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Computerized gait analysis in the rehabilitation of children with cerebral palsy and spina bifida

Jo-Anne Tomie and David Hailey

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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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Summary

- The Glenrose Hospital, Edmonton is considering routine clinical use of computerized gait analysis techniques in the management of children with cerebral palsy or spina bifida who have significant walking disorders. About 100 children per year could be examined to assist with decisions on their treatment.

- There are at least six other laboratories dedicated to analysis of human gait in Canada, but only that at the Sunny Hill Health Centre for Children, Vancouver is used for routine clinical purposes.

- There seems to be widespread opinion that modern gait analysis techniques are useful tools, though views on their clinical usefulness vary considerably.

- Evidence of clinical benefit from use of modern gait analysis techniques is sparse. These technologies seem helpful in detecting within-subject gait changes and between-subject gait differences. However, available evidence is insufficient to draw conclusions about the effects of computerized gait analysis on treatment outcomes.

- Cost per examination with a facility of the sort proposed by the hospital might be of the order of $1,800 - $2,200. Cost per patient would depend on the extent of follow-up gait analysis after treatment.

- Part of the rationale for acquiring this technology is that costs of gait analysis would be offset by a decrease in follow-up surgical procedures and associated hospital care. There could also be a major influence on patients' independence and quality of life. There are as yet no data to support these propositions.

- On the basis of information available for this report, computerized gait analysis is a potentially useful technology in the clinical management of persons with walking disabilities, but its efficacy is not established.

- It is suggested that, if computerized gait analysis is adopted for routine clinical use by the Glenrose Hospital, it should be regarded as a developing technology and its application linked to systematic collection and assessment of patient outcomes and cost data under well-defined protocols.

Introduction

This assessment of computerized gait analysis in the management of children with cerebral palsy (CP) or spina bifida (SB) has been prepared at the request of the Glenrose Hospital, Edmonton. The hospital has already undertaken developmental work towards establishing a gait analysis facility.

Advice was sought on the status of the technology in the context of its use in the clinical management at the hospital of selected children who have CP or SB. Specifically, there was interest in the use of this technology for pre-treatment decision making and post-treatment assessment.

The report reviews the available information on the use of gait analysis in clinical decision making, and then considers its potential application at the Glenrose Hospital. Details of the methodology used to obtain information are given in Appendix A.

Cerebral palsy, spina bifida, and gait disorders

Cerebral palsy (CP) is a motor disorder caused by non-progressive insult to the developing brain. Spina bifida (SB) is also a motor disorder caused by developing central nervous system injury. Details about the pathology and incidence of CP and SB are given in Appendix B.

Gait problems

A major symptom of CP is spasticity of various muscle groups (hypertonicity, hyperactivity, or resistance to passive stretch). This results in various functional problems, one of which is abnormal gait of varying forms and severity (45,71). Abnormal gait can also be a major symptom of SB (27,66).

Normal walking is developed by 4 years of age in most people, and consists of a stance phase and a swing phase (74,83). The stance phase occurs 60% of the time and begins when the heel of a foot touches the ground. The swing phase occurs 40% of the time and begins when the toes of the same foot are lifted off the ground (33). Normal walking is energy-efficient, and requires a functional balance between mobility and stability at the pelvis, hip, knee and ankle.

Muscles that are commonly spastic in children with CP and SB include those of the hip and upper leg (iliopsis and hamstrings); upper and lower leg (quadriceps, gastrocnemius, soleus, and calf muscles); and ankle muscles like the tibialis anterior. Spasticity of these muscles adversely affects the energy efficiency, required functional balance, and the stance and swing phases of normal gait.

Weakness and muscle imbalance are bigger problems for those with spina bifida (Muirhead, personal communication). The terms club foot, varus foot, valgus foot, jump knee, crouch knee, stiff knee, recurvatum knee, hemiplegia and diplegia are used by health care professionals in describing the various gait abnormalities exhibited by persons with CP and SB (18,25,71).

Treatments for gait problems

Treatments for gait abnormalities exhibited by those with CP and SB depend upon the nature and severity of the deficit in question. Less commonly used treatments include physiotherapy, isokinetic strength training, cerebellar stimulation, intramuscular injections of botulinum toxin (29) or phenol or alcohol blocks, and systemic administration of baclofen, dantrolene and diazepam. More common approaches include use of various orthotic devices, and lower extremity surgical procedures like posterior rhizotomy, tendon transfer, tendon lengthening and soft-tissue releases (4,11,16,20,25,32,49,58, 73,75,79).

Treatments for gait abnormalities are not always successful, and sometimes yield unintended side effects (e.g., stiffer walking; hip and lumbar spine instability) that may need further treatment (16,21,25,33,48,61,64). Due to difficulty in planning and predicting outcomes of lower extremity surgery, treatments for CP and SB patients often follow the 'birthday operation syndrome' (31,32,56,58). One or several operations may be performed first on ankle muscles and tendons, then on knee muscles and tendons, and finally on hip muscles and tendons, and intersurgery intervals are approximately one year (80).

Gait analysis techniques

Table 1 summarizes gait analysis techniques that have had widespread use. The techniques most relevant to this assessment are the computerized 2D and 3D kinematic and kinetic approaches.

Table 1: Gait analysis methods

Technique	Definitions or Examples	Calculation Methods
Observational and clinical	• Gross Motor Function Measure (GMFM) • Functional Ambulation Profiles • Gross Motor Performance Measure (GMPM) • Range of Motion of hip, knee and ankle joints	• manually, by filling out checklists while patients engage in various activities • measuring the effect of purposely bending a joint on the adjacent tissue and joints (manually or with goniometers)
Time-distance measures	• velocity • step length • cadence (steps per unit time)	• manually with stop watches • ink foot-print recordings • switches attached to feet or shoes • frame by frame video analysis • fibre optic sensors attached to computers
Foot contact patterns	• sequence in which various parts of the foot touch the ground	• ink footprint recordings • sensors on feet
2D and 3D kinematic features	• hip, knee and ankle joint angles • angular and linear accelerations of limb segments	• goniometers and electrogoniometers • frame by frame video analysis • computerized motion analysis systems
2D and 3D kinetic features	• ground reaction forces • hip, knee and ankle joint moments • location and linear and angular accelerations of whole body and specific joint centres of mass	• computerized analysis of data from forceplates • pressure sensors in shoes or on feet • pedobarograph
Electromyography (EMG)	• electrical activity of muscles	• tethered vs. telemetry systems • surface vs. in-dwelling electrodes • data output to paper charts, to oscilloscopes, or to computers for further processing
Energy/physiological cost	• estimated physiological cost of walking	• energy expenditure index (EEI), from algebraic manipulation of resting heart rate, walking heart rate, and walking velocity • oxygen consumption and/or carbon dioxide emission with special mechanical devices

Observational methods versus modern computerized techniques

Historically, normal and abnormal gait in patients has been appraised using clinical assessment and observation with the naked eye. These approaches are appealing because of their simplicity, rapidity and low cost. According to some commentators, they can be useful and reliable when observers are knowledgeable and experienced (40,48), or when thorough checklists of behaviors like the Gross Motor Function Measure (GMFM) or Gross Motor Performance Measure (GMPM) are used (7,19,39,50,62). However, no standardized visual gait analysis method is in universal use (50). Also, visual gait assessments are subjective, can have low inter- and intra-rater reliability (32,50,69,70), and are limited by the fact that the human eye can not detect many events simultaneously or those that occur more quickly than about $1/16^{th}$ of a second (32,40,80).

More modern gait analysis techniques (videotaping, electromyography (EMG), and computerized kinematic and kinetic analysis) allow detection of simultaneously occurring and/or fast moving events, and can have good inter- and intra-rater reliability (15,26,44,67). They shed light on details of walking that cannot be seen with the naked eye, and in so doing have allowed better understanding and definition of both normal and abnormal gait (2,42,55). Measurement of energy expenditure during walking has also been suggested as an input to decisions regarding treatment or outcome evaluation (60).

Modern gait analysis techniques are considered to be more objective and accurate than classical observational approaches, and have helped health care professionals distinguish between real disorders and secondary coping mechanisms that mask these during observational analysis (32). As a result of such additional information, it has been possible to refine, and even decide to discard use of various surgical techniques and orthotic devices. Information from gait analysis has the potential to enable 'single-event, multi-level' surgery to replace the 'single-level multi-event' or 'birthday syndrome' approaches that have often been used when treating children with neuromotor disorders (32,56). Potentially, use of modern gait analysis techniques might lead to savings for the health care system, and for patients and their families.

Modern gait analysis techniques are praised by many researchers, but have limitations and demands. Among their limitations are their artificiality and their expense. Having patients walk on short walkways with encumbering electrodes, markers and switches attached to their lower extremities might not provide the best representation of how they walk under unavoidable and varying circumstances in the real world. The techniques are labor intensive and expensive. Also, data obtained from computerized gait laboratories can be complex (72,81). Users of these techniques must therefore be well trained, extremely careful with data collection, analysis and interpretation, and aware of the numerous potential sources of error. These include the type, size and placement of electrodes and markers; effects of age, body structure, growth and stress on gait data; system errors; artifact and calibration errors; and evaluator bias (15,26,51,61,81).

Centres offering gait analysis use different computer systems and employ staff with different levels of technical expertise, and there are no set standards. Comparison between laboratories is therefore difficult, and the data collected with computerized gait analysis techniques could be subject to as many interpretations as there are interpreters (46,61).

Views about modern gait analysis techniques

There seems to be widespread opinion that modern computerized gait analysis techniques are useful tools (2,3,5,6,17,23,24,34,35,40,54,56,57). They have been widely used for research or clinical purposes (Appendix C, Tables 2 and 3). Despite this widespread acceptance, views about their clinical usefulness in terms of treatment decisions and patient outcomes vary considerably.

Gage (33) considers that clinical use of modern gait analysis techniques is essential. This view is based on his clinical experience, opinions about the accuracy of computerized gait analysis techniques, and a perceived inability of physicians to determine whether a disability is primary or secondary (coping) without their use. He also cites his 1984 finding that 19 of 20 children were considered improved after surgery when their gait was analyzed clinically, whereas only 13 of the same 20 children were considered improved when their gait was analyzed with computerized techniques.

In contrast, Watts (82) has commented that he is not against use of modern gait analysis techniques as research tools, but that he and "many pediatric orthopedic surgeons" would like to see objective, documented evidence that modern gait analysis techniques are the reliable, predictive, cost-effective tools others hope and claim they are before giving clinical use of modern gait analysis techniques their stamp of approval. Such evidence is scant in the literature.

McCoy and Rodda (51) claim that it is "becoming increasingly critical in terms of professional accountability, that gait analysis information is obtained prior to surgical intervention". Young (84) suggests, on the basis of two cases where computerized gait analysis showed abnormalities that clinical assessment and radiological examinations failed to reveal, that to ignore the potential benefits of modern gait analysis techniques is to "compromise one's diagnostic and therapeutic approach to patient care". Õunpuu et al. (55), in a review on kinetic analysis, support the clinical use of modern gait analysis techniques but also recognize some of their shortcomings. They point out that "The importance of integrating all collected data and clinical examination measures for treatment decision-making cannot be underestimated."

Saleh and Murdoch (63) compared visual gait analysis of five amputees with computerized gait analysis, and found that experienced observers were able to detect only a small percentage of gait abnormalities which were detected by the quantitative system. They suggest that quantitative gait analysis is essential, but that expensive computer-based systems, unjustifiably being equated with the phrase 'gait analysis' in recent literature, are not. Thompson (76) claims, in an article on orthopedic aspects of cerebral palsy, that although most orthopedists would agree that modern computerized gait analysis is desirable and beneficial, few would feel that it is mandatory.

Messenger and Bowker (52) sent a questionnaire about clinical usefulness of modern gait analysis techniques to 35 gait laboratories in the United Kingdom. They note that recurring in the responses was the view that modern gait analysis techniques are useful in limited circumstances but not yet in routine practice. Giannini et al. (67), claim that the potential of modern gait analysis laboratories for clinical use is "undoubtedly subordinated" to the solving of methodological problems.

Brand (8), considers that some modern gait analysis techniques do not satisfy criteria he considers essential for methods of recording gait. These include independence of mood, motivation and pain, and ability to clearly distinguish between normal and abnormal gait. He was not aware of any study that had addressed critical cost issues of gait analysis systems. Also, few if any published studies had documented clinical usefulness. In his view, gait analysis systems need to be validated and their clinical usefulness documented before they receive widespread clinical use.

Cavanagh and Henley (12), agree with the views of Brand. They point out that technological progress must not be equated with "progress in the understanding of biologic mechanisms or in the real utility of gait analysis to clinical practice". They stress the need for blinded, randomized studies on the clinical use of modern gait analysis techniques.

Evidence of efficacy

Evidence of clinical benefits of modern gait analysis techniques is weak. Only one study was found that compared outcomes of treatments based on clinical analysis alone with outcomes of treatments based on modern gait analysis techniques. In this study, by Lee et al. (48), 15 diplegic children received surgery based on computerized gait analysis findings, and 8 received surgery based on clinical analysis alone. The post-operative data were compared to the pre-operative data and to data from normal children, further detail of which was not specified. Post-operative gait was considered improved if selected parameters (time-distance measures, joint angles, EMG) approached normality.

These authors reported that the gait of 7 children did not improve after surgery, and that 5 of these children had received surgery based on clinical analysis alone. They conclude that this provided support for use of modern gait analysis techniques in clinical practice.

Other studies that used gait analysis techniques for pre-treatment decision making or post-treatment assessment resembled the remainder of the 20 representative studies shown in Table 2, Appendix C. Most had small sample sizes, and focused on the magnitude of within-subject pre-treatment versus post-treatment changes. Some used control data sets that were not well defined. Few attempted to compare decisions based on clinical analysis alone with decisions based on modern gait analysis techniques, and none compared costs.

Gage et al. (36) compared the post-operative gait data of 20 diplegic children to the pre-operative data and to control data, details of which were not given. They found that when gait was assessed clinically or by the children's parents, 19 of the 20 children were considered improved post-operatively. When gait was assessed with modern techniques, 13 of the 20 children were considered improved. They conclude from this that modern gait analysis techniques allow more objective planning and documentation of surgery, and as a result, surgical judgment should improve and errors in treatment should be reduced.

Scott et al. (64) assessed the gait of 33 patients with CP pre-operatively, 1 year after surgery (posterior adductor transfers to the ischium), and an average of 9.6 years after surgery. All patients showed functional improvement post-operatively, but the computerized gait analysis conducted at long term follow-up revealed complicating pelvic obliquity in 85% of the patients and associated hip sublaxation in 36%. The complicating factors revealed by computerized gait analysis resulted in abandonment of this surgical procedure.

Table 3 (Appendix C) shows 10 studies representative of those that used computerized gait analysis techniques for descriptive or categorizing purposes. In several of these studies, gait analysis helped to divide children with CP or SB who were otherwise diagnostically indistinguishable into groups (42,65,77,78). In the study by Tylkowski and Howell (77) the gait of 46 children with CP was assessed. Based on the computerized gait data, the children could be divided into three groups that could otherwise not be distinguished. The authors concluded that their results demonstrate that gait laboratories can differentiate causes more specifically than clinical examination alone.

Results reported in the literature seems to support claims that computerized gait analysis is helpful in detecting gait subtleties, within - subject gait changes and between - subject gait differences. It is hoped that increased detecting ability will help health care professionals make better decisions, and will improve outcomes and reduce associated treatment time and costs. However the available evidence does not allow conclusions to be drawn about the effects of gait analysis on treatment costs and outcomes. Controlled, long term studies are still required.

Gait laboratories in Canada

Laboratories dedicated to the study of human gait are located in Toronto, Waterloo, Calgary and Vancouver. Details about the equipment, use and staffing of these laboratories are shown in Table 4, Appendix C.

Costs and patient flow

Because they are used primarily for research purposes, information on the Toronto, Waterloo and University of British Columbia gait laboratories is not presented here.

The Human Performance Laboratory and the Joint Injury and Arthritis Research Centre at the University of Calgary use gait analysis primarily for research purposes, and have identical equipment. Approximate costs associated with these facilities are as follows:

Capital costs

Motion analysis hardware and software = $240,000
Kistler forceplates = $20,000 each
16 channel telemetry EMG system = $20,000
Pressure distribution systems = $10,000 to $20,000 each

Miscellaneous

Annual system maintenance = $50,000 to $100,000

The gait laboratory in the Sunny Hill Health Centre for Children in Vancouver is the newest in Canada, having commenced operation in October, 1996. It is used 80% of the time for clinical assessment of children with neuromotor disorders, and 20% for research. Orthopedic specialists, neurologists, pediatricians, sports medicine physicians and occupational and physiotherapists can refer patients to it (Alcock, personal communication).

The neuromotor division in the Sunny Hill Health Centre for Children receives approximately 1,500 referrals per year, and its gait analysis laboratory sees 3 to 4 children per week. From October, 1996 to June, 1997, 60 children were examined at the laboratory, 24 of whom had cerebral palsy and 3 of whom had spina bifida. (Alcock, personal communication).

The laboratory employs 3 people; a full time director with an M.Sc. in Kinesiology, a 0.7 time pediatric physiotherapist, and a 0.2 time orthopedic surgeon. Approximate costs for various items are as follows (Black, personal communication):

Capital costs

Motion analysis hardware and software = $350,000
(motion analysis system, forceplates and EMG setup)

Personnel

Annual wages = $150,000

Miscellaneous

Office supplies, etc. = $10,000
System maintenance and upgrading = $50,000

Children referred to the gait laboratory are primarily from British Columbia, but out of province referrals are also accepted. Data collection for each child takes 2 to 3 hours, and analysis of data another 2 to 3 hours. Employees of the gait laboratory meet once each week to discuss the data collected and to draw up reports about each child, a process that takes approximately 45 minutes per case. The reports are then sent to the referring health care professionals, for planning further treatment.

Pediatric cases from outside British Columbia and adults are billed from $600 to $1,500 for a gait assessment, depending on how detailed the assessment is (Black, personal communication). No child younger than 4 years is assessed. Normal gait patterns are not fully developed until 4 years of age in most people (74), and collecting gait laboratory data from young children is difficult because of inadequate step lengths for forceplate data collection (19), and a short attention span.

Preference for gait assessments at the Sunny Hill Centre is given to children who are to have orthopedic surgery or neurosurgery. To date, the laboratory has had 3 patients return for a second assessment. It predicts that in the future, 50% of its patients will be returning for second and third assessments after treatment.

The Glenrose Hospital proposal

Gait analysis techniques

The Glenrose Hospital's current method of gait assessment is to clinically examine and observe patients, to fill out checklists of their ability to engage in various behaviors, like the GMFM, and to make and analyze video-tapes of patients walking. The hospital wishes to continue using these approaches, and to incorporate computerized 2D and 3D kinematics and kinetics into treatment decisions (80).

The hospital currently has a 4 camera computerized movement analysis system (VICON, Oxford Instruments) and 1 forceplate (AMTI). To use this equipment for routine clinical purposes, trained and dedicated personnel to maintain equipment and to collect and analyze data are required. A need is seen for 1 or 2 more cameras and an additional forceplate.

Additional cameras would increase ability to study gait bilaterally and from different angles simultaneously. An additional forceplate would permit measurement of a more representative gait and would also make it possible to study ground reaction forces from both sides of the body simultaneously. To obtain accurate data from a standard commercial forceplate, one foot must completely contact it and the other foot and any assistive devices must remain clear of it. Obtaining as representative a gait as possible and analyzing kinetic features of gait from both sides of the body simultaneously with just one forceplate is thus difficult, or impossible (19,57).

Patient numbers and selection procedures

The Glenrose Hospital treats approximately 2,500 children with motor disorders each year. It is expected that approximately 100 children per year could benefit from use of computerized gait laboratory facilities for clinical purposes (80). The hospital proposes to use computerized gait analysis for only severely disabled, difficult-to-assess ambulatory children. Those with bilateral lower extremity deficits (diplegia) would receive preference for computerized gait analysis over patients with unilateral lower extremity deficits (hemiplegia), for example. When using current techniques, staff are more confident with decisions they make about patients with hemiplegia than with those who are diplegic (80).

Staff at the Glenrose Hospital hope that use of computerized gait analysis equipment for pre-treatment decision making and post-treatment assessment purposes will result in better surgical outcomes, including a decrease in adverse effects.

No data on treatment costs and outcomes for children with CP or SB under current management protocols were available for this assessment.

Cost and benefit considerations

Firm cost data for a computerized gait laboratory are not available. The following estimates are indicative only, and draw on information from the Glenrose Hospital and from Canadian gait laboratories. They refer to the cost of establishing and operating a gait laboratory.

With a system incorporating 6 cameras and 2 forceplates, approximate start-up and operating costs for a new computerized gait laboratory might be:

	$	$
Capital costs		
Computer equipment and software	150,000	
Cameras	70,000	
Forceplates	30,000	
Total:		250,000
Personnel	$	$
1 full time Director	50,000	
1 full time Technician	35,000	
Part time clerical staff	15,000	
Total (per year):		100,000
Miscellaneous	$	$
Office supplies	10,000	
Space rental & utilities	10,000	
Total (per year):		20,000
Total		$370,000

If the equipment were depreciated over five years, its annual cost component (undiscounted and ignoring interest foregone) would be $50,000. Annual maintenance and upgrade costs over five years might be $40,000.

The overall annual expenditure could therefore be of the order of $210,000. For a caseload of 100-120, cost per examination could be $1,800 - $2,100.

It can be expected that a substantial proportion of patients would be re-examined in the gait laboratory following treatment. Overall cost per patient would therefore be substantially higher than the cost per examination. The eventual impact of re-examinations on the availability, scheduling and cost of gait analysis is uncertain and would require close consideration. It has been suggested

(Maitland, personal communication) that there is scope to improve system efficiency and patient flow. Potentially there could be scope for reducing computer and software costs, particularly if standard assessment algorithms could be developed.

The Glenrose Hospital has already acquired some equipment for gait analysis. Additional resources sought by the hospital are as follows:

	$	$
Capital costs		
Computer equipment and software	53,000	
Camera	12,000	
Forceplate	16,000	
Total:		81,000
Personnel (per year)		100,000
Office supplies (per year)		20,000

Overall costs of a gait analysis facility at the hospital are uncertain. They would be influenced by the remaining life and replacement costs of existing measurement and computer equipment and by current maintenance arrangements.

Future budgets for the proposed gait laboratory would also be affected by acquisition of other gait analysis equipment, such as EMG, and any consequent need for additional staff and miscellaneous supplies.

It is hoped that the costs of computerized gait analysis would be offset by the decrease in number of follow-up surgical procedures and associated hospital care. There would also be expectation of greater independence and improved quality of life. Data to support such propositions are not available.

Avoidance of additional surgery or long-term consequences of failed procedures which cannot be corrected would be major gains. It is, however, unclear how many cases would be affected in this way through the availability of additional data provided by gait analysis.

Discussion

Status of computerized gait analysis

Computerized gait analysis techniques are tools that shed light on details of walking that cannot be detected with the naked eye. Their development and application have allowed better understanding and definition of both normal and abnormal gait. They have been applied to the study of a wide range of conditions, and can be modified to help shape desired behaviors.

However, while there is a considerable literature on use of computerized gait analysis techniques in research, evidence about their clinical usefulness appears to be very limited. Claims of benefit from use of gait analysis techniques seem often to be based on personal opinion, informal observation or on studies from which solid conclusions cannot be drawn about the effects of these techniques on costs and patient outcomes. Typically, studies have included small numbers of patients with inadequate or no controls. Some studies have compared sensitivity of computerized gait analysis techniques with sensitivity of observational gait analysis, or demonstrated use of modern gait analysis techniques for treatment or assessment decision-making purposes.

In general, there is an absence of data on the incremental benefits of computerized gait analysis in terms of outcomes following treatment. Also, information on comparative costs is lacking. Overall, modern computerized gait analysis techniques seem promising, but in need of further validation in terms of their impact on patient outcomes.

It has been pointed out that computerized gait analysis is an expensive, complex technology which is demanding in terms of data acquisition and analysis. There are no generally accepted standards and comparison of results from different laboratories is difficult.

A possible issue for further resolution is the extent to which all the information obtained from multivariate measurements can be condensed to provide a reliable, global evaluation technique for those providing treatment. There is also the question of the extent to which the results of gait analysis at re-assessment after treatment should be used as an outcome measure, as compared to clinical assessment and the opinions of patients and their families.

A number of points would require consideration by any centre using gait analysis for routine clinical assessment. Appropriate presentation of results and training would be necessary to enable health care professionals to use gait analysis data to guide clinical decisions. Attention would also need to be paid to quality assurance issues, and it would be useful to check the results of measurement by the gait laboratory against published findings from other centres. Also, it would be important for the gait laboratory to be well integrated within the hospital's organizational structure.

The Glenrose Hospital proposal

On the basis of information available for this assessment, it appears that the proposal from the Glenrose Hospital would entail operation of a promising, developmental technology. If a decision is taken to use the technology at the hospital for routine clinical care, then it will be important for the gait analysis laboratory to be appropriately staffed and for there to be on-going evaluation.

Given the absence of information on the clinical benefits of gait analysis, it would seem necessary for the Glenrose Hospital to validate the effectiveness of the technology through obtaining suitable outcomes data. As a first step, it would be important to document the effectiveness of current management options.

It would also be necessary to put in place mechanisms for systematic, long-term collection of outcomes data for patients who had been assessed using computerized gait analysis. Elements to be considered include patient selection, effects on management decisions, effects on patient outcomes and cost impact. Evaluation of such data would provide an indication of the effectiveness of the technology. In turn, follow-up gait analysis would provide insight as to the effectiveness of surgery or other treatments used for children with CP and SB. Such gait analysis data would need to be integrated with other clinical data.

Such requirements suggest the need for a detailed business case and well developed data collection and assessment protocols.

Appendix A : Methodology

MEDLINE was searched from 1986 to April, 1997, EMBASE from 1988 to May, 1997, PRE-MEDLINE from April to May, 1997, HealthStar from 1975 to May, 1997, and PsychInfo from 1984 to April, 1997. 'Gait', 'movement', 'motor performance', 'walking', 'cerebral palsy', 'neural tube defects', 'spinal cord malformation' and 'congenital disorders' were the subject words used, either alone or in combination, and no species, language or other limits were imposed. Tables of contents for *Gait and Posture* were viewed on the Elsevier Publishing Company's home page on the World Wide Web.

The search results were screened, first by title and then by abstract, and the literature considered to be the most relevant was obtained. Reference lists in retrieved literature were also screened.

Studies comparing outcomes of treatments decided by modern gait analysis techniques with outcomes of treatments decided by clinical assessment alone were the most wanted. Only one of these was found. Other literature of interest included reviews of gait analysis techniques, reports on their reliability and validity, and reports on studies in which modern gait analysis techniques were employed for pre-treatment decision or post-operative assessment purposes. Only a subset of the many studies of the latter kind are discussed in this report.

Other information was obtained by consultation with a number of persons with interests and expertise in computerized gait analysis, and from the home pages on the World Wide Web for the University of Waterloo, the University of Calgary and the Sunny Hill Health Centre for Children.

Appendix B : Cerebral palsy and spina bifida - pathology and Incidence

Simple definitions of CP and SB are difficult because the motor symptoms associated with them take many forms, there can be many accompanying problems (e.g., cognitive deficits, seizures, visual impairments), and they have numerous causes (32,45,66).

There are two main motor systems in the brain. The first is lateral, consisting of projections from the motor cortex and red nucleus to the spinal cord and responsible for distal body movements (those of the hands, fingers, arms, and legs). The second is ventromedial, consisting of projections from vestibular nuclei, the tectum and the reticular formation to the spinal cord and responsible for proximal body movements (whole body movements). Several other brain structures are indirectly or directly connected to the motor cortex and/or red nucleus (e.g., the basal ganglia, the thalamus, and the cerebellum), and are thought to play modulatory roles in production of movements (45).

Children with CP have varying degrees of damage to one or more of these motor structures. Children with SB have a protrusion of spinal cord tissue and membranes through defective bone somewhere in the spinal cord. They may also have varying degrees of damage to both motor and non-motor structures in the brain (e.g., hydrocephalus caused by partial closure of cerebrospinal fluid ducts, and by other factors) (45,66). The severity of impairments exhibited by children with CP and SB is dependent largely upon the severity and location of their CNS damage.

The incidence of CP is estimated at between 1.4 and 6 per 1,000 births (4,32,45). According to Vaughan et al. (79), approximately 25,000 children are born with or develop CP per year in the U.S. (79). SB is more common, affecting 5 to 10 percent of all newborns (66). Most of the spinal cord protrusions are small, undetectable by visual inspection and asymptomatic (spina bifida occulta). Only about 2 to 5 per 1,000 babies are born with impairment-inducing protrusions of the spinal cord (spina bifida cystica or meningomyelocele), which are frequently accompanied by other CNS damage. The number of females and males afflicted by CP and SB is about equal (45).

Appendix C : Use of gait analysis techniques

Table 2: Studies using modern gait analysis techniques for pre-treatment decision and/or post-treatment assessment purposes

Study	Purpose	Procedure	Gait Analysis Techniques Used	Main Findings
Adams et al. (1)	To assess effect of dorsal rhizotomy on foot contact patterns of spastic CP children	■ 14 CP children ■ 4.6 to 23.5 years old (median 6.5 years) ■ tested pre-operatively and again 6 to 14 months (mean 8.3 months) post-operatively ■ compared data to normal age-matched controls from studies by others (exact numbers not mentioned), and compared post-operative and pre-operative data	■ foot switches taped to bare feet ■ computerized 2D kinematics ■ surface EMG from 8 muscles ■ clinical exam – 1 observer – goniometric joint range of motion and muscle strength analysis	■ significant improvement in foot contact patterns, velocity and stride length (6 of 14 subjects exhibited normal pattern of ground contact with the heel post-operatively, whereas only 2 did so pre-operatively) ■ high incidence of post-operative side effects, attributed to weakness and hypotonicity in plantar flexors and to residual hamstring spasticity ■ Conclusion: selective dorsal rhizotomy improves gait of CP children by reducing spasticity; future modifications to the surgical procedure or use of orthotic devices post-surgically might be considered to deal with side-effects
Brunt and Scarborough (9)	To describe EMG patterns in CP children, and to prescribe treatments based in part on the EMG findings	■ 13 CP children ■ 7.7 +/- 3.8 years old ■ compared data to expected normal data (source of normal data not stated) ■ treatments prescribed in part on basis of EMG - 8 children operated on, 3 assessed post-operatively	■ surface EMG ■ foot ground contact with switches on feet	■ could divide the children into 3 groups based on patterns of EMG from lower extremity muscles ■ positive results for 2 of 3 children who received post-operative assessments (corrected varus deformity in one, heel-toe gait ability in the other), and mild side effect in the 3rd ■ Conclusion: that use of EMG before surgery is logical and provides an indispensable contribution to important treatment decisions
Chicoine et al. (13)	To assess effect of dorsal rhizotomy on gait of CP children	■ 90 CP children ■ compared pre-operative and post-operative data	■ observational ■ videotapes	■ variance in ability to walk post-operatively was accounted for largely by the pre-operative gait scores

Table 2: Studies using modern gait analysis techniques for pre-treatment decision and/or post-treatment assessment purposes (continued)

Study	Purpose	Procedure	Gait Analysis Techniques Used	Main Findings
Chung et al. (14)	To assess effect of psoas surgery on hip function in CP children	■ 34 CP children that had psoas surgery, and 13 CP children that did not ■ tested pre- and post-operatively ■ source of "normal" data not identified	■ 2D and 3D kinematics and kinetics with computerized VICON system ■ oxygen consumption	■ significantly improved pelvic tilt, hip flexion, hip extension moments and powers, and walking velocity and oxygen consumption –in study group than in controls ■ Conclusion: psoas lengthening improves hip kinematics and kinetics without sacrificing hip flexor power generation
Cosgrove et al. (16)	To assess effect of intramuscular botulinum toxin injections on lower limb management in CP patients	■ 26 CP children with abnormally high muscular activity in calf muscles and/or hamstrings ■ 2 to 17 years old (mean 6) ■ analysis done before drug injections and 5 days, 2, 4, 6, 10, 16, 26 weeks, and 1 to 2 years after injections	■ clinical examination ■ kinematic (joint angles and ranges of motion) with electrogoniometers ■ subjective parent rating	■ Benefits, in terms of reduced muscle spasticity, increased ambulatory status, and decreased popliteal angle of the knees during walking were marginal in 7 of the children, good but gradually relapsed in 12, and good and did not relapse after 18 months in 7.
Damiano et al. (20)	To assess effect of quadriceps femoris muscle strength training on crouch gait in CP children	■ 14 CP children ■ 6 to 14 years old (mean 9.1 +/- 2.5) ■ exercised 3 times/week for 6 weeks using ankle weights ■ contraction of muscles measured before, at the middle of and immediately after exercise program at 30, 60, 90 degrees of knee flexion ■ gait analysis before and after the exercise program	■ observational ■ electrogoniometer ■ computerized 2D and 3D kinematics with 4 camera and 15 marker ExpertVision Motion Analysis System	■ force gains at all 3 angles; greatest gains during first 3 weeks ■ 10 of the 14 children exhibited less knee flexion at initial floor contact, 7 of these showed less knee flexion at midstance, and 5 of these developed mild hyperextension ■ increased stride lengths

Table 2: Studies using modern gait analysis techniques for pre-treatment decision and/or post-treatment assessment purposes (continued)

Study	Purpose	Procedure	Gait Analysis Techniques Used	Main Findings
Duffy et al. (28)	To describe gait patterns in SB children, and to assess effect of specific surgeries on gait of SB children	■ 28 SB children, and 15 normal children ■ 4 to 18 years old (mean 10 years) ■ 10 SB children had L4, 8 had L5, and 10 had S1 lesions ■ 5 of the L4 SB children had received posterolateral iliopsoas transfers, and 3 L4, 2 L5 and 2 S1 SB children had received tibilias anterior transfers ■ detailed gait analysis done post-surgically	■ observational ■ videotaping ■ computerized 3D kinematic and kinetic data with a 5 camera VICON system and 2 AMTI force plates	■ Various differences between SB and control children were noted, and various differences between the 3 groups of SB children were noted (in pelvic tilt, hip flexion, knee flexion/extension, ankle dorsi/plantar flexion) ■ the iliopsis and tibialis transfers did not help gait of the SB children
Etnyre et al. (30)	To compare effects of different surgical techniques on gait of CP children	■ 24 spastic CP children ■ 3.5 to 18 years old (mean 7.5 +/- 4.5) ■ gait analyzed an average of 96 days before surgery, and an average of 244 days after surgery ■ compared pre-op and post-op findings ■ data were age-matched with normative data and converted to a percentage of normal for analysis. Source of normative data not identified	■ observational ■ goniometer ■ computerized 2D and 3D kinematics with 5 camera VICON system ■ surface EMG	■ 16 positive outcomes, 5 negative, 3 unchanged. No significant differences between the surgical procedures ■ positive outcomes = factors like increased velocity, stride length and cycle time; increased ankle flexion range; decreased EMG in the triceps surae

Table 2: Studies using modern gait analysis techniques for pre-treatment decision and/or post-treatment assessment purposes (continued)

Study	Purpose	Procedure	Gait Analysis Techniques Used	Main Findings
Gage et al. (36)	To demonstrate benefits of using computerized gait analysis techniques for pre-operative decision making and post-operative assessment making purposes	▪ 20 children with spastic diplegia ▪ ages 6.2 to 17.1 years ▪ gait assessed pre-operatively and 6 to 18 months post-operatively ▪ pre- and post-operative analyses compared. Data considered improved or worse if there was a change greater than 10% either (based on control data, the source is not discussed) ▪ post-operative assessment also compared with post-operative parental opinions and clinical assessments	▪ observational, clinical assessments ▪ 2D and 3D kinematics and kinetics with a 3 camera, 28 marker, computerized motion analysis system and 2 AMTI forceplates ▪ 14 channel telemetry EMG ▪ estimate of walking efficiency	▪ based on sums of linear time-distance measure, the estimate of walking efficiency, and joint and angle rotations from the computerized analysis, found that 13 patients improved, 6 were unchanged and 1 was worse ▪ the parents all thought their children improved, and 19 of the children were considered improved after observational clinical assessments
Gage and σunpuu (37)	To demonstrate use of various gait analysis techniques (EMG, computerized kinematics and kinetics) for pre-treatment decision making and post-treatment assessment making purposes	▪ 1 12 year old female ▪ 1 15 year old male ▪ 1 8 year old male ▪ tested pre- and post-operatively ▪ abnormalities described with reference to kinematics and kinetics collected from 66 normal children	▪ EMG ▪ computerized kinematics and kinetics	Many improvements noted for the 3 patients– e.g., decreased pelvic tilts, improved knee motion and decreased flexion
Krebs et al. (47)	To compare use of orthotic devices on gait of diplegic children	▪ 15 diplegic children ▪ assessed gait with each of the orthotic devices, 6 months later, polled the children regarding ultimate orthotic preference	▪ observational ▪ subjective opinions ▪ videotaping ▪ 2D and 3D kinematic analysis	No significant functional differences between the 2 orthotic devices, most children preferred the plastic-metal one

Table 2: Studies using modern gait analysis techniques for pre-treatment decision and/or post-treatment assessment purposes (continued)

Study	Purpose	Procedure	Gait Analysis Techniques Used	Main Findings
Lee et al. (48)	To compare outcomes of surgeries based on clinical analysis alone with outcomes of surgeries based on detailed gait analysis	▪ 23 diplegic children ▪ 6 to 17 years (mean 11.8) ▪ pre-op and post-op gait analysis, (time of follow-up not stated) ▪ surgery for 15 children based on gait analysis, and for 8 based on clinical analysis alone ▪ compared data to normal data, source of which is not identified	▪ observational ▪ videotaping ▪ computerized 3D kinematics with 5 camera, 17 marker VICON system ▪ surface EMG, and fine-wire EMG for deep muscles	▪ Based on the gait data, claim that 7 did not improve, and that 5 of these received surgery based on clinical analysis alone ▪ Conclude that this is support for use of gait analysis
Nene et al. (53)	To assess effect of surgery on gait of CP children	▪ 18 children ▪ 8 to 16 years old ▪ tested before and 1 and 2 years after surgery ▪ pre-op and post-op data compared	▪ standard clinical assessment ▪ video & computerized 3D kinematics and kinetics ▪ EMG with both surface and fine-wire electrodes ▪ Energy Expenditure Index (EEI)	▪ Focused primarily on EEI data, and report encouraging results ▪ hip flexion deformities completely or partially corrected in 15 children, knee flexion deformities in 8 ▪ average hamstring tightness was reduced and average knee range of motion increased ▪ 14 exhibited varying degrees of decrease in the EEI ▪ No major complications
Rose et al. (59)	To assess effect of gastrocnemius fascia lengthening on gait of CP children	▪ 20 CP patients ▪ 4 to 26 years old (mean 6) ▪ tested before surgery and 13 months after surgery ▪ pre-op and post-op data compared, changes considered positive if they moved towards normal values (not described)	▪ observational clinical assessment ▪ videotaping ▪ computerized 3D kinematics and kinetics, with 3 camera system, 20 markers, and 2 AMTI forceplates ▪ telemetry EMG with surface electrodes	Based on group means, report some positive changes (increased ankle dorsiflexion, increased knee extension at contact, and increased ankle angle at toe-off) and some unchanged data (e.g., velocity, step-length and cadence)

Table 2: Studies using modern gait analysis techniques for pre-treatment decision and/or post-treatment assessment purposes (continued)

Study	Purpose	Procedure	Gait Analysis Techniques Used	Main Findings
Rose et al. (61)	To demonstrate use of kinematics for surgical decision making and for orthotic device assessment purposes	■ 2 diplegic children ■ gait analysis done pre-operatively and 1 year post-operatively for one with and without orthotic device on for the other ■ compare pre- and post-treatment assessments, normal data referred to, source not identified	■ observational clinical assessment ■ videotaping ■ computerized 3D kinematics and kinetics ■ surface EMG	■ positive post-op results reported for patient 1 but still problems with motor control so use of an orthotic device recommended ■ the orthotic device was not helping problems noted for patient 2
Scott et al. (64)	To assess effect of adductor transfers on gait of CP patients	■ 33 CP patients ■ tested pre-operatively and 1 year after surgery without computers, and an average of 9.6 years after surgery with computerized techniques	■ observational ■ videotaping ■ photographs and radiographs ■ goniometer ■ computerized 3D kinematics with 6 camera VICON system	Most patients exhibited a functional increase in ambulatory status, but the gait analysis shed light on complications (e.g., pelvic obliquity and hip sublaxations), and many patients need further surgeries, so the surgical procedure in question was discarded at the institution.
Stott et al. (68)	To assess effect of tibialis anterior transfers on gait of SB children.	■ 7 SB children ■ 3 to 12.5 years old at surgery (mean 8 years) ■ all were community ambulators and ankle-foot orthoses users ■ gait analysis performed 24 to 60 months (mean 40) post-operatively ■ compared to age-matched normative data collected by others.	■ observational clinical assessment ■ videotaping ■ radiographs ■ computerized 3D kinematics with VICON system ■ telemetry EMG with surface electrodes ■ telemetry footswitches ■ Energy Expenditure Index	Report favorable results (e.g., decreased calcaneal deformities in all patients; increased stride lengths and velocities; decreased EEI), with some drawbacks (e.g., need for further surgeries in patients; spastic lower extremity muscles; orthotic device necessity to facilitate more normal appearing and energy efficient gait).

Table 2: Studies using modern gait analysis techniques for pre-treatment decision and/or post-treatment assessment purposes (continued)

Study	Purpose	Procedure	Gait Analysis Techniques Used	Main Findings
Sutherland et al. (75)	To compare effect of distal rectus femoris transfer and proximal rectus release on stiff-knee gait in CP children	■ 22 CP children ■ 12 got proximal releases (mean age 12.6 years at time of surgery); 10 got distal transfers (mean age 11.3 years at time of surgery) for treatment of stiff-knee gait ■ gait analyzed before and 22 months after surgery for proximal release and 12.2 months after surgery for distal transfer ■ pre-op and post-op data compared, surgical techniques compared ■ data compared with "normal" data from previous studies, details not given	■ observational ■ videotaping/filming ■ fine wire internal electrode EMG ■ computerized 2D kinematics	Found increased knee flexion and range of motion and increased velocity for both surgical groups, and found the distal transfer to have greater influence on peak knee flexion than proximal release. Did not find a tendency for crouch gait after either surgical procedure, and note importance of longer term follow-up before making solid conclusions.
Sutherland et al. (73)	To assess effect of intra-gastrocnemius muscle botulinum toxin injection on gait of CP children	■ 26 CP children ■ 2.1 to 13.8 years old (median = 5.1) ■ gait analyzed before injection and clinically every 6 weeks and via computerized techniques at 3 month intervals for 1 year after the injections ■ additional injections after each analysis given at orthopedist's discretion ■ pre- and post-injection data compared, and all data compared with age-matched control data (details not given)	■ observational clinical assessment ■ computerized 3D kinematics with 5 camera Vicon system and custom-made software ■ telemetry EMG with surface electrodes ■ fine wire implant EMG after the study to aid with presurgical decisions too	11 subjects did not complete the study – 4 moved away and 7 needed surgeries. From the others improvements were noted (e.g., increased velocity and step length, decreased external rotation of foot, increased ankle dorsiflexion, decreased spasticity of the tibialis anterior muscle). Conclude that the results are promising but that further studies need to be done, addressing cost and outcome issues, and over longer periods of time.

Table 2: Studies using modern gait analysis techniques for pre-treatment decision and/or post-treatment assessment purposes (continued)

Study	Purpose	Procedure	Gait Analysis Techniques Used	Main Findings
Vaughan et al. (79)	To assess effect of dorsal rhizotomy on gait of CP patients.	▪ 14 CP patients and 9 controls ▪ 2 to 14 years old (mean 8) for CP patients; mean 5 years old for controls ▪ gait analyzed 1 or 2 days before surgery, and 5 to 14 months (mean 9) and 36 months after surgery	▪ observational ▪ videotaping ▪ computerized sagittal plane kinematics	Report improvements (e.g., increased knee and thigh range of motion, increased stride length, increased velocity)

Table 3: Studies using modern gait analysis techniques for descriptive or categorizing purposes

Study	Purpose	Procedure	Gait Analysis Techniques Used	Main Findings
Damiano et al. (19)	To compare observational (the GMFM) to kinematic and kinetic gait analysis	■ 32 CP children (26 with spastic diplegia, and 6 with spastic hemiplegia) ■ 3 to 18 years (mean 8.9) ■ compared observational with kinematic and kinetic data via use of multiple regression with GMFM as dependent variable	■ Observational (GMFM) ■ computerized 2D and 3D time-distance, kinematics and kinetics with a 4 camera VICON motion analysis system	■ cadence, velocity, stride length, and sagittal plane hip and knee angles were good predictors of GMFM, and cadence was the best ■ kinetic data was not significantly related to the GMFM ■ conclude that the GMFM and computerized gait analysis are valid indicators of motor function in CP, further research needed to determine relative sensitivities
Delp et al. (22)	To determine whether hamstrings are short in patients with crouch gait	■ 14 CP children with crouch gait (mean 10.5 years); 10 controls (mean 12.6 years)	■ computerized 3D kinematics with 5 camera VICON system ■ graphic based biomechanical model	■ Hamstrings appeared to reach normal or longer than normal lengths during walking; psoas shorter than normal in all patients ■ Conclude that this emphasizes need to consider geometry and kinematics of multiple joints before performing surgical procedures aimed at correcting crouch gait
Duffy et al. (27)	To determine which features of gait are most responsible for increased energy consumption in SB children while walking	■ 27 SB children, and 14 normal children ■ 6 to 14 years old (mean 10)	■ observational ■ computerized 3D kinematics with 5 camera Vicon system ■ Oxygen consumption with a Cosmed K2 system	Hip adduction, pelvic obliquity and range of movement in hip were most highly correlated with oxygen consumption.

Table 3: Studies using modern gait analysis techniques for descriptive or categorizing purposes (continued)

Study	Purpose	Procedure	Gait Analysis Techniques Used	Main Findings
Hoffinger et al. (41)	To evaluate role of the hamstrings in CP patients with crouch gait	■ 16 diplegic CP children ■ 4 to 15, and 1 25 year old (average 10.5)	■ computerized 3D kinematics with ExpertVision Motion Analysis system ■ surface EMG of adductors, vastus lateralis, rectus femoris and medial hamstrings	■ Found hamstrings were not short, and were assisting with hip extension many of their patients. ■ Conclude that surgeons should be judicious with hamstring lengthening for crouch gait. Tight hamstrings are not necessarily short. Lengthening hamstrings unnecessarily could do more harm than good.
Hullin et al. (42)	To describe and classify gait abnormalities in CP patients	■ 26 CP children	■ computerized 3D kinematics and kinetics with a Kistler forceplate and a Vicon motion analysis system	Based on the gait analysis data, could divide the children into 5 groups
Kelly et al. (43)	To compare observational with kinematic gait analysis, and to derive a formula for a quality of walking score from this comparison	■ 55 CP children and 5 normal children ■ 5 to 15 years old (mean 8.2) ■ 33 males, 27 females	■ observational functional walking test ■ video analysis ■ sagittal plane kinematic analysis with a computerized CODA-3 optical tracking system	■ found that the features most discriminatory in determining a normal from an abnormal gait were balance, speed, range of motion and apparent effort
Saleh and Murdoch (63)	To compare sensitivity of visual gait analysis with sensitivity of biomechanical gait analysis	■ 5 amputees ■ compared visual and biomechanical analysis, and speak of predicted values, but do not specify where they come from	■ visual observations ■ biomechanical gait analysis (equipment not specified)	■ Experienced observers were only able to identify a small fraction of deficits seen by the biomechanical analysis ■ conclude that visual observation be coupled with simple measurement devices and biomechanical analysis for clinical assessment of gait

Table 3: Studies using modern gait analysis techniques for descriptive or categorizing purposes (continued)

Study	Purpose	Procedure	Gait Analysis Techniques Used	Main Findings
Sojka et al. (65)	To describe gait deficits of CP children who exhibit genu recurvatum	■ 10 children (6 CP and 4 age matched controls) ■ 4.5 to 10 years old	■ observational ■ videotaping ■ computerized 3D kinematics using 2 camera and 1 camcorder WATSMART system ■ footswitches ■ surface EMG	■ The CP children could be divided into 2 groups based on the gait data (e.g., hip and knee angles, stride length, cadence, and EMG) ■ Conclude that because of differences between CP children, similar treatments will not necessarily lead to similar outcomes. Further study of gait of CP children needed.
Tylkowski and Howell (77)	To describe and classify CP children with crouch gait.	■ 46 CP children ■ 10 to 12 years old (mean 11)	■ observational, with goniometers ■ computerized 3D kinematics with a 6 camera motion analysis system ■ surface EMG (fine wire if needed)	Based on the gait data, and particularly sagittal plane pelvis tilt, could divide the patients into 3 groups; were not able to do this with clinical analysis alone Conclude that their results demonstrate that gait labs can differentiate causes more specifically than clinical examination alone
Vankoski et al. (78)	To describe and classify gait abnormalities of SP children	■ 21 SP children ■ 4 to 15 years old (mean 8.4) ■ 7 males, 14 females	■ kinematics	Could divide the SB children into 2 groups, based mainly on differences between then at the pelvis and knee, and muscle weakness

Table 4: Canadian laboratories undertaking human gait analysis

Name	Equipment	Purpose	Staff
Bloorview MacMillan Centre, Toronto	▪ 4 camera VICON motion analysis system ▪ 1 Kistler forceplate ▪ 8 channel EMG (BORTEC Electronics, Calgary, Alberta)	Research, and occasional clinical assessment	▪ 1 research engineer ▪ 1 technical director ▪ 1 consulting medical director ▪ 1 PhD student
Kinesiology Department, University of Waterloo	▪ computerized motion analysis system ▪ forceplates ▪ 16 channel biotelemetry EMG	Research	▪ details not obtained
Human Performance Lab, University of Calgary	▪ 4 camera computerized motion analysis system with custom-made Kintrak software ▪ 3 Kistler forceplates ▪ tethered EMG	Research, and occasional clinical assessment	▪ approximately 80 researchers, visiting researchers, graduate students, post-doctoral fellows, and secretarial and technical staff
Joint Injury and Arthritis Research Institute, University of Calgary	▪ 4 camera computerized motion analysis system with custom-made Kintrak software ▪ 3 Kistler forceplates ▪ tethered EMG	Research, and occasional clinical assessment	▪ approximately 80 researchers, visiting researchers, graduate students, post-doctoral fellows, and secretarial and technical staff
Kinesiology Department, University of British Columbia, Vancouver	▪ 3 camera and 3 VCR Peak5 motion analysis system ▪ 1 Kistler forceplate ▪ 8 channel tethered EMG	Research	▪ details not obtained
Sunny Hill Health Centre for Children, Vancouver.	▪ 6 camera motion analysis system from Motion Analysis Inc. ▪ 2 AMTI forceplates ▪ telemetry EMG	Clinical Assessments, and occasional Research	▪ 1 full time director with an M.Sc. in Kinesiology ▪ 1 0.7 time pediatric physiotherapist ▪ 1 0.2 time orthopedic surgeon

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