Report

Development of an Educational Equipment "Dock-kun" to Help School Children Master High-quality Cardiac Massage

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ABSTRACT: One of the most effective ways to increase the cardiopulmonary resuscitation (CPR) rate of lay rescuers is through education of school children. We developed a learning tool called "Dock-kun" to help school children understand and master high-quality manual cardiac massage. With "Dock-kun," school children can visually learn about the physiology of CPR and how to correctly perform this life-saving technique by checking the amount of water, a surrogate for blood, being pumped out of the model heart and sucked back into the heart with each compression-decompression cycle. The forward flow was maximized when the high-quality cardiac massage was performed with a depth of 4.5-5.0 cm and a rate of 105-110 compressions per minute. The real-time flow of "water" and feedback to the rescuer provide a means for school children to learn high-quality cardiac massage technique and understand its related mechanophysiology. Workshops using this new educational tool will greatly contribute to widespread knowledge of the high-quality cardiac massage among school children.

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KEYWORDS: high-quality cardiac massage, Dock-kun, education, school children, mechanophysiology

Although many educational courses about basic life support (BLS) and the use of automatic external defibrillators (AED) have been developed and promoted for the public, the executing rate of life-saving cardiopulmonary resuscitation (CPR) procedures actually performed by lay rescuers each year remains too low, indicating that additional approaches are needed to improve the current situation.[1)] Since one of the most effective ways to increase the lay

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rescuer CPR rate is the education of school children,[2] the objective of our research program was to develop a new educational tool and evaluate it to determine whether it helps school children understand and master high-quality cardiac massage.

Since elementary and junior high school students were the main target of this study, an educational equipment was created for them to easily understand why and how cardiac massage should be performed for resuscitation. Furthermore, the new educational tool was developed to visualize fundamental elements of mechanophysiology of cardiac massage, allowing the students to distinguish high-quality versus poor-quality technique.[3] It is important for students to learn the procedure of cardiac massage not only by seeing it but also exercising it with both hands. As such, we developed a low-cost tool so that each student could purchase it to repeatedly practice at home with their family. We intentionally produced a new training aid using a commercially available material that has a similar function to the human heart.

Development of the prototype

This study was approved by the Research ethics committee, Faculty of Nursing, Toho University (No. 28013). The purpose and procedures of this study were explained by the authors, and informed consent was obtained from each participant of the workshop, or if appropriate, from their legal representative.

After an extensive search for commercially available materials, we found a kerosene pump which has a similar structure and function to the human heart. This kerosene pump was used as the main valving system for our new educational tool. A visual comparison between the kerosene pump and an echocardiogram of a heart during the compression phase or systole and the decompression phase or diastole is summarized in Fig. 1. When liquid (= blood) flows into the pump (=left ventricle), the outflow valve (=aortic valve) is closed and at the same time the inflow valve (=mitral valve) is opened (Fig. 1, left). When pumping out the liquid from inside the pump, conversely the outflow valve (=aortic valve) is opened and the inflow valve (=mitral valve) is closed (Fig. 1, right). Utilizing this similarity, we prepared a prototype with the kerosene pump and water that can allow visualization of the return and ejection of the blood during cardiac massage.[4] The appearance and structure of the fabricated prototype are shown in Fig. 2. The outside of the prototype was covered with transparent resin in the shape of the upper half of the human body. The model heart was created with a 3D printer, and the kerosene pump was embedded inside. We adjusted the thickness of the transparent resin to reproduce the elasticity of the thorax of the human body. When the chest is compressed with both hands, the kerosene pump in the heart is compressed and “blood” is pushed out of the heart. When the hands are released, the chest wall recoils back to its resting position due to the elasticity of the resin of the device and the water is drawn back into the “heart.” Based upon this mechanophysiology, we developed a functional prototype. We used this prototype to teach and demonstrate, in real-time, the physiology of CPR and how to optimize manual cardiac massage technique.

Four methodology specifications are known to be essential elements for high-quality cardiac massage; (1) compression rate of 100-120/min, (2) compression depth of 2 inches (5 cm), (3) full chest wall recoil after each compression, and (4) no or minimal pauses between chest compressions.[1] We designed the device to meet these specifications.

Next, we carefully and repeatedly tested the impact of chest compressions on the prototype CPR training device and identified three potential problems. First, in spite of poor CPR technique, a significant amount of “blood” could be pumped out of the heart even if the depth of the compression and recoil were insufficient. Second, the resin cracked before 1,000 chest compression cycles were performed. Third, the more the prototype resembled a real heart, the more the school children hesitated to touch it, limiting its educational effect.

The next-generation equipment with a coil spring

Based upon the observations discussed above, we improved the design of the prototype. First, 2 set of polyethylene foam were placed on the top and bottom of the equipment as a cushioning material, respectively, as shown in Fig. 3A, left. When the chest was pressed, the polyethylene foam was deformed to partially absorb the force before the pump could be pressed. As a result, “blood” could not be evacuated well from the “heart” without sufficient compression depth or full chest wall recoil. Thus, the model was able to be used to teach good technique versus the poor one. Next, issues surrounding the durability of the device after multiple compression cycles were solved using a coil spring design, as shown in Fig. 3 A, left. Further, since the shape of the kerosene pump was

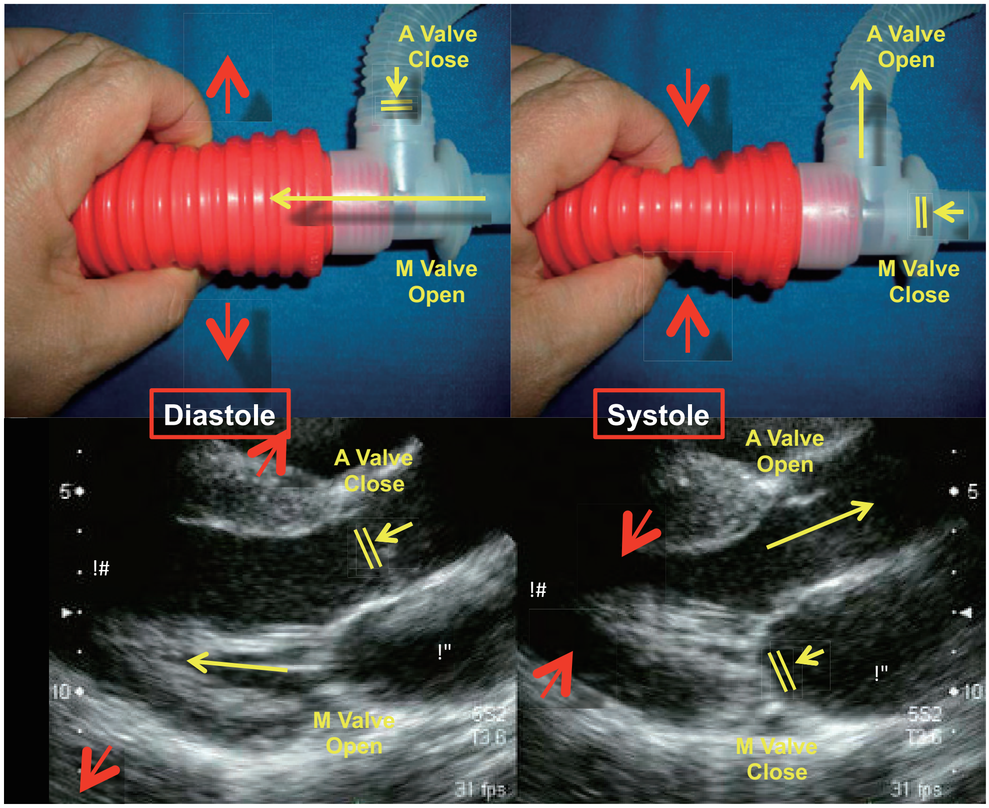

Fig. 1 Structural and functional similarities between the kerosene pump (upper photos) and actual heart recorded with echocardiography (lower photos). Upper left: An explanatory view for explaining movements of the mitral and aortic valves and flow of simulated blood when the simulated heart is in diastole. Lower left: An echocardiogram corresponding to the upper left photograph for explaining movements of the mitral and aortic valves and flow of blood in the actual heart in diastole. Upper right: An explanatory view for explaining movements of the mitral and aortic valves and flow of simulated blood when the simulated heart is in systole. Lower right: An echocardiogram corresponding to the upper right photograph for explaining movements of the mitral and aortic valves and flow of blood in the actual heart in systole.

found to be less suitable for combining the coil spring with cushioning materials, we adopted a commercially available air pump (BB type, Nozaki Manufacturing Co., Ltd., Osaka, Japan) to provide the same mechanical functionality. The educational equipment was named "Dock-kun ver. 1," in which the air pump was housed in a cylinder, and the coil spring and upper and lower cushioning materials were used. We prepared coil springs having two different elasticities that can reflect the thoracic stiffness of an adult and child. Although the compression pressure of 30 kg was ideal for performing cardiac massage on adult subjects, we set it at 15 kg for targeting children; when a child experiences a cardiac arrest at school, it is often the case that there will be no adult on the spot. Therefore, we have supposed that elementary and junior high school students are more likely to have to perform cardiac massage by themselves on that child. Thus, the optimal amount of water to simulate blood could be pumped out only when the correct chest compression and decompression were performed. As it looks quite different from the real heart, the school children were willing to practice CPR with this training tool without hesitation.

In parallel with the development of the educational equipment, we studied the optimal depth and rate of chest compression by reanalyzing the data of the "Resuscitation Outcomes Consortium (ROC) Prehospital Resuscitation Impedance Valve and Early Versus Delayed Analysis (PRIMED)" trial, which was a large-scale clinical trial of cardiopulmonary resuscitation conducted in North America; and found that 4.5-5.0 cm of depth and 105-110 rpm of rhythm resulted in compression of the highest quality.[5] Based upon this result, we adjusted the type of air pump

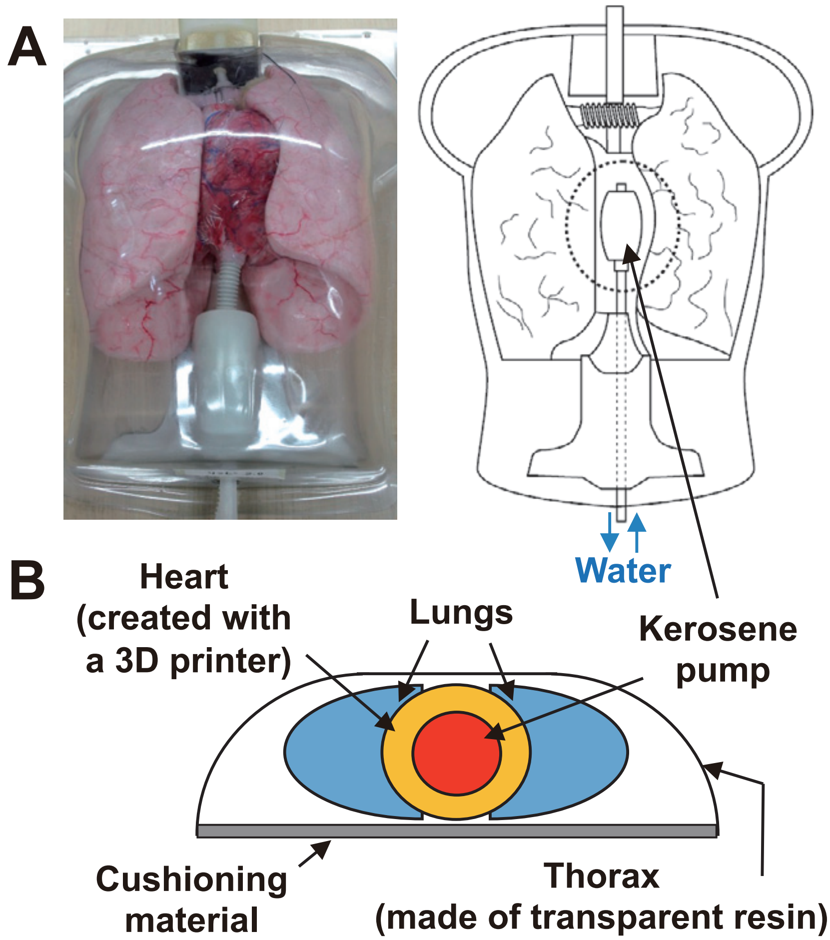

Fig. 2 External view (A) and structure (B) of prototype. A simulated heart is embedded in the chest of a mannequin of the upper half of a human body. Its forward-facing portion where the chest is present has a shape simulating the human body, while its backward-facing portion is a flat plate. In addition, simulated lungs are disposed on both sides of simulated heart.

and the material and thickness of cushioning materials so that the output of water could be maximized when the high-quality chest compressions were performed. For example, we changed the cushioning material on the top of the equipment from polyethylene foam to sponge since it can be deformed enough to absorb the force while hardly changing the shape of the pump when the cardiac massage was performed with a modest compression depth of up to 2-3 cm. In this way, we have developed an improved model of "Dock-kun ver. 1," which is named "Dock-kun ver. 2," as shown in Fig. 3.

Evaluation of "Dock-kun ver. 2" at workshops

We held teaching workshops using "Dock-kun ver. 2" for elementary school students (n = 80) and junior high school students (n = 19) in Ota Ward, Tokyo, Japan, as shown in Fig. 4. We prepared 15 sets of the devices, so that two school children could use one training aid at a time. We used transparent buckets to receive the "blood" pumped out of the heart. The buckets were marked with colored tape to indicate a volume of 1 L for students to confirm the cardiac stroke volume at a glance, which was useful to obtain real-time feedback information on the efficiency of cardiac massage.

Using "Dock-kun ver. 2," students participated in lectures and hands-on CPR and AED training. Fifth-grade elementary school pupils attended a 35-min training program, whereas first- to third-grade students of the junior high school participated in a 90-min training program depending on their schedule. The teaching seminar used training-lecture voice programs, to assure the same message was delivered to all students, and the seminar could

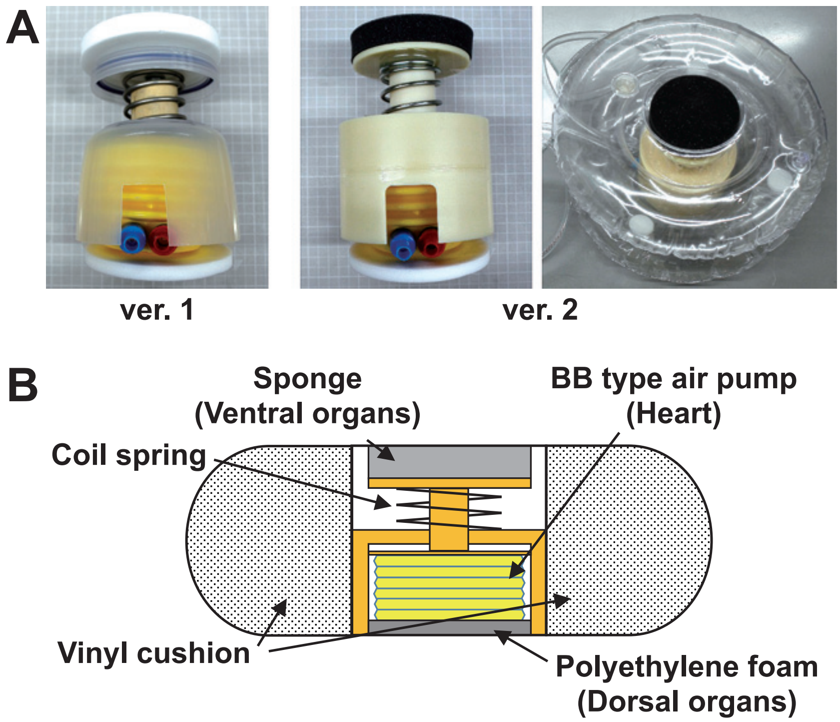

Fig. 3 External view (A) and structure (B) of "Dock-kun ver. 1" (ver. 1) and "Dock-kun ver. 2" (ver. 2). The air pump was housed in a cylinder, and the coil spring and upper and lower cushioning materials were used in both ver. 1 and ver. 2. The differences of structure between ver. 1 and ver. 2 include the type of air pump, the material and thickness of the cushioning materials, and the rigidity of the cylinder. Thus, the optimal amount of water to simulate blood could be better pumped out only when correct chest compression and decompression were performed with ver. 2 in comparison with ver. 1.

be completed within the allotted class times. Nurses at Omori Hospital, professors of the Faculty of Nursing, and graduate and undergraduate students of Toho University took part in the workshops as instructors.

The "Dock-kun" and its associated lecture were qualitatively evaluated based on comments freely given by the students. Many stated "it was nice to check whether our cardiac massage was well done in real-time." These responses indicate that the new educational equipment "Dock-kun ver. 2" helped the school children better understand how to perform the cardiac massage. In addition, some commented "it was harder than I expected," "physical strength was needed," and "it was difficult to get a knack." These comments may suggest that school children took this training program seriously and that "Dock-kun ver. 2" is an ideal tool to teach high-quality manual cardiac massage.

Another workshop was held for senior high school students at a later date, which was planned and carried out by the undergraduate students of Toho University who had attended the previous workshops at the elementary and junior high schools as instructors. In this workshop, we also received positive opinions similar to those from the elementary and junior high school students. Thus, "Dock-kun ver. 2" may be a suitable equipment for helping students aged 10-18 years learn how to perform high-quality CPR.

Summary

The intent of this project was to develop a new tool to better simulate the physiology of CPR and to help students master high-quality CPR technique. In order to meet this purpose, we created an educational tool called "Dock-kun ver. 2." The device is relatively inexpensive to make and is durable; more importantly, students readily used the device to comprehend the physiology of CPR and to acquire this life-saving technique. The real-time feedback obtained by the use of device enabled students to optimize

Fig. 4 Primary life-saving measures class using "Dock-kun ver. 2" in elementary (A, B) and junior high (C, D) schools. Note the transparent bucket, which is marked with a colored (red) tape indicating a volume of 1 L (A, B). The instructors advised the students how to perform the high-quality cardiac massage. Students assessed each other's quality of performance of cardiac massage.

their manual cardiac massage technique with an easy-to-use and fun teaching tool, and also helped them understand some of the underlying mechanophysiology of CPR. The pilot workshop programs using this educational equipment were successful according to the survey responses of the students. This simple device has the potential to significantly contribute to widespread knowledge of the high-quality cardiac massage and increase the chances that patients will receive lay rescuer CPR in the setting of a cardiac arrest.

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Conflicts of interest: The authors indicated no potential conflict of interest.

References

1) Highlights of the 2015 AHA Guidelines Update for CPR & ECC, American Heart Association, https://eccguidelines.heart.org/wp-content/uploads/2015/10/2015-AHA-Guidelines-Highlights-English.pdf (Last accessed March 2, 2017).
2) Böttiger BW, Semeraro F, Wingen S. "Kids Save Lives": Educating schoolchildren in cardiopulmonary resuscitation is a civic duty that needs support for implementation. J Am Heart Assoc. 2017; 6: 1-4.
3) Wada T, Ohara H, Nakamura Y, Cao X, Izumi-Nakaseko H, Ando K, et al. Efficacy of precordial percussion pacing assessed in a cardiac standstill *microminipig* model. Circ J. 2017; 81: 1137-43.
4) Sugiyama A, Lurie KG, inventor; Cardiac massage practice device and cardiac massage practice method. United States Patent Application Publication No.: US 2015/0279237 A1. 2015 Oct 1.
5) Sugiyama A, Duval S, Nakamura Y, Yoshihara K, Yannopoulos D. Impedance threshold device combined with high-quality cardiopulmonary resuscitation improves survival with favorable neurological function after witnessed out-of-hospital cardiac arrest. Circ J. 2016; 80: 2124-32.