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The impact of a step stool on cardiopulmonary resuscitation: a cross-over mannequin study

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Abstract

OBJECTIVE—Shallow chest compressions and incomplete recoil are common during cardiopulmonary resuscitation (CPR) and negatively affect outcomes. A step stool has the potential to alter these parameters when performing CPR in a bed but the impact has not been quantified.

METHODS—We conducted a cross-over design, simulated study of in-hospital cardiac arrest. Rescuers performed a total of four 2-min segments of uninterrupted chest compressions, half of which were on a step stool. Compression characteristics were measured using a CPR-sensing defibrillator and subjective impressions were obtained from rescuer surveys. Paired analyses were performed to measure the impact of the step stool, taking into account rescuer characteristics, including height.

RESULTS—Fifty subjects, of whom 36% were men, with a median height of 169.8 cm (range 148.6–190.5) volunteered to participate. Use of a step stool resulted in an average increase in compression depth of 4 mm ($p < 0.001$) and 18% increase in incomplete recoil ($p < 0.001$). However, unlike with incomplete recoil, the effect was more pronounced in rescuers in the lowest height tertile (9 ± 9 vs 2 ± 6 mm for those rescuers taller than 167 cm, $p = 0.006$).

CONCLUSIONS—Using a step stool when performing CPR in a bed results in a trade-off between increased compression depth and increased incomplete recoil. Given the nonlinear relationship between the increase in compression depth and rescuer height, the benefit of a step stool may outweigh the risks of incomplete release for rescuers ≤ 167 cm in height. The benefit is less clear in taller rescuers.

Keywords

cardiac arrest; chest compression; cardiopulmonary resuscitation

INTRODUCTION

Deeper chest compressions have been shown to improve patient outcomes and, as a result, the 2010 American Heart Association Guidelines on Cardiopulmonary Resuscitation and Emergency Cardiac Care now recommend at least two inches (five cm) of compression depth.¹⁻³ However, this depth is difficult to achieve in clinical practice, especially in a bed, where the majority of in-hospital cardiac resuscitations take place.⁴

One intervention that has been proposed for this patient population is the use of a step stool while delivering chest compressions.⁵⁻⁷ However, the impact of a step stool on compression depth has not been quantified. Furthermore, it is unknown if there are any unintended consequences in terms of other CPR quality parameters with the use of a step stool.

MATERIALS AND METHODS

Experimental design

A prospective, cross-over, simulated study of in-hospital cardiac arrest was conducted at a university teaching hospital between February and May 2009. We hypothesized that a step stool would result in deeper chest compressions without significantly impacting other aspects of CPR. This study was approved by the University of Chicago Institutional Review Board.

Subjects with active Advanced Cardiac Life Support (ACLS) and/or Basic Life Support (BLS) certification and trained on the 2005 Guidelines were enrolled. All subjects gave written informed consents before participation. A mannequin (Resusci Annie mannequin, Laerdal Medical, Stavanger, Norway) was placed on top of a CPR backboard on a standard hospital bed and mattress (Secure, Stryker Medical, Portage, MI, USA) set at a height of 63.5 cm, the lowest height setting of the bed. Half the subjects started compressions while standing on the floor, while the other started on a 23 cm tall industrial step stool. The first subject was allocated to a starting position randomly via coin toss, with subsequent consecutive subjects alternating group allocation. Each subject performed 4 two-minute compression segments, alternating with each 2-minute segment between standing on and off the step stool (Figure 1).

Immediately following each two-minute segment of compressions, rescuers had a two-minute break in which a five-question survey was administered regarding their level of comfort, fatigue, and impression of the quality of chest compressions they just administered. Subjective responses were scored using a five-point Likert scale where 1=strongly agree, 2=agree, 3=neutral, 4=disagree, and 5=strongly disagree. Each rescuer's age, sex, height and weight were documented. In addition, relative arm strength was determined by the duration of time the subjects could maintain a flexed-arm hang.⁸

CPR quality measurements

Compression depth, rate, duty-cycle, and incomplete recoil were measured using a CPR sensing monitor/defibrillator (MRx with QCPR, Philips Medical Systems, Andover, MA). Compression duty-cycle was defined as the ratio of the compression-time over a compression cycle.⁹ Incomplete recoil was defined as the number of compressions with more than 2.5 kg of force remaining on the chest at the end of the compression.¹⁰ CPR quality parameters displayed on the MRx monitor were hidden from rescuers and audio voice prompts were turned off. Q-CPR Review software v2.0 (Laerdal Medical, Stavanger, Norway) was used to calculate compression statistics for each cycle of compressions. Changes over time were measured for each subject by subtracting the CPR quality in the last 30 seconds of the 4 minute study to the first, with and without the step stool.

Data analysis

All calculations were performed using a statistical software application (Stata Version 11.0, College Station, TX). Means were compared using paired Students' t-test and subject-clustered, multivariate linear regression was used to adjust for potential confounding. Subgroup analyses were performed in each of the three rescuer height tertiles. Significance was set at $p < 0.05$ for all values. We powered the study to detect a difference of 5 mm, which we thought would be clinically significant, based on prior data.^{1,2} Assuming a standard deviation of 5 mm and a paired design, we calculated a sample size of 13 participants at a significance level of 0.05 and a power of 90%. Since we were not able to predict the height distribution of the participants, we increased the sample to 50 in the hopes that we could adjust the analyses for differences in subject height.

RESULTS

A total of fifty subjects volunteered to participate (Figure 1). Their demographics are shown in Table 1. The mean age of rescuers was 33 ± 10 years with a median height of 169.8 cm (range 148.6–190.5 cm). Eighteen (36%) rescuers were male.

The survey results are shown in Figure 2. Ninety-four percent of rescuers believed that their compressions were deep enough when performed on the step stool, compared to 64% without ($p < 0.001$). They also reported delivering compressions at a more appropriate rate and feeling more comfortable and less exhausted while performing compressions on a step stool. The step stool did not impact their perception of incomplete recoil ($p = 0.36$). Subjective responses were not correlated with rescuer height (data not shown).

In univariate analysis, the use of a step stool resulted in an average compression depth increase of 4 mm (50 ± 11 mm vs 46 ± 13 mm, $p < 0.001$) and 2% increase in average duty-cycle ($p < 0.001$), without a significant impact on compression rate or number of compressions (Table 2). The fraction of incomplete recoil increased by an average of 18% ($p = 0.02$). There was no significant difference in compression rate or depth decay over time with a step stool. However, subjects tended to lean more over time when on a stool ($p = 0.005$).

In multivariate analysis, there was a significant interaction with rescuer height for compression depth but not incomplete recoil, after adjusting for the other rescuer characteristics in Table 1 (data not shown). This interaction is demonstrated in the height tertile analysis in Table 3, where the benefit of improved depth was conferred primarily by the subjects in the lowest height tertile (148.6–167 cm), who had an average improvement in compression depth of 9 ± 9 mm with the step stool, compared to 2 ± 6 mm for those rescuers taller than 167 cm ($p = 0.006$). The relationship between height, step stool and incomplete release is further demonstrated in Figure 3.

DISCUSSION

We demonstrated that the use of a step stool during CPR in a bed results in improved rescuer satisfaction and increased chest compression depth. However, it does so at the cost of an increase in incomplete chest recoil. In addition, since rescuer height appears to modify the effect of a step stool on depth, but not on incomplete recoil, the relative benefit of the stool is greatest at rescuer heights ≤ 167 cm, with increased risk to benefit ratio for taller rescuers. This study is the first to quantify the impact of a step stool on CPR quality.

Previous studies have looked at the impact of rescuer positioning on compression depth in simulated settings. Perkins and colleagues did not observe differences in compression depth

between standing on the floor and kneeling on the bed, and between delivering compressions on a raised and a lowered bed.¹¹ Similarly, Chi and colleagues did not find differences in compression depth when the manikin was placed on the floor, a 37 cm table, or a 63 cm table.¹² Instead, the rescuers adjusted their motion in the various settings. These studies, however, did not measure incomplete release and did not look into the effect of rescuer height, a known correlate to compression depth.¹³

Compression depth during CPR is known to correlate with coronary perfusion pressure and deeper chest compressions have been associated with improved clinical outcomes.^{1, 2, 14–16} Kramer-Johansen and colleagues demonstrated improved survival to hospital admission in the out of hospital setting, where on average, each millimeter of increased compression depth was associated with a 5% increase in the odds of being admitted alive.² Similarly, our group has previously demonstrated that a 5 mm increase in compression depth is associated with a twofold increase in shock success in both the in-hospital and out-of-hospital settings.¹ As a result, the 4 millimeter increase associated with the use of a step stool in this study could increase the odds of short term survival by 20% or more. However, compression depth in clinical practice is one of the most challenging metrics of CPR quality to maintain during CPR and is routinely shallower than recommended guidelines.^{4, 17}

Compressing a human sternum requires a considerable amount of force.^{18, 19} The higher the rescuer's waist is relative to the patient, the more of the rescuer's body weight can be used to generate that force.⁷ Conversely, if the rescuer's waist is below the patient's chest, the entire force has to be generated by upper body strength. This is consistent with prior simulated studies that have shown taller rescuers can achieve deeper chest compressions and that it is easier to achieve deeper chest compressions when performing CPR on the floor, as opposed to an elevated surface.^{7, 20} In the in-hospital setting, it is often impractical to perform CPR on the floor, or even to climb up on the bed, which may be dangerous or cumbersome for compressor rotation. A step stool therefore has obvious appeal and the impact of the step stool on compression depth that we demonstrated is consistent with our primary hypothesis.

However, the incomplete recoil we demonstrated with the use of a step stool has potential to be harmful in clinical practice since leaving residual force on the chest during CPR impedes venous return and therefore decreases cardiac output. In a piglet model of cardiac arrest, Zuercher and colleagues demonstrated a 26% reduction in cardiac index and 33% decrease in myocardial blood flow with 20% leaning (3.6 kg of residual force).²¹ Similarly, Yannopoulos and colleagues demonstrated a 50% reduction in cerebral blood flow with 25% leaning (1.2 cm of residual compression) in an adult pig model.²² In an ideal setting, adequate compression depth could be achieved without any incomplete release. However, in clinical practice there may be a tradeoff, as we have shown here, and it would be important to understand when the benefit of increasing depth is outweighed by the harmful effects of incomplete recoil.

The importance of the step stool related increase in duty cycle is less clear. Since this variable has been shown to be related to rescuer height and victim positioning, it is not surprising that a step stool alters this variable.¹³ However, since there is very limited data on the clinical impact of duty cycle and the change from 0.39 to 0.41 keeps it well within the 0.3–0.5 range suggested by theoretical and animal studies, it is unlikely to be clinically significant.^{23–25}

Similarly, it is not clear what to make of the increase in incomplete recoil over time that we demonstrated with the use of a step stool compared to the decrease without the stool. Both groups demonstrated considerable (> 1 cm) decay in compression depth over the same time

period suggesting potential fatigue.¹⁷ It may be that fatigue can present as an increase or a decrease in leaning, depending on positioning, and thus incomplete recoil may not be a reliable indicator of fatigue.

It is interesting that the subjects in this study believed that not only their compressions were deeper, but that their compression rate was more appropriate with a step stool. This may be a product of their improved subjective comfort and decrease in reported exhaustion with the step stool. The fact that they did not recognize the increase in leaning suggests a particular insensitivity to this common practice and may argue for real-time feedback to correct.¹⁰

This study has several limitations. First, because it was performed in a simulated setting using mannequins, the results may not reflect the clinical setting. Second, because compressions were performed on a mattress and the depth calculated from an accelerometer on top of the chest, the measured depth is likely an overestimate of sternum-spinal displacement, as demonstrated by Perkins and colleagues, who calculated that 35–40% of measured depth is actually mattress compression.²⁶ In addition, rescuers were trained in the 2005 ECC guidelines which recommended a depth of 1.5–2 inches (4–5 cm), as opposed to at least 2 inches (5cm) which the current guidelines recommend. Finally, since we disabled the audiovisual feedback, it is not known whether enabling it would have protected against the incomplete recoil while enabling the increased depth associated with the step stool.

CONCLUSION

We found that a step stool increases compression depth in a height dependent manner and incomplete recoil independently of rescuer height. Since the tradeoffs between depth and incomplete release are not known, it may be reasonable for shorter rescuers (< 167 cm) to use a step stool when performing CPR in a bed, even after lowering the bed as much as possible. Taller rescuers may wish to avoid using a step stool and may even consider raising the height of the hospital bed to avoid excess leaning.

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Figure 1.
Flow chart of enrollment and group allocation. Participants start the study procedures either on or off the step stool.

Figure 2.

Subjective assessments of cardiopulmonary resuscitation. Agreement was defined as a response of agree or strongly agree on a five-point Likert scale. P-values were calculated using paired t-tests over the entire Likert scale. * $p < 0.05$. ** $p < 0.005$.

Figure 3.

The relationship between step stool associated change in compression depth, height and incomplete recoil. Each circle represents the change in compression depth for one subject attributable to the step stool. Hollow circles indicate $\leq 33\%$ incomplete recoil when standing on a step stool, while solid circles indicate $> 33\%$. A restricted cubic smoothing spline demonstrates the relationship between change in depth and height.

Table 1

Rescuer demographics.

Rescuers, <i>n</i>	50
Male Sex, <i>n</i> (%)	18 (36)
Age, mean (SD), years	33 (10)
Weight, median (IQR), kg	75 (67–95)
Height, median (IQR), cm	170 (166–178)
Body Mass Index, median (IQR), kg·m ⁻²	26 (23–33)
Flexed-arm hang time, median (IQR), s	9 (4–30)

SD, standard deviation; IQR, interquartile range

Table 2

Paired univariate comparison of CPR quality with and without a step-stool.

	No Step-stool [n=50]	Step-stool [n=50]	p-value
Total compressions	449 (110)	460 (110)	0.06
Compression rate, min ⁻¹	114 (29)	117 (28)	0.09
Compression depth, mm	46 (13)	50 (11)	<0.001
Duty-cycle	0.39 (0.06)	0.41 (0.05)	<0.001
Incomplete recoil fraction	0.33 (0.37)	0.51 (0.35)	<0.001
Rate change over 3 compression cycles, min ⁻¹	1 (15)	5 (15)	0.10
Depth change over 3 compression cycles, mm	-12 (12)	-13 (12)	0.53
Incomplete recoil change over 3 compression cycles	-0.09 (0.36)	0.07 (0.44)	0.005

Results are shown as mean (standard deviation).

Table 3

Impact of step-stool on compression depth and incomplete recoil by height tertiles.

	Lower Height Tertile [n=15]			Intermediate Height Tertile [n=19]			Upper Height Tertile [n=16]		
Height range, cm	148.6–167.0			167.6–174.0			174.5–190.5		
	No stool	Stool	p-value	No stool	Stool	p-value	No stool	Stool	p-value
Compression depth, mm	38 (8)	47 (9)	0.003	48 (11)	51 (10)	0.07	49 (15)	51 (14)	0.18
Incomplete recoil fraction	0.13 (0.24)	0.33 (0.27)	0.002	0.27 (0.29)	0.52 (0.35)	0.001	0.58 (0.42)	0.64 (0.38)	0.27

Results are shown as mean (standard deviation).