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ORIGINAL ARTICLE

Robert T. Kell · Mamdouh Farag · Yagesh Bhambhani

Reliability of erector spinae oxygenation and blood volume responses using near-infrared spectroscopy in healthy males

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Abstract The purpose of this investigation was to (1) describe the trends in oxygenation (OXY) and blood volume (BV) of the right and left paraspinal muscles during the Biering-Sorensen muscle endurance (BSME) test using near infrared spectroscopy (NIRS), and (2) assess the test-retest reliability of OXY and BV changes during the BSME in healthy males. Seventeen healthy males [age = 28.4 (9.8) years, height = 1.75 (0.05) m, body mass = 82.7 (9.1) kg; mean (SD)] completed two BSME trials within 1 week. NIRS probes were placed bilaterally at lumbar 3. The test was performed with the subject in the prone position using the following protocol: 2 min baseline, BSME, and 4 min recovery. The delta and range values of OXY and BV were used for analysis. Acceptable intra-class correlations were observed for endurance time and all the NIRS variables at the point of fatigue and at each 10% segment of the BSME during the two trials. Bland-Altman plots confirmed the reproducibility of the bilateral NIRS responses of the paravertebral muscles. The BV responses were more reliable than the OXY responses during the two trials. The OXY and BV responses of the paravertebral muscles during static contractions can be measured reliably using NIRS. Future studies should focus primarily on BV for analysis.

Keywords Blood volume · Erector spinae · Near infrared spectroscopy · Oxygenation

R. T. Kell (✉)
Faculty of Kinesiology and Health Studies,
University of Regina, Regina, SK, Canada, S4S 0A2
E-mail: robert.kell@uregina.ca
Tel.: +1-306-5854362
Fax: +1-306-5854854

M. Farag · Y. Bhambhani
Faculty of Rehabilitation Medicine, University of Alberta,
Edmonton, Alberta, T6G 2G4, Canada

Introduction

A common clinical tool for assessment of erector spinae muscle endurance, which is related to low back health, is the Biering-Sorensen test of static muscular endurance (BSME) (Alaranta et al. 1994; Biering-Sorensen 1983, 1984a, 1984b; Jørgensen and Nicolaisen 1987; Latimer et al. 1999; Mayer et al. 1995; Suni et al. 1998). The benefit of using the BSME as a clinical tool for diagnosis of low back muscular endurance is that it is easily administered, inexpensive, and there is a substantial quantity of compiled data.

Previous investigations have used the BSME as a predictor of low-back health, based on endurance time (Biering-Sorensen 1983, 1984a, 1984b; Smidt and Blandpied 1987). However, muscular endurance time is not considered to be objective, and thus a new method of low-back endurance assessment has been sought for obvious reasons. Electromyography (EMG) has been used during the BSME to examine patterns of fatigue in the lumbar musculature, and is considered to be more objective than basic endurance time, as it is not influenced by motivational factors. The reliability of this technique has been documented over both short-and long-term time intervals (Biedermann et al. 1990).

Near infrared spectroscopy (NIRS) is a non-invasive optical technique that has been used to evaluate the relative change in oxygenation (OXY) and blood volume (BV) of the working skeletal muscle located directly beneath the probe. NIRS has been employed during both during static and dynamic contraction and is based on the differential absorption properties of hemoglobin/myoglobin (Hb/Mb) in the near infrared range of 700–1,000 nm. At 760 nm, these chromophores (light-absorbing compounds) are in the deoxygenated form, whereas at 850 nm they occur in the oxygenated state. Hence, by monitoring changes in the tissue absorbency between these two wavelengths, the relative difference in muscle OXY can be obtained. The sum of the absorbency signals at these two wavelengths

indicates the relative change in BV, assuming a constant hematocrit (Chance et al. 1992; Mancini et al. 1994). Hence, the trends observed in OXY and BV are considered to be relative changes occurring at the level of the small blood vessels (arterioles, capillaries and venules) from a reference point during the test (Mancini et al. 1994).

Several recent studies (Jensen et al. 1999; McGill et al. 2000; Yoshitake et al. 2001) have used continuous wave NIRS to examine the trends in erector spinae OXY and BV during isometric contractions of the back. The evidence from these studies suggests that NIRS can be used to objectively evaluate low-back muscular endurance and fatigue. The rationale behind the application of NIRS to low back muscle endurance is that localized blood flow is known to play a prominent role in the termination of muscle contraction due to fatigue (Sjogaard et al. 1988; Yoshitake et al. 2001). Two reasons why fatigue is accelerated during a sustained isometric muscle contraction are: (1) increased intramuscular pressure (IMP) is linked with blood flow restriction to the working muscles (Barnes 1980; Bonde-Petersen et al. 1975), and (2) the metabolic rate of the working muscle is accelerated. A greater intensity of muscular contraction will result in an increased accumulation of fatigue associated byproducts (e.g., hydrogen ions) due to the augmented metabolic rate, and a greater need for oxygen to sustain the muscle contraction (Fitts 1994; Sjogaard et al. 1988; Wenger and Reed 1976). The result of these two circumstances is further exasperated by the recruitment of fast fatiguing motor units as the duration of the contraction increases, thus increasing the rate of hydrogen ion accumulation and onset of fatigue (Fitts 1994).

The BSME is considered to elicit a muscular contraction of 20–75% of maximal volitional contraction (MVC) (Jørgensen and Nicolaisen 1986; Mannion and Dolan 1994; Smidt and Blanpied 1987) which is influenced by body type and conditioning level of the subjects (Jørgensen and Nicolaisen 1986). Muscular contraction between 20% and 75% of MVC should reduce or occlude erector spinae muscle blood flow (Humphreys and Lind 1962; Jørgensen 1997). Since NIRS provides continuous non-invasive measurement of OXY and BV changes in the microcirculation (Mancini et al. 1994), and the spatial resolution of the measurement is sufficient to reflect these changes only in the active musculature (Chance and Bank 1995), the technique is attractive for the evaluation of the metabolic status of the muscle. However, if NIRS is to be an effective technique for evaluating hemodynamic changes in the low back musculature during exercise, its test-retest reliability in different postures must be established. To date, the OXY and BV trends of the erector spinae muscles during back extension in the standing and sitting postures have been examined and the reproducibility of these measurements has been established (Maikala and Bhambhani 2000). The purpose of this investigation was to (1) describe the trends in OXY and BV of the right and left erector spinae muscles during the BSME, and (2) assess the test-retest reliability of OXY and BV changes during the BSME in healthy males.

Methods

Subjects

Seventeen active, healthy male volunteers were recruited from the University of Alberta and surrounding area. The inclusion criteria for subject recruitment were as follows: (1) males between the ages of 18 and 50 years, (2) no previous history of low-back pain, (3) currently asymptomatic for low-back pain, and (4) absence of metabolic, cardiovascular, respiratory and orthopedic disorders. Their physical characteristics were [mean (SD): age = 27.4 (7.74) - years, height = 1.75 (0.05) m, weight = 81.8 (11.7) kg, and body mass index (BMI) = 26.8 (4.7)]. All subjects were right-handed males. The subjects met with the researcher individually to discuss the study and provide their written informed consent for participation. Each subject completed two BSMEs to volitional exhaustion within a 1-week period. The Health Research Ethics Board of this institution approved the test procedures described below.

BSME procedures

Upon reporting to the laboratory, the subject's height and weight were recorded using standard procedures. The subject was asked to flex at the waist to allow the researcher to locate the area of the 3rd lumbar vertebra (L3). Previous literature indicates that L3 is frequently used for placing both EMG electrodes (Biedermann et al. 1990; Kankaanpaa et al. 1998; Koumantakis et al. 2001; Moffroid et al. 1993) or NIRS probes (Yoshitake et al. 2001). Pilot testing indicated that placement at L3, approximately 3 cm to the left and right side of the vertebral column, provided a clear NIRS signal which was sensitive to changes during static and dynamic exercise. The two NIRS probes (MicroRunman; NIM, Pa., USA) were then placed bilaterally at the L3 level over the right and left erector spinae muscles on the skin surface. The probes were secured with a tensor bandage around the abdominal region so as to hold the probes in position and block out all background light. Sufficient care was taken not to occlude blood flow to the area under investigation. The subject assumed a prone position on the plinth with the face down, so that the upper half of the body, as discerned by the iliac crest, was at the breakpoint in the plinth. Two straps were lightly fastened around the subject's gluteus maximus and ankles (just superior to the medial and lateral malleoli) for stability during the test. A towel was positioned beneath the ankle straps to reduce the strain on the distal aspect of the tendo calcaneus (Achilles tendon).

The trial was initiated with a 2 min baseline with the subject resting in the prone position on the plinth. An alignment bar whose height could be adjusted was suspended from the ceiling so that it maintained contact with the upper torso while the subject was in the prone (neutral) position. Thereafter, the plinth support to the upper body was removed so as to start the BSME. The subject was asked to maintain the neutral position, as indicated by the alignment bar, by contracting the musculature of the lower back and gluteal regions while folding his arms across the chest throughout the duration of the test. The subject received moderate encouragement during the test but was not informed of the elapsed time. The test was terminated at volitional fatigue or if the subject lost contact with the alignment bar and did not re-establish contact with the bar in 2–3 s following verbal prompting. The time from the onset of the BSME to volitional fatigue was recorded as the endurance time. Thereafter, the subject was allowed to recover for 4 min while lying prone on the plinth. The second trial was completed within 1 week following the same procedures.

NIRS measurements

The NIRS unit (MicroRunman; NIM, Pa., USA) was calibrated prior to each test using the NIRCOM software provided with the instrument. The NIRS unit was calibrated while securely fastened in position over the erector spinae muscles (right and left sides) while the subject lay quietly on the plinth. A moderate penetration depth with the light intensity ranging between 100 mV and 150 mV was applied during calibration and testing. The muscle probe, which had a tungsten light source placed at a distance of 4 cm from the silicone diodes, absorbed the reflected light at 760 nm and 850 nm. The penetration depth was 60% of the optode spacing, which is the physical distance between the light source and sensor, roughly 2–2.5 cm. NIRS measurements were undertaken continuously at a frequency of 60 Hz during the baseline, BSME and recovery periods. A piece of clear plastic was placed over the photodetectors on the probe to prevent distortion of the signal due to sweat from the skin surface.

The equation used to calculate the change in optical density (OD) is based on the Modified Beer-Lambert law as follows (Chance et al. 1992; Mancini et al. 1994):

$$\text{Opticaldensity} = a \times c \times d \times B + G$$

where: a is the absorption coefficient of the chromophore (light-absorbing compound), c is the concentration of the chromophore, d is the distance between optodes on the measuring probe, B is the differential path length factor of the tissue, and G is the geometry of the tissue. One of the limitations of continuous wave NIRS is that the differential path length factor cannot be measured due to the scattering of the photons (Obrig and Villringer 1997), and therefore, the changes in concentration of the chromophores cannot be quantified. The values are presented as relative changes in OD, and thus, the trends can be qualitatively compared during exercise.

From the raw NIRS data, the relative change in OXY was calculated as the difference in OD at 760 nm and 850 nm (760–850 nm). The relative change in BV was calculated as the sum (760 nm + 850 nm) of the change in OD at the two wavelengths. Data were averaged over 5 s intervals for each phase of the test. For each subject, the OXY and BV values at the onset of the baseline period were corrected to zero for each trial. Resting OXY and BV values were determined by averaging the data 20 s prior to the start of exercise. The minimum values during the BSME (OXY_{min} and BV_{min}) and the maximum values during recovery (OXY_{max} and BV_{max}) were recorded. The delta values (OXY_{delta} and BV_{delta}) were calculated from the resting baseline minus the minimum or maximum OXY and BV values depending on the direction (increasing or decreasing) of change during exercise. The range for each of these variables was calculated as the difference between the maximum and minimum values (OXY_{ran} and BV_{ran}) throughout the total time period, including baseline, work and recovery. In order to examine the reliability of the NIRS trends during the BSME, the OXY and BV values at the same relative stage of the test (10–100% of the endurance time) were calculated for each subject and statistically analyzed.

Statistical analysis

A dependent t-test was used to compare endurance time and rating of perceived exertion between trials. A two-way repeated measures analysis of variance (trial by side) was used to compare the means of the following NIRS variables: OXY_{delta}, OXY_{ran}, BV_{delta} and BV_{ran}. Significant F ratios were analyzed using a post hoc Scheffé test. The alpha level was set at 0.05 for all statistical tests. Because numerous multiple comparisons were performed, the Bonferroni adjustment for a P value of 0.05 was applied to minimize type I error for each variable (Ottenbacher 1991). Intra-class correlations (ICCs) were used to examine the reliability of the BSME time and the four NIRS variables on the right and left sides. ICCs were also used to evaluate the reliability of the OXY and BV responses at the same relative stage of the BSME for the two trials on both sides. All statistical analyses were performed using SPSS (SPSS for Windows, version 10.0.7, copyright 1989–1999) computer package. In order to further examine the reliability of the measurements, Bland-Altman plots were used to examine the test-retest reliability (limits of agreement) between the two trials for each of these variables. This was done in the following manner: (1) the difference between the two tests for each subject was plotted against their average value of the two trials, and (2) the plots were examined to see if any data points were beyond two standard deviations (95% confidence limits) above and below the mean of the two trials (Bland and Altman 1986).

Results

Muscle OXY and BV trends

The general trends of a representative subject for right and left side erector spinae OXY (850–760 nm) and BV (850 nm + 760 nm) during the two BSME test trials to volitional fatigue are illustrated in Fig. 1A–D, respectively. The endurance times [mean (SD)] for the two trials are listed in Table 1. After a relatively stable baseline value for 2 min, muscle OXY (Fig. 1B, D) demonstrated a rapid increase during the first 30 s of the BSME and then declined from its peak for the remainder of the test. The initial increase in OXY was due to rapid decreases in both the deoxy-Hb/Mb and oxy-Hb/Mb (850 nm) signals. The decline in OXY during the latter portion of the BSME was due to a continuous decline in deoxy-Hb/Mb and a leveling off in the oxy-Hb/Mb signals. Upon termination of the BSME, muscle OXY on the right side increased very rapidly toward the baseline value within 5–10 s and remained fairly stable for the remainder of the 4-min recovery period. In contrast, generally on the left side OXY rapidly declined toward baseline levels. Muscle BV also demonstrated a rapid increase from the resting baseline value at the onset of the BSME for about 30 s. However, BV continued to increase systematically for the remainder of the BSME even though OXY showed a decline during this period. Upon termination of the BSME, BV demonstrated a sharp decline and recovered towards the resting baseline value in a manner similar to muscle OXY.

Although these overall trends were fairly consistent amongst the subjects during the two trials, there were some subtle differences in these patterns during the test. For example, the subject illustrated in Fig. 1 did not demonstrate the rapid increase in OXY on the right side at the onset of the BSME during trial 2. Instead, there was a rapid decrease in OXY during the first 30 s and a subsequent increase for the remainder of the BSME. A comparison of the OXY trend between the right and left sides for this subject indicated that right side OXY declined to a level that was below the baseline value, whereas left-side OXY remained above the baseline value during the latter portion of the BSME.

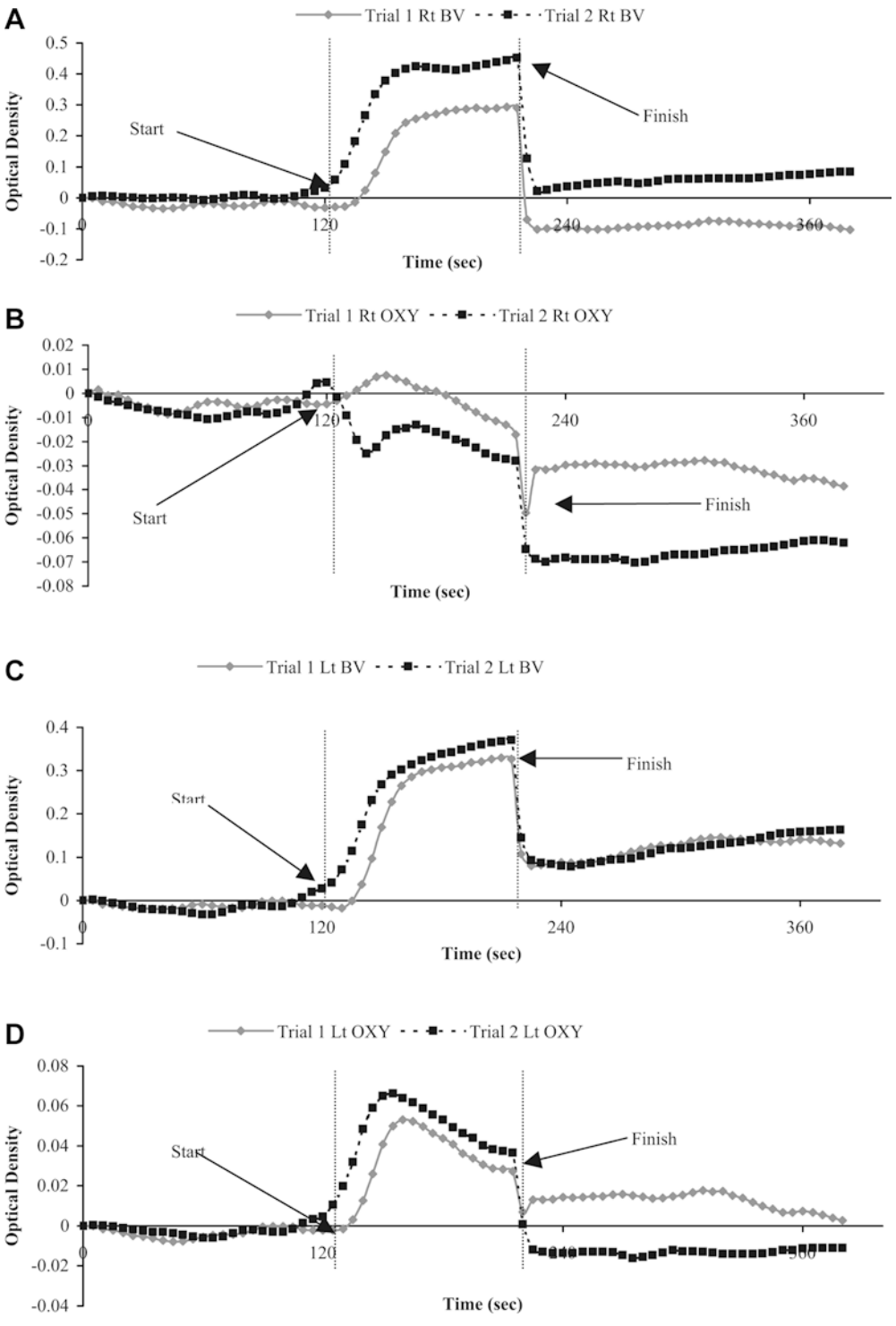

Fig. 1A–D NIRS trends of the right (*Rt*) and left (*Lt*) erector spinae muscles during the three phases of the test protocol in a single typical subject for the two trials: 2 min of baseline, Biering-Sorensen muscle endurance test, and 4 min of recovery

Reliability of muscle OXY and BV measurements

The mean values for the four NIRS variables (OXY_{delta}, OXY_{ran}, BV_{delta} and BV_{ran}) are summarized in Table 1. The *F* ratios for the two-way interactions and main effects of the ANOVA and the ICCs are presented in Table 2. No significant interactions (trial by side) or main effects were observed for each of the four NIRS variables. This implies that there were no significant differences between the two sides or the two trials for the mean values of each of these variables. The lack of significant interaction for each of these variables enabled the calculation of the average ICC for the two trials and two sides. The average ICCs for the NIRS variables ranged from 0.69 to 0.84, indicating a moderate reliability of these measurements between the two trials and sides. The ICC for endurance time was 0.98, indicating strong test-retest reliability.

Table 1 Erector spinae oxygenation and blood volume responses during the Biering-Sorensen muscle endurance test in healthy males ($n=17$). *BV* Blood volume, *OXY* oxygenation

	Side	Trial 1		Trial 2	
		Mean	SD	Mean	SD
Endurance time (s)		140.29	52.28	134.71	47.71
OXY_{delta} (OD units)	Right	0.066	0.054	0.081	0.068
	Left	0.083	0.061	0.096	0.070
OXY_{ran} (OD units)	Right	0.083	0.054	0.107	0.072
	Left	0.103	0.059	0.120	0.069
BV_{delta} (OD units)	Right	0.191	0.117	0.243	0.156
	Left	0.215	0.118	0.216	0.112
BV_{ran} (OD units)	Right	0.239	0.130	0.280	0.139
	Left	0.254	0.101	0.264	0.099

The reproducibility of the OXY and BV range and delta variables during the two test trials according to the methods proposed by Bland and Altman (1995) are presented in Figs. 2 and 3, respectively. According to this method, all the data points should lie within two standard deviations above and below the expected mean difference of the two trials. Since the aim of the study was to examine the test-retest reliability of the NIRS technique, the expected mean difference between the two trials was zero. Examination of the Bland-Altman plots in Figs. 2 and 3 indicates that at 95% confidence there were one to two outliers for the OXY values (delta and range, respectively) and one outlier for the BV values (delta and range). This suggests that there was no systematic error between the two test trials or two sides for each of these NIRS variables.

The reproducibility of the OXY and BV responses at the same relative stage of the BSME during the two trials for the right and left sides is illustrated in Fig. 4. It is evident that the trends were highly reproducible during both trials on either side. The average ICCs for the OXY and BV responses were 0.96 and 0.95, respectively.

Discussion

Muscle OXY and BV trends

The current results indicated that at the onset of the BSME, muscle OXY increased for the first 20–30 s in a majority of the subjects and then demonstrated a systematic decline below the baseline value until a minimum value was attained. In some subjects, there was a leveling off prior to the termination of the test. The changes in OXY during the initial stages of the BSME were accompanied by concomitant increases in BV, which tended to level off with the duration of the contraction. During the recovery phase, both OXY and BV reversed their trends immediately upon cessation of exercise and attained or overshot their resting baseline values during the first minute of recovery. The OXY and BV trends observed in the present study are generally consistent with those reported by other investigators that have used NIRS during static extension of the erector spinae muscles in healthy subjects. McGill et al. (2000) demonstrated that during 30-s contractions ranging between 2% and 30% MVC, there was a decline in muscle OXY which was proportional to the intensity of contraction. Jensen et al. (1999) reported that during 30 s of static back muscle extensions ranging from 5% to 80% of MVC, there was a significant reduction in tissue oxygen saturation (calculated as the ratio between the OXY and BV signals) starting at an intensity of 20% MVC, which corresponded to an IMP of 30–40 mmHg. Moreover, the decrease in tissue oxygen saturation increased with an increasing level of IMP. Neither of these studies cited reported the BV trends during the static contractions. However, Yoshitake et al. (2001) demonstrated a significant reduction in OXY during 60 s of static extension of the erectors spinae muscles, with a concomitant reduction in the BV, a trend which is in contrast to that observed in the present study. The reason for this discrepancy is unclear and needs to be further investigated. It should be noted that in all the studies cited, the investigators predetermined the duration of the erector spinae muscle contraction, whereas in the present study the contractions were sustained to voluntary fatigue.

From a physiological standpoint, we believe that the initial increase in OXY at the onset of exercise is associated with a redistribution of blood to the active motor units and not due to changes in tissue geometry because of the static nature of the contraction. This initial increase in OXY is supported by the localized increase in BV during this period (Fig. 1A, C). The redistribution of blood is controlled both by local tissue factors which

Table 2 *F* ratios and intraclass correlations coefficients (ICCs) between trials and sides for endurance time, muscle OXY and BV during the Biering-Sorensen muscle endurance test measured by near infrared spectroscopy ($n=17$)

Variables	*F* ratio* Trial by side	*F* ratio* Trials	*F* ratio* Sides	ICC
Endurance time (s)		0.106		0.98
OXY_{delta}	0.90	0.446	0.148	0.69[b]
OXY_{ran}	1.70	0.297	0.097	0.75[b]
BV_{delta}	1.21	0.898	0.197	0.84[b]
BV_{ran}	0.66	0.947	0.155	0.82[b]

*None of the *F* ratios were significant at the 0.05 level after applying the Bonferroni correction factor

[b]Average ICC calculated from measurements of two trials on the right and left sides

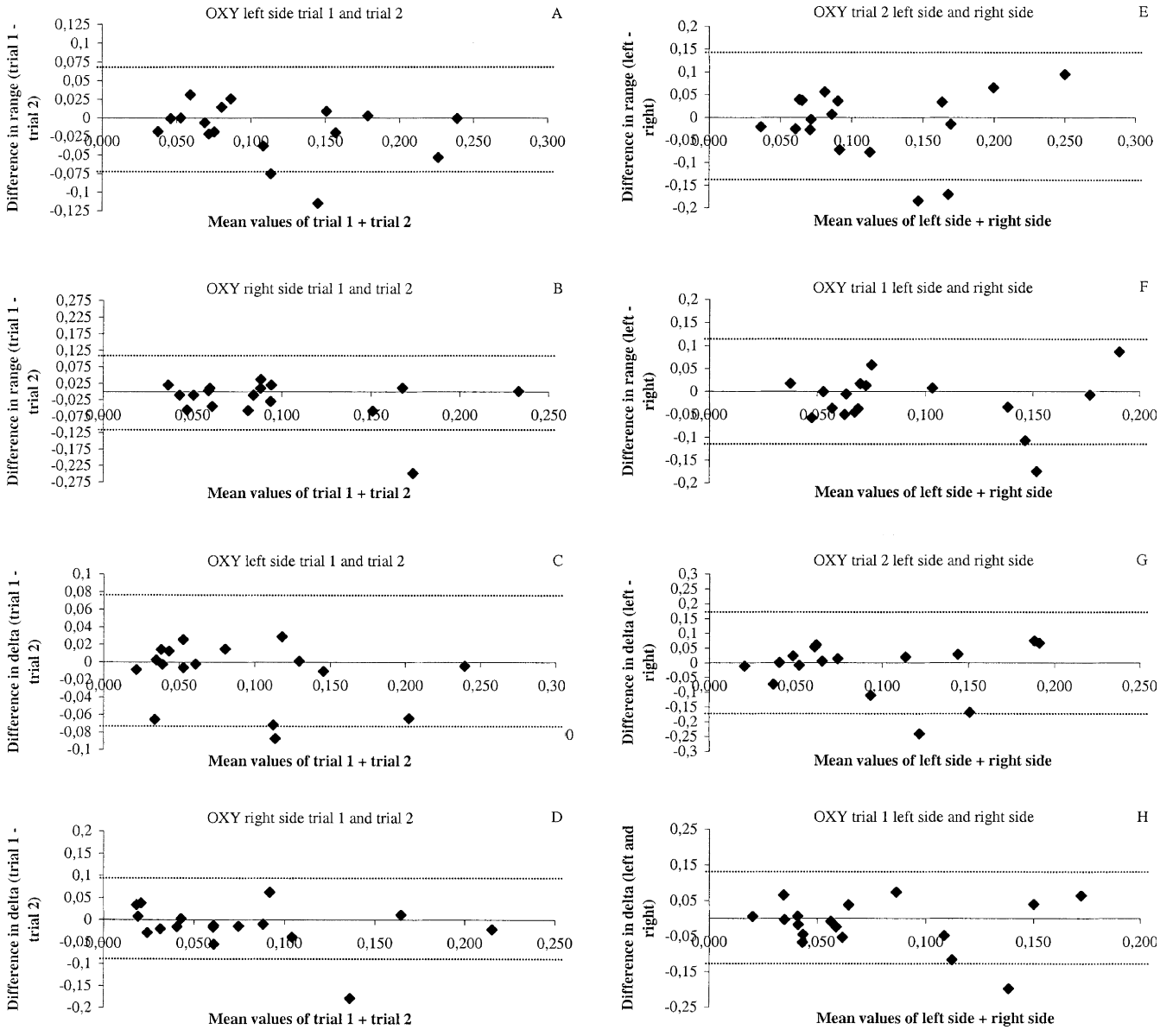

Fig. 2A–H Bland-Altman plots for the absolute sums and differences of the delta and range values in oxygenation between the two trials of the right and left erector spinae muscles during the Biering-Sorensen muscle endurance test. The *dotted lines* indicate two standard deviations above and below the mean value for that variable

stimulate vasodilation in that area (e.g., nitric oxide, adenosine), and sympathetic neural input to the exercising and non-exercising motor units (Hansen et al. 2000; Marshall 2000; Radegran and Hellsten 2000). Additionally, the increase in BV is likely related to the cardiovascular response associated with static contractions, as noted by an increase in heart rate and blood pressure (Gaffney et al. 1990; Mitchell et al. 1980).

Following the preliminary increase in both BV and OXY, BV plateaus (Fig. 1). The plateau in BV is likely due to IMP equaling intravascular pressure and thus not permitting further vasodilation, at which point OXY begins to decline (Fig. 1). The decline in OXY suggests that oxygen demand in the exercising muscle is greater than oxygen supply (Jensen et al. 1999). Muscle contraction levels of 20% of MVC have demonstrated reduced blood flow in the back extensor muscles (Bonde-Petersen et al. 1975). Since, the BSME elicits a muscular contraction that ranges between 20% and 75% of MVC (Jørgensen and Nicolaisen 1986; Mannion and Dolan 1994; Smidt and Blanpied 1987), it is possible that the decrease in OXY was due to a reduction in BV that is reflected in the NIRS signal (McGill et al. 2000).

Reliability of muscle OXY and BV measurements

In the present study the test-retest ICC for endurance time was 0.98, which is consistent with previous reports on healthy males (Keller et al. 2001; Latimer et al. 1999;

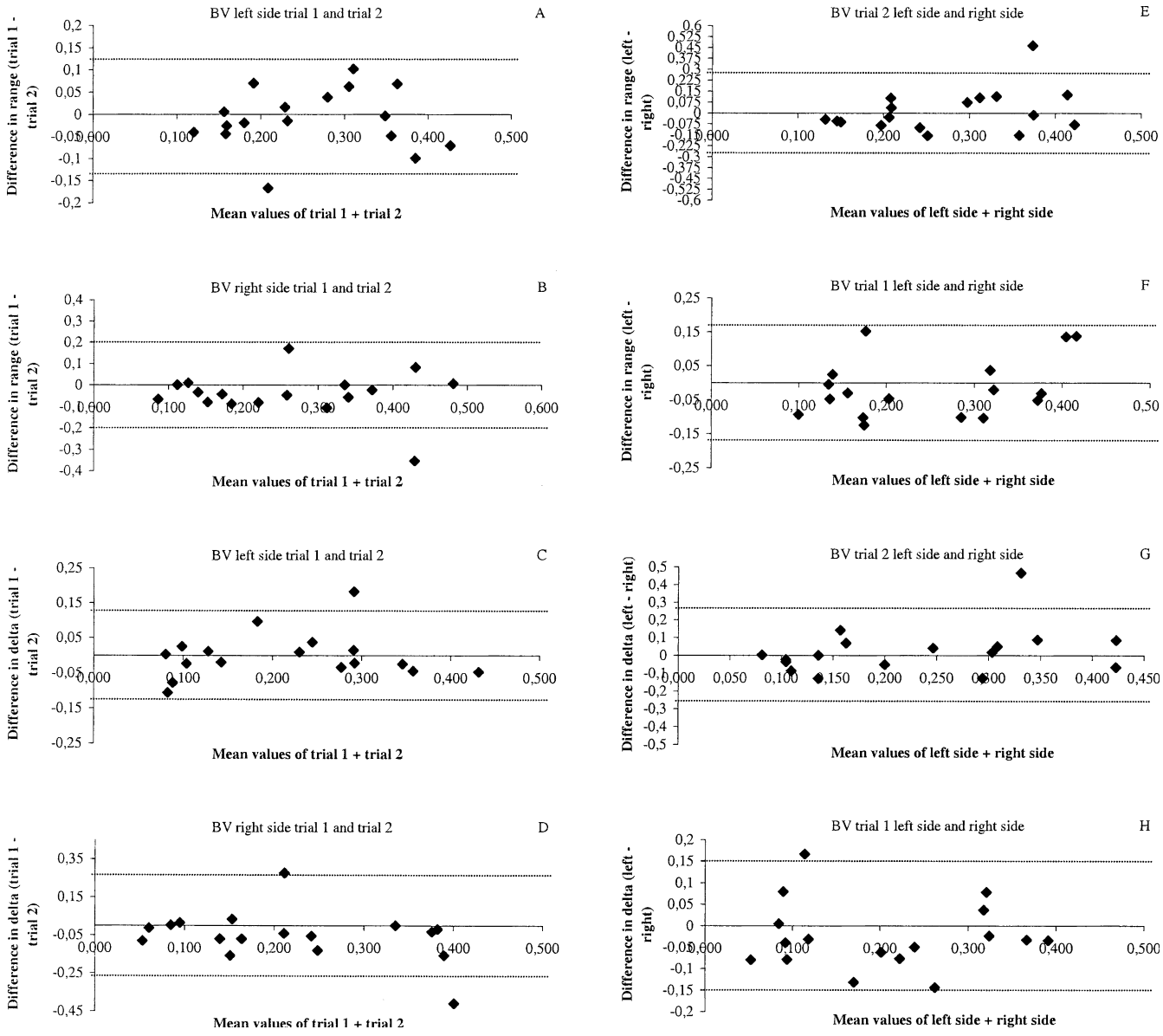

Fig. 3A–H Bland-Altman plots for the absolute sums and differences of the delta and range values in blood volume between the two trials of the right and left erector spinae muscles during the Biering-Sorensen muscle endurance test. The *dotted lines* indicate two standard deviations above and below the mean value for that variable

Moffroid et al. 1994; Moreland et al. 1997). The current results also indicated moderate to high test-retest reliability for the four NIRS variables monitored during the BSME (Table 2). ICCs ≥0.80 are considered to be acceptable, while ICCs ≥0.90 are very strong (Newton et al. 1993). Therefore, the current findings suggest that BV responses during the BSME are more reliable than the OXY responses, and therefore should be the focus of future investigations. Further, of these hemodynamic responses, the delta value is arguably the most important as it measures the amplitude of change from baseline during work, eliminating post-exercise hyperemia. To the best of our knowledge, ICC values for hemodynamic measures of the erector spinae muscle during the BSME have not been published. In related research, Maikala and Bhambhani (2000) reported significant reliability coefficients of 0.83, 0.94, 0.99, and 0.91 for the OXY_{min}, OXY_{ran}, BV_{min} and BV_{ran}, respectively, in healthy males during maximal isometric contractions of the back extensors in the sitting position. Corresponding values in the standing position were 0.84, 0.74, 0.99, and 0.99, respectively.

The reproducibility of these NIRS measurements during the BSME was further supported by the Bland-Altman plots presented in Figs. 2 and 3. As indicated earlier, the BV responses met the reliability criterion, as only one of the 17 data points was an outlier, whereas for the OXY responses one or two outliers were observed. It should be noted that one of these two subjects was an outlier for both the OXY and BV responses. It is also evident from these plots that the OXY responses of

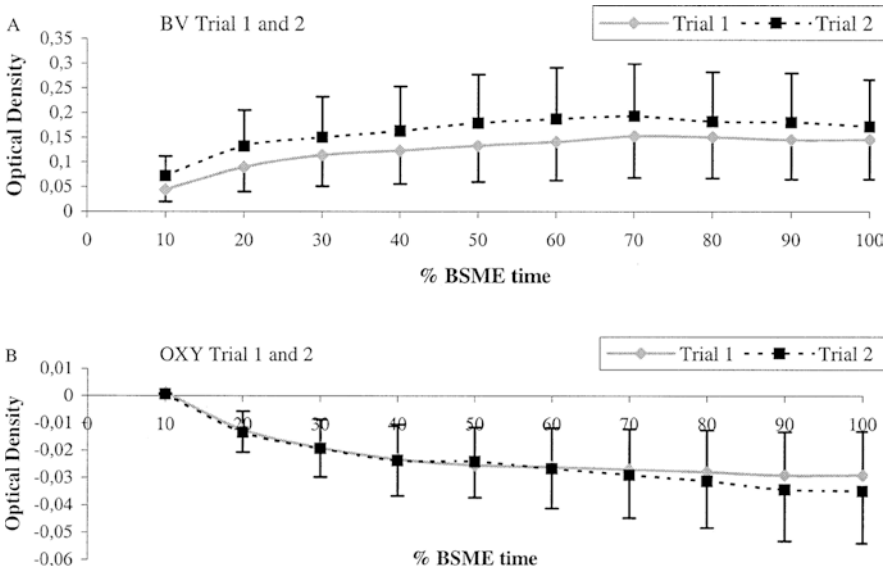

Fig. 4A, B A comparison of the near infrared spectroscopy (NIRS) trends for trials 1 and 2 at the same relative time of the Biering-Sorensen muscle endurance test in the overall group of subjects. The values of the right and left sides were pooled for analysis. The *error bars* indicate values that are one standard error above and below the mean

several subjects were on the borderline. The outlier values consisted of numerous subjects and not one or two in particular thus a physiological explanation for the outliers is difficult to envision. However, closer examination of the raw signals indicates that these were likely physiological in nature and not due to measurement error such as movement of the muscle probe. In saying this, perhaps the outliers in each case had some variation between trials, not related to probe placement, probe movement or physical fatigue, but maybe due to variation in strap tightness or a learning effect causing some change in body position.

Previous studies that have used NIRS to evaluate OXY of the erector spinae muscles during isometric contractions have used different percentages of MVC for durations ranging from 30 to 60 s (Jensen et al. 1999; McGill et al. 2000; Yoshitake et al. 2001). Hence it is important to evaluate the reproducibility of these responses not only at the point of fatigue during the BSME, but also at different stages during the test. The current study clearly demonstrated that the OXY and BV responses at each 10% segment of the two test trials were highly reproducible (Fig. 4). No significant differences were observed between the slopes of the curves for the two trials for each of these variables, implying that the tissue hemodynamic responses could be studied even for short test durations during different types of interventions with confidence. However, further research is needed to evaluate the reliability of these responses at different percentages of MVC during static back muscle contractions.

In conclusion, the results of the current study indicated that NIRS is a reliable technique for evaluating OXY and BV trends of the erector spinae muscles during the BSME in healthy men. No significant differences were observed between the two trials on the right and left sides for these variables at the point of fatigue. As well, these responses were highly reproducible at each 10% segment of the test. In general, the reliability was stronger for the muscle BV compared to the OXY variables. Future research studies that utilize NIRS should focus primarily on this variable for analysis.

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