Evaluation System for Chest Compression Training "*Shinnosuke-kun*"

Youta KOKUBO*, Ichinosuke MAEDA, Shingo HIBINO and Kouichirou MINAMI

Sumitomo Riko Company Limited has developed flexible capacitive pressure sensors, the Smart Rubber (SR) Sensor series, by drawing on the polymer-compounding technology it has developed over the decades. Applying this technology, we have developed an evaluation system for cardiac massage (chest compression) training, *Shinnosuke-kun*. This system gives real-time feedback on the chest compression depth, tempo (rhythm), recoil, and pressure point during chest compression training. The SR sensor can also evaluate the compression depth with the training mannequin placed on soft materials such as a mattress. We believe that the widespread use of Shinnosuke-kun will contribute to increasing the number of people who can conduct cardiopulmonary resuscitation (CPR) and thereby raise overall survival rates.

Keywords: pressure sensor, capacitive sensor, flexible electrodes, and chest compression

1. Introduction

In the fields of medical care, health care, and care-giving, there is a growing need for products such as wheelchairs and bedsore prevention mattresses, and a large amount of related research and development is being conducted in these areas. These kinds of products come into direct contact with the human body, and it is therefore important that sensors used in such products are flexible and capable of detecting the contact position, contact shape, and contact force. Sumitomo Riko Company Limited has developed a number of flexible capacitive pressure sensors, the Smart Rubber (SR) Sensor series to which the polymer compounding technology we have developed over the years has been applied. The technology of the SR sensor is used in SR Soft Vision (distribution version), which visualizes pressure distribution on a seat of a wheelchair or the like; SR Soft Vision (numerical value version), which converts the pressure distribution into numerical values; SR Soft Vision (whole-body version), which visualizes pressure distribution while a person is lying on a bed; and SR Active Mattress, which helps reduce bedsores by actively changing the concave/convex shape of a mattress using the pressure distribution measured with SR sensor(s). There is also a product that is capable of detecting a person leaving a bed. These products are flexible enough so as not to cause pain or discomfort while they are in direct contact with the human body, and can be used safely. This paper describes the evaluation system for cardiac massage (chest compression) training, *Shinnosuke-kun* (Fig. 1), which has been developed using this SR sensor technology.

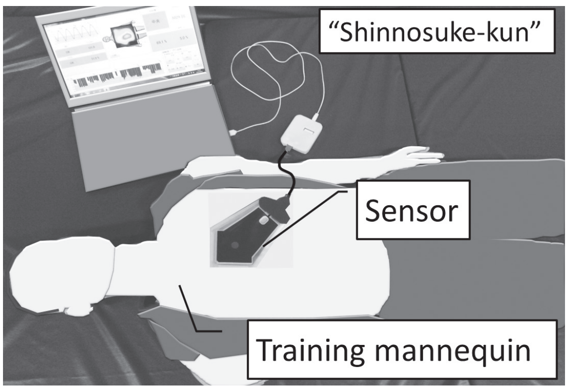

Fig. 1. Evaluation system for chest compression training Shinnosuke-kun

2. Background to Development

This section describes the importance of chest compression. The Japan Resuscitation Council Resuscitation Guidelines 2015*[1] (the Guidelines) was published by the Japan Resuscitation Council (JRC). The Guidelines states that the "chain of survival" is essential in order to save the life of a sick or injured person in an imminent state of cardiac arrest or suffocation, and enable the person to return to the society. The Guidelines cites the following four elements as vital links in this chain to achieve this:

1. Prevention of cardiac arrest
2. Early recognition of cardiac arrest and calling for help
3. Basic life support (cardiopulmonary resuscitation (CPR) and use of an automated external defibrillator (AED))
4. Advanced life support and post-resuscitation care

Basic life support includes CPR by chest compression and artificial respiration, and the use of an AED. Although such medical actions may be only a few medical actions allowed for bystanders to perform, they play a large role in the survival of a sick or injured person suffering from cardiac arrest.(1) Chest compression is conducted for the purpose of supplying oxygen to the brain by artificially making the heart function like a pump. The Guidelines defines that the optimal chest compression can be provided by applying pressure to the correct position, to the correct depth and at the correct rhythm with complete decompression between compressions and minimum suspension of the compressions.(1)

To teach people how to perform CPR appropriately, lifesaving training using a training mannequin can be conducted. In particular, since emergency medical staff perform lifesaving actions in various situations, training suitable to each situation is necessary; thus, the Shinnosuke-kun, which is easy to use and capable of providing an easy-to-understand evaluation of chest compression, has been developed using the SR sensor technology.

3. Sensor Structure and Detection Method

3-1 Basic structure

Figure 2 shows the basic structure of the SR sensor. The sensor has a dielectric layer made of flexible material such as urethane foam, and has upper and lower electrode layers with the dielectric layer in between. The electrodes on the upper electrode layer intersect orthogonally to those on the lower electrode layer. In a top view, each area of intersection of the electrodes is called a "cell," which forms a capacitor. The sensor measures the capacitance value of the capacitor when pressure is applied to the cell. The number of electrodes, the width of the electrodes, and the number of cells can be designed according to the needs of applications. All of the electrode layer materials are flexible, or flexible enough not to affect the flexibility of the electrodes. In particular, the electrodes are made from Sumitomo Riko's proprietary materials, the resistance value of which is hardly affected by elongation or deformation. Thus, the SR sensor can provide accurate measurements even when it is elongated or deformed, which makes the SR sensor a unique capacitive pressure sensor.

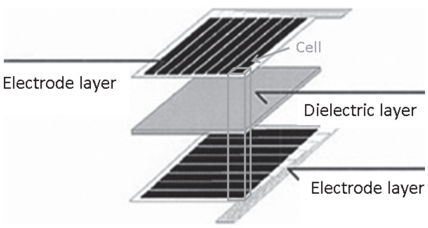

Fig. 2. Basic structure of SR sensor

3-2 Detection method

Figure 3 shows the cross-sectional structure of the capacitive pressure sensor.

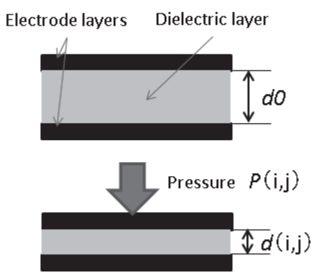

Fig. 3. Cross-sectional structure of the sensor (conceptual image)

Where the number of electrodes on the upper and the lower electrode layers are I and J respectively, $I \times J$ cells are formed in one sheet of the sensor. The cell formed by the i^{th} electrode on one electrode layer and the j^{th} electrode on the other electrode layer is defined as cell (i, j), and its capacitance C (i, j) can be represented by the following equation:

$$C(i,j) = \varepsilon_0 \varepsilon_r \frac{S(i,j)}{d(i,j)} \quad (i = 1,2,\cdots,I;\ \ j = 1,2,\cdots,J) \cdots\cdots (1)$$

where ε_0 is the dielectric constant in a vacuum, ε_r is the relative dielectric constant of the dielectric layer, S (i, j) is the electrode area of cell (i, j), and d (i, j) is the distance between the upper and lower electrodes of cell (i, j) (the thickness of the dielectric layer). d (i, j) is dependent on the pressure P (i, j) acting on cell (i, j). The distance d (i, j) between the upper and lower electrodes of each cell (i, j) can be calculated by Eq. (1) from the measurements of capacitance C (i, j) of all of the cells by sequentially switching electrodes on the upper and the lower electrode layers on and off. The distance between the upper and lower electrodes (the thickness of the dielectric layer) before being deformed is defined as *d0*. Assuming that *d0* changes to d (i, j) by pressure of P (i, j) acting on cell (i, j), the amount of deformation:

$$\Delta d(i,j) = d_0 - d(i,j) \cdots\cdots (2)$$

is a function of pressure:

$$\Delta d(i,j) = f[P(i,j)] \cdots\cdots (3)$$

Accordingly, the pressure P (i, j) acting on cell (i, j) can be obtained by the following equation:

$$P(i,j) = f^{-1}[\Delta d(i,j)] = f^{-1}[d_0 - d(i,j)] \cdots\cdots (4)$$

Assuming that the pressure is linearly proportional to the amount of deformation, the following equation can be used:

$$P(i,j) = Y \frac{d_0 - d(i,j)}{d_0} \cdots\cdots (5)$$

Here, Y represents Young's modulus of the dielectric layer.

The above describes the equation to obtain the amount of deformation of a cell in the thickness direction using the capacitance measured by the cell under pressure, and also the equation to obtain the pressure using the calculated amount of deformation. In general, however, when a cell receives pressure P (i, j), the cell is deformed in the thickness direction, and the area S (i, j) also changes (increases) at the same time. The amount of change depends on the material used. In the structure described above, open-cell urethane foam is used as a material for the dielectric layer. In addition, the rigidity of the electrode layers is sufficiently high in comparison to the urethane foam such that the change in the area of the cell due to pressure is very small compared to the change in the thickness direction of the cell. Thus, we consider the change in area S (i, j) negligible.(2)

3-3 Design of sensor used for Shinnosuke-kun

3-3-1 Design of sensor

In chest compression, the lower half of the sternum should be pressed.[1] The lower half of the sternum has a length of approximately 2.5 to 3 cm in adults. Therefore, the sensor used in Shinnosuke-kun, has a sensing area of approximately 5 cm square, in which 25 cells of 1 cm square are arranged in a 5 cell x 5 cell grid, as shown in Fig. 4.

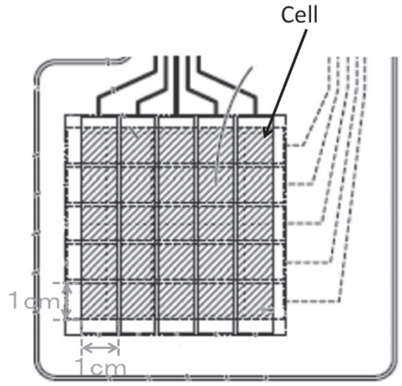

Fig. 4. Sensing portion of Shinnosuke-kun (Schematic diagram)

3-3-2 Method of converting pressure value into compression depth

The Guidelines recommends that the sternum should be pressed down by approximately 5 cm for chest compression.[1] The pressure applied to a training mannequin, which is used in chest compression training, is linearly proportional to the compression depth of the training mannequin. Therefore, the Shinnosuke-kun calculates the compression depth from the pressure applied to the cell (Fig. 5).

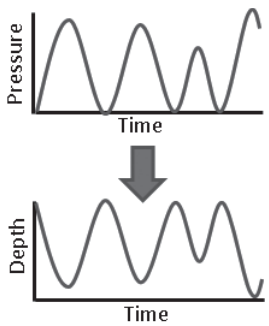

Fig. 5. Method of depth calculation for Shinnosuke-kun

4. Visualization of Pressure Point

4-1 Purpose

The pressure point is an important element in chest compression. The purpose of chest compression is to supply oxygen to the brain by pressing the lower half of the sternum to artificially make the heart function as a pump. Therefore, when the pressure point deviates significantly from the appropriate pressure point, it is likely to result in a deteriorated effect because the heart does not functioning as effectively as a pump, or damage to the ribs, etc. because pressure applied to an inappropriate point. However, in most cases, the pressure point during chest compression training has been determined just by visual evaluation, but further evaluation has not been conducted in detail. Therefore, we made an evaluation of the pressure point with the pressure distribution sensor employed in Shinnosuke-kun.

4-2 Experiment

As shown in Fig. 6, the pressure point was visualized using a sensor sheet for Shinnosuke-kun by individually detecting the pressure values applied to each cell for displaying the pressure distribution.

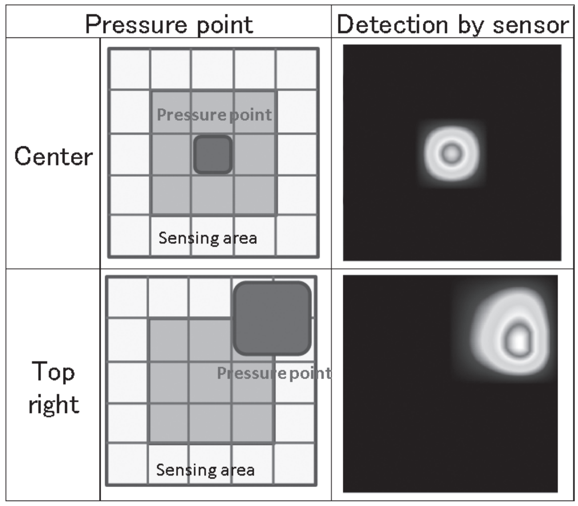

Fig. 6. Detection of pressure point

The center of the 5 cm square sensing area was marked to show the point to be pressed (Fig. 7). The sensor sheet was fixed to a training mannequin (SaveMan of Koken Co., Ltd.) at the lower half of the sternum with double-sided tape. The persons who conducted chest compression were instructed to aim at the center of the mark upon compressing the chest. The cell that received the highest pressure during chest compression was defined as the pressure point. When the pressure point was within the 3 cm square area as shown in Fig. 8 (a), the pressure point was evaluated as “appropriate,” and when the pressure point was outside this area, such cases were classified into groups depending on the side of the mannequin to which the pressure point deviated: right, left, caudal, or cranial.

When the pressure point deviated in two directions simultaneously (e.g., cranial and right), such cases were recorded as a deviation in the two directions. We included 179 participants with experience of chest compression in this experiment. Evaluation of chest compression was conducted for two minutes per person. During chest compression, the participants did not watch the screen on which the pressure distribution was displayed.

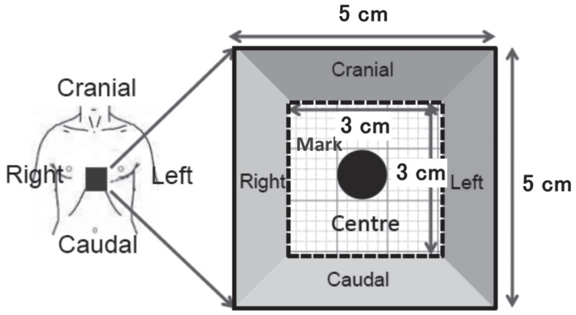

Fig. 7. Evaluation of pressure point

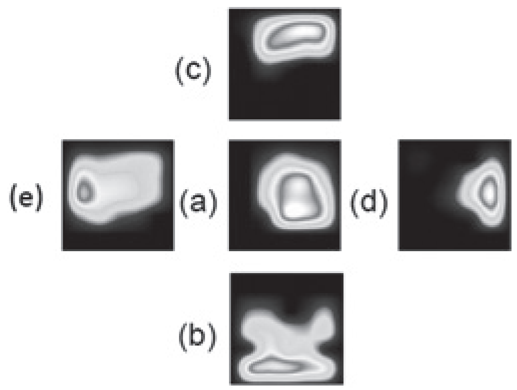

Fig. 8. Pressure distribution display during chest compression:
(a) Center, (b) Right, (c) Left, (d) Caudal, and
(e) Cranial to training mannequin

4-3 Results and consideration

As shown in Fig. 9, 65% of the participants failed to press the center. This experiment showed that many of the participants who failed to press the center had a tendency to press the right side (the side near to the person who is conducting chest compression) and the cranial side. Although the point to be pressed had been marked and the participants had been instructed to press the mark, the points they pressed often deviated from the mark.

It revealed that in chest compression, the point on which the highest pressure is applied differs depending on the person conducting the chest compression owing to individual differences such as the shape of the hand. As described above, it was confirmed that the use of Shinnosuke-kun enables us to visualize the location of the pressure point where pressure is actually applied, and also allows us to evaluate the pressure point taking even the shape of the hand of the person conducting chest compression into account.[3],[4]

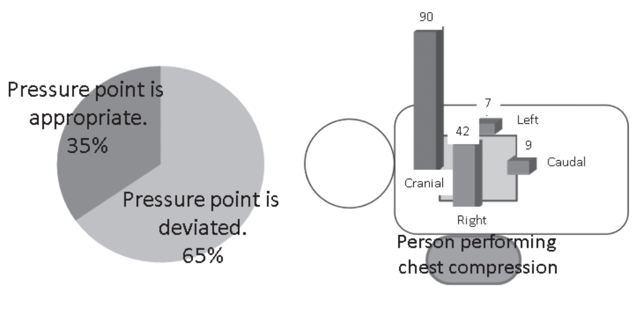

Fig. 9. Pressure point evaluation results

5. Verification of Compression Depth Measurement on Mattress

5-1 Purpose

During emergency lifesaving, CPR is conducted in various environments such as on a mattress, on a stretcher, or in an ambulance. In the Japan Resuscitation Council Resuscitation Guidelines 2015, it is suggested that the chest compression fraction (CCF), indicating the percentage of time for which chest compressions are performed during lifesaving actions be 60% or more. Therefore, suspensions of chest compression during lifesaving actions must be reduced to a minimum. This means that chest compressions should be carried out even where there is a soft material, such as a mattress, under the sick or injured person. In principle, when the material under a training mannequin is deformed like a mattress, some sensors, such as acceleration sensors or infrared sensors, are likely to overestimate the compression depth value because they are affected by the deformation. In contrast, it is considered that the Shinnosuke-kun is hardly affected by the deformation of such material because the compression depth evaluation is based on the pressure applied to the training mannequin when the hands compress the chest. Therefore, in order to confirm whether the Shinnosuke-kun is capable of evaluating the compression depth properly even on a mattress, we tested it on the floor and on a mattress, and compared the results to examine the effect due to having different materials under the training mannequin.

5-2 Experiment

Figure 10 is a schematic diagram of the test method. In order to eliminate inter-individual differences, the test was conducted using an electric servo-vibration tester (an

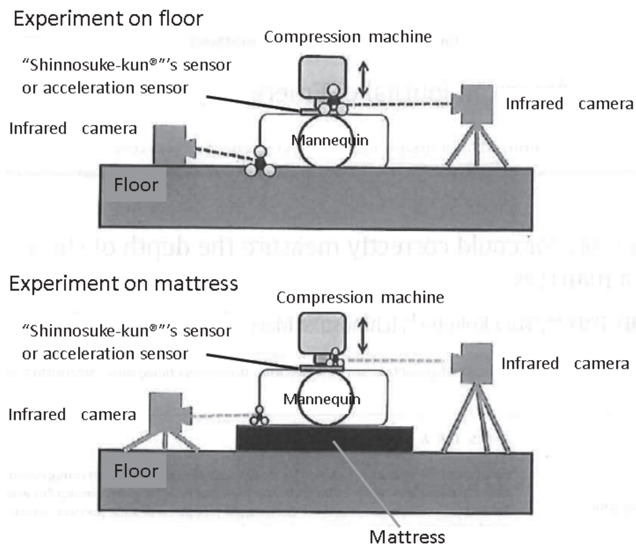

Fig. 10. Schematic diagram of experiment on mattress

electric servo-vibration durability tester of Saginomiya Seisakusho Inc.), set to a compression rate of 100 times per minute and a compression depth of 5 cm, with the Shinnosuke-kun sensor sheet inserted between a training mannequin and the tester.

For comparison, an acceleration sensor was also tested under the same conditions. During each test, the compression depth and the movement of the training mannequin were measured by using infrared cameras (Fig. 11) to obtain the values of compression depth.

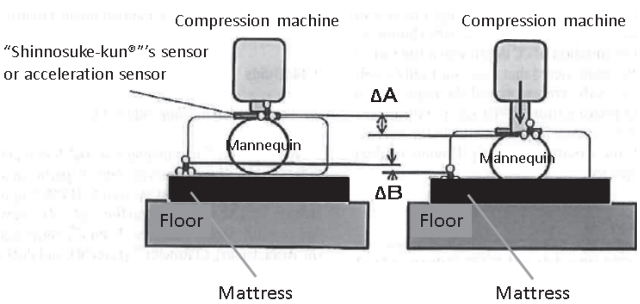

Fig. 11. Measurement of compression depth on mattress

5-3 Results and consideration

Table 1 shows the test results. In the case of testing on the floor, the training mannequin was compressed by 5 cm by the tester set to a compression depth of 5 cm, and the compression depth readings of both sensors were 5 cm, whereas in the case of testing on the mattress, the training mannequin was compressed by 4.4 cm while the mattress was deformed by 0.6 cm (Table 1-①). On the mattress, the compression depth reading of the acceleration sensor was 4.7 cm, which is larger than the compression depth by which the training mannequin was actually compressed. In contrast, the compression depth reading of the Shinnosuke-kun was 4.4 cm, indicating that it is capable of measuring compression depth without being affected by the deformation of the mattress.

As shown by the test result, the Shinnosuke-kun is capable of accurately evaluating the compression depth during chest compression even on a soft material such as a mattress.

It is therefore expected that the chest compression training using the Shinnosuke-kun will improve the quality of chest compression even on a soft material like a mattress.[5]

6. Conclusion

Using the SR sensor technology, which is proprietary technology of Sumitomo Riko Company Limited, we have succeeded in developing a product capable of converting pressure information into compression depth and displaying it in real time. The SR sensor technology has expanded the applications for pressure sensors, and has the potential to be used not only to measure pressure distribution but also to be used for variable applications in the medical, health and caregiving fields. We will strive to continue to develop useful products to contribute to the society in which we live.

• Smart Rubber and Shinnosuke-kun are trademarks or registered trademarks of Sumitomo Riko Company Limited.

Technical Terms

*1 The Japan Resuscitation Council Resuscitation Guidelines 2015: Guidelines for resuscitation established by the Guideline Preparation Committee comprising the committee members, or members of the Japan Resuscitation Committee (JRC), based on the 2015 Consensus on Science with Treatment Recommendations (CoSTR) provided by the International Liaison Committee On Resuscitation (ILCOR)

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Table 1. Test results on mattress

Location of training mannequin	ΔA Compression depth (machine setting) (cm)	ΔB Displacement of mattress (cm)	① Actual compression depth (cm) ΔA - ΔB	Sensor reading (cm)		② Difference between sensor reading and actual compression depth (cm) reading - ①	
				Acceleration sensor	Pressure sensor	Acceleration sensor	Pressure sensor
Floor	5	0	5	5	5	0	0
Mattress	5	0.6	4.4	4.7	4.4	0.3	0

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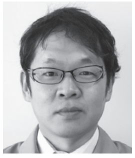

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