Evaluation of Postural Stability in Elderly With Diabetic Neuropathy

HÉLÈNE CORRIVEAU, PT, MSC
FRANÇOIS PRINCE, PHD
RÉJEAN HÉBERT, MD, MPHIL
MICHEL RAÎCHE, BSC
DANIEL TESSIER, MD
PIERRE MAHEUX, MD
JEAN-LUC ARDILOUZE, MD, MSC

OBJECTIVE — The objective of this study was to compare clinical and biomechanical characteristics of balance in diabetic polyneuropathic elderly patients and normal age-matched subjects.

RESEARCH DESIGN AND METHODS — Fifteen elderly with distal neuropathy (DNP) and 15 healthy age-matched subjects were evaluated with the biomechanical variable COP-COM, which represents the distance between the center of pressure (COP) and the center of mass (COM). Measurements were taken in the quiet position with a double-leg stance, in eyes-open (EO) and eyes-closed (EC) conditions. Subjects were also assessed with clinical balance evaluations.

RESULTS — The COP-COM variable was statistically significantly larger in the DNP group than in the healthy group in anterior-posterior (A/P) and medial-lateral (M/L) directions. Furthermore, the DNP group showed statistically significantly larger amplitudes of the COP-COM variable without vision. The severity of the neuropathy, as quantified using the Valk scoring system, was correlated with COP-COM amplitude in both directions.

CONCLUSIONS — Evaluation of the postural stability of an elderly diabetic population using the COP-COM variable can detect a very small change in postural stability and could be helpful in identifying elderly with DNP at risk of falling.

Diabetes Care 23:1187–1191, 2000

The prevalence of diabetes increases markedly in the elderly population (1). Over the course of the disease, diabetes leads to various disabilities and, at times, lifelong chronic complications, with diabetic neuropathy being the most common symptomatic complication (2). Approximately 50% of diabetic patients >60 years of age show evidence of peripheral neuropathy (3,4). Only a few studies focused on the postural problem in the elderly with diabetic neuropathy (5–9).

The small amount of evidence on the effect of distal neuropathy (DNP) on postural control could be attributable to the poor measures available to detect postural instability. Until recently, there were few reliable and valid measures that accurately described postural control in the quiet standing position for the elderly population with and without disabilities. All of these selected measures show considerable variability (10). The center of pressure (COP) variable has often been used to measure postural control. However, higher COP parameters, such as length, area, displacement, or velocity, are not necessarily indicative of a risk of falling (11). COP movements may successfully stabilize the center of mass (COM) by maintaining the COM over the base of support and thereby reducing the risk of falling (12). To overcome these limitations, it has been suggested that the combined interpretation of COP and COM displacements provides better insight into the assessment of balance than COP and COM taken separately (11,13–15). Thus, a new biomechanical variable (COP-COM), which represents the scalar distance at a given time between the COP and COM (13), has been proposed. This variable showed good test-retest and interrater reliability (16).

The work presented here addresses 2 questions: *1*) Are biomechanical COP-COM and clinical variables different in healthy and DNP elderly subjects and *2*) Is COP-COM amplitude associated with increased neuropathy severity as quantified using the scoring system devised by Valk et al. (17)?

RESEARCH DESIGN AND METHODS

Subjects

Fifteen elderly patients with type 2 diabetes with DNP and 15 healthy elderly were studied. Only diabetic subjects with neuropathy were selected because postural instability was previously found to be significantly associated with sensory neuropathy but not with diabetes per se (6). The DNP subjects were recruited from a specialty diabetes clinic. The polyneuropathy was quantified using a scoring system developed and described by Valk and colleagues (17,18). The scoring system has 4 levels of neuropathy: normal, mild, moderate, and severe. Briefly, it consists of clinical testing of *1*) sensory modalities (pinprick, light touch, vibration, and pain), *2*) the anatomic level below which light-touch sensation is impaired, *3*) muscle strength, and *4*) ankle jerk. The total score can vary between 0 and 33. A total score of 0 is graded as no polyneuropathy, 1–9 as mild, 10–18 as moderate, and 19–33 as severe polyneuropathy. This clinical evalu-

From the Department of Physiotherapy (H.C.), School of Rehabilitation Sciences, University of Ottawa, Ottawa, Ontario; the Department of Kinesiology (F.P.), Faculty of Medicine, University of Montreal, Montreal; the Gerontology and Geriatrics Research Centre (R.H., M.R., D.T.), Sherbrooke Geriatric University Institute; and the Research Group on Diabetes and Metabolism (D.T., P.M., J.-L.A.), Clinical Research Center, Centre Hospitalier Universitaire de Sherbrooke, Sherbrooke, Québec.

Address correspondence and reprint requests to Hélène Corriveau, PT, MSc, School of Rehabilitation Sciences, Physiotherapy, University of Ottawa, 451 Smyth Rd., Ottawa, ON, Canada, K1H 8M5. E-mail: hcorrive@uottawa.ca.

Received for publication 14 December 1999 and accepted in revised form 4 May 2000.

Abbreviations: A/P, anterior-posterior; COM, center of mass; COP, center of pressure; DNP, distal neuropathy; EC, eyes closed; EO, eyes open; M/L, medial-lateral; RMS, root mean square; VDT, vibration disappearance threshold; VPT, vibration perception threshold; VT, vibration threshold.

A table elsewhere in this issue shows conventional and Système International (SI) units and conversion factors for many substances.

ation was chosen because of its good intrarater reliability (r = 0.79 [CI 0.68–0.87]) and its good sensitivity and specificity (91.3 and 63.3%, respectively) for a diagnostic cut-off point >4 (18). The patients were not selected based on complaints of instability and did not present with ulceration.

Healthy subjects were recruited from a register of subjects who showed an interest in studies carried out at the research center (19). They were matched according to age, sex, height, and weight with the DNP subjects. The eligibility criteria consisted of being at least 60 years of age, living independently in the community, and having no neurological or musculoskeletal impairments, such as a history of stroke, transient ischemia attacks, Parkinson's disease, or lower-extremity joint replacement. Subjects were excluded if they reported visual somatosensory impairments or vestibular dysfunction or if they reported at least 1 fall in the past 6 months. Because of the insidious onset of diabetes, the healthy elderly had to have a fasting blood sugar level <7.8 mmol/l and an HbA_{1c} <11.1 mmol/l to be eligible for the study. The minor abnormalities found on physical examination of the healthy elderly, such as a reduction in vibration sense at the malleolus and a reduction in Achilles' tendon reflexes, are commonly associated with aging (20,21). Consequently, control subjects were selected if they scored lower than 2 on the Valk scale.

Data collection procedure

All subjects in this study were participants in a previous study, which determined the test-retest and interrater reliability of the COP-COM variable (16). Two different evaluation sessions were used to collect all of the measurements. At the first session, the subject characteristics, stability measures, and strength data were collected. At the second session, the somatosensory evaluations were performed.

Stability measure

The procedure used was the same as in the previous studies (22,23). Subjects stood quietly on 2 adjacent force platforms in a double-leg stance with feet at pelvis-width while measurements were made. Some degrees of hip external rotation were allowed to minimize discomfort and constraints on the subject's preferred position (24). To ensure that this position remained constant, tracings were taken of foot placement, and subjects were required to remain within these tracings for all of the trials. To evaluate the subjects in an ecological situation, all subjects wore flat-soled shoes usually used for walking.

The subjects were instructed to look straight ahead with their head erect and to maintain balance. Their arms were placed in a comfortable position hanging at their sides. For all subjects, data were collected for 4 successive trials lasting 120 s with eyes open (EO) with a rest period of ~5 min between trials. Then, after a rest of 10 min, all subjects performed the 2-min task 4 times with eyes closed (EC). The EO and EC conditions were repeated in the same order for all of the subjects. The 4 trials were averaged under each condition. The minimal metrically detectable difference for the COP-COM variable was estimated to be 0.01 cm in the anterior-posterior (A/P) direction and 0.02 cm in the medial-lateral (M/L) direction (22). Anthroprometric tables were used to estimate total COM. Full details of the anthropometric data marker placement protocol (25), apparatus, and methods (23) have been described in detail elsewhere and will be summarized here. The model consists of 4 trunk segments, 1 pelvis, 2 thighs, 2 legs and feet, 2 upper arms, 2 forearms, and 1 head. There were 21 infrared light–emitting diodes attached bilaterally to anatomical landmarks to define a 14-segment model. Three Optotrack sensors (Northern Digital, Waterloo, Ontario, Canada) recorded marker displacement while ground reaction forces and moments were recorded by 2 AMTI force platforms (Advanced Mechanical Technology, Watertown, MA). The Optotrak's resolution is 0.01 mm and its accuracy in root mean square (RMS) is 0.1 mm. The resolution of the AMTI force platform is 0.08 $\mu V \cdot V^{-1} \cdot N^{-1}$. The accuracy of the COP measured in the present study was 0.2 mm. Both devices were interfaced to an A/D converter with a sampling rate of 20 Hz. Data were processed on a Pentium PC using the software written for Matlab 5.1 (Mathworks, Natick, MA).

Clinical evaluations

After a rest period of ~30 min lying down on a bed, all of the clinical evaluations of sensation were done. Somatosensory function tests included evaluation of touch-pressure and vibratory perception thresholds. For the sensory tests, the subjects were in a supine position.

The full set of 20 Semmes-Weinstein monofilaments (the higher the number, the more severe the neuropathy) was used for evaluating touch-pressure sensation (26). The protocol developed by Sosenko et al. (27) was used. The lateral aspect of the distal phalanx of the first big toe was evaluated. The vibration perception threshold (VPT) was assessed using a fixed frequency (120 Hz) variable amplitude vibrometer (Vibrator IV; Somedic Instruments, Farsta, Sweden). The subject was instructed to say when the vibration first appeared (the VPT) and when it disappeared (the vibration disappearance threshold [VDT]). According to the classical methods of limits, the vibration threshold (VT) is the average of VPT and VDT. Two kinds of visual evaluations were chosen: distal acuity using the Snellen Card (28) and peripheral vision of each eye (29).

One functional evaluation of balance was administered: the modified scale developed by Tinetti (30). Tinetti's mobility scale consists of 24 balance and 16 gait maneuvers. Each item is graded on a 3-point scale, 0–2, or on a 2-point scale, 0–1, for a total score of 40.

The strength of the main muscle of the lower extremity was measured. Plantar flexor and abductor strength were tested with a handheld dynamometer (Nicholas MMT; Lafayette Instruments, Lafayette, IN). The knee extensor, hip flexor, and dorsiflexor muscles were tested with a belt-resisted method (31). The simple reaction time, the interval times between the presentation of the visual stimuli, and the tapping of the space bar were also measured (32). The computer program React II was used (React II; Life Science Associates, Bayport, NY).

Data analysis

The characteristics of the study sample are described by the mean and the SD for continuous variables and by frequency and percentage for categorical variables. The root mean square (RMS) amplitudes were calculated for the COP-COM variables in both A/P and M/L directions. The Mann-Whitney U test was used to compare control subjects with DNP subjects, and Wilcoxon's signed-rank test was used to compare vision conditions. Spearman's correlation coefficient was used to evaluate the correlation of the COP-COM variable with the index developed by Valk et al. (17). Some DNP subjects with the most severe neuropathy exceeded values for the vibratory sensation. In these cases, the subjects were assigned the maximal value possible for those tests (33). Statistical significance was assumed at $P < 0.05$ (2-tailed). A sample size of 15

Table 1—*Descriptive characteristics of the subjects*

Characteristics	Patients with DNP	Control subjects	*P*
n	15	15	—
Age (years)	68.8 ± 5.5*	69.3 ± 5.1	0.78
HbA_{1c} (mmol/l)	7.7 ± 1.5	5.7 ± 0.55	0.001
Fasting blood glucose (mmol/l)	8.0 ± 2.0	5.4 ± 0.72	0.001
Height (m)	1.6 ± 0.1	1.6 ± 0.1	0.62
Weight (kg)	75.2 ± 9.6	74.3 ± 10.4	0.97
Vision (Snellen card) (% >20/16)	33.3	93.3	0.001
Valk scale (/33)	15 ± 8.2	0.4 ± 0.8	0.001
Vibration first toe (μm)	26.8 ± 35	1 ± 0.53	0.001
Filament first toe (% >3.84)	87.7	20.0	0.002
React II (s)	0.46 ± 0.1	0.38 ± 0.6	0.007
Tinetti (/40)	35.4 ± 5.7	40 ± 0	0.002
Strength			
Right hip flexion (N)*	231.5 ± 82.6	314.1 ± 65.4	<0.001
Left hip flexion (N)	197.0 ± 108.3	312.1 ± 63.5	0.004
Right abductor (kg)†	9.4 ± 3.6	12.0 ± 2.5	0.146
Left abductor (kg)	9.4 ± 2.3	10.9 ± 1.9	0.146
Right quadricep (N)	344.1 ± 140.0	482.2 ± 133.2	0.009
Left quadricep (N)	330.3 ± 143.0	471.1 ± 124.3	0.009
Right dorsiflexion (N)	197.8 ± 86.0	244.0 ± 44.0	0.146
Left dorsiflexion (N)	193.0 ± 78.2	248.0 ± 46.7	0.063
Right plantarflexion (kg)	11.9 ± 2.9	18.0 ± 7.2	0.000
Left plantarflexion (kg)	11.6 ± 3.7	15.9 ± 6.6	0.012

Data are *n*, %, or means ± SD. *Measured with microfet; †measured with Nicholas dynamometer.

individuals per group allowed for detection of a difference of 1 SD of the COP-COM amplitude between groups with a power of 80% (34).

RESULTS — In each group, 6 women and 9 men were evaluated. Using a polyneuropathy severity index developed by Valk et al. (17), 5 DNP subjects were classified as mild, 7 as moderate, and 3 as severe polyneuropathic cases. Duration of type 2 diabetes was 15.7 ± 9.9 years. Three diabetic subjects had a peripheral vascular disease. Additionally, none of the subjects were using tricyclic antidepressants or antipsychotic drugs. Ten subjects in the diabetic group and 3 subjects in the control group were on various doses of ACE inhibitors, β-blockers, or calcium channel blockers for stable hypertension or cardiac problems. During testing, no subject in either group complained of symptoms of cerebral hypoperfusion. All normal subjects had a Valk score under 2. There were significant differences between the 2 groups in all sensory tests, the Tinetti mobility scale, and reaction time. The hip flexor, knee extensor, and plantar flexor strength were significantly different, but not the abductor and dorsal flexor muscle. A complete comparison of subject characteristics for the 2 groups is provided in Table 1.

Table 2 shows the RMS scores obtained for the COP-COM variable for both EO and EC conditions and A/P and M/L directions. A statistically significant difference was found between the 2 groups in both EO and EC conditions in A/P ($P < 0.021$ and $P < 0.005$, respectively) and M/L ($P < 0.003$ and $P < 0.002$, respectively) directions. The subjects with DNP had larger COP-COM amplitudes. However, to ensure that the 3 severe subjects included in our sample did not skew the results, we performed the analysis on the 12 mild-to-moderate subjects only, as measured with the Valk system (17). All of the differences between the 2 groups remained significant, except for the A/P direction in the EO condition ($P = 0.114$). The trend remained, but the small sample size could not yield sufficient power to establish it clearly.

Furthermore, the DNP group showed statistically significantly larger amplitudes of the COP-COM variable in the EC condition compared with the EO condition in both directions ($P < 0.001$ and $P < 0.02$, respectively). For the healthy group, the effect of vision was significantly different only in the A/P direction ($P < 0.001$).

The severity of the neuropathy, as quantified using the scoring system developed by Valk et al. (17), significantly correlated with COP-COM amplitude in the A/P ($r = 0.52$, $P < 0.003$) and the M/L ($r = -0.47$, $P < 0.009$) directions.

CONCLUSION — The main objective of this study was to compare DNP patients with healthy elderly patients using the biomechanical COP-COM variable. The neuropathy group showed less stable posture than the control group, with and without vision. The difference found between the 2 groups in the present study was 0.06 and 0.07 cm, respectively, in the A/P direction in EO and EC conditions, and 0.04 and 0.06 cm, respectively, in the M/L direction in EO and EC conditions. It was previously reported that the clinically significant dif-

Table 2—*COP-COM amplitude (in centimeters) obtained in diabetic DNP and healthy subjects for EO and EC conditions and A/P and M/L directions*

COP-COM	Patients with DNP	Control subjects	*P**
A/P			
EO	0.13 ± 0.05	0.09 ± 0.02	0.021
EC	0.20 ± 0.09	0.13 ± 0.04	0.005
EO/EC difference	0.06 ± 0.05	0.03 ± 0.04	
P†	0.001	0.001	
M/L			
EO	0.11 ± 0.04	0.07 ± 0.01	0.003
EC	0.14 ± 0.06	0.08 ± 0.02	0.002
EO/EC difference	0.03 ± 0.02	0.01 ± 0.02	
P†	0.02	0.256	

Data are means ± SD, unless otherwise indicated. *Measured by Mann-Whitney *U* test; †measured by Wilcoxon's signed-rank test.

ference for the COP-COM variable in the EO condition was 0.01 cm in the A/P and 0.02 cm in the M/L direction (22). Consequently, the difference found is clinically significant and confirms the postural instability in both directions (A/P and M/L) for the neuropathic group compared with the group of age-matched healthy elderly patients. The COP-COM variable can detect a small change in postural stability because of its high reliability (16) and the excellent resolution and accuracy of the instrument used to measure the COP-COM. Interestingly, even though the reliability of the COP-COM in the M/L direction was not as good as the reliability in the A/P direction, a statistically significant difference was found between the 2 groups. Consequently, it seems that despite the noise from the measurement error, the postural instability in the M/L direction was large enough to be detected by the COP-COM variable. These results confirm the importance of lateral stability in quiet standing on this population (35).

The difference between the healthy and DNP groups was greatest when vision was absent. The increase in the RMS amplitude in the DNP group during the EC condition compared with the control group under the same condition could underscore their reliance on vision to compensate for their somatosensory impairment. But in the M/L direction, the DNP subjects showed larger COP-COM amplitude, demonstrating a poorer performance during EO conditions than the healthy elderly during EC conditions ($P < 0.027$). Boucher et al. (7) stated that even with vision, the postural stability of the diabetic patient with DNP is impaired. However, in this latter study, vision was not evaluated. In the present study, even though vision was corrected by laser surgery for some diabetic subjects and was considered functional (over 20/25 on the Snellen test), a statistically significant difference was found between the 2 groups ($P < 0.001$) (Table 1). Our results suggest that vision was impaired enough to limit the redundancy function of the systems, which implied and confirmed the importance of both sensory systems (vision and somatosensory) in controlling postural stability in quiet standing (36).

The diabetic subjects showed weakness in some proximal muscles (hip flexor and knee extensor), but no difference was found in the abductor muscles, which were previously found to be important for lateral stability in quiet standing (37). Moreover, the statistically significant difference found between the 2 groups in both vision conditions (EO and EC) suggests that vision and peripheral sensation affect postural stability in our diabetic subjects. Consequently, muscle weakness alone could hardly be responsible for loss of postural stability. Unfortunately, a motor nerve conduction measure was not done to confirm a possibility of motor myopathy, which is a limitation of this study. Nevertheless, the results of this study confirm the presence of postural instability in the elderly with DNP diabetes and suggest abnormalities of the different systems in this population. Moreover, they confirm that it can be difficult to isolate somatosensory problems for the control of stability in diabetic patients with neuropathy (38).

The severity of the neuropathy significantly correlated with COP-COM amplitude. We used a clinical evaluation demonstrated to have a significant correlation with scores obtained from a neurophysiological examination ($r = 0.7$, $P < 0.005$) (17). Another study (7) found a significant correlation between the severity of the neuropathy and the biomechanical variable using the same index of severity.

Evaluating the postural stability of the elderly diabetic population using the COP-COM variable can detect a small change and deterioration in postural stability and could be helpful in identifying diabetic subjects at risk of falling. Using the COP-COM variable in the quiet position has several advantages. First, static posturography in the quiet position with head straight compared with other positions constitutes an easy task for elderly people with disabilities (6,9). Second, the COP-COM variable is related to falls, as shown by its good correlation with COM acceleration (13). Furthermore, in this study, the average mean of the Tinetti score for the neuropathic group is 35.4. Recent studies have demonstrated that subjects with a score lower than 36 had twice the risk of falling in the following year (39,40).

In this study, the DNP patients were not selected on the basis of complaints of instability. This means that the impairment of postural control in the elderly with DNP is not always apparent at an early stage but would be more important under challenging postural conditions. Because functional changes in both peripheral sensory and motor nerves can be present at a duration of diabetes of 4 years (41), it may be important to evaluate postural control in such patients as soon as possible to prevent injuries and other consequences of falls.

Acknowledgments — This research was funded by the Medical Research Council of Canada (grant MT4343) and the Québec Diabetes Association. The Fonds de la Recherche en Santé du Québec is also acknowledged for the scholarships awarded to H.C., F.P., and R.H.

References

1. Meneilly GS, Tessier D: Diabetes in the elderly. *Diabet Med* 12:949–960, 1995
2. Sima AAF, Greene DA: Diabetic neuropathy in the elderly. *Drugs Aging* 6:123–135, 1995
3. Young MJ, Boulton AJ, MacLeod AF, Williams DRR, Sonksen PH: A multicentre study of the prevalence of diabetic peripheral neuropathy in the United Kingdom hospital clinic population. *Diabetologia* 36: 150–154, 1993
4. Green DA, Sima AAF, Pleiffer MA, Albers JW: Diabetic neuropathy. *Ann Rev Med* 41: 303–317, 1990
5. Lord SR, Caplan GA, Colagiuri R, Ward JA: Sensori-motor function in older persons with diabetes. *Diabet Med* 10:614–618, 1993
6. Simoneau GG, Ulbrecht JS, Derr JA, Becker MB, Cavanagh PR: Postural instability in patients with diabetic sensory neuropathy. *Diabetes Care* 17:1411–1421, 1994
7. Boucher P, Teasdale N, Courtemance R, Bard C, Fleury M: Postural stability in diabetic polyneuropathy. *Diabetes Care* 18: 638–645, 1995
8. Richardson JK, Ashton-Miller JA, Lee SG, Jacobs K: Moderate peripheral neuropathy impairs weight transfer and unipodal balance in the elderly. *Arch Phys Med Rehabil* 77:1152–1156, 1996
9. Oppenheim U, Kohen-Raz R, Alex D, Kohen-Raz A, Azarya M: Postural characteristics of diabetic neuropathy. *Diabetes Care* 22:328–332, 1999
10. Geurts CH, Nienhuis B, Mulder TW: Intrasubject variability of selected force-platform parameters in the quantification of postural control. *Arch Phys Med Rehabil* 74: 1144–1150, 1993
11. Panzer VP, Bandinelli S, Hallett M: Biomechanical assessment of quiet standing and changes associated with aging. *Arch Phys Med Rehabil* 76:151–157, 1995
12. Benvenuti F, Mecaaci R, Gineprari I, Bandinelli S, Benvenuti E, Ferrucci L, Baroni A, Rabuffetti M, Hallett M, Dambrosia JM, Stanhope SJ: Kinematic characteristics of standing disequilibrium: reliability and validity of a posturographic protocol. *Arch Phys Med Rehabil* 80:278–287, 1999
13. Winter DA: *A.B.C. of Balance During Standing and Walking*. Waterloo, ON, Canada, Waterloo Biomechanics, 1995
14. Geursen JB, Altena D, Massen CH, Verduin M: A model of standing man for the description of his dynamic behaviour. *Arch*

Phys Med Rehabil 70:63–69, 1976
15. Murray MP, Seireg A, Scholz RC: Centre of gravity, centre of pressure and supportive forces during human activities. *J Appl Physiol* 23:831–838, 1967
16. Corriveau H, Hébert R, Prince F, Raîche M: Test retest and interrater reliability of the COP-COM variable of postural stability in the elderly. *Arch Phys Med Rehabil*. In press
17. Valk GD, Nauto JJP, Striners RLM, Bertelsman FW: Clinical examination versus neurophysiological examination in the diagnosis of diabetic polyneuropathy. *Diabet Med* 9:716–721, 1992
18. Valk GD, Sonnaville JJ, Houtum WHV, Heine RJ, vanEijk JTM, Bouter LM, Bertelsmann FW: The assessment of diabetic polyneuropathy in daily clinical practice: reproducibility and validity of Semmes Weinstein monofilaments examination and clinical neurological examination. *Muscle Nerve* 20:116–118, 1997
19. Desrosiers J, Hébert R, Bravo G, Dutil É: Hand sensitivity of healthy older people. *J Am Geriatr Soc* 44:974–978, 1996
20. Wu G: The relation between age-related changes in neuromusculoskeletal system and dynamic postural responses to balance disturbance. *J Gerontol* 4:M320–M326, 1998
21. Era P, Schroll M, Ytting H, Gause-Nilsson I, Heikkinen E, Steen B: Postural balance and its sensory motor correlates in 75-year-old men and women: a cross-national comparative study. *J Gerontol* 51:M53–M63, 1996
22. Corriveau H, Hébert R, Prince F, Raîche M: Intrasession reliability of the "center of pressure minus center of mass" variable of postural control in the healthy elderly. *Arch Phys Med Rehabil* 81:45–48, 2000
23. Winter DA, Patla AE, Prince F, Ishac M, Gielo-Perckak K: Stiffness control of balance in quiet standing. *J Neurophysiol* 80: 1211–1221, 1998
24. Mcllroy WE, Maki BE: Preferred placement of the feet during quiet stance: development of standardized foot placement for balance testing. *Clinic Biomec* 12:66–70, 1997
25. Winter DA: *Biomechanics and Motor Control of Human Movement.* Toronto, Wiley, 1990
26. Semmes J, Weinstein S, Gjent L, Teuber H: *Somatosensory Changes After Penetrating Brain Wounds in Man.* Cambridge, MA, Harvard University Press, 1960
27. Sosenko JM, Kato M, Soto R, Golberg RB: Sensory function at diagnosis and in early states of NIDDM in patients detected through screening. *Diabetes Care* 15:847–852, 1992
28. McGraw P, Winn B, Whitaker D: Reliability of the Snellen Card. *BMJ* 10:1481–1482, 1995
29. Bouska MJ: Perceptual evaluations. In *Temple University Rehabilitation.* Philadelphia, Research and Training Associates, Visual Systems Laboratory, 1983
30. Tinetti M: Performance-oriented assessment of mobility problems in elderly patients. *J Am Geriatr Soc* 34:119–126, 1986
31. Desrosiers J, Prince F, Rochette A, Raîche M: Reliability of lower extremity strength measurements using the belt-resisted method. *J Aging Phys Act* 6:317–326, 1998
32. Kaiser F, Korner-Bitensky NA, Mayo NE, Becker R, Coopersmith H: Response time of stroke patients to a visual stimulus. *Stroke* 19:335–339, 1988
33. Simoneau GG, Derr JA, Ulbrecht JS, Becker MB, Cavanagh PR: Diabetic sensory neuropathy effect on ankle joint movement perception. *Arch Phys Med Rehabil* 77:453–460, 1996
34. Machin D, Campbell M: *Statistical Tables for the Design of Clinical Trials.* Oxford, Blackwell Scientific Publications, 1987
35. 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* 49: M72–M84, 1994
36. Horak FB: Clinical assessment of balance disorders. *Gait Posture* 6:76–84, 1997
37. Winter DA, Prince F, Stergiou P, Powell C: Medial-lateral and anterior-posterior motor responses associated with centre of pressure changes in quiet standing. *Neurosci Res Commun* 12:141–148, 1993
38. Thomas PK: Classification, differential diagnosis, and staging of diabetic peripheral neuropathy (Review). *Diabetes* (Suppl. 1) 46:S54–S61, 1997
39. Raîche M, Hébert R, Prince F, Corriveau H: Screening community-dwelling older fallers using the Tinetti balance scale. *Lancet.* In press
40. Raîche M, Hébert R, Prince F, Corriveau H: Validité prédictive du test de Tinetti dans le dépistage du risque de chute des personnes âgées de plus de 75 ans vivant à domicile. *Can J Rehabil* 11:225–225, 1998
41. Allen C, Shen G, Patla M: Long-term hyperglycemia is related to peripheral nerve changes at a diabetes duration of 4 years. *Diabetes Care* 20:1154–1158, 1997