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NEAR-INFRARED MONITORING OF THE LUMBAR ERECTOR SPINAE MUSCLE IN HEALTHY MEN AND WOMEN DURING STATIC AND DYNAMIC ENDURANCE WORK

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Understanding muscle hemodynamics using near-infrared spectroscopy is increasingly evident in the recent spinal disorders-related literature. However, none of these human studies addressed the issue of physiological limits for the lumbar muscle within the same participants during various exercise modes. The purpose of this study is to evaluate physiological limits for the lumbar muscle during dynamic and static endurance tests. On three separate days, 22 healthy men and women performed three endurance protocols (static prone trunk extension, arm cranking, and pushing−pulling) until volitional exhaustion. For each protocol, minimum and maximum oxygenation and blood volume responses from the right lumbar erector spinae were obtained using a continuous dual wavelength near-infrared spectroscopy (Micro-Runman, NIM Inc., PA, USA). Statistical analysis showed that greatest reduction in oxygenation (minimum) were obtained during dynamic exercises: pushing−pulling (2.1 times) and arm cranking (2.03 times) versus static test ($P < 0.05$). *Physiological change* (calculated as the difference between maximum during recovery and minimum at the point of volitional exhaustion) during static test was lower [(66−75% for oxygenation) and (34−46% for blood volume)] than dynamic exercises ($P < 0.05$). Contrary to the theory that sufficient occlusion of blood flow to the lumbar muscle is possible with static trunk extension, it was concluded that a dynamic protocol until volitional exhaustion might be a good alternative in establishing near-infrared spectroscopy-derived physiological limits to the lumbar muscle. Further research is essential to identify an optimal calibration procedure for establishing true hypoxic values for the human lumbar muscle.

Keywords: Arm cranking; back muscle endurance; gender differences; oxygenation and blood volume; pushing−pulling; Sorensen test.

1. Introduction

Application of optical techniques such as near-infrared spectroscopy (NIRS) in understanding muscle microvascularity in both healthy and diseased populations has grown rapidly in the last two decades.[1−3] In particular, monitoring of lumbar muscle circulatory responses with NIRS during a variety of sports and occupational activities provides important insights into the pathophysiology associated with low-back-related musculoskeletal

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disorders. Undeniably, it was Dr Britton Chance's work in developing portable and user-friendly real-time continuous wave NIRS systems (e.g., Runman^{TM}, Micro-Runman) that paved the way for the first application of NIRS in understanding (de)oxygenation trends and venous oxygen saturation in the lumbar muscle region.[4,5] Thereafter, a surge of NIRS publications utilizing Dr Chance's invention started to emerge within the low-back muscle hemodynamics research.

Interestingly, the majority of current continuous-wave NIRS devices do not measure absolute levels of venous saturation in the muscle during performance of any activity. However, in a skeletal muscle, a complete range of oxygenation conditions is necessary to establish both the "minimum" (0% oxygenation) and the "maximum" (100% oxygenation) spectral values. To this effect, the changes in oxygenation during ischemic conditions or varying levels of physical activity are typically scaled to the overall change in the NIRS-derived hemodynamic signal, termed as "total labile signal" or "physiological calibration".[6,7] For example, physiological calibration is usually calculated as the difference in the tissue absorbency between a fully reduced condition (created through restricting the oxygen supply to the muscle under investigation by cuff ischemia or arterial clamping) and maximum oxidation (obtained by increasing the oxygen delivery).[6] Such a range helps in evaluating the role of an exercise mode or a physical activity in influencing the "true" hypoxic values of the specific muscle under study. Conversely, the vascular occlusion to the human lumbar muscle is practically impossible. To this effect, a few authors[8,9] employed *physiological change* as a proxy to physiological calibration for specific muscles, calculated as the difference between maximum (during recovery from an incremental exercise) and minimum NIRS-derived hemodynamic values (at the point of volitional exhaustion). However, it is not clear if such *physiological change* could be established for the lumbar muscle during any type of exercise. The present investigation was proposed to examine lumbar muscle oxygenation and blood volume limits during three different exercise modes until volitional exhaustion.

The prone trunk extension approach has been widely utilized and validated to evaluate static back muscle endurance and fatigue.[10] This test is reported to induce at least 40% of maximal voluntary contractions to lumbar muscles.[11] It was hypothesized that such levels of muscle contraction might result in sufficient occlusion of blood flow to the paraspinal extensor muscles.[12] However, it is not clear if physiological limits for the lumbar muscle, obtained from such a sustained static test, differ from corresponding physiological limits obtained during dynamic endurance activities. Upper body-specific activities, such as arm cranking and pushing−pulling, were chosen as dynamic exercises. These dynamic modes were investigated in a larger context of exercise performance.[13] Recruitment of trunk muscles during these selected dynamic exercises was previously reported.[14−17] Since the static test results in sufficient blood occlusion to the lumbar muscle region, it was hypothesized that the oxygenation and blood volume limits would be greater during static mode compared with dynamic mode. Women have greater percentages of slow twitch fibers, especially in the trunk musculature,[11] but have less hemoglobin than men, resulting in lower oxygen-carrying capacity.[18] Thus, a secondary hypothesis was that responses within the NIRS-monitored muscle region of interest for women would differ from men.

2. Methods

2.1. *Participants*

Written informed consent was obtained from 11 healthy men (age 23.7 ± 4.5 years, mass 77.5 ± 13.8 kg, height 176 ± 8 cm) and 11 healthy women (age 24.5 ± 3.5 years, mass 57.6 ± 9.4 kg, height 163 ± 7 cm). They all completed the Revised Physical Activity Readiness Questionnaire developed by the Canadian Society for Exercise Physiology, to identify contraindications for exercise. The experimental protocol was approved by the human research ethics board at the university.

2.2. *Test protocols*

Each participant completed static back muscle endurance, incremental arm cranking, and incremental pushing−pulling tests, on three separate days, in a random order. These tests were separated by at least one week to avoid delayed onset muscle soreness.

2.2.1. *Static back muscle endurance test*

The participant was asked to lie prone on an adjustable plinth, with the anterior border of the

iliac crest adjusted to the edge of a marker on the plinth.[10] One pillow was placed on the mid-thigh and another beneath the tibialis region, with two elastic straps positioned at mid-thigh and mid-calf region. These straps were tightened so that the participant's lower body was completely restrained at those positions. An adjustable rope with a weight attached at its end was lowered to the position between the participant's scapula to serve as a reference point for the trunk alignment. The test was initiated with a 2-min rest period. Five seconds before the endurance test began, a countdown started, and the section of the plinth supporting only the upper body was lowered at the final countdown. The participant was verbally instructed to place the arms across the chest and minimize trunk rotations throughout the endurance session and maintain contact with the reference point for as long as possible. The test was terminated when the participant was unable to maintain contact with this reference point. Thereafter, the plinth support to the upper body was immediately restored, and the participant was allowed to recover for 4 min in the prone position. Endurance time to the nearest second was recorded as the time from the onset of extension to volitional exhaustion.

2.2.2. *Incremental arm cranking*

In a seated posture, each participant completed a stepwise incremental aerobic endurance test on the ergometer (Cybex, MET 300, USA). The axis of the ergometer crankshaft was adjusted to shoulder height of each seated participant.[8,13] Position of the handle was adjusted in such a way that when the arms were fully extended, a slight flexion was present at the elbow joint. Legs and trunk were not restrained, and feet were flat on the ergometer base. The test was initiated with a 2-min rest period, followed by 2 min of cranking at no load and subsequent increments of 25 W every 2 min at 50 crank rotations per min until volitional exhaustion, or attainment of 2 or more of the end points as the limit for test termination[13]: (a) leveling off in the oxygen consumption (increase of $\leq$100 ml min^{-1}) with increasing load, (b) age predicted maximal heart rate, equated to 220-age, (c) respiratory exchange ratio of $\geq$1.10, and (d) rate of perceived exertion on the Borg scale $\geq$18. Protocol also included 2 min of active recovery (cranking at zero load) and 4 min of passive sitting recovery.

2.2.3. *Incremental pushing–pulling*

Each participant completed a stepwise incremental aerobic endurance test in standing posture on the Baltimore Therapeutic Equipment work simulator (Baltimore Therapeutic Equipment Co., Maryland, USA). Before beginning the session, the height of the push–pull lever was adjusted to each participant's elbow crease in the standing upright posture.[13] The right hand was used as the main grasping hand in this two-handed effort. The elbows were unlocked, and the participant was discouraged from trunk rotation, swaying the body, and moving the lower extremities during pushing–pulling. The participant was instructed to put the right leg (extended at the knee) backward at a comfortable distance, and the left leg forward with a slight knee flexion so that the toe was placed on a marker that was in line with the handle being pulled. Further, the participant was discouraged not to lift the heels off the floor.

The test was initiated with a 2-min rest period and was followed by 2 min of pushing–pulling a lever consisting of a straight handle with an articulating joint, in the sagittal plane at no load in the horizontal direction. Thereafter, the resistance was increased by 30 in-lb every 2 min at 50 push–pulls per min until voluntary exhaustion or attainment of 2 or more of the end points.[13] The test was terminated with 2 min of active (push–pull at zero load) and 4 min of passive standing recovery. The total power output (in W) generated was obtained at the end of exercise testing from the computer connected to the work simulator.

2.3. *Oxygenation and blood volume measurements*

A continuous dual-wave NIRS unit (Micro-Runman, NIM Inc., PA, USA) developed by Dr Britton Chance was used to evaluate relative changes in the muscle oxygenation and blood volume. This unit consists of: a near-infrared sensor; detectors that absorb light between 760 and 850 nm; and a display unit that amplifies and displays the absorbency signal. For three exercise protocols, the sensor was placed on the right erector spinae muscle at the 3rd lumbar vertebra, approximately 3 cm from the midline of the spine.[19,20] The erector spinae is a collection of three muscles: illiocostalis, longissimus, and spinalis, and covers both lumbar and thoracic

regions of the spinal cord. Since the cross-sectional area of the paravertebral muscles is largest between 1st and 4th lumbar regions, we chose the 3rd lumbar and the longissimus region for the sensor placement. More importantly, Jensen *et al.*[4] demonstrated that the distance from skin surface to the erector spinae muscle at both cranial and distal aspects in the lumbar region were well within the penetration depth of the near-infrared light.

Position of the sensor at the 3rd lumbar region from the midline of the spine was noted to the nearest millimeter and identified with a marker, thus ensuring the correct placement of the sensor on each participant for all the sessions. Skinfold thickness at the sensor location was measured twice using a skinfold caliper (Cambridge Scientific Industries, Inc., Maryland, USA) before placing the NIRS sensor on the muscle belly. Then, adipose tissue thickness (a sum of fat and skin layer) was calculated as the mean value of skinfold thickness. A piece of clear plastic was wrapped around the sensor to prevent sweat from distorting the absorbency signal. A dark tensor bandage was wrapped around the NIRS region of interest to secure it in place and minimize any loss of light. The sensor was calibrated at 760 and 850 nm wavelengths before each session. The light source−detector separation was set to 4 cm. The difference in absorbency between these two wavelengths indicated the change in oxygenation, whereas the sum indicated the change in muscle blood volume. Both oxygenation and blood volume were measured in optical density units. Optical density is defined as the logarithmic ratio of intensity of light calibrated at each wavelength to the intensity of measured light at the same wavelength.[20] Real-time data were recorded using the NIRCOM software provided by the manufacturer.

2.4. *NIRS-derived data analysis*

Oxygenation and blood volume measurements were averaged every 20 s using a customized Microsoft Excel^{TM} macro. Baseline values were recorded during the initial rest. For three protocols, minimum NIRS limits for each participant were recorded during exercise until volitional exhaustion, whereas maximum limits were recorded during recovery from the same exercise. The *physiological change* for oxygenation and blood volume responses for three protocols was calculated as the difference between the maximum and minimum values.

2.5. *Statistical analysis*

Independent "t-tests" were used to compare physical and performance characteristics of the participants. A two-way analysis of variance, with *gender* as a between-participants factor and *protocol* (static test; arm cranking; and pushing−pulling) as a repeated measure factor was used to compare oxygenation and blood volume responses. A Spearman correlation test was used to examine the relationship between logarithmic value of adipose tissue thickness and oxygenation and blood volume responses during three protocols. Since there was no normal distribution in the adipose tissue thickness of the subjects in the present study, a nonparametric Spearman correlation test was used to examine its role on the NIRS measurements. The statistical significance was considered at $P \leq 0.05$. Any significant F ratios were further analyzed with the Scheffe *post hoc* multiple comparison test. The Statistical Package for Social Sciences (version 10) was used for all statistical analyses (SPSS Inc., Chicago, USA).

3. Results

Compared to women, men were heavier ($P < 0.01$) and taller ($P < 0.05$). Endurance time (in sec) during the static test was significantly greater in women than in men (men: 139 ± 53 versus women: 203 ± 72, $P < 0.01$). Adipose tissue thickness for men (5.4 ± 1.5 mm) and women (6.0 ± 2.3 mm) were similar. In terms of dynamic exercise, aerobic capacity (in L min^{-1}) of men was highest during both exercise modes [(arm cranking — men: 2.36 ± 0.51 versus women: 1.56 ± 0.50, $P < 0.01$), (pushing−pulling — men: 1.74 ± 0.51 versus women: 1.23 ± 0.32, $P < 0.01$)].

NIRS-derived oxygenation and blood volume trends during three exercise modes in a typical female participant are shown in the Figs. 1−3. No significant interaction between the protocols and gender was observed in both NIRS-derived measures. Thus, it should be noted that values in the Figs. 4−9 are pooled values of the main effects: *exercise protocol* (Figs. 4−7) and *gender* (Figs. 8 and 9). Greatest reduction in oxygenation values

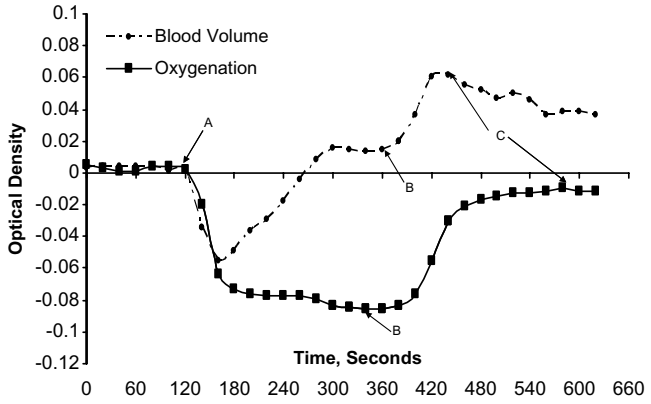


Fig. 1. NIRS-determined oxygenation and blood volume trends of a typical female in the lumbar muscle during sustained static prone trunk extension until volitional exhaustion. A, Start of trunk extension; B, Minimum at the point of volitional exhaustion; C, Maximum during recovery from static exercise.

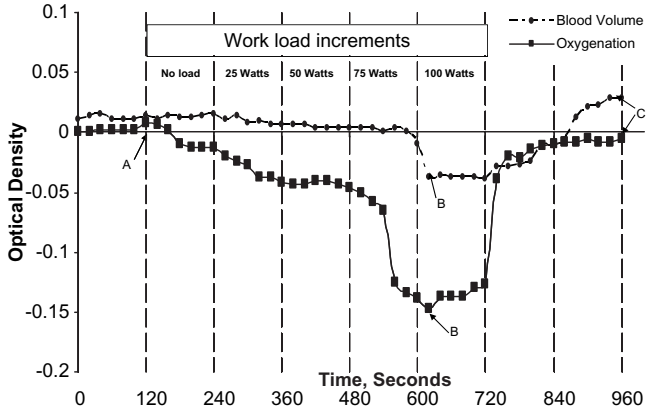


Fig. 2. NIRS-determined oxygenation and blood volume trends of a typical female in the lumbar muscle during incremental arm cranking (steps of 25 W every 2 min) until volitional exhaustion. A, Start of exercise; B, Minimum at the point of volitional exhaustion; C, Maximum during recovery from dynamic exercise.

(minimum) was obtained during pushing−pulling (2.1 times) and arm cranking (2.03 times) than the static test (Fig. 4). Minimum blood volume responses were 3.3 times higher during pushing−pulling and 3.1 times higher during arm cranking than the static test (Fig. 5). Based on the *physiological change*, the static test values were significantly lower [(66−75% for oxygenation; Fig. 6) and (34−46% for blood volume; Fig. 7)] than dynamic exercises. Gender did not influence NIRS-derived responses among the three protocols (Figs. 8 and 9). No significant correlations

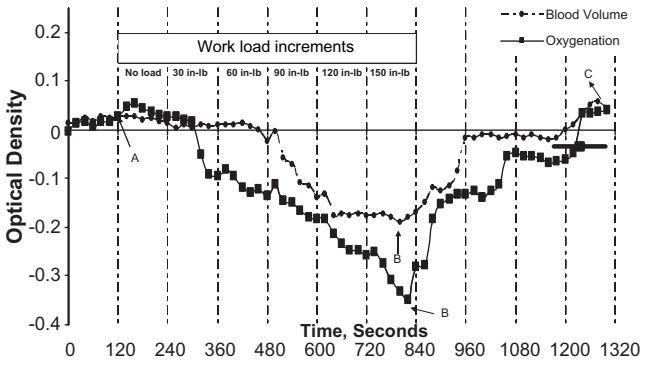
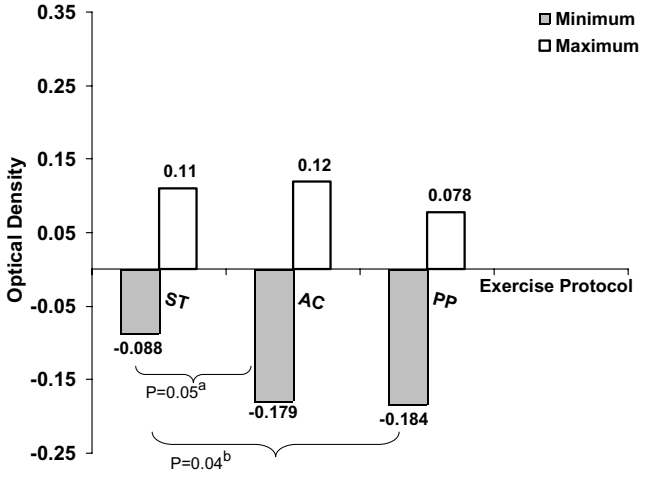


Fig. 3. NIRS-determined oxygenation and blood volume trends of a typical female in the lumbar muscle during incremental pushing−pulling (steps of 30 in-lb every 2 min) until volitional exhaustion. A, Start of exercise; B, Minimum at the point of volitional exhaustion; C, Maximum during recovery from dynamic exercise.

were found between adipose tissue thickness and NIRS-derived measurements.

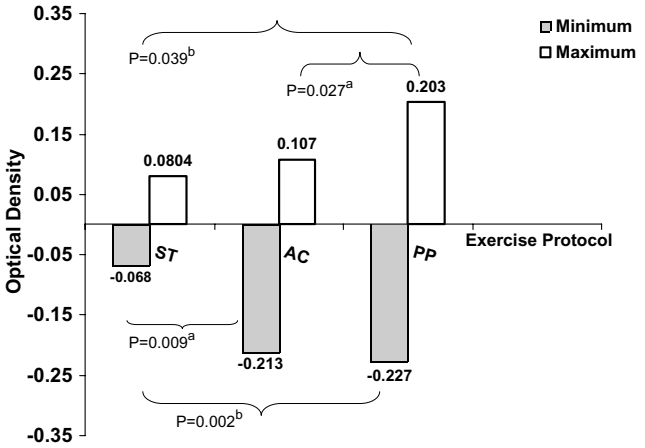
4. Discussion

In the current investigation, physiological limits for the lumbar erector spinae muscle during three different exercise modes were identified using a portable NIRS system developed by Dr Britton Chance. Although each endurance test chosen for the present study has its limitations in terms of muscle recruitment, this is the first study that evaluated lumbar muscle microvascularity, in



[a]Significant difference between static test (ST) and arm cranking (AC).
[b]Significant difference between static test (ST) and pushing−pulling (PP).

Fig. 4. NIRS-determined oxygenation responses (represented by mean values of both men and women) during three exercise protocols: minimum and maximum limits.



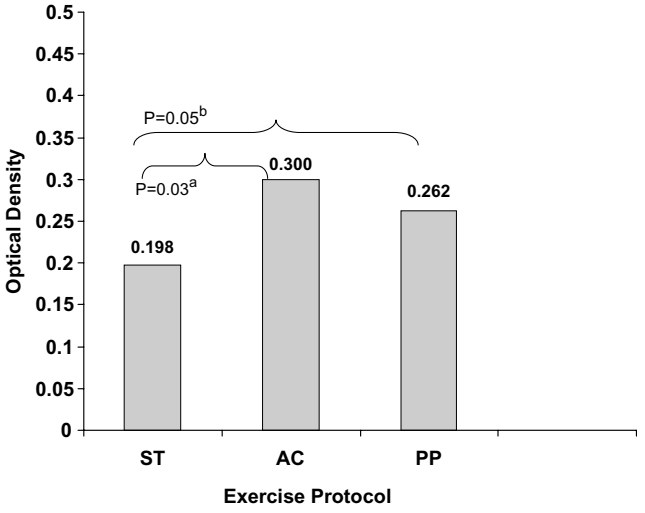
[a]Significant difference between static test (ST) and arm cranking (AC).
[b]Significant difference between static test (ST) and pushing−pulling (PP).

Fig. 5. NIRS-determined blood volume responses (represented by mean values of both men and women) during three exercise protocols: minimum and maximum limits.

both static and dynamic modes within the same participants.

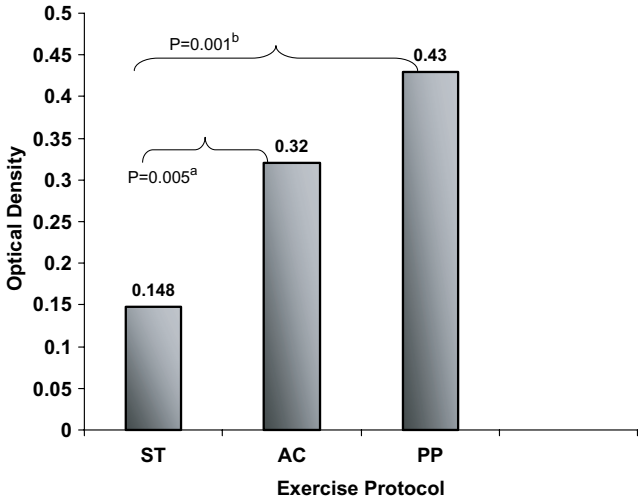
4.1. *Static back endurance exercise*

Based on the *physiological change* among three exercise modes, the static prone trunk extension test that is reported to induce ∼40% of maximal contractions might not be able to establish physiological calibration limits for the lumbar muscle.



[a]Significant difference between static test (ST) and arm cranking (AC).
[b]Significant difference between static test (ST) and pushing−pulling (PP).

Fig. 6. Physiological change in oxygenation responses (represented by mean values of both men and women) during three exercise protocols.



[a]Significant difference between static test (ST) and arm cranking (AC).
[b]Significant difference between static test (ST) and pushing−pulling (PP).

Fig. 7. Physiological change in blood volume responses (represented by mean values of both men and women) during three exercise protocols.

Unlike ischemic protocols that have been adopted to establish fully oxidized and reduced states for specific muscles,[1,22−24] the static trunk extension test was not able to occlude arterial blood flow to the lumbar muscle. This contradicts the observations of Bonde-Petersen *et al.*,[12] who suggested that such percent of maximal contractions is sufficient for occluding blood flow to the paraspinal muscles. This observation can be better understood by the NIRS trends (Fig. 1). As the contraction period increased, the majority of participants demonstrated a rapid muscle desaturation (as evidenced by the

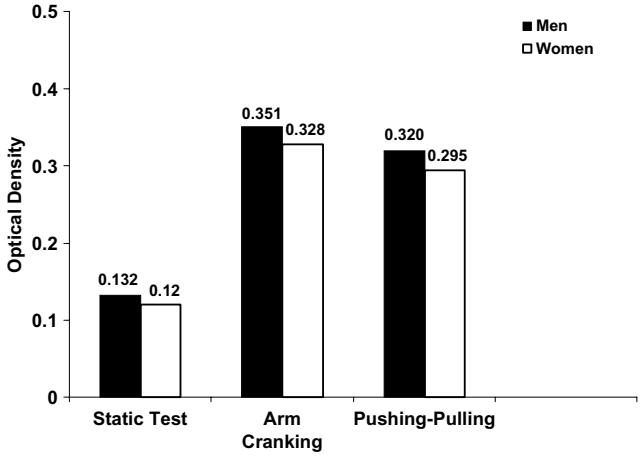


Fig. 8. NIRS-determined *physiological change* in oxygenation responses (represented by mean values) between men and women during three exercise protocols.

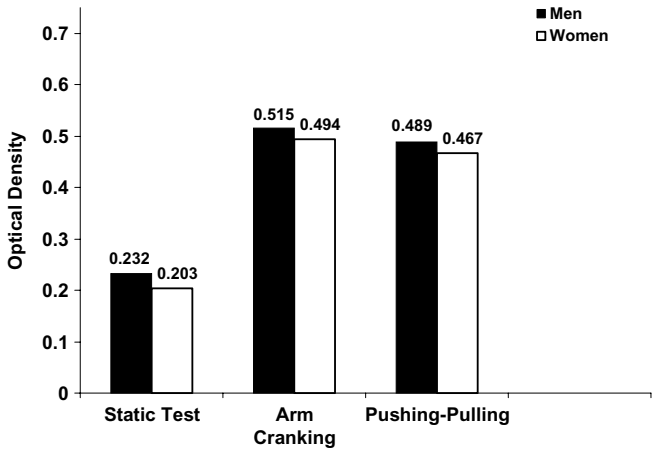


Fig. 9. NIRS-determined *physiological change* in blood volume responses (represented by mean values) between men and women during three exercise protocols.

decrease in oxygenation) resulting in restriction of blood flow due to a greater intramuscular pressure in the lumbar muscle (Fig. 1). As the exhaustion point was reached, there was a plateau in oxygenation trends, suggesting a local homeostatic adjustment over a period may result in constant capillary oxygen tension.[4] This phenomenon might further prevent decrease in hemodynamics in these paraspinal muscles. Concomitantly, as the trunk extension continued, a systematic increase in blood volume trend was observed (Fig. 1). At final stages, the majority of participants demonstrated a leveling off in blood volume trend. Such hyperemia in blood volume, with a parallel decrease in oxygenation during trunk extension until volitional exhaustion, suggests that complete occlusion of arterial flow to the lumbar muscle is not possible with this static protocol. This is an important finding because such out-of-phase hemodynamic trends in the lumbar muscle (Fig. 1) are similar to insufficient cuff occlusion trends of a few leg muscles. Rundell *et al.*[24] demonstrated hyperemia in vastus medialis and biceps femoris muscles (Fig. 9 in their paper[24]) with a simultaneous decrease in the vastus laterlais and rectus femoris muscles, suggesting a complete arterial occlusion is not feasible for all the four-leg muscles monitored. Since the erector spinae is a collection of three muscles (illiocostalis, longissimus, and spinalis) and NIRS sensor was placed on the longissimus dorsi region, the static test chosen for the present study might not have achieved complete reduced ischemic conditions, thus demonstrating hyperemic response in blood volume but decrease in oxygenation (Fig. 1). However, in theory, an increase or decrease in the optically derived muscle blood volume reflects the balance between local muscle blood flow (at the region of interest), the effect of muscular contraction on vascular hemoglobin volume, metabolic vasodilation, hemoconcentration, and capillary recruitment.[25] Therefore, one should be cautious in extrapolating the blood volume changes observed directly to the blood flow phenomenon. Nevertheless, based on the present findings, sustained static prone trunk extension cannot occlude blood flow completely to the lumbar muscle.

Endurance time during the static test was significantly greater in women (by 32%) than in men and is in agreement with several studies.[10,11,27] Greater endurance time in women might be attributed to their lower upper-body weight, and greater percentages of slow twitch fibers in the trunk musculature compared to men.[11] Mayer *et al.*[27] also hypothesized that load-to-maximum voluntary contraction ratio in women will be greater than that in men. However, both NIRS-derived responses were not significantly different during the static test. These findings suggest that, irrespective of greater holding time in women, both men and women demonstrate similar oxygen desaturation during the static test.

4.2. *Dynamic endurance exercise*

Constant gripping of the handle during arm cranking while sitting results in an additional isometric component for torso stabilization.[15] As the workload increases stepwise, the possibility of nonuniform recruitment of shoulder and trunk muscles results, reaching maximal values at peak workloads.[14] During the early stages of incremental arm cranking, involvement of arm muscles is greater; however, as the workload increases, the possibility of nonuniform recruitment of shoulder and trunk muscles results, reaching maximal values at peak workloads.[14] To this effect, the present NIRS trends in the Fig. 2 suggest that recruitment of the lumbar muscle may not be influential during lighter workloads.[14,15] However, there was a rapid decline in oxygenation at the final workloads (Fig. 2). This phenomenon indicates the importance of trunk muscle recruitment and postural stabilization needed during maximal effort of arm cranking.

Conversely, during pushing−pulling while standing NIRS-derived responses started decreasing

steadily in a majority of participants with an increase in workload (Fig. 3). A steady decrease in the oxygen saturation with increase in workload might suggest an increase in oxygen demand exceeding the muscle saturation, reflecting an increased oxygen extraction from the lumbar muscle. Interestingly, postural difference during these dynamic modes (sitting — arm cranking versus standing — pushing−pulling) did not influence NIRS-derived responses, implying that trunk muscles respond similarly during both incremental stepwise exercise modes at volitional exhaustion. To this effect, Troup and Chapman[26] demonstrated that the applied extensor forces during pushing and pulling were greater in sitting compared to standing; however, the forces transmitted by the erector spinae muscle were of similar magnitude. A similar phenomenon might have led to lack of significance in the NIRS-derived hemodynamic limits observed during pushing−pulling and arm cranking (Figs. 4−7). Furthermore, similarity observed in the peak NIRS-derived responses obtained during the dynamic protocols might suggest that the differences in peak pulmonary oxygen uptake for both genders are independent of their ability for oxygen extraction or delivery but might be a function of the size of contracting skeletal muscle mass that is being recruited. Although NIRS-derived responses are reported to be influenced by adipose tissue thickness of the skeletal muscle under investigation, the influence of skinfolds on NIRS-determined responses was not significantly correlated in the present study. These findings further suggest the sensitivity and successful application of NIRS technique in investigating localized metabolic regulation from the erector spinae muscle region.

Considering the discrepancy among the three protocols (e.g., posture — prone versus sitting versus standing; and activity type — static versus dynamic), in future, one should also evaluate and compare physiological calibration during: (1) endurance measurement — "dynamically" through the full range of motion rather than "static" tests[11,28]; (2) back extension — using force feedback at higher levels of force in standing, semi-standing or sitting[29,30]; (3) repetitive trunk dynamic extension — time-specific[31] or until volitional exhaustion (as demonstrated in the present study), or (4) applying compression on the NIRS region of interest (on the lumbar muscle) immediately after the completion of chosen low-back specific exercise.[4]

4.3. *Implications of NIRS devices developed by Dr Britton Chance in low-back disorders research*

While measurements such as pulmonary oxygen uptake and heart rate can be used to assess whole-body physiological responses (i.e., macrolevel) during physical work, these measurements do not provide information on the circulatory responses from specific muscles (i.e., at microlevel).[3] Impaired blood flow, in addition to other possible pathophysiological mechanisms, is one of the pathways implicated in a variety of work-related musculoskeletal disorders. Since NIRS-derived hemodynamic responses reflect the balance between oxygen supply and demand to the muscle region of interest, the potential application of NIRS systems (e.g., Runman™, Micro-Runman) has opened doors for many research investigations related to occupational health, specifically in the low-back muscle research.

Utilizing the Runman™ system, Jensen *et al.*[4] demonstrated that at an intramuscular pressure range of 30−40 mmHg, oxygenation in the lumbar erectors spinae muscles was significantly reduced suggesting a local homeostatic adjustment thereby constant capillary oxygen tension, thus further preventing decrease in hemodynamics in these paraspinal muscles. Maikala and Bhambhani[5] reported a prospective application of the same NIRS system for understanding low-back muscle oxygenation responses during repetitive lifting and lowering. Based on the oxygenation responses derived from the Runman™, McGill *et al.*[30] postulated that a decrease in oxygenation during seated low-back isometric extension might be due to compromised blood flow in the smaller blood vessels because the intramuscular pressure exceeds the intravascular pressure as the duration of contraction increases. These three studies were just the beginning of what is now a plethora of NIRS-related publications evidenced either in exercise- or work-induced low-back fatigue and low-back pain research.

Although a review of NIRS-related investigations utilizing these two NIRS systems is beyond the scope of this manuscript, one could not exclude the question of the reliability of NIRS-derived measurements with respect to the lumbar muscle region. To this effect, the present authors established reliability of the NIRS systems (Runman™, Micro-Runman) for understanding low-back muscle hemodynamics during different exercise modes.

Using the Runman™ system, Maikala *et al.*[19] established the reliability of NIRS in the lumbar erector spine muscle as a function of posture for a period of 2 min. These authors reported significant correlation coefficients of 0.84 and 0.83 for minimum oxygenation during maximal low-back extension in standing (legs were shoulder width apart) and sitting (on a chair without back support), respectively, and 0.99 for the minimum blood volume during both postures. During static prone trunk extension until volitional exhaustion, Maikala and Bhambhani[32] evaluated the reliability of the Micro-Runman in determining oxygenation and blood volume responses from the lumbar erector spinae in healthy men and women. Test−retest reliability, based on the intra-class correlation coefficients, for the *physiological change* were: oxygenation — men: +0.60 versus women: +0.37; blood volume — men: +0.93 versus women: +0.59, respectively. The high reliability of these two studies emphasized the fact that oxygenation and blood volume responses measured by the two NIRS systems are fairly stable over time and therefore repeated measurements are not mandatory. Furthermore, the NIRS-derived hemodynamic trends from the present study (Figs. 1−3) clearly demonstrate that NIRS-derived hemodynamic responses could be successfully applied to understand the low-back muscle physiology during a variety of activities.

5. Conclusions

The most interesting finding of the present study is the greatest desaturation observed during dynamic modes as compared to the static test. This result also suggests that although men can exhibit greater systemic responses in terms of their aerobic capacity, their peripheral limitations at the erector spinae level are similar to women among three exercises. More importantly, the present study demonstrates the excellent sensitivity of the NIRS device developed by Dr Britton Chance in detecting variation in lumbar muscle oxygenation and blood volume trends in both men and women as a function of static and dynamic low-back intensive endurance exercise modes.

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