Upper trapezius muscle tonicity, assessed by palpation, relates to change in tissue oxygenation and structure as measured by Time-Domain Near Infrared Spectroscopy

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Abstract Palpation is a diagnostic tool widely used by manual therapists despite its disputed reliability and validity. Previous studies have usually focused on the detection of Myofascial Trigger Points (MTrPs), i.e., the points within muscles thought to have undergone molecular composition, oxygenation and structural changes, altering their tonicity. Time-domain near-infrared spectroscopy (TD-NIRS) could provide new insights into soft tissue oxygenation and structure, in order to objectively assess the validity and reliability of palpation. This pilot study aims at (1) assessing the ability of TD-NIRS to detect a difference between palpably normal and hypertonic upper trapezius (UT) muscles, and (2) to estimate the reproducibility of the TD-NIRS measurement on UT muscles. TD-NIRS measurements were performed on 4 points of the UT muscles in 18 healthy participants (10F, mean age: 27.6 yrs), after a physical examination by a student osteopath to locate these points and identify the most and least hypertonic. From TD-NIRS, the most hypertonic points had a higher concentration in deoxy-([HHb]) (0.887 ± 0.253 μM, $p<0.001$) and total haemoglobin ([HbT]) (1.447 ± 0.772 μM, $p<0.001$), a lower tissue oxygen saturation (StO_2) (-0.575 ± 0.286 %, $p<0.001$), and a greater scattering amplitude factor (AF) (0.2238 ± 0.1343 cm^{-1}, $p=0.001$) than the least hypertonic points. Moreover, the intraclass correlation coefficient one-way random-effects model (ICC (1,1)) calculated for each TD-NIRS parameter and for each point revealed an excellent reliability of the measurement (Mean ± SD, 0.9253 ± 0.0678). These initial results, showing that changes in TD-NIRS parameters correlate with changes in muscle tonicity as assessed by palpation, are encouraging and show that TD-NIRS could help to further assess the validity of palpation as a diagnostic tool in manual therapy.

1 Introduction

Osteopaths are required to recognize the difference between the normal and abnormal function of a tissue [1]. Several techniques are available to determine these changes, among them the sense of touch combined with observation and motion evaluation [1]. Palpation is usually applied to assess tissue motion, soft tissue quality, to provoke pain or tenderness, and to determine bony landmark position. It is a widespread tool to diagnose soft tissue dysfunctions. However, a problem is the continued use of palpation as a diagnostic tool in osteopathic practice, despite lack of robust evidence of validity or reliability.

Myofascial trigger points (MTrPs) are the characteristic features of 'myofascial pain syndrome' (MPS) which are described as "...a regional pain syndrome characterized by myofascial trigger points (MTrP) in palpable taut bands of skeletal muscle that refer pain to a distance, and that can cause distant motor and autonomic effects." [2]. MPS are believed to be the underlying pathophysiology in most patients with chronic non-specific neck pain [2] (when there is no recognisable pathology underlying the pain). There is evidence that chronic load on the muscle causes microtubule proliferation and a restriction of blood flow resulting in local ischemia/hypoxia [3].

Time-domain near-infrared spectroscopy (TD-NIRS) is a non-invasive optical tool that is able to monitor, non-invasively, physiological (i.e., hemodynamic) and structural tissue parameters. Notably, it can measure the concentration of different chromophores, such as oxy- ($[HbO_2]$) and deoxy-haemoglobin ([HHb]) in the tissues (and thus, the total concentration in haemoglobin [HbT]) and the tissue oxygen saturation ($StO_2 = [HbO_2]/[HbT]$) [4]. Moreover, it can give an insight into tissue structure by analysing the scattering information obtained [5].
These capacities of TD-NIRS allow changes in tissue properties to be observed in MPS, which can be used to evaluate palpation validity. Therefore, this pilot study aims to assess the structure and oxygenation of healthy muscles, enabling further study on non-healthy subjects, and to assess the validity of palpation. The two specific aims set for this study are (1) to assess whether scattering and absorption parameters, as measured by TD-NIRS, differ between palpably normal and hypertonic upper trapezius muscles, and (2) to estimate the reproducibility of tissue parameters measured by TD-NIRS, using the upper trapezius muscles.

2 Methods

18 healthy adults (10F, mean age: 27.6 years) participated in this study. Participants presenting with any self-reported pathology such as acute or chronic neck pain, fibromyalgia, myopathy, radiculopathy, history of shoulder or spine surgery, cardiovascular, pulmonary or metabolic diseases were excluded. The

research protocol was reviewed and approved by the Research Ethics Committee of the UCO, London; and signed informed consent was obtained from all participants.

The examiner, a student osteopath and physiotherapist with six years' experience, palpated subject's upper trapezius muscles to identify the most and least hypertonic sites (4 sites in total, 2 on each side). Palpation was limited to the central region of the upper trapezii within 10 cm of the muscle's midline. The least amount of pressure was used to identify these sites. The participants were asked to report if the pressure used elicited tenderness and their answer was recorded. Then, the examiner marked these 4 sites using a surgical skin marker.

The TD-NIRS measurements were made using an in-house developed instrument previously described in [6]. In the present study, one source and one detector were used, allowing to record 1 channel at a time. A custom 3D printed probe was used to hold the source and detector optical fibre at a separation distance $\rho = 3$ cm when applied to the skin. The probe was manually centred on each of the 4 marked sites, with the least amount of pressure necessary to maintain skin contact. Measurements were performed in a dark room to decrease the amount of background light. TD-NIRS data were acquired sequentially for the 4 points, using 16 wavelengths, from 650 to 890 nm in steps of 15 nm, with an acquisition time of 2.5 s per wavelength. To estimate the reproducibility of the measurement, data acquisition of the 4 different sites was repeated 3 times.

The TD-NIRS data was processed offline using Matlab R2018a. We used the classical method to estimate the reduced scattering coefficient μ'_s and the absorption coefficient μ_a, where the distribution of time of flights (DTOF) are fitted to a standard homogeneous model of diffusion theory, after convolution with the IRF. Then, the absorption spectra were used to extract the hemodynamic parameters. Finally, the scattering information were analysed by fitting the scattering spectra obtained between 740 and 870 nm, to an approximation of Mie scattering. This allows to extract 2 parameters, the scattering amplitude factor (AF) and scattering power (SP).

Statistical analyses were performed using Jamovi software (2018). Descriptive statistics were calculated for demographic variables (such as age and sex). For inferential tests, the probability value was set at $p < 0.05$.

To assess the effect of muscle tonicity (most/least hypertonic) on the TD-NIRS parameters, linear mixed effects regression models were used. Participants were treated as random effects (random intercepts) to account for correlations between measurements due to measurements being repeated on the same subject. The TD-NIRS parameters were the response variables, and the muscle tonicity state was the fixed effect.

To estimate the reproducibility of tissue parameters measured by TD-NIRS, their reliability has been calculated using the intraclass correlation coefficient one-way random-effects model (ICC (1,1)).

3 Results

Primary descriptive analysis of haemodynamic TD-NIRS observations showed a bimodal distribution for [HbO_2], [HbT] and StO_2. When plotted against age and sex, it showed that these parameters were strongly dependent on these demographic variables. Hence, age and sex were included in the models as fixed effects. Inclusion of these variables led to the model residuals becoming normally distributed.

Hypertonicity was found to be statistically significant for response variables [HHb] ($F_{(1,198)} = 47.205$, $p<0.001$), [HbT] ($F_{(1,198)} = 13.53$, $p<0.001$), and StO_2 ($F_{(1,198)} = 15.42$, $p<0.001$) (Table 1). Models indicated that the most hypertonic points had [HHb] 0.887 µM and [HbT] 1.447 µM higher than the least hypertonic points, as well as a decreased StO_2 of 0.5%. In contrast, the [HbO_2] in the most and least hypertonic points exhibited no significant difference ($F_{(1,198)} = 2.78$, $p<0.097$).

A similar process was used for the scattering TD-NIRS observations and the tonicity, as the primary descriptive analysis showed a bimodal distribution, mainly related to sex and age. Modelling with AF as response variable showed that hypertonicity was statistically significant ($F_{(1,198)} = 10.657$, $p=0.001$) (Table 1). AF was 0.2238 cm^{-1} higher for the most hypertonic points compared to the least hypertonic points. However, for SP as response, tissue tonicity was not statistically significant ($F_{(1,198)} = 0.262$, $p=0.609$).

Table 1 Main statistical results of the linear mixed effects regression model between haemodynamic and scattering TD-NIRS observations and hypertonicity state, accounting for Age and Sex.

	TD-NIRS parameters	ESTIMATE	95% CONFIDENCE INTERVAL		p
		Effect Most – (Least)	Lower	Upper	
Haemodynamic	[HHb]	0.887	0.634	1.14	<0.001
	[HbO_2]	0.560	-0.099	1.22	0.097
	[HbT]	1.447	0.676	2.22	<0.001
	StO_2	-0.575	-0.863	-0.29	<0.001
Scattering	AF	0.2238	0.0895	0.3582	0.001
	SP	0.0059	-0.0167	0.0285	0.609

The residuals were examined using a Q-Q plot of residuals and found to be normally distributed. The presence of overly influential observations was checked by calculating for Cook's distances. No observation was found to be overly influential (Cook's distance < 1).

The intraclass correlation coefficients calculated for repeated observations were calculated for each TD-NIRS parameter. All ICC values indicated an excellent reliability (Table 2).

Table 2 ICC (1,1) for TD-NIRS parameters according to every point.

TD-NIRS parameters	Point 1	Point 2	Point 3	Point 4
[HHb]	0.7327	0.9275	0.8615	0.7793
[HbO_2]	0.9718	0.9797	0.9620	0.9826
[HbT]	0.9563	0.9790	0.9508	0.9854
StO_2	0.9579	0.9470	0.9583	0.9115
AF	0.9070	0.9515	0.8051	0.9678
SP	0.93269	0.9867	0.9234	0.8891

4 Discussion

Our study showed that the most hypertonic points in the upper trapezius muscle had a greater [HHb] and [HbT], a reduced StO_2, and no changes in [HbO_2] compared to the least hypertonic points as measured by TD-NIRS. This could be interpreted as a local small increased metabolic activity (greater [HHb]), where O_2 demand marginally outstrips supply (small decrease in StO_2 and no significant change in [HbO_2]) by means of an increased blood volume/flow (higher [HbT]). This hypothesis would have to be confirmed by adding an independent assessment of the blood flow to clearly differentiate the supply from the demand, which is not straightforward with NIRS measurements only. Techniques such as diffuse correlation spectroscopy (DCS) could be used in combination with TD-NIRS to do so [7]. Moreover, our participants were healthy subjects, so it remains to be seen whether the same findings would be seen in a clinical population to better understand the physiology of MPS and MTrPs.

Regarding the scattering parameters, our results showed an increase of the AF but not of the SP in the most hypertonic points compared to the least. This reflects an augmentation in the effective concentration of the scattering centres with no change in their dimension, indicating a greater density of the *same* scattering structure [5]. Thus, this suggests that the most hypertonic points were optically denser than the least hypertonic points within the upper trapezius muscle according to the TD-NIRS analysis. This is in line with previous works using different instruments such as ultrasound imaging [8], showing a difference in tissue density between MTrPs and normal sites in various muscles. However, as the NIRS measurement is not a direct measure of tissue density, further work would be needed to confirm this hypothesis.

Overall, the TD-NIRS scattering and absorption parameters seems to differ between palpably normal and hypertonic points within the upper trapezius muscles. Several limitations of this preliminary study should be acknowledged. First, in the methodology, the amount of external pressure applied by the examiner was qualitatively assessed, and more quantitative measurement is needed to standardize the measurements, such as the use of a pressure algometer. Secondly, it is worthwhile to realise that baseline muscle tonicity varies between individuals. The use of a scale or a tonicity ratio (between the most hypertonic point and the

surrounding muscle tissue) might provide with more accurate results. Then, in our study, a single practitioner performed all examinations, and inter- and intra-observer variability were not assessed. For the TD-NIRS protocol, subcutaneous adipose tissue thickness (SATT) was not measured in this study as it was thought not be significant over the upper trapezius muscle. However, it might partially explain the difference between male and female, as male tends to have a smaller SATT with respect to female [9]. Further research might see the use of a skinfold calliper to measure SATT, and/or a more complex light propagation model could be used in TD-NIRS to allow for the SATT above the muscle. Finally, in the present study the myoglobin (Mb) species was not considered. Indeed, there is a debate about the contribution of haemoglobin (Hb) and Mb to the in vivo near-infrared (NIR) signal from skeletal muscle, as it is difficult to differentiate Hb and Mb spectra since they are very similar in the NIR range [9].

In conclusion, this study shows, for the first time, a correlation between the resting tonicity state of the upper trapezius muscle, detected by palpation, and a change in the haemodynamic and scattering state measured by TD-NIRS in healthy subjects. These initial results are encouraging and show that TD-NIRS could help to further understand the physiology behind the formation of MPS and MTrPs and assess the validity of palpation as a diagnostic tool in manual therapy.

References

1. www.osteopathy.org.uk/standards/osteopathic-practice/.
2. Cerezo-Téllez, E., Torres-Lacomba, M., Mayoral-Del Moral, O. *et al.* (2016). Prevalence of Myofascial Pain Syndrome in Chronic Non-Specific Neck Pain: A Population-Based Cross-Sectional Descriptive Study. Pain Medicine (Malden, Mass.), 17(12), 2369–2377.
3. Dommerholt, J., Bron, C., & Franssen, J. (2011). Myofascial trigger points: an evidence-informed review. In: J. Dommerholt & P. Huijbregts, ed., Myofascial trigger points: Pathophysiology
4. Contini, D., Zucchelli, L., Spinelli, L., Caffini, M. *et al.* (2012). Review: Brain and muscle near infrared spectroscopy/imaging techniques. Journal of Near Infrared Spectroscopy, 20(1), 15–27.
5. Pifferi, A., Farina, A., Torricelli, A. *et al.* (2012). Review: Time-domain broadband near infrared spectroscopy of the female breast: A focused review from basic principles to future perspectives. Journal of Near Infrared Spectroscopy, 20(1), 223–235.
6. Lange, F., Dunne, L., Hale, L. *et al.* (2019). MAESTROS: A Multi-wavelength time domain NIRS system to monitor changes in oxygenation and oxidation state of cytochrome-c-oxidase. IEEE Journal of Selected Topics in Quantum Electronics, 25(1).
7. Cortese, L., Lo Presti, G., Zanoletti, M. et al. (2021). The LUCA device: a multi-modal platform combining diffuse optics and ultrasound imaging for thyroid cancer screening. Biomedical Optics Express, 12(6), 3392-3409.
8. Jafari, M., Bahrpeyma, F., Mokhtari-Dizaji, M. *et al.* (2018). Novel Method to Measure Active Myofascial Trigger Point Stiffness Using Ultrasound Imaging. Journal of Bodywork and Movement Therapies, 22(2), 374–378.
9. Ferrari, M., Muthalib, M., & Quaresima, V. (2011). The use of near-infrared spectroscopy in understanding skeletal muscle physiology: recent developments. Phil. Trans. R. Soc. A, 369, 4577–4590.