Towards a measurement of active muscle control for lumbar stabilisation

No measure described to date reflects the ability of muscles to stabilise the lumbar spine. A static model was developed in supine crook lying, to measure active rotatory control with trunk loading in the sagittal plane via low, unilateral leg load. The hypothesis was that excessive lumbar movement indicates an inability of the stabilising muscles to automatically co-ordinate appropriate muscle force to support the spine. A computerised sensor was installed to calculate force from pressure variations taking leg load. Preliminary trials showed that this static model identified individuals with poor active rotatory control. Further development of the measurement model is warranted.


Key words: Lumbosacral region (lumbar region); Spine; Torsion

Rehabilitation of the trunk muscle system is recognised as an important component of the treatment of back pain and the prevention of its recurrence (Liemohn 1990, Robison 1992, Saal and Saal 1989). The trunk muscle system has been researched extensively in order to accurately depict and define the nature of the muscle dysfunction so as to direct the most appropriate rehabilitation methods (Kishino et al 1985, Nouwen et al 1987, Stokes et al 1992, Suzuki and Endo 1983).

One of the vital functions of the trunk muscle system is to provide support and control of the joints during movement. This involves a complex interaction between many muscles, the combination of muscles and the nature of their work being dependent on the positional and directional requirements of the task (Kumar 1980, Oddsson and Thorstensson 1990, Pope et al 1986, Schultz et al 1983).

A primary function of the lumbar spine is to move and support loads in the sagittal plane. In this plane, the rectus abdominis and the long erector spinae are anatomically aligned to produce and control the primary movement, while torsional stability is reliant primarily on activity in the internal and external oblique abdominals (Bogduk and Twomey 1991). The importance of this active stability role of the oblique abdominals as well as that of the transversus abdominis is well recognised by researchers and clinicians (Gracovetsky et al 1985, Kennedy 1980, Miller and Medeiros 1987, Richardson et al 1992, Robison 1992, Tesh et al 1987, Zetterberg et al 1987).

Evidence is emerging to suggest that the oblique abdominals and transversus abdominis may not always be optimally recruited or may fatigue in their stabilising role even in normal, currently asymptomatic individuals (Caix et al 1984, Parnianpour et al 1988). If this is the case, loss of active stabilisation capacity of these muscles may be one of the possible processes involved in the development of back pain.

To investigate this possible dysfunction, it is essential to have a suitable measure to assess the stabilising capacity of the obliques and transversus abdominis muscles. Sophisticated methods already exist to measure other muscle functions such as torque production under isokinetic and isometric conditions (Langrana et al 1984, Smith et al 1985, Tredinnick and Duncan 1988). However these measures are unsuitable for specific assessment of the supporting capacity of particular muscles as they represent the torque output of all the muscles acting in synergy in that plane. A new method of measurement was required to more selectively evaluate the action of the abdominal muscles, i.e. to separate the stabilisation provided by the oblique abdominals and transversus abdominis from that of the primary action of rectus abdominis. This would permit a more specific and direct test of the capacity of the muscles.
From Page 187

performing the supporting action.

It was hypothesised that stability capacity of the oblique abdominals and transversus abdominis could be assessed by measuring the rotatory control of the lumbar spine during sagittal plane loading.

To test this hypothesis, a study was initiated with the following aims: (1) to develop a method of measurement of active positional stability of the lumbar spine on the application of a standardised sagittal load with a unilateral bias to better test rotatory control; and (2) to investigate the potential efficacy of the measurement to detect lack of active muscle stabilisation.

Development of the measurement model

To develop a method of measurement, it was necessary to design an experimental model which allowed a direct assessment of active lumbar stability under an imposed standardised load. The model aimed to reflect the trunk muscles' antigravity functional role of providing background support for limb movement and for protecting the spinal column from forces imposed through limb loading. A major part of this function requires the muscles to be active either continuously or repeatedly over long periods of time at relatively low force levels. For this reason, the model was designed to assess the appropriate recruitment of specific trunk muscles (in their supportive role) under load or during maximal efforts.

The assessment of muscle action in the sagittal plane aimed to emphasise a functional differentiation between rectus abdominis and the lateral abdominal supporting synergists.

A static model was designed to measure the automatic supporting capacity of these lateral abdominal muscles. This static model was adopted to allow measurement of both axial and sagittal plane control of trunk position under an imposed sagittal load. It was hypothesised that excessive lumbar spine movement would indicate an inability of the stabilising muscles to co-ordinate appropriate muscle force to support the spine under load.

The supine crook lying position was adopted for the model. The design utilised low load, unilateral leg weight with two different lever lengths (Figure 1). This method of loading is consistent for the individual and relevant to their body size and requirements of their trunk stabilisers. The hip was maintained in a position of 70 degrees flexion to permit a mid position of the lumbar spine and also to eliminate the influence of length of the lumbo-pelvic-hip muscles on movement of the lumbar spine.

Assessment of lumbar stability required a measurement which reflected change of position of the lumbar spine in three dimensions. This is a complex movement or positional change to measure in the required test position. Methods such as biplanar radiography (Pearcy and Tibrewal 1984) are ideal but the level of radiation exposure would prohibit their use on a wide scale. An external method of measurement was required so that it could be used safely, especially in situations where repeated measurements are needed (for example, to test the efficacy of treatment methods).

The test position precluded the use of established external methods of measurement. In response, a four air cell pressure sensor was constructed and computerised (Figure 1). It consisted of conjoined inflatable chambers made of a non-elastic material. It was inserted between the irregularly shaped lumbar surface and the testing surface. Each cell was inflated to fill the space behind the lumbar spine without causing displacement of the spine. Pilot trials had confirmed that a baseline pressure of 40 mmHg was required. The pressure sensor operates on the principle that body movement and
positional change causes volume changes in the cells which are measured as pressure changes. By recording the changes in pressure in each of the four cells simultaneously on application of leg load, an index of the direction and amount of movement of the lumbar spine could be calculated for the rotational and sagittal directions.

Calibration
Calibration of each pressure cell was carried out to obtain calibration values corresponding to each cell. This was done to adjust recording values to take into account the difference in characteristics of individual cells. It was also necessary to ensure that volume changes and thus pressure recordings from the cells resulted from lumbo-pelvic movement and positional changes and were independent of various individuals' body weight.

Trials were conducted with five subjects of both genders and varying sizes to establish the effect of their body weight on the cells when inflated behind their backs to 40mmHg. Their body weights ranged from 45kg to 120kg. The tests indicated that weights from 1.5kg to 2.5kg were related to the range of body mass supported by the cells in the supine crook lying position.

Trials with each of these baseline weights were then conducted by placing the weight on the pressure cell and inflating it to 40mmHg. Successive 0.5kg weights were added and the pressure readings recorded. Results of the calibration studies indicated that there was a linear relationship between the applied load and the pressure change with only a 7 per cent variation over all starting weights over a range from 40 to 60mmHg, the pressure variations expected in the experimental model. These results indicated that the pressure sensor could be used with confidence to measure and compare pressure variations without reference to body weight.

Stability index
In order to quantify the axial control during sagittal loading, an index was calculated utilising the pressure changes (from the baseline of 40mmHg) which occurred in each of the cells on assumption of unilateral leg load. Calculation of the rotation index involved subtracting the combined pressure changes in the left sided cells (in the case of right leg loading) from that of the right sided cells, as this reflected a subject's deviation from the starting position and therefore their ability to hold the lumbar spine steady when leg load was taken (Figure 2).

Experimental design to test the measurement model
To investigate whether this measurement model could detect a lack of automatic stability capacity of the abdominal supporting synergists, a study was designed to investigate the rotatory stability index under two experimental conditions.

In Trial 1, a subject's ability to automatically stabilise the lumbo-pelvic area was measured when they attempted to hold their trunk and leg steady when leg load was released.

In Trial 2, subjects were required to consciously activate their oblique abdominals/transversus abdominis first and to hold this contraction during assumption of the leg load. This was done to determine if a lack of appropriate activation of these stability synergists had contributed to any dynamic rotatory instability determined under the automatic conditions of Trial 1. Previous investigations have shown that abdominal setting (via an abdominal hollowing action) recruits these muscles without high levels of activation of rectus abdominis (Richardson et al 1992).

Method
Subjects
Twenty normal volunteer subjects (11 males, nine females) were included in this study. Their ages ranged from 20 to 34 years and they were of average height and weight. To be included in the study, subjects had to be able to consciously perform an abdominal setting action.
Subjects were excluded from the study if they had any musculoskeletal or neuromuscular condition or any history of back pain for which they had either sought treatment, or the pain had interrupted their normal daily activity. Subjects were also excluded if they had tightness of their erector spinae or iliopsoas muscles as examined by standard clinical muscle length tests (Evjenth and Hamberg 1984, Janda 1983).

Subjects received an explanation of the tasks they were to perform and signed an informed consent form prior to their formal entry into the study. Ethical clearance for the study was obtained from the University of Queensland Medical Ethics Committee.

Instrumentation
Each of the four cells of the pressure transducer were connected to amplifiers and data were collected on an analogue to digital converter system and stored on computer for later analysis. Each cell was connected to a hand pump with dial for individual inflation to a pre-trial base line pressure of 40mmHg.

Several other measures were taken in investigating the measurement of an active stability index. Multichannel EMG was used to ensure correct activation of the muscles during the abdominal setting action as required in Trial 2. Two medi-trace stress electrodes (Graphic Controls, Canada Ltd) were applied to the right upper and lower portions of rectus abdominis, right and left external oblique abdominals, right internal oblique/transversus abdominis group and the right lumbar paravertebral muscles adjacent at the L4, L5 level (Jonsson 1973, Pope et al 1986). An earth electrode was placed on the left anterior superior iliac spine. Skin preparation was according to Anderson and Champion (1988).

To ensure that the electrodes were correctly placed such that EMG cross talk was minimised between recording sites, several movements were performed which emphasised a particular muscle's action. Rectus abdominis activity was checked with the performance of a partial trunk curl-up, the external obliques by resisted rotation of the trunk (resistance being applied at the knees in a crook lying position), the internal oblique/transversus group by a forced, quick expiration (Basmajian and DeLuca 1985) and the lumbar paravertebral muscles by an anterior pelvic tilt, lumbar extension action.

The EMG electrodes were connected through a preamplifier (Medelec PA63) to an amplifier/filter (Medelec AA6MKIII). The data were sampled by an analog to digital converter. The data were then stored and processed on an IBM AT compatible computer. This permitted immediate viewing of the raw EMG signals as well as collection of the EMG signals for later analysis. The root mean square (RMS) processing of the EMG signal (Basmajian and DeLuca 1985) was the method used to analyse the data, which were measured in arbitrary voltage units (AVU).

A CODA-3 (Movement Techniques Ltd, UK) was employed to monitor overall body position. The CODA is a three-dimensional optical scanning device which emits three light beams to reflective prisms attached to the subject. The prism marker was placed on the side of the subject's right shoulder. In the context of this experiment, this was to ensure that subjects did not lift their shoulders when taking leg load, as this trunk curl-up action would be an extraneous influence on pressure recordings.

Procedure
Once accepted into the study, subjects were suitably undressed and EMG electrode sites prepared and electrodes attached. Subjects were positioned on the testing plinth in supine crook lying, and tasks to check correct electrode placement were performed.

The pressure sensor was placed centrally behind the lumbar spine from...
S2 to approximately L1. The CODA marker was attached and the legs positioned such that the hips were in 70 degrees flexion. The right leg was used as the test leg in all subjects and the left foot was positioned on a set of weighing scales to ensure that subjects did not push through their left foot when required to hold right leg load.

The test of automatic stability capacity was always conducted first to avoid any influence that awareness of the abdominal setting action may have on the first spontaneous test. The short lever (leg load 1) and longer lever (leg load 2) unilateral leg load conditions were randomised.

The subject’s relaxed right leg was manually supported by an experimenter in the required test position. Each cell of the pressure sensor was inflated to the baseline pressure of 40mmHg.

In Trial 1 of each leg load, the subjects were instructed to attempt to hold their trunk and leg steady when leg support was released. When a second experimenter indicated that the pressure readings of each cell of the sensor were stable at 40mmHg, simultaneous recordings of the pressure, EMG and CODA were begun and the experimenter released leg support. A five second sample of data was taken.

In Trial 2 of each leg load, subjects were first required to activate their oblique abdominals and transversus abdominis with the abdominal setting action. The correct action and maintenance of the contraction were monitored by the pressure sensor. When subjects maintained a constant increase of pressure of approximately 10mmHg in each cell, which occurs with a correct contraction (Richardson et al 1992), the procedures of Trial 1 were repeated.

Repeatability

The repeatability of a subject’s automatic stability performance in terms of the rotatory index calculated from the pressure changes and EMG activity was investigated by repeating Trial 1 of leg load 1 on six occasions in five subjects. The short lever was chosen to minimise any effect that fatigue may have had on results, which might occur if higher loads were used. One way repeated measures ANOVAs for the rotatory stability index and for the EMG values for each muscle revealed no significant differences for any parameter across the six trials. The standard deviations calculated from the ANOVAs indicated that the average variation over all trials ranged from 0.13 to 1.3 AVU for the EMG data and was 9.3 for the rotation index. The values were considered acceptable for this study.

Results

EMG

Prior to investigating the rotatory stability indices of Trial 1 (the subject’s automatic stability capacity) and Trial 2 (stability capacity with the conscious abdominal setting action), it was necessary to affirm the influence of this setting action on muscle activity.

The EMG RMS value for each muscle in Trials 1 and 2 of both leg loads were collated. A repeated measures ANOVA was used to investigate if there was any difference in the level of muscle activity between the trials for either leg load condition (IBM SAS Package, SAS Inc. 1985).

The results for leg load 1 revealed that the abdominal setting action significantly increased the activity of the right external oblique ($F(1,39) = 18.4, p < 0.0004$), the left external oblique ($F(1,39) = 15.3, p < 0.001$) and the right internal oblique/transversus abdominis group ($F(1,39) = 32.9, p < 0.0001$). There was no difference in the activity levels of the upper and lower portions of the rectus abdominis and the lumbar erector spinae (Figure 3) thus confirming that the abdominal setting action selectively activates the lateral abdominal supporting synergists. The results for leg load 2 indicated the same pattern of change of muscle activity.

CODA

The amount of displacement of the shoulder marker of the CODA was investigated to determine if a trunk curl-up action could be a variable influencing any pressure changes recorded. The data revealed that displacements in a vertical direction, indicating flexion, were only in the magnitude of a mean of 1.4mm. Such small displacements were considered to have an inconsequential influence on any pressure variations recorded with limb loading.
Rotary stability index

Calculation of the rotary stability index for Trial 1 (leg load 1) revealed that eight subjects had high indices of rotary instability (57.6 ± 21.3) compared with the other 12 subjects (24.8 ± 10.5). On the basis of these indices, the subjects were divided into two groups for further analysis (Group 1 low rotary index, Group 2 high rotary index).

The rotary index was analysed using an appropriate ANOVA to determine if there was any change in the index between Trial 1 (automatic stability capacity) and Trial 2 (stability capacity with conscious activation of the stability synergists) over both leg load conditions.

Results revealed that a significant interaction was present regardless of leg load conditions ($F_{(1,114)} = 8.77, p = 0.0045$). Conscious pre-activation of the stability muscles made little difference to the stability index of those subjects with minimal rotatory movement (Group 1) in Trial 1 (Figure 4). In contrast, subjects in Group 2 who demonstrated poorer automatic control in Trial 1 improved their rotatory index markedly in Trial 2 (Figure 4).

In addition, a Pearson correlation procedure was performed for the whole group of 20 subjects to assess whether there was a relationship between a subject’s initial rotatory index score and the amount of improvement with conscious activation of the stability muscles for both loads. The results for leg load 1 ($r = 0.58, p < 0.007$) and leg load 2 ($r = 0.5, p < 0.03$) confirmed that those with less stability initially, improved their index score most with active stabilisation for both loads.

Discussion

The aim of this study was to develop and test a measurement model which might depict and identify loss of active trunk stabilisation with particular reference to rotatory control during sagittal loading. There is currently no measure that quantifies this important muscle function.

Measurement model

The basis for the model was that lack of active muscle stabilisation would be reflected in lack of control of lumbo-pelvic position when low load was applied. A static model was developed to measure an index of rotatory stability of the lumbo-pelvic region under conditions of an imposed unilateral standard leg load. An index of this displacement was measured by a computerised four air cell pressure sensor.

The development of this measurement tool fulfilled several requirements of the model. The pressure sensor is safe and non-invasive. It can be inflated to mould to the irregularly shaped surface of the back, is highly sensitive to movement and positional change and can provide indices of displacement in three-dimensions, albeit that the rotatory component was emphasised in this model of unilateral limb weight. As revealed in the calibration studies, the pressure sensor can be used with accuracy with individuals of varying body weights.

Furthermore, in this model using low load unilateral leg weight, the pressure recordings of the lumbo-pelvic position and movement were not influenced by extraneous movements of other body parts. Negligible shoulder displacement (trunk flexion) was recorded in the trials.

Efficacy of the measure

A trial was conducted on 20 subjects to investigate whether the measurement of this model could detect lack of active stabilisation capacity of the trunk stability synergists in sagittal plane loading. To determine this, automatic stability capacity was assessed first (Trial 1). Subjects demonstrated lesser (Group 1) and greater (Group 2) rotatory stability indices in this task. The indices of these groups were then compared with those recorded when subjects voluntarily activated and held an abdominal set prior to and during leg loading. EMG results confirmed that this setting action activated the stability synergists selectively (ie external obliques, internal obliques/transversus abdominis group) and importantly dissociated their activity from that of rectus abdominis.

The results revealed that activation of the stability muscles made little difference to the rotatory stability index of those subjects with little rotatory movement (Group 1) on Trial 1. This indicates that a conscious increase in activity in the obliques and transversus abdominis did not change the ability of these muscles to control the spinal position. From this it could be inferred that these subjects were capable of automatically contracting their supporting muscles in an optimal pattern including force components of the muscles and their timing.

In contrast, subjects in Group 2 who had poorer automatic rotatory control in Trial 1 demonstrated a significant improvement in rotatory index with conscious contraction of their stability muscles (Trial 2). The inference is that these subjects did not have sufficient automatic muscle support.

It would therefore seem that the proposed static model with an imposed standard low load leg weight may be able to depict and identify loss of active trunk stabilisation.

The stability function measure

The measure developed in this study incorporated some unique features which differentiates it from other measures of muscle function. It was designed to be a direct measure of the stability function of the lateral abdominal muscles when a load was applied in the sagittal plane.

The measurement did detect differences between individuals from a normal population group. That these differences were found under very low loading conditions suggests that testing under submaximal rather than maximal loading could be a key issue. The results also confirm the important stabilising function of the transversus abdominis/internal oblique and external oblique muscles in sagittal plane loading.
The development of the measure has provided initial evidence to support the hypothesis that the lateral abdominal stability synergists may not be optimally recruited even in some asymptomatic individuals. The reasons for this lack of automatic support are yet to be fully realised. However, initial results encourage further development of this measurement model. A second prototype will need to address issues such as recruitment and timing of muscles as well as the relationship of this measurement to true muscle weakness in the lateral abdominals.

Development and refinement of the model will allow future studies to help clarify the nature of the muscle dysfunction which may initiate or perpetuate low back pain syndromes. Such knowledge is essential for the implementation of the most appropriate preventative exercise strategies.

**Conclusion**

The muscles’ ability to stabilise the lumbar spine is a function that is critical for pain-free, non-stressful activity. Objective measures of muscles’ stability function need to be developed to help clarify and quantify the nature of trunk muscle dysfunction. A measurement model, which tests the lateral abdominal muscles’ supporting capacity to control lumbo-pelvic rotary movement under an applied low, unilateral leg load has been developed. Initial trials indicate that we can detect a loss of supporting trunk muscle function and further development of the model is warranted.

**Acknowledgment**

This research was supported by a grant from the Physiotherapy Research Foundation.

**References**


