Transcutaneous Oximetry Testing and Interpretation

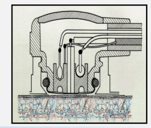
Dick Clarke, CHT

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 Vascular Screening Options

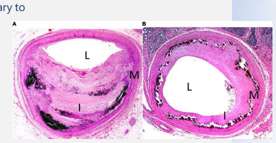
- Blood pressure
- Blood flow
- Tissue oxygen saturation
- Wound tissue thermal reflectance
- Transcutaneous tissue oxygen tension

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 O2 delivery*



Blood flow may be normal while its oxygen content is not > *undiagnosed low O_2 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 *$tcpO_2$ <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;117:97-105

THE HYPERBARIC MEDICINE SERVICE

TRANSCUTANEOUS OXYGEN SCREENING

Your Name: ____________ Date ____________

Your Primary Care Physician: ____________

You have just undergone a transcutaneous oxygen study of:

☐ **Both feet**
☐ **Your left foot**
☐ **Your right foot**

This test measures the amount of oxygen present in your tissues. The information obtained represents an assessment of the health of the blood circulation within your legs and feet.

It is a screening test, which means that additional testing may be necessary, depending upon the results. If the results are not within the normal range they should be discussed with your primary care physician who will be responsible for any decision to proceed with further testing. We have attached an article that describes the importance of this test in the evaluation of risks for healing difficulties for you to share with your primary care physician. Thank you for stopping by.

FINDINGS

Both Feet	Left Foot	Right Foot	
☐	☐	☐	**Normal exam ≥40 mmhg** *-there is presently no evidence of as oxygen delivery impairment*
☐	☐	☐	**Borderline abnormal exam 30 – 39 mmhg** *-oxgen levels are within the borderline range. Additional testing is recommeded*
☐	☐	☐	**Abnormal exam <30 mmhg** *-oxygen levels are abnormally low and additional testing should be scheduled*

Blood Pressure

Ankle-Brachial Index (ABI)

1.0-1.2/1.4 normal exam

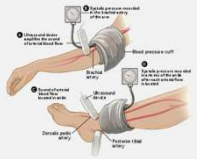
0.9-0.99 borderline exam +/- irregularity; "clinically acceptable"

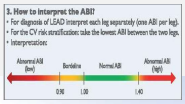
0.8-0.9 modest impairment; identify & manage risk factors

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





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

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

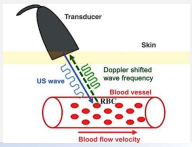
Pressure responses & predictive aspects poorly validated

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



Blood Flow

Doppler Ultrasound/Ultrasonography

Strengths

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

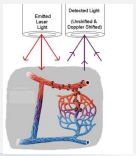
Weaknesses

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

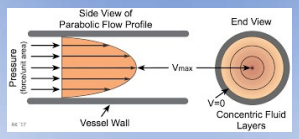
Blood Flow

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

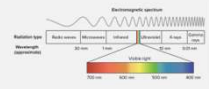
Weaknesses

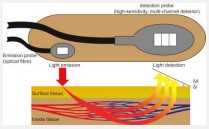
- Arbitrary perfusion scale (1-10) as flow surrogate
- Susceptible to hematocrit changes
- Signal return may include RBCs flowing below skin
- No information related to oxygen delivery

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

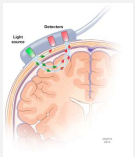


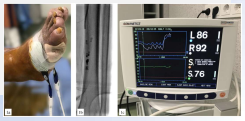


Local Tissue Oxygen Saturation

Near Infrared Spectroscopy (NIRS)

- Introduced as continuous non-invasive monitoring of brain tissue oxygen saturation (StO_2)
- Employment increasingly suggested elsewhere
- Longer wavelengths being researched



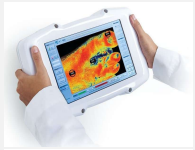


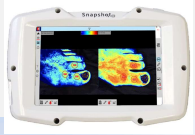
Somanetics INVOS

Local Tissue Oxygen Saturation

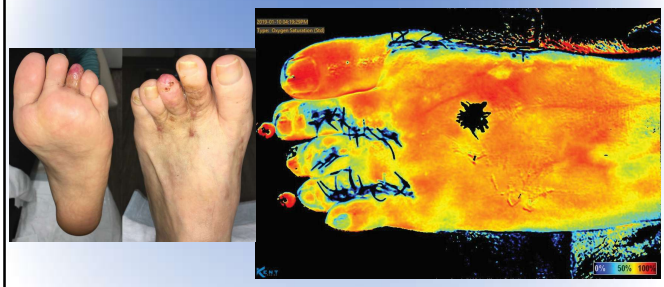
Near Infrared Imagining (NIR)

- Battery-operated, handheld device
- Single "snapshot" vs. continuous monitoring
- Initially two manufacturers: NIR vs. visible light
- Measures OxyHb; DeOxyHb > calculates StO_2

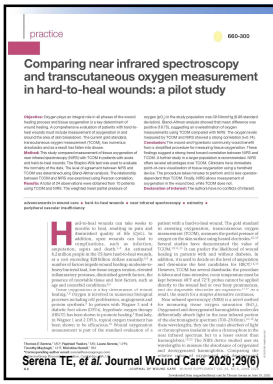




Snapshot NIR



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

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

"The gold standard for assessing oxygenation is TCOM..."

TCOM has several drawbacks
Time/labor intensive
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 injectable dyes
Immediate real-time data, avoiding delay in treatment regimen

NIRS derived mmHg O_2...*electromagnetic light reflectance from IR wavelengths measured by a patented computer interface algorithm to generate calculated OxyHb level which is mathematically converted to StO_2, that is then mathematically converted to pO_2 using standard Servinghaus dissociation curve*

TCOM derived mmHg O_2...*direct measurement free oxygen that diffuses to skin surface.*

Conclusion: Data suggests TCOM overestimates O_2 measurements vs. NIR

Local Tissue Oxygen Saturation

Near Infrared Imaging (NIR)

Strengths

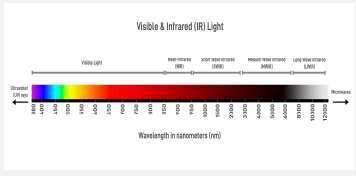
- Battery-operated handheld; high image storage capacity
- Uniquely assesses regional StO_2
- Ease of use/interpretation; touch screen display StO_2 values
- Suggested healing response tracker

Weaknesses

- Does not measure tissue oxygenation
  So, no assessment plasma-borne oxygen delivery (basis for HBO)
- Unable to direct HBO case management as per $tcPO_2$
- Presently ill-defined normal/abnormal StO_2 values; some crossover
- Presently unclear as to clinical relevance wound StO_2

Wound Thermal Reflectance

Long-Wave Infrared Thermography (LWIT)

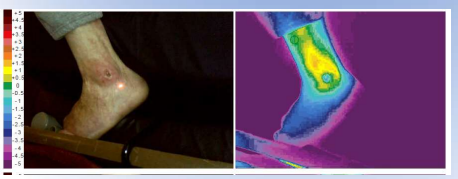


Wound Thermal Reflectance

Detects & maps thermal energy created by cellular metabolism

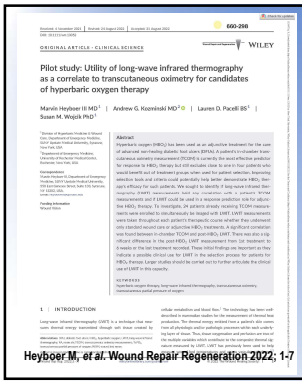
Reflects relative state of/changes in perfusion compared to healthy tissue

Does change (increase) in thermal reflectance indicate healing response?



With permission: M. Heyboer, SUNY

Wound Vision Scout



660-298

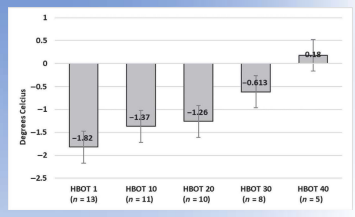
ORIGINAL ARTICLE - CLINICAL SCIENCE

WILEY

Pilot study: Utility of long-wave infrared thermography as a correlate to transcutaneous oximetry for candidates of hyperbaric oxygen therapy

Marvin Heyboer III MD[1] | Andrew G. Kozminski MD[2] | Lauren D. Pacelli BS[1] | Susan M. Wojcik PhD[1]

Heyboer M, *et al.* Wound Repair Regeneration 2022; 1-7



Wound Tissue Thermal Reflectance

Strengths

Battery-operated handheld, ease of operation

Directly measures changes in wound/tissue thermal energy

Preliminary data...correlates with TCOM improvement during ulcer healing

High quality evidence: Detects pre-visual temp. anomalies before visual pressure injuries

Weaknesses

Possible confounding factor peri-HBO changes in environmental temperature

Value as a wound management/hyperbaric screening tool not yet quantified

Transcutaneous Tissue Oxygen Tension

Transcutaneous Oximetry (TCOM)

Air breathing $tcpO_2$ values at 1.0 ATA offer no useful healing prediction
progressively decreasing values likewise offer no specific guidance
identifies local hypoxia

Oxygen breathing $tcpO_2$ values at 1.0 ATA likewise provide no useful prediction
can indicate need for additional arterial testing

In-chamber $tcpO_2$ values offer some guidance; lack statistical precision
$tcpO_2$ > 200 mmHg most associated with healing response

PeriMed PeriFlux 6000

Four-part transcutaneous oximetry screening of hyperbaric referrals

Is wound healing complicated by local hypoxia?
~ are such wounds LIKELY to benefit?

Is any such hypoxia reversible?
~ are DFU patients CAPABLE of benefiting?

Is there early evidence of response?
~ ARE these wounds appearing to benefit?

Has a therapeutic endpoint been reached?
~ have these wounds SUFFICIENTLY benefitted?

Is wound healing complicated by local hypoxia?

Normal lower extremity/foot $tcpO_2$ defined as **> 50 mmHg**

Matsen FA, et al. Surg Gynec Obstet 1980;150:525-528
Chgi S, et al. Angiology 1981;32(12):833-839
Hauser CJ, et al. Ann Surg 1981;197:197-343
Dowd GSE, et al. J Bone Joint Surg 1983;65B:79-83
Dowd GSE, et al. Clin Phys Physiol Meas 1983;4(1):65-68
Coleman LS, et al. Clin Phys Physiol Meas 1986;7(3):259-263
Dooley J, et al. Undersea Hyper Med 1997;24:235-244
Tandara AA, Mustoe TA. World J Surg 2004;28:294-300

Support of tissue viability & wound healing defined as $tcpO_2$ **≥ 40 mmHg**

Dowd GSE, et al. J Bone Joint Surg (Brit) 1983;79-83
Smart DR, et al. Diving Hyperbaric Medicine 2006;36(2):72-86
Ruangsetakit C, et al. J Wound Care 2010;19(5):202-206
Uccioli L, et al. Diabetes Care 2010;33(5):977-982

Impaired wound healing threshold defined as $tcpO_2$ **< 40 mmHg**

Hunt TK, et al. World J Surg 1987;11
Padberg FT, et al. J Surg Research 1996;60(2):365-369
Kalani M, et al. Diabetes Care 1999;22(1):147-151
Grolman RE, et al. American Surg 2001;67:1072-1080
Smart DR, et al. Diving Hyperbaric Medicine 2006;36(2):72-86
Trinka TP, et al. Diving Hyperbaric Medicine 2011;47(2):82-87

Critical limb ischemia defined as $tcpO_2$ **≤ 30 mmHg**

Cina C, et al. J Vascular Surg 1984;1(2):362-371
Bellenti JL, et al. J Vascular Surg 1995;22:485-492
Padberg FT, et al. J Surg Research 1996;60(2):365-369
Bunt TJ, et al. Ann Vascular Surg 1998;10:224-227
Benhamou Y, et al. Neph Dial Trans 2012;27(5):2066-2069
Abayazo Y, et al. European Heart J 2018;39:763-821

Is any such hypoxia reversible?

Normobaric 100% oxygen challenge tcpO2 **≥ 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;10:198-207
Niinikoski J. Wound Regen Repair 2003 ;11:458-461
Fife, CE, et al: Undersea Hyperbaric Med 2009;36(1):43-53
Moon H, et al. Undersea Hyperbaric Med 2016;43(6):641-648

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

** further arterial work-up indicated

Is there early evidence of response to HBO?

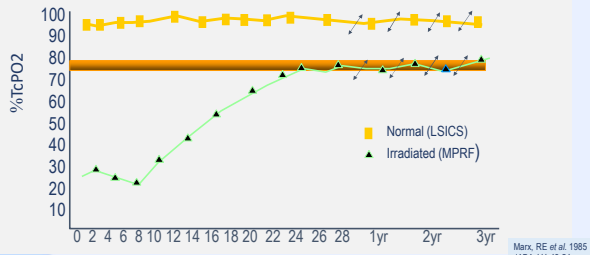
Repeat normobaric air breathing tcpO2 test after 15 treatments

"A lack of improvement in tcpO2 measurements should discourage further HBO"
Hyperbaric Oxygen Therapy Indications 14th Edition 2019

"One should see (tcpO2) changes by 10-15 HBO treatments to determine response"
Hyperbaric Oxygen Therapy Indications 15th Edition 2023

In responders, five days weekly HBO with weekly f/u tcpO2 testing

Vascular density change over time



Marx, RE *et al.* 1985
JADA;111,49-54

Has therapeutic endpoint been reached?

Support of tissue viability & wound healing defined as tcpO2 **≥ 40 mmHg**

Dewel GST, et al. J Bone Joint Surg [Br] 1983;79-83
Smart DR, et al. Diving Hyperbaric Medicine 2006;36(2):72-86
Rumpelsteikn C, et al. J Wound Care 2010;19(5):202-206
Liccioli L, et al. Diabetes Care 2010;33(5):977-982

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

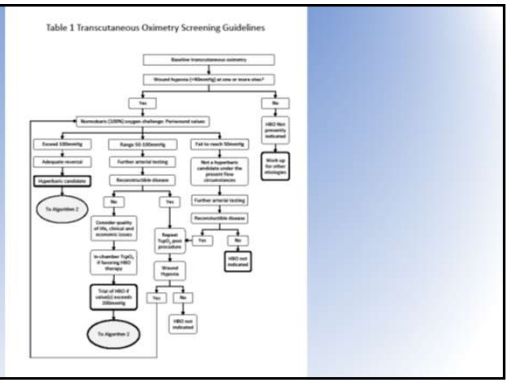
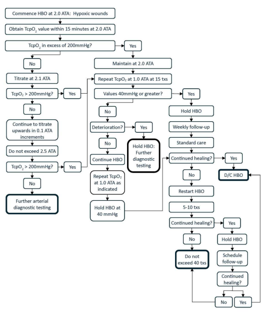


Table 2 Transcutaneous Oximetry Dosing Guidelines



Low tcpO2 predicts abnormal arteriography

96% of 66 limbs with tcpO2 < 30mmHg had abnormal arteriogram

Ballard JL, *et al.* 1995

tcpO2 <30mmHg reliable indicator of need for arteriography, with 98% limbs showing significant disease

Bunt TJ, *et al.* 1996

660-187

Original research article

The predictive value of transcutaneous oxygen tension measurement in diabetic lower extremity ulcers treated with hyperbaric oxygen therapy: a retrospective analysis of 1144 patients

CAROLINE E. FIFE, MD[a]; CEM BUYUKCAKIR, MD[b]; GORDON H. OTTO, PhD[c]; PAUL J. SHEFFIELD, PhD[d]; ROBERT A. WARRINER III, MD[e]; TOMMY L. LOVE, DO[f]; JON MADER, MD[g]

The objective of this retrospective analysis was to determine the reliability of transcutaneous oxygen tension measurement ($TcPO_2$) in predicting outcomes of diabetics who underwent hyperbaric oxygen therapy for lower extremity wounds. Six hyperbaric facilities provided $TcPO_2$ data under several possible conditions: breathing air, breathing oxygen at sea level, and breathing oxygen in the chamber. Overall, 75.6% of the patients improved after hyperbaric oxygen therapy. Baseline sea-level air $TcPO_2$ identified the degree of tissue hypoxia but had little statistical relationship with outcome prediction because some patients healed after hyperbaric oxygen therapy despite very low prehyperbaric $TcPO_2$ values. Breathing oxygen at sea level was unreliable for predicting failure, but 68% reliable for predicting success after hyperbaric oxygen therapy. $TcPO_2$ measured in chamber provides the best single discriminator between success and failure of hyperbaric oxygen therapy using a cutoff score of 200 mmHg. The reliability of in-chamber $TcPO_2$ as an isolated measure was 74% with a positive predictive value of 58%. Better results can be obtained by combining information about sea-level air and in-chamber oxygen. A sea-level air $TcPO_2$ < 15 mmHg combined with an in-chamber $TcPO_2$ < 400 mmHg predicts failure of hyperbaric oxygen therapy with a reliability of 75.8% and a positive predictive value of 73.3%. **(WOUND REP REG 2002;10:198–207)**

From the Department of Anesthesiology[a], The University of Texas Medical School at Houston, and the Memorial Hermann Center for Hyperbaric Medicine, Houston, Texas; GMMA Aerospace Medical Center[b], Eskisehir, Turkey; Belk College of Business[c], The University of North Carolina at Charlotte, Charlotte, North Carolina; Nix Wound Care and Hyperbaric Medicine Facility[d], Nix Medical Center, San Antonio, Texas; Southeast Texas Center for Wound Care and Hyperbaric Medicine[e], Conroe, Texas; Utah Center for Wound Healing and Hyperbaric Medicine[f], Bountiful, Utah; and Department of Internal Medicine[g], The University of Texas Medical Branch, Galveston, Texas.

Presented in part at the annual meeting of the Undersea and Hyperbaric Medical Society in Seattle, WA, May 1998.

Reprint requests: Caroline E. Fife, MD, 6431 Fannin, MSB 5.020, Houston, TX 77030. Fax: (713) 704-5793; E-mail: Caroline.E.Fife@uth.tmc.edu.

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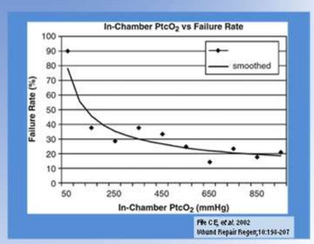
ATA	Atmosphere absolute
HBO_2T	Hyperbaric oxygen therapy
PPV	Positive predictive value
$TcPO_2$	Transcutaneous oxygen tension

Hyperbaric oxygen therapy (HBO_2T) is the inhalation of 100% oxygen by a patient enclosed in a pressure vessel or chamber. For wound healing, hyperbaric chambers are usually pressurized to simulate an atmospheric pressure 2–2.5 times sea level. The dramatic increase in plasma-dissolved oxygen achieved during HBO_2T can supply tissues with adequate oxygen to support metabolism, even if the vascular supply is compromised.[1] As a result, HBO_2T has been used as adjunctive therapy for certain types of hypoxic wounds including compromised skin grafts and diabetic lower extremity wounds. Randomized, controlled trials have shown the benefit of HBO_2T in diabetic ulcers of the lower extremity.[2–7] The economic and emotional costs of amputation and rehabilitation easily exceed the cost of

198 **Fife CE, *et al*. Wound Rep Regen 2002;10**

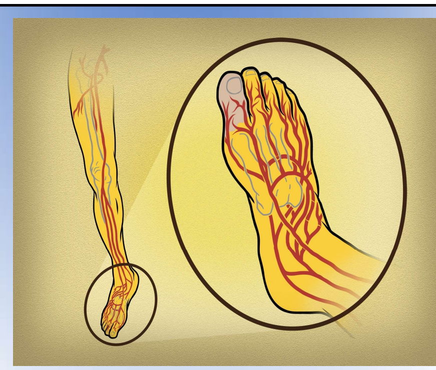


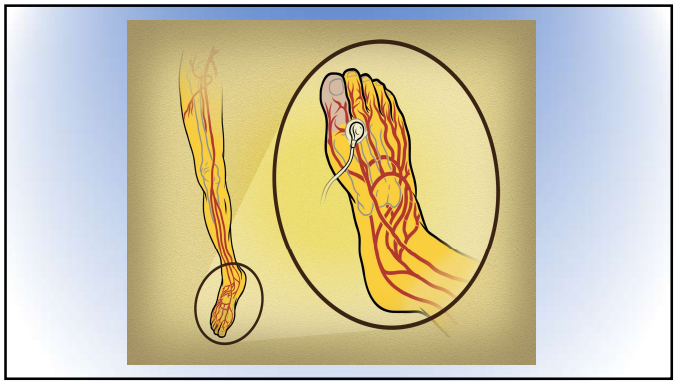
Factors influencing tcpO2

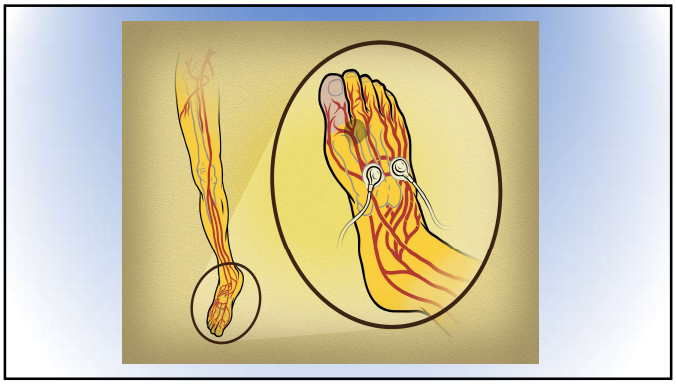
Systemic	Local
Pulmonary & cardiac function; oxygen content	Obesity
Central & peripheral vascular perfusion	Edema
Smoking/nicotine, caffeine ingestion	Increased skin thickness
Vasoactive pharmacologic agents	Cutaneous late radiation tissue injury
Environment (temperature /altitude)	Bony prominences
	Poor skin preparation
	Poor electrode attachment

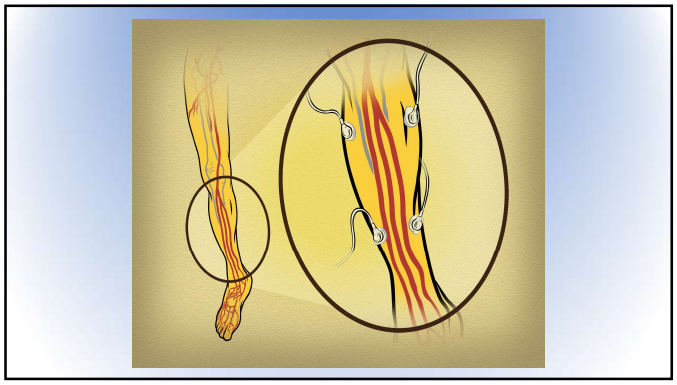
Site selection; anatomic factors

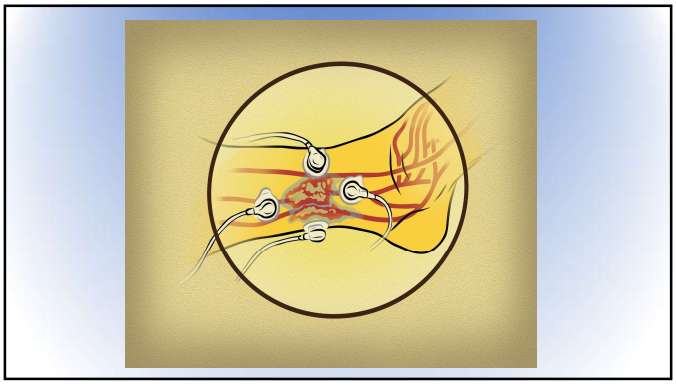
- Clear understanding of question in need of address
- Appreciate arterial anatomy associated with question
- Principal testing site(s) consistent with that determinant
- Any necessary secondary testing site(s)

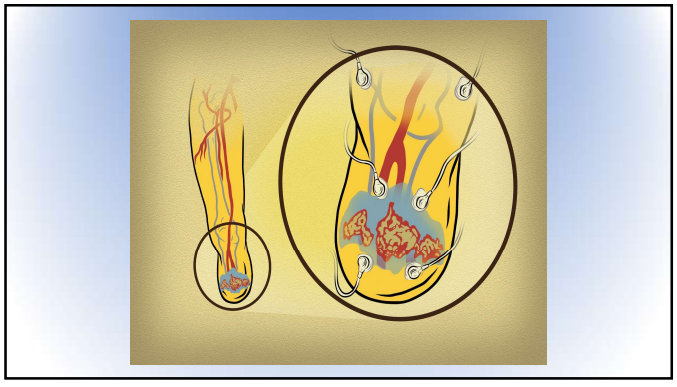













10027
Pre HBO T-Conn
3/26
10027
Post 20 treatments
4/23
10027
12 weeks post treatment
7/19

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 tcpO2 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 Surg126:1131-1134

Supplemental oxygen administration
Absence of conversion factors

Post-successful flow augmentation tcpO2 responses

Several day delay exists 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 tcpO2 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"
Caselli A, *et al.* 2005 Diabetes Medicine 22

"tcpO2 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

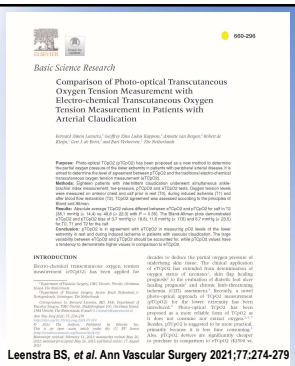
No electrochemical sensor electrode wear/replacement

No regular calibration required

Readout ~ 8 minutes; notification of steady state

40 - 44 C sensor range

Medicap, Germany: Precise 8008 Gen.2



Basic Science Research

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

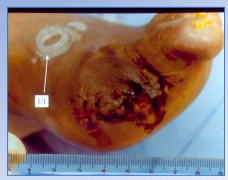
Leenstra BS, *et al.* Ann Vascular Surgery 2021;77:274-279

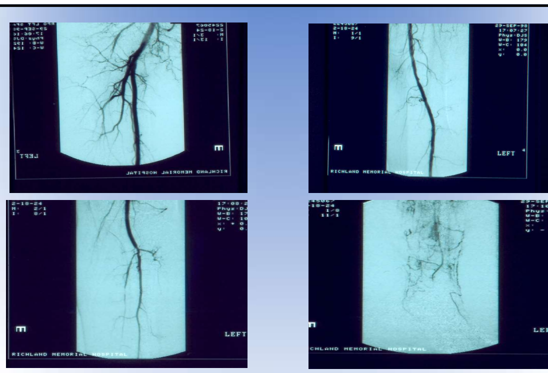
Photo-optical tcpO2 demonstrated acceptable agreement with electro-chemical tcpO2

Photo-optical values are in general higher in comparison

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

Pt. admitted, further surgery contemplated, HBO consulted





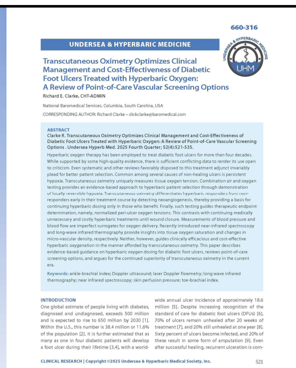
Transcutaneous Tissue Oxygen Tension

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. O2; dialysis; caffeine, nicotine
- Associated consumables expense



660-316

UNDERSEA & HYPERBARIC MEDICINE

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

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ABSTRACT

Clarke R. 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 . Undersea Hyperb Med. 2025 Fourth Quarter; 52(4):521-535.

Hyperbaric oxygen therapy has been employed to treat diabetic foot ulcers for more than four decades. While supported by some high-quality evidence, there is sufficient conflicting data to render its use open to criticism. Even systematic and other reviews favorably disposed to this treatment adjunct invariably plead for better patient selection. Common among several causes of non-healing ulcers is persistent hypoxia. Transcutaneous oximetry uniquely measures tissue oxygen tension. Combination air and oxygen testing provides an evidence-based approach to hyperbaric patient selection through demonstration of locally reversible hypoxia. Transcutaneous oximetry differentiates hyperbaric responders from non-responders early in their treatment course by detecting neoangiogenesis, thereby providing a basis for continuing hyperbaric dosing only in those who benefit. Finally, such testing guides therapeutic endpoint determination, namely, normalized peri-ulcer oxygen tensions. This contrasts with continuing medically unnecessary and costly hyperbaric treatments until wound closure. Measurements of blood pressure and blood flow are imperfect surrogates for oxygen delivery. Recently introduced near-infrared spectroscopy and long-wave infrared thermography provide insights into tissue oxygen saturation and changes in micro-vascular density, respectively. Neither, however, guides clinically efficacious and cost-effective hyperbaric oxygenation in the manner afforded by transcutaneous oximetry. This paper describes evidence-based guidance on hyperbaric oxygen dosing for diabetic foot ulcers, reviews point-of-care screening options, and argues for the continued superiority of transcutaneous oximetry in the current era.

Keywords: ankle-brachial index; Doppler ultrasound; laser Doppler flowmetry; long wave infrared thermography; near infrared spectroscopy; skin perfusion pressure; toe-brachial index.

INTRODUCTION

One global estimate of people living with diabetes, diagnosed and undiagnosed, exceeds 500 million and is expected to rise to 650 million by 2030 [1]. Within the U.S., this number is 38.4 million or 11.6% of the population [2]. It is further estimated that as many as one in four diabetic patients will develop a foot ulcer during their lifetime [3,4], with a world-wide annual ulcer incidence of approximately 18.6 million [5]. Despite increasing recognition of the standard of care for diabetic foot ulcers (DFUs) [6], 70% of ulcers remain unhealed after 20 weeks of treatment [7], and 20% still unhealed at one year [8]. Sixty percent of ulcers become infected, and 20% of these result in some form of amputation [9]. Even after successful healing, recurrent ulceration is com-

