Alberta Heritage Foundation
for Medical Research

Dynamic posturography
in the rehabilitation of stroke, brain injured and amputee patients

Christa Harstall

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This Health Technology Assessment Report has been prepared on the basis of available information of which the Foundation is aware from public literature and expert opinion, and attempts to be current to the date of publication. It has been externally reviewed. Additional information and comments relative to the Report are welcome, and should be sent to:

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Contents

Summary

- This assessment was undertaken at the request of a Regional Health Authority to provide input into a funding decision on a computerized dynamic posturography (CDP) system for use by a rehabilitation department.

- Standing balance is a variable most frequently assessed by the rehabilitation community in patients experiencing symptoms of dizziness and balance disorders. CDP provides a quantitative assessment of aspects of dynamic balance and has been used to design and monitor rehabilitation programs for patients with vestibular disorders and other neurological deficits.

- The newest CDP system by NeuroCom International Incorporated is an example of current technology. It combines the EquiTest® and SMART Balance Master® and is listed at a base price of $138,500. This system allows for quantitative evaluation of the integration of three sensory inputs (vision, proprioception and vestibular) and motor control balance.

- Studies evaluating the reliability and validity of systems which measure dynamic balance in patients with vestibular and/or balance deficits associated with stroke, brain injury or amputation were considered. Few studies have been conducted to establish the reliability of performance scores derived from CDP.

- The focus in rehabilitation is on monitoring a change in an individual patient over the course of a treatment. Hence the reliability and validity of CDP must be established for the specific patient population of interest. Further research is required not only to determine reliability and validity but also to establish a relationship between the measurements of CDP and measures related to the patient's quality of life and functional abilities.

- No controlled studies were found that considered the efficacy or effectiveness of using CDP in a rehabilitation setting for the assessment and monitoring of patients with vestibular and/or balance deficits. The strength of the evidence of CDP efficacy ranges from fair to poor.

- CDP has not been used for patients who have experienced an amputation. No studies were located that employed CDP in the rehabilitation of patients with brain injury. Most studies which specifically focused on determining the efficacy or effectiveness of CDP as an assessment and treatment monitoring tool were of weak design.

- CDP is not an established technology in the rehabilitation of vestibular and/or balanced deficits associated with stroke, brain injury and amputation.

Within the context of the Alberta health care system

- CDP should be regarded as developmental. Any utilization should be linked to well-defined data collection protocols, which include functional and clinical outcome measurements, and appropriate patient selection criteria.

- Before any use, in clinical applications or research, reliability and validity must be addressed for the specific patient group.

Introduction

This assessment was undertaken at the request of a Regional Health Authority to provide input into a funding decision on a computerized dynamic posturography (CDP) system for use by a rehabilitation department. The focus of this study was restricted to the clinical use of CDP by the rehabilitation community. Applications considered were evaluation and monitoring of balance, and balance treatment or retraining of patients with vestibular disorders, or balance deficits, associated with stroke, brain injury or amputation.

Standing balance is a variable most frequently assessed within rehabilitation (10). Adequate balance is necessary for controlled mobility and most activities of daily living.

Balance, defined in its broadest sense, "involves the capability to control upright posture under a variety of conditions and the ability of an individual to sense his or her limitations of stability" (3). Introduction of equipment capable of objectively measuring and treating balance disorders is desirable in a rehabilitation setting. There are several tests of standing balance which are applied widely to patients suspected of having balance deficits of various etiologies.

Balance disorders may be vestibular or nonvestibular in nature. Vestibular disorders include unilateral vestibular hypofunction, bilateral vestibular hypofunction (most often the result of ototoxicity), central vestibular dysfunction (which may be the result of cerebral concussion) and mixed vestibular dysfunction (16). Non-vestibular disorders that can cause or result in balance disorders include a variety of anxiety and psychological/psychiatric disorders, proprioceptive/somatosensory deficits, central lesions that are non-vestibular in nature and a variety of orthopedic problems (17), (Shepard, personal communication).

This assessment considers rehabilitation of patients with balance and postural control deficits associated with stroke and orthopedic problems which are usually non-vestibular in nature. It also focuses on patients with balance disorders associated with brain injury which may be related to central vestibular problems. The assessment and treatment of symptoms in these two groups of patients by rehabilitation professionals may vary.

A literature search (see Appendix A for methodology) was conducted concentrating on finding evidence of efficacy and/or effectiveness of CDP in providing quantitative information which may assist rehabilitation therapists in the assessment and treatment of patients with balance disorders. The literature review was supplemented by a contacting Canadian and US facilities which employ CDP. Information sought from these centres is shown in Appendix B.

Vestibular and balance rehabilitation

The treatment used for vertigo and unsteadiness depends on the cause of the symptoms. Most people with balance disorders of a peripheral vestibular nature undergo spontaneous resolution of their symptoms (39). This is due in part to the self limiting nature of most of these conditions as well as to the remarkable process of central nervous system (CNS) compensation (20,37). Occasionally, peripheral vestibular insults or lesions affecting other portions of the balance system (central vestibular or postural control system) may cause persistent symptoms of imbalance and dizziness, thereby resulting in chronic disability (20,39).

The treatment of patients with such conditions is complex. Treatments can include any combination of medication (some patients with Meniere's disease), surgery (patients with perilymphatic fistulas and tumors), and /or vestibular rehabilitation therapy (vestibular and balance therapy which may include both retraining and habituation).

Symptoms related to vertigo, disequilibrium and unsteadiness are usually associated with vestibular dysfunction but other sites of origin (non vestibular) can manifest symptoms of a similar nature (35). It is important to establish prior to rehabilitation if the symptoms resulting in a decrease of postural control and balance are related to functional deficits which may be treatable. Studies of efficacy or effectiveness of CDP in a clinical rehabilitation setting most often discuss its utilization as a component of a vestibular rehabilitation or balance retraining program.

Vestibular rehabilitation (VR) consists of an exercise program, designed by trained therapists, to help a person compensate for a loss of imbalance within the vestibular system. Patients who do not demonstrate a spontaneous resolution of symptoms such as dizziness and disequilibrium within three to six months of their onset and whose medical evaluation reveals no evidence of a progressive process may benefit from VR (20,36,37,40,42). In these patients, the CNS seems unable to adequately compensate for the inner ear deficit (40).

Other indications for the use of VR are multifactorial balance difficulties (such as seen in the elderly) and optimizing the outcome after vestibular surgery (37,42). In patients whose symptoms occur in spontaneous episodes only (for example Meniere's disease) VR may not be beneficial (37). The balance activities of VR help people maximize the use of the remaining vestibular function, their sight, and the sensation in their feet to keep their balance (2).

The utility and success of VR appears to be related to the cause of the symptoms. Only 30% of patients who have symptoms due to head injury will show improvement with VR, compared with 90% of patients without head injury and whose symptoms occur only with rapid head movement (42).

The role of CDP systems in VR are quantitative assessment of balance impairment and the designing and monitoring of rehabilitation programs. The assessment tools available

in the rehabilitation environment to evaluate standing balance after stroke are outlined by Collen (8). These have been categorized into 3 main groups depending on the sophistication of the tests and what they are measuring:

1) Global, clinical measures of balance dysfunction used primarily to guide therapy and to evaluate therapeutic outcomes. This category of measurements has been separated into three groups - timed balance tests (eg. Romberg test), rating scales (eg. Bohannon Balance Scale) and functional tests (eg. Get Up and Go).

2) Simple qualitative tests of static postural instability, used where intermediate levels of information suffice. This category includes the pedobarograph and the Nottingham Balance Platform.

3) Sophisticated instrumented perturbation techniques used to assess differential diagnoses or to evaluate more specific therapeutic intervention. This category is subdivided into three groups - systems that move the base of support, systems that move the centre of mass relative to the base of support and systems that measure where the centre of mass is relative to the base of support (eg. Balance Master®).

Dynamic posturography systems belong to the third category, which measure the ability to shift the centre of pressure or mass within the base of support and towards the perimeter (dynamic balance).

Description of posturography systems

The postural control system consists of three basic functional components: the musculoskeletal system, motor coordination and sensory organization. The sensory processes are important for orientation and balance control (11,38).There are three distinct sensory systems: vision, proprioception (gravity and stretch sensors found in muscles and joints), and the vestibular system (organs in the inner ear which detect angular and linear acceleration).

To evaluate the balance system and its ability to maintain postural control, an examination of the integration of the three sensory inputs and their ability to handle sensory conflict is needed (34). Instability can result from inappropriate interaction among the three sensory inputs. Balance control depends upon the ability to adaptively modify the relative weighting of each sensory modality according to the contextual environment.

Clinical testing of the sensory inputs for balance control began with Romberg's demonstration of postural instability (patients stand quietly with eyes open and then with eyes closed). Romberg demonstrated that subjects with somatosensory deficits became destabilized when only vestibular input was available. Subsequently, various investigators have quantified body sway and other variables that reflect maintenance of balance during the Romberg test (28). Quantitative measurements rather than subjective assessments of

balance and postural control have been made possible through the advent of forceplate technology. A forceplate may be static or dynamic.

Static platforms are equipped with strain gauges used to record the minute swaying of the body that is too fine to see with the naked eye. Use of static platforms involves a timed stance with eyes open and closed (Romberg's test), on a fixed force plate which senses vertical and in some cases horizontal (shear) force exerted by the feet on the ground during an upright stance (31). The forces are monitored and data are stored in a computer. Analysis usually includes a computation of the projection of the centre of force upon the horizontal plate as a function of time. Data on the position of the centre of force versus time can be used to compute the amplitude, speed, or frequency power spectrum of sway. The results are compared with the performance of normal individuals.

Moveable platforms can either move in the horizontal plane (translate) or rotate out of the horizontal plane, pitching the individual forward or backward (8). In addition to the computer-controlled moveable platform, a moveable visual surround may be employed. The platform or visual surround, or both, move in response to the patient's forward and backward sway, creating a disturbed proprioceptive and/or visual input to the brain. A computer analyzes the centre of force versus time responses (44).

Monsell and colleagues (29) outlined the general characteristics that would qualify a device as a CDP system. The device must be capable of measuring postural sway, perturbing the body's centre of mass, isolating visual and somatosensory inputs and quantification and signal analysis. Therefore, the use of a static forceplate employing some method for disturbing a patient's postural stability and quantification of the signal would qualify it as a CDP system. Methods for perturbing the body's centre of mass while using a static platform include vibratory stimulus applied to the calf region, galvanic stimulus of the vestibular system and head mounted air jets (38).

Following the definition of CDP by Monsell and colleagues (29), this assessment includes consideration of systems with both static (Balance Master®) and dynamic (SMART, PRO Balance Master®, Chattecx® Balance System, EquiTest®) force platforms with self initiated and external perturbations.

NeuroCom International Incorporated markets the EquiTest®, PRO Balance Master®, SMART Balance Master® and Balance Master®. The Balance Master® allows objective patient assessment and interactive training by self initiated perturbations. Both the SMART Balance Master®and the PRO Balance Master® offer assessment and training of the use of sensory inputs to balance control, in addition to the centre of gravity control training. The EquiTest® offers specific assessments of the sensory organization and motor control of balance. The newest system available combines both the EquiTest® and SMART Balance Master® systems and is listed at a base price of $138,500.

Most of the studies included in this assessment used the EquiTest® system. This system became commercially available in the United States in 1985. It includes both the evaluation of coordinated reflex motor responses after abrupt platform perturbations and

the assessment of sensory organization for control of balance. The motor control test analyses the properties of the patient's automatic postural reactions to external challenges. The sensory organization component isolates each of the principal balance senses (vision, vestibular and somatosensory) and determines the function of each in isolation as well as during interactions (23).

During the movement coordination or motor control test, the centre of mass perturbations are created through abrupt anterior or posterior (A/P) horizontal translations of the support. The translations are delivered in three increasing intensities in both directions. These may be followed by unexpected rotations about the ankles and five randomly timed toes up or toes down rotations. The latency to onset of active recovery from the unexpected perturbations is the primary output parameter measured (38).This test is used less for functional evaluation than the sensory organization tests (SOTs). The SOTs provide information on which input system cues that the patient is unable to utilize for maintaining postural control while performing a specific task (38).

The SOTs involve six stance conditions, the first two being Romberg's test. The remaining four involve instantaneous displacements of the platform or surrounding visual environment or both, simultaneously with body sway. The "sway-referenced" conditions that distort visual and somatosensory inputs increase the patient's use of vestibular inputs for balance (38). The variable that is quantified is the maximum peak to peak sway. This is calculated as a percentage of the maximum peak to peak sway movement in the sagittal (anterior/posterior) plane compared to a theoretical limit of sway. The equilibrium score is expressed as a percentage and represents the magnitude of sway in the sagittal plane for each trial of each test condition and is based on a normal value of 12.5^0 of anterior/posterior sway about the ankle joint (38).

Some researchers have classified patients according to the pattern of abnormal stance time during the six sensory conditions (5,36,38). Patient performance is compared with norms established by the manufacturer together with multiple independent centres, primarily academic in nature (38).

CDP provides quantitative assessment of certain functional aspects of dynamic equilibrium and as such it is used to design and monitor rehabilitation programs for patients with vestibular disorders and other neurological deficits (11). Abnormalities identified by CDP may be interpreted to mean that the balance disorder is caused by either biomechanical or neurological conditions (29).

Reliability and validity of dynamic posturography systems

As a first level of assessment of DP systems as a tool for rehabilitation, it is useful to consider the reliability and validity of the measurements obtained. Reliability may be defined as the consistency, the reproducibility and the repeatability of the measurement procedure (32). This means, any variation in measurement reflects variation in the variable being measured. There will also be systematic or random fluctuations due to errors of measurement. Validity refers to the measurement system's ability to actually measure what it is supposed to measure (32).

Usually in rehabilitation, the focus is on monitoring a change in an individual patient during treatment rather than differentiating among patients (33). Therefore, the concern is more with the reliability of the individual measurement results. Most of the studies located concentrate on the reliability of data provided by the measurement system.

Reliability is most frequently assessed by a coefficient such as a Pearson Product Moment Correlation Coefficient or an Intraclass Correlation Coefficient (ICC). ICC may be defined as a ratio of the variance of interest over total variance. Usually values below ICC 0.60 mean that the measurement is of questionable reliability (32). Only one study (6), used another approach to assess reliability, the generalizability theory. The generalizability theory is used to estimate the magnitude of multiple sources of measurement error and to assess reliability of measurements for specific applications of the measurements (33).

Since this technology is being considered for use in a rehabilitation setting, the aspects of validity and reliability are of prime importance. Furthermore, CDP measurements need to be linked to functional, clinical, outcomes indicators which are of relevance to the patient. Unfortunately few studies have been conducted to establish the reliability of the performance scores derived from computerized posturography (6,15). However, manufacturers have reported high intra trial reliability of measurements in control subjects (15).

Nine studies in which the researchers attempt to validate dynamic posturography for the treatment and management of patients with postural and balance disorders are detailed in Table 1. Several different posturography systems are evaluated including two assessments utilizing a static platform while employing tests of dynamic balance (4,26).

Two studies assessed the reliability and validity of the EquiTest® system (15,46). Verthem and colleagues (46) studied a group of patients diagnosed with polyneuropathy. A correlation between clinical scores (disability and ataxia) and muscle response latencies for forward perturbations, and the EquiTest® system's conditions 2, 5 and 6. Intraclass correlation coefficients ranged from poor to good using the interpretive scale mentioned by Ford-Smith and colleagues (15) in their study.

In independently living elderly adults, the SOTs of the EquiTest® system showed poor to good reliability across all 6 sensory conditions (15). Ford-Smith and colleagues (15)suggested that the Equitest's SOT protocol would be more statistically reliable if subjects were given a score for their effort to remain standing on a given trial even though they might fall during the trial. With the current scoring system, the SOT does not differentiate between those subjects who show a high amplitude A/P sway from those who are able to stand at the end of their limits of stability (LOS) until the last few seconds of the trial.

Liston and Brouwer (26) focused their study on determining the test-retest reliability and validity of data obtained from stroke patients using the Balance Master® (BM). Using the Berg Balance Scale and gait velocity as standards, the concurrent validity of the BM data was determined. The authors reported that only the BM test requiring subjects to shift their centre of gravity(COG) to randomly highlighted targets was reliable, in terms of movement and movement time. The concurrent validity was established for the dynamic measures of balance. These correlated with both the Berg Balance Scale and gait velocity outcomes.

In a recent study (4) using the Balance Master® in healthy, young subjects, Brouwer and colleagues examined the reliability of the static and dynamic measures of balance, the maximal limits of COG excursion (100% LOS) and the position of the COG relative to vertical during quiet stance. In this population, the reliability of static and dynamic measures of postural stability and balance performance was fair to good. One of the main conclusions of this study is the importance of basing balance performance on actual COG position and excursion, rather than using standard norms.

Clark and colleagues (6) took reliability testing of the PRO Balance Master® one step further by trying to establish the reliability of the limits of stability test and to determine the relative variance contributions from identified sources of measurement error. They note that the sources of measurement error associated with the various test protocols have not been adequately identified. Knowledge of the sources of error and their contribution to total error measurement would enhance the practical application of studies that have examined test-retest reliability.

Reliability was estimated by Clark et al. using the generalizability theory as opposed to intraclass correlation analysis. This model allows for the major sources of error to be isolated as well as estimating the magnitude of multiple sources of measurement error. They concluded that the 75% and 100% limits of stability tests, using the PRO Balance Master®, are reliable tests of dynamic balance when administered to healthy older adults. Reliability tests are currently being conducted on a variety of patient populations, one of which is hemiparetic patients.

Four studies assessed the reliability and validity of the Chattecx® Balance System. Three of these (10,14,25)assessed the validity and reliability in patients with hemiparesis. A number of differences among these three studies may account for some of the variances in reported results. Differences included the time period (10 or 25 seconds) each test was

used, operation of the system at 50% of its capacity, the of use different types of control groups and tests being conducted with either eyes open or closed or both conditions.

Collen (8) noted in her review of existing measurements of balance and postural control that further research should be focused on establishing validity and reliability rather than designing new measures. Measurements need to separate the postural problem into its basic functional components for interventions of balance disorders to be specific and effective.

Ideal clinical measurements for the assessment of postural control are defined by Collen as “measures that reflect both the functional abilities and quality of movements of the postural control system; measures that are both sensitive and selective for postural control deficits; measures that are reliable and valid; measures that are sensible and practical in a clinical setting; and measures that are easily communicable.” Moreover, she states, “an awareness is required that postural control may depend on age and existing pathology, as well as environment and behavioural contexts in which the balancing activity is performed. ”

Evidence of efficacy

Higher levels of assessment of CDP as a tool in rehabilitation concern evidence of its effect in influencing management decisions and patient outcomes.

To determine efficacy and effectiveness of CDP in a rehabilitation setting for patients with balance deficits associated with stroke, brain injury and amputation, most studies located used CDP within a vestibular and balance rehabilitation program. The dynamic posturography system used most frequently throughout these studies was the EquiTest®, mainly the six tests of sensory organization.

No controlled studies were found that looked at the efficacy or effectiveness of using dynamic posturography in a rehabilitation setting for the assessment and monitoring of patients with balance disorders.

Table 2 outlines eleven clinical studies. In these studies dynamic posturography measurements were used as an integral part of a rehabilitation program. Use included criterion to determine candidacy, patient classification, quantification of postural control and assessment of treatment effect. Most of these studies were prospective observational (pretest and post test) comparisons which investigated the effect of VR in samples of usually less than 50 individuals.

The largest observational study of 152 patients was conducted by Shepard and colleagues (36,39). All the patients were grouped together with the majority, 58%, having a diagnosis of unilateral peripheral disease. In 82 patients (54%) comparison of the pre- and post-therapy mean composite equilibrium scores for the sensory organization portion of dynamic posturography, demonstrated statistically significant improvement. However, the authors noted that both the pre and post scores, although significant, were near the normal

range and may not represent functional improvement. It was suggested that the change in pre and post therapy scores may be due to a learning effect. Furthermore, the posturography criterion for inclusion did not appear to influence the prognostic indications from posturography.

Herdman and colleagues (19) reported on the use of VR, employing the EquiTest® system, directly following vestibular surgery. They noted a significant difference in peak to peak forward/backward sway between normal subjects and the patients with acoustic neuroma on all sensory tests. They conclude that VR facilitates the rate of recovery as indicated by improvements in test condition 4. However, this finding is based on 4 patients with an abnormal Romberg in the VR group who returned to preoperative stability on discharge compared to 5 patients with an abnormal Romberg in the "control" group (smooth -pursuit eye movements exercises) who did not.

The patients' assessment of disequilibrium was also significantly reduced by postoperative day 5 and 6 in the VR group compared to the control group. Herdman et al. note that they do not know the functional significance of the improved stability on condition 4 and the decrease in disequilibrium reported by the patients.

Magnusson and colleagues (27) conducted a randomized, prospective study on the long term effects of physio and occupational therapy (control group) compared to sensor stimulation (treatment group) in stroke patients. They used a forced platform to record anteroposterior and lateral sway velocity and dynamics of postural control (swiftness, stiffness and damping) among the groups. They reported no difference in sway velocity between the stroke patients and normal age matched individuals.

Only one study, by Vitte et al. (45) made mention of the validity or responsiveness of dynamic posturography. Patients were grouped by diagnosis, and those with unilateral labyrinthine defect (n=5) were compared to patients with bilateral (n=5) labyrinthine defect. A significant correlation between the EquiTest® results and the modification of the optokinetic nystagmus parameters was noted. Optokinetic stimulation was used to rehabilitate these two groups of patients with balance disorders.

Szaturn and colleagues (41) studied patients with chronic peripheral vestibular disorders who were treated with biofeedback training sessions. The patients showed improvement for test conditions 3 and 4, and a reduction in left-right differences in VOR gain. However, there was no attempt to analyze agreement or correlation between these two measures.

El-Kashian et al. (11) compared the concurrent validity of the Clinical Test of Sensory Integration and Balance (CTSIB) to dynamic posturography. Data for this study were collected on a group of normal subjects and patients with vestibular disorders. They reported good correlation between CTSIB and CDP but, statistically significant differences were identified between CDP and CTSIB in detecting patterns of dysfunction. Their study also indicated statistically significant differences in composite equilibrium

scores, as measured by CDP, at baseline between the two groups which became insignificant post therapy, indicating the benefit of the rehabilitation program.

Quality of studies on dynamic posturography

A clinical measure must demonstrate that it is reliable, valid and responsive (3,24,26). A change in score should indicate a true change in patient status and differences in scores between individuals should represent true diversity between patients and not variation due to random error. Knowledge of the various sources of measurement errors allows the user to control or eliminate the error (6). Also, when multiple items are scored and summed, it is advisable to assess how the individual items relate to each other and the total score.

The other desirable property of a good clinical measure is responsiveness. That is, the ability to detect clinically meaningful changes in the status of a patient (3,12). In the absence of a gold standard, validation requires the use of several strategies and multiple cross-validation studies (3).

Until test-retest reliability is established, the information gathered with DP systems may be negligible in determining the effectiveness of treatment interventions or the success of rehabilitation methods (15). Determination of reliability is complicated further as DP seems to be an evolving technology. Clark et al. (6) noted that direct comparison of their results to other studies was not possible because the test-retest reliability of LOS movement variables are no longer available in the most recent balance master software.

It is of importance that the systems discussed in this assessment are not necessarily comparable. There was only one study (11) which compared the EquiTest® with the CTSIB (a non instrumented system of measurement). A good correlation was found (ICC 0.41-0.89) between the scores of the sensory organization portion of DP and the CTSIB technique in patients with balance disorders.

Four studies focused on determining the reliability and validity of the BM (static platform) (26)and the Chattecx® system (moveable platform) (10,14,25), as retraining tools, in patients with hemiplegia. All studies presented intraclass correlation coefficients but only one study used coefficients of concordance to other dynamic measures of balance. Even though the measurements of BM were correlated to functional tests (Berg Balance Scale and gait velocity), Liston and Brouwer (26) did not include quality of life or symptom improvement indices.

Liston and Brouwer stated that the predictive validity of the BM measures remain to be explored. They emphasized that if these measures are to be used in evaluating, training and monitoring changes in balance performance, then test-retest reliability and validity of data are essential.

Most of the studies located for this assessment used systems supplied by NeuroCom International Incorporated and relied on manufacturer's norms or data from healthy volunteers for analysis and comparisons. The authors of two studies (4,10) agreed that the

measurement systems test-retest reliability for specific patient populations cannot be inferred from studies of healthy populations. A recent study by Brouwer et al. (4) concluded that inter subject variation in resting COG position and in limits of stability, in the healthy population under study, supported the use of absolute performance measures. Therefore, they suggest that the interpretive value of data relative to standard norms is limited.

Research design differences were apparent in the studies summarized in Table 2. Some studies, particularly the largest one (36), grouped their patients together irrespective of their diagnosis, while others focused on a specific diagnostic group such as stroke (27), peripheral vestibular disorders (20) or acoustic neuroma (19). Other noticeable differences among the studies were the time of symptom onset to intervention which varied from 2 months to multiple years, the number of sessions or visits to a rehabilitation clinic, outcome measures used as adjuncts to posturography, the reporting of the sensory organization portion of CDP measurements and the variations in length of follow-up. Outcome measures included subjective assessments by patients, changes in disability status, posturography scores, measures of motion sensitivity and changes in self reported dizziness.

There were also variations in how the measurements of CDP were utilized within the studies. At times performance measures were used to select patients for rehabilitation, to determine the prognostic value of the treatment, or to measure the success of the intervention, or the system itself was used for retraining. These multiple uses of the system within the studies adds to the difficulties of interpreting the effectiveness of this technology for a specific indication.

Few of the studies addressed the relationship between vestibular impairment or compensation and the level of dizziness, balance disorder, or functional disability (7). Many CDP measurements do not relate to functional performance indicators such as gait speed, Berg Balance Scale or Get Up and Go indices (Brouwer, personal communication). Jacobson and colleagues (21) explored the relationship between results of various indices of balance function (CDP was one of the indices) and the patient's perceived balance handicap (DHI). This study was not included in Table 2, since only 58 patients out of the total sample of 367 (16%) underwent examination using the EquiTest®.

The authors suggests that the SOT is a valid criterion variable for evaluating the handicapping effects that balance disorder has on a patient's self perceived ability to function in daily life. SOT coupled with the scores obtained from the DHI could be used as outcome measures for documenting treatment benefit when used in a pretreatment protocol. However, despite the statistically significant correlation between balance function testing and perceived dizziness handicap, more than 77% of the variance in self-assessed dizziness handicap remained unexplained. Clearly, well designed research is required in this area to establish meaningful outcome measures.

The largest study (36) in which measurements of CDP were used to determine the benefits of VR used a diverse patient population with wide ranging diagnoses and variations in the times of symptom onset. The authors note that the site-of-lesion or diagnostic category has minimal impact on outcomes of VR. It is the symptoms that appear to be more important than the diagnostic category. However, Fabio (9) noted that diagnostic category had a significant influence on the predictive value of abnormal results and on the magnitude of the effect size seen with CDP.

The clinical utility of CDP is difficult to establish through research for several reasons, one of which is that there is no gold standard for comparison. Mruzek et al. (30) summarize succinctly the difficulties of conducting controlled studies for various rehabilitation programs in a population with symptoms of dizziness and balance disorders. Firstly, since vestibular lesions in general are self limiting, it is difficult to differentiate between the recovery that occurs spontaneously and the recovery that occurs as a result of the therapeutic intervention. Secondly, not only do patients with dizziness represent a wide range of diagnoses, but the duration, severity, and frequency of symptoms vary among patients with the same diagnosis. Thirdly, the nature of physical therapy requires support and encouragement which are factors that may mask the failures of the interventions under consideration. Finally, there is a need to control other factors such as lifestyle, activity levels and home and family support networks that could confound intervention outcomes.

Statements on status of the technology

In searching for evidence of effectiveness of CDP systems, position papers and consensus statements were located.

The 1992 report of the Therapeutics and Technology Assessment Subcommittee of the American Academy of Neurology (44) noted that “Posturography is a technology that is still evolving, and the literature that addresses the usefulness of posturography is sparse. A final judgment regarding its clinical effectiveness cannot be made at this time.” The report makes specific statements in relation to static and dynamic posturography. Based upon class III evidence (defined as evidence provided by expert opinion, non-randomized historical controls, or one or more case reports) “dynamic posturography is considered “promising” for use in specialized environments dedicated to the analysis and management of vestibular dysfunction (44).”

The report states that there is potential for the application of this technology in the physical therapy community but it is still investigational. This view was predicated on the fact that “no documented reports are available regarding the use of dynamic posturography by physical therapists.”. But, in the experience of the panelists “…dynamic posturography can be used to some benefit in designing physical therapy regimens for patients with balance disorders. However, the ultimate role of dynamic posturography in the field of physical therapy is yet to be determined (44).”

The American Academy of Neurology has indicated that since there was no new scientific evidence available, it was not necessary at this time to reassess and update this position on dynamic posturography (Arciniega, personal communication, 1997).

The American Academy of Otolaryngology-Head and Neck Surgery issued a statement of endorsement in April 1997: " Computerized dynamic platform posturography (CDPP) is an established test of postural stability. Much of the information provided by CDPP is unique, particularly because the data are quantitative. CDPP may be useful in the management of patients with symptoms or signs of chronic balance dysfunction when combined with the clinical history, physical examination and data from other vestibular tests. Its value depends on patient selection, technical performance of the test and interpretation by a knowledgeable clinician, and therefore the AAO-HNS endorses this modality (1)." This statement, however, applies to the diagnostic use of CDPP for vestibular disorders.

Conclusions

Well designed studies are required in all aspects of the use of CDP to define the role of this technology in the rehabilitation community.

The reliability, validity and responsiveness of the CDP systems utilized in the studies included in this assessment need to be established through further research. NeuroCom International Incorporated have developed a normative database for all their systems. It may be argued that the gathering of values for this database was an exercise that established reliability (Shepard, personal communication). However, there is some dispute about the use of these values for analysis and comparisons. The use of normative data for comparison to patients with vestibular and/or balance deficits is another area that needs to be resolved through further research.

In considering the strength of the evidence based on type of design and scientific rigor of the studies presented in Table 2, the Jovell and Navarro-Rubio classification was used (22). According to this classification, the strength of the evidence of CDP efficacy ranges from fair to poor ("Fair" relates to results from non-randomized controlled retrospective trials, cohort studies and case control studies; "Poor" refers to information from non-controlled clinical series, descriptive studies and consensus methods).

No controlled studies were found and the research design of the studies located were weak. Moreover, there were no studies comparing the different systems available to measure dynamic balance. The difficulties of conducting controlled studies for various rehabilitation interventions in a population with symptoms of dizziness and balance disorders, as noted by Mruzek, (30) means that researchers will continue to have challenges to produce the evidence needed to define CDP as established in a rehabilitation setting.

From the information available for this assessment, CDP has not been used in the amputee population. There were no studies found specific for the rehabilitation of

patients with brain injury using this technology. Treating traumatic brain injury patients with dynamic posturography is often difficult since they frequently lack the cognitive abilities necessary for rehabilitative, retraining exercises (Godbout, personal communication). As for stroke patients, there are few studies which have specifically focused on determining the efficacy or effectiveness of CPD as an assessment and monitoring tool in their treatment.

The EquiTest® system is found most frequently in the ENT environment and not in the rehabilitation department. In Alberta, the Rockyview Hearing and Balance Clinic has the EquiTest® system and the program is directed by an ENT specialist.

At the two centres contacted during this study (Appendix C) the EquiTest® was used as part of an ENT program. The majority of the patients referred had peripheral vestibular lesions. Amputee patients have not been referred to these two centres. At Centre A, the measures provided by the EquiTest® are considered to be a pivotal component for making therapy recommendations in 27% to 30% of patients.

A CDP system is expensive (11) and is likely to be only available in centres servicing large volumes of patients with equilibrium and postural control disorders. Furthermore, there are special training requirements necessary for operating CDP systems. A two year training program for physical therapists is recommended (Appendix C). These physical therapists remain dedicated to the use of CDP systems in order to maintain their expertise and skills.

Although CDP is a “promising” technology (44) further research is required. Well designed studies are needed. The reliability and validity of data generated from CDP systems need to be determined for specific diagnostic groups. The technology’s most effective use or deployment in a rehabilitation program needs to be resolved. To be a clinically useful tool, measurements derived from CDP systems should be correlated with outcome measures related to the patient’s quality of life and functional abilities.

On the basis of the information available, CDP is not an established technology in the rehabilitation of vestibular and/or balance deficits associated with stroke, amputation and brain injury. Within the context of the Alberta health care system it should be regarded as developmental. Any utilization of CDP systems should be linked to well-defined data collection protocols which include functional and clinical outcome measurements, and appropriate patient selection criteria. Before it is considered for any use, research or clinical, its reliability and validity must be established for the specific patient population of interest and the determination of the relationship of these measurements to the activities of daily living.

Table 1 : Studies on the reliability and validity of DP

Author	Design	Sample	Symptoms	Measurement	Comparison	Results
Verthem et al. 1991 (46)	Prospective case control	n=28 Polyneuropathy (PN), 19 men, 9 women, mean age 67 yrs Reference group: 29 healthy volunteers, 15 women, 14 men, mean age 73 yrs	Duration of PN 2-20 yrs (mean 6 yrs)	**Moveable platform:** EquiTest®, sensory organization & movement coordination	Nerve conduction velocities (NCV), vibrametry Clinical scores: disability & ataxia scores	Compared with controls, PN patients significantly poorer equilibrium scores for 2,3 & 6 and significantly longer latency responses in movement coordination tests Correlation between clinical scores & muscle response latencies forward perturbations (ICC 0.23-0.69) & equilibrium performance sensory organization tests 2,5 & 6 (ICC 0.4-0.61) No significant correlation for backward perturbations NCV: no correlation with DP, vibrametry & clinical scores Vibrametry: no correlation with DP *CDP objective method to study equilibrium disturbances in PN & useful for monitoring treatment effects*
Ford-Smith et al. 1995 (15)	Prospective observation study	n=40 normal volunteers, community dwelling, mean age 74.8 yrs,	no progressive neurologic, vestibular, severe cardio-vascular or musculo-skeletal disease, 40% had fallen in the last year	**Moveable platform:** EquiTest®, SOT protocol SOT was administered on 2 separate days 1 week apart	N/A	Poor (< 0.4) to good (>0.4-<0.75) to excellent (>0.75) Agreement 77% to 100% for LOB first trial & LOB on 3 trials for all conditions SOT composite score good reliability (ICC 0.66) SOT first trial - condition1&2 (0.57),3 (0.15), 4 (0.34), 5 (0.70),6 (0.43) SOT average of 3 trials - Condition 1 (0.51),2 (0.42), 3 (0.26), 4 (0.47), 5 (0.68), 6 (0.64)

Table 1 : Studies on the reliability and validity of DP (continued)

Author	Design	Sample	Symptoms	Measurement	Comparison	Results
Fife & Baloh 1993 (13)	Prospective case control series	Test n=26 patients (recruited 100 patients 26 met criteria) Control n=26 age & sex matched no symptoms of imbalance Controls & patients >75 yrs, functionally independent & community dwelling, 19 women, 7 men Patients-disequilibrium or imbalance of unknown cause	Patients vertigo > 1 yr Patient grp split into 2 subgrps for analysis (7 subgrp A markedly decreased VOR gain & diagnosed as ototoxic & 19 subgrp B unknown)	**Moveable platform:** Chatteck$^{®}$ Balance System Tests 10 sec. each, 2 static-eyes open & closed, 4 dynamic-linear & angular-eyes open & closed	Rotational vestibular testing (VOR); Tinetti gait & balance;	Linear regression and correlation analysis- consistent correlation between vestibular function & posturography performance among all subjects. Decrease in VOR gain & increase in phase lead, sway velocity increased. Tinetti & balance total score correlated with sway velocity. Poorer Tinetti scores coincided with greater sway especially during eyes closed Mean sway velocity of subgrp B differed significantly from controls only in medial-lateral tilt, eyes open
Fishman et al. 1997 (14)	Prospective observation	n=20 Recruited within hospital, mean age 57.9 yrs, 12 left & 8 right hemiparesis, 12 men & 8 women	CVA within last 12 months; 9 ambulated with assistive device, 11used a cane & 5 required an ankle orthosis	**Moveable platform:** Chatteck$^{®}$ Balance System, eyes open only, operated 50% of the unit's capacity, 10 seconds for each test condition, tests in parallel stance & step stance	Self generated upper extremity balance tasks-Functional ReachTest (FRT), arm raise & arm reach tasks	No relationship between upper - extremity balance and measures of postural sway Controlling for age, FRT, correlated (0.66-0.78) with measures of postural symmetry in parallel stance FRT moderately correlated with arm raise (0.43) & arm reach (0.44)

Table 1 : Studies on the reliability and validity of DP (continued)

Author	Design	Sample	Symptoms	Measurement	Comparison	Results
Dickstein & Zeevi 1993 (10)	Prospective case control	Grp 1 n=27 hemiparetic patients recruited from physiotherapy, mean age 72.9 yrs Grp 2 n=24 healthy subjects, no history of falls, between 64 to 81 yrs Grp 3 n=13 professional staff, between 27 to 50 yrs Grp 4 n=20 physical therapy students, between 20 to 24 yrs	Grp 1 thrombo-embolic infarction 2 weeks to 9 months prior, 18 left & 9 right hemiparesis, all could stand for one minute without external support	**Moveable platform:** Chatteck$^{®}$ Balance System 4 variables : COP X axis, COP Y axis, sway & limits of postural stability 2 days, same time, one week interval Tests 10 sec. each, 2 static-eyes open & closed, 4 dynamic-linear & angular-eyes open & closed	N/A	Non-significant differences in values of COP X & COP Y between the 2 testing periods. Difference between the 1st & 2nd significant for sway in grp 1,2 & 3 indicating sway on 2nd day significantly smaller. Significant difference in sway between all grps on day 1 & 2. Significant difference for all tests between healthy grps & grp 1. Non significant differences between healthy grps Effects on sway of platform & eyes significant for all grps Effects on COP X of platform & eyes not significant while on COP Y was significant for grp 2 & 3 Retest reliability (ICC) of sway low to moderate; COP X & COP Y high
Levine et al. 1996 (25)	Prospective observational	n= 20 volunteers, inpatients or outpatients, between 32 to 86 yrs old (mean of 69.5 yrs), 14 women & 6 men Comparisons to results of 24 elderly subjects from another study (10)	Hemaparesis secondary to unilateral cerebro-vascular accident (CVA), 14 right & 6 left hemiplegia Medication was not monitored	**Moveable platform:** Chatteck$^{®}$ Balance System Testing eyes open 25 sec. each(1 static & 2 dynamic-linear & angular) in AM prior to therapy on 3 consecutive days. Day 1 “practice” day not included in analysis Three measured variables: COP on y axis, COP on x axis & dispersion index (sway)	N/A	COP X axis highly reliable (ICC= 0.92) for static condition, moderately reliable (ICC=0.89) for angular & linear (ICC=0.83) conditions. COP Y axis unreliable (ICC <0.75) for all 3 testing protocol. Dispersion index moderately reliable for angular (ICC=0.8)& static (ICC=0.75) & unreliable for linear (ICC=0.65) *CBS is a potentially useful tool for demonstrating changes in weightbearing during recovery from CVA*

Table 1 : Studies on the reliability and validity of DP (continued)

Author	Design	Sample	Symptoms	Measurement	Comparison	Results
Clark et al. 1997 (6)	Prospective observational study	n=38 community dwelling healthy older adult volunteers, between 51-84 yrs (mean age 67.5 yrs), 21 women & 17 men	No recent history of falls (last 2 yrs.), progressive neurological, cardio-vascular, or musculo-skeletal disease. Independent ambulation	**Moveable platform:** Pro Balance Master® 75% & 100% of the subjects maximum theoretical stability limits was administered in a single testing on 3 consecutive days at the same time Subjects leaned away from midline in the direction of each of 8 on-screen targets without stepping or feet movement. Four variables were calculated: movement velocity, maximum COG, endpoint COG, directional control	N/A	Reliability estimates for the 4 variables & 3 test days ranged from moderately high to high for both 75% &100% LOS Target & interaction of subjects with the targets accounted for large proportion of the total variance in each of the LOS movement variables. For both LOS tests a significant proportion of the total variability was attributed to random error and possible sources of measurement error. Small standard error of measurement indicates a limited range of possible performance scores should be expected on future evaluations. *75% & 100% LOS tests are reliable tests of dynamic balance in this patient population.*

Table 1 : Studies on the reliability and validity of DP (continued)

Author	Design	Sample	Symptoms	Measurement	Comparison	Results
Liston & Brouwer 1996 (26)	Prospective observational	n=20 Volunteers with hemiparesis (10 left & 10 right hemisphere lesions) associated with unilateral stroke, 15 men & 5 women, mean age 64 yrs	Time since stroke 6 months to 17 years	**Static platform:** Balance Master® (BM)(6 tests-3 static & 3 dynamic-rhythmic weight shifting: side to side 50% LOS (2 & 3 sec pacing);A/P; 8 targets 75% LOS Evaluated weekly on the same day & time for 3 weeks	Berg Balance Scale (gold standard) & 10m timed gait test	Performed consistently with **Berg**, ICCs = .98 (95% CI .71-.99) & **gait** velocity, ICCs = .96 (95% CI .6 - .98). SS differences between subjects for both tests. **BM:** only shifting COG to random targets were reliable in movement time ICC = .88 (95% CI .58-.99) & path ICC = .84 (95% CI .52-.98). Static sway with eyes closed ICC = .63 (95% CI .2-.94). Other data poor in terms of test-retest reliability. SS differences between subjects. All of the dynamic BM test variables correlated with Berg & 4 of these variables correlated with gait. 3 static BM tests correlated with each other as did the dynamic BM variables except for the weight shifting tests of 2 & 3 second pacing
Brouwer et al. 1997 (4)	Prospective	n=70 Healthy subjects, between 20 & 32 yrs, 54 women & 16 men	N/A	**Static platform:** Balance Master® 3 Static tests 20 sec.-n=52, 3 test days 1 week apart 3 Dynamic tests n=33, 3 test days 1 week apart COG & LOS n=38, 3 trials	N/A	ICC values >0.75 excellent,0.6 - 0.75 good, 0.4 - 0.59 fair, <0.4 poor reliability Static & dynamic measures of sway-fair to poor (ICC <0.55) LOS & position of COG- excellent (ICC >0.75) *Intrasubject variation in resting COG position & in LOS supports the use of absolute performance measures as interpretive value of data, the use of standard norms is limited*

SOT - sensory organization test
VOR - vestibular ocular reflex
COG - centre of gravity
CBS - Chattecx® Balance System
ICC - intraclass correlation coefficient
COP - centre of pressure
CI - confidence intervals
CDP - computerized dynamic posturography
LOB - limits of balance
LOS - limits of stability
BM - Balance Master®

Table 2 : Clinical studies utilizing dynamic posturography in rehabilitation

Author	Design	Sample	Symptoms	Intervention	Measurement	Follow up	Results
Shepard et al. 1990 (39) Shepard et al. 1993 (36)	Retrospective review, before/after comparison January 1988 to May 1989 n=98 Prospective, before/after comparison May 1989 to January 1990 n=54	n=152 58% unilateral peripheral disease, 23% mixed peripheral central vestibular lesions, 8% central vestibular ocular involvement, 6% undetermined, 5% bilateral peripheral paresis 63 men,89 women aged 20-89 years (mean 52)	Symptoms for 2 months or more (mean 5 years)	customized, habituation and balance rehabilitation program	**Balance**: EquiTest® DP **Other**: disability rating score, symptom rating score & MSQ	Active therapy >2 weeks (mean 10 weeks) Switch to maintenance once no change in symptoms over a 2 to 6 week period	**Mean composite ES:** n=82 pre & post scores showed a significant improvement, both pre & post scores were near normal may not represent functional improvement **Symptom rating score:** 85% had some reduction in symptoms 9% no change; 6% worsening **Disability rating scores:** 80% decreased disability score by 1. Mean post therapy scores were significantly lower. Post therapy disability scores significantly poorer for men than for women **Mean MSQ:** n=75 patients significant improvement *Head injured patients significantly poorer outcomes for all measures*
Szturm, Ireland & Turner 1994 (41)	Prospective, randomized, before/after September 1990 to September 1992	n=23 patients volunteered randomized into Home (H) program n=12 & Rehab (R) program n=11 H grp. 7 neuritis, 1 Menier's, 3 unknown, 6 men, 5 women, aged 42 to 63 yrs R grp. 4 neuritis, I unknown, 4 trauma, 2 BPPV,1 ototoxicity, 6 men, 6 women, aged 29 to 66 yrs	Imbalance, dizziness, dis-orientation >1yr	H grp. Cooksey-Cawthorne exercises, 3 to 4 times/day at home for 15 to 20 min. R grp. 45 min. training sessions using biofeedback 3 times/wk for 12 wks	**Balance:** EquiTest® 6 tests of sensory conditioning **Other:** Chair rotations in the dark to elicit horizontal VOR & OKN	1 day prior to start of therapy; 6 weeks, 12 weeks & 5 months post therapy	R grp. Statistically significant improvement in all measures for test conditions 3 & 4 over all follow up periods. Significant reduction in left - right differences in VOR gain H grp no significant change in any measure over all periods & no trend towards improvement. No change in VOR gain. No significant change in left-right differences of the VOR time constant over 4 test periods in either group.

Table 2 : Clinical studies utilizing dynamic posturography in rehabilitation (continued)

Author	Design	Sample	Symptoms	Intervention	Measurement	Follow up	Results
Horak et al. 1992 (20)	Prospective, randomized, before/after comparison Patients, physicians & testers blinded to assignment to rehab. & general grp	n=25 Peripheral vestibular disorders (BPPN/V; inner ear concussion, reduced unilateral vestibular function) 18 to 60 yrs	Dizziness and imbalance present for 6 months	n=13 vestibular rehabilitation (VR) n=4 general conditioning (GE) n=8 medication (M)	**Balance:** EquiTest® 6 tests of sensory conditioning; duration of standing on 1 foot, eyes open & closed **Dizziness:** intensity (Borg scale) & duration (dizziness index); patient questionnaire	6 weeks	**VR**: significant reduction in postural sway test 5 & 6; duration of standing, eyes open & closed, significantly increased ;dizziness index significantly reduced; 92% significant symptomatic improvement **GE**: inconclusive EquiTest®; no significant change in duration standing; dizziness index significantly reduced; 75% significant symptomatic improvement **M:** no significant change in all 6 tests; no significant change in duration standing; dizziness index significantly reduced; 75% significant symptomatic improvement
Vitte et al. 1994 (45)	Prospective, case control before/after	n=10 cases n=5 age matched (35-58yrs) healthy volunteers 2 women and 3 men (control) Grp 1:n=5 bilateral labyrinthine defective,3 women & 2 men, 38-58 yrs, no response to caloric test Grp2:n=5 unilateral labyrinthine defective, 3 women & 3 men, 33-57 yrs, 1 to 3 months postsurgery-3 acoustic neuroma & 2 vestibular neurectomy	Patients fully compen-sated to ENT (ear, nose & throat) testing but with balance disorders	OK stimulation sessions in standing subjects	**Balance:** EquiTest®, body sway measured during OK stimulation sessions, composite ES and ES for each of the 6 tests were calculated **Other:** modification of OK nystagmus low phase velocity per stimulation & #of nystagmus beats per 10s	Number of sessions to become asympto-matic 8+/-2 (age dependent) *Time in days or weeks not available*	**Grp1:** Balance- composite ES & mean ES for test 4 were significantly increased & patients fell both pre & post therapy for tests 5 & 6. Mean OKN SPV and mean OKN frequency were significant improved **Grp2:** Balance-composite ES and mean ES for tests 4,5 & 6 were significantly increased (5 patients fell in either test 5 or 6; 2 of these patients fell in both tests) SS improvement in OKN frequency & regularity asymmetry of the OKN SPVs between right & left *At end of training program, patients were asymptomatic & a significant correlation noted between EquiTest® & modification of OKN parameters*

Table 2 : Clinical studies utilizing dynamic posturography in rehabilitation (continued)

Author	Design	Sample	Symptoms	Intervention	Measurement	Follow up	Results
Mruzek et al. 1995 (30)	Prospective, randomized, before/after study	n=24 randomly assigned prior to unilateral vestibular surgery to one of three treatment groups Grp 1, n=8, 7 acoustic neuroma & 1 Meniere's, 40-77yrs, 2men & 6 women Grp 2, n=8, 6 acoustic neuroma & 2 Meniere's, 37-79 yrs, 2 men & 6 women Grp 3, n=8, 6 acoustic neuroma & 1 Meniere's, 27-65 yrs, 7 men & 1 women	Not applicable acute vestibular lesion	Grp 1: n=8 VR with social reinforcement (SR),preop unilateral caloric reduction 29% Grp 2: n=8 VR without SR, preop unilateral caloric reduction 41% Grp 3: n=8 GE with SR, preop unilateral caloric reduction 44%	**Balance:** EquiTest®, composite equilibrium scores **Dizziness:** self perceived dizziness disability used DHI by Jacob and Newman &motion sensitivity quotient **Vestibular Compensation:** rotation chair testing	5 days, & 2,5 & 7 weeks *DHI at weeks 4 & 8 postop*	**Grp1-3:**No significant differences between groups with regard to age, gender & preop caloric status No significant differences in posturography, rotation, MSQ and DHI outcome measures **Grp1&2:**Slight reduction (not significant) in MSQ and DHI
El-Kashlan et al. 1996 (11)	Prospective, case control -	Grp one:n=69 normal volunteers, between the ages of 20-70 yrs Grp 2: n=35 vestibular dysfunction, between the ages of 20-70 yrs	Grp 2: persistent vestibular symptoms >4 months	Grp 2; 20 pts VR & 15 pts generic rehabilitation	**Balance:** EquiTest® (composite score) Balance Master® BM (static sway, static position, dynamic) Static Equilibrium: CTSIB (6 sensory tests) & standing one leg/ Tandem Romberg Dynamic Equilibrium: rapid step ups & gait	Grp 2: monthly evaluations (pre & post therapy scores) over 3 months	**DP**: SS differences between grp 1& grp 2 at baseline became insignificant post therapy **BM**: static sway SS differences between the grps at baseline remained post therapy. Static position & dynamic scores same for both grps **Static & dynamic equilibrium:** SS differences between grps. Static measure showed no SS difference between grps post therapy. Good correlation (.41-.89) between DP & CTSIB for grp 2 pre & post therapy SS differences between DP & CTSIB in detecting patterns of balance dysfunction Cohen's kappa 0.8 agreement between CTSIB & SOTs of DP *DP more sensitive than CTSIB identifying abnormal postural control & specific patterns. BM provides little clinical utility in assessment & treatment*

Table 2 : Clinical studies utilizing dynamic posturography in rehabilitation (continued)

Author	Design	Sample	Symptoms	Intervention	Measurement	Follow up	Results
Herdman et al. 1995 (19)	Prospective, randomized, case control before/after comparison study	n=19 recruited from patients scheduled for resection of acoustic neuroma and randomly assigned Grp1: n=11, acoustic neuroma,42-76 yrs, 3 men & 8 women Grp2: n=8, acoustic neuroma,35-62 yrs,3 men & 5 women Both groups were compared with age-matched normal subjects due to significant differences in age	Not applicable acute vestibular lesion	Grp1:n=11 vestibular adaptation exercises & ambulation Grp2:n=8 smooth-pursuit eye movements without head movements plus ambulation *Exercises initiated 3 days postop*	**Balance:** EquiTest® - mean ES, total sway path & frequency of sway for 6 tests Romberg test--max. score 30 sec. Sharpened Romberg test-max. score 30 sec. **Other:** Fukuda's stepping test-50 steps Gait analysis-Oculomotor test-vestibular ocular reflex **Patient's assessment:** perception of vertigo & disequilibrium by an analog scale	Monitored on daily basis for compliance over 6 day period Clinical assessment on day 3 & 6	**Grp 1 compared to Grp 2:** patient assessment, reduced disequilibrium on day 5 & 6 in grp 1, significant difference. No significance difference in vertigo assessment No difference for Romberg, sharpened Romberg or Fukida's tests. Qualitative difference in gait, 60% normal gait in grp 1 Postop day 3, 4 patients with abnormal Romberg in grp 1 returned to preop stability on test 4 by day of discharge Postop day 3, 5 patients with abnormal Romberg in grp 2 did **not** return to preop stability on test 4. Significant difference between groups. **Grp 1 & 2 compared to controls:** significant difference in mean ES on all tests between acoustic neuroma patients & age matched controls **Grp 1:** postop day 6, significant difference in mean ES between preop and postop for tests 5 & 6 **Grp 2:** postop day 6, significant difference in mean ES between preop and postop for tests 4,5 & 6
Telian et al. 1991 (43)	Retrospective case series January 1988 to December 1989	n=22 (29 of the 49 consecutive patients were evaluated by a physiotherapist, only 22 completed the course of VR) Bilateral vestibular paresis, 3 mild, 8 moderate and 11 severe Age & gender available for entire group of 49	Not available	Vestibular rehabilitation program	**Balance:** DP (system not mentioned) **Other:** Patient questionnaire, subjective improvement & change in level of disability & improvement in ambulation	Not mentioned	All had abnormal composite scores. Noted a decrease in mean posturography composite score with increasing severity, not statistically significant due to large standard deviation & small sample. Dynamic posturography not predictive of the response to VR in this patient population

Table 2 : Clinical studies utilizing dynamic posturography in rehabilitation (continued)

Author	Design	Sample	Symptoms	Intervention	Measurement	Follow up	Results
Grant et al. 1998 (18)	Prospective, randomized, before/after comparison	n=16 selected from patients admitted to hospital for rehabilitation Hemiplegia secondary to acute stroke, average age 65 yrs, 6 women & 10 men, Conventional (C) grp n=8 & Experimental (E)grp n=8	Post stroke average number of days 33	All subjects received regular physiotherapy C grp-30 min of balance training/day, 5 days/wk for 3 wks & 2 days/wk for 8 wks as out pts E grp same protocol but used visual feedback training	**Balance:** Balance Master® ,sway (LOS) eyes open & closed, 20 sec **Other:** Berg scale, Up & Go test, gait velocity 10 meters	All test done at - baseline, post training & 1 month after training had ceased	No grp difference for any tests Pooled data both grps significant improvement in Berg, TUG & gait ($p<0.002$) & reduction in sway ($p<0.03$) *Visual feedback provides no differential benefit over conventional training for patients with hemiplegia when each is provided in addition to regular rehabilitation.*
Magnusson et al. 1994 (27)	Prospective, randomized, before/after comparison	n=46 Severe hemiparesis left or right side Treatment grp: n=21 only 17 completed tests, mean age 74.9 yrs, 13 men, 4 women Control grp: n=25 only7completed tests, mean age 71.4 yrs, 5 men, 2 women Comparison with 23 normal age matched subjects (13 men,10 women, mean age 76 yrs)	Patients randomized within 10 days of stroke onset Treatment grp=7 hemispheric lesion left side & 10 right side Control grp=4 hemispheric lesion on left & 3 on the right	Treatment grp: sensor stimulation with acupuncture & electrical stimulation of 2-5 Hz twice wkly plus daily physio and occupational therapy for a 10 wk duration Control grp: daily physio and occupational therapy for 10wks	**Balance:** force platform recorded anteroposterior (vibratory stimulus to the calf muscles) and lateral plane (galvanic stimulation of the vestibular nerves) movements. **Other:** dynamics (swiftness, stiffness, damping) of postural control evaluated using validated model	Survivors of 2.7 years after onset of stroke (original study had 78 subjects)	No difference between the three groups in sway velocity (lateral or anteroposterior). Swiftness & stiffness values for treatment grp approached those of the normal subjects and showed SS difference from the values obtained for the control grp Sensory stimulation enhanced recovery of postural functions and was still significant 2 yrs after the lesion & treatment.

MSQ - motion sensitivity quotient
OK - optokinetic
SPV - slow-phase velocity
SS - statistical significance
OKN - optokinetic nystagmus
TUG - Up & Go Tests
DHI - Dizziness Handicap Index
VR - vestibular rehabilitation
VOR - vestibular ocular reflex
ES - equilibrium score
CTSIB - Clinical Test of Sensory Integration & Balance

~~Table 2 : Clinical studies utilizing dynamic posturography in rehabilitation (continued)~~

~~Table 2 : Clinical studies utilizing dynamic posturography in rehabilitation (continued)~~

~~Table 2 : Clinical studies utilizing dynamic posturography in rehabilitation (continued)~~

~~Table 2 : Clinical studies utilizing dynamic posturography in rehabilitation (continued)~~

~~***Table 1 : Reliability, validity & responsiveness of DP***~~

~~Table 1 : (continued)~~

Appendix A : Methodology for literature search

The following search strategy was employed using the terms “balance”, “equilibrium”, “posture”, “posturography”, “platform posturography”, “dynamic posturography”, “dynamic platform posturography”, “vestibular rehabilitation”, “computed posturography”, “equitest” or “balance master”:

- references from MEDLINE (1966-February 5,1998), EMBASE (1988-February 5,1998) and CINAHL (1982-December 1996) that mention the EquiTest or Balance Master technologies
- references from MEDLINE and EMBASE using the search term “dynamic platform posturography”
- other databases searched AMED (1985-February 5,1998) AMA CPGs, CMA CPGs, DARE, NEED, OCLC WorldCat, OCLC PapersFirst, Reuters Health Information services and HealthSTAR (1975-February 5,1998)
- the web (using AltaVista)

A number of search strategies were employed in MEDLINE including:

1. (exp cerebrovascular disorders or exp nervous system diseases of exp head injuries or exp amputees or exp amputation) and (exp dizziness or exp equilibrium or exp posture or dizz$.tw. or balance.tw. or equilibrium.tw. or postur$.tw.) and (exp rehabilitation or exp rehabilitation centers)
2. (equitest or balance master or neurocom).tw.
3. (dynamic and posturography$).tw.
4. (exp dizziness or exp equilibrium or exp posture or dizz$.tw. or balance.tw. or equilibrium.tw. or exp postur$.tw.) and (functional deficit$).tw.

Selected articles on studies comparing the clinical use of platform posturography to alternative technologies, reviews and position papers from professional organizations were retrieved. Upon viewing reference lists of retrieved studies other relevant articles were selected. Inclusion selection criteria were as follows: it must be a clinical study and the technology must be used in a rehabilitation setting either for retraining or monitoring patients’ treatment for balance disorders.

Appendix B : Questionnaire for telephone interview

Questionnaire to determine the usefulness of

Computerized Dynamic Posturography Systems: Assessment and Monitoring in Rehabilitation

I Background

Please provide a general description of your program including:

I.a) When did you acquire the computerized dynamic posturography system?

I.b) What system, hardware, software did you purchase?

I.c) Where is the technology located? Physiotherapy or Rehabilitation Department? Neurology, ENT, etc.?

II Operational Issues

II.a) Who is (are) the source(s) of your referrals? ENTs, neurologists, etc.?

II.b) What types of vestibular disorders and other categories of patients (e.g. stroke) are referred?

II.c) In your centre, how many patients were assessed for clinical (non-research) purposes with this technology over the fiscal year 1995/96 and/or 1996/97?

Please provide a breakdown by diagnosis, age, gender, and duration of disease, number of visits or treatments and length of treatment time from start to finish. (Please see Table II.c).

II.d) What are the annual operational costs (including costs of health care professional time, maintenance costs, etc.) for this technology? Do you have an estimate of cost per patient visit? If yes, please list the cost components.

II.e) Using percentages, what is the allocation of time, over a year, for use of the dynamic posturography system:
1) for research?
2) for clinical purposes (e.g. assessment/treatment)?

III Clinical Issues

III.a) How long does the initial assessment take? What are the components of the assessment?

1) who performs the test battery?
2) who analyzes the results?

Do the monitoring evaluations depend on the disease state or diagnosis of the patient? Please explain.

Do you have a cut-off point?

How long, on average, are patients enrolled in the program? Please list the variables which affect the length of treatment.

III.b) What expertise or training is required for the rehabilitation team for use of the dynamic posturography system?

What are the qualifications of the members on this core group/team?

Does the team composition vary depending on the type of patient treated?

How is the competency determined?

III.c) How are the patients selected who would benefit from rehabilitation therapy using the dynamic posturography system?

What criteria are used?

III.d) How has this technology changed or impacted the way in which patients are treated by physiotherapists in your centre?

How were these patients treated before the technology was available?

III.e) What are the patient outcome measures (functional or quality of life) utilized by your physiotherapy department/service to monitor treatment?

III.f) Is this technology used in conjunction with other tests?

If yes, does computerized dynamic posturography provide significant additional information regarding treatment and management of patients to warrants its expense? Yes / No Please explain.

Table II.c

Number of patients assessed with technology _____

Diagnosis	Age	Gender	Duration of disease	# of visits or treatments	Length of treatment time

Appendix C : Results of telephone interview

Telephone interviews were undertaken in August,1997. Four centres in Canada and two in the United States received the questions in advance and the responses were obtained during a follow up telephone interview. Only two centres (one Canadian and one in the USA) were able to respond.

Appendix B lists the questions but the results here will be discussed in general terms under the three main headings of : program description, operational issues and clinical issues.

Program description

Both programs are located in Ear, Nose and Throat (ENT) Departments. Centre A is located in a tertiary hospital and includes physiotherapy within its program. At Centre B the CDP system is utilized only for clinical diagnosis with one operator. Both Centres purchased the technology in the mid 1980s and have made some minor updates to the system. Both centres have the EquiTest® system.

Operational issues

Both centres have a wide source of referrals. The majority of patients with complaints of dizziness, balance or gait disorders are referred by neurologists and ENT specialists. Both centres also see patients with panic and anxiety disorders. Only Centre A rehabilitates patients with stroke. Amputee patients have not been referred to either centre.

The case mix at Centre B is 40% peripheral vestibular, 30% anxiety,10% CNS and 20% unknown with a two to one ratio of female patients. The age group varies from 20 to 80 years of age. Between 500 to 560 tests are conducted annually with a professional fee of $5,600. The initial capital equipment outlay was $109,000. The system requires minimal maintenance, only the computer has been upgraded. It is used 95% of the time for clinical purposes.

At Centre A, in 1995/96, 846 initial assessments of balance were conducted and 835 therapy visits. In 1996/97 there were approximately 1000 initial assessments and 700 treatment monitoring sessions. 60% of the patients had peripheral lesions, 14 to 20% had central lesions and 20% had a mix of peripheral and central lesions. For 4% of the patients the only abnormality was CDP. 30% of the patients were older that 65 years of age and less than 2% were under the age of 20. The annual budget for the program in direct costs are about $600,000. The program is headed by a full time Director, an Associate Director, one physiotherapist and two technicians. The annual cost of equipment and supplies in relation to CDP is less than $300. No maintenance contract is necessary but the force transducers need to be replaced occasionally and cost approximately $1,300. The system is used for research purposes 10 to 15 % of the time.

Clinical issues

The initial assessment at Centre B takes approximately 15 minutes. Approximately 25% of the patients require follow-up which takes about the same amount of time.

At Centre A, general selection criteria for patients are used. The CTSIB is used along with the patient's specific history to determine if CDP is necessary to be a part of the formal functional balance assessment. The average patient who is enrolled in therapy is involved in an 8 to 10 week home program. Head injury patients are usually involved in therapy for 8 to 12 months.

The physiotherapists at Centre A, need advanced course training in vestibular rehabilitation and have to be active in that specific area for at least 2 years.

Outcome measures utilized by Centre A include motion sensitivity quotient (this will be validated by a multicentre trial), walking and a variety of quality of life measures such as the DHI, symptom scoring scale and disability scale.

At Centre A the technology is used in conjunction with other tests for approximately 35-40% of all of the assessments. It is an important part of the overall patient workup. CDP is a pivotal component in making treatment recommendations for approximately 27 to 30% of the annual case load. CDP is not used for treatment (retraining), only for assessment.

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