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Techniques for active lumbar stabilisation for spinal protection: A pilot study

Active protection of the lumbar spine is important in prevention of back strain during exercise. This EMG study investigated three common techniques used for lumbar stabilisation : posterior pelvic tilt, lower abdominal hollowing with lumbar spine flattening and abdominal bracing. The aim was to determine which method encouraged the best stability pattern. Muscle activity was measured in obliquus abdominis, upper and lower rectus abdominis and the lumbar erector spinae. Standardisation of muscle activity against that during maximally resisted trunk rotation (already shown to illustrate an appropriate stability pattern) allowed comparisons between exercise techniques in relation to their stabilisation pattern. Results indicated that posterior pelvic tilt demonstrated the least desirable stability pattern. Both abdominal hollowing and bracing provided a more suitable pattern.

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Low back pain and problems associated with the lumbar spine have become an increasing health problem despite considerable growth in knowledge and technology over the past two decades (Mooney 1987). The condition is common in both the general and sporting populations where overload and poor postural control (Sahrmann 1987) can render the spine vulnerable to injury. The muscle system provides the major support to the loaded spine during normal function (Panjabi et al 1989). For this reason, injury would be more likely in the presence of poor muscular protection.

Lack of support by the trunk musculature can occur with the general weakness associated with a sedentary lifestyle. In addition, repetition of specific movement patterns can lead to patterns of overactivity in some muscles and a related underactivity in others. This can occur due to the repetitive activities of the work environment or from training techniques and skills of recreational pastimes and sporting activities. The proximal trunk muscles, especially the oblique abdominals, are those which most often tend to weaken (Sahrmann 1988). This pattern of weakening of the prime stabilising muscles is particularly relevant if the type of movement performed involves rapid (ballistic) repetitive movement of the extremities. Evidence that stability function is markedly reduced with such movements is beginning to be recognised clinically (Umphred 1985) as well as experimentally (Ng and Richardson 1990, Richardson and Bullock 1986).

Lack of stabilisation becomes critical when the muscles of the trunk are required to control the lumbar spine and pelvis when load is applied to the limbs during exercise techniques. This problem has been addressed to some extent by physiotherapists and teachers of physical exercise.

To prevent injury to the lumbar spine, it has been proposed that elimination of the problem exercises is the best solution. For example, Nelson (1964) advised that straight leg lowering and raising exercises should not be used for abdominal strengthening as the back is vulnerable to hyperextension strain.

Rather than completely eliminating all exercise techniques which may precipitate loss of control of the lumbar spine, many complex and diverse corrective procedures have been instigated to ensure lumbar spine stabilisation. These techniques have been devised to induce specific lumbar and pelvic co-ordination and stabilisation independent of any trunk, upper or lower limb movement.

Smidt and Blanpied (1987) suggest that asking clients to simply flatten their backs during trunk exercise should negate arching of the lower spine in the presence of insufficient abdominal strength. A similar technique of back flattening combined with a posterior pelvic tilt, is also advocated as an adequate method of achieving lumbar stabilisation (Cailliet 1984).

The technique of abdominal bracing prior to and during any loaded exercise or functional activity technique was devised by Kennedy (1980). It relies on the use of increased intra-abdominal

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pressure to stabilise the lumbar spine. The technique requires considerable skill and utilises contraction of both the oblique abdominals and lower back muscles.

It has been suggested that better stabilisation is achieved if the abdominal muscles are hollowed and the back gently flattened (Kendall and McCreary, 1983). A recent EMG study by Miller and Medeiros (1987) showed that this type of action increased the contribution of the oblique abdominals and transversus abdominis during the eccentric phase of a trunk curl exercise. In this study, subjects were asked to contemplate their navel and pull it up and against the spine with the abdominal muscles. It was considered that these instructions acted as a visualisation cue to stabilise the lumbar spine during the trunk curl exercise.

Confusion can develop when the instructor is faced with so many alternative methods of achieving control of the low back in order to negate the potentially hazardous effects of some exercises on the lumbar spine. As a result, this study aimed to investigate if any of these techniques provided an optimum pattern of muscle activity which would maximise stabilisation of the lower back during exercise.

Muscle stability patterns

The ability to analyse these proposed stabilisation techniques in terms of appropriate muscle activity, relies on knowledge already gained in anatomical and biomechanical studies as well as clinical trials investigating the contractile stabilisation mechanisms of the lumbar spine.

Although the concept of the stabilising role of the trunk muscles is acknowledged (Pope 1987), the development of a theory which identifies the muscles required to ensure ideal levels of stabilisation must be developed from the results of several experimental studies.

Zetterberg (1987) emphasised the stabilisation role of the oblique abdominals in an electromyographical study of maximal trunk exertions in standing as well as in lifting tasks. In contrast to rectus abdominis, the oblique abdominals were active in all task performances and displayed little correlation (as did the longitudinal muscles) with model predictions. This study highlights the prime stabilisation role of the oblique abdominals in comparison to rectus abdominis.

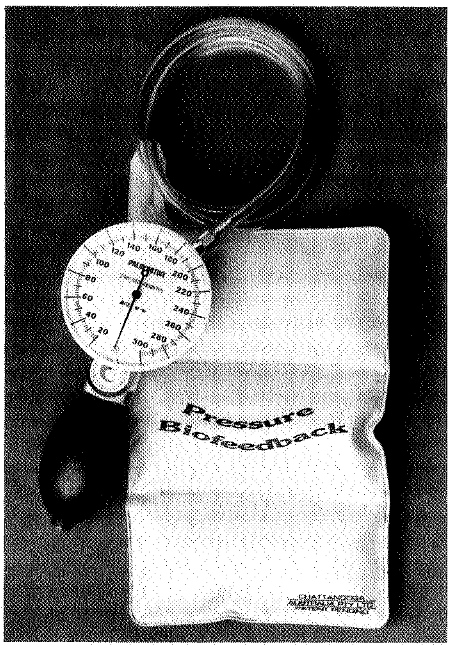

Figure 1.
The pressure biofeedback used to monitor the degree of back flattening.

In a detailed EMG study, Soderberg and Barr (1983) established that muscular control in the lumbar region was significantly lower in patients with chronic low back pain when compared to normals. These researchers suggested that the lumbar musculature was important in the control of the spine in exercises such as sit-ups. Using these and many other relevant studies, it has been previously argued by the current authors that the muscles required for lumbar stabilisation are the oblique abdominals, transversus abdominis, in co-contraction with the deep lumbar erector spinae (Richardson et al 1990). Low levels of activity were considered appropriate in the lower rectus abdominis but high levels of activity in either the upper or lower rectus abdominis were not appropriate for a good stability pattern. The fact that rectus abdominis is quite remote from the segments of the lumbar spine suggests that this muscle's primary function would appear to be in pelvic and trunk movement with only secondary emphasis on lumbar stability.

In order to evaluate different protective manoeuvres for the lumbar spine, an action which promoted a suitable co-contraction stability pattern had to be identified to serve as a baseline for comparative measurements. Previous research (Richardson et al 1990) had shown that the muscle stability co-contraction pattern was best demonstrated in isometric resisted rotation of the trunk. By comparing the levels of muscle activity in baseline resisted trunk rotation with levels during various voluntary lumbar stabilising techniques, it would be possible to determine which procedure provided the best lumbar support.

The three different techniques chosen for study were:

- Abdominal hollowing and back flattening;
- Abdominal bracing; and
- Posterior pelvic tilt.

To ensure that the result would prove useful in a variety of situations, both sitting and lying positions were used. Due to stress placed on the lumbar discs in upright sitting (Andersson et al 1974) reclined sitting was chosen as a more appropriate test position.

Method

Fifteen healthy volunteers (five males and 10 females) aged between 18 and 30 years and of average height and weight, consented to participate in the study. Subjects were excluded if they had any previous abdominal surgery or a history of back or hip pain that interfered with activities of daily living. They were further assessed for stiffness of the lumbar spine and tightness in the erector spinae and rectus abdominis muscles and excluded if loss

of flexibility was demonstrated. In addition, subjects were excluded if they were assessed to have a marked lordotic, sway back or flat back posture as these postures may indicate marked trunk muscular imbalance (Kendall and McCreary 1983, Sahrmann 1988).

Several days prior to testing, the subjects were taught the three test exercises, namely posterior pelvic tilt, lower abdominal hollowing combined with lumbar spine flattening and abdominal bracing. This was done in order to give each subject the opportunity to familiarise themselves with the exercise techniques. Subjects were instructed not to do these exercises in the 24 hours prior to testing to minimise any training or fatigue response.

Two Medi-trace stress test surface electrodes (Graphic Controls, Canada Ltd) were applied to the right upper rectus abdominis, right lower rectus abdominis, right external obliquus abdominis and right lumbar paravertebral muscles (multifidus) at the L4 and L5 level (Jonsson 1973, Pope et al 1986). An earth electrode was placed on the right anterior superior iliac spine. Skin preparation of the electrode sites was performed as described by Anderson and Champion (1988). High activation contractions were performed for each muscle to ensure that EMG crosstalk between recording sites was negligible.

Electrodes from each of the four muscles were connected through a preamplifier (Medelec PA63) to an amplifier/filter (Medelec AA6 MKIII) then to an oscilloscope for real time viewing of the raw EMG signals of each muscle. The four channels of raw signal output from the amplifier were also collected on a Cleveland 186 computer for later analysis. The root mean square (RMS) processing of the EMG signal, as suggested by Basmajian and DeLuca (1985), was considered the most appropriate method of analysing the data.

A pressure transducer (Chattanooga Australia, Pressure Biofeedback) was devised and used to monitor changes in

Figure 2.
The reclined sitting position

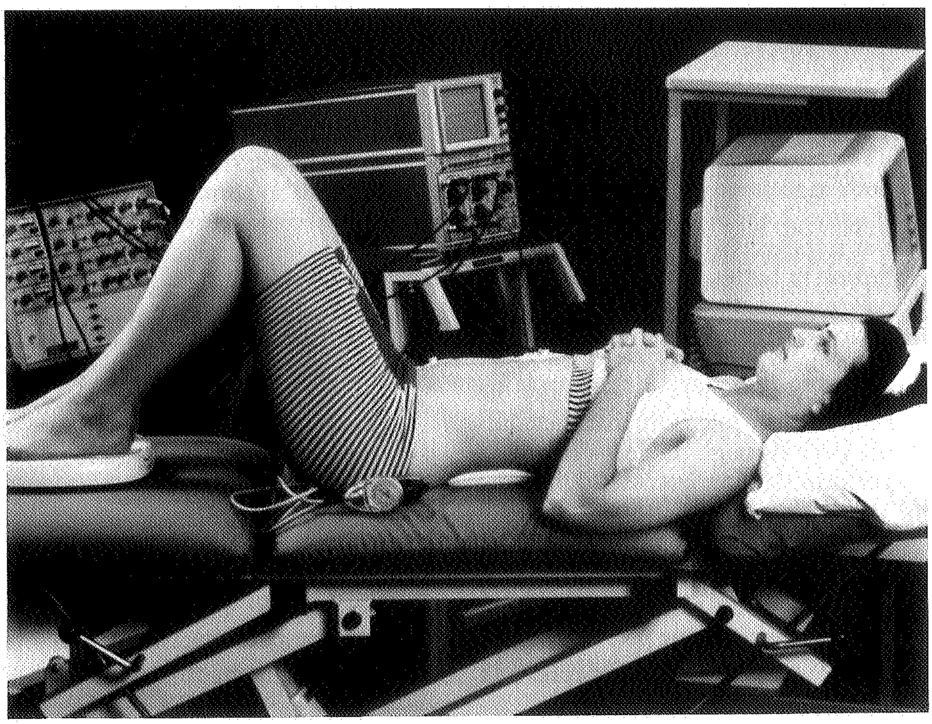

Figure 3.
The crook lying position

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the pressure that the lumbar spine exerted against the support surface during performance of the test exercises (Figure 1). It was placed centrally, behind the lumbar spine, from S2 to approximately L1. Use of such a biofeedback device was also important to determine if the subject maintained the stabilisation position once the experimenter had deemed the exercise to be performed correctly. Pressure changes were recorded for later analysis.

An initial EMG recording was taken during resisted, isometric trunk rotation exercise to the left. As it was essential that resistance be applied in the reclined sitting position (to ensure muscle lengths and joint positions remained standard), rotary resistance was applied manually by the experimenter. The subject attempted to rotate maximally and the manual resistance to the shoulders was used to prevent movement. Richardson et al (1990) have previously demonstrated that this exercise promotes trunk muscle activation in an optimal stability pattern. The EMG data recorded from this exercise was used to normalise the activity of the four muscles recorded during the trial exercises.

The three test exercises were assessed both in reclined sitting and crook lying (Figures 2 and 3). Hip flexion angle was standardised at 70 degrees of flexion in both positions. The neck position was maintained in neutral and no forward trunk flexion was permitted. In crook lying, a set of weighing scales was placed under the subjects' feet to ensure that they did not push through the feet while performing the exercises (Figure 3).

Baseline EMG recordings were collected with the subject resting in sitting and lying to ensure minimal activation of the test muscles at rest. Baseline levels in the pressure biofeedback were standardised to 40mmHg. The subject then performed each of the six exercises. Due to the complex nature of the tasks and the learning required to achieve

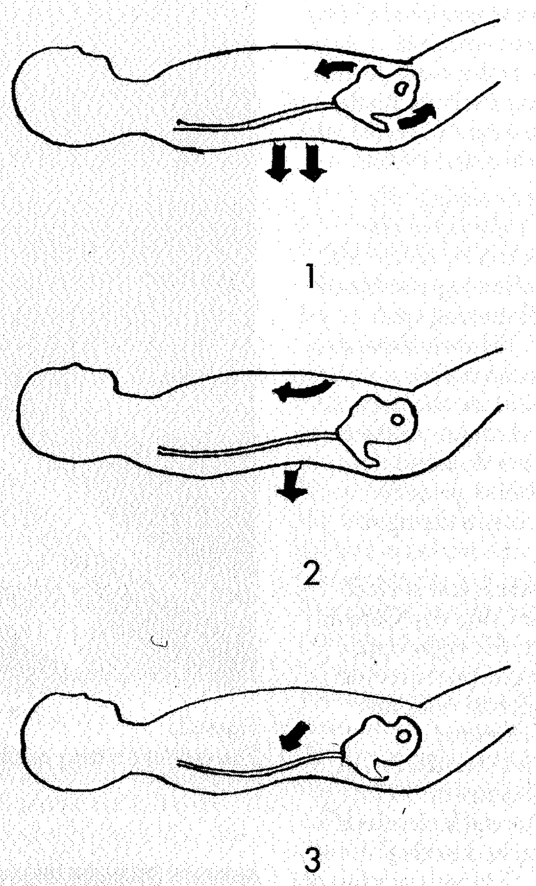

Figure 4.
Diagrammatic representation of (1) posterior pelvic tilt (2) lower abdominal hollowing combined with lumbar spine flattening (3) abdominal bracing.

Table 1.
Results of three way analysis of variance of ratioed electromyographic activity of four muscles during three exercises performed in two positions

Source	*df*	MS	*F*	*p*
Subject	14	2.55	7.16	0.0001
Muscle	3	16.80	47.26	0.0001
Position	1	0.74	2.08	0.1498
Exercise	2	25.11	70.65	0.0001
Muscle x Position	3	2.03	5.71	0.0008
Muscle x Exercise	6	5.59	15.73	0.0001
Position x Exercise	2	1.94	5.45	0.0047
Mus x Pos x Exer	6	0.88	2.47	0.0239
Error	322	0.36		

the correct pattern, two experienced clinicians verified the performance of each exercise. A two second sample of EMG data was collected when the pressure transducer indicated a stable pressure increase and the examiners were satisfied that the exercise was being performed correctly. The exercises were performed in random order both for the sitting and lying positions and for the three exercises. Two trials were performed for each exercise with the most consistent trial being accepted for analysis. A one minute rest period was allowed between trials.

The three test exercises, performed in both sitting and lying positions were as follows (Figure 3):

Posterior pelvic tilt

Subjects were instructed to perform a posterior pelvic tilt by contracting their abdominals to roll their pelvis backward while pulling their pubic symphysis up towards their chest. They were to feel an increase in pressure as their lumbar spine flattened onto the plinth. The head and upper trunk remained stable and subjects were not permitted to flex forward. They were further instructed not to push through their feet and compliance with this request was monitored by observing that no increase in pressure on the scales occurred. Subjects held this contraction while breathing in a relaxed manner.

Lower abdominal hollowing combined with lumbar spine flattening

Subjects were instructed to actively contract their abdominals up and in under their ribs so as to hollow their abdomen. They were to use this movement alone to feel an increase in pressure on their lumbar spine as it flattened onto the plinth. The head and upper trunk remained stable and subjects were neither permitted to flex forward nor push through their feet. Subjects were required to hold this contraction and continue to breathe in a relaxed manner. The performance was deemed to be incorrect if the lower rib cage depressed at any stage of the exercise.

Table 2.
Table of means and standard deviations for each muscle in all exercises in both positions

	Reclined sitting			Lying		
	Hollowing	Bracing	P Tilt	Hollowing	Bracing	P Tilt
URA	0.72	0.77	1.23	0.53	0.68	1.64
	(0.38)	(0.38)	(0.66)	(0.21)	(0.31)	(0.77)
LRA	0.57	0.82	1.92	0.75	0.88	3.26
	(0.43)	(0.69)	(1.05)	(0.48)	(0.83)	(2.39)
OA	0.35	0.42	0.76	0.28	0.34	0.79
	(0.22)	(0.23)	(0.30)	(0.09)	(0.13)	(0.39)
M	0.39	0.54	0.64	0.30	0.38	0.41
	(0.18)	(0.37)	(0.47)	(0.15)	(0.18)	(0.24)

The calculated LSD for comparisons of the means (each based on 15 observations) was 0.30.

URA – Upper Rectus Abdominis; LRA – Lower Rectus Abdominis; OA – Obliquus Abdominis; M – Multifidus

Abdominal bracing

Subjects were instructed to contract their abdominals by actively flaring out laterally in the region of the waist just above the iliac crests, as described by Kennedy (1980). They were not permitted to flex their head or trunk forward, elevate their lower ribs, protrude the abdomen or to press through their feet. Subjects were required to hold this contraction while breathing in a relaxed manner.

Once recording for all exercises was completed, the electrodes were removed and the electrode sites washed, dried and medicream applied.

Repeatability

The repeatability of performance of the exercise was examined prior to the analysis of results. The RMS EMG values for each muscle and exercise were compared across the two trials. Dependent t tests indicated no systematic differences between trials, except for lower rectus abdominis activity during hollowing in sitting and in lumbar erector spinae activity during hollowing in lying ($t_{(1,14)}$= 2.52 and 2.27 respectively). In both cases there was a tendency for more muscle activity in the second trial.

Correlation coefficients between trials for each muscle in each exercise were calculated. These revealed consistently high to good correlations (17 of the 24 were > 0.91 and 23 of 24 > 0.80) between trials for all cases except for upper rectus abdominis during bracing in sitting (r = 0.65). In examining the raw data for this exercise, it was noted that the values for all subjects on both trials were clustered around RMS values of 5 to 10 and due to the poor spread did not display a good linear relationship.

Taken overall, the results of the repeatability analyses indicated good reproduceability of EMG activity in all muscles and exercises across trials. The level of repeatability was considered more than acceptable to allow experimental effects to become evident on statistical analysis of the data.

Results

The EMG RMS value for each muscle for each exercise was expressed

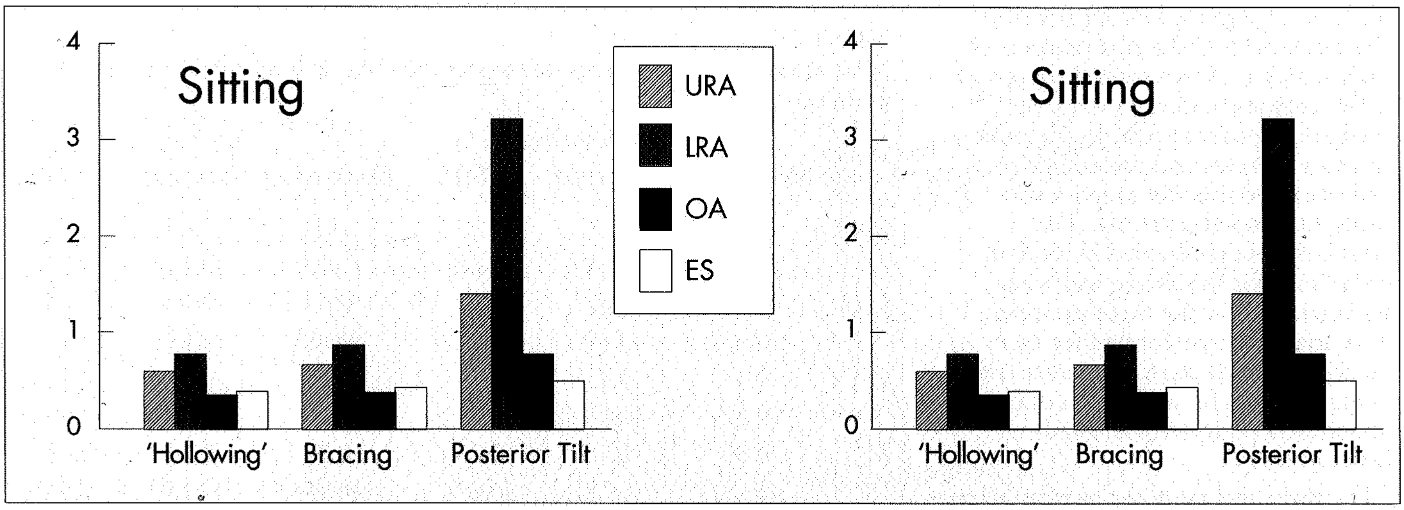

Figure 5.
Normalised EMG for each muscle for the three exercise techniques in the two positions.
(URA - upper rectus abdominis; LRA – lower rectus abdominis; OA – oblique abdominals; ES – lumbar erector spinae)

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as a ratio to the EMG RMS value obtained for the trunk rotation exercise. These ratios were then used in all analyses so comparisons of muscles across exercises and positions could be made. The aim of the analysis of results was to determine which exercise best approached the desired stability pattern and whether position influenced the pattern of muscle activity. To examine these issues, a three way analysis of variance (ANOVA) was performed using the IBM SAS Package (SAS Inc 1985).

The results (Table 1) revealed a significant three-way interaction ($p < 0.05$). This indicated that the four muscles acted differently across the three exercises. In addition, the changes in muscle activity between the exercises were dependent on the position in which the exercise was performed. All two way interactions were also significant ($p < 0.005$) as were the main effects for muscles and exercises ($p < 0.0001$). To further interpret the results, the table of means was examined and graphs generated from these values (Table 2 and Figure 5). The least significant difference (LSD) was calculated to allow post-hoc comparisons of the means.

These comparisons showed that the greatest increase in the level of activity of all muscles (except lumbar erector spinae) occurred during backward pelvic tilting. The changes were not uniform across the three abdominal muscles or the exercise positions. The increased muscle activity was most marked in the lower rectus abdominis more so in the lying than sitting position. The results for upper rectus abdominis were similar but the change in activity when pelvic tilting was performed in lying rather than sitting was not as dramatic. The degree of change in the activity of the oblique abdominals was not nearly as great, nor was the change influenced by position. Importantly the lack of similar increased activation of the lumbar erector spinae indicated that their contribution to the exercise of backward pelvic tilting relative to rectus abdominis was much reduced.

Overall there was no difference between abdominal hollowing and bracing in the activity of any of the muscles but both were very different to pelvic tilting, particularly when performed lying down. The exercise technique with the pattern of activation most like that of the trunk rotation exercise (as demonstrated by the means of all four muscles in that exercise being the most alike) was abdominal hollowing performed in either position. Bracing in either position was also relatively acceptable but backward pelvic tilting, particularly when lying, deviated markedly from the desired stability pattern of muscle activity.

In order to determine if the increases in pressure readings reflected differences between the three exercises and the two exercise positions, a two-way ANOVA was performed (Table 3). The two-way interaction of position by exercise was significant ($p < 0.0001$) which indicated that pressure changed differently for the three exercises in the two positions.

Examination of the mean changes (Table 4) revealed that the pressure readings for abdominal hollowing and bracing were similar in sitting and did not change significantly when the exercises were performed in lying. The pressure reading increased markedly in backward pelvic tilting compared to both hollowing and bracing and the change was greatest in lying. The difference in the pressure readings for pelvic tilting in the two positions was also significantly different.

Discussion

Both abdominal hollowing and bracing produced a more appropriate pattern of stabilising activity in the abdominal and back muscles than did posterior pelvic tilt. In this latter exercise, there was a marked increase in activity of rectus abdominis, a

muscle considered less able to contribute directly to lumbar spine stabilisation and protection. This was accompanied by a corresponding decrease in the proportional activation of the lumbar erector spinae (eg multifidus) in relation to the other muscles. Due to the dominance of rectus abdominis activity in posterior pelvic tilt, this technique should be considered more accurately as a movement correction pattern rather than a specific technique designed to promote lumbar stabilisation.

It would appear that abdominal hollowing or bracing, in either the sitting or lying positions, may be the techniques of choice for activating spinal support musculature. It is of interest that these two quite different exercise strategies should produce very similar muscle activation patterns. Further research is required to investigate if one technique has advantages over the other; for example, in certain biomechanical parameters, or if one is more readily learned by the client or patient.

The results of the study at this stage suggest that either of the two co-contraction techniques may prove useful clinically as methods of providing safe and effective support during resistance exercises involving the upper trunk, upper limbs or most importantly the lower limbs. An inability to hold the contraction may indicate ideal exercise loads have been exceeded.

The monitoring of these techniques using the pressure biofeedback showed some interesting preliminary results.

The pressures generated by pelvic tilt, which actively flexes the lumbar spine, were much higher than the pressures generated by the back flattening action of both the abdominal hollowing and bracing techniques. Therefore high pressure increases would indicate that the subject is strongly flexing the lumbar spine. The lower pressure increases associated with hollowing and bracing suggest a more neutral lumbar position. As both extremes of flexion and extension are potentially deleterious to the lumbar spine (Adams and Hutton 1982, Jayson 1985), the more neutral position of the lumbar spine seen in hollowing and bracing would also seem advantageous from a biomechanical viewpoint.

Table 3.
Two-way analysis of variance of pressure readings during three exercises performed in two positions

Source	*df*	MS	*F*	*p*
Subject	14	1336.37	26.87	0.0001
Position	1	3097.60	62.28	0.0001
Exercise	2	34424.31	692.08	0.0001
Position x Exercise	2	3485.73	70.08	0.0001
Error	340	49.74		

Table 4.
Means and standard deviations for pressure readings for the three exercises performed in two positions

	Reclined Sitting (mmHg)	Lying (mmHg)
Hollowing	16.33	17.73
	(7.6)	(7.5)
Bracing	16.93	16.46
	(5.5)	(5.4)
Pelvic tilting	37.07	55.33
	(10.1)	(18.2)

The LSD = 2.19 (based on 40 observations per cell).

A decline in pressure below the initial baseline seen in the more neutral position of the lumbar spine in the two favoured techniques, would indicate a loss of the stabilisation pattern associated with anterior pelvic tilting and lumbar extension.

Besides identifying the best methods to stabilise the lumbar spine during exercise, these results have implications for postural correction for activities in daily life such as lifting. In this way, the lumbar spine may be better protected from undue stress and strain. As exercise constitutes an important form of conservative treatment for patients with low back pain, these findings should also be considered by those involved in rehabilitative exercise for the trunk musculature.

Conclusion

This study was designed to examine the most effective techniques which could be used to control and protect the low back from the potentially hazardous effects of loaded exercise for the limbs. It was found that both abdominal hollowing with back flattening and abdominal bracing not only promoted a better muscular co-contraction pattern for lumbar spine stability, but also held the spine in a

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more neutral position. Backward pelvic tilting was found to be a less adequate procedure to protect the spine.

Future prospective studies are needed to determine if conscious activation of the stability muscles of the lumbar spine (until the technique becomes automatic) will significantly reduce the incidence of low back strain and pain during exercise and functional activities.

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References

Adams MA and Hutton WC (1982): Prolapsed intervertebral disc. A hyperflexion injury. *Spine* 7:184-191.

Anderson AB and Champion SHS (1988): Skin preparation for surface EMG. Proceedings of the Bicentennial National APA Conference Canberra, pp. 11-29.

Andersson BJG, Ortengren R, Nachemson A and Elfstrom G (1974): Lumbar disc pressure and myoelectric back activity during sitting. *Scandinavian Journal of Rehabilitation Medicine* 6:104-114.

Cailliet R (1984): Understand your backache: A guide to prevention, treatment and relief. Philadelphia: FA Davis.

Clancy WG (1979): Low back pain in athletes – Symposium.*The American Journal of Sports Medicine* 7:361-369.

Jayson MIV (1983): Compression stresses in the posterior elements and pathological consequences. *Spine* 8:338-339.

Jonsson B (1973): Electromyography of the erector spinae muscle.*Medicine and Sport 8: Biomechanics III.* 294-300.

Kendall FP and McCreary EK (1983): Muscles Testing and Function (3rd ed.) Baltimore: Williams and Wilkins.

Kennedy B (1980): An Australian program for management of back problems. *Physiotherapy* 66:108-111.

Miller MI and Medeiros JM (1987): Recruitment of internal oblique and transversus abdominis muscles during the eccentric phase of the curl-up exercise. *Physical Therapy* 67:1213-1217.

Mooney V (1987): Where is the pain coming from? *Spine* 12:754-759.

Nelson DO (1964): Focus on two fitness exercises.*Journal of Health Physical Education 35*:22-23.

Ng GYF and Richardson CA (1990): The effects of training triceps surae using progressive speed loading. *Physiotherapy Theory and Practice* 6:77-84.

Panjabi M, Abumi K, Duranceau J and Oxland T (1989): Spinal stability and intersegmental muscle forces: A bio-mechanical model. *Spine* 14:194-200.

Pope MH, Andersson GBJ, Broman H, Svensson M and Zetterberg C (1986): Electromyographic studies of the lumbar trunk musculature during the development of axial torques. *Journal of Orthopaedic Research* 4:288-297.

Pope MH, Svensson M, Andersson GBJ, Broman H and Zetterberg C (1987): The role of prerotation of the trunk in axial twisting efforts. *Spine* 12:1041-1045.

Richardson CA and Bullock MI (1986): Changes in muscle activity during fast alternating flexion/ extension movements of the knee. *Scandinavian Journal of Rehabilitation Medicine* 18:51-58.

Richardson C, Toppenberg R and Jull G (1990): An initial evaluation of eight abdominal exercises for their ability to provide stabilisation for the lumbar spine. *Australian Journal of Physiotherapy* 36:6-11.

Sahrmann SA (1987): Muscle imbalances in the orthopaedic and neurologic patient. Proceedings of 10th International Congress of the World Confederation for Physical Therapy. Sydney, pp. 836-841.

Sahrmann SA (1988): Adult posturing. In Kraus SL: TMJ Disorders: Management of the Craniomandibular Complex. New York: Churchill Livingstone, pp. 295-309.

Smidt GL and Blanpied PR (1987): Analysis of strength tests and resistive exercises commonly used for low back disorders. *Spine* 12:1025-1034.

Soderberg GL and Barr JO (1983): Muscular function in chronic low back dysfunction. *Spine* 8:79-85.

Umphred DA (1985): Neurological Rehabilitation. St Louis: CV Mosby Company.

Zetterberg C, Andersson GBJ and Schultz AB (1987): The activity of individual trunk muscles during heavy physical loading. *Spine* 12:1035-1040.