Transcutaneous carbon dioxide/oxygen monitoring in critical care medicine: just for children?

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Transcutaneous non-invasive monitoring technology has been around for more than thirty years. Throughout this period of time, transcutaneous monitoring has been closely linked to the care of neonates.

However, recent studies suggest that transcutaneous technology may work just as well in older children and adults. Although other technologies exist for continuous monitoring of carbon dioxide on adults, each is either not compatible with pulmonary disease or requires an invasive line.

Transcutaneous monitoring may be the only technology available that allows continuous monitoring of carbon dioxide levels in any-size patient, but without requiring an invasive line or normal cardiopulmonary function.

Transcutaneous technology for non-invasive monitoring of carbon dioxide and oxygen levels has been around for more than thirty years [1, 6].

Throughout this period of time, transcutaneous monitoring (TCM) technology has been closely linked to the care of neonates, but recent studies suggest that TCM technology may work just as well for older children and adults [2, 5, 7, 8, 9, 10].

Today, a number of innovative techniques, both invasive and non-invasive, have become available for monitoring gas exchange in the ICU patient [1]. Technologies like end-tidal carbon dioxide monitoring and indwelling arterial blood gas monitoring to follow real-time gas exchange exist, but each of these technologies have limited applications [1].

TCM may be the only technology available that allows continuous monitoring of carbon dioxide levels in any-size patient but without requiring an invasive line or normal cardiopulmonary function.

Critically ill patients require frequent or constant monitoring. Continuously monitored gas exchange is a crucial component of mechanical ventilation management [6]. Indwelling arterial blood gas monitoring can provide continuous accurate carbon dioxide measurement, but this technology requires an arterial line [1].

Not all patients who need monitoring of gas exchange will need an invasive line. This technology also requires accessing the line for placement of the sensor. Device malfunctions require re-accessing the line for subsequent sensor replacement. Frequent accessing of the invasive lines may lead to increased rates of infection.

End-tidal carbon dioxide ($ETCO_2$) monitoring is non-invasive but has been shown to provide poor correlation in patients with increased dead-space ventilation or inadequate perfusion [1, 3, 10].

Additionally, $ETCO_2$ monitors can be problematic in the non-intubated patient. $ETCO_2$ was once thought to satisfy the need for continuous CO_2 monitoring, but $ETCO_2$ has not been used widespread due to many technical and physiologic problems. $ETCO_2$ monitors are normally of two different designs, sidestream and mainstream.

The sidestream type depends upon the constant aspiration of exhaled gases via a vacuum pump. This design lends itself to pulling in condensation and mucus. Tubing occlusion is a frequent problem with this type of device [11].

Mainstream capnometry does not normally have the problem of device occlusion, but it works best when the patient is intubated or trached. Both the sidestream and mainstream capnometers are unreliable in patients who have pulmonary disease and/or uneven distribution of ventilation.

Unfortunately, this can be the majority of patients who need capnometry. Differences between $ETCO_2$ and arterial pCO_2 increase as dead space increases, the end-tidal pCO_2 represents more pCO_2 of non-perfused alveoli, diverting more from the arterial pCO_2. Interestingly, this makes the $ETCO_2$ read lower than the pCO_2 [1].

Arterial blood gas (ABG) measurement is the gold standard, but it is not the perfect answer to fill the need of frequent or continuous CO_2 monitoring. An ABG is a snapshot of a particular moment.

Additionally, many different technical errors can cause inaccuracies in reported ABG results. Frequent blood gas sampling requires multiple blood draws, patient discomfort, and blood loss.

The technology of transcutaneous monitoring has been around for approximately thirty years and has been shown to deliver a continuous non-invasive partial-pressure value of carbon dioxide accurately in infants and children.

Before the advent of pulse oximetry, the only way to obtain partial pressure of oxygen (pO_2) was by ABG. This may have been why the early emphasis in TCM was on transcutaneous oxygen. This early emphasis on transcutaneous oxygen, $tcpO_2$, earned TCM a bad reputation.

TCM may reflect arterial, venous, or capillary oxygen status. The wide differences between arterial, capillary, and venous oxygen levels led many to believe that TCM was just not accurate.

Early on, little attention was paid to transcutaneous carbon dioxide levels. Since there is only a small variation between arterial, venous, and capillary carbon dioxide levels, $tcCO_2$ is generally accurate no matter which phase of blood it is reflecting. The emergence of reliable pulse oximetry, although not perfect, has mostly satisfied the need for continuous oxygen monitoring, but TCM may be the answer to fill the need of continuous carbon dioxide monitoring.

Most textbooks reference TCM as a modality that is almost exclusively used in neonates [1, 6]. However, in actuality TCM monitors are routinely used in infant and pediatric critical care. TCM monitoring is considered a standard of care in adult vascular medicine.

In addition, recent data have come out supporting the use of TCM in critically ill adults. Increased skin-fold thickness was once thought to be a barrier to accurate transcutaneous monitoring.

Since adults have thicker skin than children, this may have led to these traditional thoughts about TCM efficacy in adults [6]. Janssens *et al* showed that TCM could be used in adults continuously over an eight-hour period for monitoring of non-invasive positive pressure ventilation without incident [5].

This study was unique in that not only did it show that TCM can be used in adults with accurate values being obtained; it also showed that the TCM could be left on one site continuously for an entire eight hours.

Normally, due to the heat involved in TCM, frequent moving of the monitor electrode is required. In their study, Janssens *et al* used a slightly lower operating temperature, 43 °C as opposed to 44 °C.

Despite the lower operating temperature, the data produced by the monitor were considered accurate. The age group of the study population was 69 ± 9 years.

Another study by Rosner *et al* of adult patients with stable chronic respiratory failure requiring gas exchange monitoring during nocturnal mechanical ventilation found that with a slight correction factor the data displayed was reliable [8].

Nelson *et al* studied the efficacy of using TCM during endoscopic retrograde cholangiopancreatography (ERCP) [10]. They found that carbon dioxide retention was more readily detected by the addition of TCM than by clinical observation and pulse oximetry alone. A study by Tatevossion *et al* looked at TCM as an early warning of ARDS in trauma patients.

They found that, compared to survivors, patients who died had a higher transcutaneous CO_2, tcpCO_2, and a lower transcutaneous O_2, tcpO_2, in the early stage of resuscitation. They concluded that TCM evaluation of tissue perfusion served as an early warning in critically injured patients during resuscitation immediately after hospital admission [9].

Many studies have shown that the values produced by TCM correlate closely to carbon dioxide levels obtained via ABG. The use of TCM allows accurate determination of CO_2 but without the invasive nature of ABG or indwelling ABG monitoring.

TCM has also been shown to provide a better correlation to arterial pCO_2 than $ETCO_2$ in both adults and children. Considering this new evidence, TCM should be considered a first-line monitor for both children and adults who need gas exchange monitoring. TCM may no longer be just for kids.

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