

# Effect of Instituting Upper Limits for Chest Compression Depth for Laypersons at Six-months After Chest Compression-Only Training: A Randomized Controlled Simulation Study

Makiko Sano 佐野 真樹子, Ryuhei Sato 佐藤 隆平, Kosuke Kiyohara 清原 康介,  
Izumi Chida 千田 いずみ, Taku Iwami 石見 拓, and Chika Nishiyama 西山 知佳

**Context/ research question:** Chest compression quality plays a major role in patient outcomes after cardiac arrest. The Japanese cardiopulmonary resuscitation (JRC) guidelines 2015 indicate that chest compression depth should be approximately 5 cm but not more than 6 cm. However, the upper limit of chest compression depth might be a barrier to the delivery of adequate chest compressions by laypersons. We hypothesized that laypersons may be able to perform chest compressions (approximately 5 cm) as per the JRC guidelines, without setting an upper limit for chest compression depth.

**Methods:** Participants were randomly assigned to either the “unlimited group” (no recommendation regarding the upper limit of compression depth) or the “limited group” (“push to approximately 5 cm, don’t push over 6 cm”) and stratified according to sex using permuted blocks. All participants completed a 15-min chest compression training session, and their compression skills were individually evaluated immediately and at 6 months after the training using the Laerdal® PC SkillReporting System at Kyoto University. The primary outcome was the median compression depth during the 2-min test period 6 months after the training.

**Results:** Seventy-two participants were enrolled; 33 participants in each group completed the study. The unlimited group performed significantly deeper chest compressions (>60 mm) immediately after the training than the limited group; however, there was no significant difference 6 months after training. Although not significant, the number of compressions with the recommended depth (49–59 mm) was higher in the limited group.

**Importance:** These results suggest that simplified instructions that do not mention the upper limit of compression depth may help people perform deeper chest compressions; however, there are concerns about the risks associated with too deep compressions. Considering the situation of out-of-hospital cardiac arrest in Japan, studies focusing on compression depths in another aged people should be considered.

In Japan, out-of-hospital cardiac arrests (OHCAs) of cardiac origin account for approximately 70,000 deaths every year (Ministry of Internal Affairs and Communications, 2019). Considerable effort has been put into strengthening the Chain of Survival, which includes provision of early cardiopulmonary resuscitation (CPR) with a focus on chest compression. Bystander CPR performance doubles the survival rate (Steill et al, 2004), and the quality of chest compression plays

a key role in this setting (Bobrow et al., 2010; Iwami et al., 2015). However, it has been shown that more than half of OHCA patients do not receive bystander CPR (Ministry of Internal Affairs and Communications, 2019). In addition, the number of survivors with favorable neurological outcomes after an OHCA remains low (Ministry of Internal Affairs and Communications, 2019).

Animal and clinical studies have demonstrated that CPR quality, which incorporates compression rate, depth, recoil, and chest compression fraction, significantly improves survival (Japan Resuscitation Council, 2016; Ristango et al., 2007; Wu et al., 2009); of these parameters, deeper chest compression is strongly associated with improved survival rates after cardiac arrest (Stiell et al., 2014; Vadeboncoeur et al., 2014). Chest compression depth greater than 50 mm is associated with good prognosis; for every 5 mm of chest compression increase in the depth of chest compression, there is a 1.3-fold increase in the rate of return of spontaneous circulation (Vadeboncoeur et al., 2014). Chest compression depth of >50 mm influences blood pressure, cardiac output, and coronary perfusion pressure (Wu et al., 2009). Thus, the 2010 Resuscitation Guideline for CPR recommended that chest compression for all adult cardiac arrest victims should be at least 2 inches/5 cm, with insufficient evidence for recommending a specific upper limit for chest compression depth (Sayre et al., 2010). However, the 2015 American Heart Association (AHA) guidelines recommended “a chest compression depth of approximately 5 cm (2 inches) (strong recommendation, low-quality evidence) while avoiding excessive chest compression depths (greater than 6 cm [greater than 2.4 inches] in an average adult) (weak recommendation, low-quality evidence) during manual CPR” (Travers et al., 2015). A compression depth of more than 6 cm has been reported to increase the risk of trauma such as sternal rib fracture and aortic rupture (Helleveuo et al., 2013; Kim et al., 2013; Yamaguchi et al., 2017).

There is insufficient information regarding real-world bystander CPR quality, and even healthcare professionals find it difficult to provide appropriate chest compressions throughout the resuscitation procedure (Stiell et al., 2014; Wik et al., 2005). There is concern that setting an upper limit for the depth of chest compressions might cause bystanders to hesitate or not perform deep chest compressions (Malta et al., 2017; Savastano

& Vanni, 2011; Swor et al., 2006), and complicated teaching methods might make it difficult for the laypersons to acquire chest compression skills. Bystanders may find it difficult to perform deep chest compressions even after training (Mayrand et al., 2015; Tanaka et al., 2017; Yeung et al., 2014), and additional information is needed regarding optimal instructions that are likely to result in correct bystander chest compressions.

The Japan Resuscitation Council Resuscitation Guideline 2015 (Japanese CPR guidelines) (Japan Resuscitation Council, 2016), based on the Consensus on Science with Treatment Recommendations published by International Liaison Committee on Resuscitation, has also set the upper limit of chest compression depth to not more than 6 cm. We hypothesized that the upper limit of compression depth set by the JRC would be a barrier to adequate chest compression during CPR for OHCA by bystanders. Therefore, this simulated randomized controlled trial aimed to compare chest compression depths between laypersons who received instructions with an upper depth limit (“push to approximately 5 cm, don’t push over 6 cm”) and those who received instructions without an upper depth limit (“push as hard as you can”).

## Methods

### Study Design and Participants

This randomized simulation study was conducted between February 2017 and August 2017. Adult participants (>18 years old) were recruited from Kyoto University and the areas surrounding Kyoto city using billboard advertisements and via the Kyoto University website. Individuals excluded from the study included those who did not speak Japanese, licensed medical professionals (doctors, registered nurses, assistant nurses, pharmacists, nutritionists, physical therapists, occupational therapists, medical engineers, paramedics, and students with a healthcare provider-related curriculum), and individuals with physical disabilities (e.g., inability to kneel on the

floor or to perform chest compressions). We also excluded individuals who had completed CPR training during the last 6 months, as the training effect was expected to last 6 months (Nishiyama et al., 2014). Participants were offered a gift card (equivalent to \$20) as an incentive to complete the 6-month evaluation.

### Randomization

Participants were randomly assigned to the “unlimited group” or the “limited group” and stratified according to sex using permuted blocks. An independent biostatistician assigned the participants to either groups according to a computer-generated randomization list. Blinding was not possible as the training assignment could not be concealed from either the participants or instructors. However, to minimize any potential measurement bias, we did not reveal the participants’ assignments to the participants and instructors until immediately before the training. Data collectors were however blinded.

### Intervention

Two designated paramedic staff members, specially trained in advance to ensure the quality of instructions, conducted 15-minute training sessions using the Laerdal® Little Anne (Laerdal Medical, Stavanger, Norway). Appendix A summarizes the 15-minute chest compression training program. The program was standardized with an instructor/participant ratio of 1:3, and the instructions were similar (with the exception of compression depth) to ensure that the quality of chest compressions was comparable in both groups. Based on the Japanese CPR guidelines (Japan Resuscitation Council, 2016), participants in both groups were educated regarding basic chest compression skills (e.g., compression rate, hand location, and recoil) but not regarding compression depth. We also provided information about the importance of chest compression on the survival of persons with sudden cardiac arrest. Every 10 seconds, a verbal prompt from the instructors instructed the unlimited group members to “push as hard as you can” and the

limited group (control) members to “push to approximately 5 cm, but don’t push over 6 cm.” During the training, all participants performed three sets of 1-minute continuous chest compressions, and participants confirmed whether or not they reached 5 cm depth based on the voice prompt from the instructor.

### Data Collection and Outcome Measures

Each participant’s chest compression skills were evaluated for 2 minutes, approximately 5 minutes post training and at 6 months after the training. Each participant individually entered the testing room and was asked to start performing chest compressions whenever they were ready. Data were collected automatically for each participant using the Laerdal® PC SkillReporting System (Laerdal Medical, Stavanger, Norway).

The primary outcome was the median compression depth (mm) 6 months after the training (assessed for 2 minutes) since evaluating CPR skills after a certain period post-training is a more powerful outcome than immediate post-training evaluation (Farhan et al., 2016; Japan Resuscitation Council, 2016; Robert et al., 2015). Educating the study participants in the control group 6 months post-training about the latest chest compression way was considered acceptable as a previous study had reported that the probability of encountering cardiopulmonary arrest after CPR training was 1.1 per 100 person-years (Nishiyama et al., 2019).

The secondary outcomes were the total number of chest compressions, both numbers and proportions of chest compressions in three depth categories ( $\leq 39$  mm, 40–59 mm,  $\geq 60$  mm), the number of chest compressions with adequate recoil, and the average chest compression rate immediately and 6 months after the training.

### Statistical Methods

The sample size was calculated to identify a significant difference in the average chest compression depth (mm) at 6 months after training. Based on our previous study of

laypersons who practiced chest compressions with a recommended depth of  $\geq 5$  cm, the average chest compression depth was 47 mm during the 2-minute test at 6 months after the training (unpublished data). Rodriguez et al. (2014) have reported a 1.2-fold difference in depth between laypersons who were instructed to “push as hard as you can” or to “push down firmly to 5 cm” (Rodriguez et al., 2014). Thus, we assumed an average chest compression depth of 39 mm at 6 months after training in the limited group. Based on an alpha error of 5% and power of 80%, 26 participants were required for each group, with a total sample size of 65 participants needed to account for a 20% post-randomization dropout rate.

All analyses were performed on an intention-to-treat basis, although participants who did not attend the training and/or evaluation were excluded from the analyses. All data were reported as numbers (%), medians (interquartile range [IQR]), or means  $\pm$  standard deviation. Data were compared between the groups using the chi-square test for categorical variables and the Mann-Whitney U test for continuous variables, as the variables were non-normally distributed. All tests were two-tailed, and p-values of  $<.05$  were considered statistically significant. All statistical analyses were performed using IBM SPSS Ver.24.0J (IBM Corp., Armonk, NY, USA).

### Ethics

This study’s protocol was approved by the appropriate institutional ethics committee of Kyoto University Graduate School of Medicine (C1249-1), and written informed consent was obtained from all participants prior to study enrollment. To ensure the participants received equivalent training, explanations regarding chest compression skills were provided based on the latest Japanese CPR guidelines after the 6-month evaluation. This study was reported according to the CONSORT statement (Kenneth et al., 2009).

## Results

### Patients and Characteristics

Of the initial 74 participants recruited, two laypersons were excluded (one was from the department of pharmacy and the other was enrolled in another cardiopulmonary resuscitation study) (Figure 1). The 72 participants were randomly assigned to two groups of 36 participants. Training sessions were completed by 33 participants in the unlimited group and 35 participants in the limited group. At 6 months after the training, 33 participants from each group (91.2% for each group) completed the follow-up evaluation of their chest compression skills.

The participants’ baseline characteristics, assessed prior to training, are shown in Table 1. There were no statistically significant differences between the two groups in terms of sex, age, witnessed sudden cardiac arrest, previous CPR training, weight, or height.

### Chest Compression Skills Immediately After Training

Table 2 shows the participants’ chest compression skills immediately after the training. The median chest compression depth was significantly greater in the unlimited group (57.0 mm [IQR: 49.5–60.0] vs. 51.0 mm [IQR: 44.5–58.0],  $p=.038$ ). There was no significant difference in the number of chest compressions with depths of  $\leq 39$  mm (0.0 [IQR: 0.0–5.5] vs. 0.0 [IQR: 0.0–36.0],  $p=.480$ ) or depths of 40–59 mm (140.0 [IQR: 18.0–197.0] vs. 165.0 [IQR: 58.5–194.5],  $p=.293$ ). Furthermore, there were no significant differences in the two groups’ proportions of chest compressions with depths of  $\leq 39$  mm (0.0% [IQR: 0.0–2.1] vs. 0.0% [IQR: 0.0–18.5],  $p=.467$ ) or depths of 40–59 mm (60.0% [IQR: 7.9–35.6] vs. 78.0% [IQR: 0.0–96.7],  $p=.082$ ). However, the unlimited group had a significantly higher number of chest compressions with depths of  $\geq 60.0$  mm (60.0 [IQR: 8.0–208.5] vs. 3.0 [IQR: 0.0–65.0],  $p=.006$ ) and a significantly higher proportion of chest compressions with

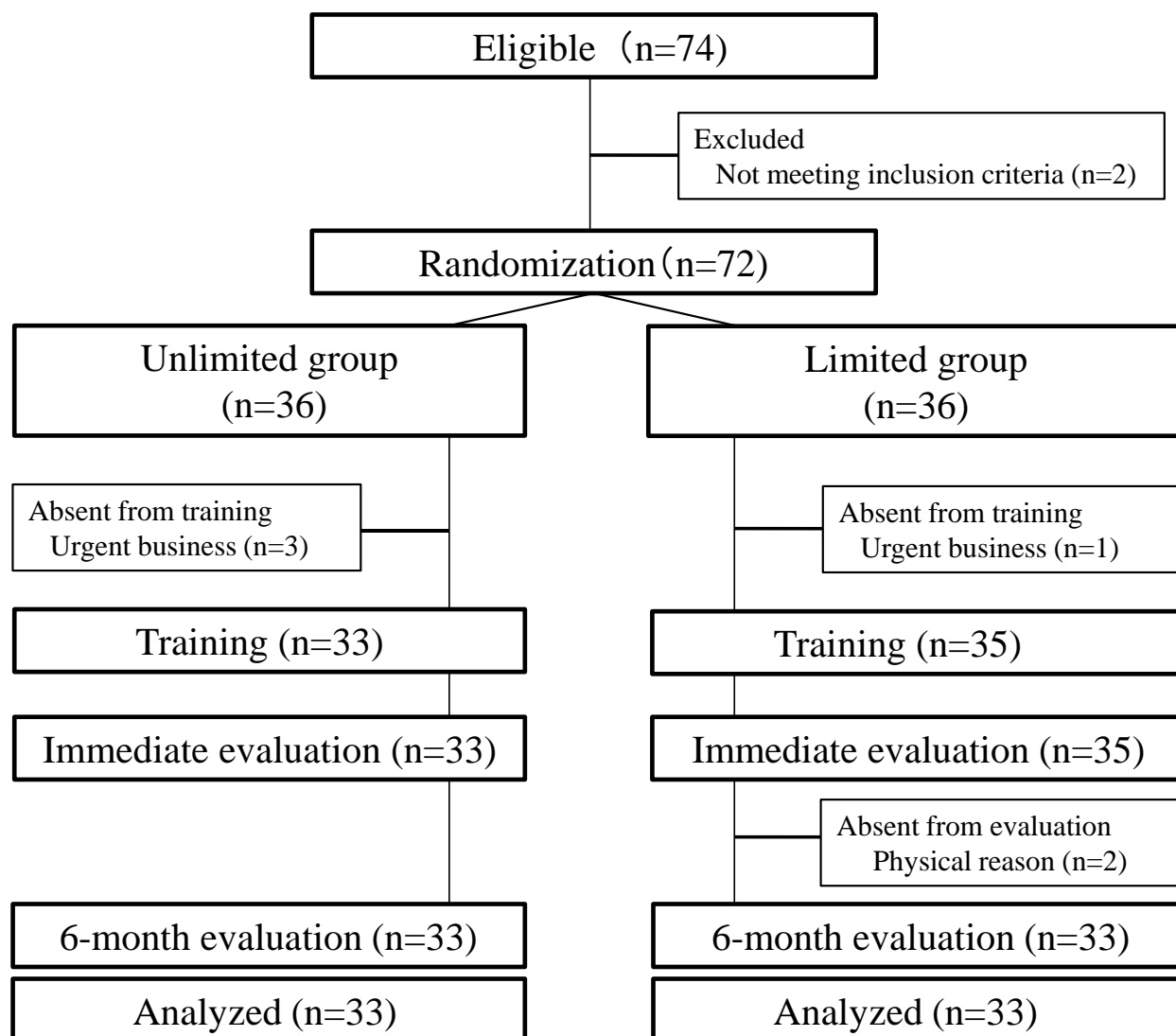


Figure 1: Flow chart of the study process

Table 1: Baseline characteristics of study

	Unlimited group (n=33)	Limited group (n=33)
Age in years, median (IQR)	26.9 (20.0-26.5)	23.0 (22.0-37.0)
Male sex, n (%)	20 (60.6)	21 (63.6)
Previously witnessed cardiac arrest, n (%)	0 (0.0)	1 (3.0)
Previous CPR training, n (%)	21 (63.6)	21 (63.6)
Height in cm, mean $\pm$ SD	165.1 $\pm$ 8.5	166.7 $\pm$ 8.9
Weight in kg, mean $\pm$ SD	60.5 $\pm$ 9.9	61.8 $\pm$ 10.6

Table 2 Chest compression skills immediately after the training

	Unlimited group (n=33)		Limited group (n=33)		p
Total number of chest compressions	225.0	(208.0 – 238.5)	212.0	(199.5 – 222.0)	0.025
Average chest compression depth, mm	57.0	(49.5 – 60.0)	51.0	(44.5 – 58.0)	0.038
Number of chest compressions					
≤39 mm depth	0.0	(0.0 – 5.5)	0.0	(0.0 – 36.0)	0.480
40–59 mm depth	140.0	(18.0 – 197.0)	165.0	(58.5 – 194.5)	0.293
≥60 mm depth	60.0	(8.0 – 208.5)	3.0	(0.0 – 65.5)	0.006
Proportion of chest compressions, %					
≤39 mm depth	0.0	(0.0 – 2.1)	0.0	(0.0 – 18.5)	0.467
40–59 mm depth	60.0	(7.9 – 35.6)	78.0	(0.0 – 96.7)	0.082
≥60 mm depth	27.4	(3.7 – 92.1)	1.2	(0.0 – 29.1)	0.012
Number of chest compressions with adequate recoil	220.0	(206.0 – 233.5)	208.5	(195.3 – 226.3)	0.120
Average chest compression rate, n/min	113.0	(104.5 – 119.0)	105.0	(99.0 – 110.5)	0.018

Note. Data are shown as median (interquartile range).

depths of ≥60.0 mm (27.4% [IQR: 3.7–92.1] vs. 1.2% [IQR: 0.0–29.1],  $p=0.012$ ).

### Chest Compression Skills at 6 Months after Training

Table 3 shows the participants' chest compression skills at 6 months after the training. Compared to the limited group, the unlimited group had a non-significantly greater median depth of chest compressions (56.0 mm [IQR: 46.5–59.5] vs. 50.0 mm [IQR: 45.5–59.0],  $p=0.256$ ). The unlimited group also had a non-significantly lower median number of chest compressions with a depth of 49–59 mm (110.0 [IQR: 42.5–180.0] vs. 150.0 [IQR: 44.0–188.0],  $p=0.753$ ). Furthermore, the unlimited group had a non-significantly higher

median number of chest compressions with a depth of ≥60 mm (62.0 [IQR: 0.0–166.0] vs. 9.0 [IQR: 0.5–129.5],  $p=0.301$ ). There was no significant difference between the two groups in the number of chest compressions with a depth of ≤39 mm (0.0 [IQR: 0.0–14.5] vs. 3.0 [IQR: 0.0–32.0],  $p=0.218$ ).

### Discussion

This simulated randomized controlled trial aimed to compare chest compression depths between laypersons who received chest compression instructions with depth limitation (“push to approximately 5 cm, don’t push over 6 cm”) and laypersons who received instructions without depth limitation (“push as hard as you can”). The

Table 3 Chest compression skills at 6 months after the training

	Unlimited group		Limited group		<i>p</i>
	<i>n</i> =33		<i>n</i> =33		
Total number of chest compressions	225.0	(201.5 – 237.5)	210.0	(194.0 – 231.5)	0.195
Average chest compression depth, mm	56.0	(46.5 – 59.5)	50.0	(45.5 – 59.0)	0.256
Number of chest compressions					
≤39 mm depth	0.0	(0.0 – 14.5)	3.0	(0.0 – 32.0)	0.218
40–59 mm depth	111.0	(42.5 – 180.0)	150.0	(44.0 – 188.0)	0.753
≥60 mm depth	62.0	(0.0 – 166.0)	9.0	(0.5 – 129.5)	0.301
Proportion of chest compressions, %					
≤39 mm depth	0.0	(0.0 – 6.9)	1.6	(0.0 – 16.5)	0.202
40–59 mm depth	51.7	(19.2 – 82.9)	73.8	(21.4 – 92.7)	0.275
≥60 mm depth	28.5	(79.6 – 58.1)	4.9	(0.2 – 58.1)	0.288
Number of chest compressions with adequate recoil	215.0	(199.0 – 237.5)	203.0	(182.5 – 227.5)	0.095
Average chest compression rate, <i>n</i> /min	113.0	(100.5 – 119.5)	105.0	(96.5 – 116.0)	0.193

*Note.* Data are shown as median (interquartile range).

unlimited group had a higher number and proportion of chest compressions with a depth of ≥60 mm, while the limited group provided more appropriate chest compressions with a depth of 40–59 mm, which is recommended by the CPR guidelines (Japan Resuscitation Council, 2016). These results suggest that simplified instruction without mentioning the upper limit of compression depth helps people provide deeper chest compressions but creates concern about too deep compressions. The results also suggest that instruction methods can affect people's CPR performance. However, there is a need for further studies to evaluate appropriate instructions in CPR training.

In contrast to our hypothesis that setting an upper limit for chest compression depth might cause insufficient chest compressions, there was no

significant difference in the median chest compression depth at 6 months after the training. This may be due to several reasons. First, compared with previous studies (Rodrigues et al., 2014; Tanaka et al., 2017; Van Tulder et al., 2014), deep chest compressions were performed both immediately after training and 6 months later regardless of the group; thus, there was probably no significant difference between the groups. In contrast to previous studies, our participants' baseline characteristics (e.g., 60% of the participants were young men and presumably had relatively good physical strength) might have influenced the chest compression depth as reported (Larsen et al., 2002; López-González et al., 2015; Oh & Kim, 2016). Second, our participants might have recalled the procedure of chest compressions easily because our training

program was designed to simply and effectively teach only chest compression skills, unlike those in previous studies (Nishiyama et al., 2008; Nishiyama et al., 2014; Rodriguez et al., 2014).

Although it was not statistically significant, the difference in chest compression depth of 56.0 mm in the unlimited group and 50.0 mm in the limited group at 6 months after training may be meaningful. Many reports suggest that laypersons may encounter difficulties in the provision of appropriate chest compressions in actual emergency settings because of anxiety about harming the patient (Shams et al., 2016), confusing situations within the emergency setting (Swor et al., 2006; Savastano & Vanni, 2011), and cumulative fatigue (Nishiyama et al., 2010). Considering the insufficient depth of chest compressions at the actual scene, deeper chest compressions in the simulation setting would result in better chest compressions in actual settings. Further research evaluating the actual performance of lay rescuers in real emergency settings is needed.

The results demonstrating the higher number of chest compressions with a depth of  $\geq 60$  mm in the unlimited group should be carefully discussed due to the potential for adverse events (Hellevo et al., 2013). Although the AHA sets no upper limits for the depth of chest compressions (Travers et al., 2015), there are potential risks. Previous studies involving paramedics have indicated that the risk of sternal rib fractures and aortic ruptures is increased at compression depths of  $>60$  mm (Kashiwagi et al., 2015; Kralj et al., 2015; Miller et al., 2014). Teaching methods with no upper limits for chest compression depth, which may allow laypersons to provide deeper compression depths, may require further consideration in terms of methods to avoid performing chest compressions that are too deep.

### Limitations

Our study had several limitations. First, the manikin was unable to measure chest compression depths of  $>60$  mm; the true average chest

compression depths might be greater than the reported data. Further research is needed to re-evaluate chest compression depths using equipment that is capable of measuring depths of  $>60$  mm. Second, 60% of our participants were young men (average age: 20 years), and the findings may not be generalizable to other age groups. Moreover, in Japan, the number of households with individuals aged  $>65$  years has been increasing rapidly (Ministry of Internal Affairs and Communications, 2018). In addition, since Japanese OHCA cases frequently involve people who are 60–80 years old and living in their homes (Ministry of Internal Affairs and Communications, 2019), and these cases are typically witnessed by spectators who are in their 50s and 60s (Tanigawa et al., 2011). Thus, it would be useful to evaluate the chest compression depths for people who are middle-aged and elderly who might have opportunities to encounter collapses in daily life. Third, chest compression skills were evaluated in a simulated setting, and laypersons' performance in a real-world setting remains unclear. Fourth, it is necessary to verify whether our chest compression training method delivers adequate chest compression skills in the process of CPR training. Fifth, a sample of 308 participants would be needed to observe statistically significant inter-group differences. We had estimated an 8.0-mm difference in average chest compression depth based on our previous data (47 mm in the unlimited group and 39 mm in the limited group), although we detected a 2.6-mm difference in the average chest compression depth with an 8.1-mm standard deviation (data not shown).

### Conclusion

Chest compression depth is likely to be greater in the unlimited group than in the limited group; however, we observed no significant difference between the groups at 6 months after the training. Considering the situation of OHCA in Japan, studies focusing on compression depths in



another aged people should be considered. Bystanders' quality of chest compression and the factors affecting chest compression depth in real-world settings must also be assessed in future studies.

### Acknowledgements

We are grateful to Masaaki Matsumoto, Keiji Akatsuka, Ayumi Iwata, Kanako Hoshi, Kanako Koike, Takumi Shinjo, Manami Hsegawa, and Erika Maeda for the collection of supporting data.

### Funding & Conflict of Interests

This study was supported by the Japanese Association for Emergency Nursing (research grant no. 55). Kyoto University provided funding to meet operational expenses. The study sponsors were not involved in the study. The authors have no financial conflicts of interest to disclose concerning the publication.

### Corresponding Author

Chika Nishiyama, nishiyama.chika.3n@kyoto-u.ac.jp

### References

- Bhanji, F., Finn, J. C., Lockey, A., Monsieurs, K., Frengley, R., Iwami, T., Lang, E., Ma, M. H., Mancini, M. E., McNeil, M. A., Greif, R., Billi, J. E., Nadkarni, V. M., & Bigham, B. (2015). Part 8: Education, Implementation, and Teams: 2015 International Consensus on Cardiopulmonary Resuscitation and Emergency Cardiovascular Care Science With Treatment Recommendations. *Circulation*, *132*(16 Suppl 1), S242-268. <https://doi.org/10.1161/cir.0000000000000277>
- Bobrow, B. J., Spaite, D. W., Berg, R. A., Stolz, U., Sanders, A. B., Kern, K. B., Vadeboncoeur, T. F., Clark, L. L., Gallagher, J. V., Stapczynski, J. S., LoVecchio, F., Mullins, T. J., Humble, W. O., & Ewy, G. A. (2010). Chest compression-only CPR by lay rescuers and survival from out-of-hospital cardiac arrest. *JAMA*, *304*(13), 1447-1454. <https://doi.org/10.1001/jama.2010.1392>
- Greif, R., Lockey, A. S., Conaghan, P., Lippert, A., De Vries, W., & Monsieurs, K. G. (2015). European Resuscitation Council Guidelines for Resuscitation 2015: Section 10. Education and implementation of resuscitation. *Resuscitation*, *95*, 288-301. <https://doi.org/10.1016/j.resuscitation.2015.07.032>
- Hellevo, H., Sainio, M., Nevalainen, R., Huhtala, H., Olkkola, K. T., Tenhunen, J., & Hopppu, S. (2013). Deeper chest compression - more complications for cardiac arrest patients? *Resuscitation*, *84*(6), 760-765. <https://doi.org/10.1016/j.resuscitation.2013.02.015>
- Iwami, T., Kitamura, T., Kiyohara, K., & Kawamura, T. (2015). Dissemination of Chest Compression-Only Cardiopulmonary Resuscitation and Survival After Out-of-Hospital Cardiac Arrest. *Circulation*, *132*(5), 415-422. <https://doi.org/10.1161/circulationaha.114.014905>
- Japan Resuscitation Council. (2016). *Japan Resuscitation Council Resuscitation Guidelines 2015*. Igaku-Shoin Ltd.
- Kashiwagi, Y., Sasakawa, T., Tamppo, A., Kawata, D., Nishiura, T., Kokita, N., Iwasaki, H., & Fujita, S. (2015). Computed tomography findings of complications resulting from cardiopulmonary resuscitation. *Resuscitation*, *88*, 86-91. <https://doi.org/10.1016/j.resuscitation.2014.12.022>

- Kim, M. J., Park, Y. S., Kim, S. W., Yoon, Y. S., Lee, K. R., Lim, T. H., Lim, H., Park, H. Y., Park, J. M., & Chung, S. P. (2013). Chest injury following cardiopulmonary resuscitation: a prospective computed tomography evaluation. *Resuscitation*, *84*(3), 361-364. <https://doi.org/10.1016/j.resuscitation.2012.07.011>
- Koster, R. W., Sayre, M. R., Botha, M., Cave, D. M., Cudnik, M. T., Handley, A. J., Hatanaka, T., Hazinski, M. F., Jacobs, I., Monsieurs, K., Morley, P. T., Nolan, J. P., & Travers, A. H. (2010). Part 5: Adult basic life support: 2010 International consensus on cardiopulmonary resuscitation and emergency cardiovascular care science with treatment recommendations. *Resuscitation*, *81 Suppl 1*, e48-70. <https://doi.org/10.1016/j.resuscitation.2010.08.005>
- Kralj, E., Podbregar, M., Kejžar, N., & Balažic, J. (2015). Frequency and number of resuscitation related rib and sternum fractures are higher than generally considered. *Resuscitation*, *93*, 136-141. <https://doi.org/10.1016/j.resuscitation.2015.02.034>
- Larsen, P. D., Perrin, K., & Galletly, D. C. (2002). Patterns of external chest compression. *Resuscitation*, *53*(3), 281-287. [https://doi.org/10.1016/s0300-9572\(02\)00026-6](https://doi.org/10.1016/s0300-9572(02)00026-6)
- López-González, Á., Sánchez-López, M., Rovira-Gil, E., González-García, A., Ferrer-López, V., & Martínez-Vizcaíno, V. (2015). Sex differences in the effort indicators during cardiopulmonary resuscitation manoeuvres on manikins. *Eur J Emerg Med*, *22*(1), 62-65. <https://doi.org/10.1097/mej.0000000000000178>
- Malta Hansen, C., Rosenkranz, S. M., Folke, F., Zinckernagel, L., Tjørnhøj-Thomsen, T., Torp-Pedersen, C., Sondergaard, K. B., Nichol, G., & Hulvej Rod, M. (2017). Lay Bystanders' Perspectives on What Facilitates Cardiopulmonary Resuscitation and Use of Automated External Defibrillators in Real Cardiac Arrests. *J Am Heart Assoc*, *6*(3). <https://doi.org/10.1161/jaha.116.004572>
- Mayrand, K. P., Fischer, E. J., & Ten Eyck, R. P. (2015). A Simulation-based Randomized Controlled Study of Factors Influencing Chest Compression Depth. *West J Emerg Med*, *16*(7), 1135-1140. <https://doi.org/10.5811/westjem.2015.9.28167>
- Miller, A. C., Rosati, S. F., Suffredini, A. F., & Schrupp, D. S. (2014). A systematic review and pooled analysis of CPR-associated cardiovascular and thoracic injuries. *Resuscitation*, *85*(6), 724-731. <https://doi.org/10.1016/j.resuscitation.2014.01.028>
- Ministry of Internal Affairs and Communications. (2018). *Future Estimates of Japan's Households (National Estimates) 2018 Estimates in 2018*. [http://www.ipss.go.jp/pp-ajsetai/j/HPRJ2018/hprj2018\\_gaiyo\\_20180117.pdf](http://www.ipss.go.jp/pp-ajsetai/j/HPRJ2018/hprj2018_gaiyo_20180117.pdf) [in Japanese]
- Ministry of Internal Affairs and Communications. (2019). *The statistical report of resuscitation in 2019*. Fire and Disaster Management Agency. [https://www.fdma.go.jp/publication/rescue/items/kkkg\\_r01\\_01\\_kyukyu.pdf](https://www.fdma.go.jp/publication/rescue/items/kkkg_r01_01_kyukyu.pdf) [in Japanese]
- Nishiyama, C., Iwami, T., Kawamura, T., Ando, M., Yonemoto, N., Hiraide, A., & Nonogi, H. (2008). Effectiveness of simplified chest compression-only CPR training for the general public: a randomized controlled trial. *Resuscitation*, *79*(1), 90-96. <https://doi.org/10.1016/j.resuscitation.2008.05.009>

- Nishiyama, C., Iwami, T., Kawamura, T., Ando, M., Yonemoto, N., Hiraide, A., & Nonogi, H. (2010). Quality of chest compressions during continuous CPR; comparison between chest compression-only CPR and conventional CPR. *Resuscitation*, *81*(9), 1152-1155. <https://doi.org/10.1016/j.resuscitation.2010.05.008>
- Nishiyama, C., Iwami, T., Kitamura, T., Ando, M., Sakamoto, T., Marukawa, S., & Kawamura, T. (2014). Long-term retention of cardiopulmonary resuscitation skills after shortened chest compression-only training and conventional training: a randomized controlled trial. *Acad Emerg Med*, *21*(1), 47-54. <https://doi.org/10.1111/acem.12293>
- Nishiyama, C., Sato, R., Baba, M., Kuroki, H., Kawamura, T., Kiguchi, T., Kobayashi, D., Shimamoto, T., Koike, K., Tanaka, S., Naito, C., & Iwami, T. (2019). Actual resuscitation actions after the training of chest compression-only CPR and AED use among new university students. *Resuscitation*, *141*, 63-68. <https://doi.org/10.1016/j.resuscitation.2019.05.040>
- Oh, J. H., & Kim, C. W. (2016). Relationship between chest compression depth and novice rescuer body weight during cardiopulmonary resuscitation. *Am J Emerg Med*, *34*(12), 2411-2413. <https://doi.org/10.1016/j.ajem.2016.09.006>
- Ristagno, G., Tang, W., Chang, Y. T., Jorgenson, D. B., Russell, J. K., Huang, L., Wang, T., Sun, S., & Weil, M. H. (2007). The quality of chest compressions during cardiopulmonary resuscitation overrides importance of timing of defibrillation. *Chest*, *132*(1), 70-75. <https://doi.org/10.1378/chest.06-3065>
- Rodriguez, S. A., Sutton, R. M., Berg, M. D., Nishisaki, A., Maltese, M., Meaney, P. A., Niles, D. E., Leffelman, J., Berg, R. A., & Nadkarni, V. M. (2014). Simplified dispatcher instructions improve bystander chest compression quality during simulated pediatric resuscitation. *Resuscitation*, *85*(1), 119-123. <https://doi.org/10.1016/j.resuscitation.2013.09.003>
- Savastano, S., & Vanni, V. (2011). Cardiopulmonary resuscitation in real life: the most frequent fears of lay rescuers. *Resuscitation*, *82*(5), 568-571. <https://doi.org/10.1016/j.resuscitation.2010.12.010>
- Sayre, M. R., Koster, R. W., Botha, M., Cave, D. M., Cudnik, M. T., Handley, A. J., Hatanaka, T., Hazinski, M. F., Jacobs, I., Monsieurs, K., Morley, P. T., Nolan, J. P., & Travers, A. H. (2010). Part 5: Adult basic life support: 2010 International Consensus on Cardiopulmonary Resuscitation and Emergency Cardiovascular Care Science With Treatment Recommendations. *Circulation*, *122*(16 Suppl 2), S298-324. <https://doi.org/10.1161/circulationaha.110.970996>
- Schulz, K. F., Altman, D. G., & Moher, D. (2010). CONSORT 2010 statement: updated guidelines for reporting parallel group randomised trials. *BMJ*, *340*, c332. <https://doi.org/10.1136/bmj.c332>
- Shams, A., Raad, M., Chams, N., Chams, S., Bachir, R., & ElSayed, M. J. (2016). Community involvement in out of hospital cardiac arrest: A cross-sectional study assessing cardiopulmonary resuscitation awareness and barriers among the Lebanese youth. *Medicine (Baltimore)*, *95*(43), e5091. <https://doi.org/10.1097/md.0000000000005091>
- Stiell, I. G., Brown, S. P., Nichol, G., Cheskes, S., Vaillancourt, C., Callaway, C. W., Morrison, L. J., Christenson, J., Aufderheide, T. P., Davis, D. P., Free, C., Hostler, D., Stouffer, J. A., & Idris, A. H. (2014). What is the optimal chest compression depth during out-of-hospital cardiac arrest resuscitation of adult patients? *Circulation*, *130*(22), 1962-1970. <https://doi.org/10.1161/circulationaha.114.008671>

- Stiell, I. G., Wells, G. A., Field, B., Spaite, D. W., Nesbitt, L. P., De Maio, V. J., Nichol, G., Cousineau, D., Blackburn, J., Munkley, D., Luinstra-Toohey, L., Campeau, T., Dagnone, E., & Lyver, M. (2004). Advanced cardiac life support in out-of-hospital cardiac arrest. *N Engl J Med*, *351*(7), 647-656. <https://doi.org/10.1056/NEJMoa040325>
- Swor, R., Khan, I., Domeier, R., Honeycutt, L., Chu, K., & Compton, S. (2006). CPR training and CPR performance: do CPR-trained bystanders perform CPR? *Acad Emerg Med*, *13*(6), 596-601. <https://doi.org/10.1197/j.aem.2005.12.021>
- Tanaka, S., White, A. E., Sagisaka, R., Chong, G., Ng, E., Seow, J., Mj, N. A., Tanaka, H., & Ong, M. E. H. (2017). Comparison of quality of chest compressions during training of laypersons using Push Heart and Little Anne manikins using blinded CPRcards. *Int J Emerg Med*, *10*(1), 20. <https://doi.org/10.1186/s12245-017-0147-6>
- Tanigawa, K., Iwami, T., Nishiyama, C., Nonogi, H., & Kawamura, T. (2011). Are trained individuals more likely to perform bystander CPR? An observational study. *Resuscitation*, *82*(5), 523-528. <https://doi.org/10.1016/j.resuscitation.2011.01.027>
- Travers, A. H., Perkins, G. D., Berg, R. A., Castren, M., Considine, J., Escalante, R., Gazmuri, R. J., Koster, R. W., Lim, S. H., Nation, K. J., Olasveengen, T. M., Sakamoto, T., Sayre, M. R., Sierra, A., Smyth, M. A., Stanton, D., & Vaillancourt, C. (2015). Part 3: Adult Basic Life Support and Automated External Defibrillation: 2015 International Consensus on Cardiopulmonary Resuscitation and Emergency Cardiovascular Care Science With Treatment Recommendations. *Circulation*, *132*(16 Suppl 1), S51-83. <https://doi.org/10.1161/cir.0000000000000272>
- Vadeboncoeur, T., Stolz, U., Panchal, A., Silver, A., Venuti, M., Tobin, J., Smith, G., Nunez, M., Karamoöz, M., Spaite, D., & Bobrow, B. (2014). Chest compression depth and survival in out-of-hospital cardiac arrest. *Resuscitation*, *85*(2), 182-188. <https://doi.org/10.1016/j.resuscitation.2013.10.002>
- van Tulder, R., Roth, D., Havel, C., Eisenburger, P., Heidinger, B., Chwojka, C. C., Novosad, H., Sterz, F., Herkner, H., & Schreiber, W. (2014). "Push as hard as you can" instruction for telephone cardiopulmonary resuscitation: a randomized simulation study. *J Emerg Med*, *46*(3), 363-370. <https://doi.org/10.1016/j.jemermed.2013.08.067>
- Wik, L., Kramer-Johansen, J., Myklebust, H., Sjørebø, H., Svensson, L., Fellows, B., & Steen, P. A. (2005). Quality of cardiopulmonary resuscitation during out-of-hospital cardiac arrest. *JAMA*, *293*(3), 299-304. <https://doi.org/10.1001/jama.293.3.299>
- Wu, J. Y., Li, C. S., Liu, Z. X., Wu, C. J., & Zhang, G. C. (2009). A comparison of 2 types of chest compressions in a porcine model of cardiac arrest. *Am J Emerg Med*, *27*(7), 823-829. <https://doi.org/10.1016/j.ajem.2008.07.001>
- Yamaguchi, R., Makino, Y., Chiba, F., Torimitsu, S., Yajima, D., Inokuchi, G., Motomura, A., Hashimoto, M., Hoshioka, Y., Shinozaki, T., & Iwase, H. (2017). Frequency and influencing factors of cardiopulmonary resuscitation-related injuries during implementation of the American Heart Association 2010 Guidelines: a retrospective study based on autopsy and postmortem computed tomography. *Int J Legal Med*, *131*(6), 1655-1663. <https://doi.org/10.1007/s00414-017-1673-8>
- Yeung, J., Davies, R., Gao, F., & Perkins, G. D. (2014). A randomised control trial of prompt and feedback devices and their impact on quality of chest compressions—a simulation study. *Resuscitation*, *85*(4), 553-559. <https://doi.org/10.1016/j.resuscitation.2014.01.015>

## Appendix A

**The 15-minute chest compression training program**

Time minute: second	Context
	Place instructor/participant ratio of 1:3
	Use 1 Laerdal® Little Anne and 1 metronome per group
	<b><i>Participants are admitted and the Instructor introduces himself</i></b>
0:00	"Today, we will be training for chest compressions, the most important component of cardiopulmonary resuscitation."
	"You will perform chest compressions for two minutes."
	"I will explain how to do chest compressions are done, so let us do it together."
0:10	<b><i>The instructor explains to the participants how to do chest compressions</i></b>
	1. Check the position of the lower half of the sternum.
	"First, let's check the flat bone in the middle of the chest called the sternum. Can you find it? Now, place the heel of your hand on the sternum."
	2. Explain that the compressions need to be at a rate of 100–120 compressions per minute. Set the metronome to 100 times/minute and ask participants to listen.
	"Listen to the metronome tempo set at 100 beats per minute and compress the lower half of the sternum 100 to 120 times each minute."
	3. Explain chest compressions depth
	"For each compression... (see intervention below)"
	<b>* To the limited group: "...push to approximately 5 cm, don't push over 6 cm"</b>
	<b>To the unlimited group: "...push as hard as you can"</b>
	4. Explain how to perform chest compressions are performed (keep your elbows straight, put your hands together, place your hands on the lower half of the sternum, and recoil).
	"This is the last step of chest compressions. Please keep your elbows straight. Cross your arms to place either hand may be on top of the other. Then position the base of your palm on the lower half of the sternum and extend your elbows firmly. Open your legs to your shoulder width, and follow this movement (the instructor demonstrates 2–3 chest compressions on Little Anne). Ensure letting the chest return to its normal position after each compression. Continuous chest compressions are lifesaving: Therefore, I will do them firmly

3:10	<b><i>Participants perform chest compressions for 3 minutes each</i></b>
	"Now, let us begin practicing. I would like to ask you to be the first participant."
3:20	Participant A: 1-minute chest compression session (1)
4:20	<b>Voice prompt every 10 seconds*</b>
4:30	Participant B: 1-minute chest compression session (1)
5:30	<b>Voice prompt every 10 seconds*</b>
5:40	Participant C: 1-minute chest compression session (1)
6:40	<b>Voice prompt every 10 seconds*</b>
6:50	Participant A: 1-minute chest compression session (2)
7:50	<b>Voice prompt every 10 seconds*</b>
8:00	Participant B: 1-minute chest compression session (2)
9:00	<b>Voice prompt every 10 seconds*</b>
9:10	Participant C: 1-minute chest compression session (2)
10:10	<b>Voice prompt every 10 seconds*</b>
10:20	Participant A: 1-minute chest compression session (3)
11:20	<b>Voice prompt every 10 seconds*</b>
11:30	Participant B: 1-minute chest compression session (3)
12:30	<b>Voice prompt every 10 seconds*</b>
12:40	Participant C: 1-minute chest compression session (3)
13:40	<b><i>The instructor explains the method of chest compression again</i></b>
	"Thank you for your effort. You must be tired. It is said that high quality chest compression can save lives. Remember to repeat the chest compressions 100 to 120 times a minute and to push the lower half of the sternum... (see intervention below) When you get tired, chest compressions tend to be shallow; therefore, please ensure that you maintain the compression strength as instructed."
	<b>*To the limited group: "...push to approximately 5 cm, don't push over 6 cm"</b> <b>To the unlimited group: "...push as hard as you can</b>
15:00	<b><i>Participants leave the room</i></b>