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

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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.\textsuperscript{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.\textsuperscript{3} There were three systematic reviews related to three main components of chest compression (CC); namely, CC rate, CC depth, and chest wall recoil.\textsuperscript{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,\textsuperscript{4,5} 2010,\textsuperscript{6,7} 2015\textsuperscript{1,2}). However, ILCOR has now moved to a continuous evidence evaluation process.\textsuperscript{8} Part of this new approach requires the ILCOR Task Forces to determine whether a sufficient body of evidence has emerged to justify revisiting 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\textsuperscript{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.\textsuperscript{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.\textsuperscript{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,\textsuperscript{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).\textsuperscript{11} In scoping reviews, formal quality assessment is not usually performed and study findings are presented in a tabular format with accompanying narrative.\textsuperscript{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.\textsuperscript{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\textsuperscript{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.\textsuperscript{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.\textsuperscript{1,2} The six studies from the 2015 ILCOR BLS CoSTR\textsuperscript{1,2} excluded from this review were two animal studies\textsuperscript{15,16} and four studies\textsuperscript{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.\textsuperscript{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 studies34-39 and one randomised study.40 Two studies involving 1848 adult patients examined chest wall recoil41,42 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 trial32 and one RCT.33 The outcomes examined were survival with favourable neurological function (one RCT33 and three observational studies25-27); survival to hospital discharge (five observational studies26-29,33); 1-month survival (one RCT33 and one observational study25); 24-h survival (two observational studies22,25); survival to hospital admission (two observational studies24,25); ROSC (one RCT33 and seven observational studies22,25-30); blood pressure (three observational studies21,26,31); end-tidal PCO2 (one RCT33 and two observational studies31,32); and shock success (one observational study23).

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.\textsuperscript{22,26,29,33} There were no significant differences reported between various CC rates on 1-month survival,\textsuperscript{25,33} 1-day survival,\textsuperscript{22,25} or admission to hospital alive.\textsuperscript{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\textsuperscript{27} and one study reported that higher mean CC rates were associated with increased likelihood of ROSC.\textsuperscript{30} None of the other studies reported a significant difference between various CC rates and ROSC.\textsuperscript{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 (SBP) and diastolic blood pressure (DBP) was unable to be ascertained.\textsuperscript{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.\textsuperscript{26} None of the other CC rates examined had a significant effect on either SBP or DBP.\textsuperscript{21,31} Of the three studies that reported end-tidal PCO\textsubscript{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\textsubscript{2}.\textsuperscript{32} The other two studies failed to show a significant association between various CC rates and changes in end-tidal CO\textsubscript{2}.\textsuperscript{31,33} One study reported that CC rates were not significantly associated with shock success.\textsuperscript{23}

\textbf{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,\textsuperscript{21-25,34-36,39,43} and one was a prospective randomised study.\textsuperscript{40} The outcomes examined were survival with favourable neurological function (three observational studies\textsuperscript{25,35,36}); survival to hospital discharge (four observational studies\textsuperscript{34-36,38}); 1-month survival (one observational study\textsuperscript{25}); 24-h survival (four observational studies\textsuperscript{25,34,35,38}); survival to the Emergency Department (ED) (one randomised study\textsuperscript{40}); survival to hospital
admission (two observational studies\textsuperscript{24,25}); ROSC (six observational studies \textsuperscript{22,25,34,35,38,39}); blood pressure (one observational study\textsuperscript{21}); shock success (two observational studies\textsuperscript{23,39}); and injury frequency (one observational study\textsuperscript{37}).

Specific CC depths (<38 mm versus 38.0-50.9 mm or \(\geq 51.0\) mm in adults;\textsuperscript{36} mean (SD) CC depth of 38.8 (11.5) mm versus 48.0 (9.2) mm in adults;\textsuperscript{25} or <51 mm versus \(\geq 51.0\) mm in children\textsuperscript{35}) were not significantly associated with survival with favourable neurological outcome.\textsuperscript{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.\textsuperscript{36} Of the four studies that examined survival to hospital discharge, one adult study reported that, compared to a CC depth of >51 mm and adjusted for confounders, survival to hospital discharge decreased when CC depth was <38 mm.\textsuperscript{34} Two adult studies reported that for each 5 mm increase in CC depth, survival to hospital discharge increased\textsuperscript{34,36}. None of the other studies reported an association between survival to hospital discharge\textsuperscript{35,38} or 1-month survival\textsuperscript{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\textsuperscript{34,38} and children\textsuperscript{35} and one reported no association between mean CC depths and 1-day survival in adults.\textsuperscript{25} In adults, for each 5 mm increase in CC depth, 1-day survival increased.\textsuperscript{34} When adjusted for confounders and compared to CC depth of <38 mm, a CC depth of 38-51 mm increased 1-day survival.\textsuperscript{38} Compared to CC depth of >51 mm, a CC depth <38 mm decreased 1-day survival.\textsuperscript{34} In children, if \(\geq 60\%\) of CCs had an average depth of \(\geq 51\) mm (compared with <60\% of average CC depth \(\geq 51\) mm), 24-h survival increased.\textsuperscript{35} The study that reported survival to the ED showed that mean CC depths of 5-6 cm had the highest survival to ED rates in adults but no p-values were reported.\textsuperscript{40}

In adults, one study showed that increased CC depth was associated with increased odds of admission to hospital alive\textsuperscript{24} with adjusted analyses showing that with each 1 mm increase in average CC compression depth, there was a significant increase in the odds of admission alive to hospital.\textsuperscript{24} The other adult study
showed no association between different mean CC depths and survival to hospital admission. 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. 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. None of the other studies reported a statistically significant relationship between ROSC and different CC depths.

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. 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).

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).

**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. 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); survival to hospital discharge (two observational studies); and ROSC (one observational study). 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. 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. Two studies reported on survival to hospital
discharge, again with conflicting results. One study reported that, compared to slow CCRV (<300 mm/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.\textsuperscript{42} The other study reported that once adjusted for confounders, there was no difference in survival to hospital discharge associated with different CCRVs.\textsuperscript{41} The one study reporting on ROSC showed no statistically significant improvement associated with a 10 mm/sec increase in CCRV.\textsuperscript{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\textsuperscript{28,35,36,38} and one RCT\textsuperscript{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),\textsuperscript{28,36,38} one adult study reported no difference in CC depth with CC rates of 100/minute and 120/minute,\textsuperscript{33} and the study in children reported no significant relationship between CC rate and CC depth.\textsuperscript{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].\textsuperscript{33} One study reported that CC depths of <51 mm versus ≥51 mm was not associated with the percentage of CC with significant leaning (>2.5 kg) in children [12\% vs 8\%, p=0.09].\textsuperscript{35}

**DISCUSSION**

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

The 2015 ILCOR BLS CoSTR1,2 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.\textsuperscript{6,7} In 2015, the recommendations regarding CC rate changed from 100/minute\textsuperscript{6,7} to 100-120/minute\textsuperscript{1,2} and the recommendations regarding CC depth were changed from at least 5cm\textsuperscript{6,7} to approximately 5cm whilst avoiding CC depths greater than 6cm.\textsuperscript{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\textsuperscript{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.\textsuperscript{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,\textsuperscript{28} supporting the 2015 ILCOR BLS CoSTR.\textsuperscript{1,2} Two of the eight studies that focused on ROSC reported that higher CC rates were associated with increased likelihood of ROSC.\textsuperscript{27,30} Of the twelve studies that focused on CC depth, again, only four\textsuperscript{24,34,35,38} reported significant relationships between CC depth and patient outcomes and the findings were concordant with the 2015 ILCOR BLS CoSTR.\textsuperscript{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.\textsuperscript{34} Three of four studies that focused on 1-day survival, reported statistically significant associations between 1-day survival and increasing CC depth.\textsuperscript{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.\textsuperscript{24} Of interest was that both studies that focused on shock success reported
increased shock success associated with deeper CC in adults. 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 and survival to hospital discharge were conflicting. The one study reporting on ROSC showed no significant effect associated with CCRV. 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. 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.

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.\textsuperscript{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.\textsuperscript{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.

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

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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 2015¹,²). 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 revisiting 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\textsuperscript{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.\textsuperscript{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.\textsuperscript{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,\textsuperscript{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).\textsuperscript{11} In scoping reviews, formal quality assessment is not usually performed and study findings are presented in a tabular format with accompanying narrative.\textsuperscript{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.\textsuperscript{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 \( \text{PCO}_2 \)) 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 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. 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. The six studies from the 2015 ILCOR BLS CoSTR excluded from this review were two animal studies and four studies 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. Eight studies
involving 14,285 patients (14,121 adults and 164 children) examined CC rate only: six observational studies,\textsuperscript{26-31} one crossover trial,\textsuperscript{32} and one randomised controlled trial (RCT).\textsuperscript{33} Seven studies involving 12,010 patients (11,228 adults, 695 age unknown, and 78 children) examined CC depth only: six observational studies\textsuperscript{34-39} and one randomised study.\textsuperscript{40} Two studies involving 1848 adult patients examined chest wall recoil\textsuperscript{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,\textsuperscript{21-31} there was one crossover trial\textsuperscript{32} and one RCT.\textsuperscript{33} The outcomes examined were survival with favourable neurological function (one RCT\textsuperscript{33} and three observational studies\textsuperscript{25-27}); survival to hospital discharge (five observational studies\textsuperscript{26-29,33}); 1-month survival (one RCT\textsuperscript{33} and one observational study\textsuperscript{25}); 24-h survival (two observational studies\textsuperscript{22,25}); survival to hospital admission (two observational studies\textsuperscript{24,25}); ROSC (one RCT\textsuperscript{33} and seven observational studies\textsuperscript{22,25-30}); blood pressure (three observational studies\textsuperscript{21,26,31}); end-tidal PCO\textsubscript{2} (one RCT\textsuperscript{33} and two observational studies\textsuperscript{31,32}); and shock success (one observational study\textsuperscript{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.\textsuperscript{26} Studies in adults were not definitive for an association between CC rate alone and favourable neurological survival.\textsuperscript{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.\textsuperscript{28} None of the
other studies reported a survival to hospital discharge benefit associated with specific CC rates.\textsuperscript{22,26,29,33} There were no significant differences reported between various CC rates on 1-month survival,\textsuperscript{25,33} 1-day survival,\textsuperscript{22,25} or admission to hospital alive.\textsuperscript{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\textsuperscript{27} and one study reported that higher mean CC rates were associated with increased likelihood of ROSC.\textsuperscript{30} None of the other studies reported a significant difference between various CC rates and ROSC.\textsuperscript{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.\textsuperscript{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.\textsuperscript{26} None of the other CC rates examined had a significant effect on either SBP or DBP.\textsuperscript{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$_2$.\textsuperscript{32} The other two studies failed to show a significant association between various CC rates and changes in end-tidal CO$_2$.\textsuperscript{31,33} One study reported that CC rates were not significantly associated with shock success.\textsuperscript{23}

\textbf{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,\textsuperscript{21-25,34-36,39,43} and one was a prospective randomised study.\textsuperscript{40} The outcomes examined were survival with favourable neurological function (three observational studies\textsuperscript{25,35,36}); survival to hospital discharge (four observational studies\textsuperscript{34-36,38}); 1-month survival (one observational study\textsuperscript{25}); 24-h survival (four observational studies\textsuperscript{25,34,35,38}); survival to the Emergency Department (ED) (one randomised study\textsuperscript{40}); survival to hospital
admission (two observational studies\textsuperscript{24,25}); ROSC (six observational studies\textsuperscript{22,25,34,35,38,39}); blood pressure (one observational study\textsuperscript{21}); shock success (two observational studies\textsuperscript{23,39}); and injury frequency (one observational study\textsuperscript{37}).

Specific CC depths (<38 mm versus 38.0-50.9 mm or \(\geq 51.0\) mm in adults;\textsuperscript{36} mean (SD) CC depth of 38.8 (11.5) mm versus 48.0 (9.2) mm in adults;\textsuperscript{25} or <51 mm versus \(\geq 51.0\) mm in children\textsuperscript{35}) were not significantly associated with survival with favourable neurological outcome.\textsuperscript{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.\textsuperscript{36} Of the four studies that examined survival to hospital discharge, one adult study reported that, compared to a CC depth of \(>51\) mm and adjusted for confounders, survival to hospital discharge decreased when CC depth was <38 mm.\textsuperscript{34} Two adult studies reported that for each 5 mm increase in CC depth, survival to hospital discharge increased.\textsuperscript{34,36} None of the other studies reported an association between survival to hospital discharge\textsuperscript{35,38} or 1-month survival\textsuperscript{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\textsuperscript{34,38} and children\textsuperscript{35} and one reported no association between mean CC depths and 1-day survival in adults.\textsuperscript{25} In adults, for each 5 mm increase in CC depth, 1-day survival increased.\textsuperscript{34} When adjusted for confounders and compared to CC depth of <38 mm, a CC depth of 38-51 mm increased 1-day survival.\textsuperscript{38} Compared to CC depth of \(>51\) mm, a CC depth <38 mm decreased 1-day survival.\textsuperscript{34} In children, if \(\geq 60\%\) of CCs had an average depth of \(\geq 51\) mm (compared with <60\% of average CC depth \(\geq 51\) mm), 24-h survival increased.\textsuperscript{35} The study that reported survival to the ED showed that mean CC depths of 5-6 cm had the highest survival to ED rates in adults but no p-values were reported.\textsuperscript{40} In adults, one study showed that increased CC depth was associated with increased odds of admission to hospital alive\textsuperscript{24} with adjusted analyses showing that with each 1 mm increase in average CC compression depth, there was a significant increase in the odds of admission alive to hospital.\textsuperscript{24} The other adult study
showed no association between different mean CC depths and survival to hospital admission. 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. 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. None of the other studies reported a statistically significant relationship between ROSC and different CC depths.

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. 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). 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).

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. 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); survival to hospital discharge (two observational studies); and ROSC (one observational study). 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. 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. Two studies reported on survival to hospital
discharge, again with conflicting results. One study reported that, compared to slow CCRV (<300 mm/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. The other study reported that once adjusted for confounders, there was no difference in survival to hospital discharge associated with different CCRVs. The one study reporting on ROSC showed no statistically significant improvement associated with a 10 mm/sec increase in CCRV.

**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 and one RCT. 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), one adult study reported no difference in CC depth with CC rates of 100/minute and 120/minute, and the study in children reported no significant relationship between CC rate and CC depth. 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]. One study reported that CC depths of <51 mm versus ≥51 mm was not associated with the percentage of CC with significant leaning (>2.5 kg) in children [12% vs 8%, p=0.09].

**DISCUSSION**

This scoping review identified 22 studies related to various CC components, eighteen of which were observational studies. There was variation in the outcomes examined and overall the most frequently reported outcomes were ROSC (n=13), survival to hospital discharge (n=12), and survival to hospital discharge with good neurological outcome (n=8). All but three studies were in adults, there was one study where the age of participants was not reported. Seventeen of the included studies focused on out-of-hospital cardiac arrest.
including one study of patients with out-of-hospital cardiac arrest requiring CPR in the ED.25

The 2015 ILCOR BLS CoSTR1,2 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. In 2015, the recommendations regarding CC rate changed from 100/minute to 100-120/minute and the recommendations regarding CC depth were changed from at least 5cm to approximately 5cm whilst avoiding CC depths greater than 6cm. 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 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. 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, supporting the 2015 ILCOR BLS CoSTR. Two of the eight studies that focused on ROSC reported that higher CC rates were associated with increased likelihood of ROSC. Of the twelve studies that focused on CC depth, again, only four reported significant relationships between CC depth and patient outcomes and the findings were concordant with the 2015 ILCOR BLS CoSTR.

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. Three of four studies that focused on 1-day survival, reported statistically significant associations between 1-day survival and increasing CC depth. 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. Of interest was that both studies that focused on shock success reported
increased shock success associated with deeper CC in adults.\textsuperscript{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\textsuperscript{41,42} and survival to hospital discharge\textsuperscript{41,42} were conflicting. The one study reporting on ROSC showed no significant effect associated with CCRV.\textsuperscript{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.\textsuperscript{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.\textsuperscript{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. 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. 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


CHEST COMPRESSION COMPONENTS
PRISMA Flow Diagram

Records identified through 2019 search (n = 3,699)
(Medline Complete n=1,593; Embase n=1,454; Cochrane n=652)

Additional records identified from 2015 ILCOR BLS CoSTR (n = 20)

Records after duplicates removed (n = 2,830)

Records screened: title and abstract (n = 2,830)

Records excluded (n = 2,777)
- 2019 search (n=2,775)
- 2015 ILCOR BLS CoSTR papers
  - Animal studies (n=2)

Full-text articles assessed for eligibility (n = 53)
- 2019 search (n=35)
- 2015 CoSTR papers (n=18)

Full-text articles excluded (n = 31)
- 2019 search
  - Conference abstracts (n=15)
  - Did not meet inclusion criteria (n=6)
  - Letter to the editor (n=2)
  - Patients not in cardiac arrest (n=2)
  - Used surrogate outcomes (CC fraction & duty cycle) (n=2)
- 2015 ILCOR BLS CoSTR papers
  - Did not meet inclusion criteria (n=4)

Studies included in synthesis (n = 22)
- 2019 search (n=8)
- 2015 ILCOR BLS CoSTR papers (n=14)


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); ETCO₂ (n=3); and shock success (n=1)

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<tr>
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<tbody>
<tr>
<td><strong>SURVIVAL WITH FAVOURABLE NEUROLOGICAL FUNCTION</strong></td>
<td></td>
</tr>
<tr>
<td>1 randomised controlled trial: 292 adults with OOHCA&lt;sup&gt;26&lt;/sup&gt;</td>
<td>In adults with OOHCA</td>
</tr>
</tbody>
</table>
| 3 observational studies: 164 children with IHCA,<sup>19,20</sup> 222 adults with IHCA,<sup>19,20</sup> and 32 adults with OOHCA & >2 minutes CPR in ED<sup>18</sup> | - compared to CC rate of 120/min, a CC rate of 100/min made no difference to CPC≤2 at 1 month following OOHCA<sup>26</sup>  
- 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<sup>18</sup>
- 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<sup>20</sup>
- 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<sup>20</sup>
- 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]<sup>19</sup>
  - 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)<sup>19</sup>
| **SURVIVAL TO HOSPITAL DISCHARGE**                                     |                                                                                                                                                                                                                      |
| 5 observational studies: 164 children with IHCA,<sup>19</sup> 390 children with OOHCA,<sup>13</sup> and 13,761 adults with OOHCA,<sup>21,22,26</sup> | 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<sup>21</sup> and a CC rate <80/min or >140/min made no difference to survival to hospital discharge.<sup>21</sup>
- adjusted 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<sup>21</sup>
- compared to a CC rate of 120/min, a CC rate of 100/min was made no difference to survival to hospital discharge<sup>26</sup>
- 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 OOHCA<sup>15</sup>
- 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<sup>15</sup>
| **1 MONTH SURVIVAL**                                                   |                                                                                                                                                                                                                      |
| 1 randomised controlled trial: 292 adults with OOHCA<sup>26</sup>      | In adults with OOHCA,                                                                                                                                                                                                  |
| 1 observational study: 32 adults with OOHCA & >2 minutes CPR in ED<sup>18</sup> | - compared to CC rate of 120/min, a CC rate of 100/min made no difference to survival at 1 month<sup>26</sup>  
- 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<sup>18</sup>
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\textsubscript{2} (n=3); and shock success (n=1)

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<tr>
<td><strong>1-DAY (24-h) SURVIVAL</strong></td>
<td>In adults with OOHCA,</td>
</tr>
<tr>
<td>1 observational study: 390 children with OOHCA\textsuperscript{15} and 32 adults with OOHCA &amp; &gt;2 minutes CPR in ED\textsuperscript{18}</td>
<td>• compared to CC rate of 100-120/min, CC rates of &lt;100/min or &gt;120/min made no difference to survival at 24 hours\textsuperscript{15}</td>
</tr>
<tr>
<td></td>
<td>• 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\textsuperscript{18}</td>
</tr>
<tr>
<td><strong>SURVIVAL TO HOSPITAL ADMISSION</strong></td>
<td>In adults with OOHCA,</td>
</tr>
<tr>
<td>2 observational study:358 adults with OOHCA\textsuperscript{17} and 32 adults with OOHCA &amp; &gt;2 minutes CPR in ED\textsuperscript{18}</td>
<td>• compared to a CC rate of 90-120/min, CC rates of &lt;90/min or &gt;120/min made no difference to survival to hospital admission\textsuperscript{17}</td>
</tr>
<tr>
<td></td>
<td>• 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\textsuperscript{18}</td>
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<tr>
<td><strong>RETURN OF SPONTANEOUS CIRCULATION</strong></td>
<td>In adults with OOHCA,</td>
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<tr>
<td>1 randomised controlled trial: 292 adults with OOHCA\textsuperscript{26}</td>
<td>• adjusted analyses showed that compared to a CC rate of 100-119/min, CC rates of &lt;80/min; 80-119/min; 120-139/min or &gt;140/min made no difference to ROSC.\textsuperscript{21}</td>
</tr>
<tr>
<td>7 observational studies: 164 children with IHCA,\textsuperscript{19} 390 children with OOHCA,\textsuperscript{15,17} 319 adults with IHCA,\textsuperscript{20,23} 13,469 adults with OOHCA,\textsuperscript{21,22} and 32 adults with OOHCA &amp; &gt;2 minutes CPR in ED\textsuperscript{18}</td>
<td>• unadjusted analyses from the same study showed that compared to CC rate of 100-119/min, a CC rate of &gt;140/min [OR=0.72, 95%CI: 0.60-0.86, p&lt;0.001] was associated with decreased ROSC following OOHCA: CC rates &lt;80/min; 80-100/min or 120-139/min made no difference to ROSC\textsuperscript{21}</td>
</tr>
<tr>
<td></td>
<td>• compared with CC rate of 120/min, a CC rate of 100/min made no difference to ROSC\textsuperscript{26}</td>
</tr>
<tr>
<td></td>
<td>• both adjusted and unadjusted analyses showed that compared with a CC rate of 80-140/min, CC rates of 0-80/min or &gt;140/min made no difference to achieving ROSC\textsuperscript{22}</td>
</tr>
<tr>
<td></td>
<td>• 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 achieving ROSC\textsuperscript{18}</td>
</tr>
<tr>
<td></td>
<td>• 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 &gt;150/min made no difference to achieving ROSC\textsuperscript{20}</td>
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<tr>
<td></td>
<td>• higher mean CC rates were associated with increased likelihood of ROSC [ROSC =90±17/min vs no ROSC 79±18/min, p=0.0033] \textsuperscript{23}</td>
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<tr>
<td></td>
<td>• compared to CC rate of 100-120/min</td>
</tr>
<tr>
<td></td>
<td>• CC rates of &lt;100/min; 120-140/min or &gt;140/min made no difference to achieving ROSC following IHCA\textsuperscript{19}</td>
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<tr>
<td></td>
<td>• CC rates of &lt;100/min or &gt;120/min made no difference to achieving ROSC following OOHCA\textsuperscript{15}</td>
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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); ETCO₂ (n=3); and shock success (n=1)

<table>
<thead>
<tr>
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<tbody>
<tr>
<td><strong>BLOOD PRESSURE</strong></td>
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<tr>
<td>In adults with OOHCA</td>
<td></td>
</tr>
<tr>
<td>- CC rates of 60/min; 80/min; 100/min; 120/min or &gt;140/min made no difference to SBP or DBP²⁴</td>
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<tr>
<td>- When SBP was measured via the femoral artery, compared to CC rate &lt;100/min and CC depth&lt;50mm (inadequate CPR quality), the combination of CC rate &gt;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&lt;0.001]¹⁴</td>
<td></td>
</tr>
<tr>
<td>- When SBP was measured via the radial artery, compared to CC rate &lt;100/min and CC depth&lt;50mm (inadequate CPR quality), the combination of CC rate &lt;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&lt;0.001]¹⁴</td>
<td></td>
</tr>
<tr>
<td>- When DBP was measured via the femoral artery, compared to CC rate &lt;100/min and CC depth&lt;50mm (inadequate CPR quality), the combination of CC rate &lt;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&lt;0.001]¹⁴</td>
<td></td>
</tr>
<tr>
<td>- When DBP was measured via the radial artery, compared to CC rate &lt;100/min and CC depth&lt;50mm (inadequate CPR quality), the combination of CC rate &gt;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&lt;0.001]¹⁴</td>
<td></td>
</tr>
<tr>
<td>In children with IHCA, compared to CC rate of 100-120/min</td>
<td></td>
</tr>
<tr>
<td>- 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</td>
<td></td>
</tr>
<tr>
<td>- CC rates of 80-&lt;100/min or &gt;140/min made no difference to SBP or DBP¹⁹</td>
<td></td>
</tr>
<tr>
<td><strong>ETCO₂</strong></td>
<td></td>
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<tr>
<td>In adults with OOHCA</td>
<td></td>
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<tr>
<td>- compared to a CC rate of 120/min, a CC rate of 100/min made no difference to mean ETCO₂²⁶</td>
<td></td>
</tr>
<tr>
<td>- CC rates of 60/min; 80/min; 100/min; 120/min; or &gt;140/min made no difference to mean PetCO₂²⁴</td>
<td></td>
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<tr>
<td>In adults with IHCA</td>
<td></td>
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<tr>
<td>- compared with CC rate of 80/min, a CC rate of 120/min was associated with increased mean ETCO₂ [13.0±1.8 mmHg vs 15.0±1.8 mmHg, p&lt;0.001] ²⁵</td>
<td></td>
</tr>
<tr>
<td><strong>SHOCK SUCCESS</strong></td>
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<tr>
<td>In adults with OOHCA,</td>
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<tr>
<td>- There was no difference in the mean CC rate in shocks that were successful versus shocks that failed¹⁶</td>
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</tbody>
</table>

ROSC = return of spontaneous circulation; ETCO₂ = 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)

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<td><strong>SURVIVAL WITH FAVOURABLE NEUROLOGICAL FUNCTION</strong></td>
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<tr>
<td>3 observational studies:</td>
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</tr>
<tr>
<td>78 children with IHCA, 28, 593 adults with OOHCA, 29 and 32 adults</td>
<td>In adults with OOHCA,</td>
</tr>
<tr>
<td>with OOHCA &amp; &gt;2 minutes CPR in ED18</td>
<td>• adjusted analyses showed that compared to a CC depth &lt;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</td>
</tr>
<tr>
<td></td>
<td>• 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</td>
</tr>
<tr>
<td></td>
<td>• 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</td>
</tr>
<tr>
<td></td>
<td>In children with IHCA,</td>
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<tr>
<td></td>
<td>• 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)</td>
</tr>
<tr>
<td>4 observational studies:</td>
<td></td>
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<tr>
<td>78 children with IHCA, 28, and 10,758 adults with OOHCA, 27, 29, 31</td>
<td>In adults with OOHCA</td>
</tr>
<tr>
<td></td>
<td>• adjusted analyses showed that compared to a CC depth &gt;51mm, a CC depth &lt;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 to hospital discharge27</td>
</tr>
<tr>
<td></td>
<td>• 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=0.04527 / aOR=1.29, 95%CI: 1.00–1.6527] and made no difference to survival to hospital discharge in one study [aOR=1.09, 95%CI: 0.94-1.27] 31</td>
</tr>
<tr>
<td></td>
<td>• adjusted analyses showed that compared to a CC depth &lt;38.0mm,29, 31 CC depths of 38.0-50.9mm, 38-51mm31 and ≥51.0mm29, 31 made no difference to survival to hospital discharge30, 31</td>
</tr>
<tr>
<td></td>
<td>• unadjusted analysis showed that compared to CC depth &lt;38mm, survival to hospital discharge was not significantly different for CC depth 38-51mm or CC depth &gt;51mm31</td>
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<tr>
<td></td>
<td>In children with IHCA</td>
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<tr>
<td></td>
<td>• 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 discharge28</td>
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<tr>
<td><strong>1 MONTH (30-DAY) SURVIVAL</strong></td>
<td></td>
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<tr>
<td>1 observational study:</td>
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<tr>
<td>32 adults with OOHCA &amp; &gt;2 minutes CPR in ED18</td>
<td>In adults with OOHCA</td>
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<td></td>
<td>• 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 survival18</td>
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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)

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<td><strong>1 DAY (24-h) SURVIVAL</strong></td>
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</tr>
<tr>
<td>4 observational studies: 78 children with IHCA,28 10,165 adults with OOHCA27,31 and 32 adults with OOHCA &amp; &gt;2 minutes CPR in ED18</td>
<td>• adjusted analyses showed that compared to a CC depth &gt;51mm, a CC depth &lt;38mm decreased 1-day survival [aOR=0.71, 95%CI: 0.61 - 0.83, p&lt;0.001] and a CC depth 38-51mm made no difference in 1-day survival27</td>
</tr>
<tr>
<td></td>
<td>• each 5mm increase in CC depth was associated with increased 1-day survival [aOR=1.05, 95%CI: 1.03 - 1.08, p&lt;0.001] in one study27 and made no difference to 1-day survival in one study31</td>
</tr>
<tr>
<td></td>
<td>• adjusted analyses showed that compared to a CC depth &lt;38.0mm, a CC depth 38-51mm increased 1-day survival [aOR=1.52, 95% CI: 1.06-2.18] and a CC depth &gt; 51mm made no difference in 1-day survival31</td>
</tr>
<tr>
<td></td>
<td>• 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 survival18</td>
</tr>
<tr>
<td><strong>SURVIVAL TO EMERGENCY DEPARTMENT</strong></td>
<td>In adults with OOHCA,</td>
</tr>
<tr>
<td>1 observational study: 312 adults with OOHCA33</td>
<td>• Mean CC depths of 5-6cm had the highest ROSC to ED rates (no p values reported)33</td>
</tr>
<tr>
<td></td>
<td>• 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<em>depth [cm]; 95% CI 0.01404-0.52973; p&lt;0.04] and for non-shockable rhythms only [−2.478 + 0.3919</em>depth [cm]; 95% CI 0.07423–0.70952; p &lt; 0.02]33</td>
</tr>
<tr>
<td></td>
<td>• 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 rhythm33</td>
</tr>
<tr>
<td><strong>SURVIVAL TO HOSPITAL ADMISSION</strong></td>
<td>In adults with OOHCA,</td>
</tr>
<tr>
<td>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 &amp; &gt;2 minutes CPR in ED18</td>
<td>• the percentage of patients who survived to hospital admission increased with increased CC depth but no statistical analysis was reported17</td>
</tr>
<tr>
<td></td>
<td>• 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</td>
</tr>
<tr>
<td></td>
<td>• 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</td>
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<td>• 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 admission18</td>
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</table>
Table 2: Outcomes of studies of chest compression depth (n=12)

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<tr>
<th>Outcome</th>
<th>Studies</th>
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<tbody>
<tr>
<td><strong>Survival with favourable neurological function (n=3)</strong></td>
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<tr>
<td><strong>Survival to discharge (n=4)</strong></td>
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<tr>
<td><strong>1-month survival (n=1)</strong></td>
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<tr>
<td><strong>1-day survival (n=4)</strong></td>
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<tr>
<td><strong>Survival to hospital admission (n=2)</strong></td>
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<td><strong>ROSC (n=6)</strong></td>
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<td><strong>Blood pressure (n=1)</strong></td>
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<td><strong>Shock success (n=1)</strong></td>
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<td><strong>Injury frequency (n=1)</strong></td>
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**RETURN OF SPONTANEOUS CIRCULATION**

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 \([aOR=1.06, 95\%CI: 1.04 - 1.08, p<0.001]\) 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] \(^{32}\)
- 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 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 ≥ 50 mm 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 \([OR=3.05, 95\% CI: 2.62-4.28, p<0.001]\) \(^{14}\)
- 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 ≥ 50 mm and CC rate >120/min had the highest odds of achieving the target DBP≥30mmHg \([OR=3.35, 95\% CI: 2.35-4.31, p<0.001]\) \(^{14}\)

**BLOOD PRESSURE**

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 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 ≥ 50 mm 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 \([OR=3.35, 95\% CI: 2.35-4.31, p<0.001]\) \(^{14}\)

**SHOCK SUCCESS**

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)

<table>
<thead>
<tr>
<th>Studies</th>
<th>Summary of findings</th>
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| 1 observational study: 170 patients with IHCA | In adults with IHCA, increased CC depths were associated with higher injury rates (p=0.06): CC depth <50 mm had an injury rate of 28%; CC depth of 50–60 mm had an injury rate of 37%; and CC depth >60 mm had an injury rate of 40%.
• 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)

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<th>Studies</th>
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<tr>
<td><strong>SURVIVAL WITH FAVOURABLE NEUROLOGICAL FUNCTION</strong></td>
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| 2 observational studies: 1848 adults with OOHCA 34,35 | • 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 | • 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. 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 | • 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)

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<th>Studies</th>
<th>Summary of findings</th>
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<td><strong>CPR QUALITY &amp; ASSOCIATION WITH OTHER CPR PARAMETERS</strong></td>
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| 1 randomised controlled trial: 292 adults OOHCA 26 | • 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 |
| 4 observational studies: 78 children with IHCA 28 and 8,021 adults with OOHCA 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