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SYMMETRY OF ELECTRO- AND ACOUSTIC MYOGRAPHIC ACTIVITY OF THE LUMBAR PARASPINAL MUSCLES IN NORMAL ADULTS

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ABSTRACT. The symmetry of paraspinal muscle activity was examined in 15 healthy adults (aged 31–60 years). Acoustic myography (AMG), which provides a measure of force, was recorded with electromyography (EMG) to assess electromechanical relationships during contraction. Bilateral recordings of EMG and AMG were made over the paraspinal muscles at the level of the 4th lumbar vertebra during a fatiguing test manoeuvre. Subjects were strapped to a hinged couch in the prone position. When the upper part of the couch was lowered, subjects maintained the upper body (above the anterior, superior iliac spines) unsupported, in the horizontal position for 60 sec. The EMG and AMG signals were full-wave rectified, integrated (IEMG, IAMG) and recorded on an ink-jet oscillograph during the fatigue test. By 60 sec of activity, IEMG had increased (right 122% ± 8.7; left 125% ± 11.8; mean ± 1 SD as a percentage of initial values) while IAMG (reflecting force) remained unaltered (right 99% ± 8.2; left 100% ± 5.3). The IAMG : IEMG ratio (reflecting efficiency of activation) thus declined (right 0.81 ± 0.08; left 0.80 ± 0.08). The similarly of changes on both sides of the spine have quantified normal symmetry of paraspinal muscle activity and could be used to assess asymmetry in patients with spinal pathology.

Key words: muscle activity, electromyography, acoustic myography, paraspinal muscles, lumbar spine.

The paraspinal muscles are vital for providing extrinsic spinal stability and epidemiological studies suggest that paraspinal muscle dysfunction is aetiologically important in low back pain (10, 11). However, the role of the musculature in low back pathology, and resultant pain, is poorly understood. Force measurements of the paraspinal muscles cannot be made directly by dynamometry so a satisfactory method of assessing paraspinal muscle strength and fatigue would be useful for investigating low back problems.

Electromyography (EMG) has been used to assess paraspinal muscle function in patients with chronic low back pain but reports are conflicting as to whether paraspinal muscle activation is abnormal and this debate has been reviewed by Nowen & Bush (12). Discrepancies are also found between reports of asymmetry of paraspinal muscle EMG activity in patients with scoliosis (15, 16).

Another more recent, non-invasive method of investigating muscle activity, acoustic myography (AMG), involves the recording of low frequency sounds which reflect the intrinsic mechanical activity of muscle (1, 14). The AMG signal, unlike EMG, can reflect force whether the muscle is fresh or fatigued but this relationship differs for brief (19, 20) and sustained (7, 13) contractions. For sustained contractions greater than 60% of maximum voluntary force, AMG reflects force but with contractions below 60% maximum the AMG may increase or vary while force remains constant (7, 13). Under controlled conditions, AMG may therefore be used as a monitor of force.

Force measurements combined with EMG have been used in limb muscles to assess the "efficiency of electrical activity" (EEA) using EMG : force ratios (4, 5). If EEA is expressed as the inverse of the EMG : force ratio (i.e. force : EMG), a reduction in EEA with fatigue would be reflected by a reduced ratio. With the discovery that AMG can reflect force, AMG and EMG ratios have been used instead of force and EMG to examine the human biceps (1) and the paraspinal muscles (3). The recent studies of EEA in the lumbar paraspinal muscles have used an unsupported, horizontal hold of the upper body which appeared to involve contractions greater than 60% of maximum force since AMG was unaltered during the test (3). This test demonstrated clear differences in EEA between normal subjects and patients with low back

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pain (3). It is therefore a potentially useful test for detecting abnormalities of paraspinal muscle activity but only the muscles on the right side of the spine were examined so any asymmetry of muscle activity which might have occurred due to unilateral symptoms was not detected. It is generally assumed that normal individuals have symmetrical right and left back muscles with respect to strength and EMG, with a small degree of variaion due to dominance and activities to be expected (17, 22). Very few studies have directly assessed and quantified this normal level of asymmetry. Comparison of absolute values of surface recordings may not be valid since recording conditions can vary, due to e.g. skin resistance, subcutaneous fat thickness, but comparison of changes in activity during fatigue may provide a more valid and functional between-side comparison.

The present study examined both right and left paraspinal muscles during an isometric fatigue test in order to establish the normal degree of symmetry in healthy subjects. Changes in EMG, AMG and EEA, using AMG:EMG ratios, were examined.

METHODS

Experimental subjects

Fifteen normal volunteers (8 male), aged 31 to 60 years (mean 38.3 years), recruited among staff and students at the University of Queensland, were studied. No subject had any significant history of back pain or had any neuromuscular, musculoskeletal or systemic disorders. Any subject undertaking specific training of the back muscles or a high level of sport involving unilateral training, e.g. tennis, was excluded. Subjects gave their written, informed consent, and the study was approved by the University of Queensland Medical Research Ethics Committee.

Recording techniques

With the subject prone, the spinous process of the fourth lumbar vertebra (L4) was palpated, using the iliac crests for reference. Two areas of skin over the right and left lower lumbar regions were prepared for surface recording by shaving, gentle abrasion with fine sandpaper and cleaning with alcohol.

Acoustic myography (AMG). The AMG technique has been described in detail elsewhere (19). Muscle sounds were recorded with piezoelectric discs (mounted on brass discs, 25 mm diameter). The AMG devices were placed over the bellies of the right and left paraspinal muscle groups (about 3 cm from the midline) at the level of L4, and secured with adhesive (Micropore) tape. Pressure transducers (MR-1K; 25 mm diameter), linked to amplifiers and a storage oscilloscope (Tektronix 5223), were then placed over each AMG device and secured with tape. A rubber strap was placed over the devices and secured around the abdomen, ensuring that the pressure over each AMG device weas equal, as indicated on the oscilloscope. The pressure with which the AMG device is secured to the skin influences the signal amplitude (Smith & Stokes, unpublished data) and pressure was monitored throughout activity to confirm that it did not alter.

Electromyography (EMG). Voluntary activation was recorded with bipolar surface EMG electrodes (Ag/Ag Cl, Red Dot, paediatric electrodes, 3M Ltd) placed longitudinally (about 5 cm apart) immediately on either side of the AMG devices on the right and left paraspinal muscles, with a common ground electrode over the spinous process of the twelfth thoracic vertebra.

Signal processing. The EMG signal was pre-amplified (Medelec PA63) and both EMG and AMG signals were amplified (Medelec AA6 Mark III), full-wave rectified and integrated (Medelec I6). The integrators' automatic voltage reset modes were set at 50 resets/second/division which produced continuously resetting signals of integrated AMG and EMG (IAMG and IEMG). Bandwidth filtering was 3.2 Hz to 160 Hz for AMG and 0.8 Hz to 800 Hz for EMG. Signals were recorded on an ink-jet recorder (Mingograph 804, Siemens Ltd).

Fatigue test manoeuvre

The isometric fatigue test used for the paraspinal muscles was similar to that described by Biering-Sorensen (2), and used to examine IAMG and IEMG activity by Cooper et al. (3). Subjects performed an isometric hold with the upper body (above the anterior superior iliac spines) unsupported over the lowered end of a hinged couch, in the horizontal prone position (Fig. 1). The lower body was secured to the couch with broad straps at the thighs and ankles. The hands were placed at the forehead with the elbows out to the sides and the neck in the neutral position. A stand was placed in front of the subject with a projecting marker which lightly touched the subject's hands in order to maintain the same position throughout the test. The subject was instructed to look downwards at a central point to prevent trunk rotation or swaying, and was asked not to take deep breaths while the ink-jet recorder was on (i.e. every 10 sec). At the end of the test the upper end of the couch was raised back to the horizontal position to support the upper body.

Experimental protocol

Repeatability of simultaneous IAMG and IEMG recordings during the test manoeuvre was assessed by performing two, five second contractions with a one minute rest between each. After two minutes rest, the fatigue test was performed by holding the horizontal prone position, against gravity, for 60 sec. Recordings were taken at 10 sec intervals during the 60 sec test period.

Analysis of data

Values for IAMG and IEMG were calculated by counting the number of resets of each signal in the same two second period, every 10 sec during activity. For each two second period, the resets were multiplied by the gain and divided by the auto-reset setting. This value was then divided by two to produce a value for IAMG units in one second, and IEMG in μVs (19).

Repeatability of IAMG and IEMG between the two, five second test contractions was examined by one-way analysis of variance (ANOVA) and the root mean square errors ($\sqrt{MSE}$; i.e. standard deviation) and coefficients of variation (CV)

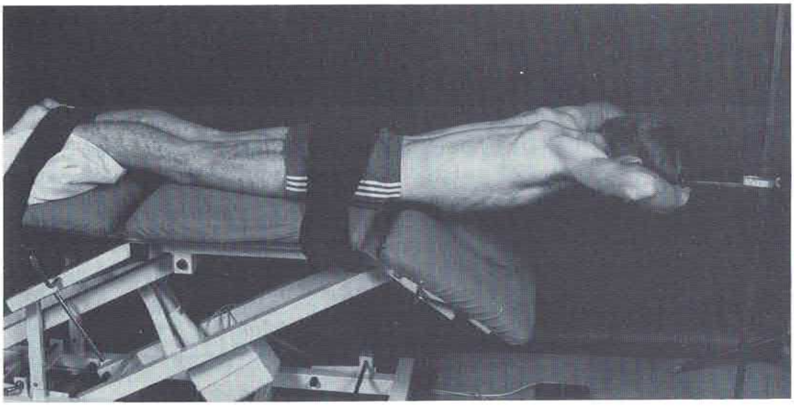

Fig. 1. Subject performing the isometric horizontal holding test, as described by Biering-Sorensen (2), which was used to fatigue the paraspinal muscles during electromyographic and acoustic myographic recordings.

were calculated from the ANOVA. The IAMG: IEMG ratios were calculated by measuring the % of initial IAMG and IEMG at 10 sec intervals during the 60 sec test. In order to normalise the data for the group, the IAMG: IEMG ratio at the beginning of activity for each subject was 1.0. The mean and standard deviation of the ratios obtained from all the subjects were then plotted on a graph with respect to time. Regression analysis was performed for each side and the slopes compared. The % changes in IAMG, IEMG and IAMG: IEMG ratios at the end of activity were compared between the right and left sides by one-way ANOVA.

RESULTS

Changes in activity at the end of the test period

At the end of the test, IEMG activity increased but IAMG activity did not alter (Table I). The changes in activity were not significantly different ($p > 0.05$) between right and left sides for IEMG, IAMG or IAMG: IEMG ratios.

Changes in IAMG: IEMG ratios during activity

The changes in IAMG: IEMG ratios during activity, indicating reduced EEA, are shown in Fig. 2. The slopes of the regression lines were the same (−0.003) for both right and left sides.

Repeatability of baseline measurements

The values for IAMG and IEMG activity during the two, five second test contractions were very repeatable (Table II).

DISCUSSION

Changes in paraspinal muscle EMG and AMG activity were symmetrical between the right and left sides. At the end of the fatigue test the EMG activity had increased while the AMG activity had remained the same. This was to be expected since EMG dissociates from force due to increased activation being required to maintain a given force as the muscle becomes fatigued (6), while AMG remains constant with force during strong contractions (7, 13). During the fatigue test, the declines in IAMG: IEMG ratios indicated reduced EEA of the paraspinal muscles which were identical on both sides.

It is not possible to determine changes in the relative components of the integrated EMG results in the present study due to the use of surface electrodes and absence of frequency analysis. However, a study of biceps brachii, which used a similar fatiguing proto-

Table I. *Percentage (%) changes in paraspinal muscle activity for integrated acoustic myography (IAMG), electromyography (IEMG) and IAMG: IEMG ratios on the right and left sides at the end of an unsupported horizontal holding test*

Means ($\bar{x}$), standard deviations (±1 SD) and ranges are shown

	% Initial	
	Right	Left
IEMG		
$\bar{x}$	122.4	125.1
SD	8.68	11.82
Range	105–138	104–148
IAMG		
$\bar{x}$	98.7	99.6
SD	8.16	5.30
Range	85–114	89–111
IAMG: IEMG ratio		
$\bar{x}$	0.81	0.80
SD	0.08	0.08
Range	0.67–0.93	0.64–0.96

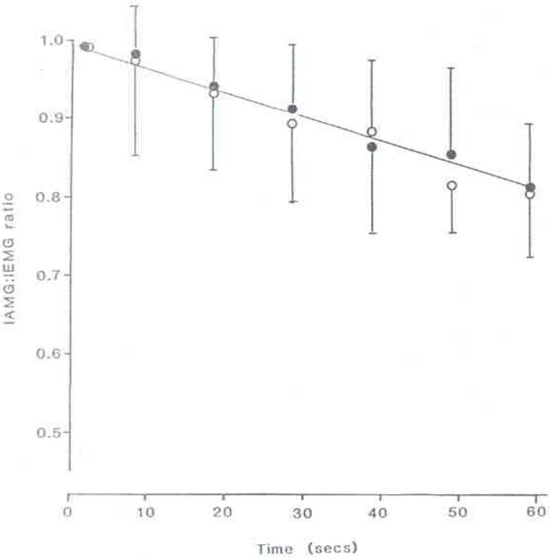

Fig. 2. Symmetry of integrated acoustic and electromyographic (IAMG : IEMG) ratios of the right and left paraspinal muscles in normal adults ($n=15$), during a 60 sec isometric fatigue test with the upper body unsupported in the horizontal prone position.

col at 50% MVC and recorded simultaneous surface and intramuscular EMG, indicated that a decrease in firing frequency and increase in recruitment occurred during fatigue (9). Changes differed during a sustained test at MVC where there was a greater decline in frequency and a decrease in recruitment (9). It is therefore likely that the horizontal position of the back was maintained by a submaximal contraction (> 60% MVC due to the unaltered AMG) which involved increased recruitment of fibres as the muscles became less efficient due to excitation-contraction coupling failure. Some of the limitations of surface EMG recordings, e.g. signals from deeper tissues may be attenuated, may also apply to AMG.

Symmetry of lumbar paraspinal muscle size has been documented in normal subjects (Hides, Cooper & Stokes, unpublished data) and asymmetry was found in patients with scoliosis (Kennelly & Stokes, unpublished data); both studies using diagnostic ultrasound imaging to measure muscle cross-sectional areas. Asymmetry of paraspinal muscle components has also been seen on computerised tomographic scans of patients with chronic low back pain (18). Such asymmetry might be detected using the present fatigue test which provides a more functional, although less specific, assessment of muscle than diagnostic imaging. Recordings over the thoracic spine

Table II. *Repeated contractions showed high reproducibility for integrated acoustic myography (IAMG) and electromyography (IEMG) for both right and left paraspinal muscles*

The mean values ($\bar{x}$) are shown. Co-efficients of variation (CV), and root mean square errors ($\sqrt{MSE}$) were calculated by analysis of variance (ANOVA)

	Right		Left	
	IAMG (units)	IEMG (μVs)	IAMG (units)	IEMG (μVs)
Trial 1 ($\bar{x}$)	23.7	166.8	20.8	133.9
Trial 2 ($\bar{x}$)	24.4	149.9	20.4	131.7
Trial 1 & 2 (grand mean)	24.1	153.9	20.6	132.8
$\sqrt{MSE}$	1.42	13.7	1.14	7.52
CV	5.9%	8.9%	5.5%	5.7%

would be more appropriate for scoliotic patients, although asymmetry of lumbar paraspinal EMG has been documented (15).

Although force (and therefore AMG) was not expected to change during the horizontal holding test, minor fluctuations in force could be detected by the AMG so that changes in EMG were more accurately reflected by the IAMG : IEMG ratios. The test could be performed without using AMG to document force as long as measures were taken (such as those described above) to ensure that the subject did not deviate from the horizontal position but minor fluctuations would probably occur and cause variation in the EMG results. Since the relationship of AMG activity to force varies according to the force of contraction (7, 13), it may not be appropriate to use AMG to monitor force during manoeuvres of the spine involving only weak contractions of the paraspinal muscles. The limitations of the AMG technique therefore need to be established for the muscle and conditions in which it is to be used. Further validation studies regarding the technical aspects of AMG, such as repeatability, are required and factors which are known to affect the AMG signal, e.g. pressure and environmental noise, should be controlled as in the present study.

Discrepancies between previous EMG findings in patients with low back pain (12) and scoliosis (15, 16) may have occurred due to the different test manoeuvres used (some of which are difficult to control) or the fact that absolute values of surface recordings were compared between normal subjects and patients. Recordings of paraspinal AMG and EMG activity made with subjects in standing showed poor repeatability of signals (21). A study of different test manoeuvres for the paraspinal muscles, including quiet standing and back extension in prone, showed that the horizontal test used in the present study produced the most reproducible recordings of EMG and AMG (8). This finding was confirmed by the present repeatability tests. The use of a standardized test, such as that described, may help to document the pattern of muscle dysfunction in different pathological conditions affecting the spine.

It is anticipated that asymmetry of activity during this objective test could be used as an indicator of abnormality and return to symmetry could be monitored during rehabilitation. It is recognised however, that chronic unilateral low back pain symptoms could lead to generalised loss of muscle function, in which case abnormal activity could be detected on both sides by the steeper slopes of changes in activity. Further validation studies of AMG are required but with careful application it may be a useful adjunct to EMG for examining electro-mechanical function.

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