Does 12 weeks of regular standing prevent loss of ankle mobility and bone mineral density in people with recent spinal cord injuries?

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The purpose of this study was to determine the effects of a 12-week standing program on ankle mobility and femur bone mineral density in patients with lower limb paralysis following recent spinal cord injury**.** An assessor-blinded within-subject randomised controlled trial was undertaken. Twenty patients with lower limb paralysis following a recent spinal cord injury were recruited. Subjects stood weight-bearing through one leg on a tilt-table for 30 minutes, three times each week for 12 weeks. By standing on one leg a large dorsiflexion stretch was applied to the ankle and an axial load was applied to the bones of the weight-bearing leg. Ankle mobility and femur bone mineral density of both legs were measured at the beginning and end of the study. Ankle mobility (range of motion) was measured with the application of a 17 Nm dorsiflexion torque. Femur bone mineral density was measured using dual energy X-ray absorptiometry (DEXA). The effect of standing was estimated from the difference between legs in mean change of ankle mobility and femur bone mineral density. The results indicated a mean treatment effect on ankle mobility of 4 degrees (95% CI 2 to 6 degrees) and on femur bone mineral density of 0.005 g/cm^2 (95% CI –0.015 to 0.025 g/cm^2). Tilt-table standing for 30 minutes, three times per week for 12 weeks has a small effect on ankle mobility, and little or no effect on femur bone mineral density. It is unclear whether clinicians and patients would consider such effects to be clinically worthwhile. **[Ben M, Harvey L, Denis S, Glinsky J, Goehl G, Chee S and Herbert RD (2005): Does 12 weeks of regular standing prevent loss of ankle mobility and bone mineral density in people with recent spinal cord injuries? *Australian Journal of Physiotherapy* 51: 251–256]**

Key words: Rehabilitation, Stretch, Ankle, Physiotherapy

Introduction

Contractures are a common and debilitating complication of spinal cord injury. They can prevent some patients from attaining an optimal level of independence (Cooper et al 1993, Grover et al 1996, Harvey and Crosbie 1999), lead to deformities (Alvin and Freehafer 1977, Cheshire and Rowe 1970), and predispose patients to pressure sores and pain (Dalyan et al 1998, Scott and Donovan 1981, Waring and Maynard 1991). Many clinicians believe that interventions involving stretch are an effective way of treating and preventing contractures (Light et al 1984, Moseley 1997, Steffen and Mollinger 1995). Animal studies (Tabary et al 1972, Tardieu et al 1981) and clinical observations support the belief that prolonged stretch produces sustained increases in soft tissue extensibility. However the findings of animal studies and clinical observations have not yet been verified with high quality clinical trials.

A systematic review by Harvey et al (2002) identified 13 randomised controlled trials designed to investigate the lasting effects of stretch. This review concluded that regular stretching produces a small, lasting increase in range of motion. However, all of the studies were on healthy 'normal' subjects, none of the reviewed trials included patients with neurological conditions or pre-existing contracture, and only four of the included trials were of 'moderate' methodological quality. More recently, two randomised controlled trials have examined the effect of 30-minute daily stretches over a four-week period in people with spinal cord injuries. The first assessed the effects of a stretch intervention on ankle mobility (Harvey et al 2000) and the second trial assessed the effect of a similar stretch intervention on hamstring muscle extensibility (Harvey et al 2003). Surprisingly, neither study found a treatment effect (mean treatment effects of 0 degrees, 95% CI –3 to 3 degrees and 1 degree, 95% CI –2 to 5 degrees, respectively) despite adequate statistical precision. It is possible that these studies did not find an effect of stretch because the benefits of stretch are not evident after only four weeks, or because stretch is only effective when applied with more torque. The primary aim of this study was, therefore, to determine the effect of larger stretch torques applied regularly over a 12-week period. A large stretch was applied to the ankle by standing patients on a tilt table with a wedge placed under the foot.

Regular standing in people with spinal cord injuries is advocated, not only for managing contracture, but also as an effective way of preventing osteoporosis (Dunn et al 1998, Goemaere et al 1994, Jaeger et al 1989). Osteoporosis is a common sequelae of spinal cord injury and predisposes these individuals to fractures (Lazo et al 2001, Ott 2001). Studies have reported a 25–50% reduction in bone mineral content in the lower limbs of people with spinal cord injury. Most bone mineral loss occurs in the first year following injury (for a comprehensive review see Ott 2001). The reasons for such extensive bone loss are not completely understood, though bone loss is generally believed to be due primarily to the loss of mechanical stress on bone and related systemic factors (Bauman and Spungen 2000, Giangregorio and Blimkie 2002). Whilst the rationale for standing is strong, only one randomised trial of the effects of standing programs on bone mineral density was found (Caulton et al 2004). This study found an accelerated standing program administered over 6 months increased vertebral volumetric bone mineral density, but not trochanteric volumetric bone mineral density, in children with cerebral palsy (mean effect 0.009 g/cm^3 or 6% of initial values, 95% CI 0.002 to 0.015 g/cm^3. The results of the study by Caulton et el are expressed as a true volumetric measure because, unlike the DEXA technique used in the present study, the methods used in that study provided a real measure of bone volume. It is not clear whether the findings of this single study on children can be applied to adults with recent spinal cord injury. Therefore the second aim of this study was to determine if a 12-week standing program reduces bone mineral loss in people who are wheelchair-dependent and paraplegic or tetraplegic.

Method

Subjects Consecutive admissions to inpatient rehabilitation at two spinal cord injury units in Sydney were screened. To be eligible for inclusion, subjects had to have sustained a spinal cord injury within the past 12 months, have commenced sitting out of bed, and have less than grade 2/5 strength in the lower limbs (the latter criterion meant all subjects were non-ambulant). Subjects were excluded if they had a history of trauma to the pelvis or legs, were unable to tolerate standing, were likely to be discharged from hospital within three months, or were thought unlikely to co-operate.

A within-subjects design was used. That is, for each subject, the intervention was applied to one leg and the contralateral leg acted as a control. The primary outcome measure was ankle mobility. A sample size calculation performed prior to the commencement of the study indicated that a sample of 20 subjects (40 legs) would provide an 80% probability of detecting a 5 degree effect of stretching on passive ankle dorsiflexion range of motion, assuming a standard deviation of 5 degrees, a loss to follow-up of 10%, and alpha of 0.05. For these calculations it was conservatively assumed that outcomes in right and left legs were independent. It was not possible to estimate reliably the sample size required for the bone mineral density aspect of the study because of the paucity of available data describing variability in the treatment effect. However, prior to the study it was specified that the standing program would need to reduce the loss of total proximal femur bone mineral density in the experimental legs by 20% of the loss in the control legs for the treatment to be deemed clinically worthwhile. This decision was somewhat arbitrary but based on expert advice from a senior medical clinician after taking into account the cost and inconvenience associated with administering the standing program. The study received ethical approval from the appropriate institutions and informed consent was obtained from all subjects.

Outcomes *Ankle mobility* Mobility of both ankles was determined by measuring passive ankle dorsiflexion with the application of a standardised torque. Measurements were performed with a device specifically designed for this purpose (Harvey et al 2003). Briefly, the device consisted of a wheel (radius = 0.15 m) mounted on the side of a footplate with its centre aligned with the centre of rotation of the footplate. The ankle joint was aligned with the centre of both the wheel and footplate. The foot, wheel, and footplate all rotated about the same axis. A 17 Nm ankle dorsiflexion torque was applied by hanging an 11 kg mass from the rim of the wheel. The angle of the footplate in relation to the horizontal position was measured with a digital inclinometer.

Figure 1. All subjects stood weight bearing through one leg on a tilt table. A block and wedge was placed under the experimental leg to ensure a stretch was applied to the experimental ankle and all weight was borne through this leg alone. The control leg was not supported.

Testing always followed the same format. Subjects lay supine on the bed with the knee positioned in extension and the ankle firmly secured in the footplate of the device. The right leg was tested before the left leg. Two measurements were taken on each leg after a 3-minute pre-stretch. In this way reflex activity around the ankle and the knee, if present, was minimised and most viscous deformation exhausted (Bohannon 1984, Magnusson et al 1995). The stretch was removed between the first and the second measurements. The procedure has been shown to have high test-retest reliability (intra-class correlation coefficient 0.95, CI 0.91 to 0.98; Harvey et al 2003).

Bone mineral density Total bone mineral density of both proximal femurs was measured using dual energy X-ray absorptiometry[a] (DEXA). The same licensed nuclear medicine technician performed all tests on the same machine. The machine was calibrated on a daily basis. Subjects were

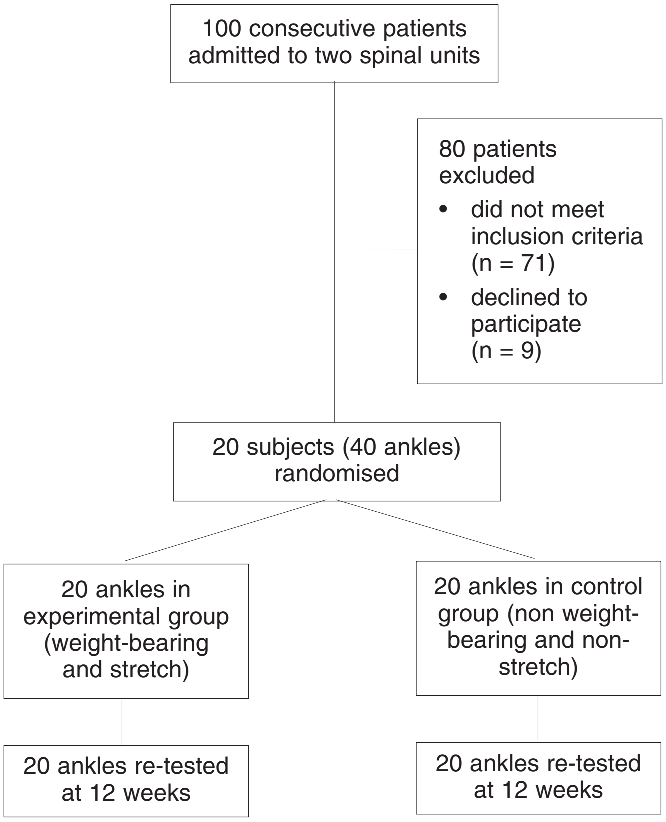

Figure 2. Flow of subjects through the study.

tested using a standardised technique recommended by the manufacturer.

Experimental protocol After completion of initial measurements, one leg was randomly allocated to the experimental (weight-bearing and stretch) condition and the other to the control (non weight-bearing and non-stretch) condition. A computer-generated random allocation schedule was determined prior to the study by one of the authors who was not otherwise involved in group allocation. To ensure concealment, the allocations were placed in sealed, opaque, sequentially numbered envelopes. The envelopes were not opened until after the initial tests had been performed. Subjects were considered to have entered the trial at this stage.

Subjects stood on a tilt table (one subject stood with a standing frame) for 30 minutes, three times per week for 12 weeks. A wedge inclined 15 degrees was placed on a high block and both were positioned under the experimental foot (weight-bearing and stretch), ensuring that a dorsiflexion torque was applied to the ankle and body weight was borne solely through this leg. In contrast, nothing was placed under the control foot (non weight-bearing and non-stretch). That is, the control foot was left in an unsupported plantarflexed position with no body weight borne through it (see Figure 1).

Subjects were encouraged to stand with the tilt table in the vertical position, however if this was not tolerated the tilt was decreased slightly, as is standard clinical practice. Subjects were not blinded, but paralysis of their legs provided them with limited opportunity to bias results inadvertently. Subjects were asked not to participate in any other weight-bearing or ankle stretch activities for the duration of the study. In addition, physiotherapists ceased all other standing, ankle stretches, and lower limb passive movements for the duration of the study.

All standing was supervised by a physiotherapist, except in one subject who stood with a standing frame unsupervised at home. He was provided with a standing diary, and his compliance was monitored by one of the investigators on a weekly basis. This subject claims not to have missed any standing sessions.

Ankle mobility was re-tested one day after completion of the 12-week treatment period. Measurements were taken at least 24 hours after the last stand by an independent physiotherapist who was blinded to allocation. Bone mineral density of the proximal femur was measured within two days of the last stand by an independent technician who was also blinded to allocation.

Data analysis Mean changes from initial to final measures were calculated for both experimental (weight-bearing and stretch) and control (non weight-bearing and non-stretch) ankles. The t-distribution was used to estimate 95% confidence intervals for between-leg differences in change. Data were analysed by intention-to-treat (Pocock 1983). One non-compliant subject's data were included in all analyses in accordance with the principles of 'intention-to-treat' and all reported results include this subject's data. However the analyses were repeated without the non-compliant subject's data. Inclusion or exclusion of this subject's data made no difference to the findings of the study.

Results

The flow of patients through the trial is given in Figure 2. One hundred patients with a recent spinal cord injury were admitted to the two spinal units over the duration of the study. Of these, 71 patients did not meet the inclusion criteria and nine declined to be involved. In total, 20 subjects participated in the study, eight with paraplegia and 12 with tetraplegia. Eighteen subjects had upper motor neuron lesions with varying amounts of spasticity. The other two subjects had lower motor neuron lesions with flaccid paralysis. The mean (SD) time since injury was 4 (2) months. The mean (SD) age, height, and weight of subjects were 34 (15) years, 173 (9) cm and 71 (15) kg, respectively. Four subjects were female and 16 were male.

The study protocol dictated that subjects stand on 36 occasions over a 12-week period. However, seven subjects received an additional one to three interventions in order to ensure that they continued standing until it was possible to test them. In addition, eight subjects were unable to receive the required number of interventions within the set time period due to factors such as illness, prolonged leave from the unit, or poor compliance. One subject was non-compliant and ceased standing after two weeks. Thus, in practice, subjects stood a mean (SD) of 34 (7) times over a mean of 12 (3) weeks. All subjects, including the non-compliant subject, were tested at the end of the 12-week stand period.

At baseline, ankle mobility and total proximal femur bone mineral density measurements were similar for the control and experimental legs (Table 1). There was large variability

Table 1. Mean (SD) pre- and post- ankle mobility (degrees) and total proximal femur bone mineral density for control and experimental legs. Total proximal femur bone mineral density is expressed as g/cm², percentage change from initial, and % change in relation to loss in control legs. The mean (95% CI) overall effects are also provided.

	Pre		Post		Overall treatment effect
	Control legs	Experimental legs	Control legs	Experimental legs	Mean (95% CI)
Ankle mobility (degrees)	17 (10)	17 (9)	12 (10)	14 (12)	4 (2 to 6)
Total proximal femur bone mineral density (g/cm²)	0.909 (0.158)	0.913 (0.140)	0.848 (0.142)	0.857 (0.131)	0.005 (–0.015 to 0.025)
Total proximal femur bone mineral density (% initial)	–	–	93.4 (4.4)	94.0 (6.1)	0.5 (–1.8 to 2.9)
Total proximal femur bone mineral density (% loss of control legs)	–	–	–	–	9.2 (–28.8 to 47.1)

across subjects in both ankle mobility and total proximal femur bone mineral density. Dorsiflexion of the control ankle with the application of 17 Nm torque ranged from 3 to 40 degrees (mean 17 degrees). Thus, some patients (n = 8) had contracture or inflexible ankles, whilst others (n = 12) did not (Moseley 2001). Total bone mineral density of the proximal femur also varied between subjects at baseline. Bone mineral density of the control legs ranged from 0.558 to 1.221 g/cm^2 (mean 0.909 g/cm^2, SD 0.158). One subject had osteoporosis and seven subjects had osteopenia at baseline (Genant et al 1994).

Figure 3 shows the change in mobility of experimental and control ankles over the course of the study. The mobility of the control ankle decreased by a mean (SD) of 5 (3) degrees over the 12-week period. The mobility of the experimental ankle also decreased, by a mean (SD) of 1 (5) degree. Hence, the mean effect of the stretching on ankle mobility was 4 degrees (95% CI 2 to 6 degrees).

Figure 4 shows the change in total proximal femur bone mineral density for the experimental and the control legs over the 12-week period. There was a mean (SD) loss in total proximal femur bone mineral density of 0.061 (0.045) g/cm^2, or 6.6% (4.4%) of initial density in the control legs, and there was a loss of 0.056 (0.052) g/cm^2, or 6.0% (6.1%) in the experimental legs. The effect of standing was, therefore, to reduce bone loss by 0.005 g/cm^2 (95% CI –0.015 to 0.026 g/cm^2), or 0.5% (95% CI –1.8% to 2.9%) of initial values. We decided, *a priori*, that the treatment must have an overall treatment effect of 20% *of the loss in bone mineral density of the control legs* (0.012 g/cm^2) to be considered effective. The overall treatment effect expressed as a percentage of the loss in the control leg was 9.2% (95% CI –28.8% to 47.1%). Thus,

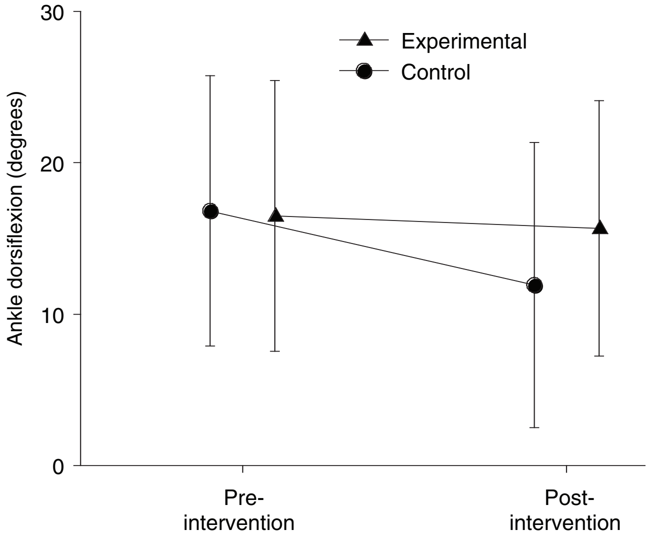

Figure 3. Mean (SD) ankle mobility (degrees) of the experimental and control legs at the beginning and end of the study. An increase in ankle angle reflects an increase in ankle mobility.

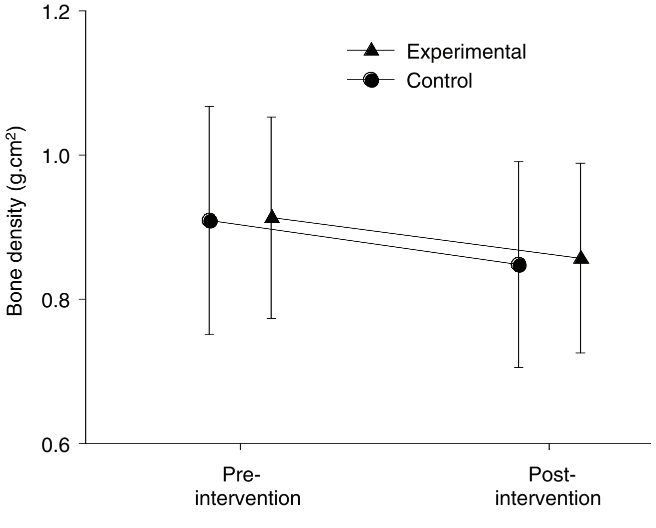

Figure 4. Mean (SD) proximal femur bone mineral density (g/cm^2) of the experimental and control legs at the beginning and end of the study.

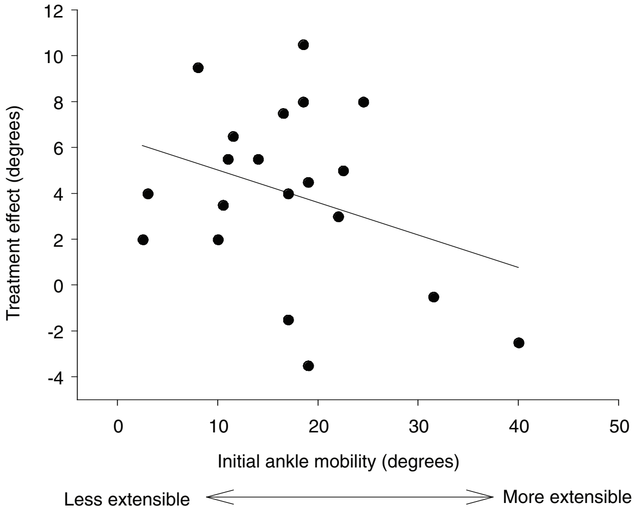

Figure 5. Mean (SD) treatment effect of the standing program on ankle mobility (difference between experimental an control legs) as a function of the initial ankle mobility of control ankle.

the estimated mean treatment effect on total proximal femur bone mineral density was less than specified as clinically worthwhile, but this estimate was associated with considerable uncertainty.

Discussion

The primary aim of this study was to determine whether regular standing, as typically applied by clinicians, is effective for treating and preventing contracture in patients with recent spinal cord injuries. The results indicate that regular standing produces a mean beneficial effect on ankle mobility of 4 degrees (95% CI 2 to 6 degrees). It is unclear whether clinicians and patients would consider such a small treatment effect as clinically worthwhile. Such decisions need to take into account patients' and physiotherapists' perceptions of the inconvenience, discomfort, and cost associated with providing a standing program. Further research is also required to ascertain the benefits of regular standing on other factors such as bladder/bowel function, spasticity, and general well-being (Dunn et al 1998, Eng et al 2001, Kunkel et al 1993).

The failure to detect a larger treatment effect on ankle mobility is consistent with the results of two recent and similar clinical trials (Harvey et al 2000, Harvey et al 2003). These studies were designed to investigate the effects of a four-week stretch program on ankle mobility and hamstring extensibility. The current study was designed to test the hypothesis that longer periods of stretch (12 weeks rather than 4 weeks) and larger stretch torques (as can be applied by standing on one leg) are required to induce changes in soft tissue extensibility. However, stretch applied under these conditions still failed to demonstrate a clear beneficial effect. Of course it is possible that the stretch torques applied in this study were still too low. However, standing one-legged on a tilt table with a wedge under the foot is generally considered an aggressive stretch treatment and physiotherapists would have good reason to be concerned about applying larger stretch torques.

In this study subjects stood for 30 minutes three times a week for 12 weeks. This is a typical standing program for a person with spinal cord injury. It is possible that patients need to stand for longer than 30 minutes and that the benefits of standing on ankle mobility are not evident within 12 weeks. Figure 3 suggests a tendency for ankle mobility to decrease over the 12-week period with a small preventative effect from standing. If this trend continued, the effects of standing would become more evident with time. However, standing programs are labour-intensive and it is generally difficult to sustain standing programs indefinitely. Regardless of these considerations our findings remain: physiotherapists and patients cannot expect to see large treatment effects from stretch interventions administered for just three months.

Subjects with varying ankle mobility were included in this study because many clinicians believe that regular stretch is effective for the treatment and prevention of contractures. In this way, the study mimicked clinical practice. It is possible that stretch administered over three months is more effective for treating contractures than for preventing them. However, a post-hoc analysis failed to detect any systematic difference (p = 0.16) in the response of the less mobile ankles to the stretch intervention than the more mobile ankles (regression coefficient = –0.14, 95% CI = –0.35 to 0.06; see Figure 5).

The secondary aim of this study was to determine the effects of regular standing on total bone mineral density of the femur. The control legs lost an average of 7% of proximal femur bone mineral density over the 12-week period, whilst the experimental legs lost 6%. This is consistent with the results of previous studies that have reported high rates of between 25% and 50% (Ott 2001) of bone mineral density loss in the first year following spinal cord injury. There are various systemic and mechanical explanations for this bone mineral density loss, though it is generally assumed that cessation of axial loading is the most likely cause. For this reason, it is believed that regular standing will prevent bone mineral density loss and should be a routine part of these patients' therapy. However, it remains unclear whether the short periods of standing, as routinely prescribed by physiotherapists, provide a sufficient mechanical stimulus to prevent bone mineral density loss. Nor is it clear whether bone mineral density loss is best prevented by standing (static loading) or with some type of cyclic loading. The results from this study suggest a beneficial mean treatment effect, albeit a small one (0.005 g/cm^2), from the standing protocol. However, there remains considerable uncertainty around this estimate (95% CI –0.015 to 0.025 g/cm^2) and it is not clear from this study that the 12-week standing protocol increases bone mineral density of the femur. Future studies need to explore the possible beneficial effects of a longer and more intensive standing program (i.e., more than 30 minutes per week applied over more than 12 weeks) in a larger sample.

This study provides no support for the practice of regular standing of patients with lower limb paralysis following spinal cord injury. Physiotherapists should not expect to see benefits on ankle mobility or femur bone mineral density from three months of regular standing. Further work is required to determine the beneficial effects of standing over many years.

Footnote [a]Hologic QDR 4000, Hologic Inc., Bedford, MA USA.

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The effect of weightbearing exercise with low frequency, whole body vibration on lumbosacral proprioception: A pilot study on normal subjects

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Patients with low back pain (LBP) often present with impaired proprioception of the lumbopelvic region. For this reason, proprioception training usually forms part of the rehabilitation protocols. New exercise equipment that produces whole body, low frequency vibration (WBV) has been developed to improve muscle function, and reportedly improves proprioception. The aim of this pilot study was to investigate whether weightbearing exercise given in conjunction with WBV would affect lumbosacral position sense in healthy individuals. For this purpose, twenty-five young individuals with no LBP were assigned randomly to an experimental or control group. The experimental group received WBV for five minutes while holding a static, semi-squat position. The control group adopted the same weightbearing position for equal time but received no vibration. A two-dimensional motion analysis system measured the repositioning accuracy of pelvic tilting in standing. The experimental (WBV) group demonstrated a significant improvement in repositioning accuracy over time (mean 0.78 degrees) representing 39% improvement. It was concluded that WBV may induce improvements in lumbosacral repositioning accuracy when combined with a weightbearing exercise. Future studies with WBV should focus on evaluating its effects with different types of exercise, the exercise time needed for optimal outcomes, and the effects on proprioception deficits in LBP patients. **[Fontana TL, Richardson CA and Stanton WR (2005): The effect of weightbearing exercise with low frequency, whole body vibration on lumbosacral proprioception: A pilot study on normal subjects. *Australian Journal of Physiotherapy* 51: 259–263]**

Key words: Lumbosacral spine, Proprioception, Whole body vibration, 2-D motion analysis, Rehabilitation, Low back pain

Introduction

In Western countries, low back pain (LBP) constitutes a major health care problem. Those who incur the majority of the cost, both personally and financially, are the ones who suffer recurrent chronic pain. Patients with low back pain are known to have altered motor control (dysfunction) in the lumbopelvic region (see Hodges 2004 for a review) and, as various methods of measuring proprioception in the region are devised, evidence is emerging that proprioception is also impaired (Brumagne et al 2000, Brumagne et al 2004, Leinonen et al 2003, Mok et al 2004, Parkhurst and Burnett 1994, O'Sullivan et al 2003). A loss of proprioception would contribute to neuromuscular dysfunction and likely poor segmental stability in low back pain patients, which may lead to an increase in the risk of injury or further injury (Brumagne et al 1999b). Therefore, to treat patients with LBP effectively, proprioception training is usually considered to be an important element of the rehabilitation exercise program.

The challenge for physiotherapists and other health care professionals is to choose the best exercise method to retrain proprioception efficiently in patients with LBP. One approach used extensively in retraining proprioception following injury to an ankle joint is weightbearing exercising on balance boards (Sheth et al 1997). Importantly, this approach improved muscle strength and proprioception not only in the ankle but in other joints including the knee, hip, and lower spine (Burton 1986). Therefore, balance boards and uneven surfaces, used in conjunction with exercise techniques, have been used for treatment of LBP patients (Richardson et al 2004).

Technological advancement has led to the development of a new form of moving exercise surface, which uses mechanical vibration, and is known as low frequency, whole body vibration (WBV). The exercise platform, which vibrates between 1 and 50 Hz, was originally developed by biomechanical engineers in Europe for use in the space program to prevent bone density changes in astronauts. More recently it has evolved into an exercise device with specific exercise performed on the vibrating platform, depending on the outcome required. Exercise programs incorporating WBV are currently being tested in the areas of sports, geriatrics, and rehabilitation (Bosco et al 1999, Rittweger et al 2002).

The beneficial effects of WBV on muscle function have been, to a large extent, deduced through research on single muscles. Most researchers suggest that vibration can improve strength, power, and flexibility of muscles (Issurin and Tenenbaum 1999), but concur that these changes are likely to be the result of vibration on the proprioceptive receptors in the muscles. Neurophysiological research in this area has focussed on the effect of hand held vibration devices on muscle spindle activity in a specific muscle. The research of Ribot-Ciscar et al (1998, 2002, 2003a, 2003b) has provided information on the way tendon vibration excites primary endings of the