INTRODUCTION

Prehospital providers treating out-of-hospital cardiac arrest (OOHCA) achieve return of spontaneous circulation (ROSC) in 35–61% of cases.1–3 Once ROSC is achieved, patients experience hemodynamic and electrophysiologic instability, which can lead to early rearrest in up to 38% of cases.4 Patients who experience early cardiac rearrest are less likely to achieve ROSC again; therefore, it is important to identify OOHCA patients with ROSC who are at risk for rearrest as a first step to identifying measures for preventing it.5,6

Limitations in the prehospital environment make hemodynamic monitoring of intra- and postarrest patients difficult. Prehospital providers use changes in electrical cardiac rhythm, heart rate, and pulse checks in the intra-arrest period and cuff-derived blood pressure in the postarrest period. Measurement of end-tidal carbon dioxide (ETCO₂) is increasingly being used by prehospital providers during cardiac arrest to predict ROSC, and is a Class IIb recommendation by the American Heart Association (AHA) for monitoring of these patients during cardiopulmonary resuscitation (CPR).7–12 The ETCO₂ is a measure of the exhaled fraction of carbon dioxide in a breath, and is low when perfusion to the lungs is poor. However, its application is limited by the requirement of an advanced airway without an air leak to ensure accuracy, and by the impact of ventilation on ETCO₂ readings independent of lung or systemic perfusion.

Real-time noninvasive near-infrared spectroscopy (NIRS) can be used to directly measure the oxygen content in tissues (StO₂) and may provide more useful information to track hemodynamic instability in the peri-arrest period. It measures the hemoglobin oxygen saturation fraction in the terminal vasculature (arterioles, capillaries, and venules) and, unlike ETCO₂, is not impacted by ventilation. NIRS has been shown to correlate with shock, but its ability to track hemodynamic instability after ROSC remains
unknown.\textsuperscript{13,14} Until now, most data using NIRS are from the intensive care and trauma literature. We sought to study the changes in \textit{StO}_2 using NIRS in patients who have OOHCA. Specifically, we wanted to compare the real-time changes after ROSC, and in the peri-arrest period, between \textit{StO}_2 and ETCO\textsubscript{2}, hypothesizing that \textit{StO}_2 would provide more reliable and earlier indications of possible rearrest. We present a case series of patients with OOHCA who had both continuous ETCO\textsubscript{2} and \textit{StO}_2 recorded in the early period of resuscitation.

### METHODS

This study was approved by the University of Pittsburgh Institutional Review Board.

#### Emergency Medical Services System

Cardiac arrest patients were treated by the City of Pittsburgh Bureau of Emergency Medical Services (EMS), an urban third-service agency that responds to all medical emergencies in the City of Pittsburgh. Two technicians trained at the paramedic level staff each ambulance. First responder services are provided by the City of Pittsburgh Bureau of Fire, which provides basic life support care prior to arrival of the ambulance, and is dispatched on all cardiac arrests. A prehospital physician affiliated with the University of Pittsburgh staffs a physician response vehicle 24 hours per day and responds to cardiac arrest cases in addition to other high-priority calls. The system responds to more than 65,000 calls each year, with approximately 300 cardiac arrests each year.

#### System Response/Care

A medical dispatcher screens all emergency calls made to a 9-1-1 center. In the event that the call is a confirmed or suspected cardiac arrest, a first responder fire engine or ladder truck (with three or four firefighter first responders), an ambulance (with two paramedics), a rescue vehicle (with two additional paramedics), and a prehospital physician (in a separate response vehicle) are dispatched to the scene.

#### Study Protocol

Fire first responders or paramedics arrived on the scene and began basic life support (BLS) interventions, including CPR and defibrillation as appropriate, followed by Advanced Cardiac Life Support (ACLS) based on the AHA 2010 guidelines. Once the physician arrived on scene and confirmed that appropriate BLS and ACLS interventions were being performed, the physician attached a noninvasive NIRS probe to the thenar eminence of the patient’s hand. Prehospital physicians have the ability to discontinue ACLS at their discretion, and as such, they were instructed to use the monitor on patients who had already experienced ROSC, who were being transported to the hospital, or who were likely to have a reasonable amount of time remaining in the resuscitation efforts. The monitor used was an InSpectra \textit{StO}_2 Tissue Oxygenation Monitor (Hutchinson Technology, Hutchinson, MN). Standard-of-care ACLS was continued and continuous \textit{StO}_2 and ETCO\textsubscript{2} monitoring was performed until the patient was declared dead at the scene or care was transferred to an emergency facility.

#### Data Collection and Interpretation

No training was provided to the prehospital physicians in the interpretation of the \textit{StO}_2 monitoring, and they were specifically instructed not to make any clinical decisions based on these values. During ACLS, all paramedics within the system use a monitor with recording capabilities. During cardiac arrests, waveform end-tidal capnography, heart rhythm, oxygen saturation, respiratory rate, and compression rate are routinely recorded via a Philips HeartStart MRx Monitor (Philips, Eindhoven, The Netherlands). End-tidal CO\textsubscript{2} monitoring is applied upon placement of any advanced airway in the prehospital setting. These data were downloaded and reviewed for research and quality improvement purposes by the study investigators.

For each case, the monitor data for \textit{StO}_2 and ETCO\textsubscript{2} were graphed. General information for each case is also provided. Time point when EMS was doing compressions was also documented on each graph as a surrogate for pulselessness. All patients had an initial cardiac arrest prior to physician arrival and \textit{StO}_2 monitor placement.

#### RESULTS

##### Case 1

This was an 84-year-old woman who experienced a witnessed cardiac arrest. Bystander CPR was performed. Upon arrival of the paramedics with CPR ongoing, the patient received 2 mg of epinephrine and 1 mg of atropine and ROSC was obtained. After placement of the \textit{StO}_2 monitor, the patient experienced rearrest and received 1 mg of epinephrine and 50 mEq of sodium bicarbonate. After the second ROSC, the patient was placed on an epinephrine infusion. The patient arrived at the emergency department with pulses. Measurement of \textit{StO}_2 showed an obvious downward trend prior to EMS notice of pulselessness (decrease of 15% over 3 minutes). After the patient regained pulses, there was an almost vertical slope to the \textit{StO}_2 curve (increase of 40% in 1 minute). The ETCO\textsubscript{2} appeared to rise in response to pulselessness.
FIGURE 1. Graph of oxygen content in tissues (StO2) for case 1: an 84-year-old woman. CPR = cardiopulmonary resuscitation; EtCO2 = end-tidal carbon dioxide.

and then decline with ROSC. The remainder of the trend had no obvious pattern (Fig. 1).

Case 2
This was a 76-year-old man who sustained a witnessed cardiac arrest and bystander CPR was performed. The patient was given a total of 5 mg of epinephrine, 150 mg of amiodarone, and 1 mg of atropine during the resuscitation. The patient arrived at the hospital with pulses. On the StO2 curves there were obvious downward trends in the StO2 readings during the time prior to loss of pulses (15% decrease in 3 minutes before initial arrest). There was also a noticeable upslope as ROSC was obtained. On the ETCO2 graph there appeared to be low points during pulselessness and higher values when ROSC was achieved (Fig. 2).

Case 3
This was an 81-year-old woman who experienced an unwitnessed cardiac arrest. Bystander CPR was performed. The patient received 4 mg of epinephrine and 50 mEq of sodium bicarbonate during resuscitation. An epinephrine infusion was used after ROSC, but the patient experienced rearrest twice on the way to the hospital. The patient arrived at the hospital without pulses and with CPR ongoing. On the StO2 tracings, there appeared to be a downward slope prior to and during pulselessness (20% over 8 minutes). There was also an obvious trend upwards after ROSC (10% over 2 minutes) (Fig. 3). There did not appear to be any obvious relationship between pulses and ETCO2.

Case 4
This was an 83-year-old woman who experienced an unwitnessed cardiac arrest. The patient had bystander CPR and defibrillation by first responders prior to EMS arrival. The patient had pulses, was breathing, and was protecting her airway on physician arrival. She was given 100 mg of lidocaine for dysrhythmias. No ETCO2 data were available, as the patient was never intubated. The StO2 measurements remained relatively stable throughout the entire period. There was no obvious downward or upward trending (Fig. 4).

Case 5
This was a 61-year-old woman who experienced a witnessed cardiac arrest. Bystander CPR was performed. The patient was given 1 mg of atropine, 1 mg of
**FIGURE 2.** Graph of oxygen content in tissues (StO2) for case 2: a 76-year-old man. CPR = cardiopulmonary resuscitation; EtCO2 = end-tidal carbon dioxide.

**FIGURE 3.** Graph of oxygen content in tissues (StO2) for case 3: an 81-year-old woman. CPR = cardiopulmonary resuscitation; EtCO2 = end-tidal carbon dioxide.
epinephrine, and 150 mg of amiodarone prior to ROSC. She arrived at the emergency department with pulses. The StO2 tracing shows a low initial value with an almost vertical change at the time of ROSC (35% over 1.5 minutes). After that time, the patient maintained an apparent constant and high-level StO2. Measurement of ETCO2 over the same time showed significant variation. There was an upward trend during arrest and at ROSC. There appeared to be a gradual trend downward over time after return of pulses (Fig. 5).

**DISCUSSION**

Current literature supports the need for rapid identification of patients who have hemodynamic instability after ROSC, which may lead to rearrest. Patients who experience rearrest in the prehospital setting have a lower likelihood of survival to both hospital admission and hospital discharge.\(^5,6\) Measurement of ETCO2 is currently perceived as the best tool that prehospital providers have for the noninvasive monitoring of hemodynamics in post–cardiac arrest patients in the out-of-hospital setting.\(^8,9\) Previous studies have shown compelling data that ETCO2 results could be used for prognostication and patient status monitoring in critical illness.\(^7−11\) Even with this tool, the rate of rearrest after ROSC remains high, and it continues to be a difficult burden to determine when and in whom a rearrest will occur.\(^6\)

NIRS has been used in other disease states to trend changes in tissue perfusion. A number of studies exist in both the surgical and cardiac literature that show good prognostic abilities of StO2.\(^12,13\) This is the first study to examine the changes in StO2 that occur after ROSC in cardiac arrest. Our preliminary findings suggest that StO2 undergoes dynamic changes in the immediate post-ROSC period and in the period preceding rearrest. The StO2 value appears to decrease prior to loss of pulses. This suggests that measurement of StO2 may be able to replace the periodic and inaccurate approach to checking manual pulses in the postarrest patient and may be predictive of deterioration prior to loss of pulses. Second, there appears to be a rapid increase in StO2 with ROSC. This suggests that StO2 could potentially replace pulse checks during CPR, which could reduce hands-off time. Also, there appears to be a constant level of StO2 in those patients who did not experience rearrest. This suggests that decreases in StO2 may be specific to hemodynamic instability and used as a marker for the need of additional interventions that may prevent rearrest, such as aggressive blood pressure...
management as catecholamines administered during the cardiac arrest wear off.

Finally, there appears to be wider variability in ETCO₂ than StO₂, which suggests that StO₂ may be more useful to create cutoff values to drive processes of care. One possible explanation for the difference in this variability could be the determining factors associated with each measure. The level of ETCO₂ is dependent both on hemodynamics and ventilatory rate. In most of these patients, the treating provider determined the breathing rate. Variability in provider practice, independent of circulatory status, can have significant impact on ETCO₂ values. At high partial pressures of oxygen, the StO₂ should be less dependent on ventilation and primarily dependent on cardiac output, making it an overall better predictor of changes in hemodynamic status.

**LIMITATIONS**

This is a case series of only five patients, so results are preliminary and summary statistics are not possible. Second, we were not able to record the exact moment the patient lost pulses, given that we did not have an invasive arterial line. Our only way to determine pulselessness was to use the time of CPR start and stop as a surrogate. We believe that this is more realistic of current prehospital care. An additional limitation is that the StO₂ monitor was able to collect more data points during the study interval than the ETCO₂ monitor. This could contribute to the StO₂ curves’ appearing smoother throughout the time course recorded and an additional benefit over current ETCO₂ monitoring.

**CONCLUSION**

Measuring peripheral tissue oximetry using a portable NIRS device has a potential role in assisting providers to monitor periarrest patients in the prehospital setting. The ability to identify hemodynamic instability could be used to proactively prevent rearrest, thus improving patient outcomes. Additionally, StO₂ may prove to be useful during CPR to reduce hands-off time by alleviating the need for periodic pulse checks. Future research is needed to determine the full capabilities of tissue oximetry and how this technology can be combined with clinical practice to improve outcomes in the vulnerable post–cardiac arrest patient population.
References