

Transcutaneous Oximetry in Clinical Practice: Consensus statements from an expert panel based on evidence.*

*Based upon proceedings of the workshop “Transcutaneous Oximetry: art, science, and practice”; June 13, 2007.

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Fife CE, Smart DR, Sheffield PJ, Hopf HW, Hawkins G, Clarke D. Transcutaneous Oximetry in Clinical Practice: Consensus statements from an expert panel based on evidence.* *Based upon proceedings of the workshop “Transcutaneous Oximetry: art, science, and practice;” June 13, 2007. Undersea Hyperb Med 2009; 36(1):43-53. Transcutaneous oximetry (PtcO₂) is finding increasing application as a diagnostic tool to assess the peri-wound oxygen tension of wounds, ulcers, and skin flaps. It must be remembered that PtcO₂ measures the oxygen partial pressure in adjacent areas of a wound and does not represent the actual partial pressure of oxygen within the wound, which is extremely difficult to perform. To provide clinical practice guidelines, an expert panel was convened with participants drawn from the transcutaneous oximetry workshop held on June 13, 2007, in Maui, Hawaii. Important consensus statements were (a) tissue hypoxia is defined as a PtcO₂ < 40 mm Hg; (b) in patients without vascular disease, PtcO₂ values on the extremity increase to a value > 100 mm Hg when breathing 100% oxygen under normobaric pressures; (c) patients with critical limb ischemia (ankle systolic pressure of ≤ 50 mm Hg or toe systolic pressure of ≤ 30 mm Hg) breathing air will usually have a PtcO₂ < 30 mm Hg; (d) low PtcO₂ values obtained while breathing normobaric air can be caused by a diffusion barrier; (e) a PtcO₂ < 40 mm Hg obtained while breathing normobaric air is associated with a reduced likelihood of amputation healing; (f) if the baseline PtcO₂ increases < 10 mm Hg while breathing 100% normobaric oxygen, this is at least 68% accurate in predicting failure of healing post-amputation; (g) an increase in PtcO₂ to > 40 mm Hg during normobaric air breathing after revascularization is usually associated with subsequent healing, although the increase in PtcO₂ may be delayed; (h) PtcO₂ obtained while breathing normobaric air can assist in identifying which patients will not heal spontaneously.

INTRODUCTION

The technique of transcutaneous oximetry (PtcO₂) allows the estimation of the partial pressure of oxygen on the skin surface by employing noninvasive heated electrodes. Pioneered over 40 years ago by Clark,(1) Silver,(2) and Hunt (3) using invasive electrodes, it has since expanded enormously,(4-7) and is used as a diagnostic

tool in many diseases to assess the oxygen tension of wounds, ulcers, and skin flaps (8-10). It is important to understand, however, that PtcO₂ values do not represent actual partial pressures of oxygen within the wound because the oximetric electrodes are placed in adjacent areas of the wound (8). While the evidence to date does suggest a correlation between PtcO₂ values and wound partial oxygen pressures, until comparison experiments are performed

and the problem of accurately measuring partial oxygen pressures within the wound solved, any such correlation must be regarded as tentative. PtcO₂ is measured under various conditions, for example while the patient is breathing oxygen in the hyperbaric chamber, referred to in this paper as “in-chamber PtcO₂.” When measured under “normobaric conditions,” that is, at ambient atmospheric pressures, we refer to this as “normobaric air” or “normobaric oxygen” measurements. The literature often refers to these as “sea level” air or oxygen measurements, but data may not have been obtained at precisely “sea level” atmospheric pressure, making “normobaric” the more accurate term.

More recently, PtcO₂ has been increasingly used as a screening tool to predict benefit from subsequent hyperbaric oxygen therapy (HBO₂T) (11-14). Despite the considerable number of reports published concerning its use in a diagnostic capacity, it has been difficult to formulate clinical practice guidelines that involve precise PtcO₂ values because the data are variable and there is a considerable range in response depending on the comorbidities among the subjects whose PtcO₂ values are being measured. Moreover, many of the reported studies have differing designs, lack comprehensive data, and the randomized controlled trials to date have involved small numbers.

In order to provide guidelines for the clinical use of PtcO₂ data, an expert panel was convened with participants drawn from the transcutaneous oximetry workshop (UHMS 2007 pre-course) held on June 13, 2007 in Maui, Hawaii.

The process of convening the expert panel started several months prior with the recognition that there were no guidelines regarding the use of transcutaneous oximetry in the field of wound care. The UHMS asked CEF to plan a specific meeting on this subject and

select participants who could contribute based on their experience and published work. Dr. Fife, who is Associate Professor at the Dept. Medicine, Div. Cardiology, University of Texas Health Science Center in Houston, included herself because she and her colleagues have performed the largest retrospective studies to date in the field; Dr. Smart, Co-Director of the Dept. Hyperbaric and Diving Medicine, Royal Hobart Hospital, Tasmania, and Chairman of the Australian and New Zealand Hyperbaric Medicine Group, was included because he had just published a comprehensive review on the subject; Dr. Sheffield, President of International ATMO, Inc., San Antonio, TX, carried out most of the pioneering work on the subject; Dr. Hopf, Professor, Dept. Anesthesiology, and Director of Translational Research, University of Utah Medical Director, Wound Care Services, LDS Hospital, Salt Lake City, has performed many of the prospective studies on the subject and was also involved in the creation of guidelines for the treatment of arterial insufficiency ulcers; Glen Hawkins is the Medical Director at Hyperbaric Health in Sydney Australia and had data from studies in that country, Dick Clarke is the Program Director of Palmetto Richland Memorial Hospital/University of South Carolina School of Medicine Hyperbaric Medicine service and has been involved with randomized controlled trials of hyperbaric oxygen therapy.

METHOD USED IN CONSENSUS MAKING

We employed a modified Delphi technique (15,16) to reach a consensus on several critical issues originally drafted by the chairperson (CEF). The issues were circulated among the 6 participants and modified until concurrence was achieved on the wording of each point. When questions or conflicts occurred, the literature was consulted. Consensus was reached on 9 issues. In addition, several other

useful points were raised, which are listed in the Discussion section. Each issue is supported by references from the literature; issues that are strongly supported by the literature are starred (*).

STATEMENTS

Normal Extremity Values

- a.* On the foot, while breathing normobaric air, the average PtcO₂ in healthy subjects is > 50 mm Hg.(4, 17-19).
- b. Normal values have not been systematically determined at altitude, but a decrease in values with increasing altitude would be expected approximately proportional to the decrease in PaO₂.
- c. PtcO₂ values in healthy subjects tend to increase from distal (the foot) to proximal (to the thigh) (5,20), although some variability has been found in other studies (17).

Definition of Hypoxia

- a.* Thirty-eight studies since 1982 suggest that hypoxia sufficient to impair or prevent wound healing is defined as PtcO₂ < 40 mm Hg (breathing normobaric air) (6,13,21-56).
- b. Although it has not been systematically evaluated, a PtcO₂ < 40 mm Hg is considered hypoxia at altitude, because the absolute value of wound oxygen appears more important than whether it results from hypoxemia, ischemia, or both (57).
- c. In patients with diabetes and renal failure, wounds can behave as though hypoxic up to a PtcO₂ of 50 mm Hg.(26, 56).
- d. PtcO₂ values obtained while breathing normobaric air can be used to predict which wounds will not heal spontaneously.

Prediction of Healing

- a. Because hypoxia predictably leads to wound healing impairment or *failure*, it is easier to determine a value below which a wound will *not* heal than to find a value above which a wound is reliably predicted *to* heal.
- b.* This is because wound healing can be impaired by many factors other than hypoxia, including venous hypertension, pressure, infection, steroids, other immunosuppressants, or inadequate nutrition (11,43,58-66).

Arterial Disease

- a. Patients with critical limb ischemia, (rest pain, gangrene, or an arterial ulcer) will almost always have a PtcO₂ < 30 mm Hg and usually less than 20 mm Hg.(41,47,49,50,67-73).
- b.* However, low air values can be caused by a diffusion barrier, such as edema, excess consumption caused by inflammation, or reversible vasoconstriction caused by cold exposure, dehydration, or pain. PtcO₂ values obtained while breathing normobaric air need to be evaluated in conjunction with the clinical history and conditions present at the time of testing (14,27,39,48,58,74,75).
- c. It is also possible that low air values are caused by microvascular disease, such as seen in patients with diabetes. Isolated low values in periwound tissue (with normal distal values) can be caused by local vasoconstriction or lack of angiogenesis, or some other process confined to the wound (76,77).

Normal Oxygen Challenge at Sea Level

- a.* In normal subjects breathing 100% oxygen at normobaric pressure, PtcO₂ values on the extremity always increase to a value > 100 mm Hg (13, 14, 17).

- b. This value has not been systematically determined at altitude, but is likely similar.
- c. Such an oxygen response indicates that significant macrovascular disease is unlikely.
- d. The normobaric oxygen challenge is the best way to determine whether low air values are due to a reversible diffusion barrier, such as edema or inflammation or to macrovascular arterial disease. $PtcO_2 < 30$ mm Hg on air and >100 mm Hg on 100% oxygen suggests adequate arterial inflow but a local barrier to oxygen diffusion (5).
- e. A $PtcO_2$ value obtained by breathing 100% normobaric oxygen that is < 30 mm Hg is consistent with severe arterial disease (13,14).
- f. If the wound is hypoxic while breathing normobaric air, and normobaric oxygen-breathing $PtcO_2$ increase to above 35mm Hg, there is a likelihood of benefiting from HBO₂T (58, 83).

Amputation Healing

- a.* A $PtcO_2$ value < 40 mm Hg obtained while breathing normobaric air is associated with a lower than normal likelihood of amputation healing (6,20, 21,24,26,27,29,31,42,55).
- b.* If the baseline $PtcO_2$ increases < 10 mm Hg while breathing 100% normobaric oxygen, this is at least 68% accurate in predicting failure of healing after an amputation in patients in whom no attempt is made nor is possible to increase wound oxygenation (e.g., revascularization or HBO₂T) (13, 27, 31, 58). (*The authors note that this would represent a poor oxygen response*).

Predicting Response to Revascularization

- a.* An increase in $PtcO_2$ to > 40 mm

Hg during normobaric air breathing after revascularization (by surgery or endovascular procedure) is a significant improvement, and is usually associated with subsequent wound healing although the increase may be delayed (28,49,50,51,53,78,79).

- b.* $PtcO_2$ values can continue to increase for as long as 28 days after revascularization (53,67,78).
- c. The literature suggests that postrevascularization $PtcO_2$ studies should not be performed until at least 3 days following the procedure, and preferably more than a week (80).

Predicting Lack of Response to Oxygen

- a. When changing from normobaric air to normobaric oxygen, if the increase in $PtcO_2$ is < 10 mm Hg, or if the $PtcO_2$ decreases, then benefit from HBO₂T is highly unlikely (at least 89% HBO₂T failure rate) (13).

Predicting Benefit from HBO₂T

- a.* A $PtcO_2$ value obtained while breathing normobaric air can assist in identifying which patients will not heal spontaneously (e.g. without HBO₂T or revascularization) (18,25,34,37,45,49, 52, 56, 81, 82). $PtcO_2$ values alone obtained while breathing normobaric air cannot be used to predict benefit of subsequent HBO₂T (11,13,58).
- b.* This is because patients with very low values obtained while breathing normobaric air, even as low as 5 mm Hg, have subsequently healed with HBO₂T, and because HBO₂T has been shown to progressively correct hypoxia in ischemic tissue (48, 58,84-88).
- c. If the wound is hypoxic while breathing normobaric air, and $PtcO_2$ values obtained while breathing 100%

normobaric oxygen increase to above 35 mm Hg, with a significant rise of >50% above the normobaric air value, there is a likelihood of benefiting from HBO₂T (58, 83).

- d.* Several published cases since 1977, using both PtcO₂ and invasive oxygen tension measurements in a variety of wound types (e.g. radiation and diabetes), have shown that baseline air oximetry values increase in response to HBO₂T (48,84-88). In the RCT conducted by Faglia et al, it was demonstrated that ischemic diabetic foot ulcer patients completing HBO₂T had a statistically significant increase in baseline air PtcO₂ values compared to non-HBO₂T controls (89). To date, however, an increase in PtcO₂ while breathing normobaric air during a course of hyperbaric oxygen treatments has not been evaluated as a *predictor* of clinical HBO₂T success.
- e. In *diabetic foot ulcers*, in-chamber PtcO₂ values are the best way to predict benefit from HBO₂T (i.e., percentage of patients who are likely to heal) (58).
- i. If the wound is hypoxic while breathing normobaric air, and a PtcO₂ > 200 mm Hg is achieved breathing hyperbaric oxygen, this is a predictor for success of subsequent HBO₂T for diabetic foot ulcers. This test is 75% accurate (58).
 - ii. Conversely, in-chamber PtcO₂ values < 100 mm Hg are closely associated with failure of HBO₂T in diabetic foot ulcers (accuracy 89%) (12,58).
 - iii. The authors note that although several studies have suggested that an ulcer with a PtcO₂ of less than 200 mm Hg obtained while breathing hyperbaric

oxygen is unlikely to heal, due to the variety of treatment modalities used in these studies, a definitive statement regarding healing prediction cannot be made based on in-chamber PtcO₂ alone (11,58).

- f. A single study by Mathieu and colleagues (1993) suggested that in pedicle musculocutaneous flap transplantation, an in-chamber PtcO₂ > 50 mm Hg was predictive of a successful outcome (90).

BEST PRACTICE SUGGESTIONS

A number of suggestions were also made regarding the use of PtcO₂ that were not based on published literature but which the authors felt might represent an approach to "best practice:"

1. A thorough assessment of the patient must be done prior to acceptance for HBO₂T (91), and the decision to treat should not be based on PtcO₂ alone.
2. With regard to HBO₂T outcome prediction, we agree that even in patients with in-chamber values < 100 mm Hg (and thus a low likelihood of HBO₂T benefit), the accuracy of this test is still only 76% (11, 58). Thus, a trial of HBO₂T continues to be a reasonable approach, if there are no other options for the patient, on a case-by-case basis. A reasonable trial of HBO₂T is regarded as 15-20 treatments.
3. There are some data to suggest that leg elevation might be a better indicator of vascular disease than failure to respond to sea level oxygen. However, since measuring the PtcO₂ while breathing

normobaric oxygen is useful for other things, such as predicting amputation healing and confirming that arterial disease is *not* present, and there is nothing to suggest that adding limb elevation adds to/enhances PtcO₂ data, one might argue that the normobaric oxygen challenge test is a more versatile test (5).

4. Mean PtcO₂ values are better predictors of healing potential than single site values (i.e., the average of PtcO₂ values from 2 or more adjacent sites of an area being studied) (83).
5. PtcO₂ measurements should be made with the patient at rest, in a supine or recumbent position, in a comfortably warm room, with the extremity covered by a sheet or blanket (19, 92-94). Measurements conducted with legs at an angle to the body are likely to result in values that cannot be compared to supine position.
6. When breathing normobaric oxygen, this portion of the test should last at least 10 minutes (92-94).
7. The standard temperature setting for the thermistor is 45°C. However, this temperature can result in skin blistering, particularly in ischemic patients. Due to issues of safety and comfort, some facilities use 44°C. However, even this one degree reduction in the thermistor temperature can result in PtcO₂ values that are 2%-3% lower than those taken at 45°C. This difference translates to about a 1 mm Hg difference at 40 mm Hg tissue PO₂ and about 6 mm Hg at 200 mm Hg tissue PO₂.
8. The regional perfusion index is the ratio of the PtcO₂ of the extremity divided by that of the chest and has been used in the past to help determine whether a low PtcO₂ value is a local or central problem, i.e. whether tissue hypoxia is due to arterial hypoxemia (5). However, the regional perfusion index appears to have little use in the hyperbaric evaluation process. Furthermore, a predictable percentage of patients have an abnormally low chest reference value, perhaps due to previous sternotomy or other conditions. An abnormally low chest reference will create a spuriously high RPI. Thus, the value of RPI in determining vascular disease is also questionable. Moreover, the absolute value of wound oxygen is probably more important in predicting healing potential.
9. It was emphasized that a “*best practice*” would be to check oxygen saturation at the time of PtcO₂ testing in all patients. Since the purpose of the chest reference is to ensure that the patient does not have arterial hypoxemia, oxygen saturation might be an easier and more accurate way to assess this, thus freeing a TCOM electrode for extremity measurements. Thus if SpO₂ is ≥ 92%, it can be assumed that arterial hypoxemia is not present, and periwound PtcO₂ values are applicable (94).
10. A low PtcO₂ normobaric air value followed by a response to breathing normobaric oxygen of > 100 mm Hg might indicate that the patient has minimal arterial disease and that any low air values are due to a diffusion barrier. Again, SpO₂ values may be helpful (see point 9). This pattern of response is reasonably predictive of healing (58).
11. A combination of technologies might be useful in diagnosing the cause of a low PtcO₂.
 - a. Skin perfusion pressure (SPP) can be used as an adjunct to

determine whether low PtcO₂ values are due to poor tissue perfusion, and the pulse volume recording can be used to assess large vessel status. SPP might also be useful in evaluating whether revascularization has led to increased arterial inflow. The increase in tissue oxygen might be delayed after successful revascularization, but it remains useful to know if inflow was increased acutely.

- b. Laser Doppler flowmetry (LDF) with heat provocation can be used to assess degrees of ischemia that might account for low PtcO₂ values (92).
- c. Pulse oximetry might be used to measure oxygen saturation of arterial hemoglobin and determine whether arterial hypoxemia is the cause of the low PtcO₂ values.

UNANSWERED QUESTIONS REQUIRING FURTHER RESEARCH

The conclusions and recommendations we have described here have been drawn from research that has significant limitations. Most of the studies were retrospective, nonrandomised, and had small numbers of patients. Even the RCTs investigating PtcO₂ in HBO₂T had small numbers and did not clearly link PtcO₂ with clinical outcomes. A larger, prospective multicenter trial is required to further clarify the role of PtcO₂ in assessment of problem wounds treated with HBO₂T. In this larger study, PtcO₂ values (normobaric air, 100% normobaric oxygen, and in-chamber oxygen) measured before and after HBO₂T, need to be carefully correlated with clinically significant outcomes. A number of basic validation studies are also

required; for example:

1. Studies to correlate invasive wound oxygen levels with PtcO₂ values.
2. Studies to link the measurements of PtcO₂ while breathing normobaric air, 100% normobaric oxygen and in-chamber oxygen, in health and disease, to determine the degree of correlation between values.
3. Studies that attempt to validate the use of breathing 100% normobaric oxygen to predict HBO₂T response.
4. Studies to determine whether an increase in PtcO₂ values while breathing normobaric air following a short therapeutic series of HBO₂T can be used as a predictor of benefit from HBO₂T, and thus used to ascertain when treatment might be discontinued.
5. Studies to determine whether averaging lower extremity values is a more accurate method of data analysis than lowest leg values in outcome prediction or vascular disease prediction.
6. Studies to determine the value of PtcO₂ measurements in predicting outcomes and response to HBO₂T in patients with and *without* diabetes who have hypoxic wounds.

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