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Controversies

The critical need for further research and development of abdominal compressions cardiopulmonary resuscitation☆

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A recent editorial on the science of basic life support (BLS) education acknowledges that, despite nearly 4 decades of public instruction in cardiopulmonary resuscitation (CPR) classes, most people who complete CPR training still do not perform effective basic CPR even immediately after training [1]. But still supports the theory that survival rates for unexpected cardiac arrest depend not only on the quality of the education given to potential caregivers but also on the validity of treatment guidelines and a well-functioning chain of survival [2]. The author emphasizes that these factors hinge on BLS training to the highest level of performance. However, a recent study concluded that even with use of real-time feedback, emergency rescuers fail to sustain chest compression quality according to current guidelines [3]. Therefore, because professional rescuers, and for that matter lay bystanders, cannot even be prompted to perform effective CPR, they certainly likely cannot be trained to perform effective CPR. Although a well-functioning chain of survival can influence survival, it can be argued that increasing the number of efficiently educated CPR providers who do not have adequate height and upper-body weight cannot. In addition to those who have a cardiac arrest with smaller hearts and thoraces, male bystanders, may be another factor that is predictive of patient survival [4,5]. The typical male rescuer is generally stronger and more physically able to perform effective CPR than the typical female rescuer. However, the hidden reason why only very few rescuers can perform effective CPR despite receiving high-quality BLS training and/or while using feedback technology is likely because the typical rescuer lacks a combination of adequate height and upper-body weight.

To perform effective rate (100-120/min) and depth (≥50 mm) CPR with complete sternal recoil, rescuers need to perform high-impulse CPR. High-impulse CPR with its high-velocity short duration compression phase and longer duration decompression phase (or duty cycle adequately <50%) not only produces superior hemodynamics but also apparently produces substantial compression-induced ventilation [6,7]. A longer decompression phase maximizes sternal recoil, thereby increasing venous return, coronary and cerebral perfusion, and inspiratory volume.

When chest compressions are performed with gasping suppressed and with enough force to achieve a compression depth of only 38 mm at a 100/min rate and a 50% duty cycle, there is no compression-induced minute alveolar ventilation [8]. Performing CPR at a rate of 100/min with a 50% duty cycle (or with the duration of compression equaling the duration of decompression) means that a compression is performed every .6 seconds with .3 seconds spent compressing the chest and .3 seconds to allow the chest to completely recoil. However, as evidenced by a lack of passive ventilation, a 38-mm compression depth is not deep enough to displace enough air from the lungs such that it is greater than the dead space [8]; it requires at least 50 mm [7] or more depending on the size of the chest for the displacement of enough air adequately above dead space. Moreover, .3 seconds is not adequate to allow complete recoil after 50 mm of compression depth [8]. To perform high-quality CPR, the compression depth not only has to be deep enough to displace adequately more air out of the lungs than dead space (≥50 mm), but also, recoil time has to be long enough to allow the lung to refill with the amount of air displaced. At a 100/min rate, this likely requires a compression duration of .2 seconds or less and decompression duration of .4 seconds or more (or duty cycle adequately <50%). High-quality CPR at a rate of 120/min (the high end of the recommended compression rate range) means compressions are performed every .5 seconds; therefore, compression must occur within .1 seconds or less because .2 seconds or more only allows .3 seconds or less for complete recoil, which as evidenced, is highly inadequate.

Rescuers without enough height and upper-body weight likely cannot perform high-quality CPR.

In general, men are taller and have significantly more upper-body weight than women, and tall men generally have greater upper-body mass than short men because of their longer torso, and they can exert more of their upper-body weight during chest compression because the higher the rescuer's waist is relative to the patient, the more of the rescuer's upper-body weight can be used to generate force [9]. Because the generation of force/depth during chest compression equals the mass of the compressor (or rescuer's upper-body weight) times acceleration (or velocity of compression), rescuers can increase their compression force by standing on a step stool to "artificially" increase the mass of the compressor by increasing the percentage of their upper weight that they can exert and/or can increase the velocity of compression by increasing their compression rate per minute up to the maximum recommended rate of 120/min. As evidenced by a manikin study of CPR to investigate the impact of a step stool on compression depth and whether there are any unintended consequences in terms of other CPR quality parameters during continuous chest compressions [9], use of a step stool resulted in an average increase in compression depth of 4 mm ($P < .001$), with the effect of being more pronounced in rescuers in the lowest height tertile (9 ± 9

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mm vs 2 ± 6 mm for those rescuers taller than 167 cm, $P = .006$), however, with the adverse consequence of an 18% increase in incomplete recoil ($P < .001$). In a manikin study of the relationship between compression rate and other measures of CPR quality including depth and recoil, it was found that adequate compression depth (≥50 mm) was best maintained with rates more than 120/min [10]. However, although they found that rescuers could significantly improve their force/depth of compression by increasing their rate of compression to more than 120/min, they significantly increased the frequency of incomplete recoil. There were significantly more incomplete chest recoils at the rate of more than 120/min than at any other rates (9.8% [<100/min], 6.3% [100-120/min], and 25.6% [>120/min]; $P = .011$).

It is likely that the rescuers who do not have significant upper-body weight (women and small men) can perform effective rate and force/depth CPR provided that the force necessary to do so is not beyond their physical ability; however, they can only do so with a duty cycle at least 50%, thereby spending too much time to reach peak adequate depth compression with too little time left to allow complete recoil before they have to apply the next chest compression. Without enough upper-body weight, rescuers cannot generate high-force chest compressions that rapidly enough decelerates to a zero velocity at maximum impact occurring at an effective depth of compression, which is necessary to allow enough time for complete sternal recoil. As evidenced, adequate height and upper-body weight of the rescuer, which may only be a characteristic of substantially sized men, may be required to perform effective CPR and could be a factor that is predictive of patient survival. Given the potential dismal reality that typical rescuers do not have the combination of adequate height and upper-body weight necessary to perform effective chest compressions CPR, further research and development of abdominal compressions CPR [8,11–14], which is a low-force [15] and "low-impulse" method of CPR [8] that likely can even be effectively applied by women and small men at duty cycles at least 50%, is critically needed.

The critical need for further research and development of abdominal compressions CPR is not only because few people can perform effective chest compressions, but also because chest compressions are highly unreliably effective due to significant variations in the thoracic configurations of both children and adults. Computed tomographic (CT) assessments of the pediatric chest (ranging from ages ≤1-10 years) estimate that when chest compressions are performed over the lower third of the sternum (the pediatric guidelines recommended hand position), the ascending aorta (AA), the left ventricular inflow tract (LVIT), left ventricular outflow tract (LVOT), or liver underlie the compression point in 0% to 8%, 66.9%, 4.4%, or 28.7% of all cases, respectively [16,17]. A study of the prevalence and outcomes of pediatric CPR on a national scale not only found independent risk factors for mortality after receiving CPR including congenital heart disease, acute renal failure, hepatic insufficiency, and sepsis but also for infants older than 1 year [18], which may be because of differences in thoracic configuration [19]. Computed tomographic assessments of adults estimate that when chest compressions are performed over the internipple line (the adult guidelines recommended hand position), the AA (18.0%-38%), the root of aorta (48.7%), the LVIT (3%-20.6%), LVOT (12.7%), left atrium (23%), and the top of the left atrium (36%) were the underlying structures [20,21]. Transesophageal echocardiography performed during standard CPR in 34 adults showed a significant narrowing of the LVOT (59% of patients) or the aortic root (41% of patients), with the degree of compression at the area of maximal compression ranging from 19% to 83% (mean +/− SD = 49 +/− 19%) [22]. It was suggested that compression over the LVOT or aortic root (including the aortic valve) can adversely affect the efficacy of CPR by increasing resistance to forward blood flow from the left ventricle. Based on the above evidence, it can be postulated that effective chest compressions CPR requires that either the LVIT or AA underlies the compression point of the sternum (or area of maximal compression underneath the sternum) [19,23]. Interestingly, in an in-hospital study of standard CPR in 100 adults, a coronary perfusion pressure (CPP) of greater than 15 mm Hg (the threshold for return of spontaneous circulation [ROSC] was maintained in only 42% of patients [24], which is similar to the 38% of patients with compression occurring over the AA plus the 3% of patients with compression occurring over the LVIT in 100 adults [21]. It could be possible that the phenomenal survival and neurologic outcome found in animals used in CPR research but not in man is because either the AA or the LVIT consistently underlies the compression point of the sternum. However, the fact that studies in pigs [25,26] have shown that interruptions of chest compressions cause a significant decrease of the aortic diastolic pressure and a major systematic decrease in blood pressure compared with the prepause pressure immediately before defibrillation, which takes several seconds (roughly a dozen compressions) to catch up the blood pressure to the level before this interruption, are consistent with the characteristics of an inertial pump mechanism [15] created at the AA [23]. Transesophageal echocardiography studies of chest compressions are needed to confirm this.

Based on the existing evidence, it is possible that abdominal compressions CPR may be necessary in children because chest compressions are either too unreliably effective or have potentially fatal consequences, which make chest compressions contraindicated [19]. Although CT evidence suggests that potentially fatal compression of the liver can be avoided when the chest is compressed at the internipple line instead of the lower third, the effectiveness of CPR can significantly decrease [16]. The LVIT or AA was the underlying structure in only 26% or 10.5% of all cases, whereas the LVOT or the root of the aorta was the underlying structure in 42% or 21.5%. A case report demonstrated that abdominal CPR even when performed during an asystolic arrest is a viable alternative to standard CPR when standard CPR is contraindicated [11]. However, it can be suggested that, in children ranging from ages 1 to 10 years, end-tidal CO_2 ($ETCO_2$)-directed chest compressions in which compression depth and rate are modified to obtain maximal $ETCO_2$ [27], may be an effective method of determining whether chest compressions at the internipple line, which avoids compression of the liver, are effective before attempting abdominal compressions CPR.

According to a mathematical model of a true "cardiac pump mechanism" in which direct compression over the LVIT occurs, maximal systemic perfusion pressure occurs at chest compression rates near 60, 120, 180, and 250/min for subjects weighing 70, 10, 3, and 1 kg, respectively [28]. It was argued that fundamental geometry and physics suggest that the most effective chest compression frequency in CPR depends upon body size and weight. It was postulated that, in neonates, there is room for improvement at the top of the compression frequency scale at rates more than 120/min, and in adults, there may be benefit from lower compression frequencies near 60/min. As suggested by this math model and their CT evidence in neonates, an adequately shallower and much more rapid compression rate than currently recommended in neonates is critical to improve the safety and effectiveness of CPR. Studies of $ETCO_2$-directed chest compressions in pigs comparing compression of the sternum using a one- or 2-finger method of chest compression, which would depend on the size of the subject (one finger for certain-sized neonates [or equivalent neonatal-sized pigs] and 2 fingers for certain-sized infants or [equivalent infant-sized pigs]) [29], vs the currently recommended 2-thumb–encircling hands method, are needed to assess which method does a better job of maintaining effective compressions that are adequately shallower and more rapid. End-tidal CO_2–directed chest compressions (using the experimentally determined most effective method) in which compression depth and rate are modified to obtain maximal $ETCO_2$ may also be an effective method of achieving optimally shallower and more rapid chest compressions in neonates.

On the one hand, the compression location currently recommended by the adult American Heart Association guidelines may not be effective in generating forward blood flow during CPR because