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Pre-shock chest compression pause effects on termination of ventricular fibrillation/tachycardia and return of organized rhythm within mechanical and manual cardiopulmonary resuscitation☆

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ABSTRACT

Background: Shorter manual chest compression pauses prior to defibrillation attempts is reported to improve the defibrillation success rate. Mechanical load-distributing band (LDB-) CPR enables shocks without compression pause. We studied pre-shock pause and termination of ventricular fibrillation/pulseless ventricular tachycardia 5 s post-shock (TOF) and return of organized rhythm (ROOR) with LDB and manual (M-) CPR.

Methods: In a secondary analysis from the Circulation Improving Resuscitation Care trial, patients with initial shockable rhythm and interpretable post-shock rhythms were included. Pre-shock rhythm, pause duration (if any), and post-shock rhythm were obtained for each shock. Associations between TOF/ROOR and pre-shock pause duration, including no pause cases with LDB-CPR, were analyzed with Chi-square test. A *p*-value <0.05 was considered statistically significant.

Results: For TOF and ROOR analyses we included 417 LDB-CPR patients with 1476 and 1438 shocks, and 495 M-CPR patients with 1839 and 1796 shocks, respectively. For first shocks with LDB-CPR, pre-shock pause was associated with TOF ($p = 0.049$) with lowest TOF (77%) for shocks given without pre-shock compression pause. This association was not significant when all shocks were included ($p = 0.07$) and not for ROOR. With M-CPR there were no significant associations between shock-related chest compression pause duration and TOF or ROOR.

Conclusion: For first shocks with LDB-CPR, termination of fibrillation was associated with pre-shock pause duration. There was no association for the rate of return of organized rhythm. For M-CPR, where no shocks were given during continuous chest compressions, there were no associations between pre-shock pause duration and TOF or ROOR.

1. Introduction

Early defibrillation is a key element in the chain of survival for patients with cardiac arrest.[1] Edelson et al.[2] demonstrated that for patients with initial ventricular fibrillation (VF) successful defibrillation was associated with shorter pre-shock chest compression pauses and deeper compressions in episodes with manual chest

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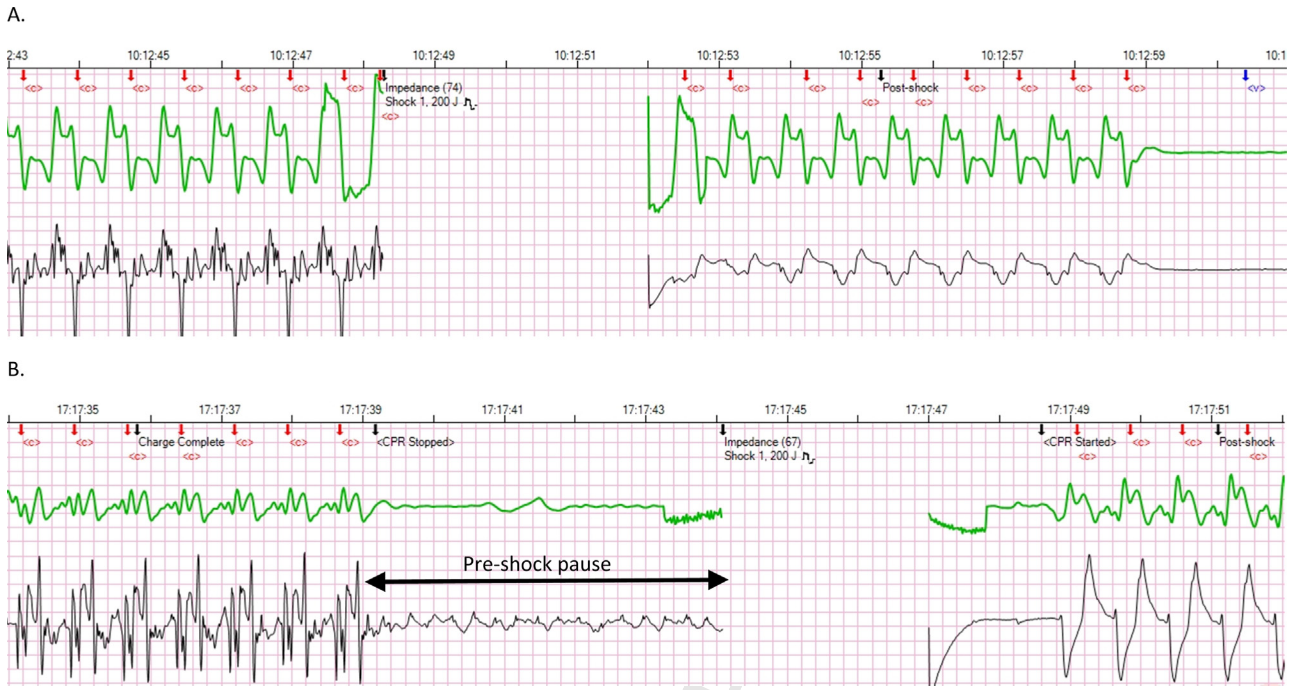

Fig. 1. Example of defibrillation attempts with load-distributing band cardiopulmonary resuscitation. Green line is impedance, and black line is ECG as seen in Code-Stat Reviewer. Cs are chest compressions. (A) Shock during ongoing chest compressions and zero second pre-shock chest compression pause. The shock terminates ventricular fibrillation. (B) A 5 s pre-shock chest compression pause that terminates ventricular fibrillation. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

compressions. CPR guidelines recommend minimizing pre- and post-shock pauses in connection with defibrillation attempts.[3] During mechanical chest compressions it is possible to shock during compressions, thus removing pauses completely (Fig. 1A).

In three recent studies evaluating survival to hospital discharge between manual and mechanical chest compressions, some patients in the mechanical chest compression group received shocks without stopping chest compressions.[4–6] One of these studies, The Circulation Improving Resuscitation Care (CIRC) trial found equivalent survival for out-of-hospital cardiac arrest (OHCA) patients of presumed cardiac aetiology who received integrated load-distributing band CPR (LDB-CPR) with Autopulse (ZOLL Medical Corporation, Chelmsford, MA) compared to high quality manual CPR (M-CPR).[4]

We wanted to investigate what effect different pre-shock chest compression pauses had on termination of ventricular fibrillation/pulseless ventricular tachycardia (TOF) and return of organized rhythm (ROOR) for CIRC patients with initial rhythm of VF or ventricular tachycardia (VT) within the mechanical and manual CPR groups. Our hypothesis was that both LDB-CPR and M-CPR patients would have higher rates of TOF and ROOR with shorter pre-shock pauses, and patients within the LDB-CPR group with zero second pre-shock pauses would have the highest TOF.

2. Methods

2.1. Study population

This was a secondary analysis of data collected during the CIRC-trial and included emergency medical services (EMS) treated adult OHCA patients of presumed cardiac aetiology between March 5, 2009 and January 11, 2011. The trial had exemption from informed consent.[4] AHA 2005 guidelines[7] were followed at the US sites and the 2005 ERC guidelines[8] at the European sites, except that 3 min CPR cycles were used in all sites.[9] Sites used sternal-apical pads position.[3]

Eligible patients had initial VF or pulseless VT, received at least one indicated shock, and had interpretable electronic defibrillator data with transthoracic impedance (TTI) and ECG. Shocks were excluded if not indicated, post-shock rhythm was not interpretable, or pre-shock pause length could not be determined.

2.2. Data collection and processing

ECG and TTI were recorded by the defibrillators [LifePak (LP) 500, 12 and/or 15 (Physio-Control, Redmond, WA) or AED Pro and/or E-series (ZOLL Medical, Chelmsford, MA)] and uploaded to a central server (CIRC database). During the CIRC trial we obtained electronic defibrillator data for 96% of all patients included in the trial.[4] Electronic files from the CIRC database were reviewed using CODE-STAT™ 8.0 or 9.0 (Physio-Control, Redmond, WA) or RescueNet® Code Review 5.5.3 (ZOLL Medical Corporation, Chelmsford, MA). Chest compressions were annotated using TTI[10] or accelerometer data, and heart rhythm using ECG. Chest compression fraction (CCF) was defined as the percentage of time when the patient received compressions during resuscitation. CCF and other CPR metrics were calculated according to methods described by Kramer-Johansen et al.[11]

Pre-shock chest compression pauses were measured from the last compression to shock delivered (Fig. 1A and B) and divided into four groups matching those used by Edelson et al.,[2] pre-shock pause ≥1–9 s, 10–19 s, 20–29 s and ≥30 s, with one added group: shock during compressions (zero second pre-shock chest compression pause).

2.3. Heart rhythm

Reviewers (JAO, MS, and LW) classified all rhythms based on electronic files as asystole, pulseless electrical activity (PEA, ≥10 organized complexes per minute), VF or VT. JAO and MS annotated all initial rhythms independently. Cases where initial rhythm annotations differed were reviewed by JAO and MS together and discussed until consensus was reached. For each shock the following were determined by JAO and LW: pre-shock rhythm, rhythm 5 and 60 s post-shock, and pre-shock compression pause duration (seconds).

Pre-shock rhythms were annotated in periods without compressions. Post-shock rhythms were mainly annotated in periods without compressions except for cases with no chest compression pause where rhythms were evaluated during compressions. During continuous LDB-CPR there is an automatic one-second compression pause after each 9th compression. For LDB cases where the post-shock rhythm was determined through compressions, the first brief pause after the rhythm annotation was used for a confirmatory rhythm evaluation. If this differed from the through-compressions annotation, JAO and LW tried to reach consensus. If no consensus, rhythm was classified as unknown. During M-CPR with compressions during rhythm evaluation, the annotated rhythm was compared with the rhythm in the pause closest to the primary annotation for a secondary rhythm evaluation. Inter-rater reliability of post-shock rhythms for all valid shocks administered during the CIRC-trial was evaluated using Kappa statistic. Cases chosen for this analysis were randomly identified from all evaluated shocks in the CIRC database by SPSS.

TOF was defined as VF/VT termination 5 s after the shock was delivered (i.e., patient could have any other rhythm including asystole),[3] and ROOR as termination of VF/VT and establishment of an organized rhythm (either ROSC or PEA) 60 s after the shock. ROOR has shown to be a more sensitive measure of relative defibrillation shock performance than TOF alone.[12] TOF and ROOR were evaluated for the first shock and for all shocks.

2.4. Statistical analysis

SPSS version 22.0 (IBM SPSS Inc., Chicago, IL) was used for statistical analyses. Normally distributed data are presented as means with standard deviation (SD), and skewed data as medians with 25th and 75th percentiles. Patients randomized to LDB-CPR or M-CPR were analyzed separately. The purpose was not to compare the two groups, but to document the effect of different pre-shock pauses on TOF/ROOR within each group. Chi-square test was used to analyze associations between pre-shock pause groups and TOF/ROOR. $P < 0.05$ was considered statistically significant. Post-shock rhythm inter-rater reliability was assessed by unweighted Kappa statistic with 95% confidence interval (CI) and evaluated according to the recommendations of Landis and Koch.[13]

3. Results

Fig. 2 shows study cohort and exclusions. Of 4231 patients enrolled in CIRC, 1657 received at least one shock with analysable defibrillator data. Shocks were excluded from analysis if they were not indicated, pre-shock pause duration was missing, or rhythm was unknown. We included 417 LDB-CPR patients receiving 1618 shocks of which we performed TOF analysis on 1480 (91%) shocks and ROOR analysis on 1453 (90%) shocks. Of 2089 shocks in 495 M-CPR patients, 1845 (88%) were included in TOF analysis and 1831 (88%) in ROOR analysis. In the 417 patients in LDB-CPR group we had 399 (96%) and 387 (93%) first shock data available and in the 495 M-CPR patients 459 (93%) and 456 (92%) first shock data available for TOF and ROOR analysis, respectively.

Patient characteristics are shown in Table 1 and CPR process data in Table 2. The inter-rater reliability for 1002 post-shock rhythms analyzed had Kappa value of 0.87 (95% CI, 0.84–0.90, $p < 0.001$).

For LDB-CPR first shock TOF and ROOR regardless of pre-shock pause were 333/399 (83%) and 98/387 (25%) and for all shocks 1183/1480 (80%), and 446/1453 (31%), respectively. LDB-CPR pre-shock chest compression pause group was significantly associated with TOF for first shock alone ($p = 0.049$), with only a trend when including all shocks ($p = 0.07$) (Table 3). The lowest TOF rate for LDB-CPR first shock was in the group with shock during compressions (77%), while ≥30 s pre-shock chest compression pauses reached the highest TOF rate (93%). There was no significant association between pre-shock chest compression pause and ROOR.

For M-CPR TOF and ROOR were 387/459 (84%), 124/456 (27%) for first shock and for all shocks 1488/1845 (81%) and 546/1831

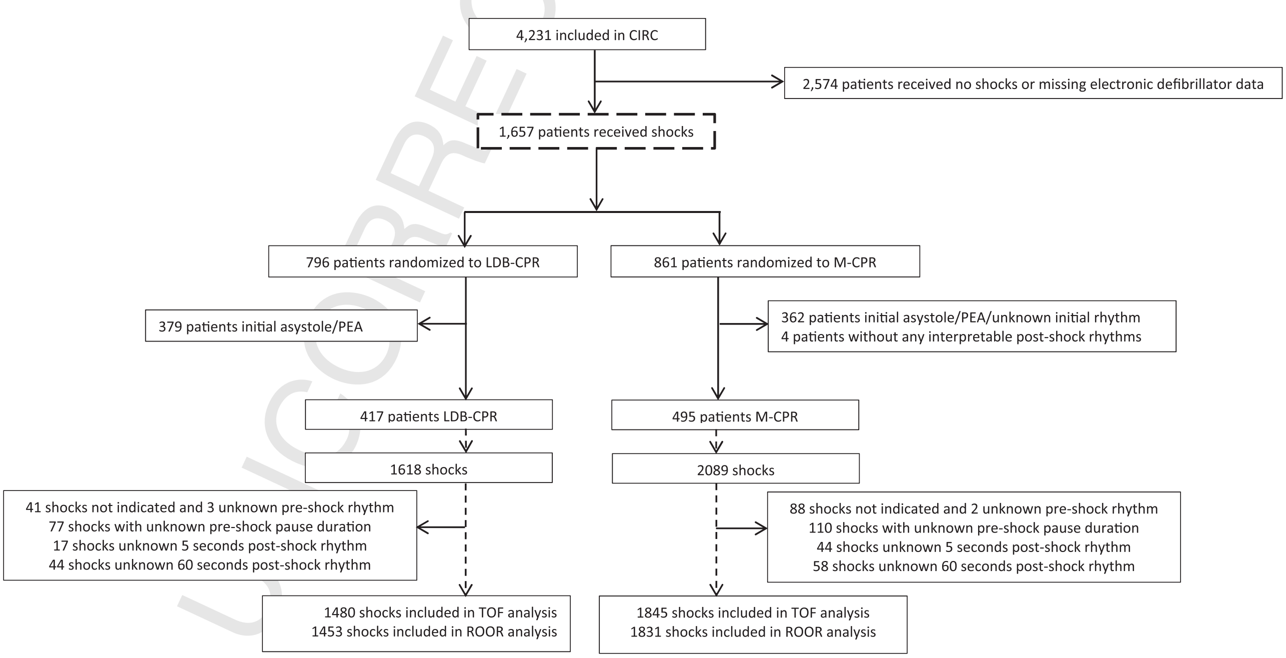

Fig. 2. Consort diagram of study cohort. CIRC – The Circulation Improving Resuscitation Care; PEA – pulseless electrical activity; CPR – cardiopulmonary resuscitation; M-CPR – patients randomized to manual CPR; LDB-CPR – patients randomized to integrated load-distributing band CPR; TOF – termination of ventricular fibrillation/pulseless ventricular tachycardia; ROOR – return of organized rhythm.

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Table 1
Patient characteristics.

	LDB-CPR (*n* = 417)	M-CPR (*n* = 495)
Mean age (SD)	62.4 (14.5)	62.4 (14.2)
Women	101/417 (24%)	123/495 (25%)
Public location	119/417 (29%)	139/495 (28%)
Bystander witnessed	272/401 (68%)	301/477 (63%)
EMS witnessed	24/401 (6%)	40/477 (8%)
Bystander CPR	234/402 (58%)	256/480 (53%)
Mean EMS response interval (m:s) (SD)	6:50 (2:52)	6:44 (2:52)
Mean 911 Call to first shock (m:s) (SD)	15:17 (5:32)	14:35 (6:10)
Mean time from vehicle arrival to first shock (m:s) (SD)	7:31 (5:01)	7:01 (5:52)
Median time from defibrillator on to first shock (m:s) (25, 75)	3:29 (1:41, 5:07)	2:51 (1:19, 4:02)

LDB-CPR – patients randomized to integrated load-distributing band CPR; M-CPR – patients randomized to manual CPR; SD – standard deviation; M:s – minutes:seconds.
(25, 75): 25th and 75th percentile.
Differences in numbers are due to missing values.

Table 2
CPR Process data.

	LDB-CPR (*n* = 417)	M-CPR (*n* = 495)
CCF from pads on to first shock (%) (SD)	60.6 (28.3)	61.2 (29.6)
CCF first 20 min (%) (SD)	77.4 (8.5)	77.3 (9.9)
Compression rate first 10 min, n/min (SD)	86.3 (12.9)*	110.4 (18.5)
Number of compressions per minute first 10 min (SD)	64.5 (10.8)	84.4 (17.7)
Number of ventilations per minute first 10 min (SD)	7.4 (3.0)	9.2 (4.0)
Median pre-shock pause (seconds) (25, 75), first shock	3 (0, 15)	7 (3, 18)
Median pre-shock pause (seconds) (25, 75)	1 (0, 12)	4 (3, 16)
Median number of shocks (25, 75)	3 (2, 5)	4 (2, 5)

LDB-CPR – patients randomized to integrated load-distributing band CPR; M-CPR – patients randomized to manual CPR; CCF – chest compression fraction; SD – standard deviation.
* The LDB-device has a frequency of 80/min, while EMS personnel were instructed to a frequency of 100/min in M-CPR.
(25, 75): 25th and 75th percentile.
Differences in numbers are due to missing values.

Table 3
Termination of fibrillation and restoration of organized rhythm within LDB-CPR compressions related to pre-shock pauses.

	LDB-CPR	
First shock, pre-shock pause	**TOF** $p = 0.049$	**ROOR** $p = 0.28$
Shock during compressions	119/155 (77%)	35/153 (23%)
≥1 < 10 s	94/109 (86%)	34/103 (33%)
10–19 s	61/71 (86%)	15/67 (22%)
20–29 s	31/34 (91%)	6/34 (18%)
≥30 s	28/30 (93%)	8/30 (27%)
All shocks, pre-shock pause	**TOF** $p = 0.07$	**ROOR** $p = 0.10$
Shock during compressions	550/704 (78%)	227/699 (33%)
≥1 < 10 s	299/377 (79%)	115/362 (32%)
10–19 s	180/224 (80%)	52/217 (24%)
20–29 s	92/105 (88%)	27/105 (26%)
≥30 s	62/70 (89%)	25/70 (36%)

LDB-CPR – patients randomized to integrated load-distributing band CPR; TOF – termination of ventricular fibrillations/ventricular tachycardia; ROOR – return of organized rhythm.
Differences in numbers for TOF and ROOR are due to missing values.
The *p*-value represents chi-squared analysis between pre-shock pause duration and TOF or ROOR.

Table 4
Termination of fibrillation (TOF) and restoration of organized rhythm (ROOR) within manual chest compressions related to pre-shock pauses.

	M-CPR	
First shock, pre-shock pause	**TOF** $p = 0.26$	**ROOR** $p = 0.74$
Shock during compressions	–	–
≥1 < 10 s	213/261 (82%)	75/258 (29%)
10–19 s	84/97 (87%)	25/96 (26%)
20–29 s	67/74 (91%)	18/75 (24%)
≥30 s	23/27 (85%)	6/27 (22%)
All shocks, pre-shock pause	**TOF** $p = 0.10$	**ROOR** $p = 0.15$
Shock during compressions[a]	28/35 (80%)	5/35 (14%)
≥1 < 10 s	932/1180 (79%)	363/1174 (31%)
10–19 s	253/309 (82%)	92/305 (30%)
20–29 s	197/228 (86%)	58/227 (26%)
≥30 s	78/93 (84%)	28/90 (31%)

M-CPR – patients randomized to manual CPR; TOF – termination of ventricular fibrillations/ventricular tachycardia; ROOR – return of organized rhythm.
Differences in numbers for TOF and ROOR are due to missing values.
The *p*-value represents chi-squared analysis between pre-shock pause duration and TOF or ROOR
[a] Represent cases where the LDB-device was wrongly used during M-CPR, and since this is an intention to treat analysis it is reported.

(30%), respectively regardless of pre-shock pause duration. There were no significant associations between pre-shock chest compression pause duration and TOF or ROOR for first shock alone or for all shocks combined (Table 4). When analysing all shocks some patients in the M-CPR group received shocks with the LDB-device and thus had shock during compressions.

4. Discussion

The present paper is to our knowledge the first clinical analysis of the impact of LDB-CPR pre-shock chest compression pauses or no pause on electrical termination of ventricular fibrillation/pulseless ventricular tachycardia (TOF) and return of organized rhythm (ROOR). The most interesting finding in this observational study was that shocks administered during continuous mechanical chest compressions did not improve TOF or ROOR. Shorter manual pre-shock chest compression pauses have previously been documented to improve TOF.[2] Administering shocks during compressions are partly based on the guideline recommendation to minimize chest compression pauses related to defibrillation attempts.[3] Of the 1480 shocks included in the TOF analysis for the LDB-CPR group, 704 (48%) shocks were delivered during on-going chest compression.

Both LINC,[5] PARAMEDIC[6] and the present CIRC–trial[4] protocols specify that defibrillation should be attempted without stopping chest compressions.[14,15] None of the studies found a difference in overall survival to hospital discharge between the mechanical and manual CPR groups. Only the present paper, based on the CIRC-trial, reports TOF and ROOR for different pre-shock pause durations or shocks during compressions. The strategy of not pausing chest compressions for defibrillation attempts has recently been questioned in a comment to the LINC-trial. Carron and Yersin[16] raise the issue that the chest wall and heart are subject to morphological changes during chest compression. They discuss if uncoordinated defibrillation during the compression-relaxation cycle may play a negative role in the intervention group based on data from Li et al. who demonstrated that the optimal timing of defibrillation were during the release (upstroke) phase for both manual and mechanical CPR in pigs.[17,18]

Wiggers et al. postulated that a shock must stop all myocytes that fibrillate.[19] Other authors believe that VF must be terminated in a critical mass of the heart (75–90% in dog), and that the shock must prevent fibrillation reinitiation.[20,21] Studies have

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shown that current distribution during a shock is affected by several components including fibre structure, ventricular anatomy, and connective tissue barriers.[22–25] If this holds true clinically, a number of uncontrolled factors during shock may influence TOF. It is estimated that only four percent of the shock energy reaches the heart.[26] Factors potentially influencing TOF include: pad orientation[27] and skin contact, heart orientation in the chest related to the pad's position, heart size, possible movements of the heart, and shock energy. Mechanical chest compressions with LDB-CPR might push the heart in different directions in the chest, thereby influencing current distribution and consequently TOF positively or negatively. The LDB-device has been reported to improve haemodynamic variables in humans[28] and animals including higher coronary perfusion pressure (CPP) compared to manual CPR.[29] Higher CPP is considered to be important for terminating VF/VT.[30] It is therefore surprising that we clinically were not able to show this with continuous compressions during defibrillation when we would expect CPP to be at the highest. We speculate that other factors such as pads position[27] relative to heart orientation and heart movement during compressions may be more important than previously considered.

Another explanation could be that delivery of shock without stopping LDB chest compressions are negatively influenced by load-distributing band devices in their distribution of the chest compression forces both bilaterally and anterior-posteriorly. We are not aware of any clinical study comparing the LDB device with the most used piston (only anterior-posterior compressions) based device (LUCAS). Esibov et al.[31] recently compared TOF for the piston-based LUCAS with manual CPR based on small numbers and according to randomization group from the LINC trial. TOF with LUCAS was 120/164 (73.2%) vs. 81/100 (81.0%) in the manual group ($p = 0.15$). With device use in the LUCAS group TOF was 68.7% for shocks delivered during ongoing chest compressions vs 76.5% for shocks during pauses ($p = 0.32$). Thus numerically the lowest TOF in the LINC study was with shocks during ongoing mechanical chest compressions, and the highest during manual CPR. We can only speculate why TOF was lower with shocks given during compressions in the present study, but in view of the piston device data from Esibov et al.[31] it seems less likely that it is explained only by the different distribution of chest compression forces with the LDB device. An alternative interpretation would be that it is more generally linked to the delivery of a shock during ongoing chest compressions in the clinical situation.

Our findings for first shock TOF within M-CPR contrast previously published negative associations between TOF and increased pre-shock chest compression pause duration with manual compressions for initial shockable rhythms. Edelson et al.[2] reported a significant ($p = 0.002$) dose-response effect on TOF when pre-shock pause duration was divided into increasing 10 second intervals for first shock in 53 patients. Our TOF data are similar to Brouwer et al.[32] who did not find an association between rate of TOF and pre-shock chest compression pause duration for manual CPR. We cannot readily explain why the present results differ from those of Edelson et al. They analyzed fewer shocks than the present study, while both studies are limited by being retrospective analyses without pause length randomization or controlling for potential confounders. It should be noted that CPR in the Edelson et al. study was performed according to pre-2005 guidelines, which differ from the 2005 guidelines used in CIRC where more focus was placed on chest compressions and a single shock strategy. Another factor might have been differences in CPR quality reported as chest compression fraction (CCF) between the studies. Edelson et al. reported median CCF of 85% for the last 30 s before the pre-shock chest compression pause. CCF prior to these 30 s is not reported, but in the primary studies underlying the study by Edelson et al. mean CCF was 52%[33] and 76%.[34] In our study mean CCF was 61% in the M-CPR group from defibrillator pads on to first shock, and 77% for the first 20 min of the resuscitation. It is possible that the heart tolerates chest compression pauses better with improved pre-pause perfusion. CCF is one CPR quality factor. Compression depth is another quality indicator,[2,35] which was not available in the present study, but available in the Edelson et al. study. The LDB-device should compress 20% of the chest anterior-posterior diameter.[36]

5. Limitations

Pause duration was not randomly assigned therefore this study identified a possible association, not causality. There are confounding factors that we could not control for including the same patient may have had several defibrillation attempts with varying pre-shock chest compression pauses. Walker et al. found that distribution of failed shocks was not random, and that first shock TOF failure often predicted low efficacy for subsequent shocks.[37] We have not adjusted for known Utstein predictors which may be confounders.[38] Compression depth was not measured. The CPR cycle was performed according to 2005 Norwegian CPR guidelines[9] with 3-min CPR cycles and not the 2005 AHA and ERC recommended 2-min CPR cycles.[7,8]

6. Conclusion

For first shocks with LDB-CPR pre-shock pause was associated with TOF, but not ROOR. For M-CPR no association was found between pre-shock pause duration and TOF or ROOR. The effect of pre-shock pause duration and shock during compressions should be further investigated.

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Clinical Trial Registration: NCT00597207 (http://clinicaltrials.gov/ct2/show/NCT00597207).

Conflicts of interest statement

All authors' institutions received funding from ZOLL for their participation in the CIRC trial. LW represents NAKOS in the Medical Advisory Board of Physio-Control. The authors have no other relevant financial conflicts of interest to report.

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