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Improving Chest Compressions Following Cardiac Arrest: Pushing Ahead

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Abstract

In Canada there are in excess of 40,000 annual cardiac arrests. Unfortunately, survival remains low following both out-of-hospital and in-hospital cardiac arrest, and many premature deaths are believed to be preventable. Studies have shown that high-quality chest compressions are key to survival, and the American Heart Association has summarized the need for: 1) adequate compression depth 2) adequate compression rate 3) avoiding leaning 4) minimizing interruptions 5) and minimizing chest rise. However, both laypersons and professionals are failing to reliably achieve these recommendations. Several devices (which provide real-time visual and audio feedback) have been developed with the goal of improving performance. Voice advisory manikins and motion capture technology utilize accelerometer technology and infrared sensors. Portable devices- including the CPREzy™, PocketCPR™, and CPRmeter™- use accelerometer or pressure sensor technology. A number of defibrillators have been modified to provide real-time feedback. Recently, two applications, iCPR and PocketCPR, have been developed to capitalize on the ubiquity and familiarity of smartphones. These novel devices have shown the potential to improve the quality of chest compressions. What is needed is further research (and development) into how to translate these exciting opportunities into improved survival following cardiac arrest.

Keywords: Chest rise; Return of spontaneous circulation; Better resuscitation

Introduction

In Canada alone there are more than 40,000 cardiac arrests per year. Survival to hospital discharge following out-of-hospital cardiac arrest ranges from 3-16% [1,2]. Following in-hospital cardiac arrest, less than 1-in-2 patients achieve return of spontaneous circulation (ROSC); approximately 1-in-3 survive to 24 hours, 1-in-4 to hospital-discharge, and 1-in-5 return to independent living [3]. In short, cardiac arrest, whether out-of-hospital or in-hospital, is a major public health issue associated with substantial premature loss of life.

Approximately 85% of cardiac arrests occur in the out-of-hospital setting. Survival depends upon a complex chain-of-survival that ultimately includes expensive hospitalization and cutting-edge technology [2,4]. However, a key initial survival determinant is whether chest compressions are of high quality (and are initiated promptly). Unfortunately, several studies (both pre-hospital and in-hospital) have demonstrated that chest compressions are often of poor quality, even when performed by professionals [5,6]. Accordingly, the American Heart Association (AHA) has argued that a "care gap" exists, and that mitigating this is a priority [1,7].

The Importance of High Quality Chest Compressions

'Better resuscitation' saves more lives [1]. As outlined by the AHA, 'better resuscitation' is closely related to 'better chest compressions' [1]. Of note, chest compressions deliver only 10-30% of normal cardio-cerebral flow, even when optimally performed. Rather than minimizing the importance of compressions, this underscores that there is no room for suboptimal performance [1]. Moreover, there is also quantitative data linking outcome with how well each of the individual components of compression are performed. By reviewing the evidence, we hope to help educators target 'better' instruction, and practitioners deliver 'better' outcomes.

Chest compression fraction (CCF) is the proportion of time during a resuscitation attempt when the patient is receiving chest compressions. Fewer interruptions are associated with increased ROSC, and increased likelihood of survival to hospital discharge [8-10]. Consensus among experts is that a CCF of 80% is both desirable and achievable [1]. Delays need not be long in duration to be clinically significant. In one study following out-of-hospital cardiac arrest, each five-second pause in chest compressions (pre-shock or peri-shock) was associated with decreased probability of survival-to-discharge of 14-18% [8]. Conversely, increased CCF has been associated with improved survival-to-discharge, such that a CCF of 61-80%, when compared to a CCF of 0-20%, had a favorable adjusted odds ratio of 3.01 (1.37-6.58) [9].

Increasing the rate of chest compressions has also been significantly associated with an improved outcome. Abella et al. [5] demonstrated that, during in-hospital cardiac arrest, the mean compression rate was significantly higher in patients that achieved ROSC, compared to those who did not (90 ± 17 vs. 79 ± 18 compressions/minute, p=0.0033) [11]. Further studies have used statistical modeling to conclude that peak effect occurs at 120-125 compressions/minute [12]. Further increases in rate may not confer additional benefit, due to factors such as the time needed to restore stroke volume, or impedance from excess intra-thoracic pressure. At rates above 120 compressions/minute, there may be an *inverse* relationship between rate and depth: only 30% of practitioners are able to achieve a depth greater than 38 mm, and only 2% achieve a depth of 51 mm [6].

While optimal chest compression depth is less clear, there is a trend towards increased survival with increased compression depth. A review of 1029 out-of-hospital cardiac arrests compared patients who received a compression depth of <38 mm versus 38-51 mm and demonstrated increased depth was associated with increased ROSC (OR 1.24 (0.90-1.70)), and survival to hospital discharge (OR 1.91 (0.95-3.83)) [6]. Another study established that, for every 5mm increase in mean compression depth, the odds ratio for successful defibrillation was 1.99 (1.08-3.66) [13]. The 2010 AHA guidelines recommend a chest compression depth of at least 50 mm (2 inches), or 1/3rd of the anterior-posterior chest ratio [14].

Incomplete recoil occurs when the rescuer leans on the patient's chest preventing the release of positive thoracic pressure. Studies involving humans are understandably limited, but animal studies have shown that leaning decreases venous return, decreases cerebral and coronary perfusion, decreases cardiac index, and decreases left ventricular myocardial flow [15]. Unfortunately, when human rescuers have been studied the majority lean at some point during chest compressions [1].

In order to improve the quality and frequency of chest compressions, the role of oxygen delivery and carbon dioxide removal (i.e. ventilation) has been de-emphasized. Tissue oxygenation is obviously still important, but the blood possesses several minutes of oxygen reserve, and whatever subsequent delivery occurs should occur with minimal disruption to cardiac contraction. Accordingly, the 2010 AHA Guidelines recommend a ventilation rate of less than 12 breaths per minute, and a ventilation volume that produces no more than visible chest rise [14].

In summary, the AHA recently published a consensus statement regarding benchmarks of quality chest compressions, and listed them by strength of evidence:

i. Minimize interruptions

ii. Compress at 100-120 beats per minute

iii. Compress 50 mm/two inches (or 1/3rd of the anterior-posterior depth)

iv. Avoid leaning: to allow for full recoil

v. Avoid excessive ventilation (<12 breaths per minute with minimal chest rise) [1].

So how are we Doing?

By comparing how well chest compressions are typically delivered against what the AHA believes is achievable and desirable, it becomes clear that there is a substantial 'care gap' [1]. For example, work by Adella et al. [5] found that physicians, nurses and medical students (resuscitating in-hospital cardiac arrests) compressed below 90 compressions/minute 28.1% of the time, and below a depth of 38 mm 37.4% of the time [5]. During in-hospital cardiac arrests, compression rates reached 100/minute only 31.4% of the time [11]. Professional out-of-hospital providers (paramedics and nurse-anesthetists) failed to compress at all 48% of the time; and when they did, the mean compression depth was only 34 mm [16]. Inadequate chest recoil (defined as residual force greater than 2.5 kg) has been identified in 91% percent of in-hospital resuscitations [17]. The data, therefore, indicate that current efforts to deliver adequate chest compressions are inadequate. One strategy is to use feedback devices to improve rescuer education and subsequent real-life performance.

Novel Devices to Improve Chest Compression Quality

Devices can be as simple as a metronome to help maintain rate, or as complex as computers that measure compression rate and depth while providing real-time audio and visual feedback (Table 1). The evidence is variable, but suggests overall that the use of feedback/prompt devices leads to better quality chest compression during both simulated and real arrests (Table 2). These devices probably also increase skill acquisition and retention [18]. Notably, it is not currently known if they are associated with improved patient outcome.

Voice advisory manikins (VAM) are CPR manikins connected to a computer, and capable of recording depth, rate and hand placement. First year health care students were randomized to a VAM versus conventional manikin. VAM was associated with better depth and a greater number of 'correct compressions', but no difference in compression rate. When testing was repeated after six weeks, the VAM group continued to perform a greater number of 'correct compressions' [19]. A similar study showed improved compression depth and hand placement in nursing students trained with VAM compared to traditional manikins [20]. Again, there was no significant difference in compression rate between the two groups.

The use of motion-capture technology to provide feedback during simulated chest compressions on standard manikins has also been investigated. One device, which used an infra-red camera combined with a 3-dimensional optical marker attached to a glove, was trialed in volunteers. This device was associated with a modest improvement in both rate and recoil. However, there was no change in recorded depth [21]. An alternative system, which utilized the Microsoft Kinect® motion-sensing device, was associated with an improvement in the frequency of 'correct' compressions: both in terms of depth and compression rate [22].

Several portable feedback devices exist that can be placed between the chest and the rescuer's hands. One device, the CPREzy™, has a pressure sensor for feedback regarding depth and recoil, and a metronome to guide rate. In a crossover manikin study of first-year medical students, those using the CPREzy™ were more likely to perform chest compressions at a correct depth and correct rate [23]. The PocketCPR™ (ZOLL Medical, Chelmsford, MA) uses an accelerometer and a metronome to provide visual and audible prompts regarding compression depth and rate. A randomized study of nurses using the PocketCPR™ on manikins, found a significantly

Feedback devices
Voice-advisory manikins (VAM)
Motion capture technologies
(or virtual reality enhanced manikins, VREM)
Infra-red camera
Microsoft Kinect™
Defibrillators with built in feedback functions
Phillips HeartStart-MrxTM with Q-CPR™
ZOLL Automated external defibrillator (AED) plus/pro™ with Real-CPR-Help™
Portable feedback devices
CPREzy™
PocketCPR™
CPRmeter™
Smartphone applications ("apps")
iCPR™
PocketCPR™ iPhone "app"

Table 1: Examples of feedback devices designed to improve the quality of compressions during CPR.

Feedback devices	The effect of using a CPR feedback device (with vs. without)					
	Compression depth			Compression rate		
	Depth (mm)*	No. at "correct" depth (%)*	P-value	Compressions (rate minute^{-1})*	No. at "correct" rate (%)*	P-value
Voice-advisory manikins (VAM)						
"Skill Reporter" [19]	40.0 vs. 36.7		0.018	106.7 vs. 106.0		ns
Motion capture technologies (or virtual reality enhanced manikins, VREM)						
Infra-red camera [21]	69.0 vs. 65.0		ns	121.5 ± 11 vs. 102.6 ± 18		<0.001
Microsoft Kinect™ (mini VREM) [22]		47.4 vs. 24.9	0.002		72.0 vs. 31.4	<0.001
Defibrillators with built in feedback functions						
Phillips Heart Start-Mrx™ with Q-CPR™ [26]	38 ± 6 vs. 34 ± 9	53 vs. 24	<0.001	109 ± 12 vs. 121±18		0.001
Investigational defibrillator						
(IDE #G020121) [27]	44 ± 10 vs. 43 ± 12		0.47	100 ± 13 vs. 104 ± 18		0.16
Portable feedback devices						
CPREzy™ [23]		71.2 vs. 34.1	≤0.01		93.7 vs. 19.8	≤ 0.01
PocketCPR™ [24]	50.8 ± 10 vs. 38.1 ± 10		0.05	101 ± 9.7 vs. 127 ± 13.8		<0.001
CPRmeter™ [25]		73.1 vs. 45.2	<0.001		94.6 vs. 62.4	<0.001
Smartphone applications						
iCPR™ [31]	37.2 ± 12 vs. 41.1 ± 13		0.57	101.1 ± 3 vs. 107.8 ± 21		<0.01
PocketCPR™ [32]	40.0 vs. 41.0		0.85	92.8 vs. 96.1		0.57
CPR=Cardiopulmonary resuscitation, VAM=voice advisory manikins, VREM=virtually enhanced manikins						
*data presented as intervention group vs. control group						

Table 2: The effect of using CPR feedback devices on compression depth and rate.

improved compression depth and a decreased compression rate that was more consistent with the goal of 100-120 compressions per minute [24]. A prototype portable feedback device has also been studied: the CPRmeter™ (Laerdal, Stavanger, Norway). This uses an accelerometer and pressure sensor to provide visual feedback on depth, rate and recoil. A randomized crossover study performed with health care professionals found that the device was associated with chest compressions of correct depth, rate, and less incomplete recoil [25].

Several defibrillators have been modified to provide audiovisual feedback. These include the Phillips HeartStart-Mrx™ (Phillips, Andover, MA) with Q-CPR™ (Laerdal, Stavanger, Norway), and the ZOLL Automated external defibrillator (AED) plus/proTM with Real-CPR-Help™ (ZOLL Medical, Chelmsford, MA). They use accelerometers to detect depth, rate and recoil (with the Phillips also using thoracic impedance from the defibrillation pads, in order to provide ventilation feedback). A relatively large cluster-randomized trial from the Resuscitation Outcomes Consortium (n=1586) evaluated real-time audio and visual feedback using Q-CPR during out-of-hospital cardiac arrest. Although CCF, compression depth, and recoil improved with the use of feedback, the study did not demonstrate an improvement in ROSC, survival to hospital arrival, or survival to hospital discharge [26]. An investigational defibrillator has also been studied in the setting of in-hospital cardiac arrest. No significant difference was found between groups when comparing compression rate and depth [27].

Using Smartphone Applications to Improve the Quality of Chest Compressions

To be of use in a cardiac arrest setting, feedback devices need to be familiar to the user and accessible as soon as possible. Accordingly, the smartphone is very appealing due to its ubiquity, portability and user-experience. Smartphones are already seeing more bedside use by healthcare professionals. However, their applications also have the potential to help laypersons during out-of-hospitals arrests. There are over six billion mobile phone subscribers in the world [28] and over

27 million in Canada alone [28,29]. Approximately 62% of mobile phone users in Canada have a smartphone. This figure has increased substantially year-on-year, and shows no sign of abating [30]. Research is badly needed to ascertain the clinical role of these devices, but the potential should be obvious.

Many smartphones have built-in accelerometers, similar to those found in custom CPR feedback devices. Currently, there are two widely available smartphone applications that provide feedback: iCPR™ and PocketCPR™. The iCPR™ requires the rescuer to wear the phone on an armband while providing compressions. It provides audio/visual reporting of compression rate and prompts the rescuer to maintain compressions between 95-105/min. Research is limited but a randomized crossover trial of this application (during two minutes of chest compressions) found that users provided rates closer to the target of 100/min. Respondents also reportedly found the device easy to use [31].

PocketCPR™ is a novel application from ZOLL Medical Corporation providing audiovisual CPR instruction and real-time feedback of compression depth and rate. The application directs users to grip their smartphone so that the device moves with each compression. One (albeit small) study evaluated this device in health care professionals. There was no improvement in chest compressions. Of note, there was also a statistically significant delay in initiation of compressions (16.8s vs. 4.8s, p<0.01) [32]. It is no foregone conclusion that these devices will improve clinical outcomes. However this is an exciting area to pursue.

In Closing

Overall, improved chest compressions are associated with improved outcomes, and several feedback devices are associated with improved quality chest compressions. What is missing is a clear evidentiary link between feedback devices and improved clinical outcomes (in either health care providers or lay persons). Technology will advance and with it the promise of ever-more portable and ubiquitous devices (including, for example, smart-watches with inbuilt accelerometers). Cooperation

between healthcare providers, innovators, researchers and educators could lead to the development, dissemination and evaluation of ever more useful devices. Regardless, we need to 'push' ahead.

Brief Summary

To increase survival following cardiac arrest the American Heart Association has called for chest compressions that are: 1) adequate depth 2) adequate rate 3) avoid leaning 4) minimize interruptions 5) and minimize chest rise. However, laypersons and professionals are failing to reliably achieve these recommendations. Novel devices (including smartphone applications) have been developed, and have been shown to improve performance. Further research is needed to ascertain if these exciting strategies will translate to improved survival.

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