The Training of Older Patients to Improve Balance

by

David De Camillis, D.C., D.A.C.R.B., F.C.C.R.S.(c), Dip. MDT

Robin Carr, Ph.D. (Kinesiology)

Contact for publication, requests for reprints, etc.:

David De Camillis, D.C. (Doctor of Chiropractic)

Suite 403 – 555 Sixth Street, New Westminster, B.C., V3L 5H1

(604) 522-5225

Ethical Standards:

Procedures followed in this study were in accordance with the Helsinki Declaration of 1975.

Statistical Evaluation:

Performed by Robin Carr, Ph.D., Langara College, Vancouver, B.C.

Abstract

The risk of accidental falls among elderly people is substantial, particularly among those who are within certain high-risk categories (e.g. reduced proprioception, muscle imbalances, and slow muscular response time). Early diagnosis of these individuals may provide opportunities for preventive measures within the chiropractic paradigm. This report outlines one approach to the assessment and management of these patients, emphasizing an attempted reduction in some of the risk factors. Assessment included the measurement of postural sway on a 'centre of pressure locator.' The treatment approach involved end-range spinal loading strategies. Results on the four subjects were promising. This was a pilot study with intent to provide information that could form the framework for a more comprehensive research project; therefore, the report includes an extensive literature review.

Introduction

Loss of balance and subsequent falls occur frequently among older people.[1-24] While the causes appear complex and multi-faceted, early detection of those with high risk factors may provide opportunities for preventive measures within the chiropractic paradigm. This report outlines a pilot study for potential assessment and management of these patients.

Review of the Literature

<u>Falls, Balance and Sway:</u>

About 30% of the population aged 65 and older who are living at home fall each year[24] and nearly one-half of all nursing home residents fall every year.[7, 25] Once an individual falls, there is a 60 - 70% chance that a subsequent fall will occur within the next six months.[15] Approximately 15% of falls result in physical injury serious enough to warrant medical attention,[26] and about 5 to 10% of falls yield serious injuries with potentially grave sequelae, including head trauma and bone fractures. The most serious fractures are generally those to the hip.[27]

Falls have many causes, [27,28] which can be roughly grouped into environmental factors, neurological diseases, and other acute illnesses.[29] Many studies have assessed risk factors for falls among the elderly.[27-43] Among those that have been suggested are decrements in balance,[44-54] psychoactive drug use,[55-61] evidence of stroke or brain injury,[62-65] and cardiovascular abnormalities.[66-67] Also implicated are Parkinsonism, blindness, drug-related hypotension, arthritis, a number of chronic disabilities, and social/psychological factors.[30,31,38,40,68-71] Tideiksaar[27] suggests the following classes of risk factors for falls: poor vision, cardiovascular problems, lower extremity dysfunction, gait and balance disorders, bladder dysfunction, cognitive dysfunction, and medications.

The risk of falls appears to be greater among women, the cognitively impaired, those who use hypnotics, tranquilizers, and diuretics[70] and those with poor physical fitness.[31, 72] Risk factors that are potentially most relevant to the chiropractor include slowed motor responses, weakness of structural support, musculoskeletal limitations and deconditioning.[31,40,73-77] Some investigators developed assessment tools to evaluate human balance performance, and attempted to detect differences between normal young and healthy older adults[49,78,79], active and inactive older adults[80] and frequent fallers and non-fallers.[45,81-83]

Falls occur when balance equilibrium is perturbed and upright posture is no longer maintained. Technically, a fall occurs when the body's centre of mass passes outside its base of support. At this point, only an external force or a change in the base of support can prevent the fall from occurring. The risk of loss of balance thus increases as the centre of mass moves towards the edge of the base of support, as occurs to varying degrees during standing postural sway. Sway is a measure of the corrective mechanisms associated with the maintenance of an upright position.[84-92]

Biomechanics force platforms provide a simple and reliable observer-independent method to assess sway, as they measure the movement of the centre of gravity (COG) in a horizontal plane. Technically, they indicate the centre of pressure (COP) acting through the feet, which reflects not only the ground reaction force necessary to oppose gravity, but also the moments of force that are produced to maintain standing posture. Although the COP is only identical to the vertical line from the COG when there is no sway, over the period of a testing trial the mean COP should be a good representation of the mean COG. (For a more complete discussion of this, see Winter[93] and Shimba[94]). Especially in quiet standing positions, the movement of the COP approximates the movement of the centre of gravity in that horizontal plane.[95]

It is generally accepted that smaller values of sway are indicative of better balance.[57] The increased amount of sway seen in the elderly [96-100] has been attributed to either biomechanical or central processing changes rather than diminished sensory or vestibular input.[54] In older people, increased sway has been associated with an increased risk of falling.[14, 66,74,83] (For example, Kirshen et al.[66] showed a clear increase in sway among men with a history of falls as compared with those who had no such history, while Lord et al. [83] showed greater lateral sway among older fallers.) Increased sway has been correlated with clinically validated measures of fall risk[53, 101] and has even been shown to be predictive of fall incidents among ambulatory subjects[11] and nursing home residents.[52] The amplitude of postural sway seems to be correlated with other kinematic measures and functional tests.[46, 64] Antero-posterior sway tends to increase with age, and sway amplitude increases with challenges to vision and proprioception.[102]

The force platforms used to measure sway are relatively simple to use, do not interfere with movement, and are not unpleasant or unsafe for subjects. They are quite expensive however, and usually have to be embedded in concrete. For these reasons, they are generally found only in universities, hospitals, or other large institutions of research.

However, the assessment of body COG position (actually COP) and sway appear to have potentially important clinical applications in various health professions, in which the use of the criterion force platforms may not always be possible. As a result, many force-plate type systems for evaluating balance and sway have now become commercially available. Roland et al.[92] reported on the use of a relatively simple and economical load-sensitive platform (the SwayWeigh) to measure lateral body sway in order to assess balance dysfunction. With it, the percentage of a patient's total weight that was borne on the right foot enabled measurement of left-right weight distribution and lateral movement of the centre of gravity. Weerdt et al.[65] had employed a similar platform to measure the rehabilitation of physiotherapy patients after cerebrovascular accidents. (In this study, measurements of postural sway were made using a centre of pressure locator (COPL) in lieu of a force platform - see details below).

Along with postural sway, Tideiksaar[27] indicated that lower extremity dysfunction is another risk factor for falls. With aging, most people tend to exercise less, the result being that tight muscles become tighter and inhibited ones become weaker.[103] Afferent-efferent neuropathways used for proprioceptive balance and reactions are used less,[104] as are central integrating processes.

Lack of exercise may also lead to discal creep, a progressive deformation of the discs under constant load [105,106]. The sagittal disc wedging in turn leads to an increase of the kyphotic curve of the thoracic spine and a decrease in the lordotic curves of the lumbar and lower cervical spine. For some older people, degradation occurs to the point where even simple standing and walking activities can pose a threat to safety.

Rehabilitation of patients with these risk factors for falling should be both specific and time efficient. Treatment should be directed at re-balancing length and strength of the musculature. Hypertonic lower limb muscles should be lengthened, and inhibited muscle groups should be facilitated. Sensory-motor exercises that challenge the balance system should be emphasized. Spinal end range loading strategies should be used to reshape discs. After several weeks of treatment and supervision, many of these patients should be able to continue on a self-management basis.

Spinal End Range Loading Strategies:

Many elderly people have rounded shoulders and a forward head posture. Multi-segmental muscle length (from origin to insertion) is changed.[107] It has been shown that the forward displacement of the cranium creates a greater vertical force on the lower cervical and upper thoracic spine.[108] The upper thoracic spine has an exaggerated kyphosis, and both thoracic and lumbar spines have a limited range of extension. The normal ratios among flexion, extension and rotation are changed.[109] The instantaneous axes of rotation of these vertebral segments are distorted and therefore become a source of nociception. For example, joint mechano-receptors become attenuated to abnormal positions, giving the person a feeling of normalcy. Kinetic chains and agonist, synergist and antagonist muscle actions change. Faulty movement patterns result.[110] Events like this may cause one's balance to be worsened.

The McKenzie approach[111-113] postulates that there is an ideal posture that people should be able to attain, and that the capacity to maintain this ideal posture can be lost through a lack of self-awareness. Sedentary lifestyles frequently produce prolonged postures in spinal flexed positions. Discal creep occurs and eventually an internal disc disruption takes place.[114,115,]

[116] At this point, tissue damage and inflammation may occur, producing scarring and possibly contractures within the more elastic host tissue (annular fibers). This internal disc derangement may be a source of nociception as pain and disturbed intersegmental movement.[117] It may also be a source of autonomic afferent stimulation [118,119] from the disc to balance centres in the CNS. These afferent fibers would probably exist as free nerve endings and their stimulation alone may affect the higher centres.[118,119,120,121]

The McKenzie approach promotes restoration of good posture, improvement of the morphology of the discs and an increase in the intersegmental spinal movement that may previously have been restricted due to the discs. By loading the discs at end range in the restricted movement plane, their internal architecture can be changed or reduced to a more normal arrangement. This reduction results in an increase of motion in the restricted plane, a decrease in pain and possibly a change in postural sway. These loading strategies may be effective after one application, or in the case of scar tissue involvement they may require up to six weeks.

Methods

Patients:

Subjects consisted of one male and three females: patient M (female, 77 years); patient N (female, 82 years), patient O (female, 80 years); and patient R (male, 70 years).

Patient N had both hips replaced. Patient R had his forefoot amputated in 1997 due to atherosclerosis, and had poor vision and a lack of depth perception that were also due to this condition.

Assessments

Dependent variables included the following:

1. EAM-T Distance

   This is the horizontal distance between the external auditory meatus and the apex of the thoracic curve with the subject standing comfortably and relaxed.

2. Extension

   This was the range of motion available in the thoracic and lumbar spines during extension.

3. Postural Sway

   This was measured on a 'centre of pressure locator' (COPL) that had previously been found to be precise and reliable in measuring postural sway[122], with twelve trials spread equally over two days (am and pm), for both the pre-test and post-test measurements.

Treatment

After the two days of pre-testing, the subjects were treated over a three to four week period. All four subjects were treated the same way for this study, using only spinal loading strategies.

McKenzie treatment protocols included those for posterior derangement and extension dysfunction of the lower cervical, thoracic and lumbar spines.[111] This included repeated, loaded end range extension of these areas as well as traction and retraction of the cervical spine.[112] Education and home exercises were also included.[113]

At the conclusion of the treatment period, two days of post-testing occurred following to the format of the pre-tests.

Analysis:

Postural sway results were analyzed using a one-way repeated measures analysis of variance (ANOVA), with alpha set at 0.05.

Results

The results for each individual are presented separately, since each patient was unique and may have responded to the treatment differently from the others. Also, the small number of subjects and lack of random sampling negate the external validity of any group findings.

The repeated measurements of postural sway on the COGL (12 on the pre-test and 12 on the post-test) allow for significance testing of the changes for each individual. One-tailed T-tests for repeated measures were used to assess significance with a 0.05 alpha level.

Patient M (Treatments: April 30, May 3, 5, 10, 13, 19, 26, 28.)

Patient M (female, 77 years) was somewhat inconsistent in showing up for her treatments, but she did report subjectively assessed improvements in her balance. This was objectively supported by the data, which describe significant reductions in both A-P and L-R sway, shown in figures 1 and 2 below. Since Patient M's sway was quite large on the pre-tests, it could be argued that there was more room for improvement in her test results.

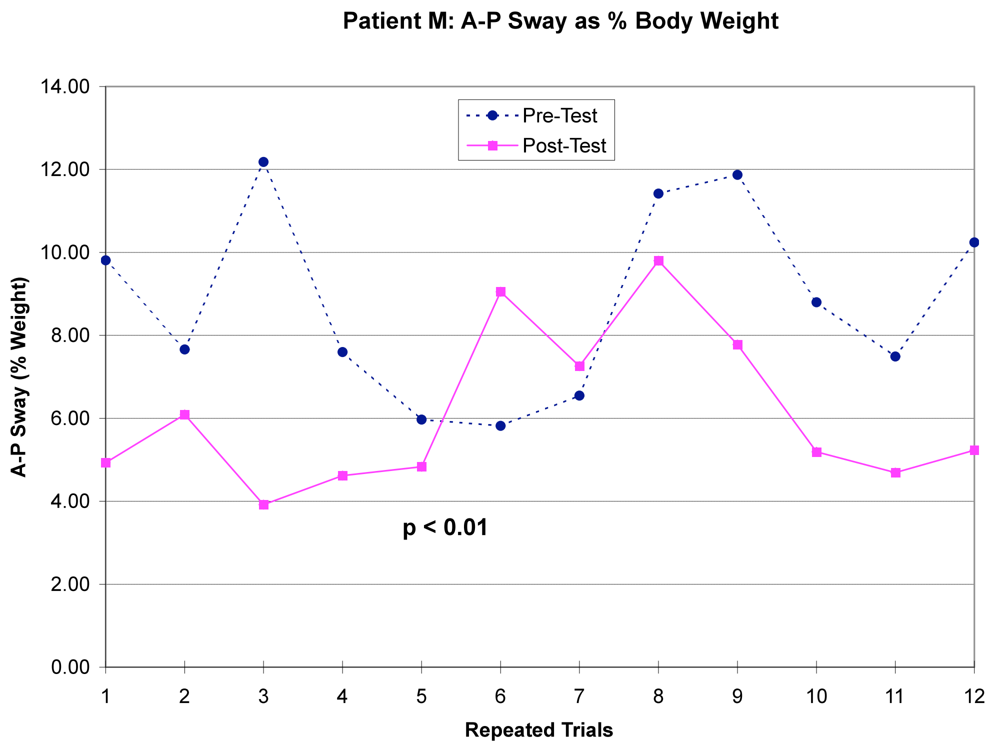

Figure 1: Patient M shows significant ($p < 0.01$) reduction in A-P sway.

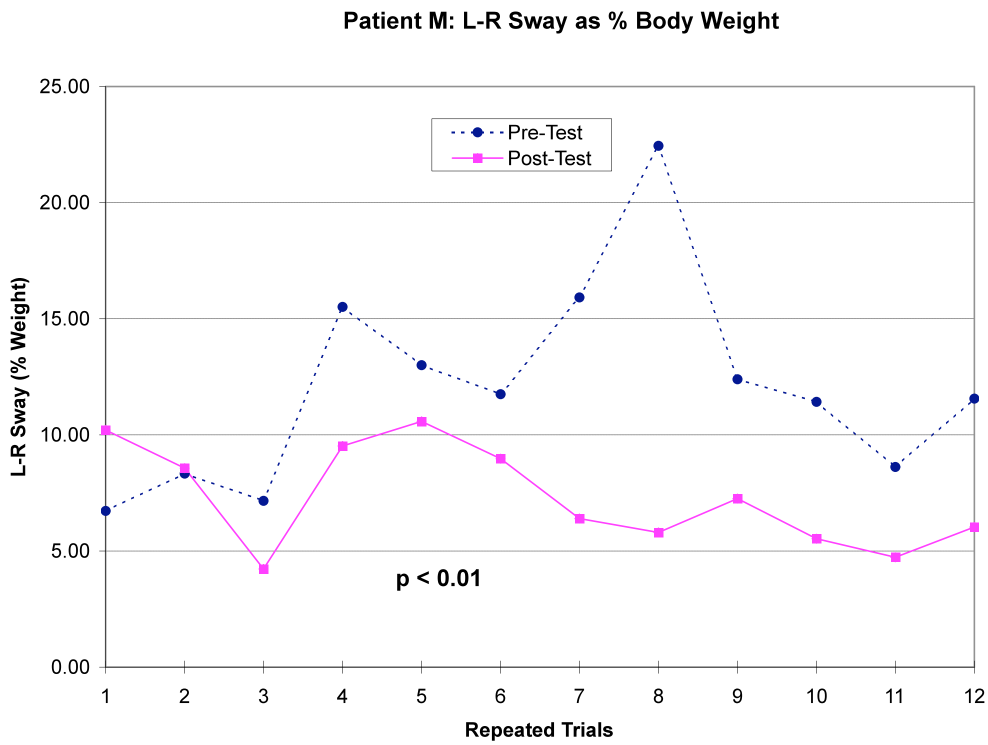

Figure 2: Patient M shows significant ($p < 0.01$) reduction in L-R sway.

Patient M	Pre-Test	Post-Test
EAM-T distance	8.25	7.00
Thoracic extension	17	15
Lumbar extension	15	20

Table 1: Summary of other results for Patient M. The EAM-T distance was reduced on the post-test, and there was a slight increase observed in lumbar extension.

Patient N (Treatments: April 28, 29, May 1, 3, 5, 8, 11, 13, 17, 20, 25, 26.)

Patient N (female, 82 years) complained after her ninth session that her left hip had become quire stiff and sore. At that time she walked with a "duck waddling" motion characteristic of a capsular pattern.

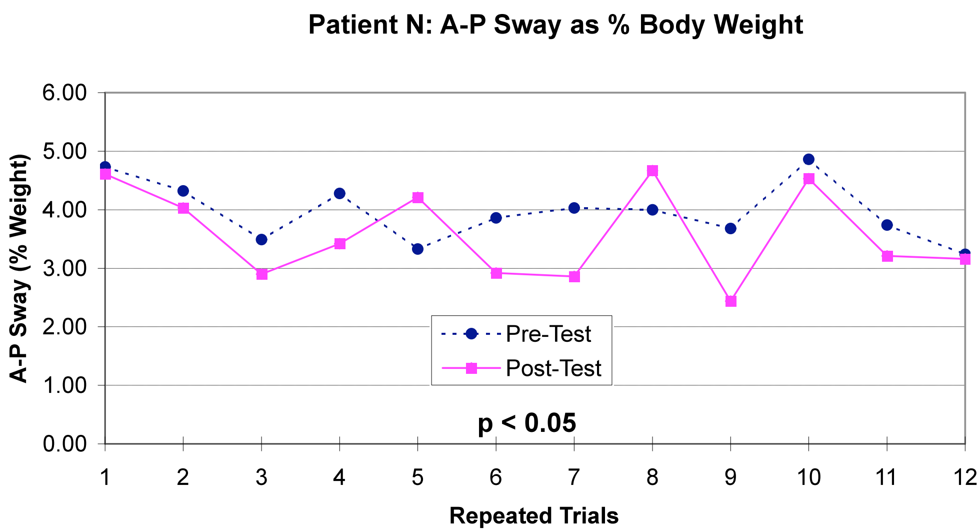

Figure 3: Patient N shows significant ($p < 0.05$) reduction in A-P sway.

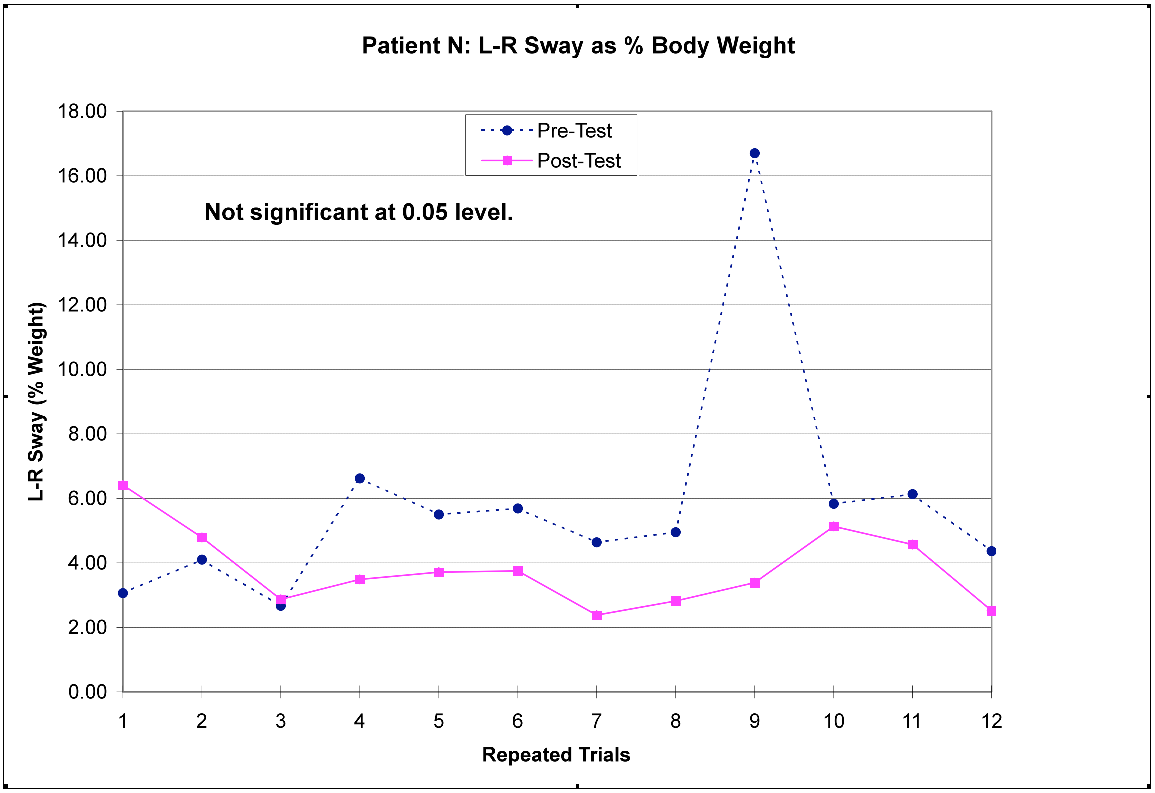

Figure 4: Patient N shows non-significant ($p > 0.05$) reduction in L-R sway. (Note: If the 9th trial in the pre-test is dismissed as an outlier due to an extreme movement or momentary loss of equilibrium, the difference between pre- and post-test results becomes significant at the 0.05 level.)

Patient N	Pre-Test	Post-Test
EAM-T distance	5.25	5.75
Thoracic extension	6	25
Lumbar extension	7	15

Table 2: Summary of other results for Patient N.

<u>Patient O</u> (Treatments: April 28, 30, May 3, 5, 7, 11, 14, 19, 26.)

Patient O (female, 80 years) was the spryest of the group, but in the final stages of testing she came down with an acute case of diverticulitis. Despite this, marked reductions were shown in her sway.

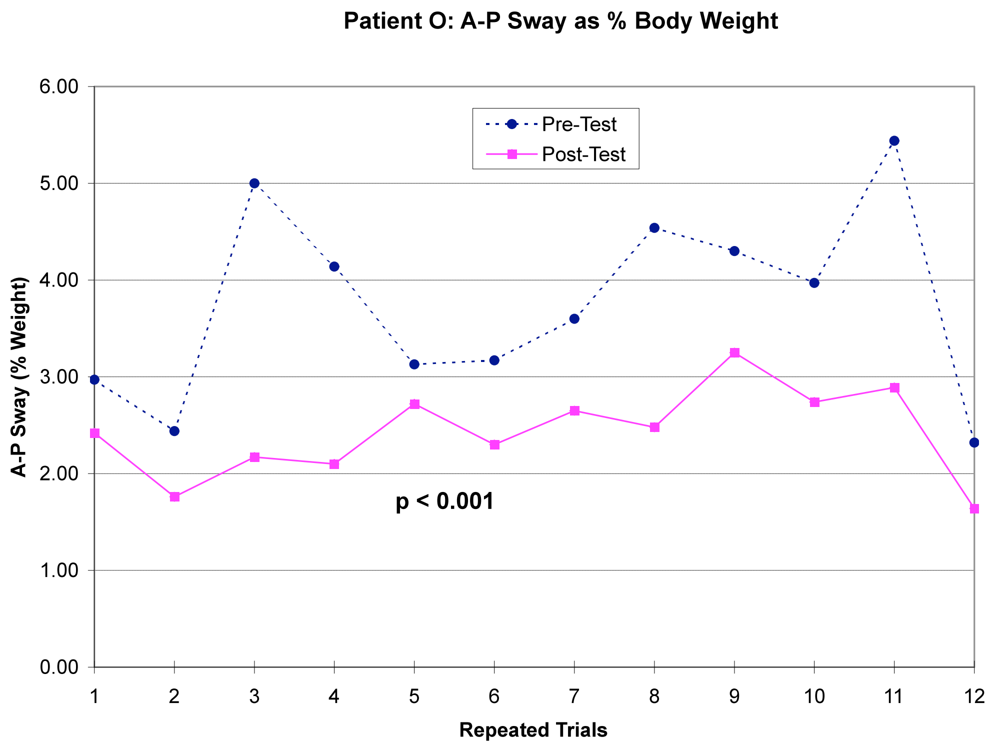

Figure 5: Patient O shows significant ($p < 0.001$) reduction in A-P sway.

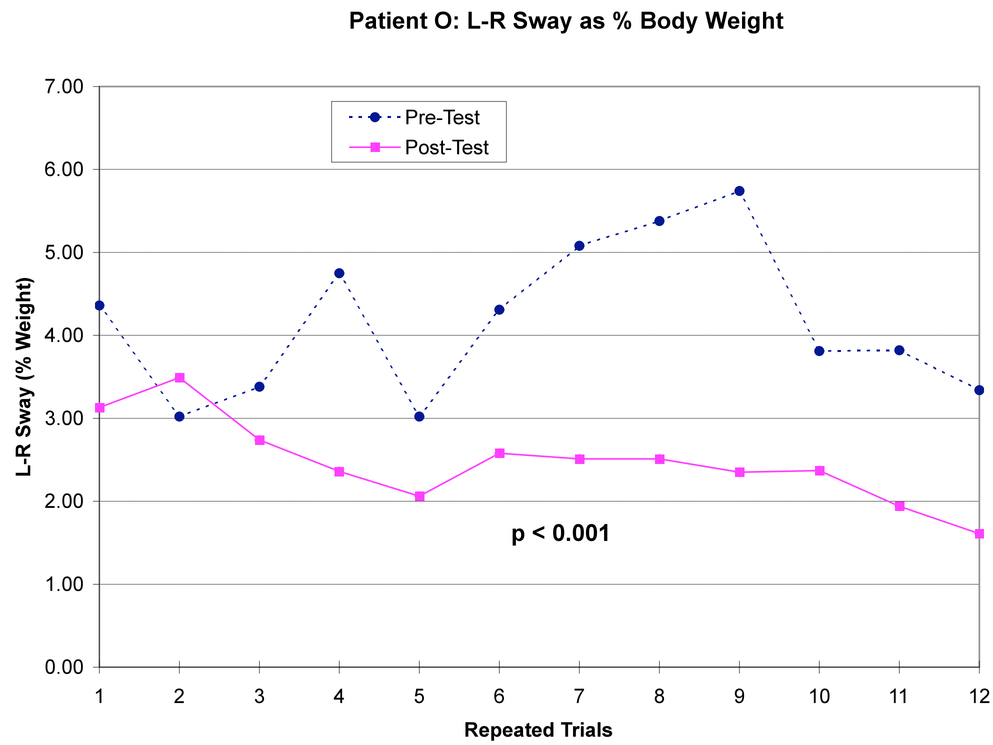

Figure 6: Patient O shows significant ($p < 0.001$) reduction in L-R sway.

Patient O	Pre-Test	Post-Test
EAM-T distance	5.00	4.00
Thoracic extension	21	15
Lumbar extension	10	18

Table 3: Summary of other results for Patient O.

Patient R (Treatments: April 30, May 5, 7, 10.)

Patient R (male, 70 years), who had his right foot amputated and who complained of poor vision and a lack of depth perception, said he was doing really well until several hours after the fifth session. Upon bending down to tie his shoelace his vision deteriorated almost instantly. Although his vision did recover over the next few days, he was then stricken with a bad flu. He only completed four treatment sessions and three of the post-test sway sessions.

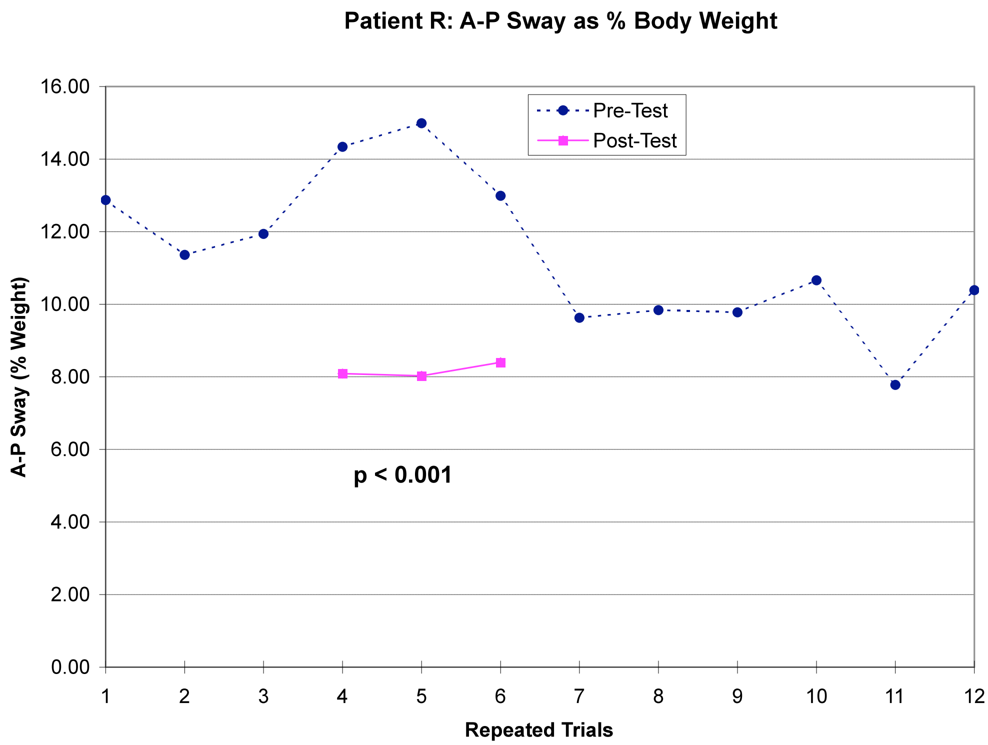

Figure 7: Patient R shows significant ($p < 0.001$) reduction in A-P sway.

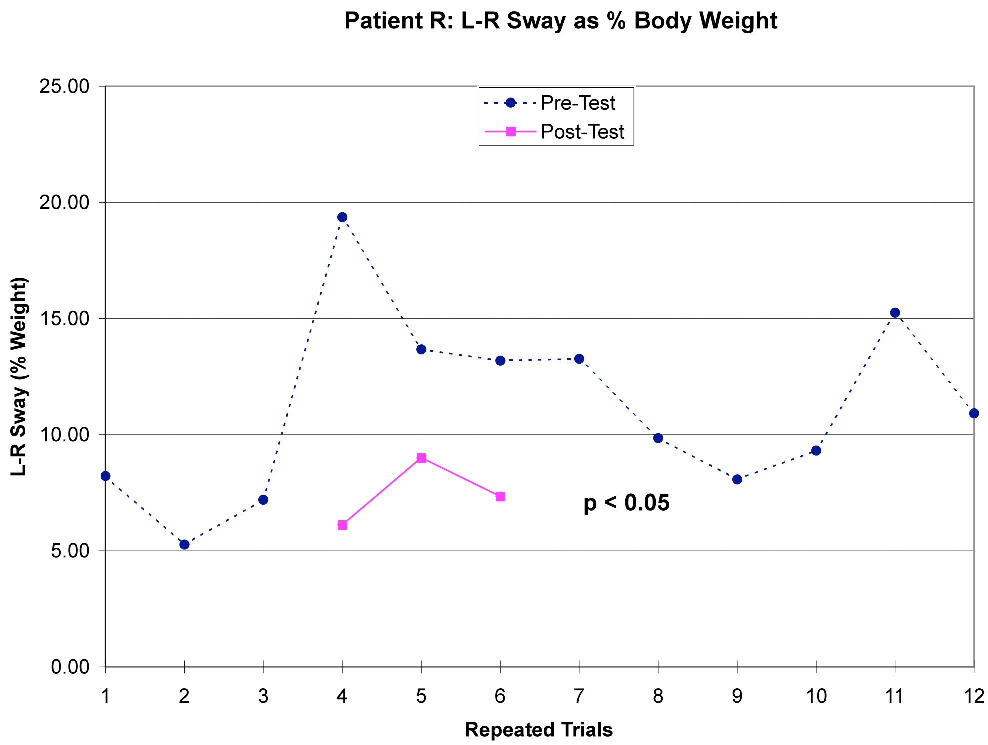

Figure 8: Patient R shows significant ($p < 0.05$) reduction in L-R sway.

Patient R	Pre-Test	Post-Test
EAM-T distance	7.50	6.89
Thoracic extension	18	15
Lumbar extension	6	

Table 4: Summary of other results for Patient R.

Discussion

It is difficult to conduct controlled clinical studies when working with older people who may be in poor general health. Intervening factors, such as sudden illness onset or other acute conditions, can impede the controls that are desired in scientific studies.

Nonetheless, significant reductions in sway were found for these subjects, as well as suggestive reductions in EAM-T distance and gains in thoracic and lumbar extension. It appears that this treatment protocol shows promise for reducing sway and thereby the risk of falls.

Furthermore, if autonomic afferents do exist in the disc, it would seem logical that their presence would be greatest where the largest sympathetic innervation is found. The upper thoracic spinal cord supplies the sympathetic nerves to the heart. It would seem reasonable to hypothesize that the upper thoracic discs also receive a supply. Perhaps the marked upper thoracic kyphosis and consequent internal disc disruptions older people often display is a key to their increased postural sway.

McKenzie has shown repeatedly the phenomenon of centralization.[123] (i.e. the proximal shift in pain patterns after or during loading strategies). Pain sensation may largely be initiated by free nerve endings and, in this case, free nerve endings in the disc. If these free nerve endings are affected by an internal disc disruption, what about others; for example, autonomic afferents? These findings imply that a useful treatment protocol was followed, and that more extensive clinical studies should be done to attempt to support these findings.

References

1. Baker SP, Harvey SH. Fall injury in the elderly. Clin Geriatr Med 1985; 1: 501-507.

2. Blake C, Morfitt JM. Falls and staffing in a residential home for elderly people. Public Health 1986; 100: 385-391.

3. Campbell AJ, Reinken J, Allan BC, Martinez GS. Falls in old age: a study of frequency and related clinical factors. Age Ageing 1981; 10: 264-270.

4. DeVito CA, Lambert DA, Sattin RW, et al. Fall injuries among the elderly: community-based surveillance. J Am Geriatr Soc 1988; 36: 1029-1035.

5. Gabell A, Simons MA, Nayak USL. Falls in the healthy elderly: predisposing causes. Ergonomics 1985; 28: 965-975.

6. Greenhouse AH. Falls among the elderly. In: Albert ML, Knoefel JE (eds) Clinical neurology of aging (2nd ed). New York: Oxford university Press, 1994; 611-626.

7. Gryfe CI, Amies A, Ashley MJ. A longitudinal study of falls in an elderly population: I. Incidence and morbidity. Age Ageing 1977; 6: 201-210.

8. Haga H, Shibata H, Shichita K et al. Falls in the institutionalized elderly in Japan. Arch Gerontol Geriatr 1986; 5: 1-9.

9. Kalchthaler T, Bascon RA, Quintos V. Falls in the institutionalized elderly. J Am Geriatr Soc 1978; 26: 424-428.

10. Lucht U. A prospective study of accidental falls and resulting injuries in the home among elderly people. Acta Socio-med Scand 1971; 3: 105-120.

11. Maki BE, Holliday PJ, Topper AK. A prospective study of postural balance and risk of falling in an ambulatory and independent elderly population. J Gerontol 1994; 49: M72-M84.

12. O'Loughlin J, Robitaille Y, Boivin JF, Suissa A. Incidence of and risk factors for falls and injurious falls among the community-dwelling elderly. Am J Epidemiol 1993; 137: 342-354.

13. Overstall PW, Exton-Smith AN, Imms FJ, Johnson AL. Falls in the elderly related to postural imbalance. Br Med J 1977; I: 261-264.

14. Overstall PW, Johnson AL, Exton-Smith AN. Instability and falls in the elderly. Age Ageing 1978; 7: 92S-96S.

15. Perry BC. Falls among the elderly: a review of the methods and conclusions of epidemiologic studies. J Am Geriatr Soc 1982; 30: 367-371.

16. Perry BC. Falls among the elderly living in high-rise apartments. J Fam Pract 1982; 14: 1069-1073.

17. Rubenstein LZ, Robbins AS, Josephson KR. The value of assessing falls in an elderly population – a randomized clinical trial. Ann Intern Med 1990; 113(4): 308-316.

18. Rubenstein LZ, Robbins AS, Schulman BL, et al. Falls and instability in the elderly. J Am Geriatr Soc 1988; 36: 266-278.

19. Sattin RW, Lambert Huber DA, DeVito CA, et al. The incidence of fall injury events among the elderly in a defined population. Am J Epidemiol 1990; 131(6): 1028-1037.

20. Sheldon JH. On the natural history of falls in old age. Br Med J 1960; 2: 1685-1690.

21. Svensson ML, Rundgren A, Larsson M, et al. Accidents in the institutionalized elderly: A risk analysis. Aging 1991; 3(2): 181-192.

22. Thapa PB, Brockman KG, Gideon P et al. Injurious falls in nonambulatory nursing home residents: a comparative study of circumstances, incidence, and risk factors. J Am Geriatr Soc 1996; 44: 273-278.

23. Walker J, Howland J. Falls and fear of falling among elderly persons living in the community: occupational therapy interventions. Am J Occup Ther 1991; 45: 119-122.

24. Tinetti ME. Falls. In: Cassel CK, Riesenberg DE, Sorenson LB, et al. (eds.) Geriatric Medicine (2nd ed.) New York: Springer-Verlag 1990: 528-534.

25. Tinetti ME. Factors associated with serious injury during falls by ambulatory nursing home residents. J Am Geriatr Soc 1987; 35: 644-648.

26. Tinetti ME, Speechley M. Prevention of falls among the elderly. N Engl J Med 1989; 320: 1055-1059.

27. Tideiksaar R. Preventing falls: How to identify risk factors, reduce complications. Geriatrics 1996; 51: 43-53.

28. Tideiksaar R, Kay AD. What causes falls? A logical diagnostic procedure. Geriatrics 1986; 41: 32-50.

29. Duthie EH. Falls. Med Clin North Am 1989; 73: 1321-1336.

30. Campbell AJ, Borrie MJ, Spears GF. Risk factors for falls in a community based prospective study of people 70 years and older. J Gerontol Med Sci 1989; 44: M112-M117.

31. Fleming B, Pendergast D. Physical condition, activity pattern, and environment as factors in falls by adult care facility residents. Arch Phys Med Rehab 1993; 74: 627-630.

32. Lipsitz LA, Jonsson PV, Kelley MM, Koestner JS. Causes and correlates of recurrent falls in ambulatory frail elderly. J Gerontology 1991; 46(4): M114-M122.

33. Nevitt MC, Cummings SR, Kidd S, Black D. Risk factors for recurrent nonsyncopal falls: A prospective study. JAMA 1989; 261: 2663-2668.

34. Prudham D, Evans JG. Factors associated with falls in the elderly: a community study. Age Ageing 1981; 10: 141-146.

35. Robbins AS, Rubenstein LZ, Josephson KR, et al. Predictors of falls among elderly people. Arch Intern Med 1989; 149: 1628-1633.

36. Ross J. Iatrogenesis in the elderly: contributors to falls. J Gerontol Nursing 1991; 17: 19-23.

37. Ryynanen OP. Health, functional capacity, health behaviour, psychological factors and falling in old age. Public Health 1994; 108: 99-110.

38. Salgado R, Lord SR, Packer J, Ehrlich F. Factors associated with falling in elderly hospital patients. Gerontology 1994; 40: 325-331.

39. Tinetti ME, McAvay G, Claus E. Does multiple risk factor reduction explain the reduction in fall rate in the Yale FICSIT Trial? Am J Epidemiol. 1996; 144: 389-399.

40. Tinetti ME, Speechley M, Ginter SF. Risk factors for falls among elderly persons living in the community. N Engl J Med 1988; 319: 1701-1707.

41. Tinetti ME, Williams TF, Mayewski R. Fall risk index for elderly patients based on number of chronic disabilities. Am J Med 1986; 80: 429-434.

42. Waller JA. Falls among the elderly – human and environmental factors. Accid Anal Prev 1978; 10: 21-23.

43. Wells BG, Middleton B, Lawrence G, et al. Factors associated with the elderly falling in intermediate care facilities. Drug Intell Clin Pharm 1985; 19: 142-145.

44. Bohannon RW, Larkin PA, Cook AC, Gear J, Singer J. Decrease in timed balance test scores with aging. Phys Ther 1984; 64: 1067-1070.

45. Cho C-Y, Kamen G. Detecting balance deficits in frequent fallers using clinical and quantitative evaluation tools. J Am Geriatr Soc 1998; 46: 426-430.

46. Ekdahl C, Jarnlo GB, Andersson SI. Standing balance in healthy subjects. Evaluation of a quantitative test battery on a force platform. Scand J Rehab Med 1989; 21: 187-195.

47. Lee WA, Deming LR. Age-related changes in the size of the effective support base during standing. Phys Ther 1988; 68: 859.

48. Manchester D, Woollacott M, Zederbauer-Hylton N, Marin O. Visual, vestibular and somatosensory contributions to balance control in the older adult. J Gerontol Med Sci 1989; 44: M118-M127.

49. Peterka RJ, Black FO. Age-related changes in human posture control: sensory organization tests. J Vestib Res 1990; 1: 73-85.

50. Ring C, Nayak US, Isaacs B. Balance function in elderly people who have and have not fallen. Arch Phys Med Rehabil 1988; 69: 261-264.

51. Stones MJ, Kozma A. Balance and age in the sighted and blind. Arch Phys Med Rehabil 1987; 68: 85-89.

52. Thapa PB, Gideon P, Brockman KG, et al. Clinical and biomechanical measures of balance as fall predictors in ambulatory nursing home residents. J Gerontol 1996; M239-M246.

53. Thapa PB, Gideon P, Fought RL et al. Comparison of clinical and biomechanical measures of balance and mobility in elderly nursing home residents. J Am Geriatr Soc 1994; 42: 493-500.

54. Wolfson L, Whipple R, Derby CA, et al. A dynamic posturography study of balance in healthy elderly. Neurology 1992; 42: 2069-2075.

55. Campbell AJ. Drug treatment as a cause of falls in old age. Drugs and Aging 1991; 1(4): 289-302.

56. Granek E, Baker SP, Abbey H, et al. Medications and diagnoses in relation to falls in a long-term care facility. J Am Geriatr Soc 1987; 35: 503-511.

57. Liu YJ, Stagni G, Walden JG, Shepherd AMM, Lichtenstein MJ. Thioridazine dose-related effects on biomechanical force platform measures of sway in young and old men. J Am Geriatr Soc 1998; 46: 431-437.

58. Ray WA, Griffin MR, Schaffner W, et al. Psychotropic drug use and the risk of hip fracture. N Engl J Med 1987; 316: 363-369.

59. Robin DW, Hasan SS, Edeki T, et al. Increased baseline sway contributes to increased postural instability in the elderly following triazolam. J Am Geriatr Soc 1996; 44: 300-304.

60. Robin DW, Hasan SS, Lichtenstein MJ, et al. Dose-related effect of triazolam on postural sway. Clin Pharmacol Ther 1991; 49: 581-588.

61. Thapa PB, Gideon P, Fought RL, Ray WA. Psychotropic drugs and the risk of recurrent falls in ambulatory nursing home residents. Am J Epidemiol 1995; 142: 202-211.

62. Dettmann MA, Linder MT, Sepic SB. Relationships among walking performance, postural stability, and functional assessments of the hemiplegic patient. Am J Phys Med 1987; 66(2): 77-90.

63. Diener HC, Dichgans J, Bacher M, Gompf B. Quantification of postural sway in normals and patients with cerebellar diseases. Electroenceph Clin Neurophysiol 1984; 57: 134-42.

64. Goldie PA, Matyas TA, Spencer KI, McGinley RB. Postural control in standing following stroke: Test-retest reliability of some quantitative clinical tests. Phys Ther 1990; 70: 234-243.

65. Weerdt W, Crossley SM, Lincoln NB, Harrison MA. Restoration of balance in stroke patients: a single case design study. Clin Rehab 1989; 3: 139-47.

66. Kirshen AJ, Cape RDT, Hayes HC, Spencer JD. Postural sway and cardiovascular parameters associated with falls in the elderly. J Clin Exp Gerontol 1984; 6: 291-307.

67. Lipsitz LA. Abnormalities in blood pressure homeostasis that contribute to falls in the elderly. In: Radebaugh TS, Hadley E, Suzman R, eds. Clinics in geriatric medicine. Philadelphia: W.B. Saunders, 1985; 637-648.

68. Cwikel J, Fried A. The social epidemiology of falls among community-dwelling elderly; guidelines for prevention. Disability and Rehabilitation 1992; 14: 113-121.

69. Macrae P, Lacourse M, Moldavon R. Physical performance measures that predict faller status in community-dwelling older adults. J Phys Ther 1992; 16: 123-128.

70. Mossey JM. Social and psychologic factors related to falls among the elderly. Clin Geriatr Med 1985; 1: 541-553.

71. Tinetti ME, Mendes de Leon CF, Doucette JT, et al. Fear of falling and fall-related efficacy in relationship to functioning among community-living elders. J Gerontol 1994; 49(3): M140-M147.

72. Era P, Heikkinen E. Postural sway during standing and unexpected disturbance of balance in random samples of men of different ages. J Gerontol 1985; 40(3): 287-295.

73. Drowatzky JN, Zuccato FC. Interrelationships between selected measures of static and dynamic balance. Res Q 1967; 38: 509-510.

74. Brocklehurst JC, Robertson D, James-Groom P. Clinical correlates of sway in old age: Sensory modalities. Age Ageing 1982; 11: 1-10.

75. Skinner HB, Barrack RL, Cook SD. Age-related decline in proprioception. Clin Orthop 1984; 184: 208-211.

76. Stelmach GE, Phillips J, DiFabio R, Teasdale N. Age, functional postural reflexes, and voluntary sway. J Gerontol Biol Sci 1989; 44: B100-106.

77. Whipple RH, Wolfson LI, Amerman PM. The relationship of knee and ankle weakness to falls in nursing home residents: An isokinetic study. J Am Geriatr Soc 1987; 35: 13-20.

78. Wolfson L, Whipple R, Amerman P, Tobin JN. Gait assessment in the elderly: a gait abnormality rating scale and its relation to falls. J Gerontol Med Sci 1990; 45: M12-M19.

79. Baloh RW, Fide TD, Zwerling L, et al. Comparison of static and dynamic posturography in young and older normal people. J Am Geriatr Soc 1994; 42: 405-412.

80. Perrin PP, Gauchard GC, Perrot C, Jeandel C. Effects of physical and sporting activities on balance control in elderly people. Br J Sports Med 1999; 33(2): 121-6.

81. Horak FB. Clinical measurement of postural control in adults. Phys Ther 1987; 67: 1881-1885.

82. Hough JC, McHenry MP, Kammer LM. Gait disorders in the elderly. Am Fam Physician 1987; 35: 191-196.

83. Lord SR, Rogers MW, Howland A, Fitzpatrick R. Lateral stability, sensorimotor function and falls in older people. J Am Geriatr Soc 1999; 47(9): 1077-81.

84. Fernie GR, Gryfe CI, Holliday PJ, Llewellyn A. The relationship of postural sway in standing to the incidence of falls in geriatric subjects. Age Ageing 1982; 11: 11-16.

85. Aalto H, Pyykko I, Starck J. Computerized posturography, a development of the measuring system. Acta Otolaryngol (Stockholm) 1988; 449: 71-75.

86. Begbie GH. The assessment of imbalance. Physiotherapy 1969; 55: 411-414.

87. Black FO, Wall C, Rockette HE, Kitch R. Normal subject postural sway during the Romberg test. Am J Otolaryngol 1982; 3: 309-318.

88. Hasan SS, Goldner DN, Lichtenstein MJ, et al. Selecting a suitable biomechanics platform measure of sway. Proc IEEE-EMBS 1990; 12: 2105-2106.

89. Hasan SS, Lichtenstein MJ, Shiavi RG. Effect of loss of balance on biomechanics platform measures of sway: Influence of stance and a method for adjustment. J Biomech 1990; 23: 783-789.

90. Hufschmidt A, Dichgans J, Mauritz KH, et al. Some methods and parameters of body sway quantification and their neurological applications. Arch Psychiatry Neurol Sci 1980; 228: 135-150.

91. Murray MP, Seireg AA, Sepic SB. Normal postural stability and steadiness: quantitative assessment. J Bone Joint Surg 1975; 57-A: 510-516.

92. Roland NJ, Smith CA, Miller IW, Jones AS, and Lesser TH. A simple technique to measure body sway in normal subjects and patients with dizziness. J Laryngol Otol 1995; 109: 189-92.

93. Winter DA, Patla AE, Frank JS. Assessment of balance control in humans. Med Prog Technol 1990; 16: 31-51.

94. Shimba T. An estimation of centre of gravity from force platform data. J Biomech 1984; 17: 53-60.

95. Lee WA. Control system framework for understanding normal and abnormal posture. Am J Occup Ther 1989; 43: 291-301.

96. Baloh RW, Corona S, Jacobson KM, et al. A prospective study of posturography in normal older people. J Am Geriatr Soc 1998; 46: 438-443.

97. Baloh RW, Corona S, Jacobson KM, et al. A prospective study of posturography in normal older people. J Am Geriatr Soc 1998; 46: 438-443.

98. Hasselkus BR, Shambes GM. Aging and postural sway in women. J Gerontol 1975; 30: 661-667.

99. Sheldon JH. The effect of age on the control of sway. Gerontol Clin 1963; 5: 128-138.

100. Matheson AJ, Darlington CL, Smith PF. Further evidence for age-related deficits in human postural function. J Vestib Res 1999; 9(4): 261-4.

101. Lichtenstein MJ, Burger MC, Shields SL, Shiavi RG. Comparison of biomechanics platform measures of balance and videotaped measures of gait with a clinical mobility scale in elderly women. J Gerontol 1990; 45: M49-M54.

102. Ring C, Nayak US, Isaacs B. The effect of visual deprivation and proprioceptive change on postural sway in healthy adults. J Am Geriatr Soc 1989: 745-749.

103. Lewit K. Manipulative therapy in rehabilitation of the locomotor system. 2nd ed. Oxford: Butterworth-Heinemann, 1991, 23-25.

104. Lewit K. Manipulative therapy in rehabilitation of the locomotor system. 2nd ed. Oxford: Butterworth-Heinemann, 1991, 18-20.

105. Simon BR, Wu JS, Carlton MW, Evans JH, Kazarian LE. Structural models for human spinal motion segments based on a poroelastic view of the intervertebral disk. J Biomech Eng 1985 107(4): 327-35.

106. Simon BR, Wu JS, Carlton MW, Kazarian LE, France EP, Evans JH, Zienkiewicz OC. Poroelastic dynamic structural models of rhesus spinal motion segments. Spine 1985, 10(6): 494-507.

107. Liebenson C. Rehabilitation of the Spine. Williams and Wilkins, 1996, 97.

108. Liebenson C. Rehabilitation of the Spine. Williams and Wilkins, 1996, 177.

109. Lewit K. Manipulative Therapy in Rehabilitation of the Locomotor System. Butterworth and Heinemann, 1991.

110. Lewit K. Manipulative Therapy in Rehabilitation of the Locomotor System. Butterworth and Heinemann, 1991.

111. McKenzie RA. The Lumbar Spine. New Zealand: 1981.

112. McKenzie RA. The Cervical and Thoracic Spine. New Zealand: 1990.

113. McKenzie RA. Treat Your Own Back, Treat Your Own Neck. New Zealand: Spinal Publications.

114. Adams MA, Hutton WC, Gradual Disc Prolapse. Spine 1985, 10;524-531.

115. Ninomiya M, Muro T, Pathoanatomy Of Lumbar Disc Herniation As Demonstrated By Computed Tomography/Discography. Spine1992, 17(11);1316-1322.

116. Schellhas KP, Smith MD, Grundy CR, Pollei SR, Cervical Discogenic Pain. Spine 1996, 21(3);300-312.

117. McKenzie A. The Lumbar Spine. New Zealand: Spinal Publications New Zealand Ltd., 1981, 16.

118. Newman PP and Paul DH. The representation of some visceral afferents in the anterior lobe of the cerebellum. J Physiol 1966; 182: 195-208.

119. Rubia FJ and Phelps JB. Responses of the cerebellar cortex to cutaneous and visceral afferents. Pflugers Arch 1970; 314: 68-85.

120. Jinkins JR, The Lumbosacral Spine. Neuroimaging Clinics Of North America 1993; 3(3):443-463.

121. Palmgren T, Gronblad M, Virri J, Kaapa E, Karaharju E, An Immunohistochamical Study of Nerve Structures in the Anulus Fibrosis of Human Normal Lumbar Intervertebral Discs. Spine 1999, 24(20);2075-2079.

122. De Camillis D and Carr R. The reliability and potential value of a specific ‘centre of pressure locator’ in chiropractic practice. JCCA 2000; 44(4): 209-22.

123. Werneke M, Hart DL and Cook D. A descriptive study of the centralization phenomenon: a prospective analysis. Spine 1999; 24(7): 676-83.