Transcutaneous Oxygen Testing of the Hyperbaric Problem Wound Referral

Radiometer Webinar Series

February 4, 2015

Disclosure

I have occasionally served as a consultant for Radiometer, Inc., and have occasionally received compensation for speaking at conferences sponsored by Radiometer, Inc.

Lecture Outline

Genesis & clinical evolution of transcutaneous oximetry

Algorithmic implementation for hyperbaric referrals

Normal, adequate, abnormal LE values

Provocative maneuvers

Site selection principals

Interpretational fundamentals

Naming Conventions

Transcutaneous oximetry

Transcutaneous oxygen (tension) testing

$TcPO_2$ vs. $tcpO_2$

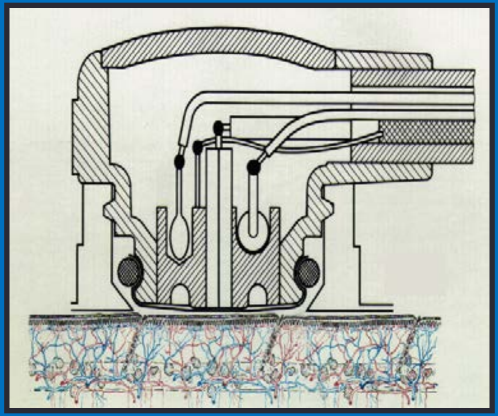
$PtcO_2$ vs. $ptcO_2$

TCOMS

Transcutaneous Oximetry

Non-invasive physiologic assessment of skin microcirculatory oxygen delivery

~ in contrast to standard hemodynamic & anatomic testing



Historical perspectives

- Neonatology
- Plastic Surgery
- Orthopedic Surgery
- Vascular Surgery

Respiration Physiology (1967) **3**, 21–37; *North-Holland Publishing Company, Amsterdam*

660-065

THE SYSTEMIC OXYGEN SUPPLY TO THE SURFACE OF HUMAN SKIN

N. T. S. EVANS AND P. F. D. NAYLOR

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Abstract. The oxygen tension at the surface of inflamed and non-inflamed forearm skin was measured with a polarographic electrode system which excluded the direct oxygen supply from the atmosphere. The tension at equilibrium on the surface of non-inflamed skin was less than 3.5 mm Hg, during the breathing of either air or oxygen. Spontaneous fluctuations in tension occurred with an R.M.S. amplitude which was about 20% of the mean tension. On skin inflamed by treatment with thurfyl nicotinate, histamine or ultra-violet light, or by stripping with Sellotape, the oxygen tension rose to about 30 mm Hg during the breathing of air, and to about 350 mm Hg during the breathing of oxygen. The effects of partial and total occlusion of the blood supply to the arm and of indirect heating of the subject were studied. The oxygen gradient from the sub-papillary capillaries to the skin surface was calculated from two sets of data, and mean values of 40 mm Hg ±9 S.D. and 45 mm Hg ±7 S.D. were obtained.

Oxygen gradient across the skin Skin oxygen tension
Skin blood flow

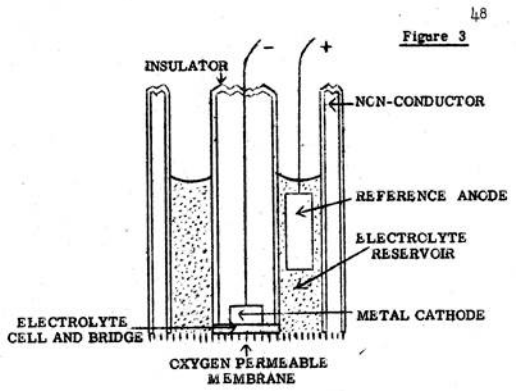
It has long been known (GERLACH, 1851) that oxygen passes into human skin from the atmosphere, and SHAW and MESSER (1931) showed that when the skin is allowed to reach equilibrium with a limited volume of gas, the oxygen tension in the gas becomes low. The oxygen tension at the skin surface when the atmospheric oxygen supply is excluded may conveniently be measured using the polarographic method. The tension thus measured is dependent upon both the oxygen tension in the superficial blood vessels of the skin and the metabolic consumption of oxygen by the epidermis and dermis. A polarographic electrode system suitable for such measurements was designed, and its construction and use in the study of forearm skin are described below.

Methods

The polarographic electrode assembly is shown in fig. 1. The cathode consisted of a platinum wire A, 25 μ in diameter, sealed by an electric heating coil into 1 mm bore soda glass tubing having an external diameter of about 5 mm. For one series of experiments electrodes were made having three or more such wires sealed separately

Accepted for publication 10 April 1967.

Evans NTS, Naylor PFD: 1967
Respiration Physiology ;3:21-37



Clark LC, *et al*. 1953
J Applied Physiology;6:189-193

Pflügers Arch. 337, 185—198 (1972)

660-114

Quantitative Continuous Measurement of Partial Oxygen Pressure on the Skin of Adults and New-Born Babies*

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and Frauenklinik der Universität Marburg, Germany

Received August 21, 1972

Summary. It is possible to perform continuous quantitative P_{O_2} measurements on vasodilated skin by means of surface Pt electrodes according to Clark when the electrode is fixed to the skin with a synthetic plastic material and in situ calibration is performed. A new in situ calibration of the P_{O_2} electrode is described. At first the skin P_{O_2} increases with O_2 inspiration. After perfusion stop the skin P_{O_2} shows a linear decrease because of the skin respiration, down to a P_{O_2} at which hemoglobin liberates chemically bound O_2. As this P_{O_2} value of hemoglobin is known it is possible to use it for calibrating the electrode. The P_{O_2} of normal skin is about 0—7 Torr. After vasodilation obtained by rubbing with a nicotinic acid derivate (Finalgon®, Anasco, Wiesbaden), P_{O_2} increases to a mean value of 38.1 (± 8.1) Torr ($n = 77$). Under these conditions, skin P_{O_2} reaches arterial values never in adults and rarely in new-born babies.

Key words: Pt Electrode — Surface P_{O_2} of Skin — in situ Calibration of the P_{O_2} Electrode — Skin Hyperaemia.

Oxygen pressure on the skin is determined by factors such as arterial oxygen pressure, skin blood circulation, skin respiration, and diffusion conditions for O_2.

Hitherto the difficulty in measuring skin P_{O_2} has consisted in the fact that there was no method for calibrating the P_{O_2} electrode in situ and that it was impossible to fix the electrode on the skin without loss of mobility of the body. For the measurement it is necessary to use electrodes of sufficient long-term stability. This was achieved by membrane-covered Pt-multiwire electrodes (Clark, 1956) which were stabilized by an intermediate layer according to Gleichmann and Lübbers (1960). A new method was developed for in situ calibration which considers the change of oxygen solubility, caused by the chemical binding of O_2 to

* Part of the results have been reported during the Workshop on Oxygen Transport in Tissue, 19—22 July, 1971, in Dortmund and at the „4. Deutsche Kongress für Perinatale Medizin", 4—6 Nov. 1971, in Berlin. The study was carried out with partial support from the German Research Council (DFG).

Pflugers Archiv: European J. of Physiology
Issue 3, p. 185-198
(no month listed)

Huch R, *et al.* 1972
Pflugers Archiv;337(3):185-198

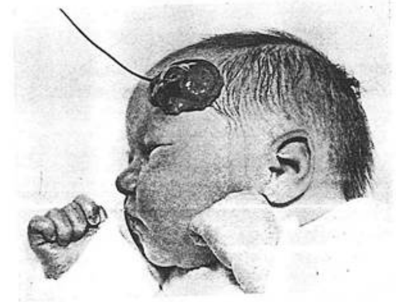

Fig. 2. P_{O_2} electrode fixed with Xantopren® to the new-born baby's head

660-023

Transcutaneous PO_2 in Flaps: A New Method of Survival Prediction

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Irvine, Calif.

Transcutaneous oxygen monitoring equipment is now used routinely in neonatal intensive care units and is potentially available also to the plastic surgeon. The original intention of transcutaneous $P_{tc}O_2$ was an attempt to determine the arterial PO_2 by noninvasive methods.[1]

The correlation with arterial oxygen has been extensively studied.[5] Tissue oxygen levels have been monitored in flaps by various means and have been shown to reflect circulation.[2,3,4] It occurred to us that $P_{tc}O_2$ might also reflect circulation in certain skin sites, assuming that a normal arterial PO_2 exists. Our initial investigation supported this theory,[5] as did Svedman's studies.[6] Although circulation of a skin flap can be assessed with microspheres, xenon scans, and fluorescein dye, these are not readily applicable to constant monitoring.

ELECTRODE CONFIGURATION AND THEORY

A transcutaneous oxygen sensor in a Clark-type configuration was used. It consisted of a silver anode and a platinum cathode (Fig. 1) surrounded by KCl electrolyte and a Mylar membrane, employing polarography to sense oxygen. A voltage of -0.7V was applied between the cathode and anode, and the current that flowed between them was directly proportional to the number of oxygen molecules reduced at the cathode.

On a normal person, the amount of oxygen coming through the skin is very small. To increase this amount, local hyperemia was produced by a heating coil inside the silver anode of the electrode. The heat capacity of the anode gave stability to temperature fluctuations, which was servocontrolled by an electronic comparitor circuit, thus maintaining the temperature set at ±0.2°C. This increase in blood flow increased the measurable amount of oxygen diffused through the skin.

Great variation is found in the actual readings. To compare one animal with another and one species with another, each flap measurement was expressed as a percent of the reading obtained in a nonoperative site on the same organism at the same time.

$$\text{Percent of normal} = \text{Flap } P_{tc}O_2/\text{normal } P_{tc}O_2$$

Thus differences in level of anesthesia, skin thickness, and so forth could be eliminated. This procedure also served as a constant check on the functioning of the equipment.

Before applying the electrode, the skin was cleaned with alcohol and then an attachment jig was placed on the skin with a double-sided adhesive (Fig. 2). A drop of water was applied to the skin under the sensor for gas and heat transfer and was then inserted into the attachment jig. Equilibration of the blood flow and gas transport took 10 to 20 minutes. The sensor we used for a major portion of the experiments was a Beckman prototype* instrument, but we also employed a radiometer† instrument and found it acceptable.

MATERIALS AND METHODS

Rabbit Experiments

Sixteen male, white New Zealand rabbits were anesthetized with intravenous sodium pentobarbital (0.5 gm/kg). Then 4 × 12 cm flaps were raised on their backs, and the flaps were made

* Beckman Instruments, Inc., Clinical Instrument Division, 2500 Harbor Blvd., Fullerton, Calif. 92636.
† Radiometer (The London Co.), 811 Sharon Drive, Cleveland, Ohio 44145.

From the Division of Plastic Surgery at the University of California, Irvine.

Achauer BM, *et al.* 1980
Plastic & Reconstructive Surg;65(6):738-745

660-009

Current Concepts Review

Determining Amputation Levels in Peripheral Vascular Disease*†

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From the Prosthetics Research Study Center, and the Limb Viability Laboratory, Department of Orthopaedics, University of Washington, Seattle

There is currently a relative and absolute increase in the number of amputations being performed for vascular disease. An aging population; a high incidence of diabetes; air, water, and food contamination; physical inactivity; poor diet; and tobacco-smoking are all indicted as contributing factors. Old and recent failed vascular reconstructions add to the load.

The success of rehabilitation following amputation is directly related to the level of limb loss. The greater the loss, the more prosthetic substitution required. Continuing improvements in prosthetic design cannot substitute for the advantages of a low level of amputation. Retention of the knee is especially important. A functional knee often will allow an elderly person to walk, whereas he or she could not do so with an above-the-knee prosthesis. It is, therefore, of the utmost importance that the surgeon be able to assess accurately the viability of the limb so that amputation can be performed at the lowest reasonable level.

A baseline level of vascular perfusion of the extremity is necessary to maintain the metabolic needs of the skin, greater perfusion being required when the skin has been traumatized. If adequate perfusion cannot be obtained by therapeutic intervention, amputation becomes necessary. In selecting the level of amputation the surgeon must balance the need for retaining optimum limb length against the necessity for obtaining primary wound-healing. Much effort has been directed toward identifying reliable predictors of healing at each of the different potential amputation levels. When available, these probability data can be combined with other information, such as the potential for rehabilitation of the individual patient, to determine the ideal level of amputation.

The techniques that are available for the assessment of circulation in the extremity may be grouped according to what is being measured (Table I): (1) extremity blood flow, (2) arterial blood flow, (3) muscle perfusion, (4) skin blood flow, (5) oxygen delivery to the skin, (6) segmental blood pressure, (7) skin blood pressure, and (8) skin function. Each of these techniques provides useful information about the circulatory status of the limb and each is to some degree predictive of the healing potential at a given level of amputation. Conversely, no single technique available today can unfailingly predict the outcome of an amputation. There are several reasons for this:

1. The act of amputation alters the blood flow in the extremity by removing distal vascular runoff as well as some collateral pathways. While healing of the amputation depends on the postoperative circulatory status, the amputation level must be selected on the basis of preoperative data.

2. Although measuring techniques can provide information about a number of the factors involved in the circulation of the extremity, none of them specifically quantitates the ability of the limb to heal after an amputation.

3. Details of surgical technique such as tissue-handling, flap length, and shape and tension of the wound vary from amputation to amputation. In each patient, different demands are placed on the healing potential of the skin and the underlying tissue.

4. The specifics of postoperative care, such as the use of rigid dressings, may alter circulation to the healing skin by modifying wound tension and local pressure.

5. Poor patient health may compromise the ability of the wound to respond to the metabolic challenge of tissue-healing.

6. Intercurrent disease such as thrombosis of the arteries to the residual limb or wound infection, or other postoperative problems such as malnutrition, pneumonia, atelectasis, and pulmonary embolism may prevent healing of an otherwise successful amputation.

A review of these factors suggests that it should be easier to predict failure than success of an amputation at a given level. In other words, if the test can demonstrate circulatory deficiency of such a degree that the con-

* Reprints are not available from the author. The Current Concepts Reviews for 1981 will be gathered as one reprint and offered for sale by The Journal in 1982.

† This work was supported in part by Veterans Administration Contract V663P-1081.

‡ Prosthetics Research Study Center, 1102 Columbia Street, Suite 409, Seattle, Washington 98104.

§ Limb Viability Laboratory, Department of Orthopaedics, University of Washington, Seattle, Washington 98195.

Burgess EM, Matsen FA 1981
Journal Bone & Joint Surg:1493-1467

660-006

Oxygen inhalation–induced transcutaneous Po_2 changes as a predictor of amputation level

Timothy R. S. Harward, M.D., Jaroslav Volny, B.S., Frank Golbranson, M.D., Eugene F. Bernstein, M.D., Ph.D., and Arnost Fronek, M.D., Ph.D., *San Diego and La Jolla, Calif.*

Noninvasive transcutaneous Po_2 ($TcpO_2$) determinations have been developed to study peripheral arterial occlusive disease. To evaluate this technique as a predictor of amputation outcome, a blind, prospective study of 101 patients undergoing 119 amputations (23 above-knee [AK], 57 below-knee [BK], and 39 forefoot) was performed. $TcpO_2$ measurements were obtained from the dorsum of the foot and 10 cm distal to the patella, both prior to and 10 minutes after inhalation of 100% oxygen. On the basis of preliminary results, initial $TcpO_2$ values >10 mm Hg or an increase >10 mm Hg after oxygen inhalation were considered to predict a successful outcome, whereas failure was predicted when the initial $TcpO_2$ value was <10 mm Hg and the increase after oxygen inhalation did not exceed the 10 mm Hg level. In the BK amputation group the test was 95% sensitive, 100% specific, and 95% accurate. Retrospective utilization of the above criteria in patients who had undergone both oxygen inhalation testing and AK amputation suggested that 9 of 17 limbs (53%) might have undergone a more distal BK amputation successfully. These results document the effectiveness of an initial $TcpO_2$ determination coupled with the response to 100% oxygen inhalation as an excellent predictor of the outcome of lower extremity amputations. (J VASC SURG 1985; 2:220-7.)

Increased emphasis on rehabilitation has encouraged the surgeon to move amputation levels as distally as possible. In an effort to predict more accurately amputation success at each level, surgeons initially attempted to correlate clinical signs (i.e., operative bleeding, skin color, and level of dependent rubor) with amputation success rates.[1-3] These findings were soon found to be unreliable and more objective methods were sought to accurately assess tissue perfusion status.

Recently Huch et al.[4,5] introduced a method for measuring the transcutaneous partial pressure of oxygen ($TcpO_2$) in neonates, which reflected the arterial Po_2 levels, provided that severe hemodynamic disturbances could be excluded (e.g., shock). A logical extension of this technique was to evaluate patients with peripheral vascular disease and, especially with rest pain, ischemic ulcers and gangrene when amputation was contemplated. Preliminary results in this laboratory demonstrated that $TcpO_2$ provided good separation between those limbs in which amputation failed and the majority of limbs in which

Table I. Classification of wound healing after amputation

Successful amputation
Per primam healing in 4 weeks
Granulation completed
No need for additional amputation
Successful amputation with prolonged healing
Delayed healing of more than 4 weeks
Granulation not completed
Eventual healing in more than 4 weeks
No need for additional amputation
Failure
Necrosis/gangrene
No granulation
Additional amputation

From the Departments of Surgery and Bioengineering, University of California, San Diego, School of Medicine, La Jolla, and The Veterans Administration Hospital, San Diego (Drs. Harward, Golbranson, Fronek, and Mr. Volny) and the Department of Surgery, Scripps Clinic and Research Foundation, La Jolla (Dr. Bernstein).

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Supported by NHLI HL-18977.

Reprint requests: Arnost Fronek, M.D., Ph.D., AMES-Bioengineering, M-005, University of California, San Diego, La Jolla, CA 92093.

Harward TRS, *et al.* 1985
Journal Vascular Surg;2:220-227

TRANSCUTANEOUS OXYGEN TENSION MEASUREMENT IN PERIPHERAL VASCULAR DISEASE

660-043

Frederick A. Matsen III, M.D., Craig R. Wyss, PH.D., Larry R. Pedegana, M.D., Richard B. Krugmire, Jr., Charles W. Simmons, Racheal V. King *and* Ernest M. Burgess, M.D., F.A.C.S., *Seattle, Washington*

THE KEY to understanding and managing the patient with peripheral vascular disease is the ability to quantify the severity of the vascular insufficiency. If available, this quantification would be a powerful means of facilitating the diagnosis of vascular disease, evaluating the natural history of different disease processes, demonstrating the effectiveness of various treatment modalities and assisting in the selection of ideal amputation levels. Several methods are of proved clinical use, such as the determination of segmental blood pressure and the measurement of the rate of ^{133}Xe washout. We are investigating a different approach to the assessment of the adequacy of local cutaneous circulation, that is, the use of the transcutaneous pO_2 sensor. Although monitoring of transcutaneous pO_2 is of established value in following the arterial pO_2 of neonates, we have also found it to be useful in quantitating oxygen delivery to the skin of adult extremities. In this article, the method, data from normal persons and our first results for patients with peripheral vascular insufficiency are presented.

METHOD

We used a standard, commercially available transcutaneous pO_2 sensor which was held to the skin with an adhesive ring. This sensor polarographically quantitated oxygen diffusing from the skin through its thin polypropylene membrane. The probe contained a thermistor controlled heating element that allowed the skin beneath the membrane to be maintained at the desired temperature. Prior to application, the system was zeroed in a sodium sulfite solution at 43 degrees C. and calibrated in water tonometered with room air, also at 43 degrees C. The stratum corneum of the skin, at the desired measurement site, was removed by repeated stripping with cellophane tape. After the probe was in place, the local skin temperature was raised to 45 degrees C. for ten minutes and then lowered to 44 degrees C. for another ten minutes or until a stable pO_2 reading was obtained. All measurements were taken with the patient in the supine position, unless otherwise specified. Standard sampling sites were 10 centimeters above the patella, 10 centimeters below the patella and on the dorsum of the foot, approximately over the medial cuneiform bone. In most persons, transcutaneous pO_2 measurements were also made over the left fourth intercostal space on the chest.

Those included in the study were 13 normal volunteers of both sexes, ranging in age from 22 to 35 years. In some normal persons, the transcutaneous pO_2 was measured with the limb in different positions in relation to the heart. Patients included four men with arteriosclerotic vascular disease and five men with diabetic vascular disease. Their ages ranged from 46 to 72 years.

In some instances, the results were available both before and after a treatment procedure, such as vascular reconstruction or amputation. In these instances, treatment was carried out by physicians not knowing the results of the pO_2 determinations. Segmental systolic blood pressures were obtained at the arm, thigh, leg and ankle with a Doppler, and an appropriately sized blood pressure cuff. Ischemic ratios were calculated by dividing the systolic blood pressure at a given leg level by the systolic brachial artery blood pressure of that patient, as described by Wagner (7).

RESULTS

In Figure 1, results are given for the 13 normal persons. The average transcutaneous pO_2 values were slightly less at the periphery than centrally. In Figure 2 is demonstrated a typical relationship of transcutaneous pO_2 measured at the foot to foot position relative to the heart in the normal

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Matsen FA, *et al.* 1980
Surgery, Gynecology & Obstetrics;150:525-528

Reprinted from the Archives of Surgery
June 1984, Volume 119

660-002

Superiority of Transcutaneous Oximetry in Noninvasive Vascular Diagnosis in Patients With Diabetes

Carl J. Hauser, MD; Stanley R. Klein, MD; C. Mark Mehringer, MD; Paul Appel, MPA; William C. Shoemaker, MD

• Transcutaneous oxygen tension $P_{tc}O_2$ is directly related to skin oxygen delivery. Regional transcutaneous oximetry (RTO) compares peripheral and truncal ($P_{tc}O_2$), yielding a regional perfusion index indicative of local limb perfusion. The relative diagnostic values of RTO, Doppler ankle-brachial pressure ratio (ABR), pulse volume recording (PVR), and toe pulse reappearance time (PRT/2) were studied in 64 limbs of patients with diabetes. These limbs were clinically classifiable into claudication, rest pain, and gangrene groups. Regional transcutaneous oximetry had a higher diagnostic accuracy than ABR ($\chi^2=27.47$, $P<.001$), PVR ($\chi^2=7.54$, $P<.01$), and PRT/2 ($\chi^2=10.99$, $P<.001$). Regional transcutaneous oximetry was universally applicable and the degree of hypoxia observed correlated with clinical symptoms. Significant hypoxia predicted large-vessel angiographic lesions, many of which were reconstructible. Regional transcutaneous oximetry should be the initial noninvasive test in diabetic peripheral vascular disease.

(*Arch Surg* 1984;119:690-694)

Nowhere is the need for accurate noninvasive vascular testing more obvious than in the patient with diabetes who has peripheral vascular disease. The diabetic limb may be compromised by accelerated atherosclerosis, arteriolar sclerosis, neuropathic injury, and decreased resistance to invasive infection. All or some of these may contribute to limb threat, but since the treatment of each pathologic entity differs, appropriate management requires clarification of which processes are of primary importance in each individual case. The overriding diagnostic and therapeutic consideration is whether limb ischemia exists and, if it does, whether it can be treated by vascular reconstruction. The anatomic feasibility of reconstruction can only be determined by angiography, but the morbidity of angiography and relative infrequence of reconstructible disease in these patients mandates a selective approach.

Noninvasive vascular diagnostic techniques assess arterial hemodynamics in the leg and have proved very helpful in the selection of patients without diabetes for arteriography.[1] Cuff occlusion tests, however, are often inaccurate in patients with diabetes[2,3] because the calcification of the arterial tree results in hemodynamics that correlate poorly with perfusion of the limb.

Regional transcutaneous oximetry (RTO) has been shown to assess limb ischemia in peripheral vascular disease directly by comparing the cutaneous oxygenation of involved limbs with that of uninvolved regions of the body.[4,5] We therefore believed that it might be uniquely suited to noninvasive diagnosis in the patient with diabetes. In this study, we compare RTO with standard noninvasive tests in the diagnosis of limb ischemia and as an aid to clinical judgment in the assessment of the need for angiography in patients with diabetes.

SUBJECTS AND METHODS

Clinical Series

During the period from July 1981 to September 1983, 46 consecutive patients admitted to Harbor/UCLA Medical Center because of vascular disease were referred for evaluation of peripheral vascular disease by transcutaneous oximetry. Patients averaged 63 years of age (range, 46 to 77 years); 25 were men and 21 women. Twenty-seven patients were insulin dependent and 19 controlled their diabetes by diet or oral hypoglycemic therapy. A significant smoking history (greater than ten pack-years) was obtained from 21 patients (46%). Thirty-four vascular reconstructive procedures were subsequently undertaken in 28 patients, ten major amputations were performed, and there were four deaths in the group.

Accepted for publication Feb 8, 1984.
From the Departments of Surgery (Drs Hauser, Klein, Appel, Shoemaker) and Radiology (Dr Mehringer), Harbor/UCLA Medical Center, Torrance, Calif.
Read before the 91st annual meeting of the Western Surgical Association, Monterey, Calif, Nov 15, 1983.
Reprint requests to Harbor/UCLA Medical Center, 1000 W Carson St, Torrance, CA 90509 (Dr Hauser).

Hauser CJ, *et al.* 1984
Archives Surgery; 119:690-694

Superiority of $tcpO_2$ Assessment

~ non-invasive lower extremity studies

Superiority of tcpO2 to Doppler studies highly significant

Hauser CJ, 1984

Regional tcpO2 had higher diagnostic accuracy than ABI; PVR & TPRT in diabetic vascular disease

Hauser CJ, 1984

tcpO2 provides most objective description of dermal metabolism & oxygen availability

Rhodes G, 1985

tcpO2 high degree of accuracy (vs. ABI; xenon-133; Doppler pressures) in predicting amputation site healing

Malone JM, 1987

Low $tcpO_2$ Predicts Abnormal Arteriography

96% of 66 limbs with $tcpO_2$ < 30mmHg had abnormal arteriogram

Ballard JL, *et al*. 1995

$tcpO_2$ <30mmHg a reliable indicator of need for arteriography, with 98% limbs showing significant disease

Bunt TJ, *et al*. 1996

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 tcpO_2 Hyperbaric Algorithm

Is wound healing complicated by hypoxia?

Is any such hypoxia reversible?

Is patient responding to HBO therapy?

Has a therapeutic endpoint been reached?

Not undertaking such determinations?
…Margolis et al. Diabetes Care 2013

What is a Normal Lower Extremity $tcpO_2$ Value?

Dermal oxygenation mapped in healthy volunteers

Eickhoff JH & Engell HC 1981
Wyss CR, et al. 1981
Franzeck UK, et al. 1982
Sheffield, PJ & Workman WT, 1985
Jonsson K, et al. 1987
Orenstein A, et al. 1988
Dowd GS, et al. 1993(a)
Dowd GS, et al. 1993(b)

a ‘normal’ $tcpO_2$ falls within a range of values (53-92 mmHg)

reasonable to conclude that normal values exceed 50 mmHg

What $tcpO_2$ Values Considered Suboptimal?

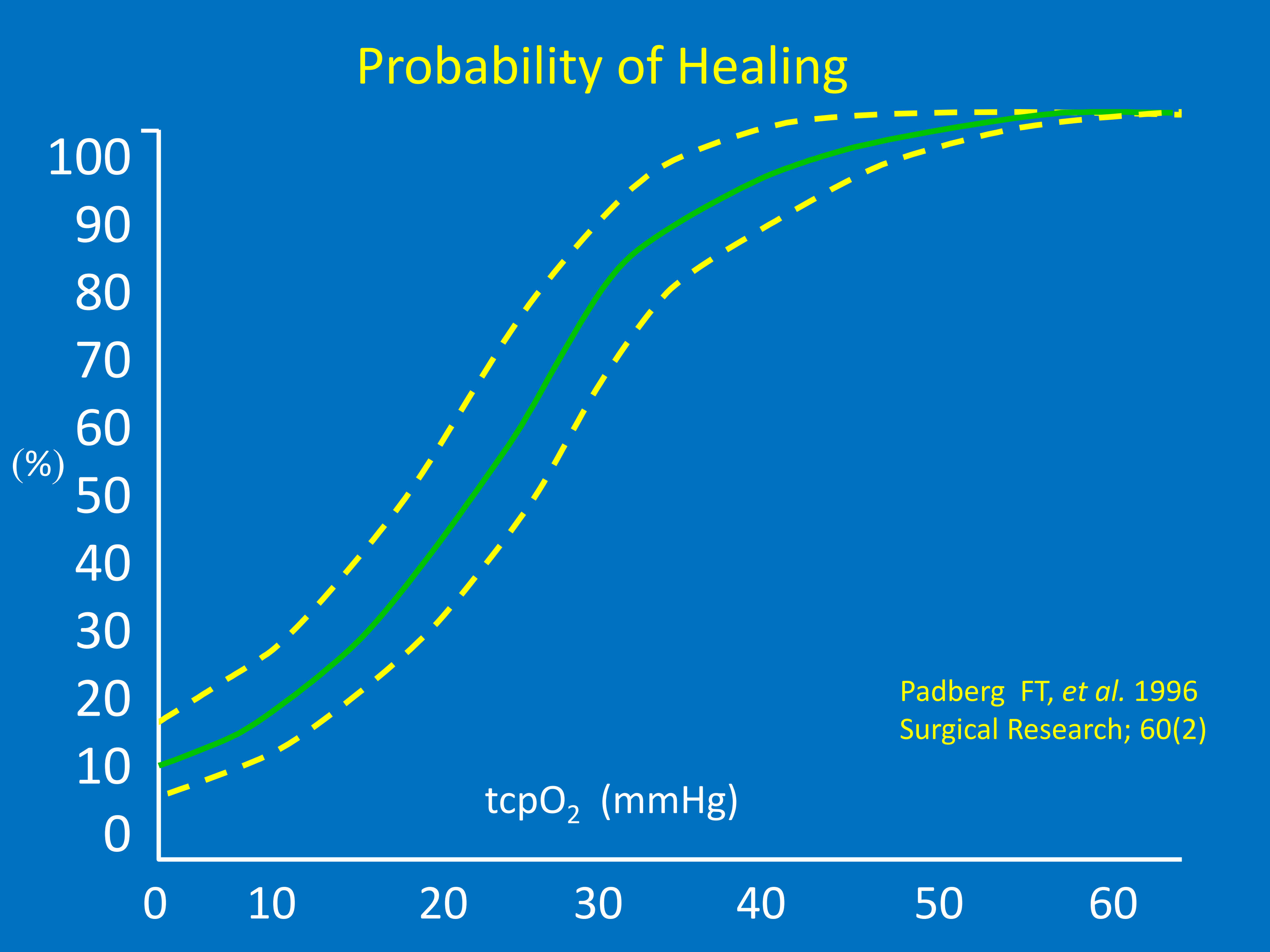
Values > 40 mmHg representative of adequately oxygenated tissue

~ normal oxidative function

Basic/clinical data suggests threshold range of < 35-40 mmHg as sub-optimal for O_2 dependent wound healing

One definition of 'critical limb ischemia' < 30mmHg

~ degree of adverse influence increases as values decrease



Probability of Healing
100
90
80
70
60
(%)
50
40
30
20
10
0
tcpO2 (mmHg)
0
10
20
30
40
50
60
Padberg FT, et al. 1996
Surgical Research; 60(2)

What About Any Control Sites?

Left second intercostal space grossly reflects state of 'central' oxygenation....*normal range 65-90mmHg (1.0 ATA)*

regional perfusion index (RPI)

Contra-lateral reference sites may represent poor comparison of normal to diseased tissue

Evolution of Provocative Maneuvers

Treadmill exercise-induced change in **R**egional **P**erfusion **I**ndex

Temporary limb ischemia-induced change in $tcpO_2$ recovery **‘TORT’**

Limb elevation-induced change in **RPI**…not limb elevation, *per se*

Each directed at assessment of PVD; surgical planning

None related to the issue of wound healing

$tcpO_2$ Provocative Manoeuver: HBO Referrals

Oxygen inhalation only provocative option that answers the key question:

Does physiologic capacity exist to respond locally to centrally delivered oxygenation?

Employable across continuum of $tcpO_2$ algorithm

Confirms adequacy of hyperbaric treatment pressure

Normobaric 100% Oxygen Challenge

Response ranges

> 300 mmHg…*regional large vessel disease unlikely*

200-300 mmHg…*minimal regional large vessel disease*

100-199 mmHg…*non-limb threatening ischemia*

51-99 mmHg…*significant ischemia: further arterial study*

< 50 mmHg…*high grade ischemia: further arterial study*

Systemic Factors Influencing $tcpO_2$

Pulmonary & cardiac function

Oxygen content

Central vascular perfusion

Peripheral vascular perfusion

Smoking, caffeine ingestion

Vaso-active pharmacologic/other such substances

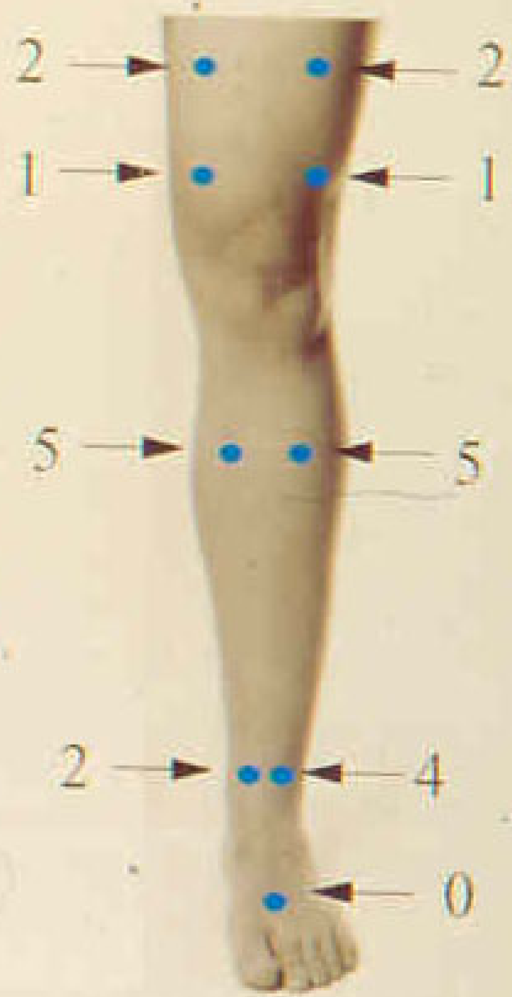
Environment (temperature /altitude)

HR: 80 yowm

Dx: Diabetic left foot gangrene

Respiratory failure

Reference: 42 mmHg (FiO_2 50%)



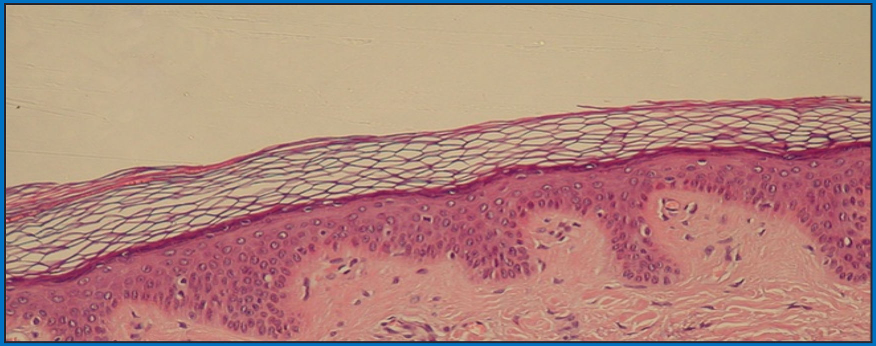
Local Factors Influencing $tcpO_2$

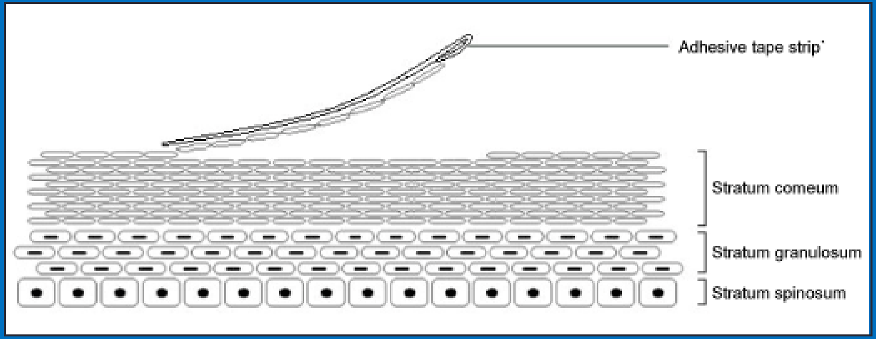
Obesity
Edema

Increased skin thickness
Cutaneous radiation tissue injury

Bony prominences

Poor skin preparation
Poor electrode attachment




Adhesive tape strip
Stratum comeum
Stratum granulosum
Stratum spinosum

Site Selection; Anatomic Factors

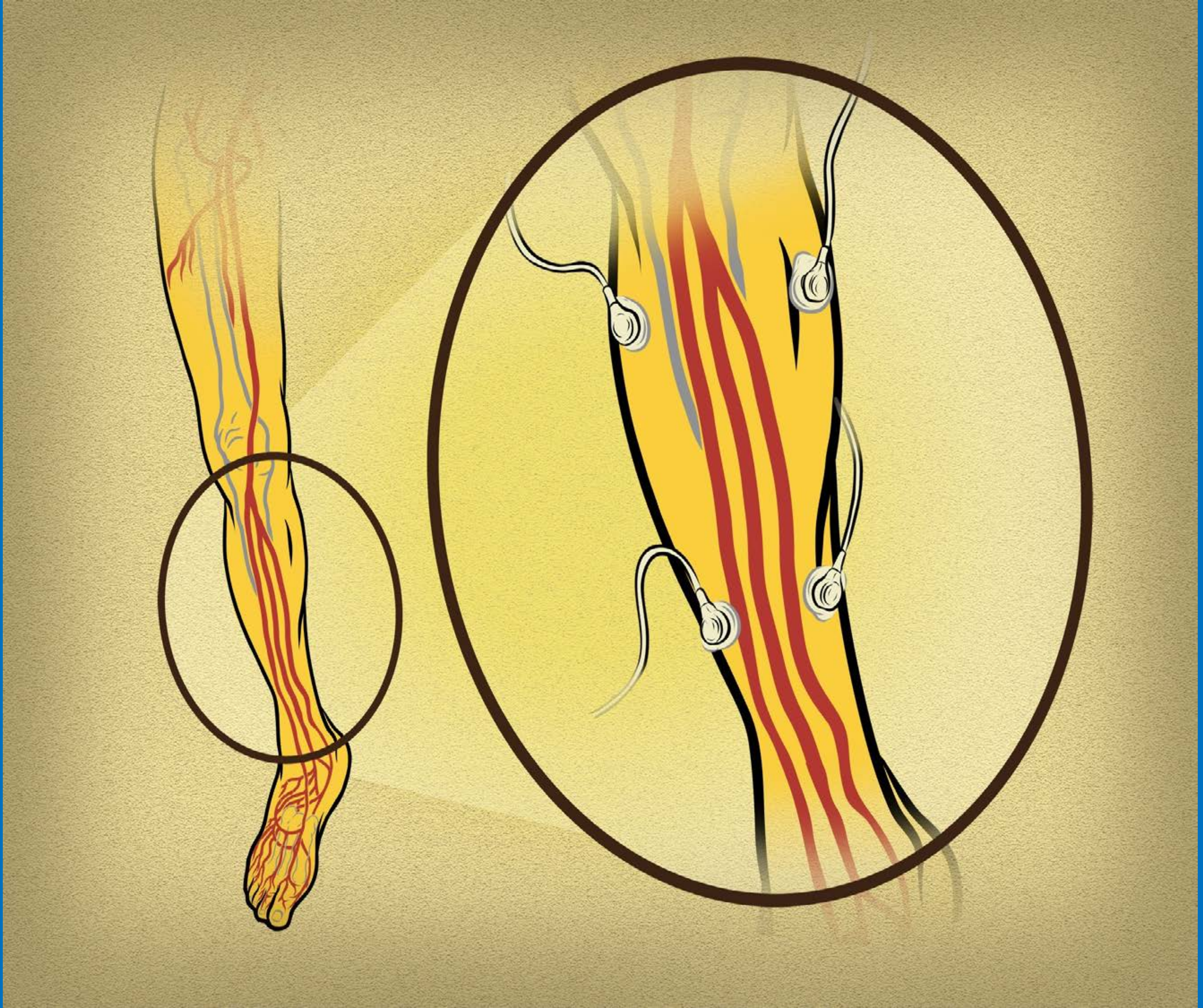
Sensor site selection straightforward enough if…

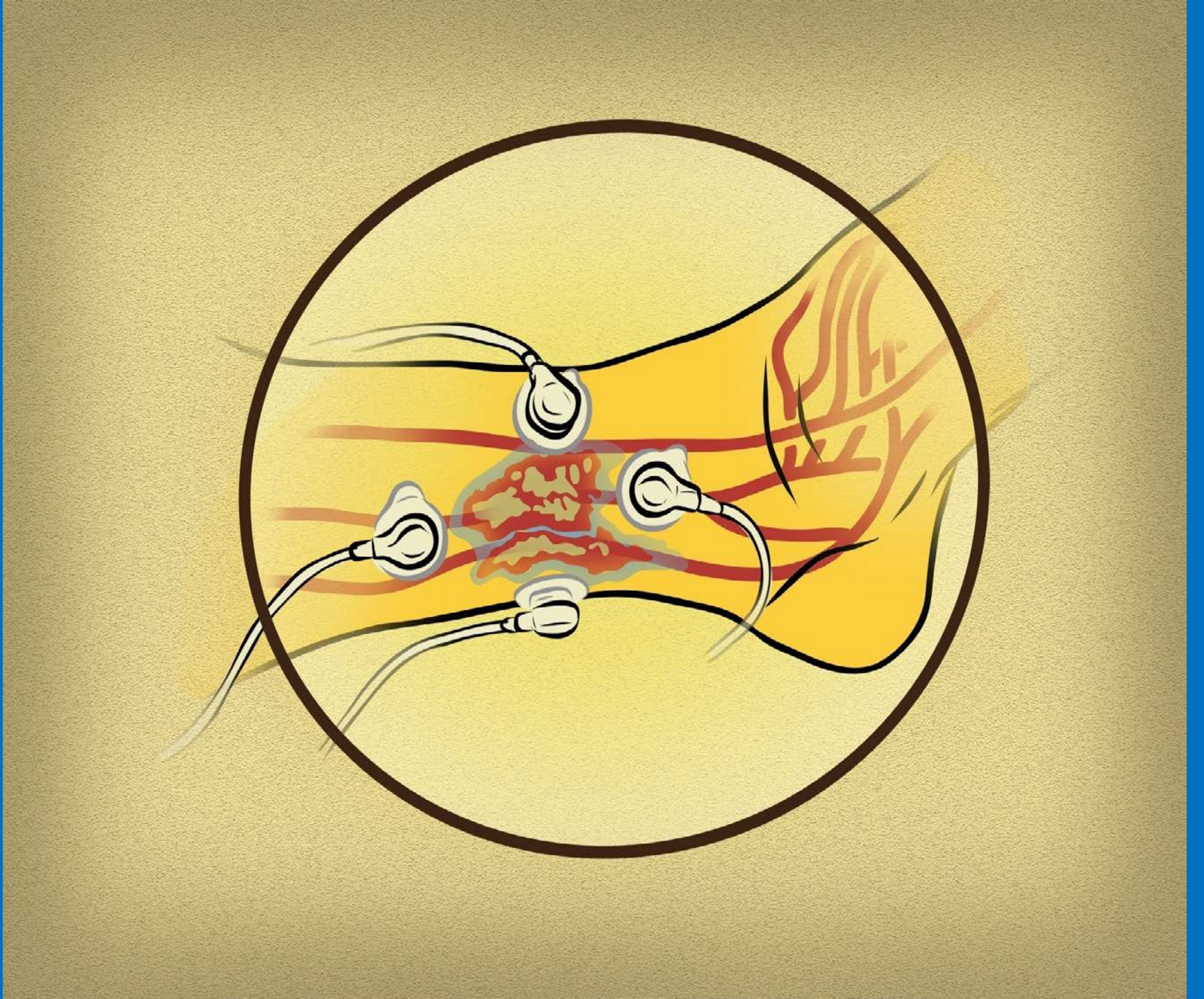
Clear understanding of question in need of address

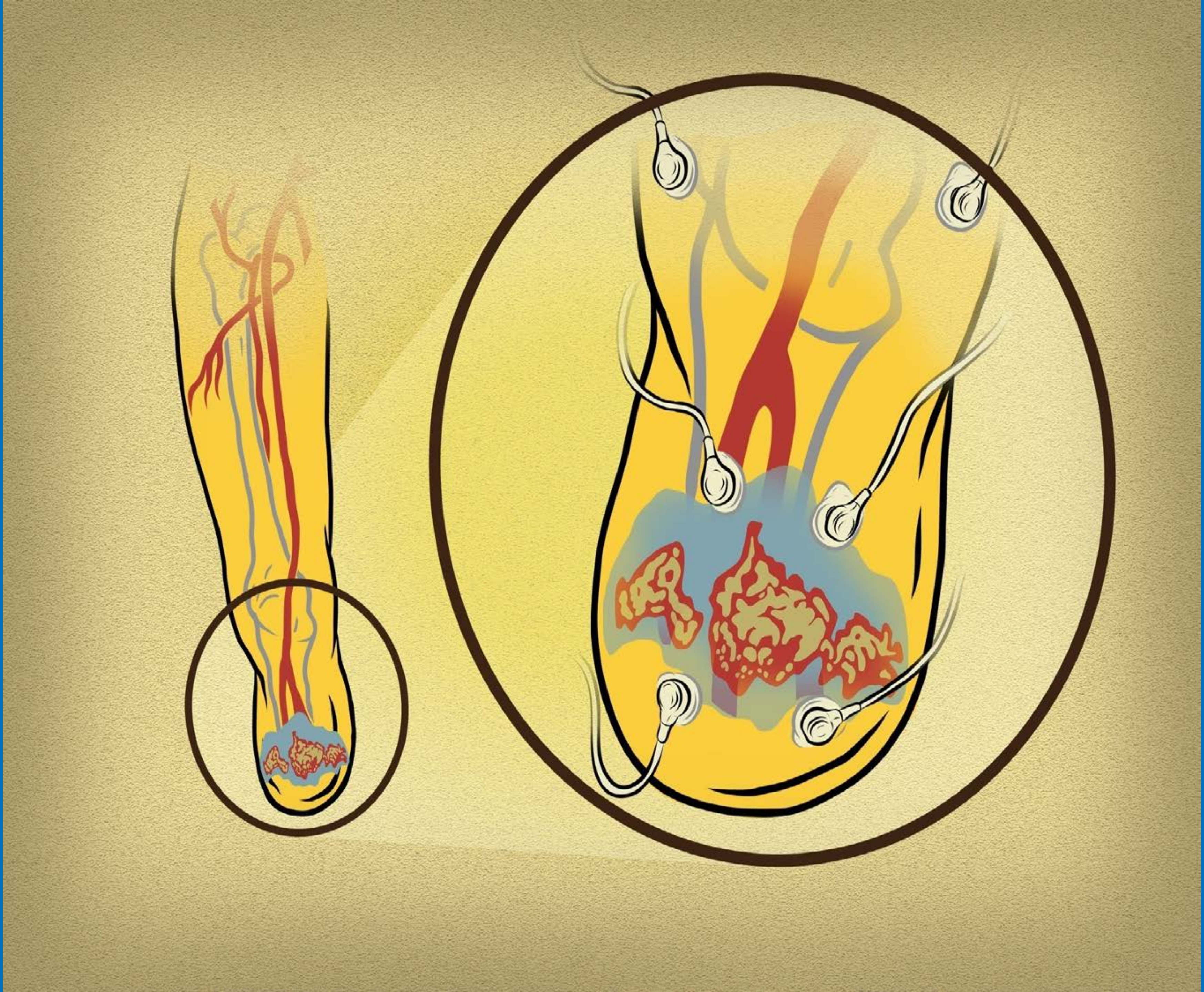
Appreciate principal determinant that answers question

Principal testing site(s) consistent with that determinant

Any necessary secondary testing site(s) incorporated







Transcutaneous Oximetry: When To Delay Testing

Immediately post hemo-dialysis

Nutritive skin perfusion impaired during dialysis, sufficient in some cases to produce chest/cardiac & leg pain

~ *significant tcpO_2 decreases in pts. with & without PVD*

Weiss T, *et al*. 1998
Neph Dial Trans; 13

Markedly edematous tissue

Edema represents a diffusion barrier between functioning capillaries & skin

Dooley J, *et al.* 1996
UHM;23(3): 167-174

Transcutaneous Oximetry: When To Delay Testing

Caffeine ingestion

Restrict caffeine-containing substances prior to tissue oximetry

~ *significant differences (S.D. 270 mmHg) in healthy subjects, sufficient to screen out otherwise suitable candidates*

Stephens M, *et al*. 1999
UHM;26(2): 93-97

Nicotine

Avoid any use for at least two hours prior to tissue oximetry

Jensen JA, *et al*. 1994
Arch Surg; 126:1131-1134

Supplemental oxygen administration

Absence of conversion factors

Peri-operative $tcpO_2$ Values

~ following limb revascularization

Measurement	Mean(mmHg)	S.D.
Preoperative	9.27**	12.14
POD #1	17.73*	15.86
POD #2	20.36*	5.61
POD #3	36.82**	18.80

** Not significant*

** * Significant p = 0.001*

Arroyo CI, *et al*. 2002
J. Foot Ankle Surg.41(4)

Possible Etiologies

Post-operative edema

Vasospasm, due to high pressures

Ischemia-reperfusion injury

Endothelial cell trauma

Micro embolic events

Effects of dye

Transcutaneous Oximetry

This evidence-based approach to hyperbaric wound healing confers:

More exacting patient selection

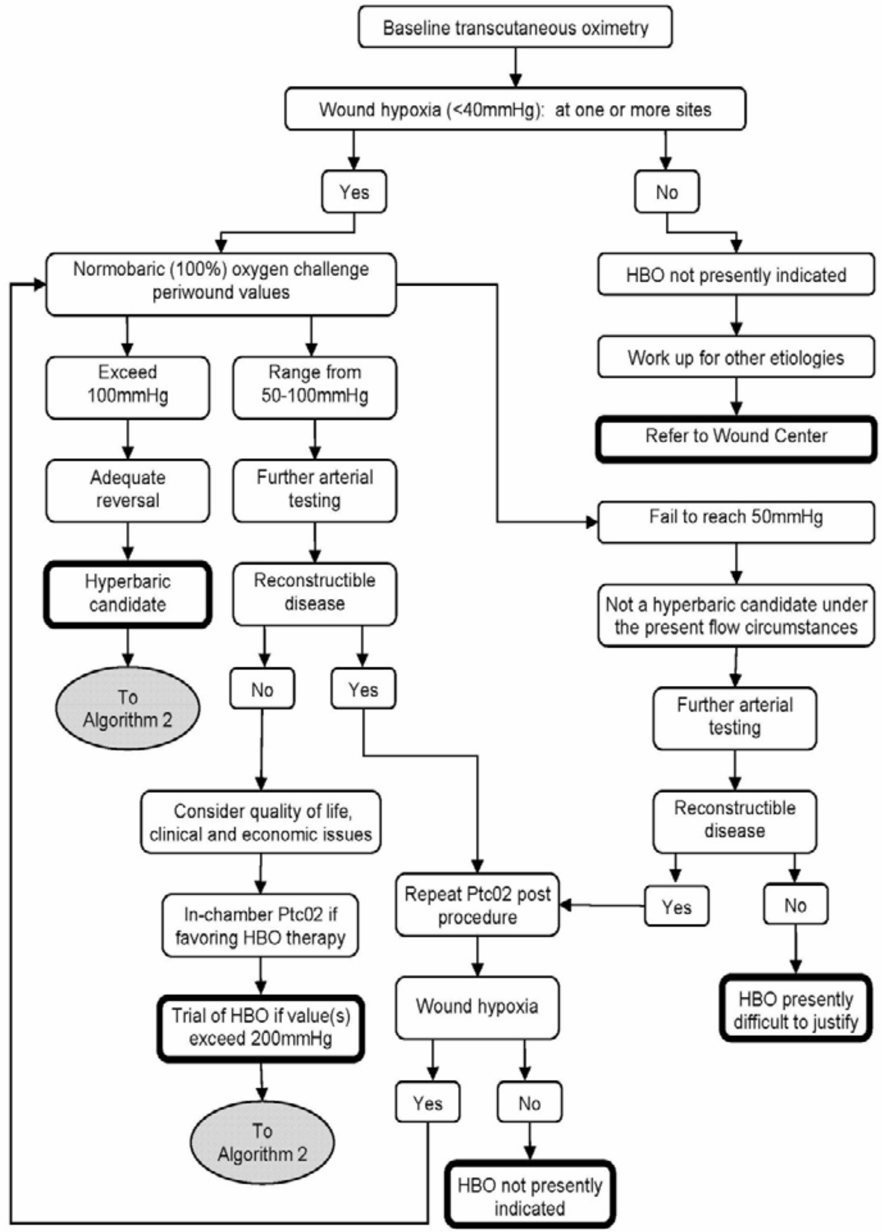
Algorithmic case management

Improved clinical outcomes

Enhanced cost-effectiveness

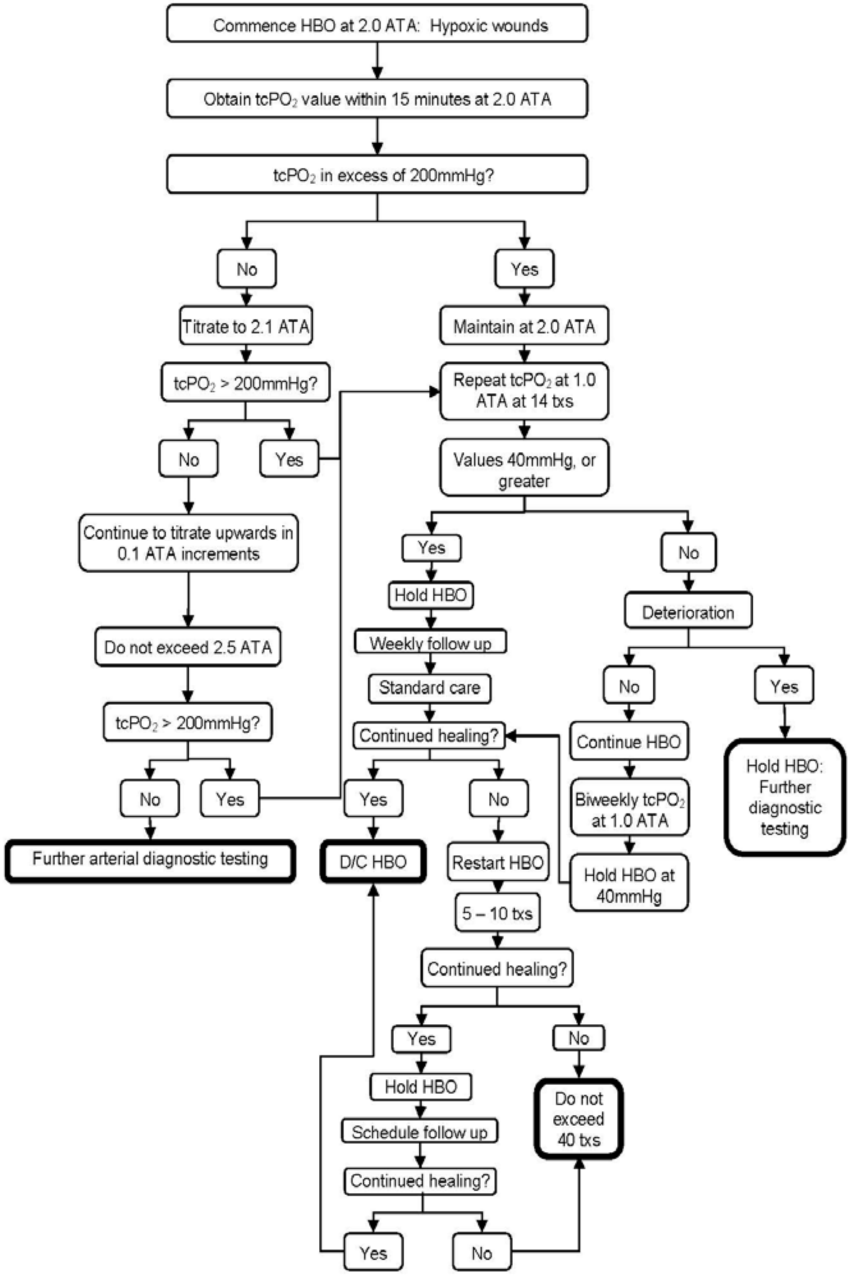
Normobaric Transcutaneous Algorithm

Algorithm 1



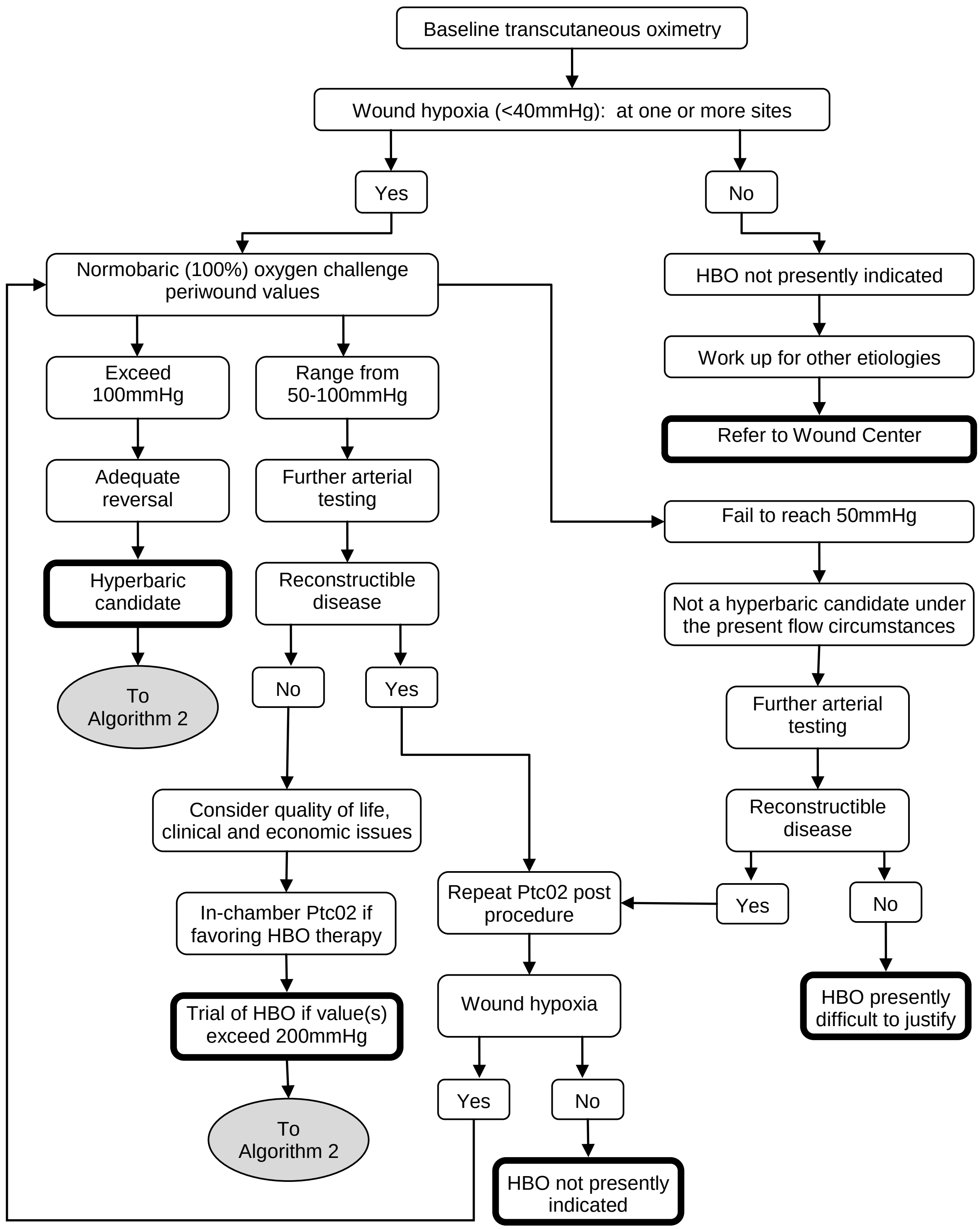
In-Chamber & Follow-Up Transcutaneous Algorithm

Algorithm 2



Normobaric Transcutaneous Algorithm

Algorithm 1



In-Chamber & Follow-Up Transcutaneous Algorithm

Algorithm 2