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Improved chest recoil using an adhesive glove device for active compression–decompression CPR in a pediatric manikin model☆

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Abstract

Objective—We developed an adhesive glove device (AGD) to perform ACD-CPR in pediatric manikins, hypothesizing that AGD-ACD-CPR provides better chest decompression compared to standard (S)-CPR.

Design—Split-plot design randomizing 16 subjects to test four manikin-technique models in a crossover fashion to AGD-ACD-CPR vs. S-CPR. Healthcare providers performed 5 min of CPR with 30:2 compression:ventilation ratio in the four manikin models: (1) adolescent; (2) child two-hand; (3) child one-hand; and (4) infant two-thumb.

Methods—Modified manikins recorded compression pressure (CP), compression depth (CD) and decompression depth (DD). The AGD consisted of a modified oven mitt with an adjustable strap; a Velcro patch was sewn to the palmer aspect. The counter Velcro patch was bonded to the anterior chest wall. For infant CPR, the thumbs of two oven mitts were stitched together with Velcro. Subjects were asked to actively pull up during decompression. Subjects' heart rate (HR), respiratory rate (RR) and recovery time (RT) for HR/RR to return to baseline were recorded.

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Conflict of interest
The authors have no conflict of interest to declare.

Subjects were blinded to data recordings. Data (mean ± SEM) were analyzed using a two-tailed paired *t*-test. Significance was defined qualitatively as $P \leq 0.05$.

Results—Mean decompression depth difference was significantly greater with AGD-ACD-CPR compared to S-CPR; 38–75% of subjects achieved chest decompression to or beyond baseline. AGD-ACD-CPR provided 6–12% fewer chest compressions/minute than S-CPR group. There was no significant difference in CD, CP, HR, RR and RT within each group comparing both techniques.

Conclusion—A simple, inexpensive glove device for ACD-CPR improved chest decompression with emphasis on active pull in manikins without excessive rescuer fatigue. The clinical implication of fewer compressions/minute in the AGD group needs to be evaluated.

Keywords

Cardiopulmonary resuscitation; Infant; Child; Active compression–decompression; Pediatric resuscitation; External chest compression

1. Introduction

Incomplete chest decompression or recoil leaves residual positive intrathoracic pressure (relative to atmospheric) that decreases venous return and thus both coronary and cerebral perfusion.[1–3] Various chest compression techniques[1,2] and devices[4] have been used to improve chest recoil during CPR in adults. Active compression–decompression CPR (ACD-CPR) requires active lifting of the anterior chest wall by the rescuer during the decompression phase of CPR.[5,6] In animals, ACD-CPR generates higher cardiac output, and coronary and cerebral perfusion pressures.[7–9] In adults, ACD-CPR improved hemodynamics during CPR[5,10] and improved resuscitation rates, both in-hospital[11,12] and out-of-hospital.[13] In adults, ACD-CPR is often manually performed with a hand-held suction cup device with a pressure gauge to compress as well as actively decompress the chest (Ambu CardioPump™),[5] or with a pneumatically driven mechanical piston device called LUCAS[4,14,15] that is applied to the chest wall. Although ACD-CPR is an optional technique for adult CPR, especially in-hospital, it is not recommended for use in children due to lack of studies[16] and because no device is available to apply this technique in infants and children.

Manual active decompression during ACD-CPR can increase rescuer work and potentially accelerate the onset of fatigue compared to S-CPR. Shultz et al. reported approximately 25% more work to perform manual ACD-CPR with a hand-held suction device compared with standard CPR in an adult manikin model.[17] In another study, 56% of the participants felt that the ACD device was not easy or was very difficult to use; taller rescuers operated the ACD device more easily.[18]

This study of ACD-CPR in adolescent, child and infant size manikins used a simple, inexpensive adhesive glove device (AGD) (1) to evaluate the feasibility to achieve ACD-CPR during lone rescuer chest compression in an adolescent, child and infant manikin model and (2) to assess the development of rescuer fatigue during AGD-ACD-CPR as judged by objective and subjective measurements as compared to S-CPR. We hypothesized

that ACD-CPR using our adhesive glove device will improve chest decompression compared to S-CPR but result in more rescuer fatigue during adolescent, child and infant manikin chest compression.

2. Materials and methods

This prospective randomized "split-plot" study was approved by the University of Florida Health Science Center Institutional Review Board and was compliant with the Health Insurance Portability and Accountability Act of 1996 (HIPAA) regulations.

2.1. Manikin and data collection system

Standard Laerdal™ (Laerdal Medical, Stavanger, Norway) adolescent (Resusci Anne, adult size), child (Resusci Junior, approximately 6 years) and infant (ALS baby trainer, approximately 3 months) manikins were modified by the Biomedical Engineering Department at the University of Florida to digitally record compression rate (CR), compression depth (CD), decompression depth (DD), compression pressure (CP) and total compressions given per minute.

For CD recording, each manikin was fitted with a linear potentiometer between the anterior and posterior chest plates close to the spring housing (Fig. 1). To record DD, the potentiometer was compressed to about 10% of the total depth under the chest plate at baseline so that the decompression phase of CPR was recorded as a negative deflection. Readings from the potentiometer were transferred to a bioamplifier by ADInstruments Power lab® Systems (Castle Hill, NSW 2154, Australia), which then sent real time continuous compression depth changes to a laptop computer. Computer software (Chart V4.1 by ADInstruments Power lab® Systems; Castle Hill, NSW 2154, Australia) was used to record chest CD and to calculate compression rate, speed and magnitude of chest recoil. The sampling rate for data collection was set at 100 data points per second.

For CP measurement, a 100 ml bag containing about 80 ml of saline was placed between the chest wall and the chest plate in each manikin (Fig. 1). Fluid-filled tubing from the bag was connected to a digital pressure transducer ISE40 with pressure range 0–1 Megapascal (MPa) (SMC Corporation, Indianapolis USA). Data from the transducer was transferred to the bioamplifier and recorded using the same software mentioned above at a sampling rate of 100 data points per second. Peak CP and mean CP were calculated using the same software. The pressure transducer was calibrated using a standard mercury manometer.

All the manikins were placed on a height adjustable hospital stretcher with wheel locks to mimic actual conditions of in-hospital CPR. Stretcher height was adjusted to the iliac crest of each rescuer for standardization.

2.2. Adhesive glove device description

The adhesive glove device consisted of an oven mitt modified to expose the fingers and thumb allowing interlocking of the fingers and an adjustable strap for proper fit on the dorsum aspect of the glove. A Velcro patch was sewn to the palmer aspect of the glove. The

counter Velcro patch was bonded to the manikin chest wall using an adhesive pad to which the Velcro patch was glued (Fig. 2A).

To perform infant ACD-CPR, the device consisted of the thumb portion of two oven mitts sewn together with the Velcro adhesive patch stitched on the underside with an encircling adjustable strap for proper fit (Fig. 2B). The counter Velcro patch was bonded to the manikin chest wall. This setup allows rescuers to perform active decompression during two-thumb CPR.

2.3. Subject recruitment and monitoring

Study subjects were recruited using IRB approved study flyers and posters throughout the University of Florida Health Science Center over 12 weeks. No subjects were recruited from PALS or BLS classes. Inclusion criteria were certified BLS or Pediatric Advanced Life Support (PALS) health care providers. Exclusion criteria were expired certification or any medical condition contraindicating exertion required for CPR. Informed consent was obtained and demographic information including age, sex, gender, weight, and height was recorded. Other data collected included time since certification, field of work and experience. A standard cardiopulmonary monitor was used to display heart rate (HR) and respiratory rate (RR) via chest leads attached to the rescuer. HR and RR were recorded by the researcher at each minute. At the end of the study session each subject completed a Likert scale based questionnaire on subjective feeling of fatigue and degree of difficulty performing CPR with the adhesive glove device.

2.4. Study protocol

After enrollment, the study objective was explained but subjects were blinded from details of the type of data and parameters recorded. Baseline HR and RR were recorded at rest once these values had stabilized. Subjects were block randomized to one of four pediatric BLS groups: (1) adolescent; (2) child two-hand; (3) child one-hand; and (4) infant two-thumb with further randomization to the order of CPR (either the AGD-ACD-CPR then S-CPR or the reverse). Patients were further randomized to either 15:2 or 30:2 CPR. For this report, we analyzed only 30:2 CPR. For these sessions, subjects were instructed to provide CPR at a compression rate of 100/min, with a compression to ventilation ratio of 30:2. The AGD-ACD-CPR group was told to actively pull up during the decompression phase, but they received no further instruction on how to perform CPR and there was no pre-trial training. All subjects were instructed to simulate mouth to mouth ventilations.

The session lasted for a maximum of 5 min, or until they were unable to perform any longer. After 5 min of CPR, rescuers rested while being monitored continuously until their HR and RR returned to baseline and they subjectively felt ready to perform CPR again. This time interval was recorded as the recovery time (RT). After recovery each subject performed CPR using the alternative technique. When both AGD-CPR and S-CPR were completed, subjects completed the study questionnaire regarding difficulty of performing CPR due to fatigue and CPR effectiveness.

2.5. Statistical consideration

Baseline was the linear potentiometer value prior to the first compression from which the CD and DD were calculated. The maximum DD for each decompression cycle was then averaged for each cycle of 30 decompressions to generate a decompression cycle mean depth. The decompression cycle means from 5 min of CPR were then averaged to generate a subject mean. Each of the subject means was then normalized by subtracting the subject mean depth from the respective baseline value. All data analyses were conducted on the normalized data using PC-SAS V9.1.3 (SAS Institute; Cary NC). For the major analyses, comparison of mean decompression difference and chest compressions given per minute, the primary inference was based on the paired difference S-CPR vs. AGD-CPR, stratified across the four manikin-techniques. The inferences were based upon the stratified *Z*-statistic, equally weighting these four strata. Assuming a correlation between repeated measures of at least 0.5 (it turned out to be higher, making this power analysis conservative), the study had over 80% power to detect a difference of 0.37 standard deviations in the raw measures at $P = 0.05$, two-sided. Where the stratified analysis was significant at $P < 0.05$, two-sided, two-sided *t*-tests for each of the four conditions were also presented.

Secondarily, we analyzed the rescuer's vital sign data, comparing mean HR increases per minute (slopes), mean RR increases (slopes), and RT between S-CPR and AGD-CPR, separately for each manikin condition, via two-sided paired *t*-tests.

3. Results

The study subjects' demographic information is shown in Table 1. Most study subjects were experienced pediatric health care providers and more than half were certified in PALS. All study subjects finished the full 5 min of CPR.

3.1. Decompression outcome variables

Among all groups, AGD-ACD-CPR resulted in statistically significant improved DD (Table 2). Significantly more subjects achieved complete CD to baseline or active decompression beyond baseline among all pediatric groups with AGD-ACD-CPR. None of the subjects in adolescent and very few subjects in child two-hand, child one-hand and two-thumb in S-CPR group achieved complete decompression to baseline (Fig. 3).

Chest CD and CP were not significantly different between AGD-ACD-CPR and S-CPR across all pediatric groups. There was no significant difference in chest compression depth over time in any group with both techniques (data not shown). There were significantly fewer chest compressions per minute with AGD-ACD-CPR compared to S-CPR with an average of 7% less in adolescent, 12% in child two-hand, 9% in child one-hand and 6% less in the infant two-thumb group (Table 2).

3.2. Fatigue variables

Objective fatigue variables included maximal increase in HR and RR from baseline during 5 min of CC and RT to baseline (Table 3). Rescuers' HR and RR increased significantly up to 50% above baseline with both techniques across all groups (data not shown). There was no

significant difference in the average increase in HR and RR over 5 min or RT within all the groups with both techniques. We found no significant difference in the rescuer's subjective feeling of fatigue between the groups with both techniques when asked, "At what minute did you want to stop CPR because of fatigue?"

4. Discussion

Our study of single rescuer chest compression using a novel adhesive glove device to perform ACD-CPR in an adolescent, child and infant manikin by health care providers showed that our device resulted in improved chest decompression without any evidence of excessive rescuer fatigue across all four groups compared to standard CPR. Our study also suggests that most pediatric health care providers do not achieve complete chest recoil while performing standard CPR in a pediatric manikin model. To our knowledge this is the first assessment of the feasibility of using ACD-CPR in children.

Although ACD-CPR improves hemodynamics and return of spontaneous circulation rates in adult cardiac arrest victims,[11,12] these hand-held devices are bulky, heavy, relatively expensive and require significantly increased work by the rescuer.[17,19,20] We developed a novel device to be used in all pediatric size patients. Our device has a simple design using a glove and Velcro as an adhesive medium between the glove and chest wall, which could be easily and quickly worn by the rescuer. Since electrode pads adhere quite firmly to skin, we believe electrode pads could be modified to have a central component over the sternum to which Velcro is bonded.

Since the glove device fits a wide range of rescuer's hands and is much lighter than the commercially available adult devices, we believe it would be easy to apply in children. As there was no pre-trial training of study subjects to practice ACD-CPR, our results suggests that the device is easy to use and requires little training to perform ACD-CPR. There were no problems with using the device during the study and study subjects found it easy to use.

No study has evaluated how much decompression depth is needed during ACD-CPR to generate a sufficient negative intrathoracic pressure to achieve improved hemodynamic effects. In a porcine model of ACD-CPR, the active decompression upward suction force was ~25 pounds, but no decompression depth was reported.[21] In our study, the mean difference of decompression (AGD-ACD-CPR minus S-CPR) was −1.8 mm in the adolescent group, −2.49 mm in the child one hand, −2.51 mm in child two-hand and −2.71 mm in the infant group. Most subjects using S-CPR did not achieve complete recoil of the chest to baseline while 38–75% of subjects in different groups using AGD-ACD-CPR achieved chest decompression to or beyond baseline. It is clear that conscious effort is needed to actively decompress the chest when using a device. Because subjects in our study had no prior device training, we believe that with training and practice rescuers will be able to achieve effective active chest decompression with our simple glove device.

There were fewer (by 6–12%) delivered compressions per minute in the AGD-ACD-CPR group than the S-CPR group, probably because it takes longer to actively decompress the chest. Although this was statistically significant across all groups, the clinical significance is not clear. Based on animal studies it is known that well performed chest compression at a

rate of 100/min generates ~25% of normal cardiac output.[22] Theoretically, 6%–12% fewer compressions in ACD-CPR group will decrease cardiac output proportionately. Conversely, ACD-CPR improves cardiac output by increasing venous return,[23,24] therefore, it is possible that fewer compressions will be counterbalanced by improved ejected volume with each compression resulting in an overall net increase of cardiac output. This effect need to be studied in animal models.

Approximately 25% more work is required to perform ACD-CPR with the existing hand-held suction device compared with standard CPR.[17] In one study, 56.4% of the participants felt that the hand-held ACD device was not easy or was very difficult to use. The group who thought the device was easy to use had a greater height, shoulder to iliac crest distance, shoulder to knee distance, and forearm length (i.e., taller rescuers operated the ACD device more easily, and women reported that device operation was more difficult).[18] We evaluated changes in the rescuer's HR and RR over 5 min and recovery time to baseline along with the rescuer's subjective impression of the degree of difficulty and onset of fatigue with each technique. We did not find evidence of increased fatigue with use of our device or any difference in chest compression depth and pressure compared to S-CPR group. Although fatigue may result in the observed reduction in delivered compressions in the ACD-CPR group, none of the other fatigue variables correlates with this; hence we believe this resulted from longer time required to actively decompress the chest.

Our study has several limitations. Although infant, child and adolescent manikins are widely applied in CPR training and resuscitation skills studies, there are intrinsic inadequacies in the model. Specifically, manikin chest stiffness and resistance may not accurately represent these characteristics in the same size human body. The maximum achievable compression and decompression depth was limited by the linear potentiometer. We designed our study to primarily assess chest compression and decompression depth and subjects were asked to simulate rescue breathing. It is likely that if asked to give rescue breaths, rescuers would spend more time delivering ventilations, reducing compression quality and number of delivered compressions/minute. The AGD-ACD-CPR group received instructions to actively pull up during the decompression phase, but no instructions were given to the S-CPR group. We wanted to compare the glove device to "wild type" resuscitation, knowing that providers had undergone BLS training since the 2005 guidelines that emphasized the importance of permitting adequate chest recoil, but we recognize that we assumed the participants had received adequate training on this aspect of CPR performance. Finally, a Hawthorne effect cannot be excluded despite subject data blinding. Since subjects knew they were being observed, their chest compression quality and effort may have been greater.

5. Conclusions

This manikin chest compression study showed that active compression decompression CPR can be achieved with the use of our novel, simple and inexpensive device with emphasis on active pull. Most health care providers do not achieve complete chest recoil during standard CPR. Use of our device to perform ACD-CPR did not result in excessive rescuer fatigue compared to S-CPR. Fewer actual compressions were given during AGD-ACD-CPR, probably because it takes longer to perform decompression. Further studies are needed to

determine the physiologic effects of AGD-ACD-CPR on delivered cardiac output and regional organ perfusion.

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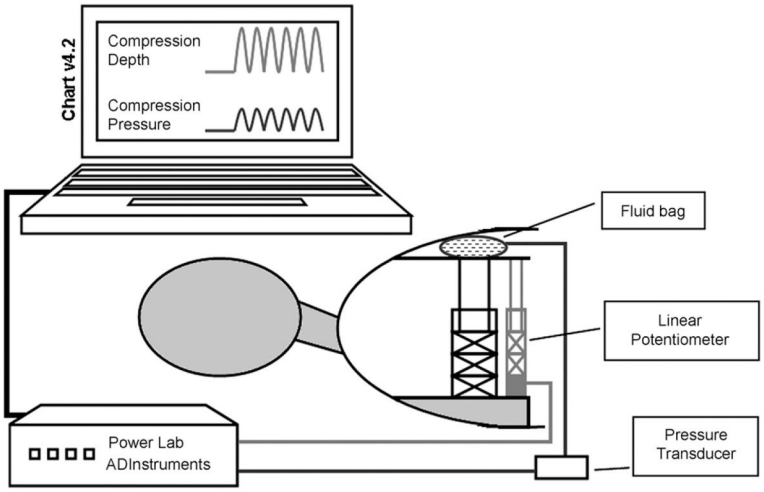

Fig. 1.
Experimental setup.

Fig. 2.

(A) Adhesive glove device for Child manikin. Palmar and Dorsal aspect of the device is shown as (a) and (b), respectively, application to manikin chest is shown as (c) and (d). (B) Adhesive glove device for infant manikin. Ventral and dorsal aspect of the device is shown as (a) and (b), respectively, application to manikin chest is shown as (c) and (d).

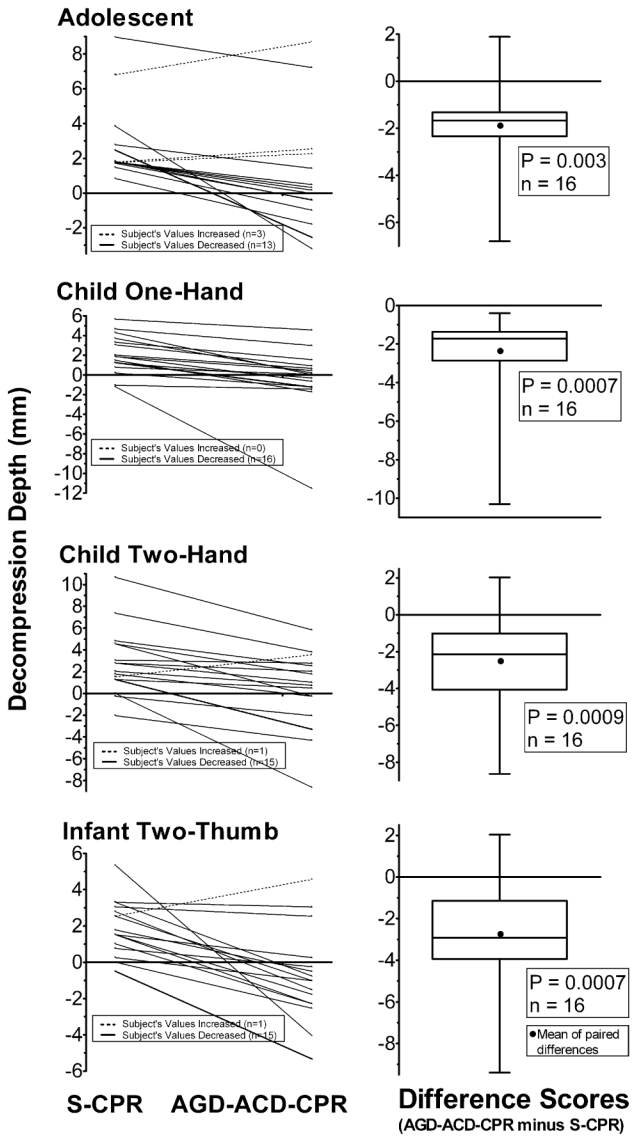

Fig. 3.

Individual rescuer's decompression data and overall difference of decompression mean AGD-ACD-CPR minus S-CPR are shown in all groups. Lower and upper borders of the box represent the 25th and 75th percentile, respectively. Outer lines represent minimum and maximum.

Table 1

Study population demographics (N = 64 subjects).

	N (%)	Mean ± SD	Range
Age (years)	64	31 ± 8	22–63
Gender			
Male	15 (23.4)		
Female	49 (76.6)		
Field of work			
Faculty	5 (7.8)		
Fellows	7 (10.9)		
Residents	19 (29.7)		
RN	16 (25.0)		
Medical/nursing students	5 (7.8)		
Others[a]	12 (18.8)		
Certification			
BLS	28 (43.7)		
Months since last BLS		14 ± 8	0–23
PALS	29 (45.3)		
Months since last PALS		13 ± 8	1–23
Both (BLS + PALS)	7 (10.9)		
Clinical experience (months)	64	52 ± 87	0–504

[a]Respiratory therapists, occupational therapists and pediatric unit clerks.

Table 2

Comparison of chest decompression and compression given for AGD-ACD-CPR vs. S-CPR over 5 min.

	AGD-CPR	S-CPR	Paired differences AGD less S-CPR	*P*-value
Mean decompression difference (mm) (stratified *P*-value <0.001)				
Adolescent two-hand (AD)	0.83 ± 3.18	2.64 ± 2.18	−1.80 ± 2.05	0.0031
Child one hand (OH)	−0.42 ± 3.39	2.06 ± 1.95	−2.49 ± 2.33	<0.001
Child two-hand (TH)	0.37 ± 3.56	2.88 ± 3.08	−2.51 ± 2.44	<0.001
Infant two-thumb (TT)	−0.81 ± 2.53	1.90 ± 1.45	−2.71 ± 2.54	<0.001
Chest compressions given/minute (stratified *P*-value <0.001)				
Adolescent two-hand (AD)	82.5 ± 22.5	90.4 ± 20.4	−7.9 ± 12.1	0.020
Child one hand (OH)	74.6 ± 23.5	85.5 ± 22.4	−10.9 ± 17.1	0.022
Child two-hand (TH)	79.5 ± 22.5	92.3 ± 23.9	−12.8 ± 14.3	0.0029
Infant two-thumb (TT)	96.4 ± 16.3	102.8 ± 21.5	−6.4 ± 11.9	0.049

Table 3

Comparison of changes in heart rate, respiratory rate and recovery time between AGD-ACD-CPR and S-CPR groups as difference of means ± standard deviations.

CPR groups	Increase/minute in HR AGD less S-CPR Mean ± SD, *P*-value	Increase/minute in RR AGD less S-CPR Mean ± SD, *P*-value	Recovery time (s) AGD less S-CPR Mean ± SD, *P*-value
Adolescent (AD)	−0.7 ± 10.9, 0.80	1.7 ± 6.8, 0.31	41.5 ± 118.4, 0.23
Child (TH)	−2.8 ± 12.6, 0.40	2.1 ± 6.3, 0.21	−36.4 ± 128.4, 0.30
Child (OH)	1.0 ± 9.7, 0.66	2.2 ± 4.3, 0.06	4.0 ± 91.3, 0.86
Infant (TT)	0.8 ± 9.1, 0.73	2.1 ± 3.1, 0.02	60 ± 308.6, 0.47