Mechanical Versus Manual Chest Compressions in Out-of-Hospital Cardiac Arrest: A Meta-Analysis

Mark Westfall, DO[1]; Steve Krantz, EMT-P[2]; Christopher Mullin, MS[3]; Christopher Kaufman, PhD[4]

Objective: The objective of this study was to conduct a meta-analysis of literature examining rates of return of spontaneous circulation from load-distributing band and piston-driven chest compression devices as compared with manual cardiopulmonary resuscitation.

Data Sources: Searches were conducted in MEDLINE, the ClinicalTrials.gov registry, and bibliographies on manufacturer websites for studies written in English.

Study Selection: Selection criteria for the meta-analysis required that studies must be human controlled (randomized, historical, or case-control) investigations with confirmed out-of-hospital cases.

Data Extraction: A total of 12 studies (load-distributing band cardiopulmonary resuscitation versus manual cardiopulmonary resuscitation = 8, piston-driven cardiopulmonary resuscitation versus manual cardiopulmonary resuscitation = 4), comprising a total of 6,538 subjects with 1,824 return of spontaneous circulation events, met the selection criteria.

Data Synthesis: Random effects models were used to assess the relative effect of treatments on return of spontaneous circulation. Compared with manual cardiopulmonary resuscitation, load-distributing band cardiopulmonary resuscitation had significantly greater odds of return of spontaneous circulation (odds ratio, 1.62 [95% CI, 1.36, 1.92], $p < 0.001$). The treatment effect for piston-driven cardiopulmonary resuscitation was similar to manual cardiopulmonary resuscitation (odds ratio, 1.25 [95% CI, 0.92, 1.68]; $p = 0.151$). The corresponding difference in percentages of return of spontaneous circulation rates from cardiopulmonary resuscitation was 8.3% for load-distributing band cardiopulmonary resuscitation and 5.2% for piston-driven cardiopulmonary resuscitation. Compared with manual cardiopulmonary resuscitation, combining both mechanical cardiopulmonary resuscitation devices produced a significant treatment effect in favor of higher odds of return of spontaneous circulation with mechanical cardiopulmonary resuscitation devices (odds ratio, 1.53 [95% CI, 1.32, 1.78], $p < 0.001$).

Conclusion: The ability to achieve return of spontaneous circulation with mechanical chest compression devices is significantly improved when compared with manual chest compressions. In the case of load-distributing band cardiopulmonary resuscitation, it was superior to manual cardiopulmonary resuscitation as the odds of return of spontaneous circulation were over 1.6 times greater. The robustness of these findings should be tested in large randomized clinical trials. (*Crit Care Med* 2013; 41:0–0)

Key Words: cardiac arrest; cardiopulmonary resuscitation; devices; meta-analysis; return of spontaneous circulation

Despite advances in therapeutic strategies and improved guidelines, morbidity and mortality rates for out-of-hospital cardiac arrest (OHCA) remain high and minimally changed from 30 years prior (1). Rates of survival vary considerably based on, but not limited to, the following factors: witnessed versus not-witnessed events, whether bystander cardiopulmonary resuscitation (CPR) was performed, time from event to arrival of emergency medical service (EMS) services, initial presenting rhythm, time from event to first defibrillation shock, availability of advanced life-support procedures, and ability to achieve return of spontaneous circulation (ROSC) (1). Rates of brain damage in survivors also vary, but it has been reported that up to half of cardiac arrest survivors have some level of residual neurologic impairment that may or may not completely resolve (2). The subsequent and ever-growing burden on healthcare costs associated with treating OHCA and the unsatisfactory survival rates warrant the investigation of alternative and/or additional therapies.

Several mechanical chest compression devices have been developed to supplement manual CPR (M-CPR) and aid rescuers at the OHCA scene. The primary concept behind the development of these devices is that a mechanical device may provide more effective and consistent CPR as compared with

[1]Theda Clark Regional Medical Center, Neenah, WI.

[2]Gold Cross Ambulance Service, Menasha, WI.

[3]The Integra Group, Brooklyn Park, MN.

[4]ZOLL Medical Corporation, Chelmsford, MA.

Dr. Westfall has received modest research grant support from ZOLL Medical Corporation. Mr. Krantz has received significant research grant support from ZOLL Medical Corporation. Mr. Mullin has served as a consultant for ZOLL Medical Corporation. Dr. Kaufman is an employee of ZOLL Medical Corporation.

For information regarding this article, E-mail: mwestfall@sirkpath.com

DOI: 10.1097/CCM.0b013e31828a24e3

M-CPR as the device would not fatigue and may provide more consistent compression recoil (upstroke phase of chest compression cycle). Furthermore, defibrillation can be performed during ongoing mechanical chest compressions, thereby reducing the perishock time which is known to be an independent predictor of survival from shockable OHCA (3). At present, there are two devices that are commercially available and have extensive published clinical data: a load-distributing band CPR (LDB-CPR) device (AutoPulse, ZOLL Medical Corporation, Chelmsford, MA) that provides circumferential thoracic compressions and a piston-driven CPR (PD-CPR) device (LUCAS, Physio-Control Inc., Redmond, WA) that provides sternal compressions. In preclinical investigations, the LDB-CPR device improved coronary perfusion pressure and myocardial blood flow (4) and resulted in superior survival and cerebral performance as compared with M-CPR (5). Similarly, preclinical porcine investigations with PD-CPR have shown improved coronary perfusion pressure, cardiac output, and ROSC rates with PD-CPR versus M-CPR (6).

Logistical and ethical challenges involved with conducting OHCA research have limited the number of studies that can be undertaken. These challenges might also contribute to why no singular clinical investigation has been able to clearly show the efficacy of mechanical chest compression devices in OHCA. A common method to assess the potential value of an intervention in such difficult research scenarios is the meta-analysis. This method requires a systematic review of all available data and the utilization of all study-level statistics to quantify the overall magnitude of the effect of the therapy across studies. The particular advantage of meta-analyses is that smaller clinical trials of varying sample sizes and designs, including observational studies, can be combined to broaden the base of data used to estimate treatment effects (7).

To date, there are limited survival data allowing the comparison of mechanical chest compression devices with M-CPR. Despite insufficient data, a large body of evidence exists on the effects of these devices on ROSC rates. The rate of ROSC may be viewed as an indicator of prehospital chest compression quality. Given that longer term (> 4 hr) survival data can be influenced by variances in treatment for OHCA patients once admitted to the hospital (i.e., utilization of hypothermia within emergency department [ED], pharmacologic and/or other interventions such as catheterization, treatment of pulmonary embolism), the difference in rates of ROSC between manual and mechanical chest compressions in the prehospital setting is less likely to be influenced by confounding factors as compared with the hospital setting. The purpose of this systematic review of literature was to examine the rates of ROSC from LDB-CPR and PD-CPR and compare with M-CPR.

MATERIALS AND METHODS

A meta-analysis was performed to compare LDB-CPR and PD-CPR with M-CPR with the primary endpoint of being the ability to achieve ROSC. ROSC was defined as any palpable pulse with measurable blood pressures for at least 1 minute. Selection criteria for the meta-analysis required that studies must be human controlled (randomized, phased, historical, or case-control) investigations with confirmed OHCA cases. Thus, studies including cardiac arrests due to trauma and preclinical animal studies were excluded. Searches were conducted in MEDLINE, the ClinicalTrials.gov registry, and bibliographies on manufacturer websites for studies written in English. The comprehensive search identified a total of 443 possible citations (MEDLINE = 376, manufacturer websites = 67) in which 63 of the citations from the manufacturer websites were duplicates from the MEDLINE search. The manufacturer websites provided an additional six studies (abstracts) with data meeting the inclusion criteria. The primary reason for exclusion was irrelevance (i.e., studies not related to mechanical chest compression use in OHCA) or preclinical/manikin studies (see **Fig. 1** for additional information). After exclusion, a total of 12 studies were found to meet inclusion criteria (**Table 1**).

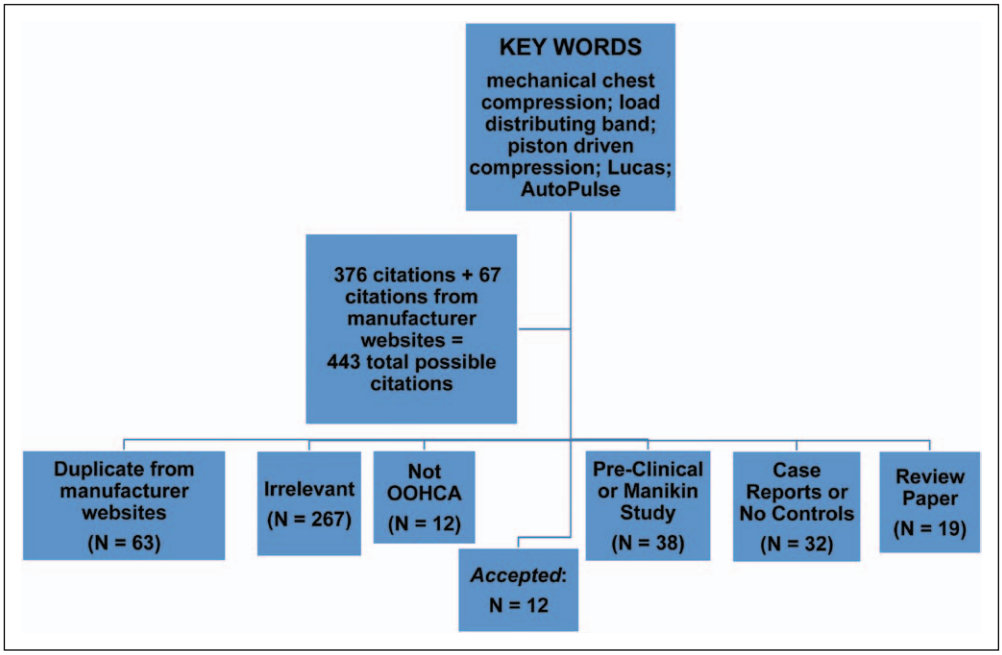

Figure 1. Flow diagram of search criteria and reason for exclusion. OHCA = out-of-hospital cardiac arrest.

Statistical Analysis

Random effects models were used to assess the relative effect of treatments on ROSC. An important metric of quality for any meta-analysis model requires a test for heterogeneity or the amount of variation in outcome between studies. Variation in outcome by study was

TABLE 1. Summary of Studies Included in the Systematic Review

Author	Study Year	Study Design	Publication Type	Participant Demographics	Adverse Events	Outcome Measured	Risk of Bias Assessment/ Quality
LDB-CPR vs M-CPR studies							
Casner et al (8)	2005	Retrospective case-control	Journal	Female = 46%, mean age = 68 ± 16, noncardiac etiology for OCHA unknown, witnessed arrest proportion unknown	Not reported	ROSC	Inadequate reporting of patient demographics, variable time of deployment of device
Ornato et al (9)	2005	Retrospective cohorts	Abstract	No detailed description provided	Not reported	ROSC	Inadequate reporting of patient demographics and adverse events
Hallstrom et al (10)	2006	Prospective, multicenter randomized controlled trial	Journal	Female = 36%, mean age = 67 ± 16, noncardiac etiology for OCHA excluded from analysis, witnessed arrest = 46.5%	Trends for reduced survival compared with M-CPR lead to early termination of study	ROSC, died at scene, survival 4 hr after 911 call, survival to hospital and to discharge, Cerebral Performance Category score	Allowed modifications of protocol between sites
Ong et al (11)	2006	Phased, observational cohort	Journal	Female = 43%, mean age = 67 ± 16, noncardiac etiology for OCHA = 75%, witnessed arrest = 49.7%	Not reported	ROSC, survival to hospital admittance and to discharge	74 of 284 patients in LDB-CPR group did not have LDB device applied, inadequate reporting of adverse events
Swanson et al (12)	2006	Retrospective cohorts	Abstract	No detailed description provided; no differences between groups for age, gender, proportion of witnessed arrest and bystander CPR	Not reported	ROSC, survival to emergency department	Inadequate reporting of patient demographics and adverse events
Steinmetz et al (13)	2008	Phased, observational cohort	Journal	No detailed description provided	Not reported	ROSC, 30-d survival	Inadequate reporting of patient demographics and adverse events
Paradis et al (14)	2009	Nonrandomized cohort	Abstract	Female = 35%, mean age =71 ± 5, noncardiac etiology for OCHA unknown, witnessed arrest = 39%	0.8% event rate including events "consistent with any form of CPR"	ROSC, ROSC sustained to emergency department	Inadequate reporting of adverse events

(*Continued*)

TABLE 1. (*Continued*). Summary of Studies Included in the Systematic Review

Author	Study Year	Study Design	Publication Type	Participant Demographics	Adverse Events	Outcome Measured	Risk of Bias Assessment/ Quality
Lundy et al (15)	2009	Phased, observational cohort	Abstract	No detailed description provided; no differences between groups for age, gender, proportion of witnessed arrest and bystander CPR	Not reported	ROSC	Inadequate reporting of patient demographics and adverse events
PD-CPR vs M-CPR studies							
Axelsson et al (16)	2006	Prospective cluster randomization	Journal	Female = 37%, median age = 73, cardiac etiology for OCHA = 66%	Rib fractures, flail chest, skin irritation, movement of device onto abdomen	ROSC, survival to hospital and to discharge, CPC score at hospital discharge	34% of patients randomized to device did not receive treatment from device, excluded nonwitnessed OHCA from analyses
Rubertsson et al (17)	2007	Randomized pilot study	Abstract	No detailed description provided; no differences between groups for age, gender, proportion of witnessed arrest and bystander CPR	Not reported	ROSC, survival to hospital and to discharge	Inadequate reporting of patient demographics and adverse events
Wilde et al (18)	2008	Observational, nonrandomized	Abstract	No detailed description provided; no differences between groups for age, gender, proportion of witnessed arrest and bystander CPR, and initial rhythm of ventricular fibrillation	Not reported	ROSC, survival at 3 mo	Inadequate reporting of patient demographics and adverse events
Smekal et al (19)	2011	Prospective randomized	Journal	Female = 32%, mean age = 69 ± 16, cardiac etiology for OCHA = 66%, witnessed arrest = 68%	Not reported	ROSC, ROSC with blood pressure above 80/50 mm Hg for at least 5 min, survival to hospital and to discharge	Inadequate reporting of adverse events

LDB-CPR = load-distributing band cardiopulmonary resuscitation, M-CPR = manual cardiopulmonary resuscitation, OCHA = out-of-hospital cardiac arrest, ROSC = return of spontaneous circulation, CPR = cardiopulmonary resuscitation, PD-CPR = piston-driven cardiopulmonary resuscitation.

assessed with Cochran's Q statistic. Forest plots, with 95% CIs, were used to assess the overall meta-analytic and study-specific treatment effects. Another metric of quality for meta-analyses is the asymmetry of the effect sizes for each respective study. This metric can be used to help determine if a single study is an outlier and if there should be concern regarding reporting bias (i.e., only studies that found significant differences were published). Funnel plots and Egger's regression test were used to assess the potential for reporting bias.

For studies where unmatched and matched cohorts were analyzed (19, 8), only the matched results were used. For the study by Hallstrom et al (10), the results of the primary endpoint (survival > 4 hr with ROSC) were used for analysis in place of "any ROSC." Analyses were performed with the *metafor* package for R, version 2.9.2 (R Development Core Team, 2009).

Because there were several potential study-specific characteristics that could have had a significant influence on the outcome variable and introduce the risk of bias, a series of meta-regression models were fit with each covariate included as a sole covariate due to the limited number of studies. Covariates examined included the year of publication, publication type (manuscript vs abstract), device type, percentage of female subjects, average age of participant, percentage of patients with witnessed OHCA, percentage of patients with bystander CPR, the percentage of patients with presenting rhythm of pulseless electrical activity, the percentage of patients with presenting rhythm of asystole, and the percentage of patients with presenting rhythm of ventricular fibrillation/tachycardia. Variables were mean centered for interpretability as appropriate.

RESULTS

A total of 12 studies (LDB-CPR vs M-CPR = 8, PD-CPR vs M-CPR = 4), comprising a total of 6,538 subjects with 1,824 ROSC events, met the selection criteria. Although an analysis combining both mechanical CPR devices produced a significant treatment effect in favor of higher odds of ROSC with mechanical CPR devices (odds ratio [OR], 1.53 [95% CI, 1.32, 1.78]; $p < 0.001$), a meta-regression examining device type (LDB-CPR and PD-CPR) yielded a p value that approached significance ($p = 0.0521$), which indicated that the magnitude of the treatment effects may not be the same for each device when being compared with M-CPR. Furthermore, when device type was analyzed separately, the treatment effect for PD-CPR was not significant (OR, 1.25 [95% CI, 0.92, 1.68]; $p = 0.151$) (**Fig. 2**). There was no evidence of heterogeneity ($Q = 1.326$; $p = 0.723$), and the estimate of total heterogeneity (τ^2) was 0.00 with none of the studies on their own achieving statistical significance for the OR. There was no evidence of asymmetry in the funnel plot, and the p value from Egger's regression test was 0.269.

The pooled meta-analytic results for LDB-CPR studies were statistically significant (with an OR 1.62 [95% CI, 1.36, 1.92], $p < 0.001$) indicating an increased odds of ROSC for LDB-CPR compared with M-CPR (**Fig. 3**). Although there was no significant evidence of heterogeneity ($Q = 10.805$, $p = 0.147$), the estimated total amount of heterogeneity (τ^2) was 0.0233 and percent of total variability due to heterogeneity (I^2) was 38.45%. All studies showed an effect in a favorable direction for LDB-CPR, and five of eight studies achieved statistical significance for the OR on their own. Although the number of studies was small, a funnel plot showed reasonable distribution with a nonsignificant test for asymmetry ($z = 0.714$; $p = 0.475$), indicating no significant statistical evidence of publication bias.

Table 1 provides additional data regarding the study quality and bias of studies included in the meta-analysis. Several studies, regardless of mechanical chest compression device type, had poor reporting of patient demographic and adverse event data indicating the need for additional better reported clinical trials. **Table 2** shows the results of the meta-regressions for the M-CPR versus mechanical CPR comparisons. Results reported include the overall adjusted meta-analytic effects and the corresponding 95% CI and p value, as well as the p value for the test of covariates (i.e., whether the covariate was significantly related to the treatment effect). For each model, the number of studies included varied as not all covariates were available for all studies. The results of the meta-regressions of the combined device types (LDB or PD) were consistent with the unadjusted results; there was a significant improved odds as compared with M-CPR (ORs ranging from 1.34 to 1.65, all $p < 0.05$). The percentage of initial rhythms presenting as ventricular fibrillation/ventricular tachycardia were the significant modifiers in

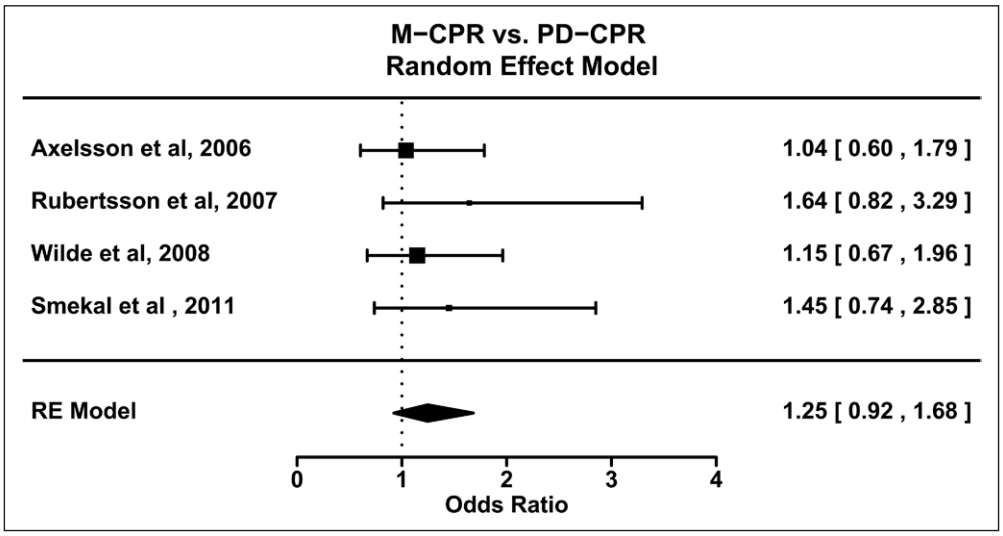

Figure 2. Results of meta-analyses comparing piston-driven cardiopulmonary resuscitation (PD-CPR) with manual cardiopulmonary resuscitation (M-CPR). A nonsignificant trend was observed for increased odds of return of spontaneous circulation with PD-CPR as compared with M-CPR.

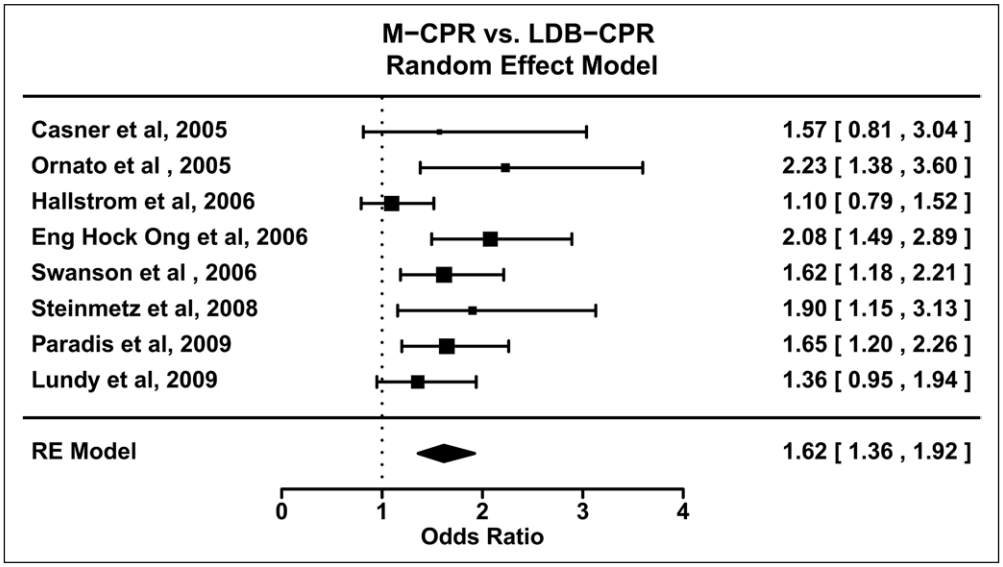

Figure 3. Results of meta-analyses comparing load-distributing band cardiopulmonary resuscitation (LDB-CPR) with manual cardiopulmonary resuscitation (M-CPR). The use of the LDB-CPR device had a significantly greater likelihood of a patient achieving return of spontaneous circulation as compared with M-CPR.

this analysis ($p < 0.05$), and the percentage of male patients approached statistical significance ($p = 0.062$).

DISCUSSION

The continued poor outcomes associated with OHCA require innovative approaches toward treating patients. Previous efforts have included advancements in pharmacologic treatment during arrest, altered recommendations for depth and rate of compressions as well as sequence of compressions to ventilations, the utilization of hypothermia postarrest, and the establishment of national, regional, and local registry databases so that these advanced methods can be tracked for efficacy. Although the application of a mechanical device for chest compressions has been available for nearly 40 years (20), it has failed to gain widespread acceptance both within the hospital and with EMS units probably because of portability and concern of the time needed to apply the device. Recent technological advances have made these devices more portable, lightweight, and quicker to implement. Definitive answers on the efficacy of these devices from the recently completed and ongoing large multicenter randomized clinical trials of each respective device are eagerly awaited. The results of this study indicate a significantly greater likelihood (e.g., approximately 60% higher odds) of achieving ROSC when using the LDB-CPR device as compared with M-CPR. A prospective randomized clinical trial is needed to determine whether improvements in ROSC with use of LDB-CPR translate to improvements in short- and long-term survival as well as neurologic outcome. The rates of ROSC reported in the studies of the PD-CPR device were similar to M-CPR. When the studies from the mechanical

TABLE 2. Manual Cardiopulmonary Resuscitation Versus Mechanical Cardiopulmonary Resuscitation Meta-Regression

Covariate	Overall Adjusted OR	Overall 95% CI	Overall Adjusted *p*	Covariate OR	Covariate 95% CI	Covariate *p*
Publication year	1.61	1.33, 1.94	< 0.001	0.972	0.86, 1.10	0.647
Publication type (journal published vs not)	1.65	1.28, 2.12	< 0.001	0.964	0.66, 1.40	0.850
% Male	1.52	1.30, 1.77	< 0.001	0.962	0.92, 1.00	0.062
Age	1.58	1.30, 1.92	< 0.001	1.063	0.95, 1.19	0.280
% Witnessed	1.51	1.12, 2.03	< 0.001	0.997	0.95, 1.04	0.897
% Cardiopulmonary resuscitation performed by bystander	1.50	1.09, 2.08	0.0142	1.005	0.96, 1.05	0.831
% Initial rhythm pulseless electrical activity	1.61	1.31, 1.99	< 0.001	1.189	0.94, 1.50	0.142
% Initial rhythm asystole	1.60	1.32, 1.94	< 0.001	1.007	0.99, 1.02	0.419
% Initial rhythm ventricular fibrillation/ventricular tachycardia	1.34	1.10, 1.62	0.003	0.958	0.92, 0.99	0.015

OR = odds ratio.

CPR devices were combined, the odds of achieving ROSC were significantly greater when using mechanical CPR as opposed to M-CPR although device type was trending toward being a significant modifier in the meta-regression analyses.

The limited amount and varied definitions of survival data for each respective device prohibited the use of that data as the outcome variable in this meta-analysis. A different meta-analytic approach was recently published on the efficacy of mechanical chest compression devices as compared with M-CPR; it included only four randomized clinical trials that were conducted across a long timeframe (1978–2006) and involved treatment of both in-hospital and out-of-hospital cardiac arrest with varying mechanical chest compression devices (21). This inhomogeneity combined with a small sample size (868 patients of which 767 came from one study) (10) reduced the statistical power of the approach and ultimately lead the authors to a conclusion that there was insufficient evidence to suggest benefit or harm of the devices based on the limited survival data (21). Although survival data are argued to be one of the highest quality and/or most clinically relevant endpoints for a given trial, the use of ROSC as the primary endpoint in this analysis may still provide a valuable assessment of efficacy of the devices. Survival, whether it is defined as survival to hospital discharge or 1-week postdischarge, is a variable that is influenced by a variety of factors that are not necessarily related to the quality of CPR performed in the field and during transport to the ED. Most of these factors are related to the quality of care in the ED (i.e., pharmacologic regimen used and hypothermia induction). The ability to achieve ROSC, however, is closely linked to adequate coronary perfusion pressure via high-quality CPR (22), and thus, the quality of CPR serves as an important variable for determining the value of the devices as compared with M-CPR.

Taken together, the results of this study highlight the potential benefit of using mechanical chest compression devices in OHCA cases. It has been reported that key components to the successful use of these devices are proper training and adequate time for deployment of the device for the given EMS crew (10, 16). Presuming that rescuers are properly trained in rapid deployment of the mechanical chest compression device, overall interruptions in chest compressions can be limited with use of it thereby allowing the rescuer to focus on other aspects of patient care. Another potential important benefit of mechanical chest compression devices is the delivery of consistent high-quality chest compressions during transport to the ED while rescuers are seated and restrained. Performance of M-CPR during transport is both ineffective and unsafe (23).

Limitations

The quality of M-CPR might have varied between studies and therefore might have affected the treatment effect estimates. It is well established that inadequate chest compression depth, rate, and release will reduce the likelihood of obtaining ROSC for a given patient. Although CPR quality data were not available for any of the studies included in the present meta-analysis, future studies comparing mechanical with M-CPR should include CPR quality data because CPR sensing and recording devices are now widely available and recommended for use. One potential barrier to the use of mechanical chest compression devices is cost. Unfortunately, data regarding the cost of lives saved or other cost-benefit financial analyses were not reported in the studies reviewed, but it is important to note that there is also a cost associated with providing the training necessary to ensure the delivery of consistent high-quality M-CPR. The studies used in the meta-analysis included four randomized trials and eight trials using primarily phased, observational cohorts, which could result in a risk of bias which we have assessed as shown in Table 1. When publication type (journal vs abstract) was included as a covariate in our meta-regression model, it was not statistically significant but that does not eliminate the chance of bias influencing our results. Other potential limitations include differences in the personnel of the first responder crews (i.e., local police/firemen, emergency medical technician, advanced life-support-trained paramedics, or physician) between studies, differences in regional policies for first responder crews and methods of M-CPR (as some of the PD-CPR studies were done in Europe and many of the LDB-CPR studies were done in the United States), and changes in standard clinical procedures for OHCA over time (for studies in which historical controls were used). Finally, the tests of moderator effects on outcomes had low statistical power given the few number of studies, and therefore, the results should be interpreted knowing this limitation.

CONCLUSIONS

In this systematic review, the combined meta-analysis of two mechanical chest compression devices compared with manual chest compressions showed a significant improvement in ROSC rates with mechanical devices, but when analyzed separately, only the LDB-CPR device was found to be superior to manual chest compressions with odds of ROSC being 1.6 times greater when using LDB-CPR. The robustness of these findings and the long-term outcome using these devices in OHCA should be tested in large randomized controlled clinical trials.

REFERENCES

1. Sasson C, Rogers MA, Dahl J, et al: Predictors of survival from out-of-hospital cardiac arrest: A systematic review and meta-analysis. *Circ Cardiovasc Qual Outcomes* 2010; 3:63–81
2. Roine RO, Kajaste S, Kaste M: Neuropsychological sequelae of cardiac arrest. *JAMA* 1993; 269:237–242
3. Cheskes S, Schmicker RH, Christenson J, et al; Resuscitation Outcomes Consortium (ROC) Investigators: Perishock pause: An independent predictor of survival from out-of-hospital shockable cardiac arrest. *Circulation* 2011; 124:58–66
4. Halperin HR, Paradis N, Ornato JP, et al: Cardiopulmonary resuscitation with a novel chest compression device in a porcine model of cardiac arrest: Improved hemodynamics and mechanisms. *J Am Coll Cardiol* 2004; 44:2214–2220
5. Ikeno F, Kaneda H, Hongo Y, et al: Augmentation of tissue perfusion by a novel compression device increases neurologically intact survival

in a porcine model of prolonged cardiac arrest. *Resuscitation* 2006; 68:109–118

6. Steen S, Liao Q, Pierre L, et al: Evaluation of LUCAS, a new device for automatic mechanical compression and active decompression resuscitation. *Resuscitation* 2002; 55:285–299
7. Stroup DF, Berlin JA, Morton SC, et al: Meta-analysis of observational studies in epidemiology: A proposal for reporting. Meta-analysis Of Observational Studies in Epidemiology (MOOSE) group. *JAMA* 2000; 283:2008–2012
8. Casner M, Andersen D, Isaacs SM: The impact of a new CPR assist device on rate of return of spontaneous circulation in out-of-hospital cardiac arrest. *Prehosp Emerg Care* 2005; 9:61–67
9. Ornato JP, Peberdy MA, Edwards DP, et al: Improvement in field return of spontaneous circulation using circumferential chest compression cardiopulmonary resuscitation. *Prehosp Emerg Care* 2005; 9:102
10. Hallstrom A, Rea TD, Sayre MR, et al: Manual chest compression vs use of an automated chest compression device during resuscitation following out-of-hospital cardiac arrest: A randomized trial. *JAMA* 2006; 295:2620–2628
11. Ong ME, Ornato JP, Edwards DP, et al: Use of an automated, load-distributing band chest compression device for out-of-hospital cardiac arrest resuscitation. *JAMA* 2006; 295:2629–2637
12. Swanson M, Poniatowski M, O'Keefe M, et al: A CPR assist device increased emergency department admission and end tidal carbon dioxide partial pressures during treatment of out of hospital cardiac arrest. *Circulation* 2006; 114:II–554
13. Steinmetz J, Barnung S, Nielsen SL, et al: Improved survival after an out-of-hospital cardiac arrest using new guidelines. *Acta Anaesthesiol Scand* 2008; 52:908–913
14. Paradis NA, Kamlan D, Ghilarducci D, et al: The California AutoPulse quality assurance registry. *Circulation* 2009; 120:S1457
15. Lundy D, McGeorge W, Silver A: Mechanical chest compressions improve short-term outcome in patients requiring CPR during transport. *Circulation* 2009; 120:S1470–1471
16. Axelsson C, Nestin J, Svensson L, et al: Clinical consequences of the introduction of mechanical chest compression in the EMS system for treatment of out-of-hospital cardiac arrest-a pilot study. *Resuscitation* 2006; 71:47–55
17. Rubertsson S, Huzevka T, Smekal D, et al: Early survival after cardiac arrest in a pilot study using the LUCAS device compared to manual chest compression during CPR. *Circulation* 2007; 116:II–386
18. Wilde RD, Weijden PV, Haan MD, et al: ROSC at hospital admission in out of hospital cardiac arrest using LUCAS. *Resuscitation* 2008; 77:S49
19. Smekal D, Johansson J, Huzevka T: A pilot study of mechanical chest compressions with the LUCAS™ device in cardiopulmonary resuscitation. *Resuscitation* 2011; 82:702–706
20. Taylor GJ, Rubin R, Tucker M, et al: External cardiac compression. A randomized comparison of mechanical and manual techniques. *JAMA* 1978; 240:644–646
21. Brooks SC, Bigham BL, Morrison LJ: Mechanical versus manual chest compressions for cardiac arrest. *Cochrane Database Syst Rev* 2011; 19:CD007260
22. Reynolds JC, Salcido DD, Menegazzi JJ: Coronary perfusion pressure and return of spontaneous circulation after prolonged cardiac arrest. *Prehosp Emerg Care* 2010; 14:78–84
23. Wik L, Kramer-Johansen J, Myklebust H, et al: Quality of cardiopulmonary resuscitation during out-of-hospital cardiac arrest. *JAMA* 2005; 293:299–304