Investigating differences in oxygen saturation values between dorsal and plantar surfaces of the first metatarsophalangeal joint in different Fitzpatrick skin types

Noor-ul-ain Chaudhry, Alexia P. Da Silva, Anne Obichere, Julie R. Boyd, Ryan O'Reilly and Rachel Forss

Citation: Chaudhry N, Da Silva AP, Obichere A et al (2024) Investigating differences in oxygen saturation values between dorsal and plantar surfaces of the first metatarsophalangeal joint in different Fitzpatrick skin types. *The Diabetic Foot Journal* 26(1): X–X

Key words

- moorVMS-OXY
- oxygen
- chromophores
- planter
- ulcer
- Fitzpatrick scale

Article points

1. The MTPJ is one of the most common sites for DFUs, with inflammation only visible after initial tissue damage has already occurred
2. Measuring oxygen saturation levels during initial inflammation may help to prevent tissue breakdown
3. The study found that assessing oxygen saturation in hypopigmented areas of differing skin types is worthy of further investigation.

Author

Noorulain Chaudry; Alexia P. Da Silva; Anne Obichere; Julie R. Boyd; Ryan O'Rielly; Rachel Forss; all Podiatrists at University of Brighton, UK

This study investigates whether there is a significant difference in oxygen saturation (SpO_2) values obtained from the dorsal and plantar surfaces of the first metatarsophalangeal joint (MTPJ) in different Fitzpatrick skin types (FSTs). The moorVMS-OXY™ tissue oxygenation system is validated for use on FSTs 1 and 2, but melanin pigmentation can interfere with its reliability. This pilot study suggests that anatomical variations in the foot greatly affect SpO_2 values compared to skin type; a step towards understanding if future prevention of plantar and dorsal ulcers can be made via measurement of SpO_2 values from pigmented areas. However, as this is a pilot study, larger-scale research needs to be conducted.

Statistics show 15% of high-risk patients with diabetes will experience a diabetic foot ulcer (DFU), of which 1.8% will have an amputation, with a 68–79% mortality rate within 5 years. The NHS expenditure for ulcer management in 2014-15 was £837–£962 million (Ahmed et al, 2010; Kerr et al, 2019; Altoijry et al, 2021). National Institute for Health and Care Excellence (NICE) guidelines NG19 suggest addressing this issue from the earliest point in treatment, where multidisciplinary teams should use specialised healthcare techniques to manage such wounds (NICE, 2015).

The first metatarsophalangeal joint (MTPJ) is one of the most common sites for DFUs (Ahmed et al, 2010). A cascade of issues leads to inflammation that is only visible after 3–10 days, when initial tissue damage has already occurred; but Collet et al (2019) report that measuring oxygen saturation levels (SpO_2) during this period can help prevent tissue breakdown. Using the moorVMS-OXY™ tissue oxygenation system (Moor Instruments, Delaware, USA) allows detection of optimal levels of SpO_2, so that effective treatment and wound healing can be managed (Ito et al, 2016; Malone-Povolny et al, 2019).

Based on white light reflectance spectroscopy, the moorVMS-OXY is non-invasive, pain-free and easy to use. Probe-to-skin contact scatters white light into tissue at 500–600nm, being absorbed by two major chromospheres: oxygen and melanin. Residing in superficial layers of the skin, melanin acts as a confounding variable and there is a significant difference of melanin concentrations between dorsum and plantar (Zonios et al, 2001). Technologies such as pulse oximetry usually overestimate SpO_2 values for dark skin (Shih et al, 2015; Bothma et al, 1996). This study aims to investigate the effect of anatomical sites and melanin, using the Fitzpatrick skin phototypes (1975) scale classification system on SpO_2 readings in healthy individuals.

Method

This research is ethically approved by University of Brighton, The School of Health Sciences Research Ethics Panel. Volunteer participants from Fitzpatrick skin types 1–6 were recruited through

Table 1. Inclusion and exclusion criteria for study participants.

Inclusion criteria	Exclusion criteria
Biphasic/triphasic pulses using doppler ultrasound	Previous heart attack
Good general health	Iron deficiency and pernicious anaemia
No wounds or poor skin integrity at first metatarsophalangeal joint	Sickle cell disease
Non-smoker	Leukaemia
Alcohol intake <14 units per week	Carbon monoxide poisoning within the last six months
No systemic conditions affecting oxygen saturation levels	Monophasic pulses
Over 18	Peripheral arterial disease
Skin type 1–6 on the Fitzpatrick scale	Smoker
	Allergy to latex or adhesive tabs
	Pregnant
	High alcohol intake >14 units per week

the university. Written and verbal informed consent were taken. Screening for inclusion and exclusion criteria, a Dopplex MD2 Bi-Directional Doppler was used to test the vascular status of participants. The moorVMS-OXY was used for measuring SpO_2; to obtain data, an OP1T probe was used along with a flexible PVC probe holder PH1-V2.

Participants were divided into three groups by Fitzpatrick skin type (FST): group 1, FST 1–2; group 2, FST 3–4; and group 3, FST 5–6. The other independent variable was site, which was also broken into two: site 1 (dorsal) and site 2 (plantar).

Table 2. Demographics of study participants.

Age	Mean 29
Gender male/female	5/14
Fitzpatrick skin types	Frequency
1	0
2	6
3	3
4	4
5	5
6	1

Results

Values for SpO_2 obtained from all 19 participants were in the normal range for the foot, suggesting that appropriate inclusion/exclusion criteria were followed, reducing bias and the chance of error (Qi et al, 2022) The mean difference for SpO_2 values between each site was significantly different 0.000001 (p value<0.05), excluding the effect of skin type. In *Table 2*, the confidence interval lacked difference, showing less probability of error as outlier values would be reduced, indicating values obtained were reliable and valid for site.

This study identified that there was no statistically significant difference for the FST of 19 participants (*Table 4*), resulting in acceptance of the null hypothesis of no difference in variables. This study showed that the amount of pigmentation nor FST created an impact on the SpO_2, and increased concentration of melanin did not act as a confounding variable. Although the p value was not significant, the level of error in each skin type group could suggest that melanin did impact SpO_2 values as there is a positive correlation seen in *Table 4*, as the skin pigmentation increases and the difference in confidence interval increases too; thus, suggesting melanin caused greater error in the results. Which are what previous studies showed, but this was not significant enough to accept the alternative hypothesis (Mujis, 2004; Qi et al, 2022).

Table 3. Univariant test for effect of site on oxygen saturation (SpO_2).

			95% confidence interval	
*Site		Mean	Lower bound	Upper bound
1. Dorsum		33.150	27.598	38.701
2. Plantar		56.014	50.463	61.566
Site comparison		**Mean difference**	***Significance**	
1. Dorsum	2. Plantar	-22.865	0.000001	
2. Plantar	1. Dorsum	22.865	0.000001	

*Univariant analysis of dorsal (1) and plantar (2) showing the site as an independent variable and its effect on the dependant variable, SpO_2 (p value <0.05, 95%)

Table 4. Univariant test for effect of Fitzpatrick skin type (FST) on oxygen saturation (SpO_2).

			95% confidence interval	
*Groups		Mean	Lower bound	Upper bound
Group 1: FST 1–2		45.157	39.349	50.965
Group 2: FST 3–4		47.289	42.167	52.411
Group 3: FST 5–6		41.300	32.428	50.172
Group comparison		**Mean difference**	***Significance**	
Group 1: FST 1–2	2: FP ST 3-4	-2.132	0.579	
	3: FP ST 5-6	3.857	0.464	
Group 2: FST 3–4	1: FP ST 1-2	2.132	0.579	
	3 FP ST 5-6	5.989	0.243	
Group 3: FST 5–6	1: FP ST 1-2	-3.857	0.464	
	2: FP ST 3-4	-5.989	0.243	

*Univariant analysis of FST 1–2 (group 1), FST 3–4 (group 2) and FST 5–6 (group 3) showing the group as an independent variable and its effect on dependant variable SpO_2 (p value<0.05, 95%).

The results of considering the impact of both independent variables on SpO_2 values are in *Table 5*. The combination in site 1 (dorsum) of groups 2 and 3 showed a significance of 0.047 (p value <0.05), suggesting that the SpO_2 on the dorsum in FST 5–6 was statistically significant compared to FST 3–4.

Discussion

The findings of this study indicate that there was a significant difference in the mean obtained in the SpO_2 values when comparing the dorsum and plantar surface of the foot p=0.000001 (p value <0.05) excluding the effect of FST (*Table 3*). When considering factors that may contribute to these results, anatomy and tissue pigmentation need to be considered (Boyle et al, 2019).

Anatomy is a major factor impacting SpO_2, the dorsal skin of the foot varies in some significant respects when compared to the plantar skin. For example, strength of tissue, thickness, pigmentation and angiosomes differ in the two regions (Kumar and Schmitt, 1997). Youngs modulus can help in understanding the skins strength and its likelihood of ulceration (Sasaki and Odajima, 1996). When considering the mechanical stresses applied to the dorsum versus the plantar surface of the foot, it is easy to appreciate that the physical stresses and strains placed on the plantar structures of the foot are considerably different to those placed on the dorsum. The plantar surface can bear 100kPa pressure through the calcaneus, hence prevents skin tearing, blistering and ulcers. Thus, if the skin on the plantar foot develops an ulcer it would require more nutritional support hence the increased vascular network. It is reported that there is a 2.9-fold greater vessel density in the plantar surface

Table 5. Univariant test for combined effect of Fitzpatrick skin type (FST) and site on oxygen saturation (SpO_2).

*Site	Groups	Mean
1: Dorsum	Group 1: FST 1–2	34.771
	Group 2: FST 3–4	39.678
	Group 3: FST 5–6	25.000
2: Plantar	Group 1: FST 1–2	55.543
	Group 2: FST 3–4	54.900
	Group 3: FST 5–6	57.600

Site	*Group comparison		Mean difference	*Significance
1: Dorsum	Group 1: FST 1–2	2: FP ST 3-4	-4.906	0.368
		3: FP ST 5-6	9.771	0.194
	Group 2: FST 3–4	1: FP ST 1-2	-4.906	0.368
		3: FP ST 5-6	14.678	0.047
	Group 3: FST 5–6	1: FP ST 1-2	-9.771	0.194
		2: FP ST 3-4	-14.678	0.047
2: Plantar	Group 1: FST 1–2	2: FP ST 3-4	0.643	0.906
		3: FP ST 5-6	-2.057	0.782
	Group 2: FST 3–4	1: FP ST 1-2	-0.643	0.906
		3: FP ST 5-6	-2.700	0.707
	Group 3: FST 5–6	2: FP ST 3-4	2.057	0.782
		1: FP ST 1-2	2.700	0.707

*Univariant analysis of FST 1–2 (group 1), FST 3–4 (group 2) and FST 5–6 (group 3) with site, dorsal (1) and plantar (2) showing the combined effect of two independent variables on dependant variable SpO_2 (p value<0.05, 95%).

of the foot as it is perfused by three different of angiosomes, whereas the dorsum is supplied by only one (Ricci, 2015; Lechner et al, 2019). This could be a factor in the significant difference of SpO_2 value 0.000001(p value <0.05) in *Table 3* for site variable. This increased perfusion is further supported by the mean SpO_2 for the dorsum being 33% and the plantar surface 56% (Boyle et al, 2015; Altoijry et al, 2021; Shabhay et al, 2021).

As well as considering the anatomical construct of the tissues, melanin content needs to be explored. There is considerably less melanin present in the plantar compared to the dorsum of the same foot (Nagaoka et al, 2007). This pigmentation difference could be one of the factors which has contributed to the significant difference in SpO_2 values obtained in this study. The moorVMS-OXY is recommended for use on FST 1–2, due to the potential interference of melanin (Qi et al, 2022). This is supported by Shaban (2013), who suggested that melanin made it difficult to distinguish between reflectance getting an equal number in the three skin type groups.

When exploring the lower and upper bound of the confidence interval of group 3, it shows that the greatest difference occurs when comparing to group 1 and 2. An explanation for that can be that although all groups had equal number of subjects there were two anomaly values that could affect the mean greatly. In *Table 2*, we can see there were no participants of FST 1 and one participant with FST 6. These values fall far from mean number of participants in each group and when added to the mean SPO_2 values it could greatly affect data input. The results found are closely comparable to Mahmoud et al (2010) and Zonios, Bykowski and Kollias (2001), whose studies have similar participant quantities and found that skin pigmentation did not affect SpO_2 values. These findings are contradictory to studies such as Finer et al (2007) and Yudovsky and Pilon (2010), who found that skin pigmentation did affect SpO_2 values, and their sample size was over 100, suggesting that the chances of type 2 errors occurring in studies with fewer participants is greater.

Limitations

Previous studies suggest that age and gender both could affect SpO_2 values in our study. Having a controlled age range and gender ratio may reduce bias by increasing the replicability of the study and result reliability. Sample size affects most studies. As a pilot study, this research was efficient at highlighting the study's biggest limitation. Machine probes such as the adhesive probes that come with the moorVMS-OXY may cause greater bias in SpO_2 readings due to factors such as sweat causing detachment of the probe from the skin. Finally, the Fitzpatrick scale may not be entirely suitable for clinical purposes due to its subjective nature.

Conclusion

There is a statistical significance in SpO_2 when comparing the dorsum and plantar values of the first MTPJ across the population group studied; however, there was insufficient data to conclusively say that any FST affected the SpO_2 values. If greater scale studies are conducted, results may become more consistent with previous findings. Assessing the SpO_2 values in hypopigmented areas of differing skin types is worthy of further investigation. ■

Ahmed ME, Tamimi AO, Mahadi SI et al (2010) Hallux Ulceration in Diabetic Patients. *The Journal of Foot & Ankle Surgery* 49(1): 2–7 doi: 10.1053/j.jfas.2009.07.005

Altoijry A, AlGhofili H, Alanazi S et al (2021) Diabetic foot and peripheral arterial disease. *Saudi Medical Journal* 42(1): 49–55 doi: 10.15537/smj.2021.1.25640

Bothma PA, Joynt GM, Lipman J et al (1996) Accuracy of pulse oximetry in pigmented patients. *South African Medical Journa*l 86(5): 594–6

Boyle CJ, Plotczyk M, Villata SF et al (2019) Morphology and composition play distinct and complementary roles in the tolerance of plantar skin to mechanical load. *Science Advances* 5(10): 1–13 doi: 10.1126/sciadv.aay0244

Collet M, Huot, B, Barthelemy R et al (2019) Influence of systemic hemodynamics on microcirculation during sepsis. *Journal of Critical Care* 52(1): 213–8 doi:10.1016/j.jcrc.2019.05.002

Ito S, Kikuta M, Koike S et al (2016) Roles of reactive oxygen species in UVA-induced oxidation of 5,6-dihydroxyindole -2-carboxylic acid melanin as studied by differential spectrophotometric method. *Pigment Cell & Melanoma Research* 29(3): 340–51 doi: 10.1111/pcmr.12469

Kerr M, Barron E, Chadwick P et al (2019) Research: Health Economics The cost of diabetic foot ulcers and amputations to the National Health Service in England. *Diabetic Medicine* 36(1): 995–1002 doi: 10.1111/dme.13973

Kumar G, Schmitt J (1997) Optimal probe geometry for near-infrared spectroscopy of biological tissue. *Applied Optics* 36(10): 2286 doi: 10.1364/ao.36.002286

Lechner A, Akdeniz M, Tomova-Simitchieva T et al (2019) Comparing skin characteristics and molecular markers of xerotic foot skin between diabetic and non-diabetic subjects: An exploratory study. *Journal Of Tissue Viability* 28(4): 200–9 doi: 10.1016/j.jtv.2019.09.004

Li Y, Lei D, Swindell W et al (2015) Age-Associated Increase in Skin Fibroblast–Derived Prostaglandin E 2 Contributes to Reduced Collagen Levels in Elderly Human Skin. *Journal Of Investigative Dermatology* 135(9): 2181–8 doi: 10.1038/jid.2015.157

Liu H, Kohl-Bareis M and Huang X (2011) Design of a tissue oxygenation monitor and verification on human skin. *Clinical And Biomedical Spectroscopy And Imaging II* 8087(1): doi 10.1117/12.889197

Mahmoud BH, Ruvolo E, Hexsel CL et al (2010) Impact of Long-Wavelength UVA and Visible Light on Melanocompetent Skin. *Journal of Investigative Dermatology* 130(1): 2092–97 doi:10.1038/jid.2010.95

Malone-Povolny M, Maloney S and Schoenfisch M (2019) Nitric Oxide Therapy for Diabetic Wound Healing. *Advanced Healthcare Materials* 8(12): 1801210 doi: 10.1002/adhm.201801210

Mujis D (2004) Doing quantitative research in education with SPSS, ISBN: 076194382X

Nagaoka T, Eikje NS, Nakamura A et al (2007). Inspection of skin hemodynamics with hyperspectral camera. *Annu Int Conf IEEE Eng Med Biol Soc*: 3357–61

NICE (2015). Diabetic foot problems: prevention and management. Available at https://www.nice.org.uk/guidance/ng19/resources/diabetic-foot-problems-prevention-and-management-pdf-1837279828933 [accessed 31.12.2019]

Qi X, Li H, Tian W, Yang Y (2022) Confidence Interval, Prediction Interval and Tolerance Interval for the Skew Normal Distribution: A Pivotal Approach. *Symmetry* 14(855): https://doi.org/10.3390/sym14050855

Ricci S (2015) The Venous system of the foot: anatomy Physiology and clinical aspects. *Phelbolymphology* 22(2): 64–76. Retrieved from https://www.phlebolymphology.org

Sasaki N, Odajima S (1996) Stress-strain curve and young's modulus of a collagen molecule as determined by the X-ray diffraction technique. *Jounal of Biomechics* 29(5): 655-8

Shaban M (2013) Pulse oximetry using white light. *Engineering: department of engineering swarthmore college* 90(1): 1–27

Shabhay A, Horumpende P, Shabhay Z et al (2021) Clinical profiles of diabetic foot ulcer patients undergoing major limb amputation at a tertiary care center in North-eastern Tanzania. *BMC Surgery* 21(1): doi: 10.1186/s12893-021-01051-3

Shih BB, Allan D, de Gruijl FR, Rhodes LE (2015) Robust Detection of Minimal Sunburn in Pigmented Skin by 785 nm Laser Speckle Contrast Imaging of Blood Flux. *Journal of Investigative Dermatology* 135(1): 1197–99 doi:10.1038/jid.2014.507

van Leeuwen–van Zaane F, Gamm U, van Driel P et al (2013) In vivo quantification of the scattering properties of tissue using multi-diameter single fiber reflectance spectroscopy. *Biomedical Optics Express* 4(5): 696 doi: 10.1364/boe.4.000696

Wassenaar E and Van den Brand J (2005) Reliability of Near-Infrared Spectroscopy in People With Dark Skin Pigmentation. *Journal Of Clinical Monitoring And Computing* 19(3): 195–99 doi: 10.1007/s10877-005-1655-0

Zonios G, Bykowski J and Kollias N (2001) Skin Melanin, Hemoglobin, and Light Scattering Properties can be Quantitatively Assessed In Vivo Using Diffuse Reflectance Spectroscopy. *Journal Of Investigative Dermatology* 117(6): 1452–7