Original articles

Transcutaneous oximetry: variability in normal values for the upper and lower limb

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Key words
Hyperbaric oxygen therapy; Oxygen; Patient monitoring; Standards; Wounds

Abstract
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Introduction: Published normal transcutaneous oxygen partial pressures ($P_{tc}O_2$) for the chest and lower limb have defined tissue hypoxia as a value of < 40 mmHg (< 30 mmHg in some patients, < 50 mmHg in others).
Aim: To determine 'normal' $P_{tc}O_2$ for the upper and lower limb in healthy, non-smoking adults using the Radiometer® TCM400 with tc Sensor E5250.
Method: Thirty-two volunteers had transcutaneous oxygen measurements (TCOM) performed on the chest, upper and lower limbs breathing air, with leg then arm elevated and whilst breathing 100% oxygen.
Results: Room-air $P_{tc}O_2$ (mmHg, mean (95% confidence interval)) were: chest: 53.6 (48.7–58.5); upper arm: 60.0 (56.1–64.0); forearm: 52.3 (44.8–55.8); dorsum of hand: 50.2 (46.1–54.3); thenar eminence: 70.8 (67.7–73.8); hypothenar eminence: 77.9 (75.1–80.7); lateral leg: 50.2 (46.2–54.2); lateral malleolus: 50.5 (46.6–54.3); medial malleolus: 48.9 (45.6–52.1); dorsum, between first and second toe: 53.1 (49.2–57.0); dorsum, proximal to fifth toe: 58.5 (55.0 – -62.0); plantar, 1st MTP: 73.7 (70.3–77.1). Nineteen subjects had at least one room-air $P_{tc}O_2$ below 40 mmHg (nine upper limb, 13 lower limb, four chest). Approximately 10% lower limb $P_{tc}O_2$ were < 100 mmHg on normobaric oxygen. Only one subject at one site had an upper limb $P_{tc}O_2$ < 100 mmHg breathing oxygen.
Conclusion: The broad dispersion in $P_{tc}O_2$ in our healthy cohort reflects the inherent biologic variability in dermal perfusion and oxygen delivery, making it difficult to define narrow, rigid 'normal' values. Thus, we cannot recommend a single $P_{tc}O_2$ value as 'normal' for the upper or lower limb. A thorough patient assessment is essential to establish appropriateness for hyperbaric oxygen therapy, with TCOM used as an aid to guide this decision and not as an absolute.

Introduction

Transcutaneous oximetry measurement (TCOM) is a non-invasive process of measuring the tissue partial pressure of oxygen through a heated sensor on the skin ($P_{tc}O_2$). Confirmation of tissue hypoxia and demonstrated responsiveness of the tissue to oxygen (O_2) in the area surrounding a wound allows selection of patients most likely to benefit from hyperbaric oxygen therapy (HBOT).[1] Lower limb hypoxia has been defined as a $P_{tc}O_2$ less than 40 mmHg[1,2,3] with values in healthy individuals ranging from 48 to 79 mmHg.[4–8] There are no corresponding normal values available for the upper limb due to inconsistences in previous studies.[9–11] We previously evaluated both upper and lower limb $P_{tc}O_2$ in cohorts of healthy volunteers, but retracted those data after discovering an error in the instrumentation we used.[12] Here, we replicate those studies with reliable instrumentation to establish normal $P_{tc}O_2$ at multiple positions on the upper and lower limb in healthy, non-smoking adult subjects using the TCM400 Transcutaneous (tc) pO_2 Monitoring System with tc Sensor E5250 and O_2 membranes (Radiometer Medical ApS, Bronshoj, Denmark).

Methods

Ethical approval for this study was granted by the Human Research Ethics Committee of the Townsville Hospital and Health Service (HREC15QTHS215). Thirty-two healthy volunteers (16 men and 16 women) were recruited from the hospital staff and general population to participate in

this study. Exclusion criteria included subjects younger than 18 years old; current or former smokers; known cardiovascular disease including treated or untreated hypertension; significant respiratory disease or any other significant medical condition. Subjects missing a limb, or with significant scarring or a skin condition on a limb, were also excluded. As subjects were required to have a plastic hood placed over their head to receive O_2 for part of the study, severe claustrophobia was a further exclusion criterion.

All participants were given a study information sheet and informed consent was obtained. Subjects refrained from consuming food or caffeine or performing heavy exercise for two hours prior to participating in the study. Subjects lay supine on a hospital bed with their head slightly raised on one pillow and were offered a blanket for comfort and to limit any vasoconstrictive effects of being cold. The room temperature was maintained between 22.0 and 22.5°C.

Basic demographic data were collected including height and weight. O_2 saturation and blood pressure were measured on both arms. Upper and lower limb pulses were recorded bilaterally. Toe pressures were measured on the randomized limb. Ankle brachial index (ABI) and toe brachial index (TBI) were calculated. Any abnormalities in the baseline observations would have led to exclusion from the study.

Participants were randomized to have 12 sensors placed on their right or left side (chest, arm and leg). The sensor sites were prepared by shaving hair if necessary, wiping clean, rubbing with an alcohol swab and drying with gauze. The chest sensor was placed at the second intercostal space in the mid-clavicular line. For the upper limb, sensors were placed: mid-way between the highest bony point on the shoulder and the olecranon process on the lateral aspect of the upper arm; 5 cm distal to the brachial crease on the lateral aspect of the lower arm; on the thenar and hypothenar eminences and centrally on the dorsum of the hand between the third and fourth metacarpal bones away from any obvious veins. For the lower limb, sensors were positioned: 10 cm distal to the lateral femoral epicondyle; 5 cm proximal to both the lateral and medial malleoli; on the dorsum of the foot attempting to avoid large superficial vessels, one between the first and second metatarsal heads and the second proximal to the fifth metatarsal phalangeal (MTP) joint and on the plantar aspect of the foot proximal to the first metatarsal phalangeal joint. The leads were secured in place with tape to prevent pull on the sensors. Subjects were requested to keep talking to a minimum during the study.

All TCOM assessments were performed by the same technician (DY) using the TCM400 $P_{tc}O_2$ Monitoring System. The TCM400 has six tc E5250 sensors and can record $P_{tc}O_2$ data from all sensors simultaneously. Two machines were used, alternating between the upper and lower limb. The electrode temperatures were pre-set to 44°C and atmospheric and zero point electrode calibrations were performed as per the manufacturer's recommendations. A humidity correction factor was calculated from the room temperature, saturated water vapour pressure and relative humidity and input into the machine according to the TCM400 operator's manual.[13] The TCM400 displays $P_{tc}O_2$ values in mmHg units.

We used the TCOM protocol described by Sheffield which is historically used in hyperbaric medicine to identify tissue hypoxia and responsiveness to hyperoxia.[14,15] Initial normobaric room air readings from all sensors were recorded after a minimum 20-minute equilibration period, allowing all sensors to stabilize.[4] The leg was then elevated 45 degrees above its resting level and placed on a foam wedge, with sensor readings recorded after five minutes. The elevation process was then repeated for the arm. The arm or leg were returned to the horizontal position for a minimum five-minute period allowing all sensor readings to re-stabilize, and another set of readings were recorded to ensure $P_{tc}O_2$ had returned to baseline. The subjects then breathed 100% O_2 for 10 minutes via a clear plastic hood with a soft neck seal, with sensor readings recorded at the end of the 10-minute period, once stabilized. At the conclusion of the session, all sites were inspected for thermal injury.

ANALYSIS

All collected data were de-identified and entered into a pre-formatted Excel worksheet. These data were subsequently exported into Stata Statistical Software: Release 11 (StataCorp LP, College Station, TX, USA) for analysis.

The primary outcome of this study was a determination of the normal range of $P_{tc}O_2$ when measured at various places on the upper and lower limbs of healthy volunteer subjects. Based on previous reports of mean normal $P_{tc}O_2$ readings ranging from 58 to 65 mmHg (upper limb)[11,16] and 48 to 79 mmHg (lower limb)[2, 4–7] with a standard deviation (SD) of approximately 10 mmHg, our sample size of 32 subjects was intended to allow us to estimate mean $P_{tc}O_2$ readings with a 95% confidence interval (95% CI) of ± 3.5 mmHg. Having 16 male and 16 female subjects also provided 80% power (with $\alpha = 0.05$) to detect a 10 mmHg difference in mean $P_{tc}O_2$ of males versus females using Student's *t*-test.

Descriptive statistics are reported for $P_{tc}O_2$ at each of the 12 sensor sites. The Shapiro-Wilk test was used to evaluate normality of the data distributions. For normally distributed data, mean, 95% CI, and/or standard deviation and range are reported. For non-parametric data, median, inter-quartile range and approximate 95% CI for the median are reported. Demographic characteristics of male and female subjects were compared using Fisher's Exact Test (FET) or Student's *t*-test as appropriate. Differences between mean $P_{tc}O_2$ for males and females were compared using Student's *t*-test when data were normally distributed, Wilcoxon Rank Sum test for non-parametric data, and FET

Table 1
Demographic and baseline characteristics of the 32 subjects; mean (SD) or number (*n*) shown;
* Female vs. Male, *t*-test, $P = 0.021$

Variable	**Male** ($n = 16$)	**Female** ($n = 16$)	**All** ($n = 32$)
Age (years)	48 (12)	52 (13)	50 (13)
< 50 years (*n*)	10	6	16
Body mass index ($kg \cdot m^{-2}$)	26.5 (5.2)	26.9 (4.2)	26.7 (4.7)
Underweight (BMI < 20) (*n*)	0	0	0
Normal (BMI 20–24.9) (*n*)	7	6	13
Overweight (BMI 25–29.9) (*n*)	6	7	13
Obese (BMI ≥ 30) (*n*)	3	3	6
Oxygen saturation (%)	98 (1)	97 (1)	98 (1)
Heart rate ($beats \cdot min^{-1}$)	61 (10)	62 (9)	61 (10)
Systolic BP (mmHg)	121 (6)	114 (9)*	117 (8)
Ankle Brachial Index	1.1 (0.1)	1.1 (0.1)	1.1 (0.1)
Toe Brachial Index	0.8 (0.1)	0.9 (0.1)	0.9 (0.1)
Toe Systolic BP (mmHg)	98 (17)	99 (10)	98 (14)

for frequency data. Correlations between baseline perfusion measures of systolic blood pressure (SBP), diastolic blood pressure (DBP), oxygen saturation (SpO_2) and toe SBP in the randomized limb and the observed room air and on-O_2 $P_{tc}O_2$ at each sensor site were evaluated using Pearson's correlation coefficient with Bonferroni correction for multiple comparisons.

Results

Demographic and baseline perfusion measures for the 32 subjects are shown in Table 1. Subjects ranged in age from 26 to 80 years. Baseline perfusion measures were clinically unremarkable in all subjects. The only statistically significant difference between female and male subjects was systolic blood pressure, but this difference was clinically irrelevant. There were no statistically significant correlations between baseline measures of perfusion and any of the $P_{tc}O_2$ measurements (data not shown*).

ROOM-AIR $P_{tc}O_2$

Figures 1 and 2 display the upper and lower limb room-air $P_{tc}O_2$ for all 32 subjects. The first column of Table 2 summarises the room-air $P_{tc}O_2$ for the chest and upper limb sensors. Four subjects had a chest sensor $P_{tc}O_2$ below 40 mmHg. The upper limb room-air $P_{tc}O_2$ readings ranged from 23 to 92 mmHg, generally increasing with more distal sensor sites. Nine subjects each had one upper limb $P_{tc}O_2$ below 40 mmHg. Notably, these nine subjects with upper limb room-air $P_{tc}O_2$ readings below 40 mmHg were distinct from the four subjects with chest room-air $P_{tc}O_2$ below 40 mmHg. The first column of Table 3 summarises the room-air $P_{tc}O_2$ data for the lower limb, which ranged from 26 to 99 mmHg, again generally increasing with more distal sites. Thirteen subjects had at least one lower limb $P_{tc}O_2$ reading below 40 mmHg. Three subjects had both upper and lower limb room-air $P_{tc}O_2$ readings below 40 mmHg, for a total of 19 of the 32 subjects having at least one room-air limb $P_{tc}O_2$ reading below 40 mmHg.

There were some differences in room-air $P_{tc}O_2$ readings between female and male subjects (Table 4). Female subjects had higher chest room-air $P_{tc}O_2$, and no female subject had a room-air chest $P_{tc}O_2$ below 40 mmHg. Female subjects also had higher room-air lateral leg $P_{tc}O_2$ and medial malleolus $P_{tc}O_2$ readings. However, there was no significant difference in the number of female and male subjects with room-air upper limb (five vs. six, FET, $P = 0.999$) or lower limb (four vs. nine; FET, $P = 0.149$) $P_{tc}O_2$ less than 40 mmHg.

$P_{tc}O_2$ WITH LIMB ELEVATION

The second column of Table 2 summarises the effect of limb elevation on room air for the upper limb. With elevation of the arm, $P_{tc}O_2$ was generally only modestly lower than the room-air $P_{tc}O_2$. However, 28 of the 32 subjects had a decrease in $P_{tc}O_2$ greater than 10 mmHg recorded for at least one upper limb sensor, and for the three most distal upper limb sensor sites the 95% confidence interval for the change in $P_{tc}O_2$ with elevation included or exceeded a decrease of 10 mmHg (data not shown*). The second column of Table 3 summarises the effect of limb elevation on room air $P_{tc}O_2$ for the lower limb. All 32 subjects (100%, 95% CI 89 to 100) had at least one lower limb $P_{tc}O_2$ decrease greater than 10 mmHg, and the 95% confidence interval for the change in

*** Footnote:** Separate data for males and females at each anatomical site breathing room air, limb elevated and breathing 100% oxygen are available from the authors or the journal office <info@dhmjournal.com>

Figure 1
Distribution of transcutaneous oxygen partial pressures (mmHg) for the chest and five upper limb sensor sites in 32 healthy volunteers breathing room-air; statistical outliers indicated by open circles

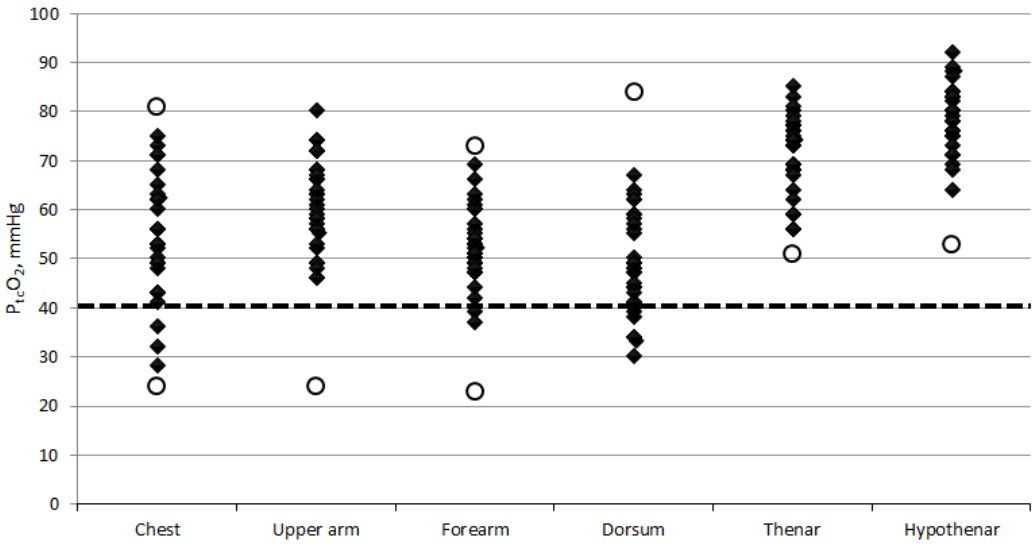
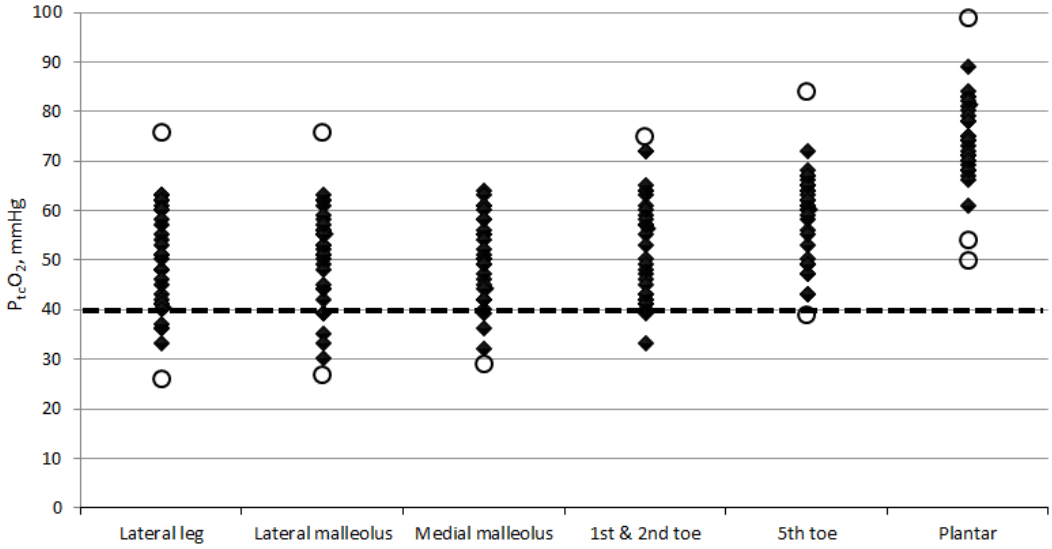


Figure 2
Distribution of transcutaneous oxygen partial pressures (mmHg) for six lower limb sensor sites in 32 healthy volunteers breathing room-air; statistical outliers indicated by open circles



$P_{tc}O_2$ with elevation included or exceeded a decrease of 10 mmHg at every lower limb sensor site (data not shown*).

There were three sex-related significant differences in $P_{tc}O_2$ with limb elevation (Table 4): at the chest, lateral leg and medial malleolus sensors, the $P_{tc}O_2$ in women was less than that observed in men, but the differences were of questionable clinical significance. There was no significant difference in the number of female versus male subjects with decreases in $P_{tc}O_2$ greater than 10 mmHg at any of the sensor sites.

$P_{tc}O_2$ BREATHING 100% OXYGEN

The final columns of Tables 2 and 3 summarise the on-O_2 $P_{tc}O_2$ for the upper and lower limbs, respectively. Although upper limb on-O_2 $P_{tc}O_2$ decreased with more distal sensor sites, all of the readings except one (on the dorsum of the hand) were greater than 100 mmHg. Similarly, the on-O_2 $P_{tc}O_2$ for the more proximal leg and malleolus sensor site measurements were all greater than 100 mmHg. However, at the three foot sensor sites on-O_2 $P_{tc}O_2$ below 100 mmHg were common, with 13 of 32 subjects having on-O_2 foot sensor site $P_{tc}O_2$ below 100 mmHg.

Table 2
Transcutaneous oxygen partial pressures (mmHg) for chest and five upper limb sensor sites in 32 healthy volunteers; mean (95% confidence interval); † [median (approx. 95% CI)] for non-normally distributed data; n/a – not applicable

Sensor	Room air (20 min)	Limb elevated (5 min)	100% oxygen (10 min)
Chest			
Mean (95% CI)	53.6 (48.7–58.5)	54.2 (49.0–59.4)	397.1 (380.1–414.1)
Range	24–81	12–74	308–500
< 40 mmHg (*n*)	4	n/a	n/a
decrease > 10 mmHg (*n*)	n/a	2	n/a
< 100 mmHg (*n*)	n/a	n/a	0
Upper arm			
Mean (95% CI)	60.0 (56.1–64.0)	59.2 (55.2–63.3)	421.1 (408.1–434.1)
Range	24–80	28–79	335–486
< 40 mmHg (*n*)	1	n/a	n/a
decrease > 10 mmHg (*n*)	n/a	3	n/a
< 100 mmHg (*n*)	n/a	n/a	0
Forearm			
Mean (95% CI)	52.3 (48.8–55.8)	47.2 (42.7–51.7)	310.1 (282.4–337.8)
Range	23–73	17–66	150–469
< 40 mmHg (*n*)	3	n/a	n/a
decrease > 10 mmHg (*n*)	n/a	7	n/a
< 100 mmHg (*n*)	n/a	n/a	0
Dorsum hand			
Mean (95% CI)	50.2 (46.1–54.3)	33.8 (27.6–39.9)	278.4 (249.7–307.2)
Range	30–84	1–74	89–440
< 40 mmHg (*n*)	5	n/a	n/a
decrease > 10 mmHg (*n*)	n/a	21	n/a
< 100 mmHg (*n*)	n/a	n/a	1
Thenar eminence			
Mean (95% CI)	70.8 (67.7–73.8)	58.5 (54.3–62.8)	229.4 (211.1–247.6)
Range	51–85	28–77	101–314
< 40 mmHg (*n*)	0	n/a	n/a
decrease > 10 mmHg (*n*)	n/a	17	n/a
< 100 mmHg (*n*)	n/a	n/a	0
Hypothenar eminence			
Mean or [median]†	77.9 (75.1–80.7)	[71.0 (63.0–73.5)]	212.4 (195.5–229.3)
Range	53–92	36–81	124–308
< 40 mmHg (*n*)	0	n/a	n/a
decrease > 10 mmHg (*n*)	n/a	11	n/a
< 100 mmHg (*n*)	n/a	n/a	0

Female subjects had significantly lower on-O_2 $P_{tc}O_2$ for the sensor placed at the fifth toe on the dorsum of the foot (Table 4), but there was no significant difference in the number of female and male subjects with on-O_2 $P_{tc}O_2$ less than 100 mmHg at this site (six vs two; FET, $P = 0.220$) or any other sensor site.

Discussion

Clinical practice guidelines for $P_{tc}O_2$ have been developed to assist the clinician in selecting appropriate patients for HBOT.[1] A thorough clinical history and exam remains essential, with $P_{tc}O_2$ results integrated as one variable in the workup. Using the reference value of 40 mmHg to define hypoxia for all locations on the lower limb would result in 16% of readings on the lateral leg and 31% of the malleoli values in our healthy subjects being classified as hypoxic. The most distal sensor sites on the palm and on the plantar aspect of the foot were the only sites where 100% of our healthy subjects had values above 40 mmHg. Overall, more than half of our 'healthy' subjects recorded a room air $P_{tc}O_2$ below 40 mmHg for at least one limb sensor site.

$P_{tc}O_2$ measurements of 30–40 mmHg have been considered to fall within a grey zone for classification of hypoxia with the value of 50 mmHg used in patients with other factors such as diabetes and renal failure.[1] Using a more conservative reference value of 30 mmHg would still classify

Table 3
Transcutaneous oxygen partial pressures (mmHg) for six lower limb sensor sites in 32 healthy volunteers; mean (95% confidence interval) ; n/a – not applicable

Sensor	Room air (20 min)	Limb elevated (5 min)	100% oxygen (10 min)
Lateral leg			
Mean (95% CI)	50.2 (46.2–54.2)	38.2 (33.5–43.0)	239.9 (214.0–265.7)
Range	26–76	11-63	111–397
< 40 mmHg (*n*)	5	n/a	n/a
decrease > 10 mmHg (*n*)	n/a	19	n/a
< 100 mmHg (*n*)	n/a	n/a	0
Lateral malleolus			
Mean (95% CI)	50.5 (46.6–54.3)	31.0 (26.4–35.6)	252.8 (226.5–279.1)
Range	27–76	1-59	114–375
< 40 mmHg (*n*)	6	n/a	n/a
decrease > 10 mmHg (*n*)	n/a	29	n/a
< 100 mmHg (*n*)	n/a	n/a	0
Medial malleolus			
Mean (95% CI)	48.9 (45.6–52.1)	28.9 (23.9–33.9)	226.3 (205.9–246.7)
Range	29–64	2-54	138–373
< 40 mmHg (*n*)	4	n/a	n/a
decrease > 10 mmHg (*n*)	n/a	29	n/a
< 100 mmHg (*n*)	n/a	n/a	0
Dorsum, 1st and 2nd toe			
Mean (95% CI)	53.1 (49.2–57.0)	35.0 (29.8–40.2)	163.8 (141.1–186.5)
Range	33–75	10-72	64–317
< 40 mmHg (*n*)	2	n/a	n/a
decrease > 10 mmHg (*n*)	n/a	28	n/a
< 100 mmHg (*n*)	n/a	n/a	5
Dorsum, 5th toe			
Mean (95% CI)	58.5 (55.1–62.0)	42.0 (37.4–46.6)	134.4 (116.2–152.6)
Range	39–84	13-72	53–238
< 40 mmHg (*n*)	1	n/a	n/a
decrease > 10 mmHg (*n*)	n/a	29	n/a
< 100 mmHg (*n*)	n/a	n/a	8
Plantar, 1st MTP			
Mean (95% CI)	73.7 (70.3–77.1)	63.2 (59.3–67.0)	165.4 (143.6–187.2)
Range	50–99	41-94	67–280
< 40 mmHg (*n*)	0	n/a	n/a
decrease > 10 mmHg (*n*)	n/a	15	n/a
< 100 mmHg (*n*)	n/a	n/a	6

five of our subjects as having hypoxic room air $P_{tc}O_2$ (three leg; two arm).

When assessing $P_{tc}O_2$, it has been common practice to place a sensor on the anterior chest wall as a central reference that is reported to provide information regarding the cardio-respiratory status of the patient. In this study, the nine subjects with upper limb $P_{tc}O_2$ below 40 mmHg all had chest $P_{tc}O_2$ above 40 mmHg. Yet, two-thirds of our healthy subjects had room air chest sensor readings lower than that of at least one arm/hand sensor reading; for 10 subjects the chest sensor reading was as much as 25 to 30 mmHg lower than at least one upper limb sensor reading. This lack of utility of the chest sensor has been reported in other studies[17] and a recent expert consensus statement confirms that a percentage of patients have an abnormally low chest $P_{tc}O_2$, and the value of this site as a central reference is questionable.[2] Owing to the unreliability of the chest sensor as a reference site we no longer use it in clinical practice.

As part of routine TCOM assessment the leg is historically elevated for five minutes.[18–20] A drop of 10 mmHg is considered indicative of significant vascular disease[21] and decreased healing in amputations.[22] Two recent vascular studies have examined this area using the TCM400. One study found a drop of less than 10 mmHg in diabetic and non-diabetic patients with severe limb ischaemia; however, their starting values were in the low teens and these patients

Table 4
Statistically significant differences in transcutaneous oxygen partial pressures (mmHg) among female and male healthy volunteers; mean (95% confidence interval) or [median (approx. 95% CI)]; † Student's t-test; ** Wilcoxon Rank Sum test

Environment / Sensor	**Male** (n = 16)		**Female** (n = 16)		***P*-value**
Room air (20 min)					
Chest	46.4	(39.3–53.4)	60.8	(55.4–66.2)	0.002†
Lateral leg	45.5	(39.1–51.9)	54.9	(50.8–59.0)	0.013†
Medial malleolus	45.0	(840.3–49.7)	52.8	(48.7–56.8)	0.012†
Limb elevated (5 min)					
Chest (arm elevated)	[46.5	(37.0–58.0)]	[64.0	(53.0–67.0)]	0.009**
Lateral leg	31.3	(24.5–38.0)	45.2	(40.1–50.3)	0.002†
Medial malleolus	23.1	(16.0–30.1)	34.7	(28.2–41.2)	0.015†
100% oxygen (10 min)					
Dorsum 5th toe	154.2	(129.4–179.0)	114.6	(89.2–139.9)	0.024†

would have been identified as having severe disease without the added leg elevation.[23] The other study used the 10 mmHg drop with elevation to stratify their patients. Ninety two percent of patients in the equivocal $P_{tc}O_2$ range for healing of 20–40 mmHg with a drop on elevation of > 10 mmHg failed to heal whereas 80% of patients who had ≤ 10 mmHg drop on elevation healed.[24] However, a drop of 10 mmHg has also been found in healthy subjects.[7] In our study, the response to elevation varied by sensor site (Tables 2 and 3). All of our subjects had a $P_{tc}O_2$ decrease greater than 10 mmHg for at least one lower limb sensor site when their leg was elevated, and all but four subjects had a $P_{tc}O_2$ decrease greater than 10 mmHg when the upper limb was elevated. This brings into question the use of this manoeuvre in assessing patients during TCOM, and we no longer use it in our unit.

Expert consensus is that in normal subjects breathing 100% O_2 at normobaric pressure, $P_{tc}O_2$ on the leg should increase to a value ≥ 100 mmHg.[8] In this study, on-O_2 $P_{tc}O_2$ below 100 mmHg were recorded on the dorsum of the hand and the three most distal lower limb sites (Tables 2 and 3). While some of these observations might represent random measurement errors, they are too persistent throughout our data for this explanation. The dorsal hand and foot sites are not straight forward measurement sites. Suitable sensor sites were dictated by the availability of flat surface areas where a fixation ring could be applied, but the sites we used are clinically relevant. These sites are dominated by bones and superficial blood vessels. In attempting to explain our low values and lack of response to 100% normobaric O_2, it is feasible that they could be due to the influence of de-oxygenated blood in the surrounding vessels or hyperoxic vasoconstriction, with females being generally more vasospastic than males.

LIMITATIONS

Our study has limitations. The conventional view is that the sole of the foot is not a good measurement site because of the thickened skin and low $P_{tc}O_2$ not being representative of the tissue below the keratin layer.[3,25] Neuropathic ulcers are common in this area and led us to include the plantar site in this study. No subjects had room-air $P_{tc}O_2$ lower than 40 mmHg at this site, although it had a poorer response to O_2. The vasomotor regulation in acral skin is very sensitive to temperature. Increased temperature leads to arteriovenous shunting and arterialization more efficiently than non-acral skin, possibly contributing to the higher room air values. These values may not represent tissue oxygenation at normal temperatures. The poorer response to 100% O_2 may reflect hyperoxic vasoconstriction. Including this site in clinical practice and further studies may be worthwhile.

Our study was also limited in that we only used the Radiometer TCM400 machine; however, a recent study comparing normal values on different Radiometer machines reported values comparable to ours.[8] Finally, our study speaks only to the specificity of upper and lower limb $P_{tc}O_2$ in healthy, disease-free non-smokers; we cannot comment on the sensitivity or specificity of $P_{tc}O_2$ in other patient groups.

Conclusions

The broad dispersion in our $P_{tc}O_2$ results reflects the inherent biologic variability in dermal perfusion and O_2 delivery making it difficult to set narrow and rigid normal values. Therefore, we cannot recommend a single $P_{tc}O2$ as normal for the upper and lower limb. Using comparative $P_{tc}O_2$ on the contralateral limb might be better for identifying 'abnormal' tissue[8] and the expected effect of an O_2 challenge; however, many patients may have bilateral disease. A thorough assessment of the patient is essential to establish appropriateness for HBOT with TCOM results used as an aid to help guide this decision and not as an absolute.

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