Study of the Activation and Oxygenation of Multifidus and Gluteus Medius Muscles During Stretching of the Lower Limb Posterior Chain: Comparison Between Two Different Executions Techniques

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ABBREVIATIONS
HHB: Deoxygenated Hemoglobin
sEMG: surface Electromyography
NIRS: Near Infrared Spectroscopy
TOI: Tissue Oxygen Index
HBO_2: Oxygenated Hemoglobin
THB: Total Hemoglobin

SUMMARY
Background. Ischiocrural (IC) stretching procedures may result in different involvement of the posterior kinetic chain and of the lumbar spine.
Objective. The aim of the study was to evaluate homolateral muscle activation and hemodynamic changes in the Multifidus (MM) and Gluteus medius (GM) muscles in healthy subjects during monolateral IC stretching by using two different execution techniques: technique A (TA: forward bending of the torso, hands in Open Kinetic Chain (OKC), leg stretched) and technique B (TB: forward bending of the torso, leg stretched with knee joint angle of 20°, hands in Closed Kinetic Chain (CKC).
Methods. A total of 12 recreationally active males (35-24±4.2 years) and 14 recreationally active females (26-22±2.3 years) volunteered to participate in the study and randomly performed TA and TB stretching of 20 s in two subsequent sessions one week apart. During execution, hemodynamic parameters obtained with near infrared spectroscopy (NIRS), namely total hemoglobin (tHb) and tissue oxygen index (TOI%), as indicators of blood flow and oxygen extraction respectively, were detected from homolateral MM, and myoelectric parameters obtained with surface bipolar electromyography (sEMG), namely root mean square (RMS) as indicator of muscle activation, were detected from homolateral GM and MM. Percentage of change (Δ%) was calculated from the beginning and the end of the 20 s recording divided into 5 s epochs for all the parameters measured.
Results. All along the 20 s procedure, compared to TB, TA stretching produced higher muscle activation both in MM and GM muscles (p<0.001), and lower tHB% change combined with higher % oxygen extraction in MM (p<0.05).
Conclusions. Stretching of the posterior kinetic chain of the lower limbs with 20° bent homolateral knee and hands in CKC prevents MM and GM overload and may represent a useful technique, alternative to classical stretching, to prevent low back pain.

KEY WORDS
Hamstrings; low back pain; near infrared spectroscopy; electromyography; stretching.

BACKGROUND

Elongation (stretching), involves different types of tissues: connective tissue, contractile proteins, muscle bands, tendons, aponeuroses, ligaments (1) and complex neurological systems regulating afferences and proprioceptive responses (2). Its efficacy, for prevention and re-educational purposes, has been extensively documented in literature (3-5). Among the various modalities of stretching, the static technique is the most frequently used and involves the slow elongation of a muscle or a muscular chain maintained to the maximum bearable (6,7) for a time varying from few seconds up to one minute (8).

The posterior kinetic chain (PKC) elasticity of the lower limbs, involving ischiocrural (IC) and triceps sural (TS) districts, is essential for the correct functionality of the lumbar district (LD) (9). There is evidence in that the IC rigidity, decreasing the physiological lumbar lordosis, may cause DL overload thus promoting low back pain (1,10). Based on these observations, the correct elongation of IC is considered a pivotal strategy to prevent and/or treat this clinically relevant condition (11).

The classic, widely adopted, IC stretching procedure requires that the ipsilateral lower limb is fully extended. In this position, IC muscles may prevent retroversion of the pelvis thus avoiding its rotation forward on the femoral heads during flexion of the trunk and subsequently overloading the LD structures and muscles.

In the present study we analyzed the level of Gluteus medius (GM) and Multifidus muscle (MM) activation, by means of surface electromyography (sEMG), and the hemodynamic parameters (total hemoglobin and tissue oxygen index as indicators of blood flow and oxygen extraction respectively), by means of near infrared spectroscopy (NIRS), of the GM and MM during IC stretching executed with TA (hands in OKC and ipsilateral lower limb stretched), and with TB (hands in CKC and ipsilateral lower limb with 20° knee joint angle) techniques in healthy young subjects.

Results obtained demonstrated that TB technique determines higher IC elongation while reducing overload on LD.

MATERIALS AND METHODS

Subjects

26 recreationally healthy young subjects (age 28.5±6.5 years; body weight 66±20 kg, height 171±18 cm), 12 males (age 30±5 years; body weight 73±8 kg, height 176±4 cm) and 14 females (age 24±2 years; body weight 62±9 kg, height 167±7 cm). The subjects were fully informed of the objectives, risks and discomfort associated with the experimental research and provided their informed consent written to participate in this study, before completing a questionnaire to assess their status of health. Exclusion criteria were: joint prostheses, prostheses, artificial implants (hip, knee, ankle and shoulder) or spinal cord plaques, lumbar or sciatica pain in the last three months, arthrodesis of the tibio-tarsica joint, tarsus, metatarsal and phalanges of the feet, paralytic arthritis, recent (less than three months) tear or lesion of the ischiocrural and/or sural triceps muscles, femorotibial arthrosis; recent surgical procedures, and BMI>30 kg/m². The study was conducted at CRIAMS-Sport Medicine Centre Voghera, University of Pavia, Italy

and was approved by the institutional local Review Board. The present study meets the ethical standards of the journal (12).

Experimental procedure

All subjects performed static IC unilateral stretching of the dominant leg using two techniques (technique A, TA and technique B, TB, see below) in two separate sessions 1 week apart, in a randomized fashion. During the same session sEMG and NIRS measurements were made in two subsequent randomized stretching procedures separated by 10 min interval. Experimental procedures were conducted between 9 and 11 a.m. at optimal temperature (22°C) and humidity (50%) environmental conditions.

Technique A (TA)

The subject, sitting on a medical table, performed unilateral static stretching for the hamstrings of the dominant leg, maintained in neutral rotation with the ankle dorsiflexed. The hip was passively flexed, with head extended, to the maximum angle which could be tolerated without stretch pain, with the knee fully extended trying to reach the feet with the hands in open kinetic chain (OKC) and this position was maintained for 20 s. For each subject the final angle was measured after stretching. The final angle was defined as that formed by the tibia and horizontal plane when the knee was passively extended from hip and knee angles at 90° flexion to the maximum extension angle which could be tolerated without stretch pain. During procedure the non-dominant leg was maintained dangling from the edge of the cot in neutral position.

Technique B (TB)

The subject sitting on a medical table, performed unilateral static stretching for the hamstrings of the dominant leg, maintained in neutral rotation with the ankle dorsiflexed. The hip was passively flexed, with head extended to the maximum angle, which could be tolerated without stretch pain. During elongation the knee joint maintained at 20° flexion; during procedure the hands were resting on the surface of the cot in closed kinetic chain (CKC). In each subject position was maintained for 20 s at the bending angle previously measured during TA (or *vice versa*).

sEMG measurement

Analog sEMG signals were captured by applying bipolar disposable circular surface electrodes (Ag/AgCl, OT Bioelettronica Torino, 1 cm diameter) with an interdistance of 2 cm. Surface electrodes were placed on the skin of the dominant leg and ipsilateral low back, parallel to the muscle

fibers, to record muscle activity of the gluteus medius (GM) and lumbar multifidus (MM) muscles. Before positioning skin, shaved if necessary, was gently abraded and cleaned with 75% alcohol to reduce electrical impedance. Electrode handling was in accordance to SENIAM guidelines (13). In GM the electrode was placed in mid-point of a line along the length of the iliac crest (IC), and placed at 34% of the distance from the greater trochanter of the femur (14). In MM the electrode was positioned 1 cm medial from line between posterior superior iliac spine and 1st palpable spinous process, lower electrode border at L4 level (15). To ensure reliability of electrode positioning every investigation was carried out by the same examiners (LC and FC). 4-resolution channel data acquisition system (Quattro Ot-Bioelettronica, Torino), consisting of a signal conditioner with a band-pass filter of 10–500 Hz and amplifier gain of 2000, input impedance 1200 GW, noise level<1 mV, was used to obtain biological signals. All data were processed and exported for analysis by a specific software (Quattro software, OT Bioelettronica, Torino). Captured sEMG activity was converted by an A/D board with a 12-bit resolution input range, sampling frequency of 2024 Hz. Average rectified value (ARV) was computed over 5 s epochs of the recorded raw EMG signal by full-wave rectification to represent the muscle activity.

NIRS

Measurements of deoxyhaemoglobin [HHb], oxyhaemoglobin [HbO2], and total haemoglobin [HbT] concentrations and the muscle % hemoglobin oxygen saturation (tissue oxygen index, TOI % %) was also calculated as (Δ HbO$_2$/(Δ HHb + Δ HbO$_2$)) × 100 were obtained with a continuous-wave tissue oximeter (NIMO, Nirox srl, Brescia, Italy).

Briefly, based on the assumption that at 975 nm the absorption coefficient is dominant over other chromophores (i.e. HbO$_2$ and HHb) and that water absorption and that the tissue scattering properties vary linearly with wavelength, the scattering spectrum is calculated at this wavelength thus allowing the estimation of absorption coefficient at 685 and 830 nm thus allowing measurements of absolute HbO$_2$ and HHb tissue concentrations. In each subject, data obtained by continuous recording were subsequently sub grouped in 5 s epoch intervals, averaged and plotted. At each time point, absolute values obtained from each subject were subsequently averaged and differences of the means obtained in TA and TB were statistically analyzed. To account for the possible influence of the fat layer (previously measured by ultrasound) on NIRS measurements, a real-time correction was applied using an algorithm includ-

ed in the software supplied with the spectrometer (Nimo Data Analysis version 2.0). For NIRS tests, the probe was placed in the same position of the sEMG electrodes only in MM, whereas GM was discarded from the analysis due its physiological curve that avoided correct positioning of the probe during stretching. To prevent artifacts from external lights the NIRS probe was firmly secured with a small velcro strap and covered with dark coating. The probe edges were marked on the skin in order to avoid any downward sliding during movements.

Statistical analysis

Linear regression was applied to the data to calculate the initial value and rate of change of ARV. Normalized rate of change for each variable was calculated as the percentage ratio between rate of change and initial value. Paired and unpaired t-test was used to compare significant differences between recorded parameters in TA vs TB and between genders respectively. The data are reported as mean ± standard deviation (SD). Statistical analysis was completed using Graphpad 5 (San Diego, California) and the significance level was set at p≤0.05.

RESULTS

Considering that no significant differences were found between males and females at every time point and for every parameter measured, data were pooled for subsequent statistical analysis.

Average percentage changes of RMS recorded at 5 s intervals between initial and final stretching are reported in **Table I** for MM and **Table II** for GM. Compared to TB, TA stretching produced significant higher muscle activation both in MM and GM muscles at every time point along the 20 s stretching procedure. As regards the hemodynamic parameters recorded in homolateral MM (**Table III**), a slightly change in blood volume (Δ% tHb) was observed in TA and TB at each time intervals without significant difference between procedures, whereas a higher oxygen extraction (Δ% TOI) was observed in TA compared to TB at 10, 15 and 20 time intervals (**Table III**), thus suggesting that an improved oxygen extraction was maintained to sustain the higher muscle activation during stretching.

DISCUSSION AND CONCLUSION

The objective of this study was to compare two different stretching techniques, TA and TB, of the IC muscles to determine which one least overload LD muscles. To this aim, by combining sEMG and NIRS techniques to study GM and MM activation and oxygenation during 20 s IC

Table I. Root Mean Square (RMS) percentage of change from baseline in homolateral Multifidus muscle at 5 s intervals during TA and TB stretching and percentage difference between TA and TB at each time point.

Δ% RMS di Multifidus (TA)			Δ% RMS di Multifidus (TB)			Δ% RMS Multifidus TA vs TB		
Time (s)	mean	SD	Time (s)	mean	SD	Time (s)	mean	SD
0	0.00	± 0.00	0	0.00	± 0.00	0	0.00	± 0.00
5	9.0	± 25.22	5	5.0	± 18.90	5	44.5	± 40.37
10	12.8	± 34.05	10	-4.0*	± 18.31	10	131.1	± 41.43
15	13.9	± 31.30	15	-13.1**	±23.51	15	194.6	± 46.75
20	17.4	± 30.69	20	-13.0**	± 31.52	20	174.4	± 55.74

* significantly different from TA (p<0.05). ** significantly different from TA (p<0.001). s, seconds; SD, Standard Deviation.

Table II. Root Mean Square (RMS) percentage of change from baseline in homolateral Gluteus medius at 5 s intervals during TA and TB stretching and percentage difference between TA and TB at each time point.

Δ% RMS Gluteus medius (TA)			Δ% RMS Gluteus medius (TB)			Δ% RMS Gluteus medius (TA vs TB)		
Time (s)	mean	SD	Time (s)	mean	SD	Time (s)	mean	SD
0	0.00	± 0.00	0	0.00	± 0.00	0	0.00	± 0.00
5	12.89	± 29.37	5	9.70	± 22.71	5	24.77	± 39.47
10	13.30	± 30.55	10	1.74	± 26.99	10	86.89	± 44.58
15	13.86	± 28.38	15	-4.64*	± 33.32	15	133.45	± 49.47
20	7.90	± 37.25	20	-8.67	± 32.34	20	209.82	± 55.79

* significantly different from TA (p<0.05). s, seconds; SD, Standard Deviation.

Table III. Total Hb (Hbtot) and TOI percentage of change from baseline in homolateral Multifidus muscle at 5 s intervals during TA and TB stretching and percentage difference between TA and TB at each time point.

Δ%Hbtot Multifidus TA			Δ%Hbtot Multifidus TB			Δ % TA vs TB		
Time (s)	mean	SD	Time (s)	mean	SD	Time (s)	mean	SD
0	0.00	± 0.00	0	0.00	± 0.00	0	0.00	± 0.00
5	23.8	± 9.30	5	21.4	± 8.61	5	9.8	± 2.33
10	21.0	± 7.03	10	16.9	± 6.50	10	19.6	± 1.89
15	18.4	± 5.75	15	17.2	± 5.32	15	6.5	± 1.76
20	17.3	± 4.91	20	15.4	± 4.63	20	10.9	± 1.57
Δ%TOI Multifidus TA			Δ%TOI Multifidus TB			Δ % TA vs TB		
Time (s)	mean	SD	Time (s)	mean	SD	Time (s)	mean	SD
0	0.00	± 0.00	0	0.00	± 0.00	0	0.00	± 0.00
5	10.1	± 3.35	5	9.8	± 3.47	5	2.9	± 1.21
10	9.5	± 2.80	10	6.8	± 2.50*	10	28.3	± 1.90
15	8.7	± 2.33	15	6.0	± 2.07*	15	31.5	± 5.65
20	8.0	± 1.97	20	4.8	± 1.92*	20	39.5	± 1.97

* significantly different from TA (p<0.05). s, seconds; SD, Standard Deviation.

stretching, the main findings were: 1) a higher muscles activation in TA compared to TB at each 5 s epochs of the stretching period; 2) no difference in the percentage change of total hemoglobin and a higher oxygen uptake detected in MM during TA compared to TB; 3) no difference in muscle activation and oxygenation in males compared to females in both stretching procedures.

Shortening or tightness of the hamstrings affects postural alignment and results in possible musculoskeletal pain. The kinematics of the lumbar district and of the Coxo-Femoral joint (CF), also called lumbar-pelvic rhythm, was studied during the flexion of the trunk in some daily activities living (ADL), in people with or without low back pain (16,17). In the bending of the trunk, upon reaching the maximum opening of the lumbar veneer joints (≈ 60°) (18), the elasticity of the IC induces a coordinated anterior rotation of the pelvis on the femoral heads (10), thus allowing an increase of the trunk bending without further stress to the DL structures (10,19). In contrast, excessive rigidity of the IC muscles, due to their proximal insertion on the ischial tuberosity, by retaining the pelvis, restricts the muscles rotation forward on the femoral heads, thus causing excessive stress in lengthening of the connective structures of the LD. This condition is associated with higher probability of fatigue of the paravertebral muscles and subsequent onset of low back pain (20). As previously demonstrated, the use of various postures during the IC stretching procedure for may result in different involvement of the PKC and of the lumbar spine (21,22). Our results, for the first time, demonstrate that stretching of the posterior kinetic chain of the lower limbs with 20° bent homolateral knee and hands in CKC prevents MM and GM overload. In fact, a lower muscles activation and contemporary lower oxygen uptake along the 20 s stretching period was observed in TB stretching. The observed differences in muscles activation

and oxygenation in TA compared to TB may be due the unfavorable lever arm with greater stress in the pivotal area of the movement, LD and the sacroiliac joint, to which it may contribute the position of the upper limbs stretched out forward without any support in an open kinetic chain. Importantly, an increased GM activation has been found both in classic IC static and in the dynamic stretching and its possible role as critical factor for lumbar pain has been hypothesized in healthy subjects, following the long lasting maintenance of the erect station (23). Therefore, TB stretching may represent a useful technique, alternative to classical static stretching, to prevent low back pain.

LIMITATIONS OF THE STUDY

This study has limitations that need to be addressed. First, no data are presented regarding GM and MM sEMG adaptation following repeated stretching procedures. Further, IC muscles activation measurement during stretching procedures was not performed. This lack hampers the possibility to unravel the contribution of concurrent involuntary hamstring muscle activity contraction in limiting the hip range of motion in the tested stretching procedures and its role in stretching training (24). Further, changes in blood flow through the muscle tissue has not been measured directly but through the blood volume ($HBO_2 + HHb$). Based on the present limitations, future studies should expand the presented data, to confirm whether beneficial lesser LD overload due to TB compared with TA is verifiable following stretch training as well as following a single stretching session.

CONFLICT OF INTERESTS

The authors declare no conflict of interests.

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