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A new method to increase the quality of cardiopulmonary resuscitation in hospital

Yeongtak Song, Jaehoon Oh, Taeho Lim, and Youngjoon Chee

Abstract— **In order to ensure that high-quality cardio-pulmonary-resuscitation (CPR) is performed, many kinds of feedback devices have been developed that are helpful for achieving correct chest compression (CC) in manikin studies. However, the mattress compression depth (MCD) can cause overestimation of chest compression depth (CCD) during CPR using a feedback device. Herein, we propose a new method using a vinyl cover that encloses the foam mattress and is compressed by vacuum pump just before performing CPR, which could increase the performance of CCs during CPR.**

For the verification, nine CPR providers performed CCs on manikin lying on five different surfaces, with the manikin's visual feedback system as follows: (surface A) no mattress on a bed frame, (surface B) on a foam mattress laid on a bed frame, (surface C) Surface B with backboard, (surface D) on a compressed foam mattress with a vacuum pump laid on a bed frame, and (surface E) Surface D with backboard. Two accelerometers were used to measure the mattress compression and chest compression depths through double integration and subtraction of the acceleration signals.

The mean (s.d.) of MCD was 5.7mm (0.6mm) on surface A, .14.9mm (1.4mm) on surface B, 14.0mm (1.3mm) on surface C, 7.0mm (0.6mm) on surface D, and 7.0mm (0.7mm) on surface E. The MCD decreased from 14.9mm (1.4mm) on Surface B to 7.0mm (0.6mm) on Surface D ($p < 0.001$), which did not differ from the MCD on Surface A ($p=0.13$).

Use of a mattress compression cover and a vacuum pump appears to increase the stiffness of the mattress. This method could decrease the mattress compression depth and help correct chest compression in hospitals.

I. INTRODUCTION

For the cardiac arrest patient, CPR (Cardio-Pulmonary Resuscitation) is known as the most basic aid in emergency situations. For high-quality CPR, the chest compression depth, cycle, and compressing point are important. According to the 2010 American Heart Association (AHA) Guideline, rescuers should compress the sternum deeper (i.e. to at least 5cm) during cardiopulmonary resuscitation (CPR) than required by past guidelines [1]. In order to ensure that high-quality CPR is performed, many kinds of feedback devices have been developed which allow for improved chest compression depth (CCD) in manikin studies [2], [3]. However, Perkins et al. observed that feedback devices overestimate CCD performed on beds in simulated cardiac arrest. They recognized that it is the mattress compression depth (MCD) that causes overestimation during CPR when using a feedback device [4]. Our previous study also found that the MCD makes up 30-40% of the total compression depth (TCD = CCD + MCD) [5]. These findings indicate that compensating for or decreasing MCD is important in performing accurate CCs during in-hospital CPR, where the victims are usually laid on a bed with a mattress.

There have been several suggestions regarding compensating for or decreasing MCD. In hospital, they use the backboard to reduce the MCD. In terms of compensation, a smart backboard containing a magnetic component with a sensor could resolve the overestimation problem [6]. The use of dual accelerometers also could measure the MCD and give the performer more accurate feedback during CPR [5]. The use of a method that compresses the chest at least 6.5cm might help to compensate for the MCD [7].

We propose a new method using a vinyl cover that encloses a foam mattress; we have termed it as "mattress compression cover". The mattress compression cover is deflated by vacuum pump just before CPR. We hypothesize that this method could decrease the MCD and result in more accurate CCDs during CPR on a foam mattress. In our previous study, we already suggested this new method and confirmed about use of vacuum pump and mattress cover [8]. In this study, we examined usefulness of the backboard in addition to previous study.

II. METHODS

A. Study participants

Nine American Heart Association (AHA) Basic Life Support (BLS) providers participated in this study. All participants signed informed consent forms prior to participation.

B. Materials and methods

To decrease MCD, the stiffness of the mattress needs to be increased, which is not comfortable for the patient. To make the mattress stiffer only while performing CPR, we compressed the mattress by pulling the air out of the mattress using a mattress compression cover and vacuum pump.

Before the experiment, we put the foam mattress into the mattress compression cover (Smartbag®, 900 X 1200mm, nylon and polyethylene, Lock&Lock Co, Korea). The foam

Yeongtak Song is with School of Electrical Engineering, University of Ulsan, Ulsan, Korea (e-mail: yeongtaksong@gmail.com)

Jaehoon Oh is with Department of Emergency Medicine, College of Medicine, Hanyang University, Seoul, Korea (e-mail: ojjai@hanmail.net)

Taeho Lim is with Department of Emergency Medicine, College of Medicine, Hanyang University, Seoul, Korea (e-mail: erthim@gmail.com)

Youngjoon Chee is with School of Electrical Engineering, University of Ulsan, Ulsan, Korea (phone: +82-52-259-1307; fax: +82-52-259-1306; e-mail: yjchee@ulsan.ac.kr)

mattress (660 X 1920 X 80 mm, soft foam with polyurethane coverage, Stryker Co., US) was cut to 660 X 960 X 80 mm for insertion into the cover. The mattress compression cover was originally designed for use in the home to reduce the volume of blankets for long-term storage. After putting a blanket into the vinyl bag, a vacuum cleaner is used to suck the air out through a one-way valve, as shown in Fig. 1. The volume of the blanket is thus decreased to save space during storage. Using a vacuum cleaner (Vegas 202 INOX, max air flow = 210 m3/h, 1100 Watt, Soteco, Italy), the deflation is complete within 5 seconds.

A Resusci Annie Modular System Skill Reporter® manikin (Laerdal Medical, Orpington, UK) was used for performing CPR in all evaluations. We added weight to the manikin for a final weight of 34 kg. A standard hospital bed frame (Transport stretcher®, 760 X 2110mm, 228 kg, Stryker Co., US) and backboard (425 X 500 X 10mm, 3 kg) were used in the experiment. We also used step stool for the short provider. The overall configuration of the experiment is shown in Fig. 1 and Table. 1. Five different experimental environments are as follow:

Surface A: No mattress on a bed frame

Surface B: On a foam mattress laid on a bed frame

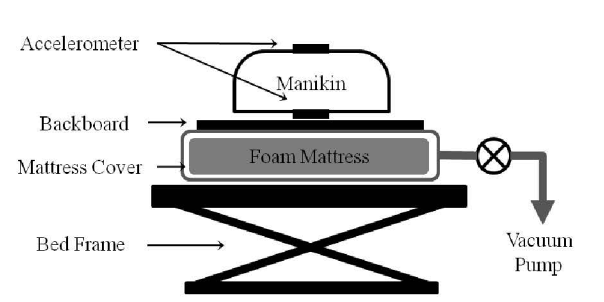
Surface C: Surface B with backboard

Surface D: On a compressed foam mattress with a vacuum pump laid on a bed frame

Surface E: Surface D with backboard.

To evaluate the effectiveness of this method, measurement of MCD and total compression depth (TCD) are required. The chest compression depth (CCD) can be calculated by subtracting MCD from TCD, which is also monitored by the Skill Reporter manikin system. We used two accelerometers (MMA 7260QT, Free Scale Semiconductor Inc., US) for these measurements [8]. One accelerometer was placed on the manikin's sternum, and the other was placed below the manikin's back, as shown in Fig. 1. The upper accelerometer measured TCD and the lower accelerometer measured MCD. The measurement of MCD using an accelerometer was established and the accuracy verified using a linear variable differential transformer (LVDT) (RDP-100S, Radian Co., Korea) in our previous studies [9].

Figure 1. Configuration of the experimental set up.



After pulling out the air from the mattress cover, the height of the mattress is decreased and the stiffness of the mattress is increased.

TABLE I. THE FIVE CONFIGURATIONS OF UNDERLYING SURFACES

Surface A	Surface B	Surface C	Surface D	Surface E
		Backboard		Backboard
	Foam	Foam	Compressed Foam	Compressed Foam
Bed Frame	Bed Frame	Bed Frame	Bed Frame	Bed Frame

C. Data collection

Each performer did CCs on manikins lying on five different underlying surfaces with the manikin's visual feedback system in the order in which the surfaces were used was randomized . The surfaces are summarized in Table 1. Verification of our idea can be seen by comparing the results using surfaces B (the foam mattress laid on the bed frame) and D (the compressed foam mattress with vacuum pump laid on the bed frame). In addition, surfaces C and E were included in this experiment to determine the effect of the use of backboard with each underlying surface. The provider stood beside the manikin, which was laid on varying surfaces. The height of the manikin's back was controlled to the height of the provider's knee using the bed and step stools for height adjustment. About 110 CCs were performed over 60 seconds in each instance in accordance with the 2010 AHA guidelines, with a 5-minute break between instances. The provider performed CCs while visual feedback from the manikin system was displayed on a computer monitor.

D. Primary outcomes

We calculated MCD for the five different surfaces to assess the effect of the mattress compression cover. Additionally, CCD and TCD were measured to determine if a sufficient CCD was achieved on each surface based on the 2010 AHA guidelines.

E. Statistical analysis

The data were analyzed using the Statistical Package for the Social Sciences (SPSS) 18.0 KO for Windows (Chicago, Illinois, US). All groups were analyzed using the Shapiro-Wilk test to test for normality. Analysis of variance (ANOVA) was used to analyze comparisons of the mattress and the actual and total compression depths on each surface. Our post hoc analysis used the Scheffe method. The values for compression depth are reported as mean ± standard deviation (s.d.). A p value < 0.05 was considered significant.

III. RESULTS

The CPR performers were all male with a median age of 34 years (range 27-41 years). The median performer weight was 85.0 kg (70-94 kg), and the median height was 174.0 cm (165-187 cm). Using the vacuum pump, the mattress was compressed to 630mm (width), 920mm (length), and 28mm (height) within approximately 5 seconds. The original size was 660mm (width), 960mm (length), and 80mm (height). As expected, significant compression was achieved for mattress height only.

The mean (s.d.) chest compression depth was 50.7mm (3.3mm) on surface A, 50.5mm (2.8mm) on surface B, 51.6mm (2.9mm) on surface C, 51.3mm (2.8mm) on surface D, and 51.8mm (2.5mm) on surface E (all p values > 0.05).

To compress to the above-mentioned CCD without MCD feedback during CPR, the TCD for the five kinds of underlying surfaces was required as shown in Fig. 2. Table 2 shows the mean (s.d.) MCD and TCD. MCD decreased by 14.9mm (1.4mm) on surface B to 7.0mm (0.6mm) on surface D ($p < 0.001$), which does not differ from the MCD on surface A (p=0.13). The TCDs were 56.4mm (3.8mm) on surface A, 58.3mm (3.0mm) on surface D (p= 0.85), and 65.4mm (3.8mm) on surface B ($p < 0.01$). Use of a backboard decreased the MCD from 14.9mm (1.4mm) on surface B to 14.0mm (1.3mm) on surface C ($p > 0.05$). With the added backboard on surface D (i.e. surface E), the MCD and TCD were 7.0mm (0.7mm, p=1.0) and 58.9mm (2.8mm, p= 0.99), respectively.

Figure 2. Compression depth on five kinds of underlying surfaces.

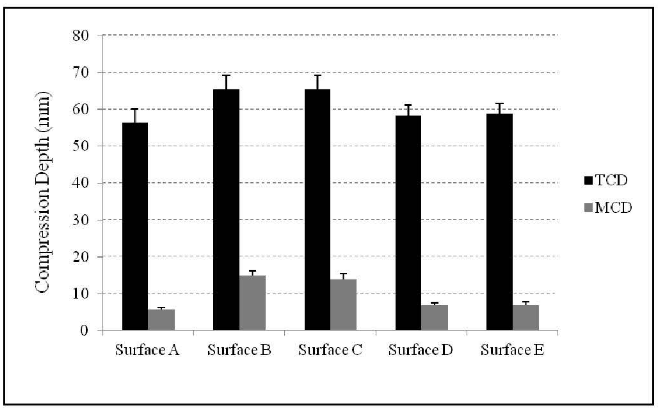


TABLE II. COMPRESSION DEPTHS IN FIVE EXPERIMENTAL CONDITIONS; MEANS (S.D.) IN MM (N=9).

	Surface A	Surface B	Surface C	Surface D	Surface E
TCD	56.4(3.8)	65.4(3.8)	65.5(3.7)	58.3(3.0)	58.9(2.8)
MCD	5.7(0.6)	14.9(1.4)	14.0(1.3)	7.0(0.6)	7.0(0.7)
CCD	50.7(3.3)	50.5(2.8)	51.6(2.9)	51.3(2.8)	51.8(2.5)

IV. DISCUSSION

Use of a feedback device during CPR could help improve the quality of CPR in terms of the appropriate compression rate, correct hand position, full chest recoil, duty cycle, and accurate compression depth [10], [11]. However, it is more difficult to provide accurate CCD feedback than the other quality factors as most feedback devices measure TCD, resulting in overestimation of CCD [4], [5]. The solution to this problem of overestimation requires the insertion of a backboard to decrease MCD. Other method is to insert the secondary sensor beneath the victim to measure MCD which can't decrease MCD. Although CCD can be monitored accurately with the secondary sensor, the total work for the rescue should deliver to the patient is the work for TCD which is greater than that for CCD. Krikscionaitiene et al. reported that lightweight rescuers require special attention to ensure CCs are performed according to the 2010 European Resuscitation Council (ERC) guidelines. If the TCD does not decrease, lightweight rescuers may not be able to perform CCs sufficiently even with feedback [12]. In this study, the MCD was 7.0 mm (0.6) and the TCD on the compressed mattress with vacuuming in advance (surface D) was 58.3mm (3.0), which is similar to the 5.7mm (0.6) and 56.4mm (3.8) on surface A (p=0.13, p=0.85). This method could decrease MCD and be helpful for lightweight rescuers when using a feedback device.

Hardley suggested increasing CCD to at least 6.5cm if the victim is lying on a mattress to compensate for MCD [7]. However, proper over-compression would be different for varying surfaces. Differences in surface type may result in different MCDs, which would interfere with the achievement of accurate CCDs during CPR. The consistent application of the above technique might be difficult in the real environment if the performer do not know the accurate MCD and victim's characteristics. This might cause harm to the victim. In contrast, our method could decrease MCD regardless of surface type and does not require over-compression depth to achieve accurate CCs.

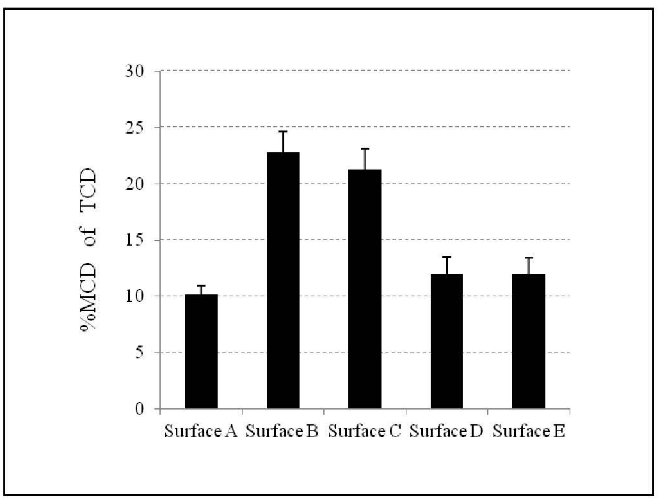
According to the 2010 AHA guidelines, there is currently insufficient evidence for the use of backboards [1]. Backboards have been the subject of many recent studies that have examined the effect of backboards used on a variety of surfaces [13]. However, even with the use of backboards, MCD remained about 20-30% of TCD. In this study, the use of a backboard decreased the MCD from 14.9mm to 14.0mm. However, this difference was not statistically significant (p=0.37). Use of a mattress compression cover and vacuum pump could decrease the MCD proportion of TCD from about 23% on surface C to 12% on surface D. Interestingly, 10% remains on the bed frame without a mattress (i.e. surface A) during CPR. Use of a mattress compression cover with a vacuum is more effective in decreasing MCD than the use of a backboard ($p < 0.01$). Adding a backboard to surface D (i.e. surface E) did not decrease the MCD more (p= 1.0). (Fig. 3)

An innovative CPR mattress with several tubes inserted for deflation improved CC efficiency from 42% (on a hospital mattress) to 81% (on a CPR mattress insert). CCs were performed to 4.5cm depth by a thumper device, and CC efficiency on a hard top table was 95% [14]. We believe that our method is simpler than the CPR mattress with tubes because the mattress compression cover can be used with existing mattress in hospital. It took about 20 seconds for The

CPR mattress deflation whereas it took 5 seconds for our mattress compression cover. When the bed displacement depth (5.7mm) in surface A is subtracted from the MCD (7.0mm) in surface D, there remains 1.3mm of MCD which is small enough for efficient CPR.

In this study, we used a manikin different from actual human patients in weight, stature, and back stiffness. We investigated the MCD on only one type of bed frame, foam mattress, and backboard. It took approximately 5 seconds to collapse the mattress with the vacuum pump. The time for mattress compression may differ with the kind of mattress and vacuum pump used. Further studies are required to compare mattress compression using different types of bed frames, mattresses, backboards, and vacuum pumps. We found that bed displacement during CPR and did not resolve when using the mattress compression cover. The solution to this problem might be a mattress compensation system such as a dual accelerometer or smart backboard containing a magnetic component with a sensor. The rescuers performed chest compressions with manikin feedback, and we did not find the efficiency of CCs without feedback during CPR. Finally, we used a commercial product as the mattress compression cover. Application to clinical situations would require adjusting the position of the suction valve and a portable pump.

Figure 3. Percentage of mattress compression depth (MCD) out of total compression depth (TCD) for five types of underlying surfaces.



V. Conclusion

In this study, we suggest a new method using a mattress compression cover. It increases the stiffness of foam mattress to decrease the mattress compression depth more than backboard. It can improve chest compression quality when performing CPR in hospitals.

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