SIE 2015 6th International Symposium on Industrial Engineering 24th-25th September 2015 FACULTY OF MECHANICAL ENGINEERING STEINBEIS ADVANCED RISK TECHNOLOGIES INNOVATION CENTER FME

OCCUPATIONAL HAZARDS IN DENTISTRY - APPLICATION OF THE NEAR INFRARED SPECTROSCOPY IN DIAGNOSTICS OF FATIGUE AND MUSCULOSKELETAL DISORDERS

Aleksandar Zunjic[1], Lidija Matija[2], Jelena Muncan[2], Ivana Mileusnic[2], Ljubisa Petrov[2]
[1]Industrial Engineering, Faculty of Mechanical Engineering, University of Belgrade, Serbia
[2]Biomedical Engineering, Faculty of Mechanical Engineering, University of Belgrade, Serbia

Abstract. *Practice in dentistry requires high degree of attention and precision during work related tasks. Awkward standing postures and sitting positions, repetitious hand and wrist movements, as well as mechanical vibrations originating from high-speed instruments can lead to development of musculoskeletal disorders. The objective of this paper is to assess suitability of application of near infrared spectroscopy as a method for evaluation of musculoskeletal disorders in dentists.*
Keywords: dentistry, ergonomics, musculoskeletal disorders, near infrared spectroscopy, aquaphotomics

INTRODUCTION

Many dentists work frequently in static, uncomfortable positions during the therapy of patients. It is necessary to indicate that these continuous positions during the time can lead to the pain, injury, or, in severe cases, to the musculoskeletal disorders, disability or premature pensioning. The adequate ergonomic design of equipment is important, in order of prevention of repetitive strain injuries and other musculoskeletal disorders.

Musculoskeletal disorders (MSD) are generally recognized as one of the most prevalent workplace injuries while health organizations around the world spend billions of dollars every year on this occupational health problem [1]. Work-related MSD frequently occur as a consequence of cumulative trauma and can influence the bones, muscles with their attachments, as well as the blood supply and nerves [2]. A significant number of research has identified that dental workers are at an increased risk of appearance of MSD, with reported prevalence rates between 64% and 93%, which negatively affects efficiency and lead to reduction in overall job satisfaction [3-5].

MSD are not an inevitable part of a dentistry profession. Paying the attention to the symptoms, identifying the occupational risk factors related to the MSD, as well as implementing of adequate health and safety measures can guarantee a long and healthy working career. In connection with the aforementioned, it is necessary to identify all relevant physiological responses in a human body, in order to provide proper ergonomic solutions for the special needs related to the dentistry practice.

Figure 1 shows a modified model of the relationship between mechanical exposure and health effects, based on the model proposed by Westgaard and Winkel [6]. According to the modified model, internal musculoskeletal load results in physiological and psychological responses covering a wide variety of effects at the system, on the level of muscles, organs, as well as on the cellular level. Such responses may include short-term development of fatigue, discomfort or pain and, on a longer time scale the health effects. The relationships between external mechanical exposure and internal biomechanical load, and between mechanical exposure and body responses were examined in laboratory studies.

Dentists during their tasks could be exposed to significant loads in the regions of the hand, forearm, upper arm, shoulder region, neck and back and lower extremities. From the posture and the way the dentists perform their tasks depend in which part of the body the fatigue will be primarily manifested, as well as the locations where MSDs could be developed over time. Although the aetiology of fatigue is not yet well understood, the general understanding is that muscular work produces inordinate increases in intramuscular pressure, therefore impairing local tissue perfusion causing fatigue and ischemia.

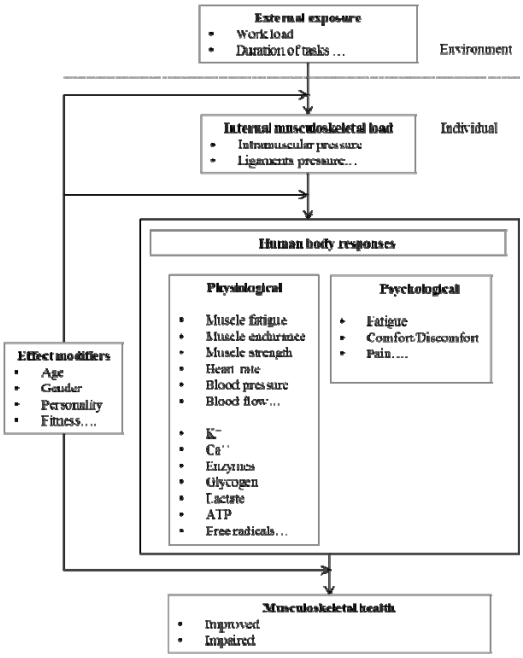

Figure 1. Model of relationship between external mechanical exposure and musculoskeletal health effects (adaptation based on [6])

Low force muscle contractions lead to the impaired oxidative metabolism, thus generating the muscle fatigue, which may be a predecessor for the appearance of muscle disorders [7]. Muscle oxygenation changes throughout of upper extremity work could provide comprehension of pathophysiological mechanisms that are connected with work-related muscle fatigue and disorders.

This paper puts an accent on applications of near infrared spectroscopy as a method of assessing parameters of exposure on the internal level, and proposes a new approach, not reported in the literature, with the potential for detection and monitoring of extensive number of parameters related to muscles functioning which could provide better insight into evaluation of the musculoskeletal disorders.

APPLICATION OF NIRS FOR ASSESSMENT OF MUSCOSKELETAL DISORDERS

Changes in musculoskeletal system can be detected using various methods. Measurement of forces, study of movements, subjective responses and electromyography measurements are frequently used to investigate musculoskeletal work-related risk factors. However, in vivo evaluations of local metabolism and hemodynamic are difficult, especially in the workplace. One of the methods that could potentially be used for this purpose is near infrared spectroscopy (NIRS). With the development of portable non-invasive optical instrumentation for measurement of the blood volume and local muscle oxygenation, studying muscle physiology as a function of ergonomic risk factors is becoming more evident.

Light manual jobs with elevated arms, which are characteristic for a work of a dentist, influence the blood flow and local tissue oxygenation of working muscle. Further, work with a monotonous or repetitive muscle activity pattern is associated with a higher risk of low back and upper extremity disorder development. There is certain evidence that signals obtained on the basis of the near-infrared spectroscopy can be used to evaluate oxidative metabolism in muscles during the work. Since this method is used in ergonomics for only short period of time, it is necessary to examine in what extent it can be used in the studies of work in dentistry practice from ergonomic aspect. Considering that different parts of the body during dentistry tasks may be exposed to different types of stresses (static, repetitive, long term), it is necessary to examine whether the NIRS method can be successfully applied to said body regions.

Near infrared spectroscopy is a non-invasive method, which uses the near-infrared part of the electromagnetic spectrum (680-2500 nm). In the near-infrared part of the electromagnetic spectrum, oxygenated blood is absorbed at 800 nm, whilst at 760 nm it is mostly absorbed by deoxygenated haemoglobin (Figure2). During a muscle action, the intramuscular pressure reduces the blood flow making a decrease in blood volume and oxygenation of tissues. NIRS can be succesfully used as a measure of changes in oxygenation in muscles during contraction, revealing variations in the level of oxygenation by giving information about the levels of deoxygenated and oxygenated haemoglobin, local blood circulation, as well as in the blood volume in muscles during work [8].

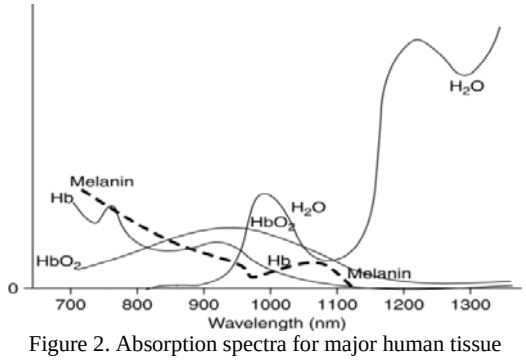

Figure 2. Absorption spectra for major human tissue chromophores: oxygenated haemoglobin (HbO_2), deoxygenated haemoglobin (Hb), melanin, and water (H_2O) over wavelengths in NIR range.

By using this technique, tissue oxygenation can be measured in the area of tissues in a working physiological setting, which improves specificity and has clear advantages as compared to other methods [9]. Near infrared spectroscopy has been increasingly used for discovering the relationship between fatigue development and the lack of oxygen

[10]. Additionally, NIRS is a sensitive tool which can be used to discriminate pathological and normal states [11]. Thus, NIRS has a diagnostic role in assessing the presence and scope of both metabolic and circulatory irregularities as well.

Earliest reports on NIRS as diagnostic applications date from 1977 [12]. Ozaki et al. later examined venal blood to determine the level of deoxyhemoglobin on the back of a hand [13]. Sowa and co-workers used NIRS imaging as a non-invasive technique to discover the effects of restricted blood flow and ischemia [14]. Mancini et al. used NIRS for estimation of skeletal muscle oxygenation by using differential absorption properties of haemoglobin [15]. Ischemia in the forearm was studied by Mansfield et al. in 1997 [16]. Reduced blood flow [17] or decreased muscle oxygen availability [18] have been associated with fatigue. It has been suggested that impaired blood flow and reduced muscle tissue oxygenation during continuous repetitive work contribute to the development of work-related MSD [19, 20].

It has been shown that low-force static muscle contractions [21] such as computer mouse work [22] can produce a decrease in local tissue oxygenation. Subjects that experienced great tension and fatigue showed a significant drop in forearm oxygenation when time pressure and accuracy were imposed on the work to be performed [22]. NIRS was successfully used in the assessment of haemoglobin kinetics and tissue oxygenation in the shoulder muscles [30]. Lin and co-workers have successfully used the NIRS to assess the effect of various work/rest ratios on oxygenation and blood volume in forearm flexor and extensor muscles during repetitive handheld power tool operations [31]. Crenshaw and associates demonstrate NIRS sensitivity in the assessment muscle contractile characteristics, oxygenation and hemodynamics of the finger flexors during a VDT mouse point and click task [32]. However, the NIRS results over the right lumbar erector spinae were not remarkably altered over time, and exhibited poor relationships with the perceived low back discomfort records for standing and seated exposures [33].

Possibilities of applications of aquaphotomics in the frame of NIRS

Beyond the state of art in NIRS of muscle fatigue, there is one novel framework which utilizes a part of near infrared spectra not previously known to be useful - the region of the 1st overtone of water. Variations in spectra caused by water are often regarded as a nuisance in vibrational spectroscopy. However, this new approach, called Aquaphotomics [23] utilizes exactly this region. Variations in water spectral pattern have been discovered systematically as a result of various changes (concentrations of solutes, concentrations of molecules which don't even absorb light in the NIR range such as metals etc., temperature, light illumination etc.). These findings lead to conclusion that water spectral pattern can be used to extract information on the sources of changes [23]. Aquaphotomics has been successfully used in various diagnostic applications [24-29].

We can conclude that Aquaphotomics has the potential for simultaneous measurements and monitoring of many physiological parameters related to muscle fatigue. It is thus worthwhile to focus research efforts in this direction.

CONCLUSION

This study has shown that NIRS method can be used for the assessment of work load in dentists. The method has disadvantage in the assessment of static work load for sedentary and standing positions in the connection of the region of lower back. However, in all other mentioned cases this method shows high potential for application for the purposes of assessment of MSDs in dentists.

Besides, this study has shown that Aquaphotomics approach also has the potential of application in the framework of NIRS method. However, this approach requires extensive laboratory research for the purposes of obtaining novel information in connection with the possibility of detection of muscle fatigue and MSDs.

REFERENCES

[1] Hayes M, Taylor J, Smith D. Predictors of work-related musculoskeletal disorders among dental hygienists. International Journal of Dental Hygiene. 2012;10:265-9.

[2] Graham C. Ergonomics in dentistry, Part 1. Dentistry today. 2002;21:98.

[3] Puriene A, Janulyte V, Musteikyte M, Bendinskaite R. General health of dentists. Literature review. Stomatologija. 2007;9:10-20.

[4] Hayes MJ, Smith DR, Cockrell D. An international review of musculoskeletal disorders in the dental hygiene profession. International dental journal. 2010;60:343-52.

[5] Anton D, Rosecrance J, Merlino L, Cook T. Prevalence of musculoskeletal symptoms and carpal tunnel syndrome among dental hygienists. American journal of industrial medicine. 2002;42:248-57.

[6] Westgaard RH, Winkel J. Guidelines for occupational musculoskeletal load as a basis for intervention: a critical review. Applied Ergonomics. 1996;27:79-88.

[7] Perrey S, Thedon T, Bringard A. Application of near-infrared spectroscopy in preventing work-related musculoskeletal disorders: Brief review. International Journal of Industrial Ergonomics. 2010;40:180-4.

[8] Taelman J, Vanderhaegen J, Robijns M, Naulaers G, Spaepen A, Van Huffel S. Estimation of muscle fatigue using surface electromyography and near-infrared spectroscopy. Oxygen Transport to Tissue XXXII: Springer; 2011. p. 353-9.

[9] Perrey S. Non-invasive NIR spectroscopy of human brain function during exercise. Methods. 2008;45:289-99.

[10] Tachi M, Kouzaki M, Kanehisa H, Fukunaga T. The influence of circulatory difference on muscle oxygenation and fatigue during intermittent static dorsiflexion. European journal of applied physiology. 2004;91:682-8.

[11] Van Beekvelt MC, Colier WN, Wevers RA, Van Engelen BG. Performance of near-infrared spectroscopy in measuring local O2 consumption and blood flow in skeletal muscle. Journal of Applied Physiology. 2001;90:511-9.
[12] Jobsis FF. Noninvasive, infrared monitoring of cerebral and myocardial oxygen sufficiency and circulatory parameters. Science. 1977;198:1264-7.
[13] Ozaki Y, Matsunaga T, Miura T. Nondestructive and noninvasive monitoring of deoxyhemoglobin in the vein by use of a near-infrared reflectance spectrometer with a fiber-optic probe. Applied spectroscopy. 1992;46:180-2.
[14] Sowa MG, Mansfield JR, Scarth GB, Mantsch HH. Noninvasive assessment of regional and temporal variations in tissue oxygenation by near-infrared spectroscopy and imaging. Applied spectroscopy. 1997;51:143-51.
[15] Mancini DM, Bolinger L, Li H, Kendrick K, Chance B, Wilson JR. Validation of near-infrared spectroscopy in humans. Journal of Applied Physiology. 1994;77:2740-7.
[16] Mansfield JR, Sowa MG, Scarth GB, Somorjai RL, Mantsch HH. Fuzzy C-means clustering and principal component analysis of time series from near-infrared imaging of forearm ischemia. Computerized medical imaging and graphics. 1997;21:299-308.
[17] Byström S, Kilbom Å. Physiological response in the forearm during and after isometric intermittent handgrip. European journal of applied physiology and occupational physiology. 1990;60:457-66.
[18] Hogan MC, Richardson RS, Kurdak S. Initial fall in skeletal muscle force development during ischemia is related to oxygen availability. Journal of Applied Physiology. 1994;77:2380-4.
[19] Carayon P, Smith MJ, Haims MC. Work organization, job stress, and work-related musculoskeletal disorders. Human Factors: The Journal of the Human Factors and Ergonomics Society. 1999;41:644-63.
[20] Van Galen GP, Müller ML, Meulenbroek RG, Van Gemmert AW. Forearm EMG response activity during motor performance in individuals prone to increased stress reactivity. American journal of industrial medicine. 2002;41:406-19.
[21] Jensen BR, Jørgensen K, Hargens AR, Nielsen PK, Nicolaisen T. Physiological response to submaximal isometric contractions of the paravertebral muscles. Spine. 1999;24:2332.
[22] Heiden M, Lyskov E, Djupsjöbacka M, Hellström F, Crenshaw AG. Effects of time pressure and precision demands during computer mouse work on muscle oxygenation and position sense. European journal of applied physiology. 2005;94:97-106.
[23] Tsenkova R. Introduction: Aquaphotomics: Dynamic spectroscopy of aqueous and biological systems describes peculiarities of water. 2009.
[24] Jinendra B, Tamaki K, Kuroki S, Vassileva M, Yoshida S, Tsenkova R. Near infrared spectroscopy and aquaphotomics: Novel approach for rapid in vivo diagnosis of virus infected soybean. Biochemical and biophysical research communications. 2010;397:685-90.
[25] Tsenkova R. AquaPhotomics: water absorbance pattern as a biological marker for disease diagnosis and disease understanding. NIR news. 2007;18:14-6.
[26] Tsenkova R. Aquaphotomics: water absorbance pattern as a biological marker. NIR news. 2006;17:13.
[27] Tsenkova R. Aquaphotomics: the extended water mirror effect explains why small concentrations of protein in solution can be measured with near infrared light. NIR news. 2008;19:12-3.
[28] Tsenkova R. Aquaphotomics: acquiring spectra of various biological fluids of the same organism reveals the importance of water matrix absorbance coordinates and the aquaphotome for understanding biological phenomena. NIR news. 2008;19:13-5.
[29] Chatani E, Tsuchisaka Y, Masuda Y, Tsenkova R. Water Molecular System Dynamics Associated with Amyloidogenic Nucleation as Revealed by Real Time Near Infrared Spectroscopy and Aquaphotomics. 2014.
[30] Jensen BR, Krag IR, Bronee L, Crenshaw AG. Tissue oxygenation and haemoglobin kinetics as a function of depth in two shoulder muscles differing in fibre-type composition. Industrial ergonomics. 2010;40:135-139.
[31] Lin JH, Maikala RV, McGorry R, Brunette C. NIRS application in evaluating threaded-fastener driving assembly tasks. Industrial ergonomics. 2010;40:146-152.
[32] Crenshaw AG, Komandur S, Johnson PW. Finger flexor contractile properties and hemodynamics following a sustained submaximal contraction: A study using electrical stimulation and near-infrared spectroscopy. Industrial ergonomics. 2010;40:153-160.
[33] Callaghan JP, Gregory DE, Durkin JL. Do NIRS measures relate to subjective low back discomfort during sedentary tasks? Industrial ergonomics. 2010;40:165-170.