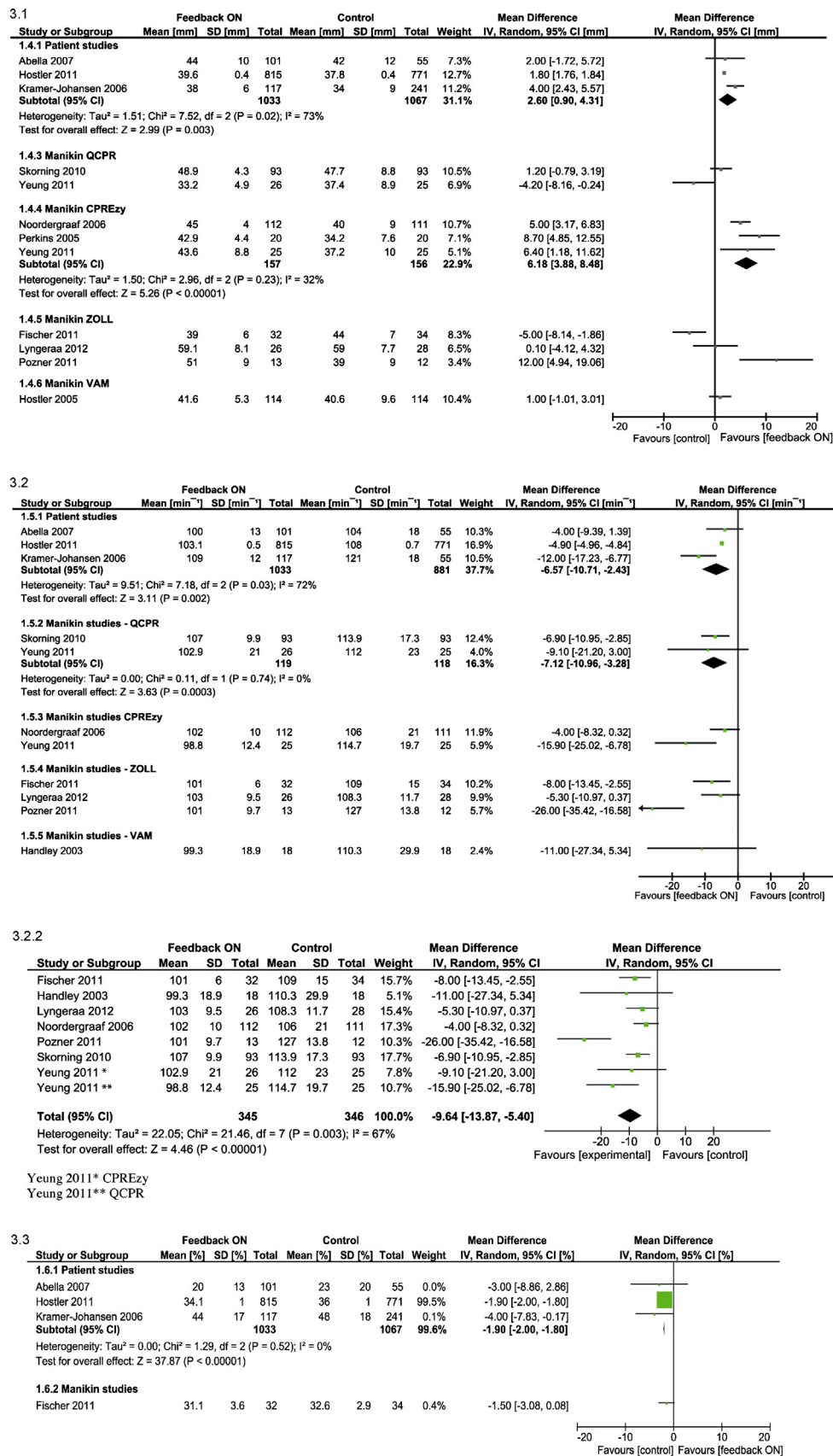Favours [control] Favours [feedback ON]

Fig. 3. CPR quality – comparison of feedback vs. control. (3.1) Chest compression depth [mm]. Patient and manikin studies – sub-grouped by device type. All patient studies used QCPR device. (3.2) Chest compression rate [min⁻¹]. Patient and manikin studies – sub-grouped by device type. All patient studies used QCPR device. (3.2.2) Chest compression rate [min⁻¹]. Manikin studies only, no sub-grouping. (3.3) No-flow fraction [%]. Patient and manikin studies – sub-grouped by device type. All patient studies used QCPR device.

helpful and none reported that it increased user perception of fatigue.

3.7. Subgroup analysis

Human studies have been discussed separately from manikin studies. Manikin studies have been sub-analysed by device type used. There was only one study involving IHCA in patients[31] and removing it from the analysis did not change the outcomes of meta-analyses of patient studies.

3.8. Risk of bias across studies

Evidence of heterogeneity varied depending on outcome assessed. For patient outcomes in the human studies heterogeneity was low ($I^2 = 0\%$). For the outcome of CC rate and depth there was significant evidence of heterogeneity with I^2 values of 72% and 73% respectively. For the outcome measure of NFF, I^2 was 0% suggesting homogeneity.

Heterogeneity amongst manikin studies was also high with I^2 of 67% and 87% respectively for CC rate and depth. This remained following subgroup analysis, ranging from 0 to 86% for CC rate and 32 to 90% for CC depth. Meta-analysis was not performed for subgroups with $I^2 > 75\%$.

To explore heterogeneity attributable to publication bias, funnel plots were drawn, but no marked asymmetry was observed (Appendix 3).

4. Discussion

Overall, the evidence is not sufficiently robust to determine the effectiveness of feedback devices in improving outcomes following cardiac arrest. Only three studies (one cluster randomised, two non-randomised) with a total of 2100 human subjects were identified following an extensive search of the literature. The studies were clinically heterogeneous, of variable quality and reported on different outcome variables. The only available data on neurologically intact survival came from one study,[16] which reported no significant change when real time feedback was used. This[16] showed some evidence of improved survival to hospital discharge when only the later stages of the study were analysed, it was not statistically significant. Nor was there any evidence of a change in survival outcome or ROSC from any of the human studies.

Both manikin and human studies provided evidence that real-time feedback enables a wide range of HCPs to follow life support guidelines more closely within a broad range of settings. Although there was not uniform improvement in CPR variables throughout all studies, there is a significant body of evidence to suggest that audiovisual feedback devices can guide a rescuer to provide deeper CC, at a rate closer to that recommended, and reduce NFF when used in real time whilst delivering CPR. This is consistent with the conclusion from the previous systematic review by Yeung et al.,[13] that there was good evidence supporting the use of feedback devices during training to provide skill acquisition and retention.

A variety of reasons explain why the improvement in CPR variables was not translated into improved patient outcomes. Firstly, effective CPR is just one of many links in the chain of survival and all links need to be in place to allow survival. Without early CPR and bystander delivery of CPR the effect of improving the quality of CPR once trained rescuers arrive may be diminished. Secondly, the improvement in CC variables may be too small to make a noticeable difference to survival especially if the improvements are inconsistent. Additional support may be necessary to increase the magnitude of these improvements, such as staff training and familiarization with the devices, as was seen in the Hostler study,[16] which only compared the later stages of use to control the outcomes

that trended towards improvement. Other adjuncts may include post-event feedback sessions that have been shown to increase the extent of improvement in some centres.[37,44]

Many of these studies were based on the 2000 ILCOR resuscitation guidelines which place less emphasis on reducing interruptions to CC and maintaining a CC rate of at least 100 per minute than the 2010 version. Device feedback resulted in reducing the mean CC rate, which may not be advantageous. The optimal rate of chest compression in CPR remains unknown. Current advice to compress at a rate of 100/minute or greater comes from large mammal studies in which a rate of 100/min was compared with 80/min and showed significantly better coronary perfusion, cardiac output and survival.[45] Clinical studies in adults have also shown end-tidal carbon dioxide levels, a surrogate marker of cardiac output during CPR, to be higher with a chest compression rate of 120/min when compared with 80/min.[46] Another recent study found an increase in odds of ROSC with increasing CC rates up to 125/min;[47] this was not associated with a similar change in survival to discharge.

Few recent studies evaluate the use of feedback devices with 2010 ILCOR guidelines. There is one such multicenter study underway, comparing the use of the QCPR device with and without post debriefing feedback with an estimated recruitment of over 900 patients in the UK.[48] There is an understandable lack of evidence of patient outcomes dependent on what CC rate and depth the feedback device is set to prompt the provider to. Although this could be incredibly useful and interesting data it would be ethically difficult.

Limitations

As described above, our systematic review was challenged by significant statistical and clinical heterogeneity among the studies. Various feedback devices were used, different CPR guidelines were applied, HCPs differed in clinical experience, and different outcomes reported. Study quality varied and it is questionable whether evidence provided by manikin studies can be applied to cardiac arrest in humans.

One particular limitation of including a variety of feedback devices is that they differ in the way that feedback is delivered. For example CPREzy gives guidance feedback whereas QCPR gives corrective feedback and this may result in different responses from the user. This varied response of the user depending on type of feedback provided may explain some of the difference in performance of the various devices (Figs. 3.1 and 3.2). Caution should be used when interpreting data with various device types grouped together (Fig. 3.2.2).

Other devices are available to aid CPR providers in performing high quality CPR such as mobile applications,[49] motion sensing devices[50] and metronomes[51] and some have been used by non-HCPs to aid CPR provision in lay providers.[49,50] These devices were determined to be out of the scope of this systematic review, but would provide an interesting area for future research.

Authors conclusion

There is a significant body of evidence to suggest that the use of real-time feedback devices during a resuscitation attempt can result in rescuers providing CC parameters close to recommendations. The anticipated result of an improvement in patient outcome has not been observed, although there has been no deterioration in outcome either. Real-time feedback may be useful in both teaching scenarios and clinical settings to increase awareness of CPR technique and improve CC quality.

Further research is warranted into the ability of these devices to improve patient outcomes given that the new resuscitation guidelines include a faster target CC rate and more emphasis on

reducing interruptions to CC. Further research is also awaited on the ability of combining real-time feedback and post-event debriefing to improve outcomes. This must be done in conjunction with optimisation of all other elements of the chain of survival including improving rates of bystander CPR and timely access to post-resuscitation care.

Conflict of interest statement

Judith Finn receives partial salary support from St John Ambulance (Western Australia); has received travel reimbursement from the American Heart Association for attendance at ILCOR meetings; and travel reimbursement from the Australian Resuscitation Council for teaching on Advanced Life Support Instructor courses.

Judith Finn is the Director of the Australian Resuscitation Outcomes Consortium and Co-Chair of the ILCOR Education, Implementation and Teams Taskforce.

Ian Jacobs is the Clinical Services Director at St John Ambulance Western Australia has received travel reimbursement from the Australian Resuscitation Council for attendance at ILCOR meetings for teaching on Advanced Life Support courses. Ian Jacobs is Western Australian and National Chair of the Australian Resuscitation Council and Co-Chair of ILCOR.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.resuscitation.2013.12.012.

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