

# **Transcutaneous Oximetry Testing and Interpretation**

---

**Dick Clarke, CHT**



## Transcutaneous Oximetry's Evidence-Based Importance

*Pro-Con analysis of hyperbaric wound referral vascular screening options*

Primary Training in Hyperbaric Medicine  
Columbia, South Carolina

### Non-invasive physiologic assessment of skin microcirculatory oxygenation



### Non-Invasive POC Extremity Arterial Screening Options

- Blood pressure
- Blood flow
- Tissue oxygen saturation
- Wound tissue thermal reflectance
- Transcutaneous tissue oxygen tension

### Laying the framework

HBO therapy routinely employed in the management of diabetic foot ulcers

HBO DFU efficacy & effectiveness data conflicting

HBO costly, frequently involves many weeks/several month commitment, not without risk

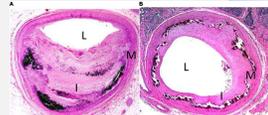
Even reviews favorably disposed to HBO therapy uniformly plead for better patient selection

Emerging NIRS & LWIR thermography technologies

**Tissue viability, limb preservation & wound healing a function of oxygen availability**

### Blood pressure & blood flow common oxygen delivery surrogates

*Blood pressure* may be normal during development of calcinosis  
> falsely elevated ABIs +/- reduced pedal perfusion secondary to intima build-up and/or wall thickening  
> *undiagnosed low O<sub>2</sub> delivery*



*Blood flow* may be normal while its oxygen content is not > *undiagnosed low O<sub>2</sub> delivery*

*anatomic and/or physiologic dead space > ventilation-perfusion mismatch*  
*physiologic shunt per ARDS, pulmonary edema, alveolar collapse, pulmonary AVM*  
*anemia, elevated altitudes*

### Risk factors for diabetic amputation

Pathophysiologic Factor	Odds Ratio
Cutaneous circulation tcpO <sub>2</sub> <20 vs. >40mmHg	161
Peripheral arterial circulation Doppler ABI <0.45 vs. 0.70	55.8
Neuropathy lacking distal vibratory sense	15.1
Ulcers become infected	10.1

Reiber GE, et al. 1992  
Ann. Int. Med. 117:871-883

#### THE HYPERBARIC MEDICINE SERVICE

##### TRANS CUTANEOUS OXYGEN SCREENING

Your Name: \_\_\_\_\_ Date: \_\_\_\_\_

Your Primary Care Physician: \_\_\_\_\_

You have just undergone a non-invasive oxygen study of:

Both feet

Your left foot

Your right foot

This test measures the amount of oxygen present in your tissue. The information obtained represents an assessment of the health of the blood circulation within your leg and foot.

This is a screening test. It is not a diagnostic test. It is not intended to replace a physical examination. If the results are not within the normal range, they should be discussed with your primary care physician. If you have any questions, please contact the Hyperbaric Medicine Service. The test results are available to you in about 15 minutes. The approximate cost of the test is \$100.00. Please contact your primary care physician for more information. Thank you for stopping by.

##### FINDINGS

Right Left Right  
Foot Foot Foot

Normal oximetry  
which is generally considered an oxygen delivery requirement

Borderline abnormal oximetry <30 mmHg  
single limb or within the borderline range. Additional testing is recommended

Abnormal oximetry <20 mmHg  
single limb or within the abnormal range. Additional testing should be scheduled

### Blood Pressure

#### Ankle-Brachial Index (ABI)

1.0-1.2/1.4 normal exam  
 0.9-0.99 borderline exam +/- irregularity; "clinically acceptable"  
 0.8-0.9 modest impairment; identify & manage risk factors  
 0.5-0.8 greater impairment (50-80% perfusion); specialist referral  
 < 0.5 severe disease (< 50% perfusion); specialist referral

> 1.2/1.4 abnormal exam c/w incompressible vessels  
 clinically significant calcification may be present prior to this range

**2. How to Interpret the ABI?**  
 • For diagnosis of PAD interpret each leg separately (see ABI per leg)  
 • For the CV risk stratification take the lowest ABI between the two legs  
 • Interpretation:

European Society Vascular Surgery 2018

### Blood Pressure

#### Ankle-Brachial Index (ABI)

##### Strengths

- Long-standing most widely recognized/employed screening tool
- Relative ease of testing; not operator dependent
- Standardized interpretation largely c/w MRI/MRA findings

##### Weaknesses

- Only assesses macro-vasculature
- Doesn't localize disease
- Doesn't assess below level of ankle cuff
- No information related to oxygen delivery

### Blood Pressure

#### Toe-Brachial Index (TBI)

0.7 essentially normal exam  
 <0.7 c/w arterial occlusive disease

### Blood Pressure

#### Toe-Brachial Index (TBI)

##### Strengths

- Assesses all-important foot/digits
- Relative ease of testing; not operator dependent

##### Weaknesses

- Lack of well-established grading system
- Not obtainable with Hallux; Ray; Ray revision; TMA amputations
- Confounded by calcification; no formal elevated index guidance
- No information related to oxygen delivery

© Robert A. Christman

### Blood Pressure

#### Skin Perfusion Pressure (SPP)

Minimum BP required for restoration of microcirculatory & capillary flow  
 Laser light strikes RBCs as flow resumes > Doppler (wavelength shift) effect  
 Interrogates shifted & unshifted light; places arbitrary value on shifted light = RBCs

50-100 mmHg considered normal range  
 30-50 mmHg marginal ischemia +/- PAD symptoms  
 <30 mmHg CLI; wound healing/limb preservation problematic

Vasamed Sensilase

### Blood Pressure

#### Skin Perfusion Pressure

##### Strengths

- Unaffected by calcification
- Unaffected by mild-moderate edema
- Can be used when TBI not possible
- Assesses microcirculation

##### Weaknesses

- Pressure responses & predictive aspects poorly validated
- No information related to oxygen delivery

### Blood Flow

#### Doppler Ultrasound/Ultrasonography

- Pulsed sound waves transmitted to area of interest
- Undergoes Doppler (shift in pitch) effect when bouncing off moving objects
- Returning sound interrogated to determine RBC speed & direction

Lifedop L250

### Blood Flow

#### Doppler Ultrasound/Ultrasonography

**Strengths**

- Widely accepted & ubiquitous screening device
- Accurate & reliable
- Simple to use
- Unaffected by vessel calcification & very low flow rates

**Weaknesses**

- Resolution not great enough for microcirculation
- No information related to oxygen delivery

### Blood Flow

#### Laser Doppler Flowmetry (LDF)

- Another Doppler-based technology; near infrared low power laser light
- Interchangeable probes for shallow & deeper penetration
- Assesses velocity & direction of RBCs
- Filters out reflected unshifted/scattered light ("noise")
- Generates proportional shifted light scale as estimate of flow

#### Laser Doppler Flowmetry (LDF)

### Blood Flow

#### Laser Doppler Flowmetry

**Strengths**

- Accurate & reliable; hematocrit WNL
- Simple to use
- Unaffected by vessel calcification & very low flow rates

**Weaknesses**

- Arbitrary perfusion scale (1-10) as flow surrogate
- Susceptible to hematocrit changes
- Signal return may include RBCs flowing below skin
- No information related to oxygen delivery

### Local Tissue Oxygen Saturation

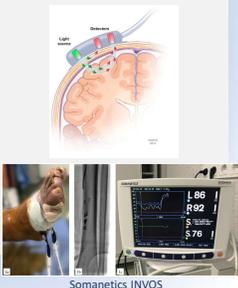
#### Near Infrared Spectroscopy (NIRS)

- Emits light (just outside visible spectrum) to area of interest
- Detects various reflective light spectrum differences
- Selectively measures OxyHb & DeoxyHb reflectance values
- Calculates percent "tissue" oxygen saturation

### Local Tissue Oxygen Saturation

#### Near Infrared Spectroscopy (NIRS)

- Introduced as continuous non-invasive monitoring of brain tissue oxygen saturation (StO<sub>2</sub>)
- Employment increasingly suggested elsewhere
- Longer wavelengths being researched



Somanetics INVOS

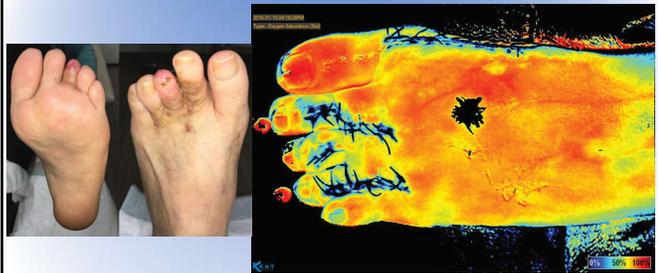
### Local Tissue Oxygen Saturation

#### Near Infrared Imaging (NIR)

- Battery-operated, handheld device
- Single "snapshot" vs. continuous monitoring
- Initially two manufacturers: NIR vs. visible light
- Measures OxyHb, DeOxyHb > calculates StO<sub>2</sub>



Snapshot NIR



With permission: Today's Wound Clinic/Kent Imaging

#### practice

### Comparing near infrared spectroscopy and transcutaneous oxygen measurement in hard-to-heal wounds: a pilot study

**Abstract:** The gold standard for assessing oxygenation is TCOM. TCOM is a serial diastacks Transfluor intense. Room temp must be between 68-72F. Probes cannot be placed in wound bed. Disposable are expensive.

**Advantages of NIRS vs. TCOM:**  
 Non-invasive  
 Does not require skin contact  
 Does not require spectrophotometry  
 Immediate real-time data, avoiding delay in treatment regimen

**NIRS derived mmHg O<sub>2</sub>:** electromagnetic light reflectance from IR wavelengths measured by a patented computer interface algorithm to generate calculated OxyHb level which is mathematically converted to StO<sub>2</sub>, that is then mathematically converted to pO<sub>2</sub> using standard Severinghaus dissociation curve

**TCOM derived mmHg O<sub>2</sub>:** direct measurement free oxygen that diffuses to skin surface

**Conclusion:** Data suggests TCOM overestimates O<sub>2</sub> measurements vs. NIRS

Serena TE, et al. Journal Wound Care 2020;29(6)

### Local Tissue Oxygen Saturation

#### Near Infrared Imaging (NIR)

##### Strengths

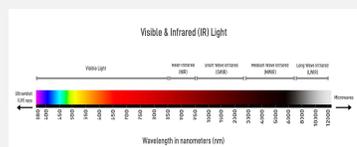
- Battery-operated handheld; high image storage capacity
- Uniquely assesses regional StO<sub>2</sub>
- Ease of use/interpretation; touch screen display StO<sub>2</sub> values
- Suggested healing response tracker

##### Weaknesses

- Does not measure tissue oxygenation  
 So, no assessment plasma-borne oxygen delivery (basis for HBO)
- Unable to direct HBO case management as per tcPO<sub>2</sub>
- Presently ill-defined normal/abnormal StO<sub>2</sub> values; some crossover
- Presently unclear as to clinical relevance wound StO<sub>2</sub>

### Wound Thermal Reflectance

#### Long-Wave Infrared Thermography (LWIT)






### Is any such hypoxia reversible?

**Normobaric 100% oxygen challenge tcpO<sub>2</sub> ≥ 100 mmHg per NRB mask @ 14-16 lpm**

Strauss MB, et al. Foot Ankle Int. 2002;23(10):933-937  
 Fife CE, et al. Wound Regen Repair. 2002;10:188-207  
 Middelkoop J. Wound Regen Repair. 2003;11:458-464  
 Fife CE, et al. Undersea Hyperbaric Med. 2009;36(1):43-53  
 Misson H, et al. Undersea Hyperbaric Med. 2010;43(5):441-448

- > 300 mmHg... ◊ normal distal arterial perfusion
- 200-300 mmHg... ◊ minimal occlusive disease
- 100-199 mmHg... ◊ moderate occlusive disease
- 51-99 mmHg... ◊ significant occlusive disease \*\*
- < 50 mmHg... ◊ highest grade occlusive disease \*\*

\*\* further arterial work-up indicated

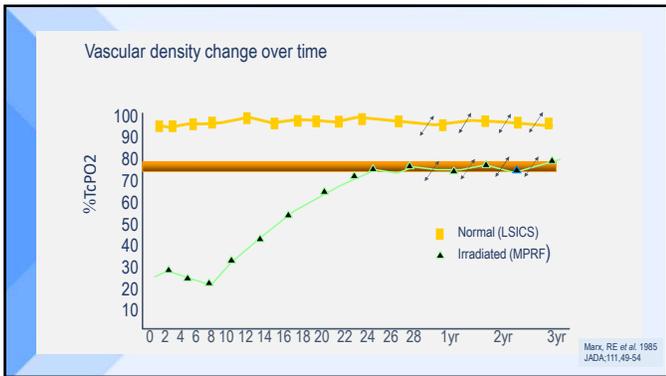
### Is there early evidence of response to HBO?

Repeat normobaric air breathing tcpO<sub>2</sub> test after 15 treatments

*"A lack of improvement in tcpO<sub>2</sub> measurements should discourage further HBO"*  
**Hyperbaric Oxygen Therapy Indications 14<sup>th</sup> Edition 2019**

*"One should see (tcpO<sub>2</sub>) changes by 10-15 HBO treatments to determine response"*  
**Hyperbaric Oxygen Therapy Indications 15<sup>th</sup> Edition 2023**

In responders, five days weekly HBO with weekly f/u tcpO<sub>2</sub> testing



### Has therapeutic endpoint been reached?

Support of tissue viability & wound healing defined as tcpO<sub>2</sub> ≥ 40 mmHg

David GSE, et al. J Bone Joint Surg [Am]. 2002;79-B  
 Sherrill CR, et al. Orthop Sports Med Rehabil. 2006;8(2):22-26  
 Ramgopal KR, et al. J Wound Care. 2013;23(3):202-206  
 Givoni G, et al. Diabetes Care. 2010;33(2):377-382

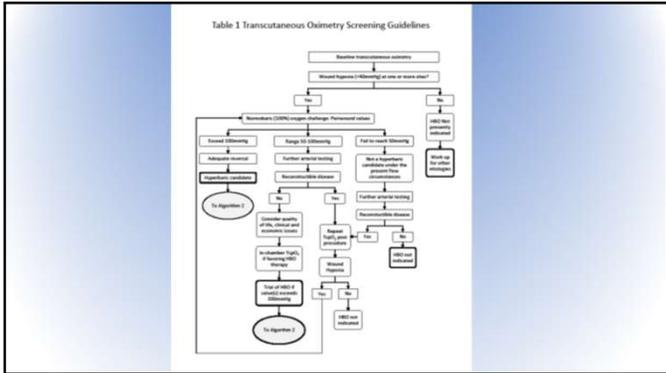
### Four-step transcutaneous oximetry screening of hyperbaric referrals

Is wound healing complicated by local hypoxia?  
 < 40 mmHg

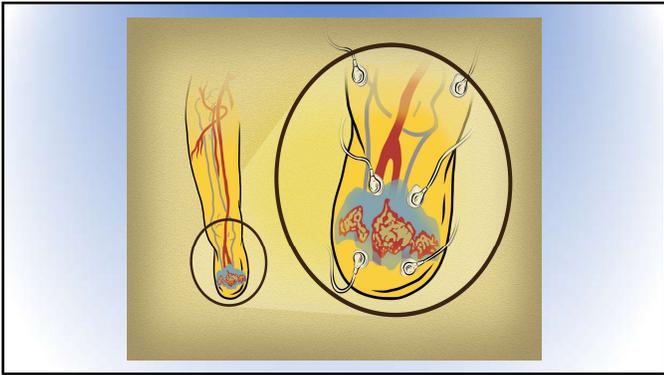
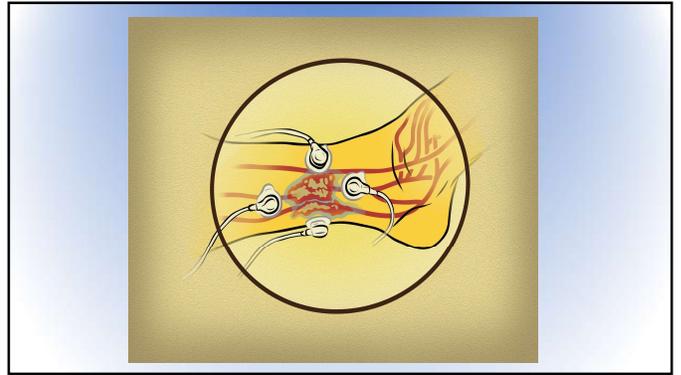
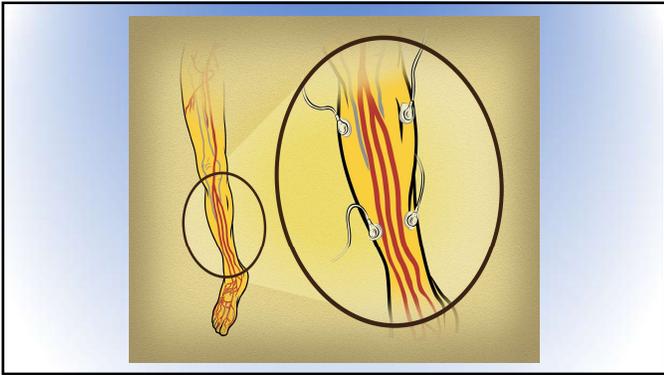
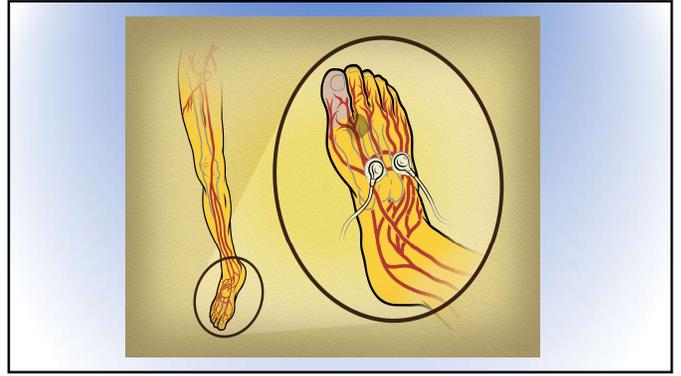
Is any such hypoxia reversible?  
 ≥ 100 mmHg

Is there early evidence of response to HBO?  
 after 15 treatments

Has a therapeutic endpoint been reached?  
 peri wound value(s) ≥ 40 mmHg









### When to delay testing

- Immediately post hemo-dialysis**  
Nutritive skin perfusion impaired during dialysis, sufficient in some cases to cause chest/cardiac & leg pain  
- significant tcpO<sub>2</sub> decreases in pts. with & without PVD  
*Weiss T, et al. 1998 Neph Dial Trans. 13*
- Markedly edematous tissue**  
Diffusion barrier between functioning capillaries & skin  
*Stephens M, et al. 1999 UHM 26(2):93-97*
- Caffeine ingestion**  
Restrict caffeine-containing substances prior to testing  
*Dooley J, et al. 1996 UHM 23(3):167-174*
- Nicotine**  
Avoid any use for at least two hours prior to testing  
*Jensen JA, et al. 1994 Arch Surg 126:1131-1134*
- Supplemental oxygen administration**  
Absence of conversion factors

### Post-successful flow augmentation tcpO<sub>2</sub> responses

- Several day delays exist from revascularization to significantly improved skin oxygenation  
- even 3 days postop, 5/11 pts still had values < 30 mmHg  
*Arroyo CI, et al. 2002 J Foot Ankle Surg 41(4)*
- "It takes 3-4 weeks after PTA for tcpO<sub>2</sub> values to reach optimal levels for wound healing"  
- "findings suggest that, when surgery can be delayed, best time to perform aggressive debridement/minor amps. is 3-4 weeks post PTA"  
*Casali A, et al. 2005 Diabetes Medicine 22*
- "tcpO<sub>2</sub> continued to increase up to 8 weeks after PTA, while ABI remained constant"  
- "perhaps revascularization in sparsely perfused areas causes increase in angiogenesis processes leading to an increase in capillary function?"  
*Pardo M, et al. 2015 British J Radiology 88*

Possible etiologies:  
Post-operative edema; vasospasm due to high pressures; ischemia-reperfusion injury; endothelial cell trauma; micro embolic events; effects of dye; angiogenesis processes

Newly introduced sensor technology based on fluorescence  
no oxygen consumption

No electrochemical sensor electrode wear/replacement

No regular calibration needed

Readout ~ 8 minutes; notification of steady state

40 - 44 C sensor range

Medicap, Germany: Precise 8008 Gen.2

1950-206

**Basic Science Research**

**Comparison of Photo-optical Transcutaneous Oxygen Tension Measurement with Electro-chemical Transcutaneous Oxygen Tension Measurement in Patients with Arterial Claudication**

*Leenstra BS, et al. Ann Vascular Surgery 2021;77:274-279*

Photo-optical tcpO<sub>2</sub> demonstrated acceptable agreement with electro-chemical tcpO<sub>2</sub>

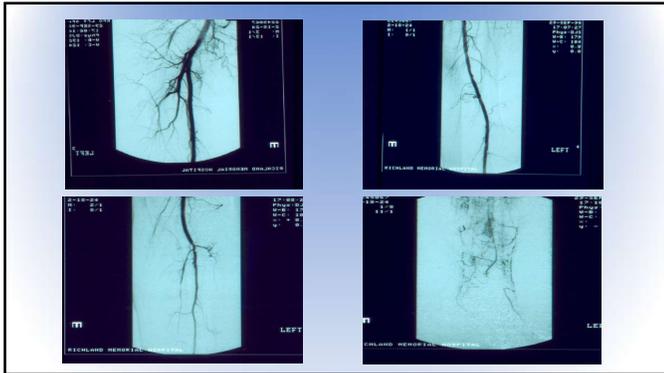
Photo-optical values are in general higher in comparison

**INTRODUCTION**

Quantitative assessment of tissue oxygenation is essential for the diagnosis and management of peripheral artery disease (PAD). The ankle-brachial index (ABI) is the gold standard for diagnosis of PAD, but it does not provide information on tissue oxygenation. Transcutaneous oxygen tension (tcpO<sub>2</sub>) is a non-invasive method to assess tissue oxygenation. Photo-optical tcpO<sub>2</sub> (PO-tcpO<sub>2</sub>) and electro-chemical tcpO<sub>2</sub> (EC-tcpO<sub>2</sub>) are two methods to measure tcpO<sub>2</sub>. PO-tcpO<sub>2</sub> is a non-invasive method that uses a light source and a detector to measure the fluorescence of a fluorescent dye in the skin. EC-tcpO<sub>2</sub> is a method that uses a small electrode to measure the oxygen concentration in the skin. The aim of this study was to compare PO-tcpO<sub>2</sub> and EC-tcpO<sub>2</sub> in patients with PAD.

74-year-old DM underwent left great toe amputation secondary to ischemia; primary closure via rotational flap  
FAU: tenderness 1st metatarsal & plantar surfaces, erythema & edema; ischemic superior flap

PT admitted, further surgery contemplated, HBO consulted



### Transcutaneous Tissue Oxygen Tension

**Strengths**

- Directly measures tissue oxygen tension; Hb bound & plasma borne
- Unique composite indicator of micro & macro vascular health
- In-chamber testing capability
- Guides evidence-based case management
- Demonstrated to improve clinical outcomes
- Enhances cost-effectiveness

**Weaknesses**

- Requires more training than other options to gain competence
- Site selection inconsistency
- More time consuming (~ 30 minutes)
- Limitations; diffusing barriers; suppl. O<sub>2</sub>; dialysis; caffeine; nicotine
- Associated consumables expense

**UNDERSEA & HYPERBARIC MEDICINE**

660-316

**Transcutaneous Oximetry Optimizes Clinical Management and Cost-Effectiveness of Diabetic Foot Ulcers Treated with Hyperbaric Oxygen: A Review of Point-of-Care Vascular Screening Options**

**James S. Goss, MD, FRCPC**

National Research Service, Colorado, South Carolina, USA  
[jgoss@underseahyperbaric.com](mailto:jgoss@underseahyperbaric.com)

**ABSTRACT**

**OBJECTIVE:** Diabetic foot ulcers (DFUs) are a leading cause of lower extremity amputation. Transcutaneous oximetry (TcPO<sub>2</sub>) is a non-invasive, point-of-care method for measuring tissue oxygenation. This review examines the clinical utility of TcPO<sub>2</sub> in the management of DFUs, particularly in the context of hyperbaric oxygen (HBO) therapy. The review discusses the pathophysiology of DFUs, the role of hypoxia in wound healing, and the evidence supporting the use of TcPO<sub>2</sub> to guide HBO treatment. Key findings include that TcPO<sub>2</sub> measurements can identify patients who are most likely to benefit from HBO, and that TcPO<sub>2</sub> monitoring can help optimize the duration and intensity of HBO therapy. The review also discusses the limitations of TcPO<sub>2</sub> and the need for further research to establish its role in the standard of care for DFUs.

**INTRODUCTION**

Diabetic foot ulcers (DFUs) are a leading cause of lower extremity amputation. Transcutaneous oximetry (TcPO<sub>2</sub>) is a non-invasive, point-of-care method for measuring tissue oxygenation. This review examines the clinical utility of TcPO<sub>2</sub> in the management of DFUs, particularly in the context of hyperbaric oxygen (HBO) therapy. The review discusses the pathophysiology of DFUs, the role of hypoxia in wound healing, and the evidence supporting the use of TcPO<sub>2</sub> to guide HBO treatment. Key findings include that TcPO<sub>2</sub> measurements can identify patients who are most likely to benefit from HBO, and that TcPO<sub>2</sub> monitoring can help optimize the duration and intensity of HBO therapy. The review also discusses the limitations of TcPO<sub>2</sub> and the need for further research to establish its role in the standard of care for DFUs.

**CONCLUSION** Transcutaneous oximetry (TcPO<sub>2</sub>) is a valuable tool for the management of diabetic foot ulcers. It can help identify patients who are most likely to benefit from hyperbaric oxygen therapy and help optimize the duration and intensity of HBO treatment. Further research is needed to establish its role in the standard of care for DFUs.

CLINICAL RESEARCH | Copyright © 2024 Undersea & Hyperbaric Medicine Society, Inc. | 523