CHEST COMPRESSION COMPONENTS (RATE, DEPTH, CHEST WALL RECOIL AND LEANING): A SCOPING REVIEW

AUTHORS

Julie Considine
Deakin University, School of Nursing and Midwifery/ Centre for Quality and Patient Safety Research, 1 Gheringhap St, Geelong, Victoria, Australia 3220
Professor and Director, Centre for Quality and Patient Safety Research – Eastern Health Partnership, 5 Arnold St, Box Hill, Victoria, Australia 3128
International Liaison Committee on Resuscitation, Basic Life Support Task Force, Dallas, Texas, United States
Conflicts: None

Raúl J. Gazmuri
Director, Resuscitation Institute and Professor of Medicine and Professor of Physiology & Biophysics, Rosalind Franklin University of Medicine and Science
Section Chief, Critical Care and ICU Director, Captain James A. Lovell Federal Health Care Center, 3001 Green Bay Road, North Chicago, Illinois, USA
International Liaison Committee on Resuscitation, Basic Life Support Task Force, Dallas, Texas, United States
Conflicts: None

Gavin D Perkins
Warwick Clinical Trials Unit, University of Warwick, Coventry, CV4 7AL, UK
Critical Care Unit, University Hospitals Birmingham NHS Foundation Trust, Birmingham, B9 5SS
International Liaison Committee on Resuscitation, Basic Life Support Task Force, Dallas, Texas, United States
Conflicts: Co-chair ILCOR, Board member European Resuscitation Council, Executive member Resuscitation Council (UK), Editor Resuscitation

Peter J. Kudenchuk
Division of Cardiology/Electrophysiology Services, University of Washington, 1959 NE Pacific Street, Seattle, Washington, USA 98195-6422
Medical Program Director, King County Medic One, Public Health, Seattle & King County, Washington USA
International Liaison Committee on Resuscitation, Basic Life Support Task Force, Dallas, Texas, United States
Conflicts: National Institutes of Health (NIH) grant support as principal investigator of the SIREN Network at the University of Washington; (unpaid) volunteer American Heart Association Guidelines Update Writing Group

Theresa M. Olasveengen
Department of Anesthesiology, Oslo University Hospital, PO Box 4956 Nydalen Oslo 0424, Norway.
International Liaison Committee on Resuscitation, Basic Life Support Task Force, Dallas, Texas, United States
Conflicts: None

Christian Vaillancourt
Professor of Emergency Medicine and Research Chair in Emergency Cardiac Resuscitation, University of Ottawa; Senior Scientist, Ottawa Hospital Research Institute, Civic Campus, Clinical Epidemiology Unit, Rm F649, 1053 Carling Ave., Ottawa, Ontario, Canada K1Y 4E9
International Liaison Committee on Resuscitation, Basic Life Support Task Force, Dallas, Texas, United States
Conflicts: None

Chika Nishiyama
Department of Critical Care Nursing, Kyoto University Graduate School of Human Health Science, Address: 53 Shogoin Kawahara-cho, Sakyo-ku, Kyoto 606-8507, Japan
International Liaison Committee on Resuscitation, Basic Life Support Task Force, Dallas, Texas, United States
Conflicts: None

Tetsuo Hatanaka
Professor, Emergency Life-Saving Technique Academy, 3-8-1 Oura, Yahatanishi, Kitakyushu.
800-0213 Fukuoka, Japan
International Liaison Committee on Resuscitation, Basic Life Support Task Force, Dallas, Texas, United States
Conflicts: None

Mary E. Mancini
Professor and Sr. Associate Dean for Education Innovation, Baylor Professor for Healthcare Research, The University of Texas at Arlington, College of Nursing and Health Innovation
411 S. Nedderman Drive, Box 19407, Arlington, Texas 76019-0407
International Liaison Committee on Resuscitation, Basic Life Support Task Force, Dallas, Texas, United States
Conflicts: None

Sung Phil Chung
Professor, Emergency Medicine, Gangnam Severance Hospital, Yonsei University, 211 Eonju-ro, Gangnam-gu, Seoul, Korea
International Liaison Committee on Resuscitation, Basic Life Support Task Force, Dallas, Texas, United States
Conflicts: None

Raffo Escalante-Kanashiro
Departamento de Emergencias y Áreas Críticas, Unidad de Cuidados Intensivos, Instituto Nacional de Salud del Niño, Lima, Peru and Chair InterAmerican Heart Foundation/Emergency Cardiovascular Care International Liaison Committee on Resuscitation, Basic Life Support Task Force, Dallas, Texas, United States
Conflicts of interest: none

Peter Morley
Director of Medical Governance, Senior Specialist, Intensive Care, The Royal Melbourne Hospital, 300 Grattan Street, Parkville, Victoria, Australia, 3050
Professor and Director of Medical Education, Royal Melbourne Hospital Clinical School, Faculty of Medicine, Dentistry and Health Sciences, The University of Melbourne, Grattan Street, Parkville, Victoria, Australia, 3010
International Liaison Committee on Resuscitation, Basic Life Support Task Force, Dallas, Texas, United States
Conflicts of interest: None

CHEST COMPRESSION COMPONENTS (RATE, DEPTH, CHEST WALL RECOIL AND LEANING): A SCOPING REVIEW

ABSTRACT

Aim

To understand whether the science to date has focused on single or multiple chest compression components and identify the evidence related to chest compression components to determine the need for a full systematic review.

Methods

This review was undertaken by members of the International Liaison Committee on Resuscitation and guided by a specific methodological framework and the Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for scoping reviews (PRISMA-ScR). Studies were eligible for inclusion if they were peer-reviewed human studies that examined the effect of different chest compression depths or rates, or chest wall or leaning, on physiological or clinical outcomes. The databases searched were MEDLINE complete, Embase, and Cochrane.

Results

Twenty-two clinical studies were included in this review: five observational studies involving 879 patients examined both chest compression rate and depth; eight studies involving 14,285 patients examined chest compression rate only; seven studies involving 12,010 patients examined chest compression depth only, and two studies involving 1,848 patients examined chest wall recoil. No studies were identified that examined chest wall leaning. Three studies reported an inverse relationship between chest compression rate and depth.

Conclusion

This scoping review did not identify sufficient new evidence that would justify conducting new systematic reviews or reconsideration of current resuscitation guidelines. This scoping review does highlight significant gaps in the research evidence related to chest compression components, namely a lack of high-level evidence, paucity of studies of in-hospital cardiac arrest, and failure to account for the possibility of interactions between chest compression components.

Key words: resuscitation; cardiopulmonary resuscitation; CPR; chest compression; basic life support; advanced life support; scoping review

CHEST COMPRESSION COMPONENTS (RATE, DEPTH, CHEST WALL RECOIL AND LEANING): A SCOPING REVIEW

INTRODUCTION

In 2015, the International Liaison Committee on Resuscitation (ILCOR) published the International Consensus on Cardiopulmonary Resuscitation (CPR) and Emergency Cardiovascular Care (ECC) Science with Treatment Recommendations (CoSTR) on Adult Basic Life Support (BLS) and Automated External Defibrillation.[1,2] This CoSTR was underpinned by systematic reviews of 23 PICO questions (Population, Intervention, Comparator, Outcome) and the Grading of Recommendations, Assessment, Development, and Evaluation (GRADE) methodological approach.[3] There were three systematic reviews related to three main components of chest compression (CC); namely, CC rate, CC depth, and chest wall recoil.[1,2] However, these systematic reviews were performed specifically for each component and did not take into account their potential interactions. In addition, chest wall leaning was not evaluated as a parameter independent of chest wall recoil.

Traditionally ILCOR has published BLS CoSTRs in 5-year cycles (2005,[4,5] 2010,[6,7] 2015[1,2]). However, ILCOR has now moved to a continuous evidence evaluation process.[8] Part of this new approach requires the ILCOR Task Forces to determine whether a sufficient body of evidence has emerged to justify re-visiting a previous CoSTR or whether the previous recommendations may still be considered valid. In November 2018, at the ILCOR meeting in Chicago, the BLS Task Force decided to reactivate the PICOs related to CC rate, CC depth, and chest wall recoil, acknowledging that further work was required to understand whether there was new science published to date that provided more information on these CC components as discrete entities or whether studies have reported interactions between these CC components. Therefore, a scoping review was undertaken with the following aims: i) to understand whether the science to date has focused on single CC components or interactions between CC components and ii) to identify the evidence related to the CC components to determine whether the body of evidence published since the 2015 BLS CoSTR[1,2] indicates the need for a full systematic review of the evidence related to CC components.

The purpose of scoping reviews is to identify the available evidence related to a specific topic.[9] The major difference between scoping reviews and systematic reviews is that scoping reviews have a broader inclusion criteria whereas traditional systematic reviews address a narrow, clearly defined question.[9] In addition, the primary outcome of a scoping review is the volume of literature, types of studies conducted, and the outcomes examined, to date rather than pre-defined clinical outcomes that are typically examined in a systematic review. In this scoping review, we present the types of studies of CC components conducted and the outcomes examined understand to address the first aim, and data related to clinical outcomes are presented to address the second aim.

METHODS

This scoping review was guided by the methodological framework developed by Arksey and O'Malley,[10] which comprises the following elements: identify the research question; search for relevant studies; select studies; chart the data; collate, summarise, and report the results according to the Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for scoping reviews (PRISMA-ScR).[11] In scoping reviews, formal quality assessment is not usually performed and study findings are presented in a tabular format with accompanying narrative.[12]

Search strategy and inclusion criteria

The search strategy was the same as that used for the 2015 ILCOR BLS CoSTR systematic reviews on CC rate, CC depth, and chest wall recoil.[1,2] In addition, chest wall leaning was also considered as a separate measurement from chest wall recoil. The full search strategy is available in Appendix 1. Studies were considered eligible for inclusion if they were peer-reviewed human studies that prospectively or retrospectively compared the effects of interventions listed below on physiological (e.g., blood pressure and end-tidal PCO_2) or clinical outcomes (e.g., return of spontaneous circulation (ROSC) and survival to a defined time point):

- two or more CC depths measured in millimetres, centimetres, or inches OR
- two or more CC rates measured in compressions per minute OR
- two or more measures of chest wall recoil OR
- two or more measures of leaning or leaning versus no leaning.

Full chest wall recoil is defined as the sternum returning to a neutral position during the decompression phase of CPR.[13] Chest wall leaning is when the rescuer fails to completely release pressure on the chest wall between compressions, preventing full chest wall recoil.[13] Unpublished studies or studies published in abstract form only, manikin studies, animal studies, and studies that did not specifically address the PICO questions related to CC rate, CC depth, chest wall recoil, and leaning were excluded.

Data sources

The following databases were searched: MEDLINE complete, Embase, and Cochrane. The searches that informed the 2015 BLS CoSTR[1,2] were conducted on the following dates: CC rate 9 December 2013; CC depth 11 November 2013 and chest wall recoil 14 April 2014. This subsequent search was date limited from 1 November 2013 to 20 June 2019 to identify studies published since the 2015 ILCOR BLS CoSTR.[1,2]

Study selection

The results of this most recent search and all of the 20 studies included in the 2015 ILCOR BLS CoSTR[1,2] (CC rate n=5, CC depth n=10, and chest wall recoil n=5) were downloaded into Microsoft Excel (2016), duplicates were identified and removed. Two authors (JC and RJG) independently screened titles and abstracts of studies against the selection criteria. Full text articles from the 2019 search and 2015 ILCOR BLS CoSTR[1,2] assessed as potentially eligible for inclusion in this review were independently screened against the inclusion criteria (JC and RJG). Disagreements were resolved by discussion and consensus. The inclusion / exclusion criteria used in this scoping review were different to those used in the 2015 CoSTR: the 2015 CoSTR included animal studies and in the 2015 CoSTR CC components were treated as separate entities and there was no requirement in the that two or more CC rates, depths, measures of recoil or leaning be compared.

Data extraction and charting

Data were extracted by a single author (JC) and ratified by co-authors (CN, TMO, RJG, SPC). For each CC component (CC rate, CC depth, chest wall recoil and chest wall lean), the characteristics of each study were extracted including: the author(s); year of publication; study design; country; population; intervention and comparator; major findings; and outcome(s) examined.

RESULTS

After removal of duplicates, our search returned 2,830 publications. Two 2015 ILCOR BLS CoSTR[1,2] studies were excluded during title and abstract screening because they were animal studies. In total, 53 full text publications were screened for eligibility: 35 studies from the 2019 search and 18 studies from the 2015 ILCOR BLS CoSTR.[1,2] Following screening of the 53 full-text publications, 31 were excluded because they were abstract only publications (n=15), did not meet the inclusion criteria (n=10), were studies of patients not in cardiac arrest (n=2), used surrogate outcomes (n=2) or were letters (n=2). Twenty-two studies were included in the final review (Figure 1). Eight were new studies identified by the 2019 search and fourteen were studies from the 2015 ILCOR BLS CoSTR.[1,2] The six studies from the 2015 ILCOR BLS CoSTR[1,2] excluded from this review were two animal studies[15,16] and four studies[17-20] that did not compare two or more CC components.

Study characteristics

The characteristics of the included studies are summarised in Appendix 2. Five observational studies involving 879 patients (489 adults and 390 children) examined both CC rate and CC depth.[21-25] Eight studies involving 14,285 patients (14,121 adults and 164 children) examined CC rate only: six observational studies,[26-31] one crossover trial,[32] and one randomised controlled trial (RCT).[33] Seven studies involving 12,010 patients (11,228 adults, 695 age unknown, and 78 children) examined CC depth only: six observational studies[34-39] and one randomised study.[40] Two studies involving 1848 adult patients examined chest wall recoil[41,42] and no studies were identified that examined different measures of leaning. In this scoping review, preference was given to non-imputed data over imputed data.

Chest compression rate

There were thirteen studies involving 15,164 patients (14,610 adults and 554 children) that reported outcomes associated with CC rate: a summary of outcomes is presented in Table 1 and detailed evidence summary tables are in Appendix 3. Eleven were observational studies,[21-31] there was one crossover trial[32] and one RCT.[33] The outcomes examined were survival with favourable neurological function (one RCT[33] and three observational studies[25-27]); survival to hospital discharge (five observational studies[26-29,33]); 1-month survival (one RCT[33] and one observational study[25]); 24-h survival (two observational studies[22,25]); survival to hospital admission (two observational studies[24,25]); ROSC (one RCT[33] and seven observational studies[22,25-30]); blood pressure (three observational studies[21,26,31]); end-tidal PCO_2 (one RCT[33] and two observational studies[31,32]); and shock success (one observational study[23]).

There was absence of a consistent association between CC rate and survival with favourable neurological outcome, which varied depending on the study population (children versus adult), study size, and whether adjusted for potential confounders. One study reported that CC rate of <100/min was associated with increased survival with favourable neurological outcome in children compared to a CC rate of 100-120/min.[26] Studies in adults were not definitive for an association between CC rate alone and favourable neurological survival.[25,27,33] Of the five studies that examined survival to discharge, one study reported that when adjusted for confounders including CC depth and CC fraction, survival to hospital discharge was lower at CC rates of 80-99/min and 120-139/minute compared to a rate of 100-119/minute.[28] None of the other studies reported a survival to hospital discharge benefit associated with specific CC rates.[22,26,29,33] There were no significant differences reported between various CC rates on 1-month survival,[25,33] 1-day survival,[22,25] or admission to hospital alive.[24,25] Of the eight studies that reported on ROSC, one study reported that compared to a reference CC rate of 100-120/minute, a CC rate of 121-140/minute was associated with increased ROSC[27] and one study reported that higher mean CC rates were associated with increased likelihood of ROSC.[30] None of the other studies reported a significant difference between various CC rates and ROSC.[22,25,26,28,29,33]

Of the three studies that reported on blood pressure, one study reported CC rates in combination with depth so the specific effect of CC rate on systolic blood pressure (SPB) and diastolic blood pressure (DBP) was unable to be ascertained.[21] One study reported that, compared with a reference CC rate of 100-120/minute, a CC rate of 120-140/minute was associated with decreased SBP in children.[26] None of the other CC rates examined had a significant effect on either SBP or DBP.[21,31] Of the three studies that reported end-tidal PCO_2, one reported that compared to a CC rate of 80/minute, a CC rate of 120/minute was associated with an increased mean end-tidal CO_2.[32] The other two studies failed to show a significant association between various CC rates and changes in end-tidal CO_2.[31,33] One study reported that CC rates were not significantly associated with shock success.[23]

Chest compression depth

There were twelve studies involving 12,664 patients (11,729 adults, 240 children, and 695 with age not available) that reported data related to CC depth: a summary of outcomes is presented in Table 2 and detailed evidence summary tables are in Appendix 4. Eleven were observational studies,[21-25,34,36-39,43] and one was a prospective randomised study.[40] The outcomes examined were survival with favourable neurological function (three observational studies[25,35,36]); survival to hospital discharge (four observational studies[34-36,38]); 1-month survival (one observational study[25]); 24-h survival (four observational studies[25,34,35,38]); survival to the Emergency Department (ED) (one randomised study[40]); survival to hospital admission (two observational studies[24,25]); ROSC (six observational studies [22,25,34,35,38,39]); blood pressure (one observational study[21]); shock success (two observational studies[23,39]); and injury frequency (one observational study[37]).

Specific CC depths (<38 mm versus 38.0-50.9 mm or ≥51.0 mm in adults;[36] mean (SD) CC depth of 38.8 (11.5) mm versus 48.0 (9.2) mm in adults;[25] or <51mm versus ≥51.0 mm in children[35]) were not significantly associated with survival with favourable neurological outcome.[25,35,36] However, one adult study reported that each 5 mm increase in mean CC depth was associated with increased survival with favourable neurological outcome.[36] Of the four studies that examined survival to hospital discharge, one adult study reported that, compared to a CC depth of >51mm and adjusted for confounders, survival to hospital discharge decreased when CC depth was <38 mm [34] Two adult studies reported that for each 5 mm increase in CC depth, survival to hospital discharge increased[34,36]. None of the other studies reported an association between survival to hospital discharge[35,38] or 1-month survival[25] and specific CC depths.

Four studies reported on 1-day survival: three reported statistically significant relationships between 1-day survival and CC depth in adults[34,38] and children[35] and one reported no association between mean CC depths and 1-day survival in adults.[25] In adults, for each 5 mm increase in CC depth, 1-day survival increased.[34] When adjusted for confounders and compared to CC depth of <38mm, a CC depth of 38-51mm increased 1-day survival.[38] Compared to CC depth of >51mm, a CC depth <38mm decreased 1-day survival.[34] In children, if ≥60% of CCs had an average depth of ≥51mm (compared with <60% of average CC depth ≥51mm), 24-h survival increased.[35] The study that reported survival to the ED showed that mean CC depths of 5-6cm had the highest survival to ED rates in adults but no p-values were reported.[40]

In adults, one study showed that increased CC depth was associated with increased odds of admission to hospital alive[24] with adjusted analyses showing that with each 1mm increase in average CC compression depth, there was a significant increase in the odds of admission alive to hospital.[24] The other adult study showed no association between different mean CC depths and survival to hospital admission.[25] Of the six studies that reported on ROSC, in children, adjusted analyses showed that if ≥60% of CCs had an average depth of ≥51mm compared with <60% of average CC depth ≥51mm), ROSC increased.[35] In one study of adults, when shocks were delivered after five minutes of CC, a CC depth > 5 cm compared with CC depth < 5 cm was associated with higher transient ROSC.[39] None of the other studies reported a statistically significant relationship between ROSC and different CC depths.[22,25,34,38]

The study examining the effect on blood pressure, reported CC depths in combination with CC rates so the specific association of CC rate with SPB and DBP could not be ascertained.[21] One study reported on shock success and suggested that deeper CC were associated with greater likelihood of shock success: the mean (SD) CC depths were 39(11)mm for successful shocks and 29(10)mm for unsuccessful shocks (p=0.004)[23] One study reported on injury frequency and showed that increased CC depths were associated with higher injury rates (p=0.06) and the mean (SD) CC depth of patients with injuries was 56 (11) mm versus 52 (8) mm in patients with no injuries (p=0.04).[37]

Chest wall recoil

There were two studies involving 1,848 adults that reported data related to chest wall recoil, specifically on CC release velocity (CCRV): both were observational studies.[41,42] A summary of outcomes is presented in Table 3 and detailed evidence summary tables are in Appendix 5. The outcomes examined were survival with favourable neurological function (two observational studies[41,42]); survival to hospital discharge (two observational studies[41,42]); and ROSC (one observational study[41]). The two studies reporting survival with favourable neurological outcome had conflicting results. One study reported that different CCRVs made no difference to survival with favourable neurological outcome.[41] The other study reported that, compared to slow (<300mm/s) CCRV, fast CCRV (≥400 mm/s) was associated with increased survival with favourable neurological outcome but there was no association between moderate CCRV (300–399.9 mm/s) and survival with favourable neurological outcome.[42] Two studies reported on survival to hospital discharge, again with conflicting results. One study reported that, compared to slow CCRV (<300mm/s), fast CCRV (≥400 mm/s) was associated with increased survival to hospital discharge, but again there was no association between moderate CCRV (300–399.9 mm/s) survival to hospital discharge.[42] The other study reported that once adjusted for confounders, there was no difference in survival to hospital discharge associated with different CCRVs.[41] The one study reporting on ROSC showed no statistically significant improvement associated with a 10mm/sec increase in CCRV.[41]

Interactions between CPR parameters

Five studies involving 8,400 patients (8,313 adults and 78 children) reported on relationships between CPR parameters: four observational studies[28,35,36,38] and one RCT[33]. A summary of outcomes is presented in Table 4 and detailed evidence summary tables are in Appendix 6. All studies reported on the association between CC rate and CC depth: three studies reported a significant decrease in CC depth as CC rate increased ($p<0.001$),[28,36,38] one adult study reported no difference in CC depth with CC rates of 100/minute and 120/minute,[33] and the study in children reported no significant relationship between CC rate and CC depth.[35] One study reported a significant decrease in mean (SD) CC fraction when CC rate was increased from 100/minute to 120/minute [95.9% (3.1%) vs 94.3% (5.1%), $p=0.008$].[33] One study reported that CC depths of <51mm versus ≥51mm was not associated with the percentage of CC with significant leaning (>2.5 kg) in children [12% vs 8%, $p=0.09$].[35]

DISCUSSION

This scoping review identified 22 studies related to various CC components, eighteen of which were observational studies.[21-31,34-39,41,42] There was variation in the outcomes examined and overall the most frequently reported outcomes were ROSC (n=13),[22,25-30,33-35,38,39,41] survival to hospital discharge (n=12),[22,26-29,33-36,38,41,42] and survival to hospital discharge with good neurological outcome (n=8).[25-27,33,35,36,41,42] All but three studies[22,26,35] were in adults, there was one study where the age of participants was not reported.[39] Seventeen of the included studies focused on out-of-hospital cardiac arrest[21-24,27-

[29,31,34,36,38,39,41,42] including one study of patients with out-of-hospital cardiac arrest requiring CPR in the ED.[25]

The 2015 ILCOR BLS CoSTR[1,2] treatment recommendations for chest compressions are to: i) *recommend* a chest compression depth of approximately 5cm (2 inches) (strong recommendation, low-quality evidence) while avoiding excessive chest compression depths greater than 6cm (2.4 inches) in an average adult (weak recommendation, low-quality evidence) during manual CPR; ii) *recommend* a manual chest compression rate of 100–120/min (strong recommendation, very-low-quality evidence); and iii) *suggest* that rescuers performing manual CPR avoid leaning on the chest between compressions to allow full chest wall recoil (weak recommendation, very-low-quality evidence). This scoping review identified 8 new studies since publication of the 2015 ILCOR BLS CoSTR.[1,2] However, none of the new studies identified reported sufficient new evidence that would prompt performing new full systematic reviews or reconsideration of treatment recommendations related to CC components.

The studies included in this review were published between 1988 and 2018, during which time there have been a number of changes to international resuscitation guidelines and specifically recommendations related to CCs.[1,2,4-7] In 2000, rescuers were instructed to provide 2 to 5 rescue breaths and perform CC at a rate of 100/min, depth of 4-5cm allowing complete recoil after each compression, and a compression:ventilation ratio of 15:2 in adults.[44,45] In children, rescuers were instructed to provide two rescue breaths and perform CC at a rate 100/min, depth of 1.5-2.5cm in infants, 10-1.5 inches in small children and 1.5-2.0 inches in larger children allowing complete recoil after each compression and a compression:ventilation ratio of 5:1.[46,47] In 2005, rescuers were instructed to provide two rescue breaths and then perform CC at a rate of 100/minute and at a depth of *at least* 4-5cm, allowing complete recoil of the chest after each compression.[4,5] For the first time, a universal compression:ventilation ratio of 30:2 was recommended for all patients in 2005, with the caveat that healthcare professionals providing two-rescuer CPR in infants or children should use a compression:ventilation ratio of 15:2.[4,5] In 2010, rescuers were instructed to commence CPR with chest compressions (at a rate of *at least* 100/minute, to a depth of *at least* 5cm, and with a compression:ventilation ratio of 30:2) in patients who were unresponsive and not breathing normally.[6,7] In 2015, the recommendations regarding CC rate changed from 100/minute[6,7] to 100-120/minute[1,2] and the recommendations regarding CC depth were changed from *at least* 5cm[6,7] to approximately 5cm whilst avoiding CC depths greater than 6cm.[1,2] The dynamic nature of resuscitation guidelines makes the use of historical data and interpretation of results from studies that used now obsolete CPR parameters from older guidelines problematic.

Studies evaluating associations between CC components and patient outcomes presented conflicting results. Of the thirteen studies that focused on CC rate, only four[26-28,30] reported significant associations between CC rate and patient outcomes. One of the three studies that focused on survival with favourable neurological outcome reported that slower CC rates (<80-100/minute) improved this outcome in children.[26] The largest of the five studies that examined survival to discharge, reported that CC rates of 80-99/minute or 120-139/minute were associated with decreased survival to hospital discharge in adults compared to a reference rate of 100-120/minute,[28] supporting the 2015 ILCOR BLS CoSTR.[1,2] Two of the eight studies that focused on ROSC reported that higher CC rates were associated with increased likelihood of ROSC.[27,30] Of the twelve studies that focused on CC depth, again, only four[24,34,35,38] reported significant relationships between CC depth and patient outcomes and the findings were concordant with the 2015 ILCOR BLS CoSTR.[1,2]

The largest of the four studies focused on survival to hospital discharge reported decreased survival with shallow CCs (<38mm) compared to >51mm and a positive association between increasing CC depth and survival to hospital discharge in adults.[34] Three of four studies that focused on 1-day survival, reported statistically significant associations between 1-day survival and increasing CC depth.[34,35,38] One of the two studies that focused on admission to hospital alive also reported an increased odds of survival associated with increased CC depth in adults.[24] Of interest was that both studies that focused on shock success reported increased shock success associated with deeper CC in adults.[23,39] There were only two studies of chest wall recoil: both were in adults with OOHCA, highlighting an area for future research. The results related to favourable neurological outcome[41,42] and survival to hospital discharge[41,42] were conflicting. The one study reporting on ROSC showed no significant effect associated with CCRV.[41] Of the five studies that reported on the interaction between CC rate and CC depth, three reported an inverse association: as CC rate increases, CC depth decreases.[28,36,38] This finding calls into question the value of appraising the evidence associated with each component of CC in isolation.

Strengths and limitations

This review is the first to identify and map the available evidence related to CC rate, CC depth, and chest wall recoil and report on potential interactions between these CC parameters. The strengths of this review are the systematic search technique, precise inclusion and exclusion criteria, and comprehensive data extraction. The limitations of this review are that we only accessed publications in English. As this was a scoping review rather than a systematic review, risk of bias and quality assessments of the included studies were not performed.[12]

There is also a lack of high-level evidence as the research to date has been dominated by observational studies, many of which were single site cohort studies with modest sample sizes. The larger observational studies to date have used epidemiologic registry data which, although collected prospectively, may have limitations in describing associations, rather than definitive relationships that can only be established by controlled randomised trials. The majority of the studies identified in this review were focused on out-of-hospital cardiac arrest highlighting a major gap in research in the in-hospital context.

CONCLUSIONS

This scoping review demonstrated that the majority of studies focused on a single CC component, whereas a number of studies suggest the presence of confounding interactions that prompt caution when evaluating any CC component in isolation. Although this scoping review has not identified sufficient new evidence to prompt new systematic reviews or reconsideration of current resuscitation guidelines, it highlights significant gaps in the research evidence related to CC components, namely a lack of high-level evidence, paucity of studies of in-hospital cardiac arrest, and failure to account for the possibility of conflicting interactions between chest compression components. Future studies should take into account the possibility of interactions between CC components, specifically CC rate and depth as recommendations about one component have the potential to compromise another.

ILCOR statement

This review includes information on resuscitation questions developed through the continuous evidence evaluation process, managed by the ILCOR.[48] The questions were developed by ILCOR Task Forces, using strict conflict of interest guidelines. In general, each question was assigned to two experts to complete a detailed structured review of the literature, and complete a detailed evidence evaluation. Evidence evaluations are discussed at ILCOR meetings to reach consensus and will be published on the ILCOR CoSTR website.[48] The conclusions published in the ILCOR CoSTR consensus document may differ from the conclusions of this review because the CoSTR consensus will reflect input from other evidence evaluation review authors and discussants and will take into consideration implementation and feasibility issues as well as new relevant research.

Acknowledgements

The authors wish to acknowledge the contribution of members of the International Liaison Committee on Resuscitation Basic Life Support Task Force to this scoping review.

REFERENCES

1. Perkins GD, Travers AH, Berg RA, et al. Part 3: Adult basic life support and automated external defibrillation. 2015 International Consensus on Cardiopulmonary Resuscitation and Emergency Cardiovascular Care Science With Treatment Recommendations. Resuscitation 2015;95:e43-e69.
2. Travers AH, Perkins GD, Berg RA, et al. Part 3: Adult Basic Life Support and Automated External Defibrillation 2015 International Consensus on Cardiopulmonary Resuscitation and Emergency Cardiovascular Care Science With Treatment Recommendations. Circulation 2015;132:S51-S83.
3. Schünemann H, Brożek J, Guyatt G, Oxman A, eds. *Handbook for grading the quality of evidence and the strength of recommendations using the GRADE approach.* Retrieved 16 June 2019 from https://gdt.gradepro.org/app/handbook/handbook.html; 2013.
4. International Liaison Committee on Resuscitation. Part 2. Adult basic life support. 2005 international consensus on cardiopulmonary resuscitation and emergency cardiovascular care science with treatment recommendations. Resuscitation 2005;67:187-200.
5. International Liaison Committee on Resuscitation, American Heart Association, European Resuscitation Council. Part 2: Adult Basic Life Support. Circulation 2005;112:III-5-III-16.
6. Koster RW, Sayre MR, Botha M, et al. Part 5: Adult basic life support: 2010 International consensus on cardiopulmonary resuscitation and emergency cardiovascular care science with treatment recommendations. Resuscitation 2010;81:e48-e70.
7. Sayre MR, Koster RW, Botha M, et al. Part 5: adult basic life support: 2010 international consensus on cardiopulmonary resuscitation and emergency cardiovascular care science with treatment recommendations. Circulation 2010;122:S298-S324.
8. Morley PT. Towards a more continuous evidence evaluation: A collaborative approach to review the resuscitation science. Resuscitation 2017;118:A1-A2.
9. Munn Z, Peters MDJ, Stern C, Tufanaru C, McArthur A, Aromataris E. Systematic review or scoping review? Guidance for authors when choosing between a systematic or scoping review approach. BMC Med Res Methodol 2018;18:143.
10. Arksey H, O'Malley L. Scoping studies: towards a methodological framework. Int J Soc Res Methodol 2005;8:19-32.
11. Tricco AC, Lillie E, Zarin W, et al. PRISMA extension for scoping reviews (PRISMA-ScR): Checklist and explanation. Ann Intern Med 2018;169:467-473.
12. Grant MJ, Booth A. A typology of reviews: an analysis of 14 review types and associated methodologies. Health Info Libr J 2009;26:91-108.
13. Kleinman ME, Brennan EE, Goldberger ZD, et al. Part 5: Adult Basic Life Support and Cardiopulmonary Resuscitation Quality. 2015;132:S414-S435.

14. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. Ann Int Med 2009;151:264-269.
15. Yannopoulos D, McKnite S, Aufderheide TP, et al. Effects of incomplete chest wall decompression during cardiopulmonary resuscitation on coronary and cerebral perfusion pressures in a porcine model of cardiac arrest. 2005;64:363-372.
16. Zuercher M, Hilwig RW, Ranger-Moore J, et al. Leaning during chest compressions impairs cardiac output and left ventricular myocardial blood flow in piglet cardiac arrest. 2010;38:1141.
17. Hostler D, Everson-Stewart S, Rea TD, et al. Effect of real-time feedback during cardiopulmonary resuscitation outside hospital: prospective, cluster-randomised trial. 2011;342:d512.
18. Fried DA, Leary M, Smith DA, et al. The prevalence of chest compression leaning during in-hospital cardiopulmonary resuscitation. Resuscitation 2011;82:1019-1024.
19. Niles D, Nysaether J, Sutton R, et al. Leaning is common during in-hospital pediatric CPR, and decreased with automated corrective feedback. 2009;80:553-557.
20. Edelson DP, Litzinger B, Arora V, et al. Improving In-Hospital Cardiac Arrest Process and Outcomes With Performance Debriefing. 2008;168:1063-1069.
21. Sainio M, Hoppu S, Huhtala H, Eilevstjønn J, Olkkola KT, Tenhunen J. Simultaneous beat-to-beat assessment of arterial blood pressure and quality of cardiopulmonary resuscitation in out-of-hospital and in-hospital settings. Resuscitation 2015;96:163-169.
22. Sutton RM, Case E, Brown SP, et al. A quantitative analysis of out-of-hospital pediatric and adolescent resuscitation quality--A report from the ROC epistry-cardiac arrest. Resuscitation 2015;93:150-157.
23. Edelson DP, Abella BS, Kramer-Johansen J, et al. Effects of compression depth and pre-shock pauses predict defibrillation failure during cardiac arrest. Resuscitation 2006;71:137-145.
24. Kramer-Johansen J, Myklebust H, Wik L, et al. Quality of out-of-hospital cardiopulmonary resuscitation with real time automated feedback: A prospective interventional study. Resuscitation 2006;71:283-292.
25. Riyapan S, Naulnark T, Ruangsomboon O, et al. Improving quality of chest compression in thai emergency department by using real-time audio-visual feedback cardio-pulmonary resuscitation monitoring. 2019;102:245-251.
26. Sutton RM, Reeder RW, Landis W, et al. Chest compression rates and pediatric in-hospital cardiac arrest survival outcomes. Resuscitation 2018;130:159-166.
27. Kilgannon JH, Kirchhoff M, Pierce L, Aunchman N, Trzeciak S, Roberts BW. Association between chest compression rates and clinical outcomes following in-hospital cardiac arrest at an academic tertiary hospital. Resuscitation 2017;110:154-161.

28. Idris AH, Guffey D, Pepe PP, et al. Chest Compression Rates and Survival Following Out-of-Hospital Cardiac Arrest. Crit Care Med 2015;43:840-848.
29. Idris AH, Guffey D, Aufderheide TP, et al. The relationship between chest compression rates and outcomes from cardiac arrest. Circulation 2012;125:3004-3012.
30. Abella BS, Sandbo N, Vassilatos P, et al. Chest Compression Rates During Cardiopulmonary Resuscitation Are Suboptimal A Prospective Study During In-Hospital Cardiac Arrest. Circulation 2005;111:428-434.
31. Ornato JP, Gonzalez ER, Garnett AR, Levine RL, McClung BK. Effect of cardiopulmonary resuscitation compression rate on end-tidal carbon dioxide concentration and arterial pressure in man. Crit Care Med 1988;16:241-245.
32. Kern KB, Sanders AB, Raife J, Milander MM, Otto CW, Ewy GA. A Study of Chest Compression Rates During Cardiopulmonary Resuscitation in Humans: The Importance of Rate-Directed Chest Compressions. Arch Int Med 1992;152:145-149.
33. Hwang SO, Cha K-C, Kim K, et al. A Randomized Controlled Trial of Compression Rates during Cardiopulmonary Resuscitation. J Korean Med Sci 2016;31:1491-1498.
34. Stiell IG, Brown SP, Nichol G, et al. What is the optimal chest compression depth during out-of-hospital cardiac arrest resuscitation of adult patients? 2014;130:1962-1970.
35. Sutton RM, French B, Niles DE, et al. 2010 American Heart Association recommended compression depths during pediatric in-hospital resuscitations are associated with survival. Resuscitation 2014;85:1179-1184.
36. Vadeboncoeur T, Stolz U, Panchal A, et al. Chest compression depth and survival in out-of-hospital cardiac arrest. Resuscitation 2014;85:182-188.
37. Hellevuo H, Sainio M, Nevalainen R, et al. Deeper chest compression – More complications for cardiac arrest patients? Resuscitation 2013;84:760-765.
38. Stiell IG, Brown SP, Christenson J, et al. What is the role of chest compression depth during out-of-hospital cardiac arrest resuscitation? Crit Care Med 2012;40:1192-1198.
39. Babbs CF, Kemeny AE, Quan W, Freeman G. A new paradigm for human resuscitation research using intelligent devices. Resuscitation 2008;77:306-315.
40. Bohn A, Weber TP, Wecker S, et al. The addition of voice prompts to audiovisual feedback and debriefing does not modify CPR quality or outcomes in out of hospital cardiac arrest – A prospective, randomized trial. Resuscitation 2011;82:257-262.
41. Cheskes S, Common MR, Byers AP, Zhan C, Silver A, Morrison LJ. The association between chest compression release velocity and outcomes from out-of-hospital cardiac arrest. Resuscitation 2015;86:38-43.

42. Kovacs A, Vadeboncoeur TF, Stolz U, et al. Chest compression release velocity: Association with survival and favorable neurologic outcome after out-of-hospital cardiac arrest. Resuscitation 2015;92:107-114.
43. Sutton RM, Niles D, French B, et al. First quantitative analysis of cardiopulmonary resuscitation quality during in-hospital cardiac arrests of young children. Resuscitation 2014;85:70-74.
44. European Resuscitation Council. Part 3: Adult Basic Life Support. Resuscitation 2000;46:29-71.
45. American Heart Association. Part 3: Adult Basic Life Support. Circulation 2000;102:I22-I59.
46. American Heart Association. Part 9: Pediatric Basic Life Support. Circulation 2000;102:I253-I290.
47. European Resuscitation Council. Part 9: Pediatric Basic Life Support. Resuscitation 2000;46:301-341.
48. International Liaison Committee on Resuscitation (ILCOR). www.ilcor.org. Accessed 20 June, 2019.

CHEST COMPRESSION COMPONENTS (RATE, DEPTH, CHEST WALL RECOIL AND LEANING): A SCOPING REVIEW

AUTHORS

Julie Considine
Deakin University, School of Nursing and Midwifery/ Centre for Quality and Patient Safety Research, 1 Gheringhap St, Geelong, Victoria, Australia 3220
Professor and Director, Centre for Quality and Patient Safety Research – Eastern Health Partnership, 5 Arnold St, Box Hill, Victoria, Australia 3128
International Liaison Committee on Resuscitation, Basic Life Support Task Force, Dallas, Texas, United States
Conflicts: None

Raúl J. Gazmuri
Director, Resuscitation Institute and Professor of Medicine and Professor of Physiology & Biophysics, Rosalind Franklin University of Medicine and Science
Section Chief, Critical Care and ICU Director, Captain James A. Lovell Federal Health Care Center, 3001 Green Bay Road, North Chicago, Illinois, USA
International Liaison Committee on Resuscitation, Basic Life Support Task Force, Dallas, Texas, United States
Conflicts: None

Gavin D Perkins
Warwick Clinical Trials Unit, University of Warwick, Coventry, CV4 7AL, UK
Critical Care Unit, University Hospitals Birmingham NHS Foundation Trust, Birmingham, B9 5SS
International Liaison Committee on Resuscitation, Basic Life Support Task Force, Dallas, Texas, United States
Conflicts: Co-chair ILCOR, Board member European Resuscitation Council, Executive member Resuscitation Council (UK), Editor Resuscitation

Peter J. Kudenchuk
Division of Cardiology/Electrophysiology Services, University of Washington, 1959 NE Pacific Street, Seattle, Washington, USA 98195-6422
Medical Program Director, King County Medic One, Public Health, Seattle & King County, Washington USA
International Liaison Committee on Resuscitation, Basic Life Support Task Force, Dallas, Texas, United States
Conflicts: National Institutes of Health (NIH) grant support as principal investigator of the SIREN Network at the University of Washington; (unpaid) volunteer American Heart Association Guidelines Update Writing Group

Theresa M. Olasveengen
Department of Anesthesiology, Oslo University Hospital, PO Box 4956 Nydalen Oslo 0424, Norway.
International Liaison Committee on Resuscitation, Basic Life Support Task Force, Dallas, Texas, United States
Conflicts: None

Christian Vaillancourt
Professor of Emergency Medicine and Research Chair in Emergency Cardiac Resuscitation, University of Ottawa; Senior Scientist, Ottawa Hospital Research Institute, Civic Campus, Clinical Epidemiology Unit, Rm F649, 1053 Carling Ave., Ottawa, Ontario, Canada K1Y 4E9
International Liaison Committee on Resuscitation, Basic Life Support Task Force, Dallas, Texas, United States
Conflicts: None

Chika Nishiyama
Department of Critical Care Nursing, Kyoto University Graduate School of Human Health Science, Address: 53 Shogoin Kawahara-cho, Sakyo-ku, Kyoto 606-8507, Japan
International Liaison Committee on Resuscitation, Basic Life Support Task Force, Dallas, Texas, United States
Conflicts: None

Tetsuo Hatanaka
Professor, Emergency Life-Saving Technique Academy, 3-8-1 Oura, Yahatanishi, Kitakyushu.
800-0213 Fukuoka, Japan
International Liaison Committee on Resuscitation, Basic Life Support Task Force, Dallas, Texas, United States
Conflicts: None

Mary E. Mancini
Professor and Sr. Associate Dean for Education Innovation, Baylor Professor for Healthcare Research, The University of Texas at Arlington, College of Nursing and Health Innovation
411 S. Nedderman Drive, Box 19407, Arlington, Texas 76019-0407
International Liaison Committee on Resuscitation, Basic Life Support Task Force, Dallas, Texas, United States
Conflicts: None

Sung Phil Chung
Professor, Emergency Medicine, Gangnam Severance Hospital, Yonsei University, 211 Eonju-ro, Gangnam-gu, Seoul, Korea
International Liaison Committee on Resuscitation, Basic Life Support Task Force, Dallas, Texas, United States
Conflicts: None

Raffo Escalante-Kanashiro
Departamento de Emergencias y Áreas Críticas, Unidad de Cuidados Intensivos, Instituto Nacional de Salud del Niño, Lima, Peru and Chair InterAmerican Heart Foundation/Emergency Cardiovascular Care International Liaison Committee on Resuscitation, Basic Life Support Task Force, Dallas, Texas, United States
Conflicts of interest: none

Peter Morley
Director of Medical Governance, Senior Specialist, Intensive Care, The Royal Melbourne Hospital, 300 Grattan Street, Parkville, Victoria, Australia, 3050
Professor and Director of Medical Education, Royal Melbourne Hospital Clinical School, Faculty of Medicine, Dentistry and Health Sciences, The University of Melbourne, Grattan Street, Parkville, Victoria, Australia, 3010
International Liaison Committee on Resuscitation, Basic Life Support Task Force, Dallas, Texas, United States
Conflicts of interest: None

CHEST COMPRESSION COMPONENTS (RATE, DEPTH, CHEST WALL RECOIL AND LEANING): A SCOPING REVIEW

ABSTRACT

Aim

To understand whether the science to date has focused on single or multiple chest compression components and identify the evidence related to chest compression components to determine the need for a full systematic review.

Methods

This review was undertaken by members of the International Liaison Committee on Resuscitation and guided by a specific methodological framework and the Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for scoping reviews (PRISMA-ScR). Studies were eligible for inclusion if they were peer-reviewed human studies that examined the effect of different chest compression depths or rates, or chest wall or leaning, on physiological or clinical outcomes. The databases searched were MEDLINE complete, Embase, and Cochrane.

Results

Twenty-two clinical studies were included in this review: five observational studies involving 879 patients examined both chest compression rate and depth; eight studies involving 14,285 patients examined chest compression rate only; seven studies involving 12,010 patients examined chest compression depth only, and two studies involving 1,848 patients examined chest wall recoil. No studies were identified that examined chest wall leaning. Three studies reported an inverse relationship between chest compression rate and depth.

Conclusion

This scoping review did not identify sufficient new evidence that would justify conducting new systematic reviews or reconsideration of current resuscitation guidelines. This scoping review does highlight significant gaps in the research evidence related to chest compression components, namely a lack of high-level evidence, paucity of studies of in-hospital cardiac arrest, and failure to account for the possibility of interactions between chest compression components.

Key words: resuscitation; cardiopulmonary resuscitation; CPR; chest compression; basic life support; advanced life support; scoping review

CHEST COMPRESSION COMPONENTS (RATE, DEPTH, CHEST WALL RECOIL AND LEANING): A SCOPING REVIEW

INTRODUCTION

In 2015, the International Liaison Committee on Resuscitation (ILCOR) published the International Consensus on Cardiopulmonary Resuscitation (CPR) and Emergency Cardiovascular Care (ECC) Science with Treatment Recommendations (CoSTR) on Adult Basic Life Support (BLS) and Automated External Defibrillation.[1,2] This CoSTR was underpinned by systematic reviews of 23 PICO questions (Population, Intervention, Comparator, Outcome) and the Grading of Recommendations, Assessment, Development, and Evaluation (GRADE) methodological approach.[3] There were three systematic reviews related to three main components of chest compression (CC); namely, CC rate, CC depth, and chest wall recoil.[1,2] However, these systematic reviews were performed specifically for each component and did not take into account their potential interactions. In addition, chest wall leaning was not evaluated as a parameter independent of chest wall recoil.

Traditionally ILCOR has published BLS CoSTRs in 5-year cycles (2005,[4,5] 2010,[6,7] 2015[1,2]). However, ILCOR has now moved to a continuous evidence evaluation process.[8] Part of this new approach requires the ILCOR Task Forces to determine whether a sufficient body of evidence has emerged to justify re-visiting a previous CoSTR or whether the previous recommendations may still be considered valid. In November 2018, at the ILCOR meeting in Chicago, the BLS Task Force decided to reactivate the PICOs related to CC rate, CC depth, and chest wall recoil, acknowledging that further work was required to understand whether there was new science published to date that provided more information on these CC components as discrete entities or whether studies have reported interactions between these CC components. Therefore, a scoping review was undertaken with the following aims: i) to understand whether the science to date has focused on single CC components or interactions between CC components and ii) to identify the evidence related to the CC components to determine whether the body of evidence published since the 2015 BLS CoSTR[1,2] indicates the need for a full systematic review of the evidence related to CC components.

The purpose of scoping reviews is to identify the available evidence related to a specific topic.[9] The major difference between scoping reviews and systematic reviews is that scoping reviews have a broader inclusion criteria whereas traditional systematic reviews address a narrow, clearly defined question.[9] In addition, the primary outcome of a scoping review is the volume of literature, types of studies conducted, and the outcomes examined, to date rather than pre-defined clinical outcomes that are typically examined in a systematic review. In this scoping review, we present the types of studies of CC components conducted and the outcomes examined understand to address the first aim, and data related to clinical outcomes are presented to address the second aim.

METHODS

This scoping review was guided by the methodological framework developed by Arksey and O'Malley,[10] which comprises the following elements: identify the research question; search for relevant studies; select studies; chart the data; collate, summarise, and report the results according to the Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for scoping reviews (PRISMA-ScR).[11] In scoping reviews, formal quality assessment is not usually performed and study findings are presented in a tabular format with accompanying narrative.[12]

Search strategy and inclusion criteria

The search strategy was the same as that used for the 2015 ILCOR BLS CoSTR systematic reviews on CC rate, CC depth, and chest wall recoil.[1,2] In addition, chest wall leaning was also considered as a separate measurement from chest wall recoil. The full search strategy is available in Appendix 1. Studies were considered eligible for inclusion if they were peer-reviewed human studies that prospectively or retrospectively compared the effects of interventions listed below on physiological (e.g., blood pressure and end-tidal PCO_2) or clinical outcomes (e.g., return of spontaneous circulation (ROSC) and survival to a defined time point):

- two or more CC depths measured in millimetres, centimetres, or inches OR
- two or more CC rates measured in compressions per minute OR
- two or more measures of chest wall recoil OR
- two or more measures of leaning or leaning versus no leaning.

Full chest wall recoil is defined as the sternum returning to a neutral position during the decompression phase of CPR.[13] Chest wall leaning is when the rescuer fails to completely release pressure on the chest wall between compressions, preventing full chest wall recoil.[13] Unpublished studies or studies published in abstract form only, manikin studies, animal studies, and studies that did not specifically address the PICO questions related to CC rate, CC depth, chest wall recoil, and leaning were excluded.

Data sources

The following databases were searched: MEDLINE complete, Embase, and Cochrane. The searches that informed the 2015 BLS CoSTR[1,2] were conducted on the following dates: CC rate 9 December 2013; CC depth 11 November 2013 and chest wall recoil 14 April 2014. This subsequent search was date limited from 1 November 2013 to 20 June 2019 to identify studies published since the 2015 ILCOR BLS CoSTR.[1,2]

Study selection

The results of this most recent search and all of the 20 studies included in the 2015 ILCOR BLS CoSTR[1,2] (CC rate n=5, CC depth n=10, and chest wall recoil n=5) were downloaded into Microsoft Excel (2016), duplicates were identified and removed. Two authors (JC and RJG) independently screened titles and abstracts of studies against the selection criteria. Full text articles from the 2019 search and 2015 ILCOR BLS CoSTR[1,2] assessed as potentially eligible for inclusion in this review were independently screened against the inclusion criteria (JC and RJG). Disagreements were resolved by discussion and consensus. The inclusion / exclusion criteria used in this scoping review were different to those used in the 2015 CoSTR: the 2015 CoSTR included animal studies and in the 2015 CoSTR CC components were treated as separate entities and there was no requirement in the that two or more CC rates, depths, measures of recoil or leaning be compared.

Data extraction and charting

Data were extracted by a single author (JC) and ratified by co-authors (CN, TMO, RJG, SPC). For each CC component (CC rate, CC depth, chest wall recoil and chest wall lean), the characteristics of each study were extracted including: the author(s); year of publication; study design; country; population; intervention and comparator; major findings; and outcome(s) examined.

RESULTS

After removal of duplicates, our search returned 2,830 publications. Two 2015 ILCOR BLS CoSTR[1,2] studies were excluded during title and abstract screening because they were animal studies. In total, 53 full text publications were screened for eligibility: 35 studies from the 2019 search and 18 studies from the 2015 ILCOR BLS CoSTR.[1,2] Following screening of the 53 full-text publications, 31 were excluded because they were abstract only publications (n=15), did not meet the inclusion criteria (n=10), were studies of patients not in cardiac arrest (n=2), used surrogate outcomes (n=2) or were letters (n=2). Twenty-two studies were included in the final review (Figure 1). Eight were new studies identified by the 2019 search and fourteen were studies from the 2015 ILCOR BLS CoSTR.[1,2] The six studies from the 2015 ILCOR BLS CoSTR[1,2] excluded from this review were two animal studies[15,16] and four studies[17-20] that did not compare two or more CC components.

Study characteristics

The characteristics of the included studies are summarised in Appendix 2. Five observational studies involving 879 patients (489 adults and 390 children) examined both CC rate and CC depth.[21-25] Eight studies involving 14,285 patients (14,121 adults and 164 children) examined CC rate only: six observational studies,[26-31] one crossover trial,[32] and one randomised controlled trial (RCT).[33] Seven studies involving 12,010 patients (11,228 adults, 695 age unknown, and 78 children) examined CC depth only: six observational studies[34-39] and one randomised study.[40] Two studies involving 1848 adult patients examined chest wall recoil[41,42] and no studies were identified that examined different measures of leaning. In this scoping review, preference was given to non-imputed data over imputed data.

Chest compression rate

There were thirteen studies involving 15,164 patients (14,610 adults and 554 children) that reported outcomes associated with CC rate: a summary of outcomes is presented in Table 1 and detailed evidence summary tables are in Appendix 3. Eleven were observational studies,[21-31] there was one crossover trial[32] and one RCT.[33] The outcomes examined were survival with favourable neurological function (one RCT[33] and three observational studies[25-27]); survival to hospital discharge (five observational studies[26-29,33]); 1-month survival (one RCT[33] and one observational study[25]); 24-h survival (two observational studies[22,25]); survival to hospital admission (two observational studies[24,25]); ROSC (one RCT[33] and seven observational studies[22,25-30]); blood pressure (three observational studies[21,26,31]); end-tidal PCO_2 (one RCT[33] and two observational studies[31,32]); and shock success (one observational study[23]).

There was absence of a consistent association between CC rate and survival with favourable neurological outcome, which varied depending on the study population (children versus adult), study size, and whether adjusted for potential confounders. One study reported that CC rate of <100/min was associated with increased survival with favourable neurological outcome in children compared to a CC rate of 100-120/min.[26] Studies in adults were not definitive for an association between CC rate alone and favourable neurological survival.[25,27,33] Of the five studies that examined survival to discharge, one study reported that when adjusted for confounders including CC depth and CC fraction, survival to hospital discharge was lower at CC rates of 80-99/min and 120-139/minute compared to a rate of 100-119/minute.[28] None of the other studies reported a survival to hospital discharge benefit associated with specific CC rates.[22,26,29,33] There were no significant differences reported between various CC rates on 1-month survival,[25,33] 1-day survival,[22,25] or admission to hospital alive.[24,25] Of the eight studies that reported on ROSC, one study reported that compared to a reference CC rate of 100-120/minute, a CC rate of 121-140/minute was associated with increased ROSC[27] and one study reported that higher mean CC rates were associated with increased likelihood of ROSC.[30] None of the other studies reported a significant difference between various CC rates and ROSC.[22,25,26,28,29,33]

Of the three studies that reported on blood pressure, one study reported CC rates in combination with depth so the specific effect of CC rate on systolic blood pressure (SPB) and diastolic blood pressure (DBP) was unable to be ascertained.[21] One study reported that, compared with a reference CC rate of 100-120/minute, a CC rate of 120-140/minute was associated with decreased SBP in children.[26] None of the other CC rates examined had a significant effect on either SBP or DBP.[21,31] Of the three studies that reported end-tidal PCO_2, one reported that compared to a CC rate of 80/minute, a CC rate of 120/minute was associated with an increased mean end-tidal CO_2.[32] The other two studies failed to show a significant association between various CC rates and changes in end-tidal CO_2.[31,33] One study reported that CC rates were not significantly associated with shock success.[23]

Chest compression depth

There were twelve studies involving 12,664 patients (11,729 adults, 240 children, and 695 with age not available) that reported data related to CC depth: a summary of outcomes is presented in Table 2 and detailed evidence summary tables are in Appendix 4. Eleven were observational studies,[21-25,34,36-39,43] and one was a prospective randomised study.[40] The outcomes examined were survival with favourable neurological function (three observational studies[25,35,36]); survival to hospital discharge (four observational studies[34-36,38]); 1-month survival (one observational study[25]); 24-h survival (four observational studies[25,34,35,38]); survival to the Emergency Department (ED) (one randomised study[40]); survival to hospital admission (two observational studies[24,25]); ROSC (six observational studies [22,25,34,35,38,39]); blood pressure (one observational study[21]); shock success (two observational studies[23,39]); and injury frequency (one observational study[37]).

Specific CC depths (<38 mm versus 38.0-50.9 mm or ≥51.0 mm in adults;[36] mean (SD) CC depth of 38.8 (11.5) mm versus 48.0 (9.2) mm in adults;[25] or <51mm versus ≥51.0 mm in children[35]) were not significantly associated with survival with favourable neurological outcome.[25,35,36] However, one adult study reported that each 5 mm increase in mean CC depth was associated with increased survival with favourable neurological outcome.[36] Of the four studies that examined survival to hospital discharge, one adult study reported that, compared to a CC depth of >51mm and adjusted for confounders, survival to hospital discharge decreased when CC depth was <38 mm [34] Two adult studies reported that for each 5 mm increase in CC depth, survival to hospital discharge increased[34,36]. None of the other studies reported an association between survival to hospital discharge[35,38] or 1-month survival[25] and specific CC depths.

Four studies reported on 1-day survival: three reported statistically significant relationships between 1-day survival and CC depth in adults[34,38] and children[35] and one reported no association between mean CC depths and 1-day survival in adults.[25] In adults, for each 5 mm increase in CC depth, 1-day survival increased.[34] When adjusted for confounders and compared to CC depth of <38mm, a CC depth of 38-51mm increased 1-day survival.[38] Compared to CC depth of >51mm, a CC depth <38mm decreased 1-day survival.[34] In children, if ≥60% of CCs had an average depth of ≥51mm (compared with <60% of average CC depth ≥51mm), 24-h survival increased.[35] The study that reported survival to the ED showed that mean CC depths of 5-6cm had the highest survival to ED rates in adults but no p-values were reported.[40]

In adults, one study showed that increased CC depth was associated with increased odds of admission to hospital alive[24] with adjusted analyses showing that with each 1mm increase in average CC compression depth, there was a significant increase in the odds of admission alive to hospital.[24] The other adult study showed no association between different mean CC depths and survival to hospital admission.[25] Of the six studies that reported on ROSC, in children, adjusted analyses showed that if ≥60% of CCs had an average depth of ≥51mm compared with <60% of average CC depth ≥51mm), ROSC increased.[35] In one study of adults, when shocks were delivered after five minutes of CC, a CC depth > 5 cm compared with CC depth < 5 cm was associated with higher transient ROSC.[39] None of the other studies reported a statistically significant relationship between ROSC and different CC depths.[22,25,34,38]

The study examining the effect on blood pressure, reported CC depths in combination with CC rates so the specific association of CC rate with SPB and DBP could not be ascertained.[21] One study reported on shock success and suggested that deeper CC were associated with greater likelihood of shock success: the mean (SD) CC depths were 39(11)mm for successful shocks and 29(10)mm for unsuccessful shocks (p=0.004)[23] One study reported on injury frequency and showed that increased CC depths were associated with higher injury rates (p=0.06) and the mean (SD) CC depth of patients with injuries was 56 (11) mm versus 52 (8) mm in patients with no injuries (p=0.04).[37]

Chest wall recoil

There were two studies involving 1,848 adults that reported data related to chest wall recoil, specifically on CC release velocity (CCRV): both were observational studies.[41,42] A summary of outcomes is presented in Table 3 and detailed evidence summary tables are in Appendix 5. The outcomes examined were survival with favourable neurological function (two observational studies[41,42]); survival to hospital discharge (two observational studies[41,42]); and ROSC (one observational study[41]). The two studies reporting survival with favourable neurological outcome had conflicting results. One study reported that different CCRVs made no difference to survival with favourable neurological outcome.[41] The other study reported that, compared to slow (<300mm/s) CCRV, fast CCRV (≥400 mm/s) was associated with increased survival with favourable neurological outcome but there was no association between moderate CCRV (300–399.9 mm/s) and survival with favourable neurological outcome.[42] Two studies reported on survival to hospital discharge, again with conflicting results. One study reported that, compared to slow CCRV (<300mm/s), fast CCRV (≥400 mm/s) was associated with increased survival to hospital discharge, but again there was no association between moderate CCRV (300–399.9 mm/s) survival to hospital discharge.[42] The other study reported that once adjusted for confounders, there was no difference in survival to hospital discharge associated with different CCRVs.[41] The one study reporting on ROSC showed no statistically significant improvement associated with a 10mm/sec increase in CCRV.[41]

Interactions between CPR parameters

Five studies involving 8,400 patients (8,313 adults and 78 children) reported on relationships between CPR parameters: four observational studies[28,35,36,38] and one RCT[33]. A summary of outcomes is presented in Table 4 and detailed evidence summary tables are in Appendix 6. All studies reported on the association between CC rate and CC depth: three studies reported a significant decrease in CC depth as CC rate increased (p<0.001),[28,36,38] one adult study reported no difference in CC depth with CC rates of 100/minute and 120/minute,[33] and the study in children reported no significant relationship between CC rate and CC depth.[35] One study reported a significant decrease in mean (SD) CC fraction when CC rate was increased from 100/minute to 120/minute [95.9% (3.1%) vs 94.3% (5.1%), p=0.008].[33] One study reported that CC depths of <51mm versus ≥51mm was not associated with the percentage of CC with significant leaning (>2.5 kg) in children [12% vs 8%, p=0.09].[35]

DISCUSSION

This scoping review identified 22 studies related to various CC components, eighteen of which were observational studies.[21-31,34-39,41,42] There was variation in the outcomes examined and overall the most frequently reported outcomes were ROSC (n=13),[22,25-30,33-35,38,39,41] survival to hospital discharge (n=12),[22,26-29,33-36,38,41,42] and survival to hospital discharge with good neurological outcome (n=8).[25-27,33,35,36,41,42] All but three studies[22,26,35] were in adults, there was one study where the age of participants was not reported.[39] Seventeen of the included studies focused on out-of-hospital cardiac arrest[21-24,27-

[29,31,34,36,38,39,41,42] including one study of patients with out-of-hospital cardiac arrest requiring CPR in the ED.[25]

The 2015 ILCOR BLS CoSTR[1,2] treatment recommendations for chest compressions are to: i) *recommend* a chest compression depth of approximately 5cm (2 inches) (strong recommendation, low-quality evidence) while avoiding excessive chest compression depths greater than 6cm (2.4 inches) in an average adult (weak recommendation, low-quality evidence) during manual CPR; ii) *recommend* a manual chest compression rate of 100–120/min (strong recommendation, very-low-quality evidence); and iii) *suggest* that rescuers performing manual CPR avoid leaning on the chest between compressions to allow full chest wall recoil (weak recommendation, very-low-quality evidence). This scoping review identified 8 new studies since publication of the 2015 ILCOR BLS CoSTR.[1,2] However, none of the new studies identified reported sufficient new evidence that would prompt performing new full systematic reviews or reconsideration of treatment recommendations related to CC components.

The studies included in this review were published between 1988 and 2018, during which time there have been a number of changes to international resuscitation guidelines and specifically recommendations related to CCs.[1,2,4-7] In 2000, rescuers were instructed to provide 2 to 5 rescue breaths and perform CC at a rate of 100/min, depth of 4-5cm allowing complete recoil after each compression, and a compression:ventilation ratio of 15:2 in adults.[44,45] In children, rescuers were instructed to provide two rescue breaths and perform CC at a rate 100/min, depth of 1.5-2.5cm in infants, 10-1.5 inches in small children and 1.5-2.0 inches in larger children allowing complete recoil after each compression and a compression:ventilation ratio of 5:1.[46,47] In 2005, rescuers were instructed to provide two rescue breaths and then perform CC at a rate of 100/minute and at a depth of *at least* 4-5cm, allowing complete recoil of the chest after each compression.[4,5] For the first time, a universal compression:ventilation ratio of 30:2 was recommended for all patients in 2005, with the caveat that healthcare professionals providing two-rescuer CPR in infants or children should use a compression:ventilation ratio of 15:2.[4,5] In 2010, rescuers were instructed to commence CPR with chest compressions (at a rate of *at least* 100/minute, to a depth of *at least* 5cm, and with a compression:ventilation ratio of 30:2) in patients who were unresponsive and not breathing normally.[6,7] In 2015, the recommendations regarding CC rate changed from 100/minute[6,7] to 100-120/minute[1,2] and the recommendations regarding CC depth were changed from *at least* 5cm[6,7] to approximately 5cm whilst avoiding CC depths greater than 6cm.[1,2] The dynamic nature of resuscitation guidelines makes the use of historical data and interpretation of results from studies that used now obsolete CPR parameters from older guidelines problematic.

Studies evaluating associations between CC components and patient outcomes presented conflicting results. Of the thirteen studies that focused on CC rate, only four[26-28,30] reported significant associations between CC rate and patient outcomes. One of the three studies that focused on survival with favourable neurological outcome reported that slower CC rates (<80-100/minute) improved this outcome in children.[26] The largest of the five studies that examined survival to discharge, reported that CC rates of 80-99/minute or 120-139/minute were associated with decreased survival to hospital discharge in adults compared to a reference rate of 100-120/minute,[28] supporting the 2015 ILCOR BLS CoSTR.[1,2] Two of the eight studies that focused on ROSC reported that higher CC rates were associated with increased likelihood of ROSC.[27,30] Of the twelve studies that focused on CC depth, again, only four[24,34,35,38] reported significant relationships between CC depth and patient outcomes and the findings were concordant with the 2015 ILCOR BLS CoSTR.[1,2]

The largest of the four studies focused on survival to hospital discharge reported decreased survival with shallow CCs (<38mm) compared to >51mm and a positive association between increasing CC depth and survival to hospital discharge in adults.[34] Three of four studies that focused on 1-day survival, reported statistically significant associations between 1-day survival and increasing CC depth.[34,35,38] One of the two studies that focused on admission to hospital alive also reported an increased odds of survival associated with increased CC depth in adults.[24] Of interest was that both studies that focused on shock success reported increased shock success associated with deeper CC in adults.[23,39] There were only two studies of chest wall recoil: both were in adults with OOHCA, highlighting an area for future research. The results related to favourable neurological outcome[41,42] and survival to hospital discharge[41,42] were conflicting. The one study reporting on ROSC showed no significant effect associated with CCRV.[41] Of the five studies that reported on the interaction between CC rate and CC depth, three reported an inverse association: as CC rate increases, CC depth decreases.[28,36,38] This finding calls into question the value of appraising the evidence associated with each component of CC in isolation.

Strengths and limitations

This review is the first to identify and map the available evidence related to CC rate, CC depth, and chest wall recoil and report on potential interactions between these CC parameters. The strengths of this review are the systematic search technique, precise inclusion and exclusion criteria, and comprehensive data extraction. The limitations of this review are that we only accessed publications in English. As this was a scoping review rather than a systematic review, risk of bias and quality assessments of the included studies were not performed.[12]

There is also a lack of high-level evidence as the research to date has been dominated by observational studies, many of which were single site cohort studies with modest sample sizes. The larger observational studies to date have used epidemiologic registry data which, although collected prospectively, may have limitations in describing associations, rather than definitive relationships that can only be established by controlled randomised trials. The majority of the studies identified in this review were focused on out-of-hospital cardiac arrest highlighting a major gap in research in the in-hospital context.

CONCLUSIONS

This scoping review demonstrated that the majority of studies focused on a single CC component, whereas a number of studies suggest the presence of confounding interactions that prompt caution when evaluating any CC component in isolation. Although this scoping review has not identified sufficient new evidence to prompt new systematic reviews or reconsideration of current resuscitation guidelines, it highlights significant gaps in the research evidence related to CC components, namely a lack of high-level evidence, paucity of studies of in-hospital cardiac arrest, and failure to account for the possibility of conflicting interactions between chest compression components. Future studies should take into account the possibility of interactions between CC components, specifically CC rate and depth as recommendations about one component have the potential to compromise another.

ILCOR statement

This review includes information on resuscitation questions developed through the continuous evidence evaluation process, managed by the ILCOR.[48] The questions were developed by ILCOR Task Forces, using strict conflict of interest guidelines. In general, each question was assigned to two experts to complete a detailed structured review of the literature, and complete a detailed evidence evaluation. Evidence evaluations are discussed at ILCOR meetings to reach consensus and will be published on the ILCOR CoSTR website.[48] The conclusions published in the ILCOR CoSTR consensus document may differ from the conclusions of this review because the CoSTR consensus will reflect input from other evidence evaluation review authors and discussants and will take into consideration implementation and feasibility issues as well as new relevant research.

Acknowledgements

The authors wish to acknowledge the contribution of members of the International Liaison Committee on Resuscitation Basic Life Support Task Force to this scoping review.

REFERENCES

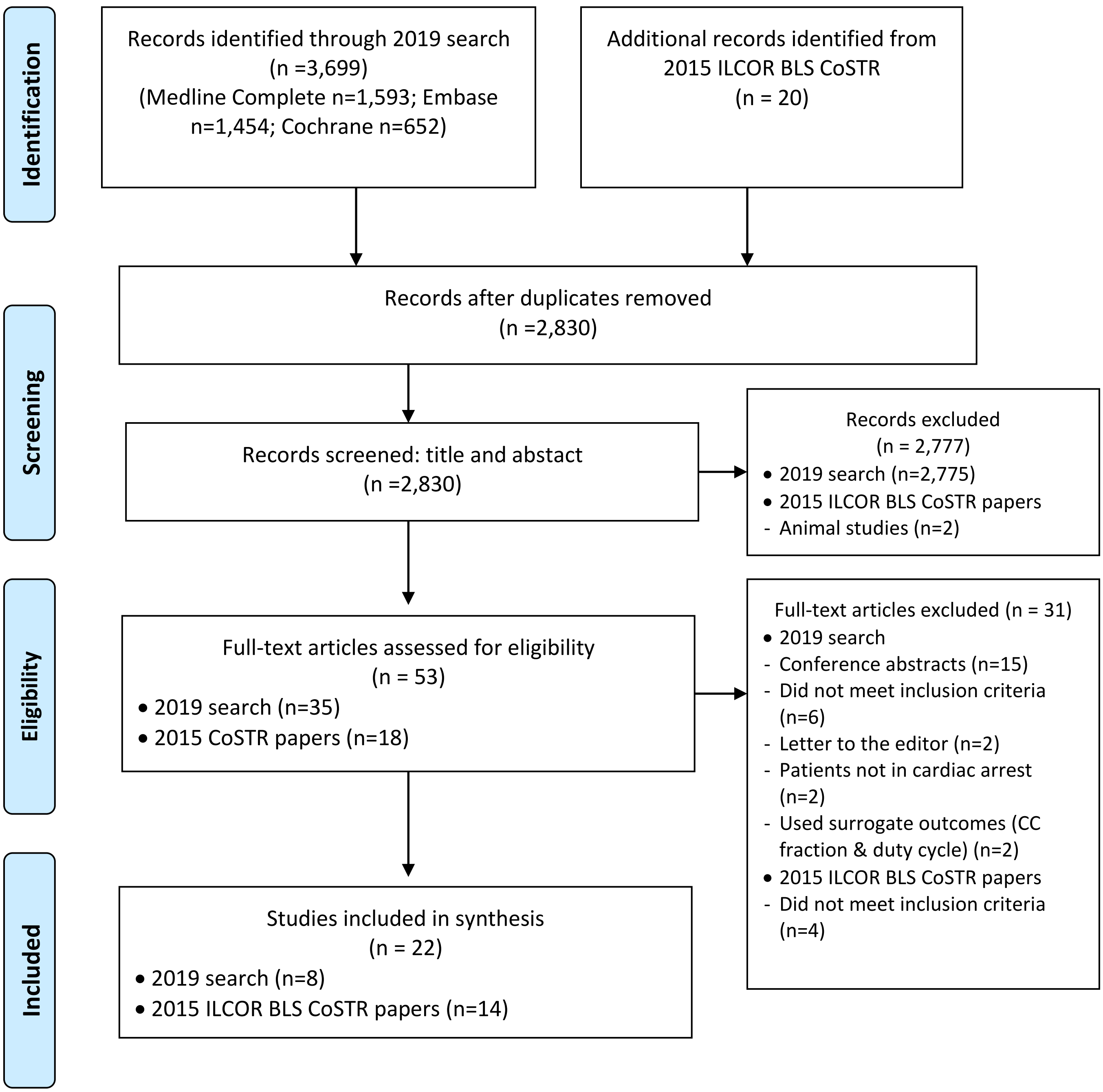
1. Perkins GD, Travers AH, Berg RA, et al. Part 3: Adult basic life support and automated external defibrillation. 2015 International Consensus on Cardiopulmonary Resuscitation and Emergency Cardiovascular Care Science With Treatment Recommendations. Resuscitation 2015;95:e43-e69.
2. Travers AH, Perkins GD, Berg RA, et al. Part 3: Adult Basic Life Support and Automated External Defibrillation 2015 International Consensus on Cardiopulmonary Resuscitation and Emergency Cardiovascular Care Science With Treatment Recommendations. Circulation 2015;132:S51-S83.
3. Schünemann H, Brożek J, Guyatt G, Oxman A, eds. *Handbook for grading the quality of evidence and the strength of recommendations using the GRADE approach.* Retrieved 16 June 2019 from https://gdt.gradepro.org/app/handbook/handbook.html; 2013.
4. International Liaison Committee on Resuscitation. Part 2. Adult basic life support. 2005 international consensus on cardiopulmonary resuscitation and emergency cardiovascular care science with treatment recommendations. Resuscitation 2005;67:187-200.
5. International Liaison Committee on Resuscitation, American Heart Association, European Resuscitation Council. Part 2: Adult Basic Life Support. Circulation 2005;112:III-5-III-16.
6. Koster RW, Sayre MR, Botha M, et al. Part 5: Adult basic life support: 2010 International consensus on cardiopulmonary resuscitation and emergency cardiovascular care science with treatment recommendations. Resuscitation 2010;81:e48-e70.
7. Sayre MR, Koster RW, Botha M, et al. Part 5: adult basic life support: 2010 international consensus on cardiopulmonary resuscitation and emergency cardiovascular care science with treatment recommendations. Circulation 2010;122:S298-S324.
8. Morley PT. Towards a more continuous evidence evaluation: A collaborative approach to review the resuscitation science. Resuscitation 2017;118:A1-A2.
9. Munn Z, Peters MDJ, Stern C, Tufanaru C, McArthur A, Aromataris E. Systematic review or scoping review? Guidance for authors when choosing between a systematic or scoping review approach. BMC Med Res Methodol 2018;18:143.
10. Arksey H, O'Malley L. Scoping studies: towards a methodological framework. Int J Soc Res Methodol 2005;8:19-32.
11. Tricco AC, Lillie E, Zarin W, et al. PRISMA extension for scoping reviews (PRISMA-ScR): Checklist and explanation. Ann Intern Med 2018;169:467-473.
12. Grant MJ, Booth A. A typology of reviews: an analysis of 14 review types and associated methodologies. Health Info Libr J 2009;26:91-108.
13. Kleinman ME, Brennan EE, Goldberger ZD, et al. Part 5: Adult Basic Life Support and Cardiopulmonary Resuscitation Quality. 2015;132:S414-S435.

14. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. Ann Int Med 2009;151:264-269.
15. Yannopoulos D, McKnite S, Aufderheide TP, et al. Effects of incomplete chest wall decompression during cardiopulmonary resuscitation on coronary and cerebral perfusion pressures in a porcine model of cardiac arrest. 2005;64:363-372.
16. Zuercher M, Hilwig RW, Ranger-Moore J, et al. Leaning during chest compressions impairs cardiac output and left ventricular myocardial blood flow in piglet cardiac arrest. 2010;38:1141.
17. Hostler D, Everson-Stewart S, Rea TD, et al. Effect of real-time feedback during cardiopulmonary resuscitation outside hospital: prospective, cluster-randomised trial. 2011;342:d512.
18. Fried DA, Leary M, Smith DA, et al. The prevalence of chest compression leaning during in-hospital cardiopulmonary resuscitation. Resuscitation 2011;82:1019-1024.
19. Niles D, Nysaether J, Sutton R, et al. Leaning is common during in-hospital pediatric CPR, and decreased with automated corrective feedback. 2009;80:553-557.
20. Edelson DP, Litzinger B, Arora V, et al. Improving In-Hospital Cardiac Arrest Process and Outcomes With Performance Debriefing. 2008;168:1063-1069.
21. Sainio M, Hoppu S, Huhtala H, Eilevstjønn J, Olkkola KT, Tenhunen J. Simultaneous beat-to-beat assessment of arterial blood pressure and quality of cardiopulmonary resuscitation in out-of-hospital and in-hospital settings. Resuscitation 2015;96:163-169.
22. Sutton RM, Case E, Brown SP, et al. A quantitative analysis of out-of-hospital pediatric and adolescent resuscitation quality--A report from the ROC epistry-cardiac arrest. Resuscitation 2015;93:150-157.
23. Edelson DP, Abella BS, Kramer-Johansen J, et al. Effects of compression depth and pre-shock pauses predict defibrillation failure during cardiac arrest. Resuscitation 2006;71:137-145.
24. Kramer-Johansen J, Myklebust H, Wik L, et al. Quality of out-of-hospital cardiopulmonary resuscitation with real time automated feedback: A prospective interventional study. Resuscitation 2006;71:283-292.
25. Riyapan S, Naulnark T, Ruangsomboon O, et al. Improving quality of chest compression in thai emergency department by using real-time audio-visual feedback cardio-pulmonary resuscitation monitoring. 2019;102:245-251.
26. Sutton RM, Reeder RW, Landis W, et al. Chest compression rates and pediatric in-hospital cardiac arrest survival outcomes. Resuscitation 2018;130:159-166.
27. Kilgannon JH, Kirchhoff M, Pierce L, Aunchman N, Trzeciak S, Roberts BW. Association between chest compression rates and clinical outcomes following in-hospital cardiac arrest at an academic tertiary hospital. Resuscitation 2017;110:154-161.

28. Idris AH, Guffey D, Pepe PP, et al. Chest Compression Rates and Survival Following Out-of-Hospital Cardiac Arrest. Crit Care Med 2015;43:840-848.
29. Idris AH, Guffey D, Aufderheide TP, et al. The relationship between chest compression rates and outcomes from cardiac arrest. Circulation 2012;125:3004-3012.
30. Abella BS, Sandbo N, Vassilatos P, et al. Chest Compression Rates During Cardiopulmonary Resuscitation Are Suboptimal A Prospective Study During In-Hospital Cardiac Arrest. Circulation 2005;111:428-434.
31. Ornato JP, Gonzalez ER, Garnett AR, Levine RL, McClung BK. Effect of cardiopulmonary resuscitation compression rate on end-tidal carbon dioxide concentration and arterial pressure in man. Crit Care Med 1988;16:241-245.
32. Kern KB, Sanders AB, Raife J, Milander MM, Otto CW, Ewy GA. A Study of Chest Compression Rates During Cardiopulmonary Resuscitation in Humans: The Importance of Rate-Directed Chest Compressions. Arch Int Med 1992;152:145-149.
33. Hwang SO, Cha K-C, Kim K, et al. A Randomized Controlled Trial of Compression Rates during Cardiopulmonary Resuscitation. J Korean Med Sci 2016;31:1491-1498.
34. Stiell IG, Brown SP, Nichol G, et al. What is the optimal chest compression depth during out-of-hospital cardiac arrest resuscitation of adult patients? 2014;130:1962-1970.
35. Sutton RM, French B, Niles DE, et al. 2010 American Heart Association recommended compression depths during pediatric in-hospital resuscitations are associated with survival. Resuscitation 2014;85:1179-1184.
36. Vadeboncoeur T, Stolz U, Panchal A, et al. Chest compression depth and survival in out-of-hospital cardiac arrest. Resuscitation 2014;85:182-188.
37. Hellevuo H, Sainio M, Nevalainen R, et al. Deeper chest compression – More complications for cardiac arrest patients? Resuscitation 2013;84:760-765.
38. Stiell IG, Brown SP, Christenson J, et al. What is the role of chest compression depth during out-of-hospital cardiac arrest resuscitation? Crit Care Med 2012;40:1192-1198.
39. Babbs CF, Kemeny AE, Quan W, Freeman G. A new paradigm for human resuscitation research using intelligent devices. Resuscitation 2008;77:306-315.
40. Bohn A, Weber TP, Wecker S, et al. The addition of voice prompts to audiovisual feedback and debriefing does not modify CPR quality or outcomes in out of hospital cardiac arrest – A prospective, randomized trial. Resuscitation 2011;82:257-262.
41. Cheskes S, Common MR, Byers AP, Zhan C, Silver A, Morrison LJ. The association between chest compression release velocity and outcomes from out-of-hospital cardiac arrest. Resuscitation 2015;86:38-43.

42. Kovacs A, Vadeboncoeur TF, Stolz U, et al. Chest compression release velocity: Association with survival and favorable neurologic outcome after out-of-hospital cardiac arrest. Resuscitation 2015;92:107-114.
43. Sutton RM, Niles D, French B, et al. First quantitative analysis of cardiopulmonary resuscitation quality during in-hospital cardiac arrests of young children. Resuscitation 2014;85:70-74.
44. European Resuscitation Council. Part 3: Adult Basic Life Support. Resuscitation 2000;46:29-71.
45. American Heart Association. Part 3: Adult Basic Life Support. Circulation 2000;102:I22-I59.
46. American Heart Association. Part 9: Pediatric Basic Life Support. Circulation 2000;102:I253-I290.
47. European Resuscitation Council. Part 9: Pediatric Basic Life Support. Resuscitation 2000;46:301-341.
48. International Liaison Committee on Resuscitation (ILCOR). www.ilcor.org. Accessed 20 June, 2019.

CHEST COMPRESSION COMPONENTS
PRISMA Flow Diagram



From: Moher D, Liberati A, Tetzlaff J, Altman DG, The PRISMA Group (2009). *P*referred *R*eporting *I*tems for *S*ystematic Reviews and *M*eta-*A*nalyses: The PRISMA Statement. PLoS Med 6(7): e1000097. doi:10.1371/journal.pmed1000097

For more information, visit www.prisma-statement.org.

Table 1: Outcomes of studies of chest compression rate (n=13)

Survival with favourable neurological function (n=4); survival to hospital discharge (n=5); 1 month survival (n=2); 24-h survival (n=2); survival to hospital admission(n=2); ROSC (n=8) ; blood pressure (n=3); $ETCO_2$ (n=3); and shock success (n=1)

Studies	Summary of findings
SURVIVAL WITH FAVOURABLE NEUROLOGICAL FUNCTION	
1 randomised controlled trial: 292 adults with OOHCA[26] 3 observational studies: 164 children with IHCA,[19] 222 adults with IHCA,[19,20] and 32 adults with OOHCA & >2 minutes CPR in ED[18]	In adults with OOHCA • compared to CC rate of 120/min, a CC rate of 100/min made no difference to CPC≤2 at 1-month following OOHCA[26] • compared to a mean (SD) CC rate of 139.3 (8.9)/min, a mean (SD) CC rate of 117.2 (7.4) /min made no difference to CPC 1-2 at 30-days[18] In adults with IHCA • compared to CC rate of 100-120/min, CC rates of 121-140/min or >140/min made no difference to survival with favourable neurological outcome (CPC<3) or preservation of neurological status at hospital discharge following IHCA[20] • sensitivity analysis showed that none of the CC rates tested (121-130/min; 130-140/min; 140-150/min; or >150/min) made a difference to survival with favourable neurological outcome following IHCA[20] In children, compared to CC rate of 100-120/min • a CC rate <100/min was associated with increased survival with favourable neurological outcome following IHCA* [aRR=2.12, 95%CI: 1.09-4.13, p=0.027][19] • CC rates of 120-140/min or >140/min made no difference to survival with favourable neurological outcome following IHCA (PCPC 1-3 or no worsening) [19]
SURVIVAL TO HOSPITAL DISCHARGE	
5 observational studies: 164 children with IHCA,[19] 390 children with OOHCA,[15] and 13,761 adults with OOHCA,[21,22,26]	In adults with OOHCA, • adjusted analyses showed that compared to a CC rate of 100-119/min, CC rates of 80-99/min [aOR=0.73, 95%CI:0.57-0.93, p=0.011] or 120-139/min [aOR=0.63, 95%CI: 0.45-0.88, p=0.007] decreased survival to hospital discharge[21] and a CC rate <80/min or >140/min made no difference to survival to hospital discharge.[21] Unadjusted analyses from the same study showed that compared to CC rate of 100-119/min, CC rates of 80-99/min [OR=0.80, 95%CI 0.68-0.96, p=0.013]; 120-139/min [OR=0.83, 95%CI 0.70-1.0, p=0.044] or >140/min [OR=0.58, 95%CI 0.42-0.81, p=0.004] decreased survival to hospital discharge[21] • adjusted analyses showed that compared with a CC rate of 80-140/min, CC rates of 0-80/min or >140/min made no difference to survival to hospital discharge.[22] Unadjusted analyses from the same study showed that compared to CC rate of 80-140/min, a CC rate of >140min [OR=0.51, 95%CI: 0.27-0.98, p=0.04] decreased survival to hospital discharge[22] • compared to a CC rate of 120/min, a CC rate of 100/min was made no difference to survival to hospital discharge[26] In children, • compared to a CC rate of 100-120/min, CC rates of <100/min; 120-140/min; or >140/min made no difference to survival to hospital discharge following IHCA[19] • compared to a CC rate of 100-120/min, CC rates of <100/min or >120/min made no difference to survival to hospital discharge following OOHCA[15]
1 MONTH SURVIVAL	
1 randomised controlled trial: 292 adults with OOHCA[26] 1 observational study: 32 adults with OOHCA & >2 minutes CPR in ED[18]	In adults with OOHCA, • compared to CC rate of 120/min, a CC rate of 100/min made no difference to survival at 1 month[26] • compared to a mean (SD) CC rate of 139.3 (8.9)/min, a mean (SD) CC rate of 117.2 (7.4) /min made no difference to 30-day survival[18]

Table 1: Outcomes of studies of chest compression rate (n=13)

Survival with favourable neurological function (n=4); survival to hospital discharge (n=5); 1 month survival (n=2); 24-h survival (n=2); survival to hospital admission(n=2); ROSC (n=8) ; blood pressure (n=3); $ETCO_2$ (n=3); and shock success (n=1)

Studies	Summary of findings
1-DAY (24-h) SURVIVAL	
1 observational study: 390 children with OOHCA[15] and 32 adults with OOHCA & >2 minutes CPR in ED[18]	In adults with OOHCA, • compared to CC rate of 100-120/min, CC rates of <100/min or >120/min made no difference to survival at 24 hours[15] • compared to a mean (SD) CC rate of 139.3 (8.9)/min, a mean (SD) CC rate of 117.2 (7.4) /min made no difference to survival to hospital admission[18]
SURVIVAL TO HOSPITAL ADMISSION	
2 observational study:358 adults with OOHCA[17] and 32 adults with OOHCA & >2 minutes CPR in ED[18]	In adults with OOHCA, • compared to a CC rate of 90-120/min, CC rates of <90/min or >120/min made no difference to survival to hospital admission[17] • compared to a mean (SD) CC rate of 139.3 (8.9)/min, a mean (SD) CC rate of 117.2 (7.4) /min made no difference to survival to hospital admission[18]
RETURN OF SPONTANEOUS CIRCULATION	
1 randomised controlled trial: 292 adults with OOHCA[26] 7 observational studies: 164 children with IHCA,[19] 390 children with OOHCA,[15] 319 adults with IHCA,[20,23] 13,469 adults with OOHCA[21,22] and 32 adults with OOHCA & >2 minutes CPR in ED[18]	In adults with OOHCA, • adjusted analyses showed that compared to a CC rate of 100-119/min, CC rates of <80/min; 80-119/min; 120-139/min or >140/min made no difference to ROSC.[21] Unadjusted analyses from the same study showed that compared to CC rate of 100-119/min, a CC rate of >140/min [OR=0.72, 95%CI 0.60-0.86, p<0.001] was associated with decreased ROSC following OOHCA: CC rates <80/min; 80-100/min or 120-139/min made no difference to ROSC[21] • compared with CC rate of 120/min, a CC rate of 100/min made no difference to ROSC[26] • both adjusted and unadjusted analyses showed that compared with a CC rate of 80-140/min, CC rates of 0-80/min or >140/min made no difference to achieving ROSC[22] • compared to a mean (SD) CC rate of 139.3 (8.9)/min, a mean (SD) CC rate of 117.2 (7.4) /min made no difference to ROSC[18] In adults with IHCA, • compared to CC rate of 100-120/min, a CC rate of 121-140/min [OR=4.48, 95%CI: 1.42-14.14, p=0.010] was associated with increased ROSC and CC rate of >140/min made no difference to achieving ROSC[20] • sensitivity analysis showed CC rates of 121-130/min [OR=5.17, 95%CI:1.38-19.45, p=0.015] or 130-140/min [OR=4.21, 95%CI: 1.28-13.84, p=0.018] were associated with increased ROSC following IHCA: CC rates of 140-150/min or >150/min made no difference to ROSC[20] • higher mean CC rates were associated with increased likelihood of ROSC [ROSC =90±17/min vs no ROSC 79±18/min, p=0.0033] [23] In children, compared to CC rate of 100-120/min • CC rates of <100/min; 120-140/min or >140/min made no difference to achieving ROSC following IHCA[19] • CC rates of <100/min or >120/min made no difference to achieving ROSC following OOHCA[15]

Table 1: Outcomes of studies of chest compression rate (n=13)

Survival with favourable neurological function (n=4); survival to hospital discharge (n=5); 1 month survival (n=2); 24-h survival (n=2); survival to hospital admission(n=2); ROSC (n=8) ; blood pressure (n=3); $ETCO_2$ (n=3); and shock success (n=1)

Studies	Summary of findings
BLOOD PRESSURE	
3 observational studies: 164 children with IHCA,[19] 57 adults with OOHCA[14,24]	In adults with OOHCA • CC rates of 60/min; 80/min; 100/min; 120/min or >140/min made no difference to SBP or DBP[24] • When SBP was measured via the femoral artery, compared to CC rate <100/min and CC depth<50mm (inadequate CPR quality), the combination of CC rate >120/min and CC depth ≥ 50 mm had the highest odds of achieving the target SBP≥85mmHg [OR=4.40, 95% CI: 3.27-5.91, p<0.001][14] • When SBP was measured via the radial artery, compared to CC rate <100/min and CC depth<50mm (inadequate CPR quality), the combination of CC rate <100/min and CC depth ≥ 50 mm had the highest odds of achieving the target SBP≥85mmHg [OR=11.19, 95% CI: 8.65-14.48, p<0.001][14] • When DBP was measured via the femoral artery, compared to CC rate <100/min and CC depth<50mm (inadequate CPR quality), the combination of CC rate <100/min and CC depth ≥ 50mm was the only combination that achieved the target DBP≥30mmHg [OR=2.06, 95% CI: 1.86-2.27, p<0.001][14] • When DBP was measured via the radial artery, compared to CC rate <100/min and CC depth<50mm (inadequate CPR quality), the combination of CC rate >120/min and CC depth ≥ 50 mm had the highest odds of achieving the target DBP≥30mmHg [OR=3.35, 95% CI: 2.62-4.28, p<0.001][14] In children with IHCA, compared to CC rate of 100-120/min • a CC rate of 120-140/min [estimate effect -4.07, 95%CI: -7.17 to -0.97, p=0.010] was associated with a decrease in SBP [19] • CC rates of 80-<100/min or >140/min made no difference to SBP or DBP[19]
$ETCO_2$	
1 randomised controlled trial: 292 adults with OOHCA[26] 2 observational studies: 23 adults with IHCA[25] and 18 adults with OOHCA[24]	In adults with OOHCA • compared to a CC rate of 120/min, a CC rate of 100/min made no difference to mean $ETCO_2$[26] • CC rates of 60/min; 80/min; 100/min; 120/min; or >140/min made no difference to mean $PetCO_2$[24] In adults with IHCA • compared with CC rate of 80/min, a CC rate of 120/min was associated with increased mean $ETCO_2$ [13.0±1.8 mmHg vs 15.0±1.8 mmHg, p<0.001] [25]
SHOCK SUCCESS	
1 observational study: 60 adults with OOHCA and IHCA[16]	In adults with OOHCA, • There was no difference in the mean CC rate in shocks that were successful versus shocks that failed[16]

ROSC = return of spontaneous circulation; $ETCO_2$ = end-tidal carbon dioxide; OOHCA=out-of-hospital cardiac arrest; CPR=cardiopulmonary re4susciation; ED=emergency department; IHCA=in-hospital cardiac arrest; CC=chest compression; /min=per minute; SD=standard deviation; CPC = cerebral performance category; aRR=Adjusted Relative Risk of Outcome; PCPC = Paediatric Cerebral Performance Category; OR=odds ratio; 95%CI = 95% confidence interval; AOR=adjusted odds ratio; SBP = systolic blood pressure; DBP = diastolic blood pressure; mmHg=millimetres of mercury; CPR = cardiopulmonary resuscitation

Table 2: Outcomes of studies of chest compression depth (n=12)

Survival with favourable neurological function (n=3); survival to discharge (n=4); 1-month survival (n=1); 1-day survival (n=4); survival to the emergency department (n=1); survival to hospital admission (n=2); ROSC (n=6) ; blood pressure (n=1); shock success (n=1) and injury frequency (n=1)

Studies	Summary of findings
SURVIVAL WITH FAVOURABLE NEUROLOGICAL FUNCTION	
3 observational studies: 78 children with IHCA,[28] 593 adults with OOHCA,[29] and 32 adults with OOHCA & >2 minutes CPR in ED[18]	In adults with OOHCA, • adjusted analyses showed that compared to a CC depth <38.0mm, CC depths of 38.0-50.9mm and ≥51.0 mm made no difference to survival with favourable neurological outcome (CPC 1-2)[29] • each 5 mm increase in mean CC depth increased survival with favourable neurological outcome (CPC 1-2) [aOR=1.30, 95%CI: 1.00–1.70] [29] • compared to a mean (SD) CC depth of 38.8 (11.5) mm, a mean (SD) CC depth of 48.0 (9.2) mm made no difference to survival with favourable neurological outcome at hospital discharge (CPC 1 or 2)[18] In children with IHCA, • unadjusted analyses of index cardiac arrests (n=78) show that if ≥60% of CCs had an average depth of ≥51mm, there was no difference in survival with good neurological outcome (PCPC 1-2 or no change from baseline)
SURVIVAL TO HOSPITAL DISCHARGE	
4 observational studies: 78 children with IHCA,[28] and 10,758 adults with OOHCA,[27,29,31]	In adults with OOHCA • adjusted analyses showed that compared to a CC depth >51mm, a CC depth <38mm decreased survival to hospital discharge [aOR=0.69, 95%CI: 0.53 - 0.90, p<0.001] and a CC depth 38-51mm made no difference in survival to hospital discharge[27] • each 5mm increase in CC depth was associated with increased survival to hospital discharge in two studies [aOR=1.04, 95%CI: 1.00 - 1.08, p=0.045[27] / aOR=1.29, 95%CI: 1.00–1.65[29]] and made no difference to survival to hospital discharge in one study [aOR=1.09, 95%CI: 0.94-1.27] [31] • adjusted analyses showed that compared to a CC depth <38.0mm,[29,31] CC depths of 38.0-50.9mm,[29] 38-51mm[31] and ≥51.0mm[29,31] made no difference to survival to hospital discharge[29,31] • unadjusted analysis showed that compared to CC depth <38mm, survival to hospital discharge was not significantly different for CC depth 38-51mm or CC depth >51mm[31] In children with IHCA • Unadjusted analyses of index cardiac arrests (n=78) show that if ≥60% of CCs had an average depth of ≥51mm, there was no difference in survival to hospital discharge[28]
1 MONTH (30-DAY) SURVIVAL	
1 observational study: 32 adults with OOHCA & >2 minutes CPR in ED[18]	In adults with OOHCA • compared to a mean (SD) CC depth of 38.8 (11.5)mm, a mean (SD) CC depth of 48.0 (9.2) mm made no difference to 30-day survival[18]

Table 2: Outcomes of studies of chest compression depth (n=12)

Survival with favourable neurological function (n=3); survival to discharge (n=4); 1-month survival (n=1); 1-day survival (n=4); survival to the emergency department (n=1); survival to hospital admission (n=2); ROSC (n=6) ; blood pressure (n=1); shock success (n=1) and injury frequency (n=1)

Studies	Summary of findings
1 DAY (24-h) SURVIVAL	
4 observational studies: 78 children with IHCA,[28] 10,165 adults with OOHCA[27,31] and 32 adults with OOHCA & >2 minutes CPR in ED[18]	In adults with OOHCA, • adjusted analyses showed that compared to a CC depth >51mm, a CC depth <38mm decreased 1-day survival [aOR=0.71, 95%CI: 0.61 - 0.83, p<0.001] and a CC depth 38-51mm made no difference in 1-day survival[27] • each 5mm increase in CC depth was associated with increased 1-day survival [aOR=1.05, 95%CI: 1.03 - 1.08, p<0.001] in one study[27] and made no difference to 1-day survival in one study[31] • adjusted analyses showed that compared to a CC depth <38.0mm, a CC depth 38-51mm increased 1-day survival [aOR=1.52, 95% CI: 1.06-2.18] and a CC depth > 51mm made no difference in 1-day survival[31] • compared to a mean (SD) CC depth of 38.8 (11.5)mm, a mean (SD) CC depth of 48.0 (9.2) mm made no difference to 30-day survival[18] In children with IHCA, • when adjusted for year of arrest, gender, and first documented rhythm, if ≥60% of CCs had an average depth of ≥51mm, 24-h survival increased [aOR=10.3, 95%CI: 2.75-38.8, p<0.001] [unadjusted 70% vs 16%]
SURVIVAL TO EMERGENCY DEPARTMENT	
1 observational study: 312 adults with OOHCA[33]	In adults with OOHCA, • Mean CC depths of 5-6cm had the highest ROSC to ED rates (no p values reported) [33] • Logistic regression analysis showed that CC depth had a significant effect on survival to ED for both shockable and non-shockable rhythms [−1.465 + 0.2719*depth [cm]; 95% CI 0.01404-0.52973; p<0.04] and for non-shockable rhythms only [−2.478 + 0.3919*depth [cm]; 95% CI 0.07423–0.70952; p < 0.02] [33] • Based on these regression models, ROSC to ED could be achieved for 50% of cases with a CC depth of 5.38cm for all presenting rhythms and 6.32cm for non-shockable presenting rhythm[33]
SURVIVAL TO HOSPITAL ADMISSION	
2 observational study: 358 adults with OOHCA (analysis limited to 284 patients with complete quality data for CC depth) [17] and 32 adults with OOHCA & >2 minutes CPR in ED[18]	In adults with OOHCA, • the percentage of patients who survived to hospital admission increased with increased CC depth but no statistical analysis was reported[17] • when adjusted for witnessed arrest and sex, each 1mm increase in CC depth was associated with increased survival to hospital admission [OR=1.05, 95%CI: 1.01-1.09, p=0.011] [17] • unadjusted analyses showed that each 1mm increase in CC depth was associated with increased survival to hospital admission [OR=1.05, 95%CI: 1.01-1.09, p=0.009] [17] • compared to a mean (SD) CC depth of 38.8 (11.5)mm, a mean (SD) CC depth of 48.0 (9.2) mm made no difference to survival to hospital admission[18]

Table 2: Outcomes of studies of chest compression depth (n=12)

Survival with favourable neurological function (n=3); survival to discharge (n=4); 1-month survival (n=1); 1-day survival (n=4); survival to the emergency department (n=1); survival to hospital admission (n=2); ROSC (n=6) ; blood pressure (n=1); shock success (n=1) and injury frequency (n=1)

Studies	Summary of findings
RETURN OF SPONTANEOUS CIRCULATION	
6 observational studies: 78 children with IHCA,[28] 390 children with OOHCA,[15] 10860 adults with OOHCA,[27,31,32] and 32 adults with OOHCA & >2 minutes CPR in ED[18]	In adults with OOHCA, • adjusted analyses showed that compared to CC depth >51mm, CC depths of <38mm [aOR=0.70, 95%CI: 0.60 - 0.80, p<0.001] and 38-51mm [aOR=0.86, 95%CI: 0.75 – 0.97, p<0.001] decreased ROSC [27] • adjusted analyses showed that compared to CC depth <38mm, CC depths of 38-51mm or >51mm made no difference ROSC[31] • each 5mm increase in CC depth was associated with increased ROSC [aOR=1.06, 95%CI: 1.04 - 1.08, p<001] in one study[27] and made no difference to ROSC in one study[31] • unadjusted analysis if 202 patients who received more than one shock showed that compared to a CC depth of <4.78cm, a CC depth of ≥4.78cm was not associated with higher transient ROSC [32] • for shocks delivered after 5 minutes of CC, a CC depth >5cm compared with CC depth <5cm was associated with higher transient ROSC [23.4% vs. 8.2%, p=0.008] [32] • compared to a mean (SD) CC depth of 38.8 (11.5)mm, a mean (SD) CC depth of 48.0 (9.2) mm made no difference to ROSC[18] In children with OOHCA, • adjusted analyses showed that and compared to CC depth ≥38mm, a CC depth <38mm made no difference to ROSC.[15] Unadjusted analysis from the same study of 153 patients with CC depth data showed that compared to CC depth ≥38mm, a CC depth <38mm increased the likelihood of ROSC (49.4% vs. 29.7%; p=0.01)[15] In children with IHCA, • when adjusted for year of arrest and first documented rhythm, if ≥60% of CCs had an average depth of ≥51mm, the likelihood of ROSC increased [aOR=4.21, 95%CI:1.34-13.2, p=0.014] [unadjusted 74% vs 31%][28]
BLOOD PRESSURE	
1 observational study:39 adults with OOHCA[14]	In adults with OOHCA , • when SBP was measured via the femoral artery, compared to CC rate <100/min and CC depth<50mm (inadequate CPR quality), the combination of CC depth ≥ 50 mm and CC rate >120/min had the highest odds of achieving the target SBP≥85mmHg [OR=4.40, 95% CI: 3.27-5.91, p<0.001][14] • when SBP was measured via the radial artery, compared to CC rate <100/min and CC depth<50mm (inadequate CPR quality), the combination of CC depth ≥ 50 mm and CC rate <100/min had the highest odds of achieving the target SBP≥85mmHg [OR=11.19, 95% CI: 8.65-14.48, p<0.001][14] • when DBP was measured via the femoral artery, compared to CC rate <100/min and CC depth<50mm (inadequate CPR quality), the combination of CC depth ≥ 50mm and CC rate <100/min was the only combination that achieved the target DBP≥30mmHg [OR=2.06, 95% CI: 1.86-2.27, p<0.001][14] • when DBP was measured via the radial artery, compared to CC rate <100/min and CC depth<50mm (inadequate CPR quality), the combination of CC depth ≥ 50 mm and CC rate >120/min had the highest odds of achieving the target DBP≥30mmHg [OR=3.35, 95% CI: 2.62-4.28, p<0.001][14]
SHOCK SUCCESS	
1 observational study: 60 adults with OOHCA or IHCA[16]	In adults with OOHCA, • mean (SD) CC depth was 39(11)mm for successful shocks and 29(10)mm for unsuccessful shocks (p=0.004) [16] • with increasing pre-pause CC depth, the percentage of successful shocks increased: <26mm = 50%; 26-38mm = 60%; 39-50mm = 88%; and >50mm = 100% (p=0.008) [16] • adjusted for pre-shock pause duration, out-of-hospital location, male sex, age (1-year increase), and time to shock (1-min increase), each 5mm increase in CC depth increased shock success [aOR=1.99, 95%CI: 1.08-3.66, p=0.028][16]

Table 2: Outcomes of studies of chest compression depth (n=12)

Survival with favourable neurological function (n=3); survival to discharge (n=4); 1-month survival (n=1); 1-day survival (n=4); survival to the emergency department (n=1); survival to hospital admission (n=2); ROSC (n=6) ; blood pressure (n=1); shock success (n=1) and injury frequency (n=1)

Studies	Summary of findings
INJURY FREQUENCY	
1 observational study: 170 patients with IHCA[30]	In adults with IHCA, • increased CC depths were associated with higher injury rates (p=0.06): CC depth <50mm had an injury rate of 28%; CC depth of 50–60mm had an injury rate of 37%; and CC depth >60 mm had an injury rate of 40% [30] • the mean (SD) CC depth of patients with injuries was 56(11) mm versus 52(8) mm in patients with no injuries (p=0.04) [30]

ROSC=return of spontaneous circulation; IHCA=in-hospital cardiac arrest; OOHCA = out-of-hospital cardiac arrest; CPR=cardiopulmonary resuscitation; ED=emergency department; CC=chest compression, mm=millimetres; CPC = cerebral performance category; aOR=adjusted odds ratio; 95%CI = 95% confidence interval; SD=standard deviation; PCPC = paediatric cerebral performance category; cm=centimeters; SBP=systolic blood pressure; DBP=diastolic blood pressure

Table 3: Outcomes of studies of chest wall recoil (n=2)
Survival with favourable neurological function (n=2); survival to discharge (n=2); ROSC (n=1)

Studies	Summary of findings
SURVIVAL WITH FAVOURABLE NEUROLOGICAL FUNCTION	
2 observational studies: 1848 adults with OOHCA[34,35]	In adults with OOHCA, • adjusted analyses show that for each increase of 10mm/second in CCRV there was no significant effect on neurologically intact survival to discharge [34] • compared to slow CCRV (<300 mm/s), a fast CCRV (≥400 mm/s) [aOR 5.774, 95%CI 1.907 - 17.477] increased survival with good neurological outcome and a moderate CCRV (300–399.9 mm/s) made no difference to survival with good neurological outcome (CPC 1-2) [35]
SURVIVAL TO DISCHARGE	
2 observational studies: 1848 adults with OOHCA[34,35]	In adults with OOHCA, • compared to slow CCRV (<300 mm/s), a fast CCRV (≥400 mm/s) [aOR 5.913, 95%CI 1.949 - 13.838] increased survival to hospital discharge and a moderate CCRV (300–399.9 mm/s) made no difference to survival to hospital discharge[35] • adjusted analyses showed that CCRV made no difference to survival to hospital discharge.[34] Unadjusted analyses from the same study showed that compared to CCRV of ≤300 mm/s, CCRVs of 301-400mm/sec [OR=2.62, 95%CI: 1.59-4.32] and >400mm/sec [OR=3.28, 95%CI: 1.72-6.25] increased likelihood of survival to hospital discharge[34]
ROSC	
1 observational study: 1137 adults with OOHCA[34]	In adults with OOHCA, • adjusted analyses showed that for each increase of 10mm/second in CCRV, there was no significant difference in the likelihood of ROSC[34]

OOHCA = out-of-hospital cardiac arrest; CCRV = chest compression release velocity; mm=millimetres; aOR = adjusted odds ratio; CPC=cerebral performance category

Table 4: Interactions between CPR parameters (n=5)
Survival with favourable neurological function (n=2); survival to discharge (n=2); ROSC (n=1)

Studies	Summary of findings
CPR QUALITY & ASSOCIATION WITH OTHER CPR PARAMETERS	
1 randomised controlled trail: 292 adults OOHCA[26] 4 observational studies: 78 children with IHCA[28] and 8,021 adults with OOHCA [21,29,31]	In adults with OOHCA, • compared with a CC rate of 100/min, a CC rate of 120/min was associated with decreased mean (SD) CC fraction [95.9% (3.1%) vs 94.3% (5.1%), p=0.008] but made no difference to mean CC depth[26] • three studies reported a statistically significant inverse relationship between CC rate and CC depth (eg. as CC rate increases, CC depth decreases)[21,29,31] In children with IHCA, • compared to CC depth of <51mm, a CC depth ≥51mm made no difference to the % of CC with leaning >2.5kg or to the median CC rate[28]

OOHCA = out-of-hospital cardiac arrest; IHCA=in-hospital cardiac arrest; CC=chest compression; /min=per minute; %=percentage; kg=kilograms