performance category level 3 to level 5, CPC3–5). The mean age of the population was 67 years old; 69% of the participants were male; 68% were residents; 15% had a shockable rhythm; the witness rate was 58%; the bystander CPR rate was 45%; the mean response time was 7.7 min; scene time interval was 12.3 min; and transport time was 6.5 min. We found that defibrillation by EMS, hyperkalemia (K > 5.0 mEq/L), and acidosis (pH < 7.35) were related to our primary and secondary outcomes in our parameters. The cut-off points were set for K and pH, close to the upper limit of normal and lower limit of normal, respectively. We used Odds ratios calculated via adjusted potential confounding factor and positive predictive values (PPVs) and negative predictive values (NPVs) to predict survival outcome. Obvious correlation was found in adjusted OR between death prior to discharge and K > 5 mEq/L (OR = 2.9, 95% CI: 1.97–5.23) and trend to unfavorable neurological outcome (OR = 3.1, 95% CI: 0.47–32.37). The acidosis (pH < 7.35) was related to death prior to discharge and poor CPC (OR = 6.3, 95% CI: 2.14–23.4; OR = 65.4, 95% CI: 6.87–395.5, respectively). Death prior to discharge and unfavorable CPC, were strongly related with no EMTs defibrillation at scene (OR = 5.3, 95% CI: 1.47–13.49; OR = 23.4, 95% CI: 3.46–234.3, respectively). OHCA patients with acidosis (pH < 7.35) even persistent high performance CPR were at a higher risk of death prior to discharge, and a unfavorable neurological outcome (PPVs of 77.2%, 95.8%, and 98.9%, respectively). Moreover, non-shockable rhythms of AED at scene are also strongly related with survival outcomes. Such patients were more likely to die before discharge and to have poor neurological outcomes (PPVs of 93.2% and 97.4%, respectively).

In past studies, Sauter found that a lower pH and a higher lactate level are associated with higher mortality rates in the emergency department, predict in-hospital mortality and have a cardiac failure-related death probability of >0.5 [5-7]. Martinell showed that a non-shockable rhythm could be one predictor of poor outcomes in OHCA (other predictors were age of patients, location of cardiac arrest, time to basic life support to return of spontaneous circulation, corneal reflex, epinephrine treatment, acidosis, and PaCO2) and is associated with poor neurological outcomes [3]. Consistent with previous studies, we noticed that patients with initial non-shockable rhythm at scene were at a higher risk to mortality and had an unfavorable neurological status. Our data suggests that acidosis and non-shockable rhythm at scene are important predictors of poor outcomes in OHCA patients. These findings were associated with a poor prognosis for cardiac arrest. If, after persistent high-quality CPR, OHCA patients have acidosis and no AED shock, they have higher probability to die prior to discharge and unfavorable CPC outcomes.

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Blood refill time: Clinical bedside monitoring of peripheral blood perfusion using pulse oximetry sensor and mechanical compression

Letter to the Editor:

Shock states can be detected rapidly by measuring the capillary refill time (CRT) or other measures of blood refill time (BRT) at the peripheral body parts of patients [1,2]. CRT is defined as the time required for a distal capillary bed (*e.g.*, fingertip) to regain its color after receiving enough compression to cause blanching [1,3]. CRT measured at the bedside is promulgated as an acceptable method to identify circulatory shock in critically ill patients [1,2]. However, since the measurement of CRT involves visual inspection of fingertip color, it is subject to inter-observer variability [4,5] and may be unreliable [1].

The optical technology of infrared spectroscopy has been used to noninvasively measure the concentration of hemoglobin and oxygen saturation [6]. This technology is used in pulse oximetry and it can trace blood in tissues and be used to monitor BRT at the fingertips [2,7]. Since blood is a major component affecting skin color (oxyhemoglobin is visually perceived as red and deoxyhemoglobin as blue), this technology can provide an alternative measure of skin color change that does not rely on visual inspection. Driven by the motivation to develop objective and reliable measures of peripheral blood perfusion, we applied a new method of analysis that uses the pulse oximetry waveform. In

addition, we created a mechanical compression device that applies firm pressure to the fingertip. The combination of these two components allows for a precise, consistent, and objective measure of BRT.

The purpose of this report is to show how the technology works *in vivo*. The peripheral perfusion of a healthy volunteer subject was altered by cooling down the fingertip temperature, which was observed by our device. We measured BRT and fingertip temperature before and after changing the conditions wherein the subject's hand was at room temperature and then immersed in cold water. This report provides clinicians a fine perspective of how blood flows when they perform CRT measurements in clinical settings.

The study was approved by University of Pennsylvania. All procedures were performed in a climate controlled environment at an ambient temperature of 20–22 °C. We measured BRT under two different conditions: hands at room temperature (ROOM TEMPERATURE) and immersed in cold water (COLD, 15 ± 2 °C). The hand was immersed in a cold water bath for 5 min and then BRT was measured inside a temperature controlled box. A thermocouple sensor was attached to the fingertip as an adjunction to the BRT sensor.

We defined BRT as the time required for a fingertip to recover its blood volume after release from compression. The device consists of two components (Fig. 1): a measuring device and a fingertip compression device. A pulse oximeter (OLV-3100, Nihon Kohden Corporation, Tokyo, Japan) was used as the measuring device to capture pulse oximetry waveforms. We used one wavelength (infrared light: 940 nm) to trace the change in hemoglobin concentration that reflects the recovery of blood flow to the fingertip.

The fingertip compression device is composed of an air pump and a finger-cap with a polyurethane soft bladder. The air pump supplies air to the bladder when measuring BRT. The device controls the pressure of the inflated bladder at approximately 400 mm Hg. The duration of the bladder inflation is 5 s. The device deflates the bladder pressure 5 s after inflation. The thermocouple sensor was attached to the side of the fingertip in order to avoid interference with either the transmission light from the pulse oximetry sensor or the fingernail compression with the polyurethane bladder (Fig. 2).

Light intensity was recorded by the measuring device and the data were analyzed thereafter. The light intensity transmitted through the fingertip increases during compression as blood, which is the major absorber of the light, is squeezed out of the fingertip. The compression phase is followed by the release phase during which the light intensity returns to the original level (Fig. 3). The measuring device captures the changes in the transmitted light intensity and records the waveforms. The curve describing the recovery phase of the intensity

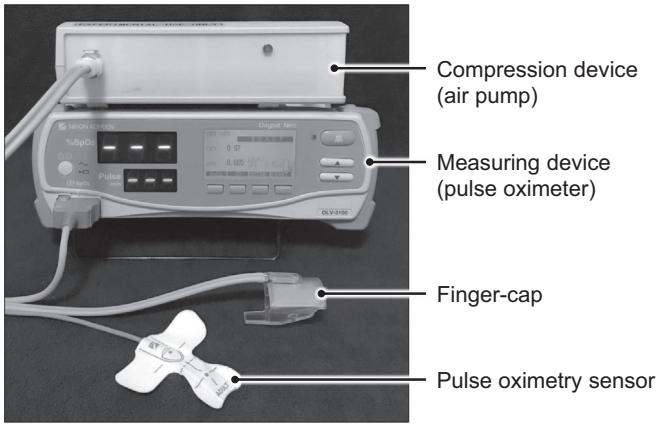

Fig. 1. The investigation device is composed of two devices, which are modified pulse oximeter (measuring device) and compression device. A pulse oximetry sensor is attached to the measuring device and the compression device controls a bladder cuff inside a finger-cap.

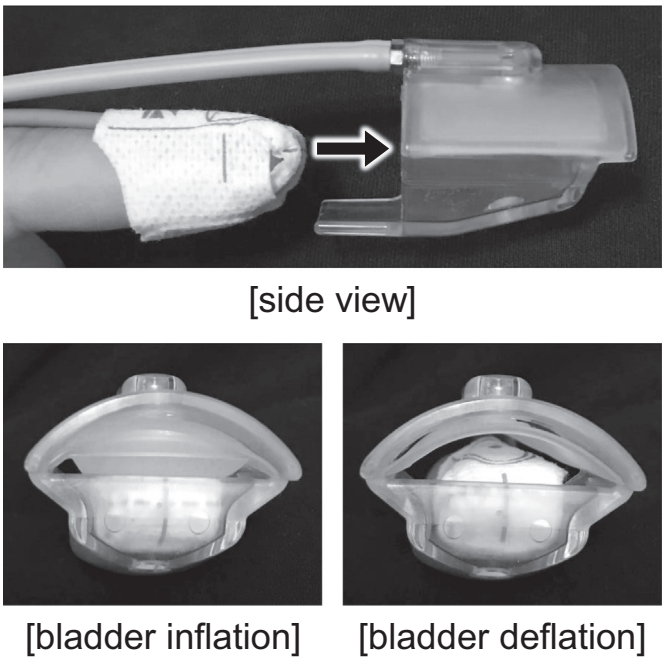

Fig. 2. The inflation and deflation of a polyurethane soft bladder cuff are controlled by the compression device.

waveform (intensity returning to its original levels) is modeled as an exponential decay using the least squares method. The time to achieve 90% return of the intensity was reported as BRT.

Fig. 3A shows the light intensity curve from the fingertip at room temperature, where Fig. 3B shows the altered intensity curve at lowered fingertip temperature. BRT was 1.6 s with a fingertip temperature of 29.3 °C at room temperature. Our device successfully detected prolonged BRT after the fingertip temperature was cooled down to 22.8 °C and BRT at this condition was 5.8 s.

Prolonged BRT induced by low fingertip temperature was observed well by our device. This technology provides clinicians a fine perspective of how blood flows through the fingertip following release from firm compression. Clinical implications of the technology include both continuous monitoring and spot check measurement. For example in ICU or operation room, the device can be used to measure BRT repeatedly. The trend in repeated measurements may provide patient's information about the alteration of peripheral blood perfusion over time. For spot check measurements, the device can be used for detecting the alteration of peripheral blood perfusion in both acute and chronic conditions. It can be used in pre-hospital or emergency department for triaging patients. It can be also used for diagnosing peripheral artery disease. This technology provides an objective measure of peripheral perfusion and may provide more reliable results than a subjective visual assessment.

Conflict of interest and sources of funding

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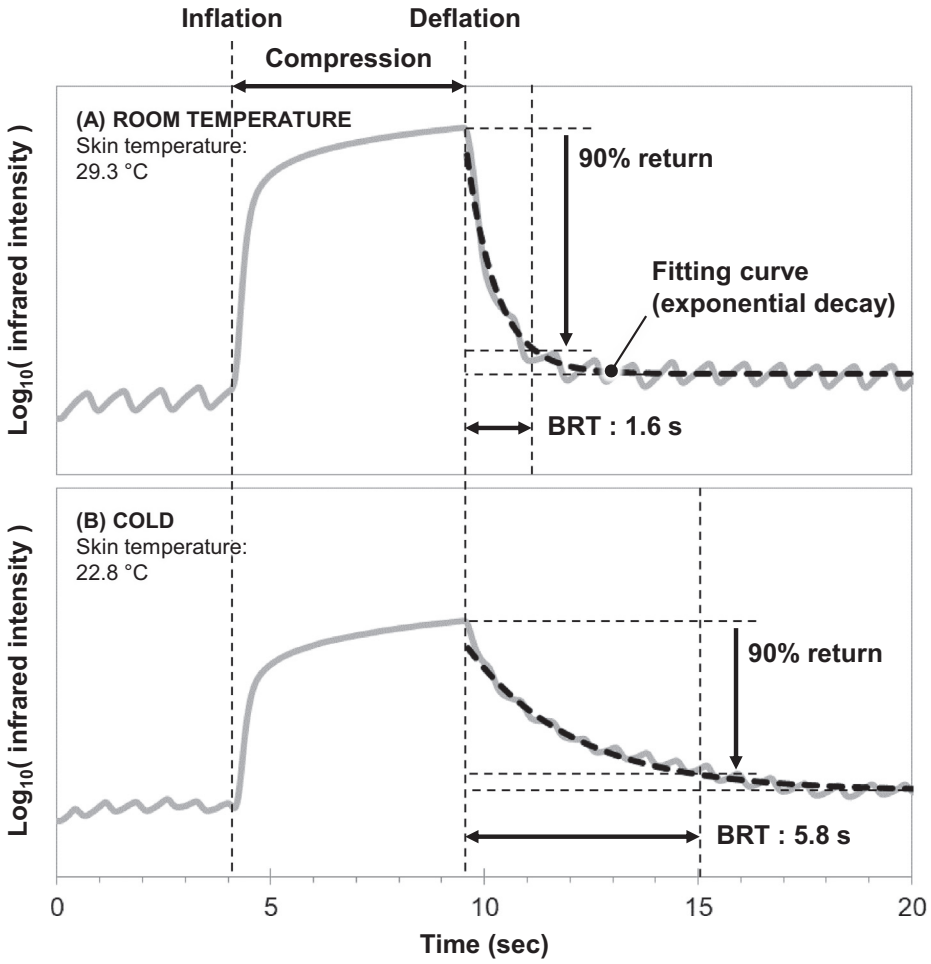

Fig. 3. The measuring device captures the changes in the transmitted light intensity and records the waveforms. The time to achieve 90% return of the intensity was reported as BRT. BRT was measured at two different temperature conditions of a healthy subject.

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