AARC Clinical Practice Guideline: Transcutaneous Monitoring of Carbon Dioxide and Oxygen: 2012

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An electronic literature search for articles published between January 1990 and September 2011 was conducted by using the PubMed, CINAHL, SCOPUS, and Cochrane Library databases. The update of this clinical practice guideline is the result of reviewing a total of 124 articles: 3 randomized controlled trials, 103 prospective trials, 1 retrospective study, 3 case studies, 11 review articles, 2 surveys and 1 consensus paper on transcutaneous monitoring (TCM) for P_{tcO_2} and P_{tcCO_2}. The following recommendations are made following the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) criteria: (1) Although P_{tcCO_2} has a good correlation with P_{aCO_2} and is a reliable method to evaluate plasma CO_2 levels, it is recommended that arterial blood gas values be compared to transcutaneous readings taken at the time of arterial sampling, in order to verify the transcutaneous values, and periodically as dictated by the patient's clinical condition. (2) It is suggested that P_{tcCO_2} may be used in clinical settings where monitoring the adequacy of ventilation is indicated. (3) It is suggested that P_{tcO_2} and P_{tcCO_2} may be used in determining the adequacy of tissue perfusion and monitoring of reperfusion. (4) It is suggested that TCM should be avoided in the presence of increased thickness or edema of the skin and/or subcutaneous tissue where the sensor is applied. (5) It is recommended that sites used for a TCM be changed as often as necessary and that they be alternated and observed to avoid thermal injury. Manufacturer recommendations should be followed. *Key words: clinical practice guidelines; hyperbaric oxygen therapy; reperfusion; transcutaneous monitoring; transcutaneous carbon dioxide; transcutaneous carbon dioxide monitoring; transcutaneous oxygen; transcutaneous oxygen monitoring.* [Respir Care 2012; 57(11):1955–1962. © 2012 Daedalus Enterprises]

TCM 1.0 INTRODUCTION

Since pulse oximetry is considered the standard of care for noninvasive monitoring of oxygen levels, routine transcutaneous monitoring (TCM) of oxygen pressure (P_{tcO_2}) has fallen out of favor. While some studies in infants[1-3] have shown that TCM of P_{O_2} may be more reliable than monitoring oxygenation via S_{pO_2}, most of the studies are focused on TCM of carbon dioxide pressure (P_{tcCO_2}), which is considered an accurate and clinically acceptable estimate of the P_{aCO_2}.[4-13]

TCM 2.0 DESCRIPTION/DEFINITION

A transcutaneous (TC) monitor measures the skin-surface P_{O_2} and P_{CO_2} to provide an estimate of the P_{aO_2} and

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P_{aCO_2}. The measurements obtained include P_{tcO_2} and P_{tcCO_2}. The TC monitor device induces hyperperfusion of the capillaries by increasing the local temperature of the skin at the sensor site. The externally applied heat alters the solubility of CO_2 in the blood and increases the metabolic rate of the skin by approximately 4–5% for every degree Celsius, resulting in local production of CO_2.[14] The sensor, usually a Severinghaus electrode, will calculate the P_{CO_2} electrochemically, usually by a change in pH of an electrolyte solution. Additionally, a temperature correction is used to address the epithelial CO_2 produced by heating the skin.[1,15-20] A Clark electrode, which is composed of a platinum cathode and silver anode, measures the P_{O_2}.[21]

Each manufacturer's calibration protocol for the TC monitor sensor should be followed. After the sensor is calibrated, the skin must be cleaned of all oils, soaps, and dead skin. Once the site is cleaned, then a sensor fixation ring should be placed in a highly vascularized area. The preferred location to obtain TC measurements in neonates and small pediatric patients is the upper chest. Alternative sites may be the lateral side of the abdomen, chest, buttock, inside of the upper thigh, forearm, the zygomatic bone, the ear lobe, cheeks, or the forehead.[22-26] In order to achieve accurate P_{tcO_2} the skin probe temperature must be 44°C, which may lead to injury or burning of the skin, particularly in patients with thin or damaged skin.[27] By contrast, monitoring of the P_{tcCO_2} is reliable with skin temperature even as low as 37°C.[1,28] Most TC monitors allow the reduction of the probe temperature to minimize the risk of thermal injury.[29] Correlation with arterial blood gases is recommended to ensure accuracy of the values obtained by TC monitor.[29] When monitoring P_{tcCO_2} only, use of lower skin probe temperatures increases the systematic overriding of TC measurement and may allow for longer periods of contact time between the skin and the sensor, for up to 8–12 hours. This option may be especially important for neonatal population compliance with the minimal handling approach promoted in their care. However, changing sites as often as every 2 hours may be necessary in small premature neonates to avoid thermal injury.

After the fixation device is in place, 1–2 drops of either contact gel or normal saline should be placed inside the ring. This improves the accuracy of the sensor and makes the diffusion of gases more efficient. The sensor is then placed into the ring and usually snaps into place. The ring must create enough of a seal to prevent leaks or formation of air bubbles, as ambient air reaching the sensor affects measured values.

TCM 3.0 SETTING

TCM may be performed by trained personnel in a variety of settings that include, but are not limited to hospitals, extended care facilities, and patient transport.[20,22,30] It is utilized in the following specific clinical settings to determine the presence of hypoventilation or respiratory depression:

3.1 Mechanical ventilation, including conventional modes of ventilation,[31-33] high-frequency ventilation,[27,34] steady state high frequency jet ventilation,[35] and noninvasive ventilation.[34-39]

3.2 Bronchoscopies or procedures requiring sedation[23,40-45] or patient-controlled analgesia[46-48]

3.2.1 Prolonged laparoscopic surgery procedures[49]

3.3 Sleep studies[50-55]

3.3.1 P_{tcO_2} may have an increased role in detecting sleep hypoventilation and assessing the efficacy of treatment of sleep disorders.[56]

3.4 Pulmonary function studies, including stress testing and bronchoprovocation[12,39,57-59]

3.5 Trending HCO_3^- in diabetic ketoacidosis[60]

3.6 Apnea testing[61]

3.7 Transportation of a patient[9,29]

3.8 Evaluation of tissue perfusion[27,43,62-67]

3.9 Evaluation of postoperative hypercarbia[9,68,69]

3.10 Evaluation of hyperventilation during phonation of patients with vocal cord disorders[70,71]

3.11 Titration of long-term oxygen therapy[72]

TCM 4.0 INDICATIONS

The use of TCM is indicated in patients who either lack arterial access or have the need for continuous monitoring of oxygen and carbon dioxide with minimal blood draws.[60] TCM allows the assessment of:

4.1 adequacy of oxygenation and/or ventilation[2,9,10,13,22,25,29,30,37,50,73-76]

4.2 response to diagnostic and therapeutic interventions, as evidenced by P_{tcO_2} and/or P_{tcCO_2} values[2,22,29,30,37,38,64,67,74,77]

4.2.1 Weaning and extubation decisions may be made based on P_{tcCO_2} measurement alone.[78,79]

4.3 TC oxygen index (P_{tcO_2}/F_{IO_2}), which can be used as an early marker of hypoperfusion and mortality[62,63]

4.3.1 A ratio less than 200 should prompt evaluation and intervention.[61]

4.4 tissue perfusion status and revascularization in wound care and peripheral arterial occlusive disease[80]

4.4.1 P_{tcO_2} is used in wound care and hyperbaric oxygen therapy as an effective tool to monitor critical limb ischemia.

4.4.1.1 A P_{tcO_2} on the affected limb should be maintained between 30–40 mm Hg to maintain adequate perfusion. A P_{tcO_2} less than 30 mm Hg may indicate poor perfusion to that limb, and a P_{tcO_2} less than 10 mm Hg is considered incompatible with spontaneous healing process.[81,82]

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4.4.1.2 P_{tcO_2} is useful in the determination of optimal amputation level. A P_{tcO_2} of 30 mm Hg is considered the critical dividing value that separates successful from unsuccessful amputation stump healing.

4.5 monitoring response to therapy in patients with diabetic ketoacidosis, as P_{tcCO_2} correlates with serum HCO_3^- levels[59]

TCM 5.0 CONTRAINDICATIONS

There are no documented absolute contraindications for use of TCM. In patients with poor skin integrity and/or adhesive allergy, alternative monitoring devices to TCM should be considered.[29]

TCM 6.0 HAZARDS/COMPLICATIONS

P_{tcO_2} and/or P_{tcCO_2} monitoring is considered a safe procedure. The most common hazards and complications of TCM are:

6.1 Misinterpretation of falsely elevated or decreased levels of O_2 and CO_2 that may lead to inappropriate treatment of the patient.[75,83,84] P_{tcO_2} underestimates P_{aO_2} and P_{tcCO_2} overestimates P_{aCO_2}. While some manufacturers have incorporated correction factors into the device software, what TCM really measures is skin P_{O_2} and P_{CO_2}, not P_{aO_2} and P_{aCO_2} per se.[75,83,84]

6.2 Thermal injury may occur at the sensor site (eg, erythema, blisters, burns, skin tears).[10,16,22,85-87]

TCM 7.0 DEVICE LIMITATIONS/VALIDATION OF RESULTS

P_{tcO_2} is an indirect measurement of P_{aO_2} and does not reflect oxygen delivery or oxygen content. Complete assessment of oxygen delivery requires knowledge of hemoglobin saturation and cardiac output. P_{tcCO_2} is an indirect measurement of P_{aCO_2}, but knowledge of delivery and content is not necessary to use P_{tcCO_2} for assessment of ventilation.

Factors that may affect readings, limit precision, or limit the performance or application of a TC monitor include:

7.1 Device Related

7.1.1. Although some newer designs make application quicker and simpler, setup is labor intensive.[33]

7.1.2 Prolonged stabilization time is required following electrode placement, typically up to 5–10 min, but varies by manufacturer.[9,33,38,84,88]

7.1.3 While the theoretical basis for mandatory heating of the P_{tcO_2} electrode in newer TC monitors has not been established,[17,89,90] manufacturers suggest heating the electrode to produce valid results.

7.1.3.1 Some clinical studies suggest that valid results may be obtained with P_{tcCO_2} electrodes operated at lower than recommended temperatures or with no heat.[14,27,91,92]

7.1.4 Improper calibration, trapped air bubbles, leaks in the fixation device, and damaged membranes and their detection may result in misinterpretation of the values and erroneous changes in therapy.[14,21,30,84]

7.1.4.1 If too much saline or contact gel is applied, a leak may be created between the skin and the fixation device.

7.2 Clinical

The following clinical situations may result in falsely elevated or decreased P_{tcO_2} and P_{tcCO_2} values:

7.2.1 Presence of hyperoxemia ($P_{aO_2} > 100$ mm Hg) (elevated P_{tcO_2})[14,86,89]

7.2.2 The presence of a hypoperfused state (shock, acidosis)[61,93] and vasoactive drug administration[61] may result in decreased P_{tcO_2} and P_{tcCO_2}. However, the use of newer TCM devices and placement of the sensor near the carotid artery have improved the correlation between P_{aO_2} and or P_{aCO_2} in this clinical situation.[4,25,31,45,55,83,94]

7.2.3 Improper electrode placement or application (elevated P_{tcO_2}; decreased P_{tcCO_2})[84]

7.2.4 Increased thickness or edema of the skin and/or subcutaneous tissue (decreased P_{tcO_2} and P_{tcCO_2})[24,53,61,84,95]

7.2.5 Increased capillary blood flow induced by movement of the patient, either by self or due to routine care, may increase P_{tcO_2} and P_{tcCO_2}.[22,96,97]

7.2.6 Placement of the sensor site on the distal part of an extremity may result in lower readings, due to vasoconstriction limiting blood flow.[14,15,24]

7.2.6.1 Some TC monitors allow for the use of the ear area (eg, tragus) as a TC monitoring site. Studies have shown that the ear is an acceptable place for TC monitoring[8,25,27,98]; however, in some cases the ear is not an acceptable place, as it may interfere with a procedure (eg, neurosurgery, maxillofacial surgery).

7.2.6.2 The ear sensor is less susceptible to detachment with patient movement and does not have to be removed for chest x-rays or other chest imaging procedures.[22,45]

7.3 Validation

Arterial blood gas values should be compared to TC readings taken at the time of arterial sampling, in order to validate the TC values. This validation should

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be performed initially and periodically, as dictated by the patient's clinical condition.[10,99-102]

7.3.1 During validation studies in patients with physiologic shunts, the electrode site and arterial sampling site should be on the same side of the shunt when measuring P_{tcO_2}.[50,84,102] However, recent studies show that P_{tcCO_2} is not affected by shunts or ventilation-perfusion mismatching, when compared to P_{aCO_2}.[9,17,103]

7.3.2 When a discrepancy exists between TC, measured arterial values, and the clinical presentation of the patient, possible causes should be explored before results are reported. Monitoring at alternative sites, recalibration, or equipment replacement may reduce discrepancies. If such steps do not remedy the disparity, TCM results should not be acted upon or recorded in the patient's medical record. Instead, a statement describing the TC use and the corrective action should be included in the patient's medical documentation, and some other mode of monitoring should be established (eg, pulse oximetry, end-tidal CO_2 [P_{ETCO_2}] monitoring, arterial blood analysis). The absolute limits that constitute unacceptable discrepancies vary with patient condition and specific device.[92,104,105] Clinical judgment must be exercised.

7.3.3 When comparing or correlating values for P_{CO_2}, the P_{tcCO_2} value is typically higher than P_{aCO_2}. However, the P_{tcCO_2} is a good surrogate of the P_{aCO_2} and sometimes and may provide a better estimate of P_{aCO_2} than P_{ETCO_2}.[10,11,27,31,68,74,106-110] Reading an accurate P_{CO_2} value with a TC monitor requires more time than measuring P_{ETCO_2}, due to the required period of stabilization of the TCM.[102,111]

7.3.3.1 Although the acceptable clinical range of agreement for P_{tcCO_2} is $\pm$ 7.5 mm Hg,[4] the manufacturer's recommendations should be followed.

TCM 8.0 ASSESSMENT OF NEED

8.1 When direct measurement of arterial blood is not available or accessible in a timely fashion, P_{tcO_2} and/or P_{tcCO_2} measurements may temporarily suffice if the limitations of the data are appreciated.[11]

8.2 TC blood gas monitoring is appropriate for continuous and prolonged monitoring (eg, during mechanical ventilation, CPAP, and supplemental oxygen administration), but has limitations when used on an intermittent basis.[10,14,49,75]

8.3 P_{tcO_2} values can be used for diagnostic purposes, as in the assessment of functional shunts (eg, persistent pulmonary hypertension of the newborn) or persistent fetal circulation, or to determine the response to oxygen challenge in the assessment of congenital heart disease.[39,67,99,100]

TCM 9.0 ASSESSMENT OF OUTCOME

9.1 Results should reflect the patient's clinical condition (ie, validate the basis for ordering the monitoring).[15,18,30,97]

9.2 Documentation of results, therapeutic intervention, and/or clinical decisions based on the TC measurements should be noted in the patient's medical record.

TCM 10.0 RESOURCES

10.1 Equipment

TC monitor, electrodes, calibration gases, and associated supplies. TC monitor should have been validated by the manufacturer, using appropriate quality control procedures and clinical reliability studies.

In order to help assure consistency of care based on TC blood gas readings, the operator should verify:

10.1.1 High and low limit alarms are set appropriately

10.1.2 Appropriate electrode temperature is set

10.1.3 Electrode placement site is appropriate and systematic electrode site change occurs

10.1.4 Specific manufacturer's recommendations for maintenance, operation, and safety are complied with

10.1.4.1 Some devices incorporate newer technologies to improve monitoring of oxygen and carbon dioxide by:

10.1.4.1.1 allowing measurement of S_{pO_2}, P_{tcO_2}, and P_{tcCO_2}, together or separately, through a miniaturized carbon dioxide tension P_{CO_2}/S_{pO_2} single sensor that monitors both P_{aCO_2} and oxygen saturation by pulse oximetry (S_{pO_2})[22,25]

10.1.4.1.2 stabilizing TC values faster through the addition of a heat function

10.1.4.1.3 showing the clinician, through a relative heating index, how much power the unit is using to warm the site

10.1.4.1.4 maximizing measurement in low perfusion states through the incorporation of a compensatory heating probe

10.2 Personnel

Actively licensed and credentialed respiratory therapists or other credentialed healthcare providers with equivalent training and demonstrated ability to exercise the necessary clinical judgment, to assess the pa-

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tient, and to perform the essential tasks of monitor calibration and application.[10]

TCM 11.0 MONITORING

The monitoring schedule of patient and equipment during TCM should be integrated into the patient assessment and vital signs determinations. Results should be documented in the medical record and should detail the conditions under which the readings were obtained. Additional documentation includes:

11.1 The date and time of measurement, TC reading, patient's position, respiratory rate, and activity level

11.2 F_{IO_2} or supplemental oxygen flow, specifying the type of oxygen delivery device

11.3 Ventilatory mode and settings

11.4 Electrode placement site, electrode temperature, and time of placement

11.5 Results of simultaneously obtained P_{aO_2}, P_{aCO_2}, and pH when available

11.6 Clinical appearance of the patient, subjective assessment of perfusion, pallor, and skin temperature

TCM 12.0 FREQUENCY

TC blood gas monitoring should be continuous for development of trending data. Placement for intermittent and short duration measurements (ie, spot checks) is not appropriate.[15,50,112]

TCM 13.0 INFECTION CONTROL

No special precautions are necessary, but standard precautions (as described by the Centers for Disease Control) are recommended.[113]

13.1 The device probe should be cleaned between patient applications, according to manufacturer recommendations.

13.2 The external portion of the monitor should be cleaned by methods according to manufacturer recommendations in between patient use.

TCM 14.0 RECOMMENDATIONS

The following recommendations are made following the Grading of Recommendations Assessment, Development, and Evaluation (GRADE)[114] criteria:

14.1 Although P_{tcCO_2} has a good correlation with P_{aCO_2} and is a reliable method to evaluate plasma CO_2 levels, it is recommended that arterial blood gas values be compared to TC readings taken at the time of arterial sampling, in order to verify the TC values, and periodically as dictated by the patient's clinical condition. (1A)

14.2 It is suggested that P_{tcCO_2} may be used in clinical settings where monitoring the adequacy of ventilation is indicated. (2B)

14.3 It is suggested that P_{tcO_2} and P_{tcCO_2} may be used in determining the adequacy of tissue perfusion and monitoring of reperfusion. (2B)

14.4 It is suggested that TCM should be avoided in the presence of increased thickness or edema of the skin and/or subcutaneous tissue where the sensor is applied. (2B)

14.5 It is recommended that sites used for a TCM be changed as often as necessary and that they be alternated and observed to avoid thermal injury. Manufacturer recommendations should be followed. (1C)

TCM 15.0 CPG IDENTIFYING INFORMATION AND AVAILABILITY

15.1 Adaptation

Original Publication: Respiratory Care 1994:39(12): 1176–1179.

15.2 Guideline Developer

American Association for Respiratory Care Clinical Practice Guidelines Steering Committee.

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