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Development and Evaluation of a Corrective Feedback System Using Augmented Reality for the High-quality Cardiopulmonary Resuscitation Training

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***Abstract*—In an effort to improve lay rescuers' knowledge and skills in cardiopulmonary resuscitation (CPR), we developed a system that enables high-quality CPR by improving the perceptions of and skills in CPR. The proposed system can evaluate user CPR actions in real time. Particular characteristics of this system are the use of distance and pressure sensors for laypeople to achieve the necessary posture during CPR chest compression and the provision of audiovisual corrective feedback using augmented reality (AR). This system is anticipated to contribute to high-quality CPR training.**

Keywords—AR; corrective feedback; posture detection; Kinect; high-quality CPR

I. INTRODUCTION

CPR is an emergency measure for injured or ill persons who suffer cardiopulmonary arrest. CPR is a technique used alone or in conjunction with an automated external defibrillator (AED; medical device). Everyone should be able to perform CPR. When performing CPR, it can be difficult to assume the correct position for compression of the sternum, and training in specialized skills is required. Evidence indicates that performing CPR in an incorrect position results in insufficient power (compression load) being applied to the heart from the sternum, making it impossible to achieve sufficient compression depth and therefore preventing resuscitation [1]. Known methods of acquiring CPR and AED usage skills include reading available literature and participating in workshops held by medical facilities and public organizations [2-5]. MiniAnne (individual resuscitation dummy), which is mainly used in such workshops, is the standard training tool. Feedback by means of a clicker function whereby a clicking sound is heard when chest compression is performed correctly makes it possible for all participants to simultaneously understand compression strength alone. However, this method cannot be used for qualitative evaluation of excessive compression, incorrect compression direction and incorrect tempo.

In this study, we developed a system for the real-time evaluation of chest-compression quality using MiniAnne (Laerdal Medical Japan, Inc.) and conducted a questionnaire survey for the system evaluation. For this system, we developed software controlling Kinect for Windows v2 and the Wii Balance Board. For the system interface, we used augmented reality (AR) technology to monitor the state of the participant's actual posture. The system made it possible to offer visual and auditory corrective feedback during practice. We believe that making this system publicly available as a training material for individual practice could contribute to laypeople training necessary CPR skills.

II. EMERGENCY RESPONSE TO CASES OF OUT-OF-HOSPITAL CARDIAC ARREST

Types of commonly performed CPR in Japan are Basic Life Support (BLS)/Advanced Cardiovascular Life Support (ACLS) by the American Heart Association (AHA) and BLS/ALS (Advanced Life Support) by the Japan Resuscitation Council and the Japan Foundation for Emergency Medicine. According to the Guideline Update 2015, as the situation clearly differs between in-hospital cardiac arrest (IHCA) and out-of-hospital cardiac arrest (OHCA), patients are divided into OHCA and IHCA cases and appropriate treatment methods are specified for both. This paper focuses on increasing the quality of lay rescuer CPR and describes a visual and auditory corrective feedback system for training of high-quality CPR for OHCA.

Emergency response to cases of OHCA is a process involving perception of the event and a request to the emergency response system for dispatch, immediate and high-quality CPR[5-7], rapid defibrillation, emergency medical services, ALS and treatment following the return of spontaneous circulation(Fig.1)[8]. Lay rescuers need to respond appropriately to perceive the event, make a request to the emergency response system for dispatch, and immediately implement high-quality CPR and rapid defibrillation. Meanwhile, regional communities support patients who suffer from OHCA, with evidence suggesting that cardiopulmonary arrest onset rates and prognosis reported in the US differ greatly by region. It has been reported that the OHCA patient survival rate after one month can be improved by correct CPR and AED use by bystanders. Bystanders, who do not necessarily have any medical training, need to perform public access defibrillation (PAD) until an emergency medical service (EMS) provider team that has received specialized training can take over (Fig. 1)[8]. Thus, the regional and layperson level of OHCA resuscitation needs to be improved.

III. THE IMPORTANCE OF CHEST COMPRESSION AND WHAT IS ANTICIPATED OF LAYPEOPLE

Chest compression must be unceasingly performed at a tempo of 100–120 repetitions per minute. For adult patients, the compression depth must be at least 5 cm but no more than 6 cm. Chest compression plays an important role in CPR. Injured or ill persons in a state of cardiopulmonary arrest must be rapidly treated. Recent evidence has demonstrated that chest compression is even more important than rescue breathing. Therefore, even lay rescuers who have not received training must correctly perform chest compression. It is important high-quality CPR [7].

Fig. 2 shows the length of interruptions for pre-defibrillation chest compression and clinical effect (percentage of cases in which shock was successful) [1]. Fig. 2 shows the results of a study targeting 60 cases of cardiopulmonary arrest in which the defibrillation success ratio decreased with longer pre-defibrillation CPR interruption time. Accordingly, it is important that chest compression be performed unceasingly for a set period of time [8]–[12].

CPR performed with correct posture was considered to be extended position compression, whereas CPR performed with incorrect posture was considered to be bent position compression. Fig. 3 compares extended and bent position compression force in chest compression in an experiment to determine parameters. This experiment showed that the extended position resulted in greater compression load than the bent position. Therefore, it was confirmed that correct chest compression is performed by means of extended position compression.

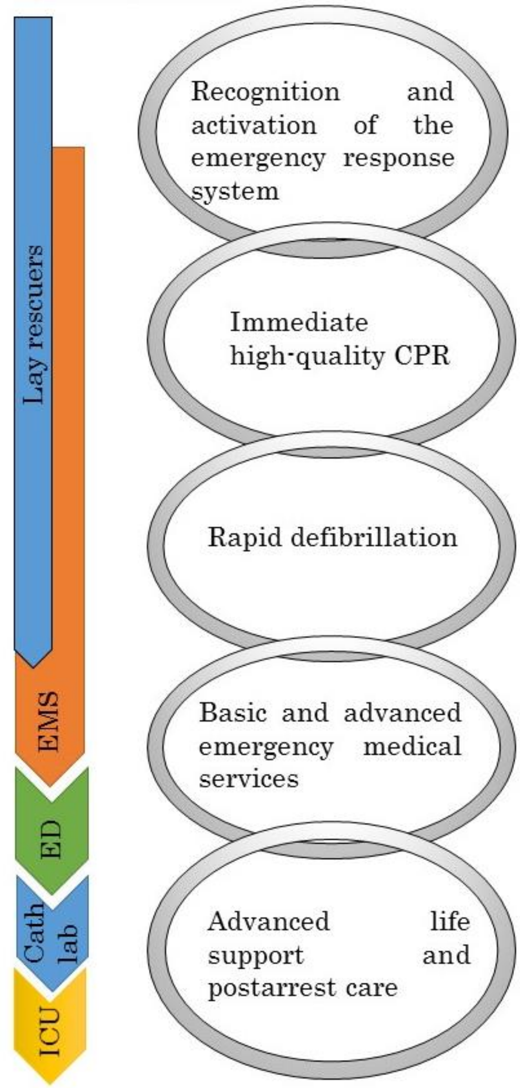

Fig. 1. OHCA chains of survival

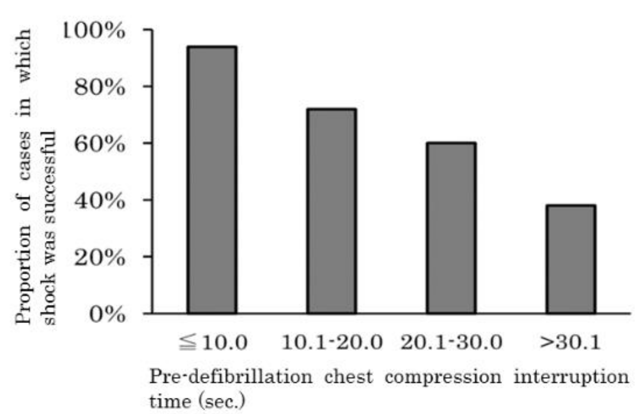

Fig. 2. Pre-defibrillation chest-compression interruption time and clinical effects

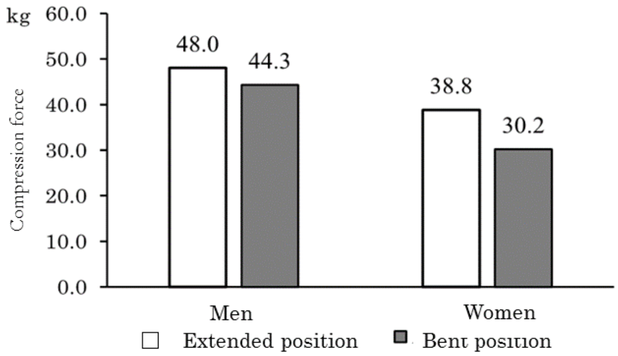

Fig. 3. Verification of extended and bent position chest compression

IV. CPR REQUIREMENTS AND SYSTEMIZATION

The requirements of correct chest compression are “compression depth of at least 5 cm but no more than 6 cm, performed at 100 - 120 repetitions per minute.” Compression is unceasingly performed with minimal interruption time (⩽10 s) [8]. During compression, the fingers must not come into contact with the thoracic wall in the center of the chest of the injured or ill person. This can be achieved by applying compression so that external force is perpendicular from the elbow joint to the base of the palm [8]. It has been reported that on average, compression force of ⩽50 kg is required to achieve a compression depth of 5 cm [12]. With the present system, a Kinect sensor detects whether the humerus and forearm bone are in the extended or bent position while a Wii Balance Board sensor detects force (kg) during compression and this information is gathered and processed in the main system module in order to perform evaluation.

The user (learner) performs chest compression on a chest-compression practice mannequin that has been installed on top of the Wii Balance Board. As shown in Fig. 4, the main system quantitatively evaluates user compression force acquired through the Wii Balance Board while simultaneously estimating (angle estimation determination) the posture and state of both arms, acquired through the Kinect sensor camera, to determine whether the arms are in the extended or bent position. The system can follow the position of the user’s arms using the abovementioned data and perform virtual conversion with AR to display information on the user side communication monitor that is in front of and directly below their line of sight. Thus, evaluation (with comments) can be used to confirm displacement in position during chest compression for each compression in real time.

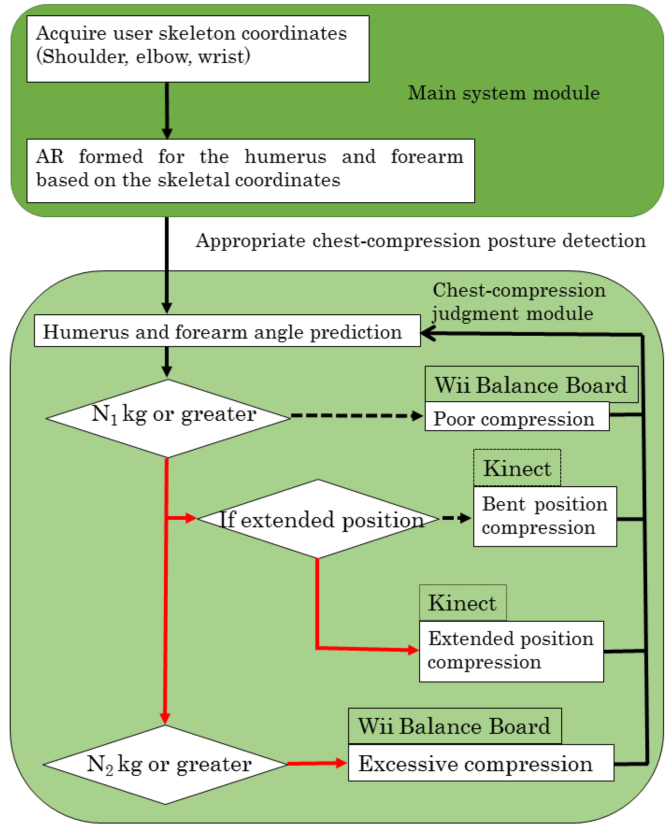

Fig. 4. Outline of system and chest-compression determination processing

V. OVERALL SYSTEM COMPOSITION

The system was developed using Microsoft Visual Studio 2013 and .NET Framework 4.5 with the C# language. The system was composed of (1) Kinect for Windows v2, (2) a Wii Balance Board, (3) a communication monitor installed on the floor, (4) MiniAnne (CPR/AED learning tool kit), (5) a Bluetooth USB adapter, and (6) a Windows OS notebook PC. Fig. 5 shows a diagram of the system’s basic settings.

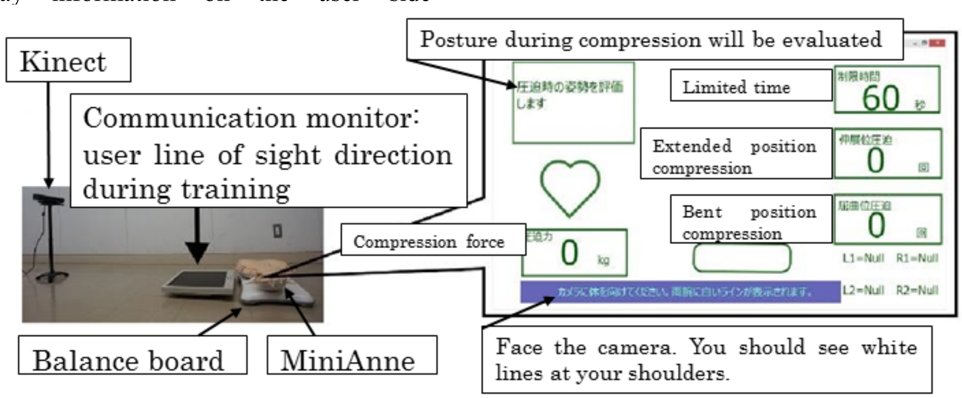

Fig. 5. Image of the system’s basic settings

VI. Main functions

A. AR display function in compression posture

In the system, user posture footage taken with the Kinect sensor camera was displayed with various items of information superimposed using AR. As shown in Fig. 6, "both shoulders and arms were shown with white lines" to emphasize them as a way to confirm acquisition success when attempting to acquire user skeleton information upon system startup. Users perceive the AR display for estimating arm, shoulder, and head posture while correcting posture maintenance according to the goal of the arms being in the extended position. This makes it possible to learn correct chest-compression posture.

Fig. 6. Extended position compression (left) and bent position compression (right) with AR

B. Function for compression tempo recall and compression force state

The system was setup so that a beep sounded 100 times per minute during system startup. When the user starts chest compression, the beep sound disappears, and the display color of a heart symbol on the communication monitor switches between three colors (hot pink, light pink, black) so that the compression tempo can be learnt visually. Compression parameters were displayed as N_1, N_2 on Fig. 4. Judgments detected using the Wii Balance Board were displayed as "poor compression" for N_1 kg or below and "excessive compression" for N_2 kg or higher. When the user is judged to be performing excessive compression, the entire monitor turns red and shows a warning. The parameters for poor compression and excessive compression were set according to preliminary investigation results.

C. Arm angle displacement estimation using the Kinect sensor

User posture displacement was estimated by obtaining and processing data for the coordinates for three points acquired by the Kinect sensor (shoulder, elbow, and wrist). When making an estimation of the left elbow from the left shoulder, the angle displacement of the segment composed of a point from the left shoulder of coordinate to another point from the left elbow of coordinate was used to derive cosine values and make a judgment. However, at the present time there is a possibility of misrecognition in natural refraction environment due to natural light etc. Improvement of recognition system is a future work.

D. Angle alert display function

In this system, the composition of angles estimated by the Kinect sensor (from left shoulder to left elbow, from left elbow to left wrist, from right shoulder to right elbow, from right elbow to right wrist) was detected in order to judge whether the arms were in the extended or bent position. To make the judgment, threshold values were derived with four angles from both arms as standards and AR was used to superimpose alerts on the communication monitor each time the arms deviated from the required angles.

E. Achieved value learning feedback save function

1) As shown in Fig. 7, after performing chest compression for 1 min, an achievement learning evaluation module that added evaluation comments to the number of times extended position compression, bent position compression, and excessive compression were achieved was fitted to the system. Fig. 8 shows that results were returned to the user through learning feedback display in accordance with the number of times extended and bent position compression were achieved, and these results were simultaneously saved in the system. Reflecting the output of this function, the user can continuously learn about high-quality CPR.

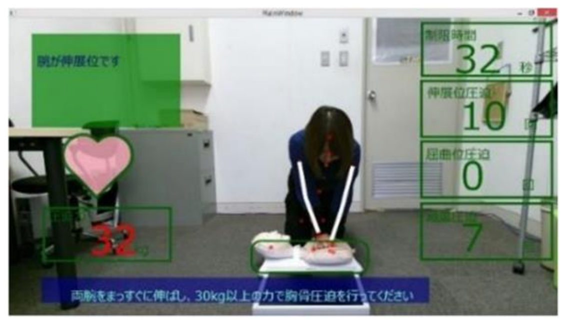

Fig. 7. Floor placement communication monitor display

Fig. 8. Achievement learning feedback screen transition

VII. Evaluation of system

A. Evaluation methods

Our validation targeted 48 subjects who gave their consent after receiving a prior explanation of the details of the investigation. In the CPR workshop, the participants received an explanation of basic knowledge on CPR and communication by the system before performing CPR individually. The questionnaire survey covered questions on the utility of the system developed in this study and questions on learning and skills training in CPR. Subjects answered according to five levels. Question items are follows:

- Q1. Are you already aware of cardiac massage and able to perform it?
- Q2. Were you able to understand about cardiac massage in this training?
- Q3. Were you able to perform cardiac massage as you intended?
- Q4. Were you able to implement compression in accordance with the speaker sound?
- Q5. Were you able to use the monitor display (Compression force. Number display) as a reference?
- Q6. Were you able to use your arm display (posture) from the monitor footage as a reference?
- Q7. Were you able to use the color of the heart symbol on the monitor footage as a reference?
- Q8. Were you able to learn the necessary compression force for cardiac massage?
- Q9. Were you able to perform compression while paying attention to posture and arm angle?
- Q10. Do you have any intention of coming when there is opportunity for training again?
- Q11. Were you able to realize any problems you had with your own arms, posture or tempo (frequency)?
- Q12. Were you able to become interested in cardiac massage?
- Q13. Before the training, could you judge a person, for example, a family member of acquaintance who had fallen over and stopped breathing as being in cardiopulmonary arrest and perform cardiac massage?
- Q14. Going forward (after the training), can you judge a person, for example, a family member of acquaintance who has fallen over and stopped breathing as being in cardiopulmonary arrest and perform cardiac massage?

Question 1 (Q1) is a question on the prior knowledge of CPR. Q2 and Q3 are questions about training situation (understanding and response). Q4 to Q7 are questions about the function of the proposed system. Q8 to Q12 are questions to confirm the effect by using the proposed system, that is, to be useful. Q13 and Q14 are questions about training, before and after comparison.

B. *Questionnaire survey results and discussion*

Fig. 9 shows the response rate of the 5-point scale to the question. Fig. 10 shows the average and standard deviation for the answer results.

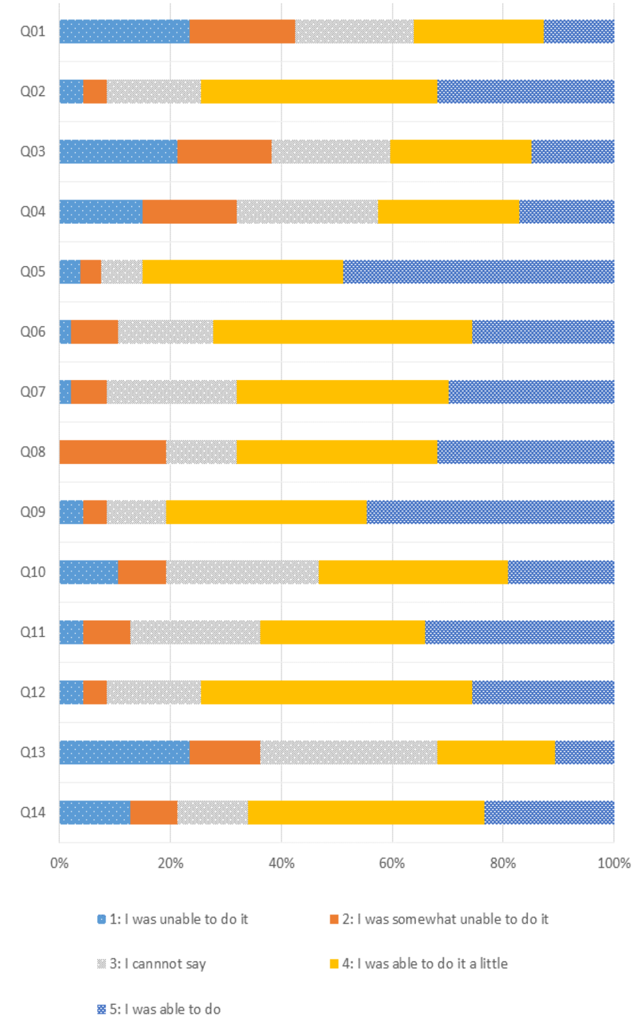

Fig. 9. Response rates in five levels for each question

Based on the questionnaire survey results, we clarified some features (Fig.9, Fig.10). First, in the state before training, the answer average for Question 1 was close to 3-point on 5-point scale, which was intermediate, and its bias was not large (Fig. 10). Next, the effect after the training was discussed from the answer results of Questions 2 and 3. It was useful to learn the basic knowledge of CPR. However, one training did not result in perfect acquisition of CPR. It is suggested that it is necessary to continue training repeatedly. This also means that the user noticed that it is not an easy task to master high-quality CPR. In other words, it can be said that users understand the necessity of the proposed system. The answer to the question about the evaluation of the proposed system (Q4 to Q7) was not so high for auditory information, but high evaluation was given for visual information. Finally, when comparing Questions 13 and 14, there was a difference in the change before and after the training. This shows the effect of training.

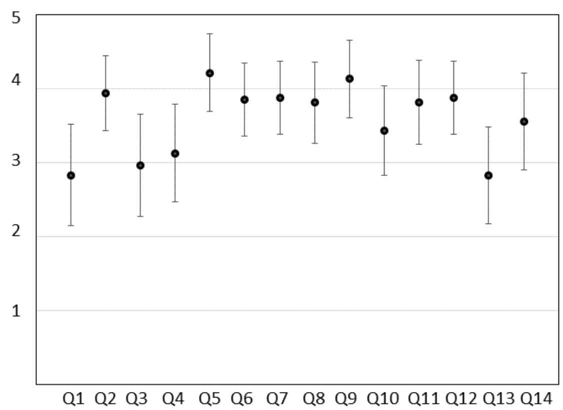

Fig. 10. Average and standard deviation in five levels for each question

VIII. CONCLUSION

In an effort to improve lay rescuers' knowledge and skills in CPR training, we developed a system that enables high-quality CPR by improving the perceptions of and skills in CPR. Especially, this paper described a visual and auditory corrective feedback system for training of high-quality CPR for OHCA and conducted a questionnaire survey for the system evaluation. Although the proposed system was found to improve It appears that in addition to learning with the proposed system, further awareness-raising and educational activities on CPR are needed through organizations, such as governments and municipal bodies.

REFERENCES

[1] D. P. Edelson, B. S. Abella, J. Kramer-Johansen, et al, "Effects of compression depth and pre-shock pauses predict defibrillation failure during cardiac arrest," Resuscitation, Vol.71, No.2, pp.137-145, 2006.

[2] P. Iserbyt, L. Theys, P. Ward, N. Charlier, "The effect of a specialized content knowledge workshop on teaching and learning Basic Life Support in elementary school: A cluster randomized controlled trial," Resuscitation, Vol.112, pp.17-21, 2017.

[3] P. Iserbyt, L. Mols, N. Charlier, "Learning Basic Life Support (BLS) with tablet PC's in reciprocal learning at school: are videos superior to pictures? A randomized controlled trial," Resuscitation, Vol.85, pp.809–813, 2014.

[4] N. Mpotos, S. Lemoyne, P. A. Calle, E. Deschepper, M. Valcke, K. G. Monsieurs, "Combining video instruction followed by voice feedback in a self-learning station for acquisition of Basic Life Support skills: A randomised non-inferiority trial," Resuscitation, Vol.82, No.7, pp.896-901, 2011.

[5] J. Yeung, D. Okamoto, J. Soar, G.D. Perkins, "Aed training and its impact on skill acquisition, retention and performance: a systematic review of alternative training methods." Resuscitation, Vlo.82, No.6, pp.657–664, 2011.

[6] F. Semeraro, F. Taggi, G. Tammaro, G. Imbriaco, L. Marchetti, E. L. Cerchiari, "iCPR: a new application of high-quality cardiopulmonary resuscitation training," Resuscitation, Vol. 82, pp.436-441, 2013.

[7] J. P. Nolan, "High-quality cardiopulmonary resuscitation," Current Opinion in Critical Care, Vol.20, No.3, pp.227-233, 2014.

[8] American Heart Association, "Highlights of the 2015 American heart association guidelines update for cardiopulmonary resuscitation and emergency cardiovascular care," 2015.

[9] M. J. Kellum, K. W. Kennedy, G. A. Ewy, "Cardocerebral resuscitation improves survival of patients with out-of-hospital cardiac arrest," The American Journal of Medicine, Vol.119, No.4, pp.335-340, 2006.

[10] H. Losert, F. Sterz, K. Kohler, G. Sodeck, R. Fleischhackl, P. Eisenburger, A. Kliegel, H. Herkner, H. Myklebust, J. Nysaether, A. N. Laggner, "Quality of cardiopulmonary resuscitation among highly trained staff in an emergency department," Archives Internal Medicine, Vol.166, No.21, pp.2375-2380, 2006.

[11] R. A. Berg, A. B. Sanders, K. B. Kern, R. W. Hilwig J. W. Heidenreich, M. E. Porter, G. A. Ewy, "Adverse hemodynamic effects of interruption chest compressions for rescue breathing during cardiopulmonary resuscitation for ventricular fibrillation cardiac arrest," Circulation. Vol.104, No.20, pp.2465-2470, 2001.

[12] A. E. Tomlinson, J. Nysaether, J. Kramer-Johansen, P. A. Streem, E. Dorph, "Compression force-depth relationship during out-of-hospital cardiopulmonary resuscitation," Resuscitation, Vol.72, No.3, pp.364-370, 2007.

[13] V. M. Zatsiorsky, B. I. Prilutsky, "Biomechanics of Skeletal Muscles," Human Kinetics, 2012.