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# 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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*[1]Department of Medicine, Division of Cardiology, University of Texas Health Science Center, Houston, TX 77030, [2]Department of Hyperbaric and Diving Medicine, Royal Hobart Hospital, Hobart, Tasmania, Australia, [3]International ATMO, Inc., San Antonio, TX 78205, [4]Department of Anesthesiology, University of Utah, East Salt Lake City, UT 84132, [5]Department of Hyperbaric and Diving Medicine, Prince of Wales Hospital, Randwick, NSW, Australia, [6]National Baromedical Services, Columbia, SC 29203*

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 ($PtcO_2$) 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 $PtcO_2$ 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 $PtcO_2$ < 40 mm Hg; (b) in patients without vascular disease, $PtcO_2$ 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 $PtcO_2$ < 30 mm Hg; (d) low $PtcO_2$ values obtained while breathing normobaric air can be caused by a diffusion barrier; (e) a $PtcO_2$ < 40 mm Hg obtained while breathing normobaric air is associated with a reduced likelihood of amputation healing; (f) 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 post-amputation; (g) an increase in $PtcO_2$ to > 40 mm Hg during normobaric air breathing after revascularization is usually associated with subsequent healing, although the increase in $PtcO_2$ may be delayed; (h) $PtcO_2$ obtained while breathing normobaric air can assist in identifying which patients will not heal spontaneously.

## INTRODUCTION

The technique of transcutaneous oximetry ($PtcO_2$) 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 $PtcO_2$ 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 $PtcO_2$ values and wound partial oxygen pressures, until comparison experiments are performed

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and the problem of accurately measuring partial oxygen pressures within the wound solved, any such correlation must be regarded as tentative. $PtcO_2$ 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 $PtcO_2$." 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, $PtcO_2$ has been increasingly used as a screening tool to predict benefit from subsequent hyperbaric oxygen therapy ($HBO_2T$) (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 $PtcO_2$ values because the data are variable and there is a considerable range in response depending on the comorbidities among the subjects whose $PtcO_2$ 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 $PtcO_2$ 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

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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 $PtcO_2$ 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 $PaO_2$.

c. $PtcO_2$ 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 $PtcO_2$ < 40 mm Hg (breathing normobaric air) (6,13,21-56).

b. Although it has not been systematically evaluated, a $PtcO_2$ < 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 $PtcO_2$ of 50 mm Hg.(26, 56).

d. $PtcO_2$ 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 $PtcO_2$ < 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. $PtcO_2$ 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,* $PtcO_2$ values on the extremity always increase to a value > 100 mm Hg (13, 14, 17).

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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 oxgen-breathing $PtcO_2$ increase to above 35mm Hg, there is a likelihood of benefiting from $HBO_2T$ (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 $HBO_2T$) (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 $HBO_2T$ is highly unlikely (at least 89% $HBO_2T$ failure rate) (13).

*Predicting Benefit from $HBO_2T$*

a.* A $PtcO_2$ value obtained while breathing normobaric air can assist in identifying which patients will not heal spontaneously (e.g. without $HBO_2T$ 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 $HBO_2T$ (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 $HBO_2T$, and because $HBO_2T$ 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%

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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 $HBO_2T$ (58, 83).

d.* Several published cases since 1977, using both $PtcO_2$ 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 $HBO_2T$ (48,84-88). In the RCT conducted by Faglia et al, it was demonstrated that ischemic diabetic foot ulcer patients completing $HBO_2T$ had a statistically significant increase in baseline air $PtcO_2$ values compared to non-$HBO_2T$ controls (89). To date, however, an increase in $PtcO_2$ while breathing normobaric air during a course of hyperbaric oxygen treatments has not been evaluated as a *predictor* of clinical $HBO_2T$ success.

e. In *diabetic foot ulcers*, in-chamber $PtcO_2$ values are the best way to predict benefit from $HBO_2T$ (i.e., percentage of patients who are likely to heal) (58).
   i. If the wound is hypoxic while breathing normobaric air, and a $PtcO_2$ > 200 mm Hg is achieved breathing hyperbaric oxygen, this is a predictor for success of subsequent $HBO_2T$ for diabetic foot ulcers. This test is 75% accurate (58).
   ii. Conversely, in-chamber $PtcO_2$ values < 100 mm Hg are closely associated with failure of $HBO_2T$ in diabetic foot ulcers (accuracy 89%) (12,58).
   iii. The authors note that although several studies have suggested that an ulcer with a $PtcO_2$ 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 $PtcO_2$ *alone* (11,58).

f. A single study by Mathieu and colleagues (1993) suggested that in pedicle musculocutaneous flap transplantation, an in-chamber $PtcO_2$ > 50 mm Hg was predictive of a successful outcome (90).

## BEST PRACTICE SUGGESTIONS

A number of suggestions were also made regarding the use of $PtcO_2$ 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 $HBO_2T$ (91), and the decision to treat should not be based on $PtcO_2$ alone.
2. With regard to $HBO_2T$ outcome prediction, we agree that even in patients with in-chamber values < 100 mm Hg (and thus a low likelihood of $HBO_2T$ benefit), the accuracy of this test is still only 76% (11, 58). Thus, a trial of $HBO_2T$ 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 $HBO_2T$ 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 $PtcO_2$ while breathing

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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 $PtcO_2$ data, one might argue that the normobaric oxygen challenge test is a more versatile test (5).

4. Mean $PtcO_2$ values are better predictors of healing potential than single site values (i.e., the average of $PtcO_2$ values from 2 or more adjacent sites of an area being studied) (83).
5. $PtcO_2$ 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 results 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 45ºC. However, this temperature can result in skin blistering, particularly in ischemic patients. Due to issues of safety and comfort, some facilities use 44ºC. However, even this one degree reduction in the thermistor temperature can result in $PtcO_2$ values that are 2%-3% lower than those taken at 45ºC. This difference translates to about a 1 mm Hg difference at 40 mm Hg tissue $PO_2$ and about 6 mm Hg at 200 mm Hg tissue $PO_2$.
8. The regional perfusion index is the ratio of the $PtcO_2$ of the extremity divided by that of the chest and has been used in the past to help determine whether a low $PtcO_2$ 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 $PtcO_2$ 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 $SpO_2$ is $\geq$ 92%, it can be assumed that arterial hypoxemia is not present, and periwound $PtcO_2$ values are applicable (94).
10. A low $PtcO_2$ 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, $SpO_2$ 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 $PtcO_2$.
    a. Skin perfusion pressure (SPP) can be used as an adjunct to

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determine whether low $PtcO_2$ 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 $PtcO_2$ 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 $PtcO_2$ 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 $PtcO_2$ in $HBO_2T$ had small numbers and did not clearly link $PtcO_2$ with clinical outcomes. A larger, prospective multicenter trial is required to further clarify the role of $PtcO_2$ in assessment of problem wounds treated with $HBO_2T$. In this larger study, $PtcO_2$ values (normobaric air, 100% normobaric oxygen, and in-chamber oxygen) measured before and after $HBO_2T$, 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 $PtcO_2$ values.
2. Studies to link the measurements of $PtcO_2$ 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 $HBO_2T$ response.
4. Studies to determine whether an increase in $PtcO_2$ values while breathing normobaric air following a short therapeutic series of $HBO_2T$ can be used as a predictor of benefit from $HBO_2T$, 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 $PtcO_2$ measurements in predicting outcomes and response to $HBO_2T$ in patients with and *without* diabetes who have hypoxic wounds.

## REFERENCES

1. Clark LC Jr, Wolf R, Granger D, Taylor Z. Continuous recording of blood oxygen tensions by polarography. *J Appl Physiol* 1953; 6:189-193.
2. Silver IA. Some observations on the cerebral cortex with an ultra micro membrane covered oxygen electrode. *Med Electr Biol Eng* 1965; 3:377-387.
3. Hunt TK. A new method of determining tissue oxygen tension. *Lancet* 1964; 2:1370-1371.
4. Hauser CJ, Shoemaker WC. Use of transcutaneous $PO_2$ regional perfusion index to quantify tissue perfusion in peripheral vascular disease. *Ann Surg* 1983; 197:337-43.
5. Hauser CJ, Appel P, Shoemaker WC. Pathophysiologic classification of peripheral vascular disease by positional changes in regional transcutaneous oxygen tension. *Surgery* 1984;

http://archive.rubicon-foundation.org



95:689-693.

6. White RA, Nolan L, Harley D, et al. Non-invasive evaluation of peripheral vascular disease using transcutaneous oxygen tension. *Am J Surg* 1982;144:68-75.
7. Lübbers DW. History of transcutaneous $PO_2$ measurement. *Crit Care Med* 1981;9:693.
8. Smart DR, Bennett MH, Mitchell SJ. Transcutaneous oximetry, problem wounds and hyperbaric oxygen. *Diving Hyperb Med* 2006; 36:72-86.
9. Niinikoski JH. Clinical hyperbaric oxygen therapy, wound perfusion, and transcutaneous oximetry. *World J Surg* 2004;28:307-11.
10. Rich K. Transcutaneous oxygen measurements: implications for nursing. *J Vasc Nurs* 2001;19:55-59.
11. Fife CE, Buyukcakir C, Otto GH, Sheffield PJ, Love TL, Warriner RA 3rd. Factors influencing the outcome of lower-extremity diabetic ulcers treated with hyperbaric oxygen therapy. *Wound Repair Regen* 2007; 15:322-331.
12. Strauss MB, Bryant BJ, Hart GB. Transcutaneous oxygen measurements under hyperbaric oxygen conditions as a predictor for healing of problem wounds. *Foot Ankle Int* 2002; 23:933-937.
13. Grolman RE, Wilkerson DK, Taylor J, Allinson P, Zatina MA. Transcutaneous oxygen measurements predict a beneficial response to hyperbaric oxygen therapy in patients with non-healing wounds and critical limb ischaemia. *Am Surg* 2001; 67:1072-1080.
14. Sheffield PJ. Measuring tissue oxygen tension: a review. *Undersea Hyperb Med* 1998; 25:179-188.
15. Fowles J, ed. Handbook of Future Research. Westport, CT: Greenwood Press, 1978.
16. Adler M, Ziglio E, eds. Gazing into the Oracle: The Delphi Method and its Application to Social Policy and Public Health. London: Jessica Kingsley Publishers, 1996.
17. Dooley J, King G, Slade B. Establishment of reference pressure of transcutaneous oxygen for the comparative evaluation of problem wounds. *Undersea Hyperb Med* 1997; 24: 235-244.
18. Dowd GSE, Linge K, Bentley G. Measurement of transcutaneous oxygen pressure in normal and ischaemic skin. *J Bone Joint Surg* 1983; 65B:79-83.
19. Wipke-Tevis DD, Stotts NA, Williams DA, Froelicher ES, Hunt TK. Tissue oxygenation, perfusion, and position in patients with venous leg ulcers. *Nurs Res* 2001;50:24-32.
20. Pola P, Tondi P, Dal Lago A, Santoliquido A, Gerardino L, Massari I. Transcutaneous oximetry is useful in vascular pathology if a cutaneous reference map and a maximal exercise test are used. *Vasc Endovas Surg* 1996; 30:117-122.
21. Burgess EM, Matsen FA, Wyss CR, Simmons CW. Segmental transcutaneous measurements of PO2 in patients requiring below the knee amputation for peripheral vascular insufficiency. *J Bone Joint Surg* 1982; 64A:378-382.
22. Dowd GS, Linge K, Bentley G. The effect of age and sex of normal volunteers upon the transcutaneous oxygen tension in the lower limb. *Clin Phys Physiol Meas* 1983; 4:65-68.
23. Hauser CJ, Klein SR, Mehringer M, Appel P, Shoemaker WC. Assessment of perfusion in the diabetic foot by regional transcutaneous oximetry. *Diabetes* 1984; 33:527-531.
24. Katsamouris A, Brewster DC, Megerman J, Cina C, Darling RC, Abbott WM. Transcutaneous oxygen tension in selection of amputation level. *Am J Surg* 1984; 147:510-517.
25. Cina C, Katsamouris A, Megerman J, et al. Utility of transcutaneous oxygen tension measurements in peripheral arterial occlusive disease. *J Vasc Surg* 1984; 1:362-371.
26. Wyss CR, Matsen FA, Simmons CW, Burgess EM. Transcutaneous oxygen measurements on limbs of diabetic and non-diabetic patients with peripheral vascular disease. *Surgery* 1984; 95: 339-345.
27. Harward TRS, Volny J, Golbranson F, Bernstein EF, Fronek A. Oxygen inhalation-induced transcutaneous $PO_2$ changes as a predictor of amputation level. *J Vasc Surg* 1985; 2:220-227.
28. Rhodes GR, Skudder P (Jr). Salvage of ischaemic diabetic feet. Role of transcutaneous oxygen mapping and multiple configurations of in situ bypass. *Am J Surg* 1986; 152:165-171.
29. Dowd GS. Predicting stump healing following amputation for peripheral vascular disease using the transcutaneous oxygen monitor. *Ann R Coll Surg Engl* 1987; 69:31-35.
30. Johnson WC, Grant HI, Baldwin J, Hamilton JV, Dion JM. Supplemental oxygen and dependent positioning as adjunctive measures to improve forefoot tissue oxygenation. *Arch Surg* 1988; 123:1227-1230.
31. Bongard O, Krähenbuhl B. Predicting amputation in severe ischaemia. *J Bone Joint Surg* 1988; 70B:465-467.
32. Lalka SG, Malone JM, Anderson GG, Hagaman RM, McIntyre KE, Bernhard VM. Transcutaneous oxygen and carbon dioxide pressure monitoring to determine limb ischaemia and to predict surgical outcome. *J Vasc Surg* 1988; 7:507-514.
33. Kram HB, Appel PL, Shoemaker WC. Comparison of transcutaneous oximetry, vascular hemodynamic measurements, angiography, and clinical findings to predict the success of peripheral vascular reconstruction. *Am J Surg* 1988; 155: 551-558.
34. Wyss CR, Harrington RM, Burgess EM, Matsen FA. Transcutaneous oxygen tension as a predictor of success after an amputation. *J Bone Joint Surg* 1988; 70A:203-207.
35. Ameli FM, Stein M, Provan JL, Aro L, St Louis EL. Comparison between transcutaneous oximetry and ankle-brachial pressure ratio in predicting runoff

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and outcome in patients who undergo aortobifemoral bypass. *Can J Surg* 1989; 32:428-432.
36. Ameli FM, Stein M, Provan JL, Aro L, Prosser R. Predictors of surgical outcome in patients undergoing aortobifemoral bypass reconstruction. *J CardiovascSurg* (Torino) 1990; 31:333-339.
37. Pecoraro RE Ahroni JH, Boyko EJ, Stensel VL. Chronology and determinants of tissue repair in diabetic lower extremity ulcers. *Diabete*s. 1991; 40:1305-1313.
38. Lantsberg L, Goldman M. Laser Doppler flowmetry, transcutaneous oxygen tension measurements and Doppler pressure compared in patients undergoing amputation. *Eur J Vasc Surg* 1991; 5:195-197.
39. Wattel FE, Mathieu MD, Fossati P, Neviere RR, Coget JM. Hyperbaric oxygen in the treatment of diabetic foot lesions. Search for healing predictive factors. *J Hyperb Med* 1991; 6:263-268.
40. Stein M, Ameli MF, Gray R, Elliott D, Grosman H, Aro L. Angiographic assessment of arterial outflow: predictive value of a new classification system. *J Vasc Interv Radiol* 1991; 2:365-370.
41. Scheffler A, Rieger H. A comparative analysis of transcutaneous oximetry ($tcPO_2$) during oxygen inhalation and leg dependency in severe peripheral arterial occlusive disease. *J Vasc Surg* 1992; 16:218-224.
42. Chambon JP, Desmyttere J, Grard C, Alsberghe MC, Devulder B, Quandalle P. Study of static transcutaneous oximetry before amputation in patients with arteritis. *J Chir* (Paris) 1992; 129:352-256.
43. Reiber GE, Pecoraro RE, Koepsell TD. Risk factors for amputation in patients with diabetes mellitus. A case control study. *Ann Intern Med* 1992; 117:97-105.
44. Ubbink DT, Jacobs MJHM, Tangelder GJ, Slaaf DW, Reneman RS. The usefulness of capillary microscopy, transcutaneous oximetry and laser Doppler fluximetry in the assessment of the severity of lower limb ischaemia. *Int J Microcirc* 1994; 14:34-44.
45. Yablon SA, Novick ES, Jain SS, Graves DE. Postoperative transcutaneous oxygen measurement in the prediction of delayed wound healing and prosthetic fitting among amputees during rehabilitation. A pilot study. *Am J Phys Med Rehabil* 1995; 74:193-198.
46. Ballard JL, Eke CC, Bunt TJ, Killeen JD. A prospective evaluation of transcutaneous oxygen measurements in the management of diabetic foot problems. *J Vasc Surg* 1995; 22:485-492.
47. Claeys LG, Horsch S. Transcutaneous oxygen pressure as predictive parameter for ulcer healing in endstage vascular patients treated with spinal cord stimulation. *Int Angiol* 1996; 15:344-349.
48. Dooley J, Schirmer J, Slade B, Folden B. Use of transcutaneous pressure of oxygen in the evaluation of edematous wounds. *Undersea Hyperb Med* 1996; 23:167-174.
49. Bunt TJ, Holloway GA. $TcPO_2$ as an accurate predictor of therapy in limb salvage. *Ann Vasc Surg* 1996; 10:224-227.
50. Ray SA, Buckenham TM, Belli AM, Taylor RS, Dormandy JA. The predictive value of laser Doppler fluximetry and transcutaneous oximetry for clinical outcome in patients undergoing revascularization for severe leg ischaemia. *Eur J Vasc Endovasc Surg* 1997;13:54-59.
51. Hanna GP, Fujise K, Kjellgren O, et al. Infrapopliteal transcatheter interventions for limb salvage in diabetic patients: importance of aggressive interventional approach and role of transcutaneous oximetry. *J Am Coll Cardiol* 1997; 30:664-669.
52. Kalani M, Brismar K, Fagrell B, Jorneskog G. Transcutaneous oxygen tension and toe blood pressure as predictors for outcome of diabetic foot ulcer. *Diabetes Care* 1999; 22:147-151.
53. Caselli A, Latini V, Lapenna A, et al. Transcutaneous oxygen tension monitoring after successful revascularization in diabetic patients with ischaemic foot ulcers. *Diabetic Med* 2005; 22:460-465.
54. Poredos P, Rakovec S, Guzic-Salobir B. Determination of amputation level in ischaemic limbs using $tcPO_2$ measurement. *Vasa* 2005; 34:108-112.
55. Zgonis T, Garbalosa JC, Burns P, Vidt L, Lowery C. A retrospective study of patients with diabetes mellitus after partial foot amputation and hyperbaric oxygen treatment. *J Foot Ankle Surg.* 2005; 44:276-280.
56. Padberg FT, Back TL, Thompson PN, Hobson RW 2nd. Transcutaneous oxygen ($TcPO_2$) estimates probability of healing in the ischaemic extremity. *J Surg Res* 1996; 60:365-369.
57. Chang N, Mathes SJ. Comparison of the effect of bacterial inoculation in musculocutaneous and random-pattern flaps. *Plast Reconstr Surg* 1982;70:1-10.
58. Fife CE, Buyukecakir C, Otto G, et al. The predictive value of transcutaneous oxygen tension measurement in diabetic lower extremity ulcers treated with hyperbaric oxygen therapy: a retrospective analysis of 1144 patients. *Wound Rep Regen* 2002; 10:198-207.
59. Ryan TJ. Infection following soft tissue injury: its role in wound healing. *Curr Opin Infect Dis.* 2007; 20:124-128.
60. Trent JT, Falabella A, Eaglstein WH, Kirsner RS. Venous ulcers: pathophysiology and treatment options. *Ostomy Wound Manage* 2005; 51:38-54.
61. Anstead GM. Steroids, retinoids, and wound healing. *Adv Wound Care* 1998; 11:277-285.
62. Fleischli JW, Adams WR. Use of postoperative steroids to reduce pain and inflammation. J Foot Ankle Surg 1999; 38:232-237.
63. Mandal A. Do malnutrition and nutritional supplementation have an effect on the wound healing process? *J Wound Care* 2006; 15:254-257.

http://archive.rubicon-foundation.org




64. Arnold M, Barbul A. Nutrition and wound healing. *Plast Reconstr Surg* 2006;117(7 Suppl):42S-58S.
65. Busti AJ, Hooper JS, Amaya CJ, Kazi S. Effects of perioperative antiinflammatory and immunomodulating therapy on surgical wound healing. *Pharmacotherapy* 2005; 25:1566-1591.
66. Colin D, Saumet JL. Influence of external pressure on transcutaneous oxygen tension and laser Doppler flowmetry on sacral skin. *Clin Physiol* 1996; 16:61-72.
67. Stalc M, Poredos P. The usefulness of transcutaneous oximetry in assessing the success of percutaneous transluminal angioplasty. *Eur J Vasc Endovasc Surg*. 2002; 24:528-532.
68. Wroblewski T, Hryszczykowa L. The use of segmental pressure index and transcutaneous oxygen tension in the diagnosis of peripheral arterial occlusive disease in geriatric patients. *Mater Med Pol* 1991; 23:40-42.
69. Ubbink DT, Gersbach PA, Berg P, Amann W, Gamain J. The best $TcpO_2$ parameters to predict the efficacy of spinal cord stimulation to improve limb salvage in patients with inoperable critical leg ischemia. *Int Angiol* 2003; 22:356-363.
70. Petrakis E, Sciacca V. Prospective study of transcutaneous oxygen tension ($TcPO_2$) measurement in the testing period of spinal cord stimulation in diabetic patients with critical lower limb ischaemia. *Int Angiol* 2000; 19:18-25.
71. Schmidt C, Adechokan S, Mouhli J. Laser-Doppler flowmetry and arterial diseases of the limbs. Correlations with measurement of transcutaneous oxygen pressure. *J Mal Vasc* 1996; 21:294-298. French.
72. Novo S, Coppola G, Milio G. Critical limb ischemia: definition and natural history. *Curr Drug Targets Cardiovasc Haematol Disord* 2004; 4:219-225.
73. Norgren L, Hiatt WR, Dormandy JA, et al. Inter-Society Consensus for the Management of Peripheral Arterial Disease (TASC II). *Eur J Vasc Endovasc Surg* 2007; 33(Suppl 1):S1-75.
74. Franzeck UK, Haselbach P, Speiser D, Bollinger A. Microangiopathy of cutaneous blood and lymphatic capillaries in chronic venous insufficiency (CVI). *Yale J Biol Med* 1993; 66:37-46.
75. Kolari PJ, Pekanmaki K, Pohjola RT. Transcutaneous oxygen tension in patients with post-thrombotic leg ulcers: treatment with intermittent pneumatic compression. *Cardiovasc Res* 1988; 22:138-141.
76. Belcaro G, Christopoulos A, Nicolaides AN. Diabetic microangiopathy treated with elastic compression—a microcirculatory evaluation using laser-Doppler flowmetry, transcutaneous $PO_2/PCO_2$ and capillary permeability measurements. *Vasa* 1990; 19:247-251.
77. Zimny S, Dessel F, Ehren M, Pfohl M, Schatz H. Early detection of microcirculatory impairment in diabetic patients with foot at risk. *Diabetes Care* 2001; 24:1810-1814.
78. Wagner HJ, Schmitz R, Alfke H, Klose KJ. Influence of percutaneous transluminal angioplasty on transcutaneous oxygen pressure in patients with peripheral arterial obstructive disease. *Radiology* 2003; 22:791-797.
79. McMahon JH, Grigg MJ. Predicting healing of lower limb ulcers. *Aust N Z J Surg* 1995; 65:173-176.
80. Arroyo CI, Tritto VG, Buchbinder D, et al. Optimal waiting period for foot salvage surgery following limb revascularization. *Foot Ankle Surg* 2002; 41:228-232.
81. Oishi CS, Fronek A, Golbranson FL. The role of non-invasive vascular studies in determining levels of amputation. *J Bone Joint Surg* 1988; 70A:1520-1530.
82. Pinzur MS, Sage R, Stuck R, Ketner L, Osterman H. Transcutaneous oxygen as a predictor of healing in amputations of the foot and the ankle. *Foot Ankle Int* 1992; 13:271-272.
83. Sheffield PJ, Dietz D, Posey KI, Ziemba TA, Bakken B. Use of transcutaneous oxygen tension measurement and laser Doppler with local heat provocation to assess patients with problem wounds. In: Petri M, Andric D, Ropac D, eds. Proceedings 1st Congress of Alps-Adria Working Community on Maritime, Undersea, and Hyperb Med. Split, Croatia: Croatian Maritime, Undersea and Hyperb Med Soc of Croatian Med Assoc, 2001: 341-343.
84. Urayama H, Takemura H, Kasajima F, Tsuchida K, Katada S, Watanabe Y. Hyperbaric oxygenation therapy for chronic occlusive arterial diseases of the extremities. *Nippon Geka Gakkai Zasshi.* 1992 Apr;93(4):429-33. Japanese.
85. Sheffield PJ, Workman WT. Transcutaneous tissue oxygen monitoring in patients undergoing hyperbaric oxygen therapy. In: Huch R, Huch A, eds. Continuous transcutaneous blood gas monitoring. New York: Marcel Dekker, 1983:655-660.
86. Marx RE, Johnson RD, Kline SN. Prevention of osteoradionecrosis: a randomized prospective clinical trial of hyperbaric oxygen versus penicillin. *J Am Dent Assoc* 1985; 3:49-54.
87. Thorn JJ, Kallehave F, Westergaard P, Hansen EH, Gottrup F. The effect of hyperbaric oxygen on irradiated oral tissues: transmucosal oxygen tension measurements. *J Oral Maxillofac Surg* 1997; 55: 1103-1107.
88. Marx RE, Ehler WJ, Tayapongsak P, Pierce LW. Relationship of oxygen dose to angiogenesis induction in irradiated tissue. *Am J Surg.* 1990; 160:519-524.
89. Faglia E, Favales F, Aldeghi A, et al. Adjunctive systemic hyperbaric oxygen therapy in treatment of severe prevalently ischemic diabetic foot ulcer. *Diabetes Care* 1996; 19:1338-1343.
90. Mathieu D, Neviere R, Pellerin P, Patenotre P, Wattel F. Pedicle musculocutaneous flap transplantation: Prediction of final outcome by transcutaneous oxygen measurements in hyperbaric oxygen. *Plast*

http://archive.rubicon-foundation.org



*Reconstr Surg* 1993; 91:329-334.

91. Fife CE, Warriner RA III. Hyperbaric oxygen therapy applications in wound care. In: Sheffield PJ, Fife CE (eds). Wound Care Practice, 2nd Ed. Flagstaff, AZ: Best Publishing, 2007:947-980.
92. Dietz DA, Sheffield PJ. Non-invasive wound assessment tools. In: Sheffield PJ, Fife CE (eds). Wound Care Practice, 2nd Ed. Flagstaff, AZ: Best Publishing, 2007:129-174.
93. Sheffield PJ, Buckley. Transcutaneous oximetry. In: Sheffield PJ, Fife CE (eds). Wound Care Practice, 1st Ed. Flagstaff, AZ: Best Publishing, 2004:117-136.
94. Shah JB, Ram DM, Fredrick E, Otto GH, Sheffield PJ. Determination of ideal $PtcO_2$ measurement time in evaluation of hypoxic wound patients. *Undersea Hyperb Med* 2008; 35:41-51.