Accuracy assessment of different finger placements for cardiopulmonary resuscitation on infants

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***Abstract*— The assessment of cardiopulmonary resuscitation (CPR) is important for training as well as CPR related research to validate new method or to confirm efficacy of existing one. Infant CPR, in particular, has been received great attention due to its controversy over appropriateness of or superiority between two different methods, two-finger (TF) and two-thumb (TT) CPR, suggested by the resuscitation council. Accordingly, the development of assessment tool that is capable of reliably investigating different CPR techniques has become critical. One of the most challenging task in the infant CPR is to provide consistent and accurate finger placement throughout the performance. Here, we suggest a new method to measure accuracy of the finger placement for both TF and TT CPR using manikin-integrated digital measuring system developed in the previous study. Center of forces of force sensitive resistance sensors used for assessing different finger placements were measured in each compression and scattered on 2D plane to quantitatively and qualitatively probe the finger position. The appearance of the scattered data turned out to be significantly different depending on the performance capability. In the comparison between beginners and experts, stdY and meanDist were significant parameters differentiating these two groups for both techniques, meaning beginners are poor at providing consistent forces along y direction and targeting a specific region while relatively good at balancing in x direction.**

I. Introduction

Young children, especially those younger than 1 year old, are highly vulnerable and have higher rate of unintentional injury-related death than that of all ages [1-2]. Therefore, appropriate cardiopulmonary resuscitation (CPR) for very young children and infants is particularly important.

For infant CPR, there are two different techniques recommended by the guidelines from the resuscitation council (e.g. American heart Association AHA, European Resuscitation Council (ERC)), a two-finger (TF) technique with lone rescuer, which is to compress the sternum with two fingers, and a two-thumb (TT) technique with two or more rescuers, which is to compress with two thumbs by encircling the infant's chest with both hands [3]. However, the existing guidelines have often caused a controversy over the effectiveness, particularly for finger placement by requiring optimization of the performance [4-6], arguing for TT technique in preference to TF technique [7-12], or even proposing a new method for an alternative [13] while some have confirmed adequateness of the current one [14].

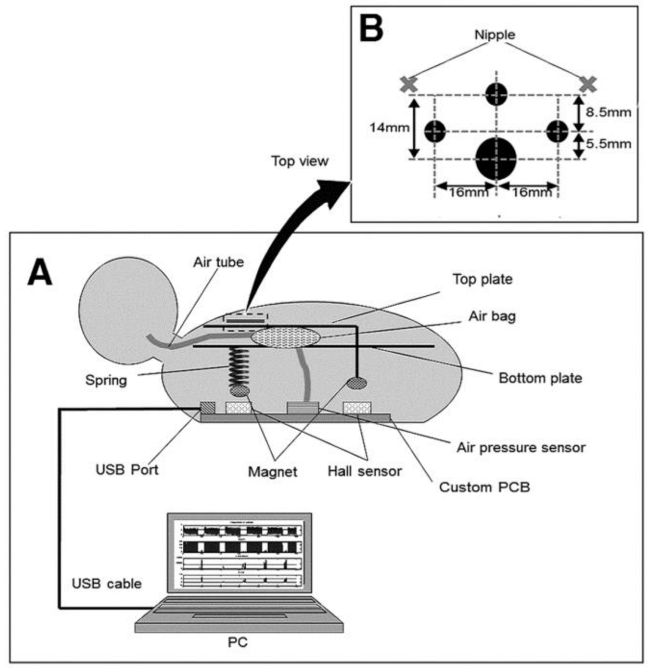

Fig 1. (A) Schematic of data acquisition process through the remodeled manikin. Printed circuit board (PCB) where sensors as well as other electrical axillaries including a universal serial bus (USB) port are mounted; (B) Four force sensitive resistance (FSR) sensors are located just below the nipple line in the chest in diamond shape [21].

Compared to adults, infants have relatively small region for heart compression, which is located at lower third of their sternum and therefore accurate finger placement is critical. With inaccurate location, xiphisternum or abdomen may be pressed instead, causing a rupture of the liver [15].

However, there have been great difficulties in evaluating accuracy of finger placement due to the lack of proper assessment tool that successfully discerns two different techniques and analyzes the position in a quantitative manner. In conventional assessment tools, simple on-off lightings or

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those in different colors were the only indications of right or wrong [16-20] and precise analysis for real-time finger placement usually required expensive sensors to be integrated which is not economically beneficial for commercial products.

In this study, we used the previously developed manikin-integrated, digital measuring system in which correct/incorrect labels for the finger placement using four force sensitive sensors placed in diamond shape were initially created and demonstrated by simulating with beginners and experts assuming that an appropriate CPR assessment system would successfully differentiate personal level of the performance [21]. Here, we made the same strategy to suggest new method of measuring accuracy of finger placements based on COF diagram for more quantitative and qualitative assessment compared to the previous one.

II. MATERIALS AND METHODS

A. *Diamond shaped FSR sensors*

In the manikin-integrated digital measuring system (Fig.1A), four force sensitive resistance (FSR) sensors with two different sizes were attached to its chest in a diamond shape. Their characteristics of generating different values for pressing center and edge with the same amount of the pressing force allowed to attain proper sensitivity for discriminating the TT from the TF technique and evaluating each of their proper positions (Fig.1B). For example, correct finger placement for TF technique produced considerable amount of pressure for top and bottom sensor with small amount of pressure for right and left ones. Large output values for either right or left sensor with TF technique indicate deviation of the two fingers from the center to either side. Similarly, when those two fingers were slightly positioned downward, top sensor would produce lower pressure value due to edge pressing, indicating wrong position. On the contrary, with slight upward position, the top sensor would give considerable amount of pressure while the bottom sensor gives small amount of pressure since the edge of it is pressed instead of the center. With different size of top and bottom FSR sensors, it was possible to attain those sensitive detections. Therefore, in the previous study, output values at the end of each compression exerting maximum compression force on the FSR sensors were only considered to assess finger placement based on the strategy of discerning between center and edge pressing. The output values were assessed in three different level, "Right", "Wrong", and "Grossly Wrong" to provide performance score [21]. However, in this study, we made a different approach with the same design of FSR sensors by taking account entire procedure of compression in the assessment.

B. *Data collection and analysis*

In this study, the same data from the previous study (total 32 data sets - 8 data sets from the four groups each, beginners carrying out TF, beginners TT, experts TF, and experts TT) were used. Assuming that center of force (COF) of the four FSR sensors would indicate relative finger placement during each compression, it was estimated by following (1) and plotted each time they were pressed to assess accuracy of the finger placement (Fig. 2).

$$X_{center\ of\ force} = \frac{-16 \cdot V_{left} + 16 \cdot V_{right}}{V_{left} + V_{right}}$$

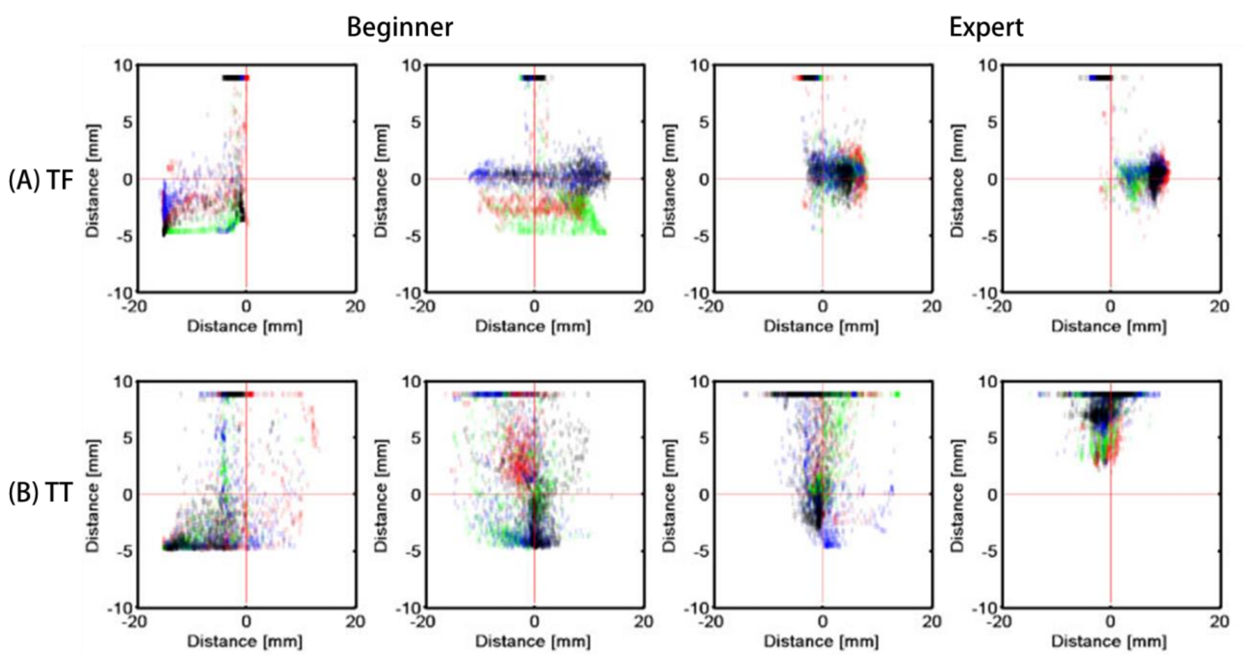

Fig 2. 2D scatter diagram of center of forces (COFs) plotted in different colors according to time quarters (1st - red, 2nd- green, 3rd – blue, 4th – black). (A) Comparison of COF diagram between beginners and experts for TF CPR, who achieved finger placement scores 0.87, 7.4, 18, and 20 out of 20 respectively in the previous study. (B) Comparison of COF diagram between beginners and experts for TT CPR, who achieved finger placement scores 1.6, 7.8, 15, and 20 out of 20 respectively in the previous study.

$$Y_{center\ of\ force} = \frac{-5.5 \cdot V_{bottom} + 8.5 \cdot V_{top}}{V_{bottom} + V_{top}} \quad (1)$$

, where V is an output voltage from the FSR sensor.

Unlike the method of measuring finger placement described in the previous work [21], in which output values from FSR sensors only at the end of each compression were considered, entire output values during each compression were collected in order to additionally reflect position variations while exerting and releasing forces. COFs for each of those variations were calculated and resulted in a 2D scatter diagram (Fig. 2), where each value is labeled in four different colors according to equally spaced time quarters (1st - red, 2nd- green, 3rd – blue, 4th – black) (Fig. 2). The diagram therefore visualizes change of finger placement during CPR procedure. Moreover, consistency of the placement throughout the performance can be determined by richness of the color as each colored marker has a certain amount of transparency, making the region darker depending on the increasing number of its overlapping. In order to demonstrate feasibility of COF diagram as the basis for measuring accuracy of finger placement, we carried out analysis on the data distribution for each with three parameters (2), standard deviation in respect to x and y (stdX and stdY) direction, mean position in the entire CPR procedure (meanP), and mean distance from the mean position (meanDist) by assuming that the consistency of the performance and force balance in either x or y direction or the both would differ among subjects depending on their performance.

$$stdX = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n}}$$

$$stdY = \sqrt{\frac{\sum_{i=1}^{n}(y_i - \bar{y})^2}{n}}$$

$$meanP = \sqrt{\bar{x}^2 + \bar{y}^2}$$

$$meanDist = \frac{\sum_{i=1}^{n}\sqrt{(x_i - \bar{x})^2 + (y_i - \bar{y})^2}}{n} \quad (2)$$

III. Results

In addition to evaluating “Right”, “Wrong”, and “Grossly Wrong” placement for both techniques in the previous work [21], we further investigated accuracy of the placement more in a qualitative and quantitative manner with estimation of COF of FSR sensors considering entire process of individual compression. As a result, the appearance of scattered data for each subject turned out to be different by the performance capability. In the comparison between beginners and experts, stdY and meanDist were significant parameters differentiating these two groups for both techniques, meaning beginners were poor at providing consistent forces along y direction and targeting a specific region while relatively good at balancing in x direction (Fig. 3). Therefore, force balancing in y direction should be emphasized in CPR training. For this statistical analysis, non-parametric Mann-Whitney U test was used. We also evaluated correlation between the analytical parameters from COF diagram and performance scores resulted from the previous study without distinction of techniques. As a result, meanDist turned out to have significant correlation with performance scores, meaning ability to deliver forces on a targeted region was highly considered for assessing accuracy of finger placement in the previous scoring system (Table I).

IV. Discussion

The visualization of finger placement with COF diagram enables more quantitative and qualitative analysis by considering entire period of individual compression and visualizing variations of finger placement according to time,

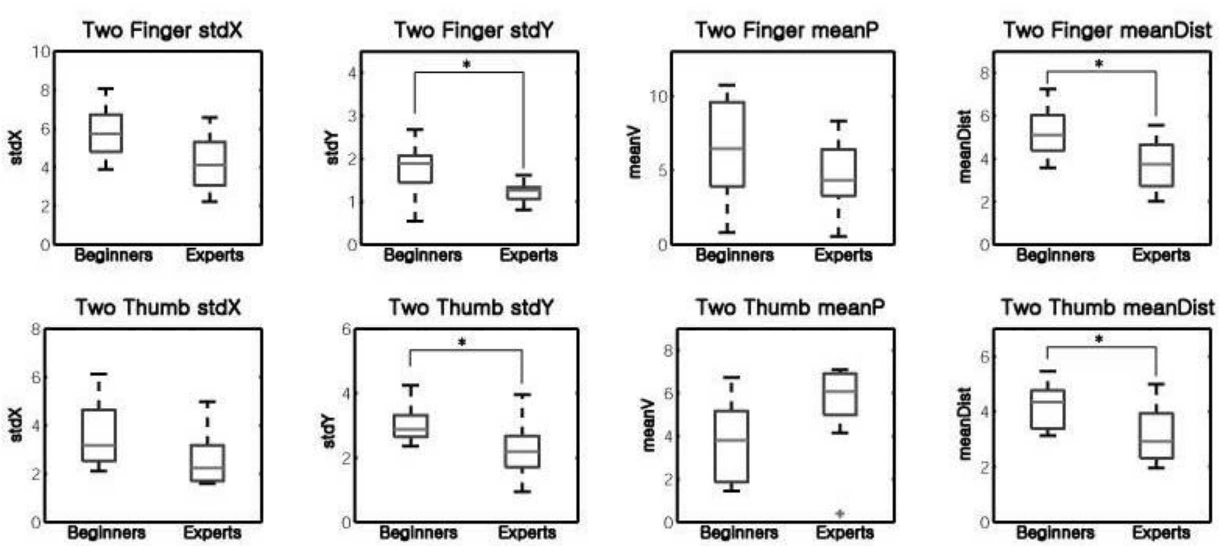

Fig 3. Comparison of analytical parameters (stdX, stdY, meanP, and meanDist) between beginners and experts for two-finger (TF) technique (upper row) and for two-thumb (TT) technique (lower row). Single asterisk (*) and double asterisks (**) indicate P<0.05 and P<0.01, respectively.

TABLE I
CORRELATION BETWEEN "PLACEMENT OF FINGERS" SCORE [21] AND ANALYTICAL PARAMETERS

		stdX	stdY	meanP	meanDist
"Placement of Fingers" score	Pearson Correlation	-.282	-.333	-.255	-.428*
	Sig. (2-tailed)	.118	.063	.160	.015
	N	32	32	32	32

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2- tailed).

and therefore provides additional information compared to the previous scoring system for the finger placement. As it identifies whether there are specific tendencies causing poor performance, we were able to provide one important messages that force balancing in y direction more than just delivering consistent compression should be emphasized in CPR training since beginners were turned out to be poor at providing consistent forces along y direction while relatively good at balancing in x direction. This visualization technique based on COF diagram therefore would further promote previously developed manikin integrated digital measuring system for better evaluation for example by providing supplementary information along with scoring system or by leading to define "Right", "Wrong", and "Grossly Wrong" more reliably with better qualitative and quantitative basis, which had been defined through repetitive simulation with an aid of pediatricians in the previous study.

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