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Using of Transcutaneous Oximetry (tc*p*O2) as Indicated Test at Hyperbaric and Wound Care

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ABSTRACT : *Transcutaneous oxygen pressure (TcPO2) is a non-invasive method for assessing tissue oxygenation. TcPO2 has several advantages, including its simplicity, low cost, and the ability to continuously monitor tissue oxygenation. However, TcPO2 also has several limitations that may affect its accuracy, including the influence of skin perfusion, skin thickness, and the presence of edema or necrosis. In this review, we discuss the advantages and limitations of TcPO2 in the assessment of tissue oxygenation, and provide recommendations for the optimal use of TcPO2 in clinical practice.*

Hyperbaric oxygen (HBO) therapy may be a useful adjunct in the treatment of patients with wounds associated with critical limb ischemia. These patients either cannot undergo a successful bypass or may not heal after vascular reconstruction alone. Identification of patients likely to benefit from HBO is essential before treatment, as this therapy is time-consuming, costly, and not without risk. Transcutaneous oxygen measurements (TCOM) can be used to evaluate the degree of hypoxia in ischemic tissue.

KEYWORDS: *transcutaneous oxygen pressure, TcPO2, tissue oxygenation, non-invasive, tissue perfusion, transcutaneous oxygen monitor, clinical practice.*

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I. INTRODUCTION

Transcutaneous oxygen pressure (TcPO2) is a non-invasive method for assessing tissue oxygenation. It is typically measured using a transcutaneous oxygen monitor or transcutaneous oxygen tension (TcPO2) monitor, which measures the partial pressure of oxygen in the tissues just beneath the skin [1]. TcPO2 is a valuable tool in the assessment of tissue perfusion and oxygenation, and has been used in a variety of clinical settings, including critical care, wound care, and geriatric care. Despite its widespread use, TcPO2 has several limitations that may affect its accuracy, including the influence of skin perfusion, skin thickness, and the presence of edema or necrosis. The purpose of this review is to discuss the advantages and limitations of TcPO2 in the assessment of tissue oxygenation, and provide recommendations for the optimal use of TcPO2 in clinical practice [2,3].

John Abernathy made the first observation that human skin is permeable to gases in 1793 when he saw that it emits small amounts of carbon dioxide [4]. Heyrovsky established in 1925 that the produced current was proportional to the electrolyzed material tension in the surrounding liquid (i.e., O2 in TcPO2) when a suitable voltage was applied to a mercury electrode [4]. Numerous fields can benefit from polarography, and Jaroslav Heyrovsky's work earned him the 1959 Chemistry Nobel Prize. The values of the cutaneous oxygen tension have been shown by Baumberger and Goddfriend to mirror arterial partial pressures of oxygen (PaO2) [4].

By 1950, researchers were measuring the O2 tension of living tissues using platinum electrodes. Leland Clark, Jr. created a novel paleographic electrode in 1954 that produced a more homogeneous O2 layer by covering the platinum cathode with a semipermeable membrane [5]. Huch et al. first described the use of heated Clark electrodes as a workable technique to track skin surface (transcutaneous) pO2 in 1972. These tools were first used in clinical settings to track neonatal O2 levels before, during, and after delivery [6]. TcPO2 was discovered to closely approximate PaO2 levels, but when blood flow was impaired, TcPO2 solely reflected local O2 delivery [7].

On 38 lower limbs, Esato et al. found a significant difference between grade II and IV and a negative connection between the Fontaine categorization grade and the TcPO2 [8]. Additionally, there was a strong correlation between ankle systolic pressure and TcPO2 decline in LE-PAD patients [9]. The LE-PAD Fontaine categorization, the location of the vascular obstruction, and hemodynamic compensation by the patency of the calf arteries all affect TcPO2 readings. After observing a reduction in TcPO2 in these patients' lower extremities, Franzeck et al. proposed utilizing TcPO2 to determine the ideal amputation level in patients with LE-PAD in 1982 [10]. The objective of this study is to evaluate the advantages and limitations of transcutaneous oxygen pressure (TcPO2) in the assessment of tissue oxygenation, and to provide recommendations for the optimal use of TcPO2 in clinical practice.

II. THE TCPO2 TECHNIQUE

TcPO2 measurement is a metabolic test while ankle brachial index, plethysmography, and Doppler systolic pressure are hemodynamic indexes. Wyss et al. showed that when PaO2 is normal or near normal, a curvilinear relationship exists between TcPO2 values and local perfusion pressures. Therefore, when the perfusion pressure is high, a small decrease in perfusion pressure causes only a small decrease in TcPO2. Conversely, when the perfusion pressure is low, a small decrease in perfusion pressure causes a much greater decrease in TcPO2 which may even reach zerommHg despite blood flow evidenced using other techniques [11]. Furthermore, it was pointed out that a null TcPO2 value did not indicate that no oxygen is reaching the tissue but rather that the oxygen delivery equals or exceeds the metabolic consumption of the skin [12].

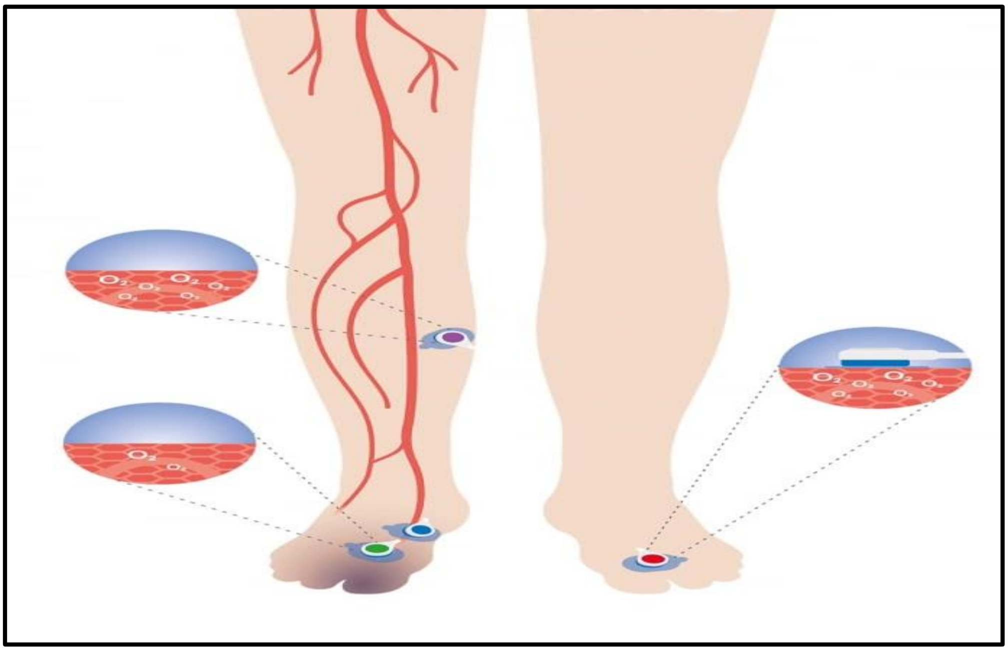


Fig.1. Less oxygen close to the wound

Figure 1 depicts the decrease in oxygen levels close to a wound. In this illustration, it is shown that the oxygen levels are lower near the wound compared to other areas on the body. This decrease in oxygen levels can occur due to a variety of factors, such as decreased blood flow to the area, infection, or inflammation. The lower oxygen levels can slow down the healing process and increase the risk of complications, such as tissue death (necrosis).

In medical practice, the use of transcutaneous oximetry ($TcPO_2$) can be helpful in detecting and monitoring the oxygen saturation levels close to a wound. The $TcPO_2$ sensor is placed near the wound and the resulting measurement is used to assess the oxygenation status in the area. By continuously monitoring the $TcPO_2$ values, healthcare providers can adjust the patient's treatment as needed to improve the oxygenation and promote healing. Figure 2 depicts the PeriFlux 6000 $tcpO_2$ system, which is a device used for transcutaneous oximetry ($tcpO_2$). The PeriFlux 6000 $tcpO_2$ system is a non-invasive method for measuring the oxygen saturation in the blood. The sensor emits light to measure the oxygen saturation in the blood vessels underneath the skin and the monitor displays the resulting measurement in real-time.

Fig. 2. PeriFlux 6000 tcpO2 System

The PeriFlux 6000 $tcpO_2$ system is commonly used in both inpatient and outpatient settings, particularly in patients with respiratory or cardiovascular conditions. The system is quick and painless to use and provides healthcare providers with accurate and real-time information about the patient's oxygenation status. Figure 3 depicts the PeriFlux 6000 Combined System, which is a device used for measuring microvascular blood flow and transcutaneous oxygen saturation ($tcpO_2$). The PeriFlux 6000 Combined System is a non-invasive method for assessing the microvascular function and oxygenation status in the blood.

The PeriFlux 6000 Combined System uses laser Doppler flowmetry and transcutaneous oxygen measurement to assess microvascular blood flow and $tcpO_2$, respectively. The measurement results are displayed on the monitor in real-time and can be used by healthcare providers to make informed decisions about the patient's treatment and to adjust it as needed. The use of the PeriFlux 6000 Combined System provides healthcare providers with accurate and real-time information to ensure the best possible outcomes for the patient. The sensor is applied to the skin by a flat, double-sided adhesive ring. The oxygen diffuses according to its pressure gradient from the capillary loops through the avascular epidermis towards the skin surface electrode. In clinical practice, there is no consensus regarding the exact position of the electrode which is determined for each case by the operator considering the ischemic status of the lower limbs and local habits. Consistent and reproducible values are obtained when the required local arterialization is achieved by heating the oxygen electrode itself [15]. An electrode heated to 45 °C transmits a temperature of about 43 °C on the skin, and this temperature is well tolerated for several hours [15]. Heating allows the elimination of variations in local circulation induced by patient anxiety, pain, and $PaCO_2$, which largely control vascular tone

A normal $TcPO_2$ is considered around 60 mmHg whatever the electrode location [16]. Interestingly, $TcPO_2$ can be used whatever the etiology of extremities' arterial insufficiency. Indeed, no significant difference was found in the $TcPO_2$ indices between arteriosclerosis and thromboangiitis obliterans, nor among different sites of peripheral vascular occlusion [8].

Fig. 3. PeriFlux 6000 Combined System

Also, the performances of $TcPO_2$ measurement were found to be similar in diabetic and non-diabetic patients [17]. Similarly, body mass index variation did not affect $TcPO_2$ measurements [18].

Overall, the $TcPO_2$ values are affected by numerous factors including temperature in the tissues, the degree of oxygen metabolism in tissues, the circulatory status, the peripheral blood perfusion, and the local skin and anatomical conditions [19]. Measurement at the preferred amputation level is preferred but not always possible when the epidermis is thin (because of edema and inflammation). Bony prominences, such as superficial vein and tendon, should be avoided as they restrict the capillary blood flow. Furthermore, it is widely accepted that measurements in a sitting position with the lower extremity in a vertical position can lead to false positive results. Conversely, smoking and coffee consumption, pain, and anxiety may lead to vasoconstriction and under-estimate $TcPO_2$ value as shown in Table 1.

Table 1 lists the conditions that can affect the reliability of transcutaneous oximetry (tcpO2). TcpO2 is a widely used non-invasive method for measuring the oxygen saturation in the blood, but certain conditions can interfere with the accuracy of the measurement. Some of these conditions include:

Table 1: Condition affecting Transcutaneous Oximetry (tcpO2) reliability.

	Under Estimation	**Over Estimation**
Skin quality	Cutaneous sclerosis	Inflammation
	Edema	
Room temperature	$<22C^{O}$	$>24C^{O}$
	Air flow (door open)	
Electrode location	Bone prominence	
	Superficial tendon	
	Superficial vein	
Patient related	Patient talking	Setting (over decubitus)
	Pain	
	Anxiety smoking or coffee < 2 h	

It is important to note that these conditions can affect the accuracy of tcpO2 measurements, but they do not necessarily mean that the tcpO2 is not a useful tool. By recognizing these potential sources of error, healthcare providers can adjust their interpretation of the tcpO2 readings and use them in conjunction with other diagnostic tools to make informed decisions about the patient's treatment. Finally, evaluators should keep in mind the reproducibility. The reliability of TcPO2 measurements was evaluated in ten elderly normal subjects: The TcPO2 values were obtained on three separate occasions at two-week intervals, and the measurement-to-measurement variation averaged at 8 mmHg. The size of the confidence intervals could be reduced substantially by taking the mean of two or more TcPO2 measurements taken at separate times [20].

Similarly, an older study published in 1978 by Gothgen and Jacobsen focused on 20 patients between 19 and 80 years scheduled for Ear-Nose-Throat or eye surgery and without pulmonary and cardiovascular symptoms or signs. Two electrodes, heated to 43 °C, were placed symmetrically at the level of the third rib on the right and left mid-clavicular lines. TcPO2 measurements were recorded every 5 min after stabilization and electrodes were switched. Results did not differ significantly between sides and with time. The standard deviation between measurements at the same location was between 0 and 15 mmHg, and the 95% confidence interval did not exceed ±7.5 mmHg [21]. This standard deviation corresponds to the accuracy found for oxygen tension measurements in automatic blood gas analyzers and was at this time accepted for clinical use [22].

III. TREATMENT

HBO therapy involves the administration of pure oxygen at an increased atmospheric pressure to promote oxygenation in the body. The therapy is used to treat a variety of conditions, including wounds that are slow to heal, gas gangrene, carbon monoxide poisoning, and decompression sickness. During HBO therapy, the patient is placed inside a hyperbaric chamber where they breathe 100% oxygen while the pressure inside the chamber is increased. The increased pressure allows more oxygen to dissolve in the bloodstream, thereby increasing the oxygen saturation levels. The tcpO2 measurement is used to monitor the oxygen saturation levels near the wound during the therapy, allowing healthcare providers to adjust the treatment as needed to promote optimal healing.

The use of tcpO2 in conjunction with HBO therapy can help to improve the healing process, reduce the risk of complications, and increase the overall effectiveness of the therapy. By continuously monitoring the tcpO2 readings during the treatment, healthcare providers can ensure that the patient is receiving the appropriate amount of oxygen and that the therapy is having the desired effect on the patient's condition.

Figures 4, 5 shows the 8 leads for TCOM which refers to the TcpO2 measurements taken at eight different locations on the body. The graph in Figures 6, 7 typically has eight lines, each representing the TcpO2 measurement at a specific location. The eight locations where TcpO2 measurements are typically taken are: the upper arm, forearm, chest, abdomen, upper leg, lower leg, foot, and toe. The graph can be used to evaluate the oxygen supply to the tissues at each of these locations, which can provide important information about the overall circulation and oxygenation of the body.

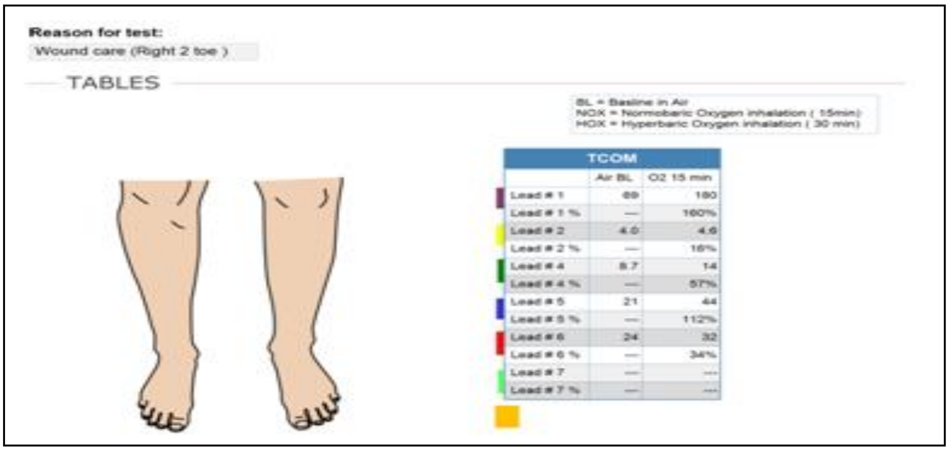
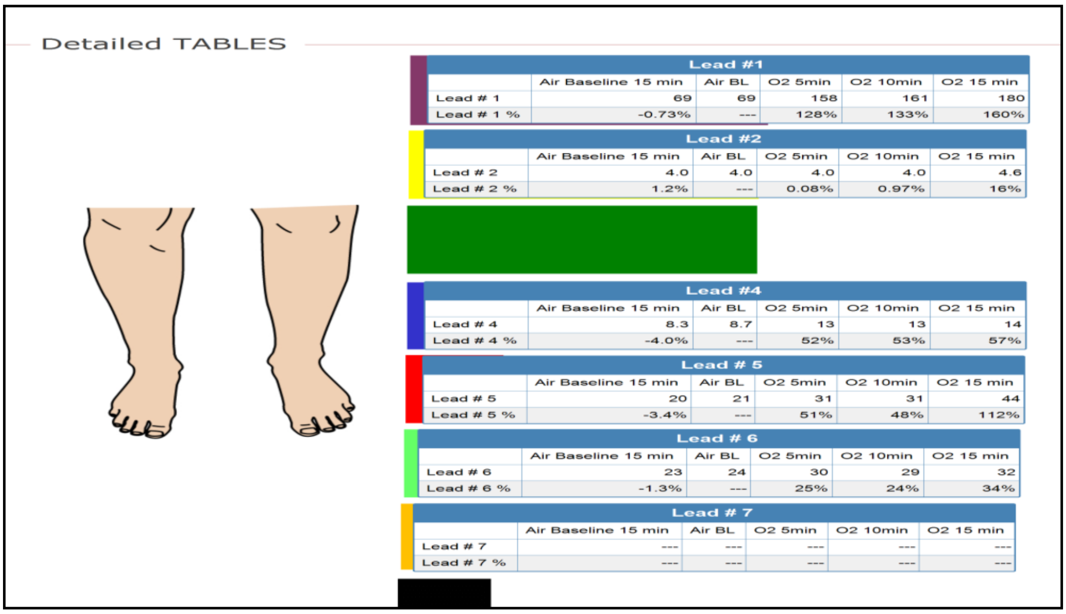


Fig. 4: Reason for test



Lead #1					
	Air Baseline 15 min	Air BL	O2 5min	O2 10min	O2 15 min
Lead # 1	69	69	158	161	180
Lead # 1 %	-0.73%	---	128%	133%	160%

Lead #2					
	Air Baseline 15 min	Air BL	O2 5min	O2 10min	O2 15 min
Lead # 2	4.0	4.0	4.0	4.0	4.6
Lead # 2 %	1.2%	---	0.08%	0.97%	16%

Lead #4					
	Air Baseline 15 min	Air BL	O2 5min	O2 10min	O2 15 min
Lead # 4	8.3	8.7	13	13	14
Lead # 4 %	-4.0%	---	52%	53%	57%

Lead # 5					
	Air Baseline 15 min	Air BL	O2 5min	O2 10min	O2 15 min
Lead # 5	20	21	31	31	44
Lead # 5 %	-3.4%	---	51%	48%	112%

Lead # 6					
	Air Baseline 15 min	Air BL	O2 5min	O2 10min	O2 15 min
Lead # 6	23	24	30	29	32
Lead # 6 %	-1.3%	---	25%	24%	34%

Lead # 7					
	Air Baseline 15 min	Air BL	O2 5min	O2 10min	O2 15 min
Lead # 7	---	---	---	---	---
Lead # 7 %	---	---	---	---	---

Fig. 5: Detailed Table

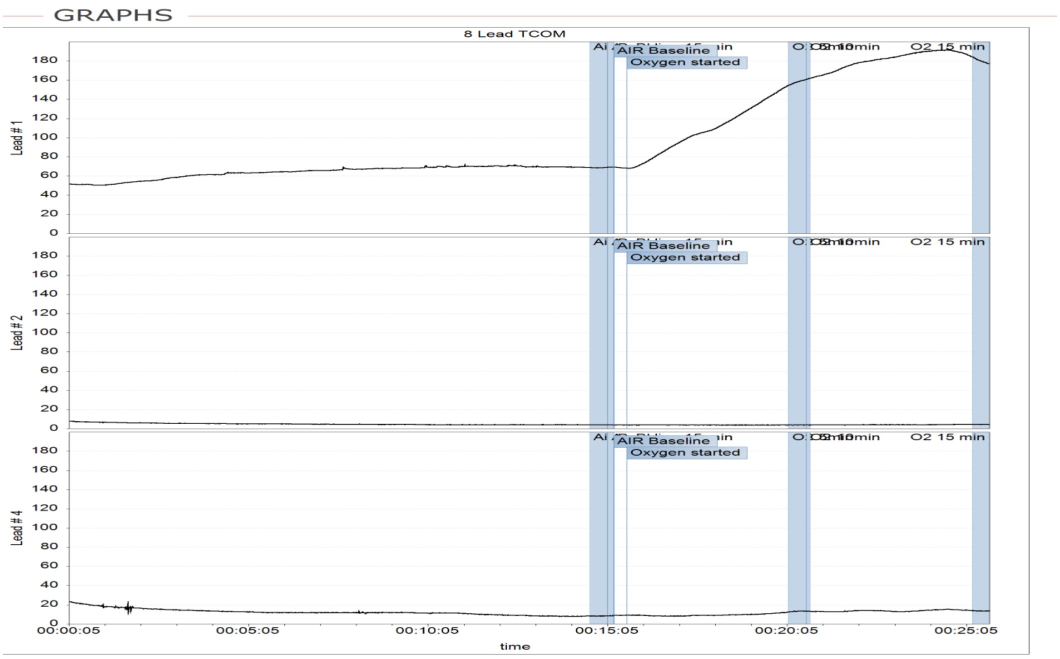


Fig. 6: TcpO2 test, electrodes graphs

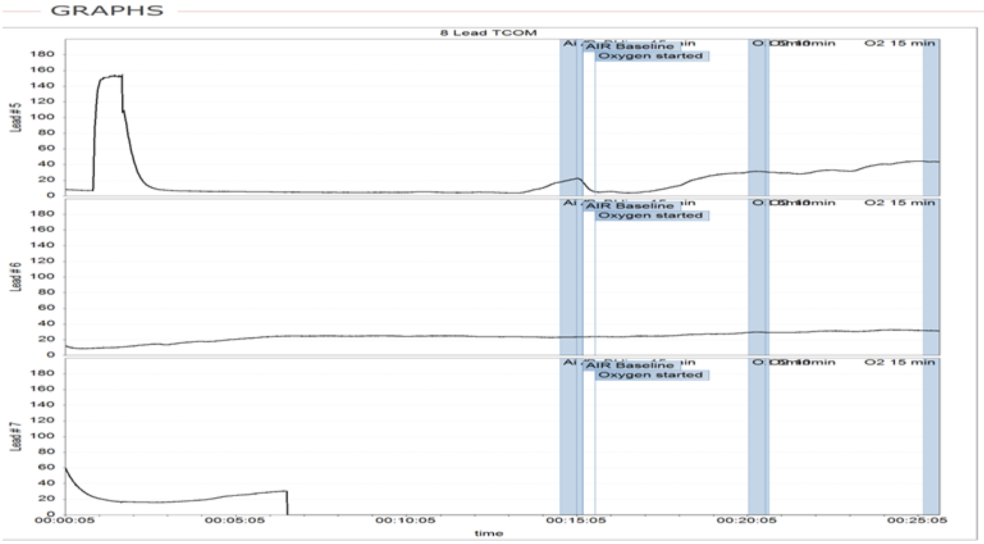


Fig. 7: TcpO2 test, electrodes

To perform the TcpO2 test, electrodes must be calibrated as per the company guideline before connected to the patients. TcpO2 measurements usually require at least two or three sites. The more sites assessed, the better the oxygenation picture. Thus, one set of electrodes are placed on viable tissue (e.g. the chest) as a control and placed another sets around the wound in different spot (e.g. legs or feet). The electrodes mildly heat the skin to increase blood flow into the area. As well Oxygen given to the patient to see if that increases oxygen levels in the tissue. Thus, it is measures the local oxygen tension in the skin deriving from the local capillary (nutritive) blood perfusion. The procedure is safe and does not pose the patient at risk for complications. The most significant drawback of the treatment is the duration of the measurement which takes about 45 minutes. Results are reported as the absolute values of the tissue (in mmHg).

Without comorbidities, wounds are thought to be able to heal if the oxygen tension is above 50 mmHg. In the presence of comorbidities, such as diabetes or edema, a higher value is likely needed. As Patients with oxygen tensions less than 20 mmHg are likely to need revascularization to promote adequate wound healing. The TcpO2 reading as showing in Table 2.

Table 2: TcpO2 Reading

TcpO2 Reading		
TcpO2 Reference values		Used to define
On Air baseline	When breathing 100 % normobaric oxygen	
50-70 mmHg	>100 mmHg	Normal- adequate wound healing.
< 40 mmHg	50-100 mmHg	Impaired Wound Healing for HBOT chamber challenge test.
< 20 mmHg	< 50 mmHg	Critical Limb Ischemia/ tissue hypoxia for vascular review.

A thorough clinical assessment of the patient is essential to establish appropriateness for hyperbaric oxygen treatment, among these measuring TcpO2 while the patient is inside the chamber breathing 100% oxygen at 2 ATA to 2.5 ATA (in-chamber TcpO2 measurement) is accepted as the most reliable method of identifying patients most likely to benefit from HBOT. TcpO2 measurement is a valuable tool that can be used for a variety of purposes related to wound care and peripheral arterial disease. Specifically, TcpO2 measurement can be used to assess periwound oxygenation over time, classify peripheral arterial disease, diagnose critical limb ischemia, predict the outcome of non-healing wounds, and even suggest an optimal amputation level. Additionally, TcpO2 measurement can help identify which patients may benefit from hyperbaric oxygen therapy (HBOT), making it a useful tool in treatment planning. Overall, TcpO2 measurement offers healthcare providers a non-invasive and reliable method for assessing tissue oxygenation and guiding clinical decision-making in the context of wound care and peripheral arterial disease management. To ensure accurate and reliable results, there are several factors that healthcare providers should consider to improve TcPO2 performance.

Firstly, it is crucial to ensure that the transcutaneous oxygen monitor is calibrated and functioning correctly. Using the appropriate sensors and electrodes for the patient's skin type and condition is also important. This can help ensure that the measurement accurately reflects tissue oxygenation levels. Additionally, selecting an appropriate site on the patient's skin, such as the upper chest or thigh, is crucial. Avoiding areas of skin with poor perfusion or thick layers of fat or muscle can also help to improve accuracy. Healthcare providers should ensure that the patient's skin is clean and dry before applying the sensor and electrode to avoid any interference with the measurement. If the patient experiences discomfort or the measurement appears to be inaccurate, healthcare providers should remove the sensor and electrode. Regularly checking and adjusting the sensor and electrode to ensure good contact with the skin is also important. Using TcPO2 in combination with other methods of assessing tissue oxygenation, such as arterial blood gas analysis or pulse oximetry, can help healthcare providers obtain a more comprehensive picture of a patient's oxygenation status. By taking these steps to improve TcPO2 performance, healthcare providers can ensure accurate and reliable measurements, which can aid in clinical decision-making and improve patient outcomes. By optimizing TcPO2 performance, healthcare providers can obtain valuable information about tissue oxygenation levels in a non-invasive way, which can aid in the diagnosis, management, and treatment of a wide range of medical conditions.

IV. CONCLUSIONS

$TcPO_2$ is a precise reflection of the skin perfusion in optimal conditions of measurements. Surgeons must take into account all confounding factors to interpret $TcPO_2$ values, mostly edema. Importantly, $TcPO_2$ values should not be used as the sole criterion to define lower limb amputation level, but always be evaluated together with the patient's characteristics (angiography), clinical judgement, and comorbidities (coronary artery disease, cerebrovascular disease, mobility before amputation). No consensus on $TcPO_2$ threshold that could guarantee amputation healing is currently available. However, one should keep in mind that strategy behind the use of $TcPO_2$ is to offer the most distal amputation level in spite of pejorative clinical criteria of ischemia. Data is missing to evaluate whether clinicians should use absolute or relative values of $TcPO_2$, as well as (in case of use of relative values) the position of the control site, the place of the oxygen inhalation test, and elevation measurements in current practice, irrespective of the time spent for the measurements to be performed.

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