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Can pulse check by the photoplethysmography sensor on a smart watch replace carotid artery palpation during cardiopulmonary resuscitation in cardiac arrest patients? a prospective observational diagnostic accuracy study

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ABSTRACT

Objective The purpose of this study was to assess whether a photoplethysmography (PPG) sensor in a smart watch can accurately recognise the return of spontaneous circulation (ROSC) in cardiac arrest patients compared with carotid artery palpation.

Methods This prospective observational study was conducted on 50 out-of-hospital cardiac arrest patients who visited the emergency department (ED) of one tertiary hospital. As soon as the patient arrived at the ED, advanced cardiac life support was carried out immediately. At this time, three smart watches were attached to the carotid artery, forehead and wrist and were checked for pulse measurements every 2 min. In the case of ROSC, blood pressure, heart rate and heart rate regularity were confirmed, and pulse was simultaneously measured at three sites with smart watches. In the case of no ROSC, only the pulse was measured at three sites with the smart watches.

Results There were 33 males (66%) and the mean age was 68±11.57 years. In 14 patients (28%), spontaneous circulation was recovered through cardiopulmonary resuscitation, and all survived. The sensitivity and specificity of manual palpation were 78.6% and 90.4%, respectively. False-positive and false-negative rates were 9.6% and 21.4%, respectively. Smart watches at all three sites had the same or higher sensitivity than manual palpation. The sensitivity of the smart watch was the highest, at 100%, in the carotid region and the lowest, at 78.6%, in the wrist region. The specificity of the smart watch was the highest, at 100%, in the wrist region and the lowest, at 78.7%, in the carotid region.

Conclusion Compared with manual pulse check, the PPG sensor embedded in the smart watch showed the same sensitivity and a higher specificity for recognising ROSC when measured at the wrist.

Strengths and limitations of this study

- We studied the feasibility of using smart watches for the recognition of cardiac arrest or return of spontaneous circulation during cardiopulmonary resuscitation.
- In this study, we attempted to investigate whether the limits of manual pulse checking can be overcome by using smart watches.
- Each investigator was blinded to the values measured to increase confidence in the results.
- One limitation of this study is the use of just one smart watch (Galaxy Fit).
- Another limitation is that we did not investigate other environments and situations in a prehospital setting.

INTRODUCTION

Carotid artery palpation of a cardiac arrest patient is key to allowing the rescuer to recognise the return of spontaneous circulation (ROSC) and determine the next action.[1] However, 'carotid artery palpation' is recommended only by the healthcare provider and does not exclude the possibility of error even if performed by an expert.[2 3] The recognition of ROSC using capnography, arterial blood pressure monitoring and ultrasound is highly reliable, but these techniques are not always available, especially in out-of-hospital settings.[4] Therefore, a more accurate and simple way to recognise ROSC than 'carotid artery palpation' would help less experienced rescuers make accurate decisions. In a recent animal study, photoplethysmography (PPG) was reported to be available in cardiac arrest situations.[5] Most current smart watches have PPG sensors for pulse measurement. PPG, the technology found in standard pulse oximeters, measures light reflectance in tissue to detect arterial pulsations. Therefore, the aim

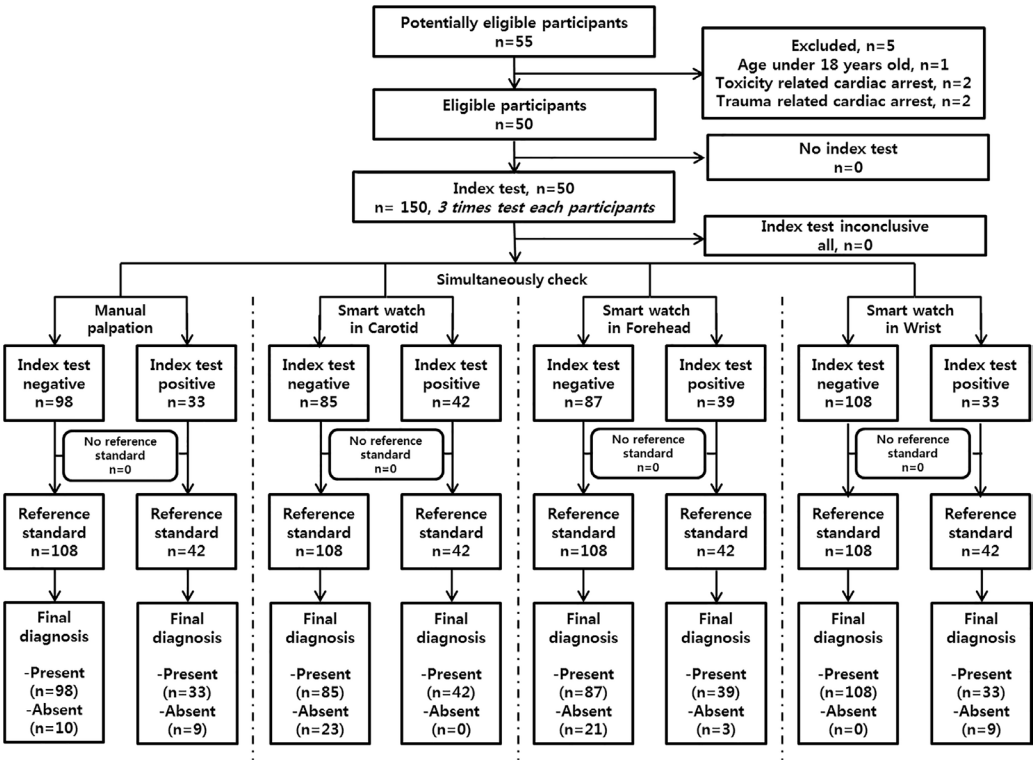

Figure 1 Flow diagram.

of this study is to identify whether the PPG sensor of a smart watch is more accurate than 'carotid artery palpation' for ROSC recognition in cardiac arrest situations.

METHODS

Study design

This study was designed as a prospective observational study. Subjects were out-of-hospital cardiac arrest (OHCA) patients who visited the emergency department (ED) of one tertiary hospital from August to December, 2016. In total, 44 cases were calculated as needed for the sample size based on sensitivities in the wrist, forehead and carotid found in the 10-case pilot study. The sample size was analysed using G-power V.3.1.2 (Heine Heinrish University, Düsseldorf, Germany); we estimated that 44 participants would be adequate for this study, with an α error of 0.05, a power of 0.8 and an effect size of 0.847 with a difference in absolute risk of 10%. During the study period, 55 out-of-cardiac arrest patients were transferred to the ED. Exclusion criteria were age under 18 years and trauma-related or toxicity-related cardiac arrest; five patients were excluded from the study. We registered the study protocol in Clinical Trials before the study initiation (Clinicaltrials.gov: NCT02866188).

Study protocol

Figure 1 shows the flow chart. All three emergency physicians were prepared for cardiopulmonary resuscitation (CPR) in every-day duty except for holidays. A substantial number of emergency physicians were required for this study. Therefore, the study was conducted only on weekdays, with a small number of patients and a large workforce. When an OHCA patient arrived at the ED, the CPR team including one emergency physician immediately began advanced cardiac life support according to the American Heart Association guidelines. Simultaneously, three smart watches were attached to the patient using Hypafix Transparent by the other emergency physician at three different body locations: the radial artery on the wrist, the carotid artery in the carotid region and the forehead. We stopped chest compression every 2 min and checked the pulse with cardiac rhythm analysis, the three smart watches and the carotid artery palpation technique simultaneously. Palpation was conducted by one emergency physician of the CPR team, whereas during chest compression, whether a pulse due to compression

Table 1 Pulse checking results for the return of spontaneous circulation for all conventional methods and the three smart watch method

Method of pulse checking	Sensitivity (%)	Specificity (%)	False positive (%)	False negative (%)
Carotid palpation	78.6	90.4	9.6	21.4
Pulse check by smart watch				
In the carotid region	100	78.7	21.3	0
In the forehead region	92.9	80.9	19.1	7.1
In the wrist region	78.6	100	0	21.4

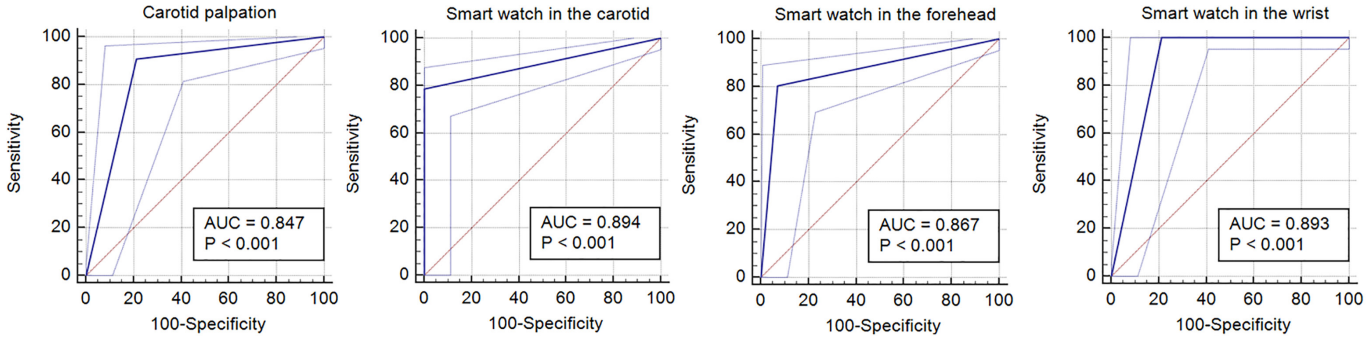

Figure 2 Receiver operating characteristic curves of each method including manual palpation and the smart watch on the carotid, forehead and wrist area under the curve, (95% CI); carotid palpation: 0.847 (0.779 to 0.900); smart watch on the carotid: 0.894 (0.833 to 0.938); smart watch on the forehead: 0.867 (0.802 to 0.917); smart watch on the wrist: 0.893 (0.832 to 0.937). AUC, area under the curve.

was detected by each smart watch was confirmed. When ventricular fibrillation was perceived, we instantly delivered a shock without checking the pulse. When the rhythm was asystole, we started chest compression without checking the pulse. When other rhythms were observed, the pulse was checked for up to 10 s by the one emergency physician of the CPR team, and the $ETCO_2$ measurement and echocardiographic evaluation was conducted by another emergency physician. At that time, an emergency physician in charge of manual palpation was blind to the $ETCO_2$, PPG and echo results. During the 10 s of checking for ROSC, the emergency physician who was in charge of manual palpation first reported the presence or absence of pulsation, and the other two emergency physicians sequentially revealed the $ETCO_2$, PPG and echocardiographic findings. ROSC was defined as sudden increases in $ETCO_2$ in waveform capnography[1] and left ventricle contraction in echocardiography. ROSC was not determined based only on echocardiographic findings and was ultimately judged by considering BP, self-respiration, SpO_2, $ETCO_2$ and carotid pulsation with echocardiographic left ventricular (LV) function visual assessment. During CPR, a total of three pulse measurements were performed for each patient using smart watches. Furthermore, to confirm that the heart beat was measured with the smart watch at the time of asystole, the pulse was checked with the smart watches when asystole occurred, after the CPR was stopped because there was no ROSC.

We checked the arterial pulse with the 'Samsung Gear Fit' (Samsung Electronics, Suwon, Korea) smart watch in this study. When using the Gear Fit to measure pulse, a regular wave form was measured within 10 s, and the heart rate was displayed on the Gear Fit screen. In all cases, we used a LUCAS (Physio-Control, Washington, USA) for chest compression.

Outcomes and statistical analysis

The primary outcomes of this study are the sensitivity, specificity and false-positive and false-negative rates of each measured result. Receiver operating characteristic (ROC) curves for the primary outcomes were added. All statistical analyses were performed using SPSS software V.17.0. Measures of sensitivity (the proportion of true positives) and specificity (the proportion of true negatives) were calculated for the presence or absence of ROSC. The χ^2 test was performed to compare the sensitivities and specificities between the conventional method and smart watch method for detecting ROSC.

The patient and public involvement statement

The purpose of this study was to evaluate the diagnostic value of a smart watch in patients with cardiac arrest who were prospectively evaluated. The specific method used in this study was developed considering the characteristics of the PPG sensor, and the patients and public did not

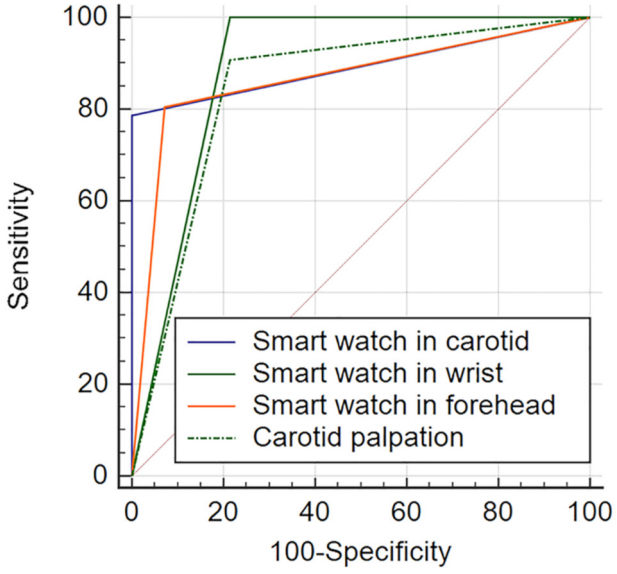

Figure 3 Comparison of the receiver operating characteristic curves for manual palpation and the smart watch on the carotid, forehead and wrist smart watch on the carotid versus wrist: p=0.99; smart watch on the carotid versus forehead: p=0.21; smart watch on the carotid versus carotid palpation: p=0.19; smart watch on the wrist versus forehead: p=0.44; smart watch on the wrist versus carotid palpation: p<0.01; smart watch on the forehead versus carotid palpation: p=0.51.

Table 2 Individual evaluation of false-positive cases using photoplethysmography with a smart watch and the palpation method

ROSC case number	Manual check	Smart watch			Vital sign with HR regularity
		Carotid	Forehead	Wrist	
ROSC 1	No	Yes	Yes	Yes	BP 60/40, HR 98, regular rhythm
ROSC 2	No	Yes	Yes	No	BP 64/41, HR 86, irregular rhythm
ROSC 3	Yes	Yes	Yes	No	BP 72/46, HR 71, irregular rhythm
ROSC 4	No	Yes	Yes	Yes	BP 69/41, HR 80, regular rhythm
ROSC 5	Yes	Yes	Yes	Yes	BP 70/40, HR 56, regular rhythm
ROSC 6	Yes	Yes	Yes	Yes	BP 118/69, HR 103, irregular rhythm
ROSC 7	Yes	Yes	Yes	Yes	BP 102/55, HR 121, regular rhythm
ROSC 8	Yes	Yes	Yes	Yes	BP 100/70, HR 62, regular rhythm
ROSC 9	Yes	Yes	Yes	No	BP 107/80, HR 72, irregular rhythm
ROSC 10	Yes	Yes	Yes	Yes	BP 172/83, HR 102, regular rhythm
ROSC 11	Yes	Yes	Yes	Yes	BP 140/80, HR 55, regular rhythm
ROSC 12	Yes	Yes	No	Yes	BP 142/72, HR 110, irregular rhythm
ROSC 13	Yes	Yes	Yes	Yes	BP 104/81, HR 65, regular rhythm
ROSC 14	Yes	Yes	Yes	Yes	BP 90/50, HR 58, regular rhythm

BP, blood pressure; HR, heart rate; ROSC, return of spontaneous circulation.

participate in the study design. Since the study subjects were cardiac arrest patients, a recruitment process for this study was not necessary. For the same reason, the time required to participate in the study was not separately assessed or adjusted.

RESULTS

A total of 150 pulse checks were recorded during CPR in 50 OHCA patients. There were 33 males (66%) and the mean age was 68±11.57 years. In 14 patients (28%), spontaneous circulation recovered through CPR, and all survived. Heart rate was measured at all sites with smart watches during chest compression in all patients. The mean heart rate per minute measured by PPG sensors in each region during chest compression was as follows: in the carotid region (100.42±0.70); in the forehead region (100.80±0.86) and in the wrist region (100.88±1.35).

Pulse checking results for the pulse detection are shown in table 1. The sensitivity and specificity of manual palpation were 78.6% and 90.4%, respectively. The false-positive and false-negative rates were 9.6% and 21.4%, respectively. The smart watches at all three sites had the same or higher sensitivity than manual palpation. The sensitivity of the smart watch was highest, at 100%, in the carotid region and lowest, at 78.6%, in the wrist region. The specificity of the smart watch was highest, at 100%, in the wrist region and lowest, at 78.7%, in the carotid region. However, in asystole after the termination of CPR, heart rate was not measured by a smart watch in all patients. False positivity (21.3%) of PPG was highest in the carotid region and lowest (0%) in the wrist. False negativity was lowest, at 0%, in the carotid sensor and highest, at 21.4%, in the wrist.

We obtained statistically significant ROC curves from the carotid palpation results from the emergency physician and measurements of each position using the smart watch to confirm the presence or absence of the pulse (figure 2). The area under the curve value of the carotid and wrist regions monitored by the smart watch was larger than that of the other methods. In addition, the results of the smart watch on the wrist were statistically significantly better than carotid palpation by the emergency physicians (P=0.001, figure 3).

In the sub-analysis of false positivity, the PPG sensor did not detect ROSC when the ECG rhythm was irregular (table 2). Moreover, blood pressure was lower in several cases in which pulse could not be detected by the manual palpation method.

DISCUSSION

Carotid artery palpation is not highly accurate in the recognition of ROSC. In this study, although carotid artery palpation was performed by an emergency physician, the accuracy remained low. However, because carotid artery palpation does not require additional equipment, it is an important method for recognise ROSC in out-of-hospital

settings, especially when resources are lacking.[1] PPG can detect blood flow in blood vessels. Recently, Wijshoff *et al*[5] confirmed that PPG could potentially be used to detect the presence or absence of spontaneous pulse in an animal experiment when both compression and ventilation were stopped and that unnecessary interruptions during pulse checks could be avoided. Various smart watches developed in recent years have a PPG sensor. If ROSC can be accurately recognised with these cheap and readily available devices, healthcare providers can make more accurate judgements in cardiac arrest situations.

In this study, the PPG sensor showed the same or higher sensitivity and specificity than manual palpation. The results differed for each PPG sensor site. The sensor attached to the carotid artery region had the highest sensitivity in detecting ROSC, perhaps because the carotid sensor is the closest of all the sensors to the heart. On the other hand, the wrist sensor showed 100% specificity. The carotid sensor was sensitive, but its false-positive rate was very high. In contrast, although the sensitivity of the wrist sensor was relatively low, it was equivalent to the sensitivity of manual palpation; furthermore, the false-positive rate was very low. In CPR situations, the wrist sensor appears to provide the best quality information when judging whether the rescuer should immediately resume chest compressions because false positives are much more dangerous than false negatives.

In this study, the PPG sensor detected blood flow with relatively high sensitivity but in some cases did not detect ROSC even in the presence of an actual heartbeat, which represented an irregular ECG rhythm in most cases. The above finding is because the pulse check algorithm of the smart watches in the time and frequency domains was designed to process artefacts between 3 and 10 s, which is the interval between each respiration in humans, in order to process signals. However, if the signal is irregular, the process is complicated.[6] Three patients in whom ROSC was not detected by manual palpation had a very low systolic blood pressure of 60; it is thought that in these patients, the pulse was weak enough that a human could not detect it by palpation.

This study has the following limitations. Because all the measurements were made in an indoor environment, the results could differ in prehospital settings, which are more affected by light and temperature variation. This method may also be difficult to apply in an environment where patients are being transported or where vibrations are present. In addition, the method may be difficult to apply in trauma patients who have an insufficient circulating blood volume.

Because this study was conducted only on Korean patients, we did not consider the effects of race. Additionally, the patients were generally older and did not reflect the characteristics of younger age groups. Regarding these limitations, Sviridova *et al* reported that the difference in PPG sensor function by race was not significant[7] and Nippolainen *et al* reported a significant age-related effect on PPG sensor function.[8] Thus, further studies including age-by-age comparisons should be conducted to assess age-related effects.

CONCLUSION

The PPG sensor embedded in the smart watch showed the same sensitivity and high specificity for recognising ROSC compared with the manual pulse check when measured by wrist.

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Patient consent for publication Not required.

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Data sharing statement This study was conducted on patients with cardiac arrest. Individual patient data is inaccessible and cannot be shared because it is sensitive patient data. If you want to use or access the data, please contact the corresponding author.

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