Clinical application of transcutaneous oxygen tens

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Assessment of tcpO_2 before and during hyperbaric oxygen treatment predicts the chance for a successful outcome.

Introduction

Transcutaneous oxygen measurement ($ptcO_2$, TCOM, tcpO_2) has become a popular non-invasive tool for wound assessment and selection of patients for hyperbaric oxygen (HBO) treatment (**Fig. 1**).

Transcutaneous pO_2 measurement was originally used in neonatology [1], and is now commonly used in pediatrics ICU [2], plastic surgery [3], vascular surgery [4], anesthesiology [5], orthopedics [6], and hyperbaric medicine [7].

In 1994, Matos and Nunez [8] reviewed a series of tissue oxygenation studies and concluded that tcpO_2 was clinically useful in determining healing potential, selecting amputation level, evaluating revascularization procedures, and assessing severity and progression of peripheral vascular disease.

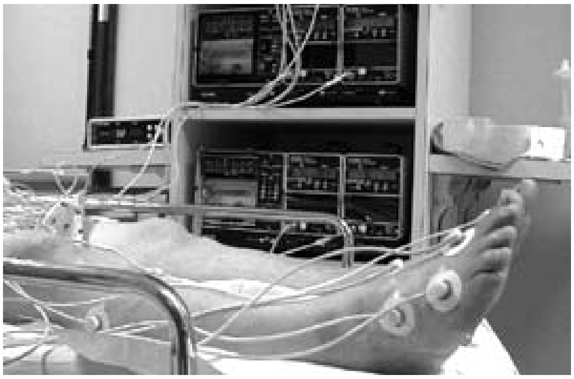

FIG. 1a

FIG. 1b

FIG 1a and 1b: Application of tc electrodes for assessment of a patient for hyperbaric oxygen treatment (photos by D. A. Davoli).

In order to aid oxygen migration to the skin surface where it can be analyzed, the non-invasive sensor must cause physiological changes in the underlying tissue.

Heating the sensor to 42-45 oC transfers heat to the skin surface that dilates capillaries, opens skin pores, decreases oxygen solubility, and shifts the oxyhemoglobin curve to the right for a more ready release of oxygen [9].

In the absence of heat, diffusion of oxygen from tissue to skin surface contributes less than 3.5 mmHg to the pO_2 at that location [10]. At present, transcutaneous sensors will not adhere to a moist surface, so tcpO_2 values are collected near the wound.

Assessment of the data's significance to the wound requires careful interpretation. A control sensor is placed on the skin at the second intercostal space of the chest.

Normal tissue oxygen tension

Table I contains "normal" tcpO_2 values of Dooley et al [11], obtained from 72 subjects (53 males, 19 females) at the chest, calf, and mid foot. It reveals a significant gender difference at the calf. Data obtained at 2 atm abs were reported by Hart *et al* [12].

tcpO_2 as a predictor of successful amputation site without HBO

A number of patient studies without HBO confirmed that normal healing of an amputation site requires a tcpO_2 value of at least 40 mmHg [13], or regional perfusion index (RPI = limb/chest tcpO_2) of about 0.6 [14].

White & Klein [13] reviewed 8 patient studies of transcutaneous pO_2 values for 260 amputees and concluded that a tcpO_2 value of 40 mmHg or greater was required for a successful outcome of amputation. Hauser [14] assessed 159 wounds (93 local débridements and 66 amputations) in 113 high-risk diabetic patients with peripheral vascular disease. tcpO_2 values were obtained at four sites on the limbs and compared to chest controls to obtain the regional perfusion index (RPI = wound tcpO_2/chest tcpO_2).

Hauser reported excellent outcome when RPI > 0.6, and poor outcome when RPI < 0.4 [14].

tcpO_2 as a predictor of wound healing with HBO

Monitors from several manufacturers have been used effectively for transcutaneous oxygen studies [15].

Tissue oxygen assessment with transcutaneous pO_2

Ambient pressure (atm abs)/ Breathing media	1.0 air	1.0 O_2	2.0 O_2	2.4 O_2
Representative tissue oxygen tension values (mmHg)				
Chest [11]	67±12	450±54	—	1312±112
Calf, Male [11]	49±14	281±78	—	1027±164
Calf, Female [11]	59±12	367±59	—	1174±127
Mid foot [11]	63±13	280±82	—	919±214
Limb [12]	49	325	696	—

TABLE I: tcpO_2 values in healthy subjects at progressively increased inspired pO_2.

Currently, the TINA, TCM3 and TCM30 (Radiometer Medical A/S, Copenhagen) are the only monitors with sensors that have been tested and shown to be compatible with pure-oxygen chambers [15].

Fire safety considerations require the monitor to remain outside a pure-oxygen chamber. There is controversy as to the predictive value of tcpO_2 taken at atmospheric pressure or under hyperbaric conditions.

tcpO_2 under atmospheric conditions

Pecoraro *et al* [16] found tcpO_2 values to be useful as predictors of healing in diabetic patients, and in selecting patients for adjunctive HBO to correct underlying tissue hypoxia, either alone or in combination with revascularization.

Brakora and Sheffield [17] concluded that diabetic patients whose periwound tcpO_2 values are above 40 mmHg (non-diabetic patients above 30 mmHg) should have sufficient tissue oxygenation to heal.

Conversely, diabetic patients whose periwound tcpO_2 values are below 40 mmHg (non-diabetic patients below 30 mmHg) were considered to have tissue hypoxia appropriate for HBO, provided there was a significant rise in tcpO_2 during oxygen challenge. Gorman [18] conducted a review of diabetic foot wounds and concluded that patients who have relative tcpO_2 values greater than 85 % (% of chest control) and ankle pressure greater than 90 mmHg will heal without oxygen.

Conversely, those with relative tcpO_2 values less than 20 % and ankle pressure less than 75 mmHg are unlikely to heal. Using Gorman's criteria, candidates for HBO would be those patients whose relative tcpO_2 values were in the range 20 to 85 % with an ankle pressure between 75-90 mmHg.

Sheffield and Workman [19] reported improved baseline tcpO_2 at the wound site taken at 7-day intervals while the patients received HBO therapy.

Marx *et al* [20] achieved an RPI of 0.8 in irradiated tissue from the head and neck within four weeks of starting HBO therapy, and established a protocol of 20 preoperative HBO treatments before reconstruction of the mandible.

Sheffield [21] retrospectively found that diabetic patients with forefoot wounds (n = 84) had an 8-fold increase in likelihood of successful outcome with HBO, when baseline transmetatarsal tcpO_2 values were greater than 30 mmHg as compared to tcpO_2 values less than 30 mmHg ($p < 0.05$).

tcpO_2 under hyperbaric conditions

In 1983, Sheffield and Workman [22, 23] used a Radiometer TCM1 monitor to record the first known tcpO_2 data under hyperbaric conditions (100 % O_2 at 2.4 atm abs, 238 kPa), reporting values above 1000 mmHg.

Recently a number of investigators have suggested that the best predictor of wound healing success might be tcpO_2 conducted under hyperbaric conditions, but their suggested absolute values varied widely.

Myers and Emhoff [24] reported that diabetic patients (n = 11) with below-the-knee tcpO_2 values less than 20 mmHg, would heal if 900 to 1,100 mmHg could be achieved on the initial HBO exposure. Wattel *et al* [25] concluded that tcpO_2 values above 450 mmHg during HBO were predictive of healing in diabetic patients with plantar ulcers.

Campagnoli *et al* [26] reported that diabetic patients (n = 24) healed if tcpO_2 values were above 400 mmHg during HBO, and observed that the faster the rise, the greater the likelihood of an efficient support microcirculation, which would improve the chance of a favorable outcome.

Strauss *et al* [27] measured tcpO_2 in 87 patients with problem foot wounds and reported that 98 % healed when tcpO_2 measured over 200 mmHg during HBO (100 % O_2 for 90 min at 2 atm abs, 202 kPa).

tcpO_2 assessment method

Several methods have been used to assess tcpO_2 to predict healing potential: **1)** a single tcpO_2 value taken adjacent to the wound; **2)** a map of multiple sites around the wound; **3)** a map of several sites on the affected limb; and **4)** a comparison of periwound or amputation-site values expressed as a percentage of chest control values.

The preferred method seems to be a map of at least three sites. But regardless of the assessment method, it is important to be consistent. There should be a standard approach to positioning the sensor that accounts for the normal circulation to the limb.

This will provide more consistent data and allow data among a group of patients to be compared. Our tcpO_2 assessment procedure and a typical tcpO_2 map of standardized sites on the legs are shown in **Table II** and **Fig. 2**, respectively.

Table III gives an example of the results obtained using this tcpO_2 assessment procedure.

Assessment	Time required (min)
Electrode equilibration (air)	15
Baseline tcpO_2 (air)	5
Elevate limb (air)	5
Baseline tcpO_2 (check for electrode drift)	5
100 % oxygen challenge	10
Baseline tcpO2 (check for electrode drift)	5
Total evaluation time	45

TABLE II: tcpO_2 assessment procedure for mapping the skin surface.

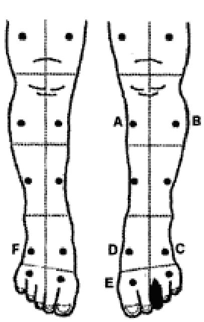

FIG 2: Typical tcpO_2 mapping of the legs with six electrodes plus chest control.

Interpretation of data

Some investigators [17, 25, 27] predict success by interpreting the actual tcpO_2 values. Others [14, 18, 20] calculate a regional perfusion index (RPI = limb tcpO_2/ chest tcpO_2). There is no consensus on the best method for collecting or interpreting the data.

However, it is clear that interpretation demands careful assessment of the tissue on which the sensor is placed. tcpO_2 values can be elevated if the sensor is positioned over an artery, or if there is a leak under the fixation ring.

On the other hand they, can be lowered if the sensor is positioned over bone, or if the patient uses tobacco products. tcpO_2 values in smokers were 10 % below that of non-smokers [22], and remained significantly reduced for about an hour after smoking [28].

But there is evidence of improved tissue oxygenation after a few days of smoking cessation [29]. tcpO_2 values may also be lowered by several pathological conditions: edema, active infection or inflammation, thick or sclerotic skin, occluded vessels, severed vessels (flap), or irradiated tissue.

The data interpreter must consider all these factors. The physician interpreter of the tcpO_2 data in **Fig. 2** considered the hypoxic tissue near the wound that responded to the oxygen challenge, and recommended HBO to prevent further necrosis and to help control infection [21].

Summary

Sufficient clinical experience is being published to justify transcutaneous pO_2 measurement, but the procedures require rigorous protocol and the interpreter must consider the limits of the technology.

Best results are obtained from a dedicated, qualified technician who measures at standardized sites on the limb. The data suggests that the best predictor of success with HBO-treated cases might be tcpO_2 data collected under hyperbaric conditions.

Region		Control	Electrode A	Electrode B	Electrode C	Electrode D	Electrode E	Electrode F
$tcpO_2$ (mmHg)								
Supine	20 min. Air	57	44	50	2	45	9	58
45 degree Elev.	5 min. Air	54	25	39	1	24	2	39
Supine	5 min. Air	50	40	41	2	43	7	49
Supine	10 min. O_2	290	79	88	4	178	40	67
Supine	5 min. Air	96	48	47	3	47	10	62

TABLE III: Example of the results obtained after assessment of $tcpO_2$ using the electrode mapping depicted in Fig. 2.

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