Appendix A:

Alphabetical Listing of Participant Personal Statements on Gait Analysis in Rehabilitation Medicine

Mark F. Abel, M.D.

The major reasons why clinicians have questioned the utility of motion analysis is that it requires the acquisition of new knowledge related to gait mechanics. When the MRI was introduced for musculoskeletal imaging, clinicians were resistant to learn the technology because it did not offer anything over CT scans. However, it is now been accepted as a vital part of diagnostic imaging. Similarly, with motion analysis, a new technology must be learned. Although many people take care of children with cerebral palsy, only a minority understand how to read gait data. However, I feel it is an important part of following the progress of people that have neuromuscular conditions. Establishment of a standard format and education of clinicians is clearly needed.

Another glaring problem which undermines the use of these laboratories is that validity of the instruments has not been clearly established. Multiple variables including temporal, kinematic, and kinetic can be measured and we are only beginning to appreciate the variability of these measures.

In summary, gait laboratories should have an important role in both basic and clinical medicine. Once the reliability of the measures have been established, characterization of clinical conditions affecting motor control and following progress of these conditions should be possible and best achieved using motion analysis. Collaboration between laboratories, I believe, is extremely important not only to answer the questions of variability but also to expand into the arena of outcome assessment.

Gordon J. Alderink, MS, P.T.

The Center for Human Kinetic Studies (CHKS) was established through the joint efforts of Grand Valley State University and Mary Free Bed Hospital & Rehabilitation center in 1992. The primary objective of the lab is to provide a service to the orthopedic and rehabilitation physicians in Western and Northern Michigan to aid in their treatment decision processes by providing objective, reliable data related to gait and other movement dysfunctions. The CHKS is also committed to clinical research, which is carried out by lab staff and Grand Valley State University physical therapy faculty and graduate students. Our staff have been involved with the clinical motion analysis community by attending nationally held clinical gait conferences, staying abreast of the many critical issues that are impacting clinical motion analysis, and by being involved in activities related to standardization of motion analysis laboratories. We are pleased with our development to this point, but are concerned about several issues, including: 1) Reimbursement and lack of specific CPT or other payment codes for computerized gait analysis (CGA); 2) Inadequate understanding of how CGA can or should be used by rehabilitation specialists; 3) Under utilization by orthopaedists and rehabilitation specialists (both physicians and therapists); 4) Lack of universal acceptance of CGA as a valid and reliable clinical tool (many insurance companies consider CGA as experimental or research); and 5) How CGA may be utilized in an environment increasingly dominated by managed care.

Through the insight and work of Simon, Sutherland, Perry, and Gage (and many others) CGA has been used for clinical decision-making for approximately 20 years. As a result CGA has become the standard of care where it is available. CGA has made it possible for clinicians to make more precise treatment decisions (with more confidence) and measure their outcomes accurately and reliably. Outcome studies using CGA have made it possible for surgeons to improve their treatment decisions. For example, rectus femoris lengthening for the child with spastic diplegia has been replaced by a transfer technique, partly because of the information that CGA was able to provide. Although the orthopaedists have benefited from CGA, it seems that rehabilitation specialists have not taken advantage of this technology for the treatment of stroke, traumatic brain injury and amputation. CGA has had a major impact in the management of certain patients and has been shown to be cost effective, reliable and objective, but there are several issues that need to be addressed: 1) With the proliferation of new motion analysis laboratories standardized procedures need to be established; with standardized procedures the consistency of data will be improved and payers will more likely accept CGA as standard care (not experimental); 2) Rehabilitation specialists (physicians and physical therapists) and payers (private and public need to be educated on the benefits of CGA; 3) Specific CPT codes need to be established for CGA; and 4) An accreditation process for motion analysis laboratories would also help insure quality of care.

Because CGA is not readily available to everyone, observational gait analysis becomes a very important clinical tool. This tool has been used by rehabilitation specialists for many years. It is

convenient, very cost effective and available to all. However, it may not be as valid or reliable as CGA. I do not believe that this tool is being used consistently and with standardized procedures by those in rehabilitation medicine. At the CHKS we use observational gait analysis in conjunction with CGA and have adopted the terminology and procedures established by J. Perry and Ranchos Los Amigos. I believe that their operational definitions and procedures are precise and easy to apply. Recently, researchers at Rancho studied and reported on the validity of objective observational gait analysis, using CGA as the standard for comparison. Their results were reasonably good. Since observational gait analysis will probably not be replaced by CGA I believe that better standardization of those procedures need to be established.

Recommendations:

1) Educate the rehabilitation community on the utilization of CGA.
2) Establish standards of care regarding the use of CGA.
3) Educate payors (private or public) on the use of CGA.
4) Establish payment codes that are specific to CGA.
5) Examine how CGA will be utilized in a management care environment, where cost containment and efficacy will be the goals.
6) Continue basic and clinical research using computerized biomechanical analysis to analyze how it can be used to cost effectively enhance the practice of orthopaedic and rehabilitation specialists.
7) Establish the validity and reliability of observational gait analysis and standardize those procedures to enhance the clinical practice of those who do not have CGA.

Sherry I. Backus, M.A., P.T.

Gait analysis has increased not only in the scope of the types of patient being referred for gait analyses, but also in the availability of the technology to perform these tests and the nature of the inferences/recommendations being drawn from these tests. There are several issues related to each of those three areas that need to be addressed to ensure consistent quality care is being provided to people with disabilities.

1. **Increased outcomes research.** There has been a greater emphasis in all areas of rehabilitation to facilitate outcomes based research. This shift has only just begun to occur in the gait analysis literature. The majority of the literature that relates gait analysis to outcomes research is in the CP patient population, and even in this population, there are gains to be made. In addition, there are few outcome studies in other patient population groups. The effectiveness and justification of this costly evaluative technique must be determining and quantifying the pre-operative/pre-treatment characteristics (kinematics, kinetics) that influence post-operative/post-treatment function and outcomes. It is not simply sufficient to document an increase in knee flexion angle by 20 degrees, the functional benefits need to be documented also.
2. **Expanded applicability to a variety of disabilities.** The use of gait analysis in the CP patient population forms the basis for many clinical and research gait laboratories. However, the role of clinical gait analysis in persons with other neurologic, orthopaedic and balance dysfunctions is poorly documented. Certainly gait abnormalities have been described in a variety of conditions, but the practical implications and ramifications for treatment and surgical selection have not been documented. While this relates in part to outcomes research, it also relates to a lack of knowledge of how the information gained from gait analysis can be applied to recommendations and treatment suggestions. The usefulness of gait analysis in the clinical setting needs to be better communicated to a side variety of health professionals and patients. In addition, the limitations of gait analysis need to be understood so that appropriate referrals are made. X-rays are an inefficient way to determine knee ligament instability, and similarly, gait analysis may not be a cost effective evaluative tool for every diagnosis; these limitations need to be better understood.
3. **Standardization.** This has been a topic of sub-committees, task forces, vendors, and across many institutions. These discussions have highlighted the difficulties in standardization of measurement techniques, testing protocols, terminology, and reporting formats to name a few areas. The implications for clinical gait analysis are apparent as testing services may be provided at one institution for a physician/clinician in another institution. The challenge is to allow not only multi-center research studies, but also interpretation of clinical data that is not institution specific.

In order to advance gait analysis in rehabilitation medicine, the following are recommended:

1. Development and funding for outcomes research across a variety of disabilities.

2. Increased awareness to health care providers, third party payers, and patients as to the benefits and limitations of gait and functional movement analysis. As providers, we must be as cost aware as are the patients and payers, and as providers, we must continue to document that those unique measurements made during gait analysis have some meaningful relationship to treatment options and prognosis.

3. Continued improvements in standardization across testing institutions.

4. Inclusion of all facilities providing gait and functional movement analyses in these processes. As the amount of local expertise and technology in a facility is varied, and the locations ("gait laboratories," out-patient settings, private practitioners offices, etc.) where gait analyses are performed expand, communication of advances and standards need to be widely disseminated.

Claire C. Bassile, Ed.D., P.T.

The research community is keenly aware of the 'potential' impact that gait analysis information can have on the treatment intervention for individuals with disability. This relationship has been established for determining the orthopedic surgical procedures in children with cerebral palsy. The application of gait analysis in identification of impairment(s) as well as influencing nonsurgical treatment interventions (i.e., physical therapy) in other clinical populations has not been investigated thoroughly. Lastly, the literature that is available on these issues has not been widely disseminated to the health professionals which rehabilitate individuals with gait impairments. Therefore, I would urge federal funds be allocated for studies which:

1. Target a variety of clinical populations and identify the relationship of impairment(s) to functional limitation in gait.

2. Utilize gait analysis information in the development of treatment implications for clinical populations.

3. Seek to document the efficacy of a particular treatment intervention through the use of gait analysis and identifies at what level (pathology, impairment, functional outcome) the improvement is occurring.

4. Identify gait analysis tool(s) or methodology(ies) which provide the most appropriate/sensitive measures for the clinical populations investigated.

5. Identify the appropriate/sensitive measures in a clinical population under investigation which may predict functional outcome.

6. Follow clinical populations longitudinally and seek to distinguish plasticity of the CNS vs. Compensation in recovery of gait function, critical periods of opportunity for plasticity of the CNS post injury and treatment intervention choices.

7. Address a variety of locomotor functions in clinical populations, not just overground locomotion but transitions to locomotion, obstacle avoidance, speed changes in locomotion, unlevel surface locomotion and locomotion patters other than 2 feet (e.g., power w/c, manual w/c-one hand, one foot; two hands; one hand).

8. Utilize appropriate control groups from which to compare treatment efficacy. For example, investigations into the efficacy of a particular physical therapy treatment on the gait of individuals post-stroke usually reveals that the control group is receiving conventional PT. In other words, treatment with a theoretical framework based on the writings of Brunnstrum or the Bobaths. Presently the motor learning framework is being advanced. These are not appropriate control

groups. The control group should be another group with equal time spent in conventional ambulation training.

9. Look at the best ways to educate health professionals and consumers regarding the merits of gait analysis for different clinical populations.

John A. Buford, P.T., Ph.D.

There are three basic issues in clinical gait analysis. First is the depth and quality of the analyses, second is the selection and optimal presentation of results pertinent to the management of the case at hand, and third is the definition of indications for the analyses and incorporation of the results into the clinical decision-making process. These three are linked. For example, if the goal is to decide between two possible canes, observational gait analysis combined with a stopwatch and a metered walkway may be adequate. Thus, the quality of the data need not be extravagant, the clinical decision making process would be straightforward, and the cost of an error would probably be small. On the other hand, if the objective is to decide whether a hydraulic or a friction knee in a A/K prosthesis results in lower shear forces in the skin of the residual limb, then a more sophisticated analysis may be indicated and the cost of an error could potentially be large.

Our central task is to identify branch points in the clinical decision-making process where alternatives may significantly affect functional outcome depending on how well the treatment of the identified gait deficit matches the appropriate response for the actual gait deficit. In other words, if the clinical observation led to an improper identification of the deficit, but some form of gait analysis (however simple or sophisticated) would have led to proper identification of the deficit, and the cost of applying the 'wrong solution' was significant in terms of the functional ability of the patient, then there is a problem that gait analysis can solve. Finding these critical branch points in the path of the clinician and showing how we can be helpful should be our first mission. In support of that mission, we need effective communication of results from reliable analyses.

Major Recommendations

1) Identify branch-points in the clinical decision making process where gait analysis would change the decision, the resulting treatment, and the functional outcome of the patient. Determine diagnosis (disability) specific indications for gait analysis and weight costs against benefits. Establish high-priority for research along these lines.

2) Achieve consensus for the reporting format of results of gait analysis through debate of issues and establishment of a process for selecting and maintaining standards. Limit participants to the clinical gait analysis community so that we, the most important consumers of the information, get what we want.

3) Achieve consensus for the standard accuracy requirements for gait analysis through debate of issues and establishment of a process for selecting and maintaining standards. Include participants from industry, end-users (gait laboratories), professional societies, and other stake holders.

Minor Recommendations

1) Kinetic analyses should be three-dimensional and should always include the influences of inter-segmental dynamics. Currently available software makes this straightforward. The old justification of expensive computer time and limited data storage space no long applies. The full analysis can provide critical details in rapid parts of the cycle (e.g., pre-swing, swing or running).

2) The scope of "gait labs" must be expanded to include "motion analysis" in a more generic sense. Research along the lines of Major Recommendation 1 should be a priority to see if and how we can help, for example, in the management of upper extremity movement disorders and other problems aside from gait.

Carmen L.N. de Castro and Licia Saadi, M.D., Msc

Our suggestions for future work and development:

1 - Hardware and software advancements

a) Visualization systems - linking objective data with subjective observations through the use of representations data upon video recording.

b) Real time operation - to reduce the data time elaboration, to improve the accuracy and permit the use in clinical situations that requires fast comparison of information like orthosis and prosthesis alignments.

c) Creation of dedicated software to evaluate the equipment precision - to evaluate the calibration's effectively during all homogenous acquisitions.

d) Development of analysis of another relevant locomotor tasks - like stair ascent or descents, rising from a chair.

e) Creation of dedicated software to assess locomotor function for specific applications - joining stride, kinematics, kinetics, and muscular function measurements with evaluation of postural steadiness and energy consumption that can indicate the disability in several clinical conditions: stroke, fall prevention in geriatrics, Parkinson's disease, amputees, cerebral palsy, etc.

2 - Co-operation between gait centers

a) To share experience and expertise and greater dialogue between the centers and clinical community - in order to develop clear reasonable objectives would be particularly beneficial.

b) Determination of guidelines in methodology of the several equipments for movements analysis to clinical use - including data normalization, units standardization, form and method of data presentation.

3 - Medical Education - education of medical specialists about:

a) Indication of instrumentation requirements as better diagnostic tool in specific pathological groups - for example: the quantification of pressure distribution under the diabetic foot requires a baropodometer while the orthoses and prostheses proper alignment evaluation requires the measurement of force vectors by a force plate. A correct interpretation of electromyogram of a cerebral palsy child requires a foot switch or camera recording of joint kinematics.

b) Indication of the best locomotor task to analyze specific pathologies - It seems that many knee pathologies are better analyzed during stair ascent or descents and rising from a chair can stress the hip more than gait.

D.S. Childress, Ph.D.

1. Language, nomenclature, and definitions continue to produce communication barriers that impede progress toward clinical application of "gait analysis." International standards development, similar to what happened with EKG analysis 50 or more years ago, will need to come about.

2. Gait analysis equipment needs to be located in clinical environments where it is easily accessible by clinicians who are looking for solutions to real problems.

3. Gait analysis laboratories need to be problem driven, not technology driven. Problem setting needs to be clinically based. Gait analysis results need to answer questions related to real problems that cannot be answered in any other way.

4. The issue of data overload must be addressed either by simplification methods (data reduction) or by development of better graphical display systems, etc.

5. A significant proportion (say 20%) of the activities of clinical gait laboratories needs to be directed toward hypothesis testing, not merely data gathering and analysis.

6. Visualization systems need to be developed that bring together subjective and objective domains to assist with communication between clinicians, engineers, and scientists and to assist in the process of understanding.

7. Some "real-time response" modalities need to be available for experimentation that is response directed.

8. Modeling and theory are not developed to the point that allow models and theoretical principles to be used to aid analysis, interpretation, instrument improvement, etc.

9. Simple, easy-to-use, low cost, low maintenance systems--perhaps dedicated to specific pathologies--have yet to be developed and should be considered.

10. It may be incorrect to base clinical treatment decisions on a kind of differential diagnosis that relies mainly on comparisons of pathological gait data with so-called normal gait data.

Kim Coleman, M.S.

The field of gait analysis is challenged to prove its worth. Because the work is still largely descriptive, research laboratories often encounter great difficulty securing funding in a climate which demands results clearly applicable to clinical and commercial endeavors. Clinical laboratories work to move beyond description by applying technical analyses to medical and rehabilitation interventions. But because there are a few widely accepted standards for translating description into prescription, the approach to clinical gait analysis varies considerably across sites.

In order to significantly advance the application of gait analysis to rehabilitation medicine, I believe we must 1) strengthen the link between scientific investigations of gait and the clinical application of results, and 2) assimilate the data and insights gained through the many site-specific approaches to clinical gait analysis and begin to build a more unified standardized approach. To accomplish this, the two main areas on which I think we ought to focus are the development of standards and the dissemination of information.

Standards

A) Standards for the Reporting of Data from Academic and Clinical Research.

Because of the complexity of human gait, the subtle and interrelated nature of its deviations and adaptations, and the widely varying methods of study and reporting, the field of gait analysis has been slow to establish a comprehensive description of what we do know. The results of similar studies often do not agree, but even when they do, it can be very difficult to determine how they fit with those related studies to broaden the overall understanding of gait.

We are faced with the challenge of assimilating the vast amount of gait data available into a comprehensive picture. Already organizations like the International Society of Biomechanics, the CAMARC group, the Scoliosis Society, and the Clinical Gait Analysis Group have begun to take steps in that direction by working to establish standards for the reporting of data. The ISB's Recommendations for Standardization in the Reporting of Kinematic Data, which was published in the Journal of Biomechanics last year and touched off a spirited debate in the field, is one such effort. I believe we need to extend these efforts throughout the field.

B) Standards for the Assessment of Function: the Link between gait analysis and clinical intervention.

The clinical identification of gait abnormalities through detailed laboratory testing and analysis has become quite common. However, we are much less adept at assessing the

consequence of a given gait deviation to a patient's functionality in his/her life beyond the walls of the laboratory. The gait pattern employed by a person at any one time results from a complex interaction of many factors such as skeletal structure, muscular strength, joint range of motion, physical pain, level of fatigue, and emotional state. Consequently, it is often tricky business to determine whether an observed gait abnormality is a beneficial or detrimental adaptation. To complement the descriptive capabilities of laboratory gait analysis, we need tools which reach outside of the laboratory and into the patient's normal daily environment to give feedback on what the patient is actually able and choosing to do. In other words, we need a general, widely accessible means of measuring real world functionality which will provide the framework from within which specific measures of gait character can be interpreted for the purposes of prescribing and guiding treatment , and assessing outcome. The measures should be simple and inexpensive to obtain, and straight-forward to interpret. They should reflect, rather than be confounded by, day-to-day variability in actual gait functionality. Finally, they should be understood to represent a gross overview somewhat like age, height, weight and blood pressure do in general medicine.

To effect this link between gait laboratory testing and the clinical application of results, I believe we ought to take the following steps:

1. Establish standard definitions of real world ambulatory functionality. These might be similar to the Medicare functional level classifications set forth in the 1994 DMERC Policy for Lower Limb Prosthetics, but based on more measurable parameters.

2. Seek/develop practical, widely accessible "overview" measures of real world gait functionality based on the established definitions. Some factors I would like to see considered in the definition and measurement of real world functional levels include:
   - -the ability to perform high intensity bursts of activity
   - -the ability to sustain given levels of activity
   - -the ability to maintain mobility after periods of activity
   - -the ability to negotiate obstacles and varied terrain
   - -the spontaneous/deliberate quality of activity
   - -the overall amount of activity performed.

3. Validate the overview measures with respect to their ability to provide:
   a. meaningful, standardized assessments of functional status.
   b. reference for guiding the interpretation of more detailed gait laboratory testing.
   c. standardized means of assessing outcome.

Dissemination of Information

In conjunction with establishing standards for the reporting of gait data and the assessment of functionality, I believe we ought to establish a digital forum for the communication

and assimilation of results from academic and clinical research world wide. The expansion of Internet/Web technologies has recently enabled rapid and widespread international communication among researchers and clinicians in all fields. Already, groups such as the ISB have established data bases for research results which can be accessed by members over the Web. I believe we are in need of a clinically-oriented data base through which gait analysis data can be reported, evaluated, assimilated with other clinically-relevant data, and accessed efficiently.

Rory Cooper, Ph.D.

Gait analysis has been used to describe locomotion of people for years. A vast majority of the gait analysis research has focused on the lower extremities. Some work addresses locomotion of unimpaired individuals, other work on athletes, and still other work on people with various physical impairments. The trend for the future is towards greater study to understand, prevent, and treat injuries. Although, work in sports is likely to continue. Human gait analysis is traditionally defined as the study of bi-pedal locomotion with the lower extremities. Within this definition, gait studies have included ambulation with prostheses, ambulation with orthoses, and ambulation without assistive devices. Gait research has been helpful in understanding walking and running for people with and without various forms of impairments. Several conferences have been held, and research priorities have been implemented. However, gait analysis needs to take a broader view within rehabilitation.

Ambulation which is performed with the use of the upper extremities has not received adequate attention. However, pushrim driven wheelchairs, arm propelled lever driven devices, arm crank driven devices, and electric powered wheelchairs are all important forms of ambulation, which require further research and development. Although these forms of mobility are not classically defined as "gait," they do exhibit distinct patterns which are identifiable, and alterable. Moreover, conservative and aggressive therapies have been developed to treat people with disabilities who use their upper extremities for propulsion without substantial biomedical analysis. Studies have shown that a majority of long-term manual wheelchair users develop repetitive strain injuries. The progression of RSI presents several complex clinical research questions. Often, wheelchair users do not have the range of mobility options which are available to people who can walk. Wheelchairs are also evolving, and quantitative studies are required to determine their safety, efficacy, and proper fit. Gait research for upper extremity, wheeled locomotion can help to address RSI, propulsion efficiency, postural support during propulsion, and activities of daily living. This research will lead to better wheelchairs, and provide guidance for clinical practice.

Pushrim propelled wheelchairs are slowly being augmented by other means of manual wheeled mobility. Arm-crank and arm-lever drive wheelchairs are becoming more popular as mobility devices, recreational devices, and as exercise devices. Biomedical analyses of these devices is required to insure their safe and effective design. The devices offer substantial promise for improving the health and well-being of many people with disabilities.

Research into this area could help reduce the incidence of RSI, and cardiovascular disease.

Electric powered wheelchairs may not be thought of as gait, but the methods developed through gait analysis can be applied to improve the mobility of people with arm impairments. Issues of dynamic stability and postural control during electric powered wheelchair driving are gait

questions. Positioning of input devices for optimal control of the wheelchair in a variety of environments is also an important research problem. Another very pressing question for researchers and clinicians is when to choose an electric wheelchair over a manual wheelchair. There are many clinical, social, and personal, implications associated with this decision. Further research is required to provide a foundation for selecting the appropriate answer for each individual.

Lower extremity gait analysis has made many important contributions. The definition of gait among lower extremity researchers has been broadly defined. Within the context of rehabilitation, alternative forms of mobility are of paramount importance. Gait analysis must include analysis of motion controlled by the upper extremities. The combined resources of the lower extremity gait researchers, upper extremity gait researchers, and rehabilitation professionals can have tremendous positive impact on people with disabilities.

Rebecca Craik, Ph.D., P.T.

The gait literature is filed with rich *descriptions* of walking performance detailing how walking differs with age, sex, body weight, etc. An assumption underlying the descriptions is that understanding "normal" performance will provide a foundation for understanding the walking strategies adopted in the presence of pathology. A single variable has not been identified that, like body temperature, serves to screen for the presence of pathology. Instead it is usual to find statements in the literature concluding that a complete evaluation of gait requires the collection of kinematic, kinetic and electromyographic variables.

The approaches to research, clinical evaluation and treatment of problems of gait have not differed significantly from the times of Eberhart, Inman, and Saunders. We have fancier tools to measure more and very complex variables, but we still don't know what to measure, how to use the measurements to guide treatments, or how to treat across a variety of medical diagnosis. The relationship between the nervous system, the musculoskeletal system, the environment and function remains unknown. We have a long way to go.

Some suggested needs:

1) Determine what the reference standard is in gait for persons with an array of functional problems. Is the goal of treatment to restore function or to help the person compensate? The goal should influence the standard by which performance is evaluated.

2) Move beyond description of walking ability and identify modifiable factors, i.e., those that are amenable to treatment.

3) Develop a model of walking performance that identifies major determinants of gait. Intervention will continue based on the untested assumption that there is a relationship between some impairment and disability until major determinants of recovery are identified.

4) Develop a model of walking performance that merges neuroscience, biomechanics, and function.

5) Develop a classification scheme of walking performance that moves the clinical away from medical diagnosis and towards a focus on functional ability. The classification scheme would lead to critical paths for selective intervention.

6) Determine functional requirements for walking that relate impairment, disability and handicap.

7) Shift attention beyond biomedical factors that limit recovery of walking ability to include psychosocial factors.

8) Determine the effectiveness of intervention on reducing the discrepancy between optimal and actual recovery of walking ability.

Diane L. Damiano, Ph.D., P.T.

Rehabilitation medicine serves to improve the lives of individuals with disabilities, and assessment tools such as clinical gait analysis must contribute to this mission if they are to be successful. While few would argue the value of gait and motion laboratories for the advancement of biomechanical knowledge of normal and pathological movement, the extent of their clinical applicability is still controversial. Unlike radiographic technologies such as X-ray, computed tomography, and magnetic resonance imaging, gait analysis has failed to establish itself as a necessary clinical service. In addition, clinical utilization of gait laboratories is limited not only by philosophical differences in medical practice, but also by geographic or financial inaccessibility.

So why is it that gait analysis has failed to attain the mainstream support of the medical community? Gait analysis has been used extensively to evaluate the complex multi-joint gait abnormalities in cerebral palsy, but even for this population no documentation exists establishing that the use of this assessment leads to improved functional motor outcomes. Gait analysis can objectively document motor status in an ambulatory individual at a single point in time or measure very precisely the change in ambulatory function over time. However, its ultimate importance rests on whether its use alters treatment decisions in a positive direction. Therefore the central issue is this: *Does the addition of gait analysis in the clinical assessment of a person with a disability contribute substantially to improving treatment outcomes, or could the same result be achieved in the absence of gait analysis?* If gait analysis does indeed improve outcomes, then gait laboratories should become a standard of care for those with complex walking disorders. This should then spark an increase in the number of laboratories and their usage, and accessibility should (within a reasonable amount of time) no longer be an issue. However, if gait analysis is shown to be a useful evaluative tool but yet does not appreciably affect outcomes, survival as a clinical service would be seriously impaired. We in this field need to be proactive by conducting or facilitating research that demonstrates the clinical effectiveness of gait analysis in minimizing disability.

A second major issue concerns the validity of the two assumptions that are implicit in the use of gait analysis in rehabilitation medicine. The first assumption we make is that walking is an important skill to these patients and their families. Indeed, one of the first questions that parents will ask when informed that their child has cerebral palsy is, "Will my child ever walk?" Most of the interventions offered throughout childhood, and even extending into adolescence and adulthood, such as bracing, surgery and physical therapy, are aimed at improving or maintaining this skill. However, the patients themselves must determine the importance of walking in their daily lives, since all of these interventions have physical, emotional, and financial trade-offs associated with them. The second assumption is that gait ability is representative of performance on other motor tasks. Gait laboratories have responded to this concern by expanding their assessments to include different aspects of gait such as stair climbing and fast

walking, or by adding assessments of energy cost and other functional and disability assessments concurrently. As the clinical scope of gait analysis broadens to more comprehensively assess gross motor performance, the ability of these laboratories to assess functional outcomes should similarly increase.

In conclusion, as gait analysis laboratories have proliferated, so has the scientific body of knowledge on cerebral palsy as well as other neuromotor and musculoskeletal disorders, enhancing our understanding of the motor pathology and altering the types of interventions prescribed. I am confident that gait analysis will continue to be a valuable assessment and research tool in rehabilitation medicine, and I hope that future research will provide justification for the incorporation of gait analysis as a standard practice for clinical decision making in persons with disabilities.

Howard J. Dananberg, DAM

Gait analysis is a broad topic reflecting many technologies combined to view a wide range human locomotive dysfunctions. In the cost conscience medical marketplace however, the application of *all* of these technologies for *each* case may not be an effective utilization of services. This position paper describes the use of in-shoe plantar foot pressure analysis during gait combined with two view-video analysis as a cost effective method of treatment for patients with chronic postural pain (CPP) (i.e., lower back pain). While the all encompassing measurements required for scientific research are a necessity, a relatively simple gait assessment is highly acceptable for its clinical application in the CPP patient population. An explanation as to its rational, methods and effectiveness follows.

In normal, bipedal human walking, it is essential to step up and over the weight bearing limb. For this to occur, the thigh extends out from under the hip, as the body simultaneously advances forward over the planted foot. The foot, through a highly complex mechanism, serves as a functional pivot or fulcrum point while bearing the full weight. Sagittal plane (forward) motion of the body over the foot is thereby permitted and coupled with concurrent self bracing mechanisms of not only the foot, but the lower back, head and neck as well.[1,2] Although taken for granted, this complex sagittal plane pivot fails far more commonly than previously recognized and can upset the chain of events in the entire body as it attempts to pass over it.[3] Due to its subtle nature, it has been overlooked as a potential cause to other CPP entities yet can be detected using plantar foot pressure sensing technology. Many seemingly unrelated CPP syndromes resolve when a failure of this sagittal plane motion of the foot joints is objectively assessed and treated. In a paper published in 1990[4] and subsequently referred to in other publications,[5,6] 77% of patients having failed multiple prior therapies and considered at medical endpoint for chronic postural pain (i.e., lower back pain) demonstrated 50-100% improvement at a two year F/U point when primary sagittal plane motion blockage at the foot was addressed. This is despite the fact that no obvious foot symptoms were evident in any of this patient group. The results of pain reduction are understandable through well established research previously performed within the neuroscience community on the function of pain sensing nerves (primary afferent nociceptors). Their transmissions appear to be modulated (transmission threshold of pain increases or decreases) based on their interrelationship with motion detecting proprioceptors (A and A mechanoreceptors). Constantly repeated abnormal motion patterns (typical of walking) act as a repetitive strain type injury and sensitize the common nociceptive/proprioceptive synaptic sites (wide dynamic range cells) in the spinal cord. Chronic pain is perceived and perpetuated by continued aberrations in subject's gait. Once detected, this cycle can be broken by a treatment method which can produce normal motion patterns and can specifically relate to sagittal plane foot function. The lasting effect described in the study cited was achieved when patients were evaluated via gait analysis using two-view video examination to verify the effects of custom foot orthotics objectively fabricated using in-shoe plantar foot pressure sensing systems. Due to the physics of weight transfer, the appearance of

the force/time curves calculated by in-shoe plantar foot pressure sensing systems can be used to determine the effectiveness (or lack thereof) of sagittal plane motion during single support. The classic, normal double hump curve can depict sequential sagittal plane pivot when viewed segmentally (heel/forefoot). Detection of sagittal plane motion blockage by viewing variations in curve shape is possible (flattening of the central depression, shifting of the higher peak to the heel from the forefoot, examining total heel contact duration and comparing left to right, alterations of the slopes of the curve within the central depression, etc.) due to failures in various foot motions to occur at specific times. A test foot orthotic capable of altering sagittal plane motion can therefore be fabricated, then evaluated and adjusted repeatedly until the desired effect is achieved. This effect is confirmed by easily identifiable motion markers using a two-view video system to assess pre-test and post-test orthotic fabrication. These markers include hip extension during single support, arm swing symmetry, direction of hip and knee joint motion during single vs. double support phase, torso motion, shoulder drops, head tilts and movements. Due to the relatively inexpensive nature of inshoe pressure and video systems, this type of examination can be used in the rehabilitation of lower back and other CPP patients in any community based medical setting and can therefore have long-term cost saving benefits.

Recommendations:

1) Establish a research program which can correlate foot level sagittal plane motion with plantar foot pressuring sensing analysis.

2) Develop interdisciplinary working groups to facilitate communication channels for the propagation of clinically relevant information.

3) Both government and private industry fund interdisciplinary research which can explore cost effectiveness via outcome based study of inshoe plantar foot pressure sensing analysis combined with two view video analysis for the evaluation and treatment of lower back and other chronic postural pain patients.

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Roy Benjamin Davis, III, Ph.D.

Over the past 15 years, clinical gait analysis has found good utilization in the assessment of pathological gait where motions are often complex and difficult for the fixed observer to fully appreciate. The most wide-spread use of clinical gait analysis is for the evaluation of persons with cerebral palsy in treatment planning (predominately orthopaedic surgery associated with tendon transfer/release, muscle lengthening, derotational osteotomy).[1-4] Other examples of clinical pathologies currently served to some degree by gait analysis include amputation, degenerative joint disease, poliomyelitis, myelomeningocele, stroke, and traumatic brain injury. Clinical gait analysis is also useful in the documentation of gait-related changes that occur because of treatment (again predominately associated with surgery). This clinical research is vitally important in the enhancement of the knowledge base associated with analysis, both on a patient-by-patient basis and also in studies that examine the functionality of a particular brace design.[5]

With this basis, how can clinical gait analysis approaches be strengthened further and its use be expanded with respect to Rehabilitation Medicine?

1. While gait data collection processes have matured over the past decade thereby producing more accurate and reliable information for interpretation, challenges remain. Most notably, gait models based on more reliable joint centering algorithms (particularly for the hip) would improve further gait analysis results associated with joint kinetic information. Even more importantly, gait models that either account for or are less susceptible to "skin movement artifact" would substantially improve the quality of the data (particularly those data associated with patients with obesity).

2. Additional clinical research is needed that documents changes in gait biomechanics associated with different patient treatment approaches. This research in particularly important in treatment alternatives commonly employed in Rehabilitation Medicine, e.g., physical therapy, orthotic management. As indicated above, this outcome research is essential for improving our use of clinical gait analysis data.

3. Formal training in gait analysis techniques and its clinical application must be expanded. In general, exposure by physicians and other clinicians to clinical gait analysis during medical school and residencies is limited. This impedes the incorporation of gait information in the treatment decision-making process. At the same time, gait analysis technologies must continue to strive to improve the ways in which gait information is presented for clinical interpretation.

4. The expense of gait analysis may be an impediment to its increased clinical utilization in Rehabilitation Medicine. A typical charge for a full clinical gait analysis ranges from approximately $1,000 to $2,500 depending on the facility and the specifics of the service

provided. This amount is consistent with the amount of time that is allocated to gait data collection, processing, interpretation, and report generation. Relative to the cost of surgical intervention and in the context of its permanency, the expense of gait analysis appears generally acceptable to both consumers and payors. However, the current cost of gait analysis may impede its use in clinical decision making associated with generally less expensive treatment alternatives such as physical therapy, the administration of spasmolytic medications (e.g., Baclofen), and orthotic use. Consequently, efforts to improve the efficiency of clinical gait analysis processes may be warranted, i.e., improving its either perceived or actual cost/benefit ratio.

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Robert C. Dean, Jr.

Gait Analysis is an important tool for fitting/aligning lower-limb prostheses. V02 measurements demonstrate that walking power varies considerably as a function of the quality of the socket fit, for both trans-femoral (AK) and trans-tibial (BK) amputees, and with the alignment of the mechanism. It is especially important to AK's that the geometrical parameters be correctly set; that is, the angles and offsets between: socket axis, knee-rotation axis, shank axis, ankle axes and foot centerline. Customarily, alignment is based upon visual observation by the prosthetist of the amputee walking over a short path (usually 3-5 m), forcing the amputee to turn frequently. Research shows that at least three strides are necessary to reach steady-state so the simulation of ordinary ambulation is usually poor. Most often, there is no simulation of walking on rough ground, and of the most hazardous for AKs... the excursion of downramps. Rarely is the speed of walking varied. For the BK, running performance is ignored.

Research at SII has demonstrated that the use of a special treadmill which can be pitched up or down angled left or right with speed variable from 0-10 mph is a very useful, and a relatively inexpensive tool for prosthesis alignment. The addition of a force plate under the belt and a belt-tension dynamometer, with V02 instrumentation and intersocket pressure measurements can yield a complete set of vital information about gait, power demand and, eventually we hope, a direct measure of the quality of socket fit and prosthesis alignment. We call this gait analyzer an "Ambulation Simulator."

The most important characteristic of a lower-limb prosthesis is the interface between the amputee's anatomy and the mechanism i.e., the socket interface. The majority of amputees report unsatisfactory, even painfuted with his/her prosthetist and moves, as frequently as possible, to another prosthetist. This is very expensive therapy given that AK prostheses today in the U.S. costs AKs $10-20,000 and BK, $6-12,000. One of the principle reasons for the high cost is that the prosthetist finds it necessary to produce 2-5 trial sockets before a "satisfactory" fit is achieved. But, that fit is "satisfactory" to only 25% of lower-limb amputees.

CAD-CAM has been applied extensively for manufacturing sockets, but with no better results than the conventional art produces. That is, CAD-CAM cannot generate the critical fit between anatomy and socket. Today, it is only the hands of an experienced prosthetist that can achieve a "good" fit and that fit is not really "good" with or without CAD-CAM, and even with the hands of a most accomplished prosthetist.

Our research has now identified the reason for this wholly unsatisfactory situation. That is, the stump anatomy is constantly changing in volume, for both BK and AK amputees. For example, active BKs sometimes require the donning of one stump sock in the am, with the addition of four more socks during the day! Personal experience (54 years as an AK) proves that my stump changes volume diurnally by 60 mL/1500 mL (4%). Tests with SII's variable-geometry

socket reveal that the AK amputee can sense a volume change of < 1% as "looseness," insecurity (especially for full suction retention) and, with a variation of 1%, the output of unsocial noises. There is no way that even the world's best prosthetist can fit a stump which varies diurnally 4% in volume. The problem is more severe for women with a large monthly volume change (5-10%) added on top of the diurnal variation. Similarly, for kidney dialysis, illness and exercise.

There is no science of socket fitting today because there is no commercial equipment available to accommodate the volume fluctuations of the residual limb. However, variable-geometry sockets should become ubiquitous for the lower-limb amputee within the next decade. Likewise, by use of the Ambulation Simulator described above, a data bank of dynamic pressure distributions during ambulation could become available to guide the prosthetist in designing the socket and testing the quality of fit.

Given the current need and the projection above, the Ambulation Simulator should become a widely-used tool for lower-limb prosthetists, and within the next decade. The cost to the Nation of providing the Ambulation in prosthetic rehabilitation which will obtain.

Sandra W. Dennis, P.T., MSHCM

The application of computerized gait analysis to the field of Rehabilitation Medicine has undergone dramatic growth and many changes over the past two decades. The use of gait analysis to assist with surgical decision making has improved surgical outcomes and decreased health care costs. The growth and expansion of gait analysis laboratories throughout the United States has created several issues which need to be addressed if gait analysis is to remain a viable tool to assist with treatment planning. Several of the issues that need to be addressed to advance the field of gait analysis are listed below:

1. Steps need to be taken to ensure adequate funding for clinical and research activities performed in gait analysis laboratories. If adequate funding is not available gait analysis laboratories will not be able to continue providing services. Steps must be taken to standardize the services provided by gait laboratories (see number 3), to educate third party payors and funding agencies as to the value of gait analysis, and to work to establish accepted reimbursement codes for the services provided.

2. Additional research is needed to document the value of gait analysis in Rehab Medicine. Improved collaboration among gait laboratories to participate in multi-center research projects would produce more meaningful results. Standardization between gait laboratories and making public domain research tools more accessible would facilitate multi center research. Additional research is needed on the value of gait analysis from a quality of care and from a cost containment perspective. The results of previous and future studies should be utilized to educate physicians, third party payors and potential patients about the value of gait analysis.

3. Comprehensive gait analysis needs to become more standardized and a mechanism for accrediting laboratories needs to be established. This will allow physicians, health care professionals, third party payors, funding agencies and patients to be educated and will provide a consistent meaning when the term "gait analysis study" is used. This will also help to insure the quality and value of the services provided.

4. The ease and accuracy of data collection needs to be improved. A more accurate way of measuring the rotational deformities of the shank needs to be developed including a more accurate way of determining the ankle joint center. The data collection process remains rather complex and it would be beneficial to continue to seek ways to simplify it. Developing a way to collect motion data with a less cumbersome marker set would improve accuracy and decrease the complexity of the data collection process.

5. A way to look at the projected effect of a proposed surgery on the individual's walking ability needs to continue to be developed. This will provide an additional tool to assist with maximizing surgical outcomes.

These recommendations for advancing the field of gait analysis are overlapping and cannot be addressed in isolation. Accomplishing any one of these recommendations will have a positive impact on several of the other areas identified. Collaboration among health care professionals working in the various gait laboratories across the country is the key to successful advancement of the field. The areas to focus on must be prioritized and we must work together to achieve success and insure the future of gait analysis into the 21st century.

John F. Ditunno, Jr., M.D.

The analysis of gait dysfunctions has always been an integral part of Rehabilitation Medicine. Recently, the development and refinement of motion analysis systems which provide the ability to evaluate electromyographic, kinematic and kinetic aspects of gait has provided clinicians and researchers with objective data regarding gait dysfunctions. However, although the availability of such systems is increasing, the practical application of their use remains limited. In order to increase the effectiveness of this technology in providing patient care and as an outcome tool for research, the following recommendations are made:

-Develop easily utilized tools for the analysis and interpretation of the data collected.

-Develop more cost and space-efficient analysis systems.

-Develop guidelines on how to statistically manage the data for research purposes.

Daniel J. Driscoll, M.D., Ph.D.

One area that probably receives insufficient attention in gait analyses is the underlying biological basis for various gait abnormalities. Ameliorating the abnormality is certainly important, but equally important is understanding what caused it.

Identifying gene mutations that cause ataxia can lead to better understanding of the biological basis for the disturbance of gait. This knowledge can then be used to design rational therapies. For certain conditions the responsible mutant gene has been identified (e.g., Ataxia Telangiectasia and Friedreich Ataxia) or the chromosomal region localized (e.g., Angelman syndrome), while for other conditions (e.g., Cerebral Palsy) there are still many mysteries as to the etiology.

Recommendations: Encouraging research to identify the biological bases for various gait disturbances including the role certain genes play.

Jack R. Engsberg, Ph.D.

In order to effectively assess the efficacy of a given treatment it is necessary to have outcome measures that encompass many domains related to medical rehabilitation. The National Center for Medical Rehabilitation Research (NCMRR) of the National Institute of Child Health and Human Development (NICHD) at the National Institutes of Health (NIH) has defined five domains: 1) Pathophysiology (interruption of or interference with normal physiological and developmental processes or structures), 2) Impairment (loss or abnormality of cognitive, emotional, physiological, or anatomical structure or function, including all losses or abnormalities, not just those attributable to the initial pathophysiology), 3) Functional Limitation (restriction or lack of ability to perform an action in the manner or within the range consistent with the purpose of an organ or organ system), 4) Disability (inability or limitation in performing tasks, activities, and roles to levels expected within physical and social contexts), and 5) Societal Limitations (restriction, attributal to social policy or barriers, which limits fulfillment of roles or denies access to services and opportunities that are associated with full participation in society).

Results from gait analysis would be one example of an efficacy measure in the Functional Limitation domain. While gait is a very important functional measure, at least two limitations must be recognized with its use. The first is that it only evaluates gait and the results may not be extrapolated to other important functional activities. For example, results from a gait analysis do not measure the ability to transition from sit to stand or bed to chair. Measures taken from these or other functional tasks may be even more relevant than gait since they affect more of the disabled population than gait. The second limitation is that the results for a gait analysis may not be appropriate for outcome assessment in other domains. For example, during an evaluation, gait analysis may identify that an impairment is present at the ankle. However it cannot assess the level of impairment since during gait the ankle is generally not move through its greatest range of motion. In a normal ankle during gait the total excursion is about 30 degrees, yet over 65 degrees of excursion is generally possible. Separate impairment measures quantifying total ankle range of motion, maximum joint torques, or power adjunct to a gait analysis may be more appropriate.

Gait analysis is one important tool in evaluating efficacy in the functional domain. However, it should not be considered the only functional activity that should be evaluated, nor should its results be used in assessing outcomes in other domains. Additional tests in the functional domain relevant to the population of interest and other efficacy measures specific to their respective domains should be integrated to produce a comprehensive outcome assessment.

Alberto Esquenazi, M.D.

Introduction and Overview

Conventional gait analysis may be thought of as the observation, measurements, quantification and analysis of physiological and mechanical walking parameters in order to make a clinical decision on how to improve gait. As such, modern gait analysis laboratories have the potential to evaluate the causes, outline suitable short- and long-term strategies for treatment, and to gauge progress and measure efficacy of interventions for gait and movement-related impairments.

Patients who are referred for gait evaluation often include those patients with neurological or orthopedic condition that affect the motor control system (e.g., brain injury, spinal cord injury, cerebral palsy, stroke, multiple sclerosis), musculoskeletal actuator systems (e.g., post polio, peripheral nerve injuries as well as orthopedic trauma/injuries or joint degeneration and amputation). This types of dysfunctions may necessitate one or more of the following modes of intervention: physical rehabilitation, pharmacology, mechanical interventions and surgery. Physical rehabilitation may include exercises to increase range of motion, strength and/or coordination nerve and motor point blocks using phenol and botulinum toxin are common modes of pharmacological intervention to relieve spasticity or to improve contractures when combined with other interventions. Common mechanical intervention include using wedges and lifts in shoes, splinting, bracing, orthotic and prosthetic alignment modifications, as well as recommendations for surgery.

In order to make recommendations as noted above, physical data is often collected. The most common type of such data is visual. Visual inspection of gait combined with a physical examination reveals a great deal about the walking dysfunction, but generally may be just the beginning pint for a more comprehensive instrumented gait evaluation. Electromyographic activity, temporo-spatial footfall parameters, whole body kinematics and kinetics, as well as energy consumption (metabolic or mechanical) data may need to be assessed. Modern gait laboratories are capable of collecting all of the above data and sometimes more in an attempt to understand what factors may be causing a particular dysfunction. Gait analysis technology allows data collection to be done in a relatively short period of time and with clinically useful accuracy. Equinovarus posture at the ankle foot system may be used as an example. At least five different muscle groups alone or in combination may be contributing to such abnormal posture (tibialis anterior, tibialis posterior, extensor hallucis longus, gastrocnemius and lack of peroneal activation). Dynamic EMG analysis permits specific muscle identification and enhances the ability to differentiate between the muscles contributing to ankle deformity allowing proper correction.

Gait analysis has come a long way towards achieving the above stated goal of obtaining a more complete understanding of the factors which produce the dysfunction that give rise to observed gait deviations. However gait analysis has not reached a state which allows such a clear understanding in all cases or for different environmental conditions.

Future Direction of Gait Analysis

It is not that current analysis methods have been providing spurious measurements. They are certainly useful and help to drive the clinical decision-making process in a large number of cases. However, current methods are only a part of the complete picture. The current analysis methods may be too narrow or are looking at only one or a few levels of this complex task. Traditional gait analysis has evolved around measuring quantities which can be seen or felt or measured in a controlled environment laboratory. Probably most sciences begin around information which is easily obtained - usually visual examination. To this day, this is still a large and important part of medicine in general and gait analysis in particular. Evolution has occurred in making more things "visible." EMG electrodes allow us to see, quite literally, when muscles are working properly, out of sequence or when they are not working at all. Motion analysis systems have made information about the forces and moments across joints fairly readily available. Our scope of vision has expanded over the years. We have advanced from observing the motions of the body to understanding the forces which give rise to those motions. Hopefully this has taken us one step closer to the source of the problem and the potential solutions.

It is common practice in medicine to search for the causes of a problem and base the solution around that rather than to merely treat the symptoms. In like fashion to truly understand some of the more complex problems which confront clinicians in gait analysis today, it is important to fully understand the source of these problems. An example of such problems may be in the area of compensation mechanisms employed by patients with gait deficiencies. What gives rise to these compensation mechanisms? How is one scheme selected over other options that are potentially available? What are the criteria employed in choosing the selected response? (e.g., safety, speed, energy efficiency, etc.). The answer indeed lies in understanding how the brain processes information and perhaps even more importantly, *what* information the brain selects to make such a decision. The limitations of our current purely physical models is a good indicator that more information and likely information of a different type is needed to fully understand this problem.

Perhaps we can analyze gait under different environmental conditions, physical demands or perhaps measure different areas - at the motor control or neural level as opposed to the currently physically observable/tangible level or measuring forces, movements, muscle activities.

Gait/biomechanics scientists have models which are very complex from a purely mechanical standpoint - and they have not been sufficient to predict how movement patterns occur. This may be perhaps because the motor control/neural input levels haven't yet been included in the

models. Even the "neural network" models which, despite the eponymous relation to a higher level of input, have been largely unsophisticated enough to completely and accurately characterize gait. This may be due to the fact that although they implicitly include physiological data from the neural level, these data are only by accident or by luck. As scientists, we have not been able to explicitly include such inputs. But due to the way in which neural networks pair inputs to outputs, generating maps/links/relationships between physiological input and output data may have taken preliminary steps to providing at least at some level a "neural" input. In any case, the explicit data used in most neural network models has been still of the physical nature - such as forces, joint moments, powers, spatial orientation, joint angles, muscle activity and the like, and thus they are in reality no more sophisticated in terms of their ability to fully characterize gait than are the traditional mathematical musculoskeletal models of the past.

It is unclear, today, how to incorporate neural input into existing models, or what other parameters or information we should attempt to record to better understand the very complex task of walking. Undeniably other steps need to be explored in our search to move the understanding of gait to the next level. With information that better describes and assess gait we will be able to develop and apply the best treatment interventions to the benefit of our patients.

Virginia Graziani, M.D.

The analysis of gait abnormalities has been an important part of Rehabilitation Medicine for many years. Recently, there has been an increase in the number of clinical gait laboratories as well as an increase in the literature of the use of these assessments in evaluation of gait disorders and interventions. Gait analysis can be useful in planning treatment for individual patients, most importantly in pre-operative evaluations, as well as in evaluating prosthetic and orthotic devices. These assessments may also be used to objectively evaluate pharmacological and surgical interventions that are intended to improve gait in certain patient populations. However, gait analysis has not yet gained wide spread use clinically. Some of the issues that may contribute to this are that clinicians feel that this technology may not be easily accessible to their patients, that the procedure may be too cumbersome or painful, and that the information obtained may not be clinically interpretable. As a research tool , there is reluctance to use this technology because of concerns regarding the analysis and interpretation of the large amount of data generated, as well as the time it takes to collect the data.

In order to promote the effective use of gait analysis for clinical and research purposes, working groups of gait specialists should reach a consensus on several issues, including:

A minimum data base necessary for analysis. Although all laboratories should be able to assess all types of disabilities (i.e., general laboratories as opposed to a specific laboratory for amputees, a specific laboratory for cerebral palsy), the minimum data base needed for a specific disability may vary.

-Recommendations regarding the interpretation of the observed abnormalities and the potential causes of each abnormality.

-Guidelines regarding recommendation to be made (and by whom) in reference to potential interventions to address the abnormalities demonstrated (i.e., surgery, injections, oral pharmacological agents, intrathecal baclofen, therapy program, orthotics, etc.).

-How to practically handle large number of patients or multiple assessments for research purposes.

-How to statistically analyze the data generated for research purposes.

Clear recommendations and guidelines provided by a group of gait specialists will further the effective use of gait analysis for individual patients as well as in outcome analysis of treatment interventions for specific patient populations.

Nasreen F. Haideri, M.E., B.S.

Gait Analysis as a Clinical Decision-Making Tool:

Is gait analysis a useful clinical decision-making tool? This question arises again and again, but still we have little documented proof that gait analysis leads to improved surgical decision-making or treatment intervention. Providing this documentation is a difficult assignment, in fact traditional methods of clinical decision making have never had to be validated as astringently. Several authors have demonstrated the accuracy of gait analysis over visual observation which has helped to validate clinical research. Others have utilized gait analysis to document outcomes associated with specific treatment regimes. However, few have defined specific functional measures to identify and describe particular impairments. More published work in this area would provide clinicians with information necessary to incorporate gait analysis techniques into their practice. There are several hindrances, discussed below, which will require attention in order to facilitate this type of applied gait analysis research and thus promote the expansion of gait and movement analysis in rehabilitation.

Standardization:

A major setback in the development of gait analysis as a clinical tool is the lack of standardization. Some steps towards this have been taken, for example, Winter's ad hoc committee which devised standards for reporting electromyographic data and, more recently, Ounpuu's compilation of terminology which was present to the AACP&DM Gait Lab Committee in 1994. Standardization would provide a framework and language to allow the results of gait analysis to be taught and transmitted universally.

Labs which conduct gait and movement analyses should be subject to accreditation or certification by some standards. Lack of this process has allowed several manufacturers of video capture equipment to advertise inexpensive gait analysis systems and many facilities which take sequential pictures of patients walking to call themselves gait labs. It is not necessary to immediately impose strong criteria to allow facilities to consider themselves certified, but rather distinction should be made between those facilities that actually generate evaluations with treatment recommendations and those that do no more than provide video documentation.

The first step in this has been accomplished, we have formed a society, the North American Society for Clinical Gait and Movement Analysis. This society should now advance the development of standardization and accreditation.

Modeling:

The development of diagnosis specific models will be required to allow application of movement

analysis on a wider range of pathologies. Our institution sees patients with a variety of diagnoses characterized by atypical anatomy. Examples of this are patients with clubfoot, slipped capital femoral epiphysis, amputees, leg length discrepancy, and dislocated hips. Most of the clinical models commercially available for gait analysis have incorporated work done on normal adult anatomy to obtain anatomical references such as relative joint center locations, segment mass moments of inertia, and muscle origin and insertion locations. Such parameters are not currently available for pediatric populations or pathological conditions. Clearly, this introduces error in analyzing patients with such unusual anatomical profiles.

Some research work is being conducted in this area. Several groups have been working on more extensive models of the foot, and mathematical computations for six degree of freedom models of joints are available. In the future, using imaging technology to be able to study the underlying pathological anatomy and implementing this into models of gait analysis would be beneficial. For example, patients with extreme femoral focal deficiency or shortening of the femur do not have a normal hip joint. In some cases, the hip is fused and the anatomical knee joint is used to flex and extend the hip joint of a prosthesis. At our institution, these patients often will have CT scans and 3D reconstruction done of their pelvis, hip and knee. This information has been used to pinpoint the actual joint location which can then be used in a gait model. Published research in these areas would be most useful.

Future Directions in Basic Research and Methodology:

We have done much work to facilitate automated collection of kinematic data. Analysis of movement began with sequential photography, moved into video, then with computer advances became more automated, until finally moving up to the passive I.R. systems commercially available. Electric goniometers and active kinematic systems have improved as well. As the new era of High Density TV and computer animation explodes, there may be much to offer the field of gait analysis. Perhaps markerless kinematics will become feasible as resolution of video improves. Advances in imaging techniques combined with increased accuracy of motion data and computer animation could allow surgeons to better visualize and quantify precise deviations of a patient from normal. Once the effects of treatment intervention are more thoroughly quantified, it is possible that clinicians could actually try out different interventions on modes of their patients and visualize the probable outcome.

There is always the need for basic research prior to advancing applied research and clinical work. One area of basic research that is just beginning to surface in the clinical domain is control system theory. Forward solution models used to predict the behavior of biological systems will provide a more comprehensive understanding of the CNS, its control mechanisms, and movement strategies. This will ultimately help advance areas such as the design of prosthetic and orthotic devices. Linear optimal control and fuzzy control methodologies need to be investigated to develop a controller which can regulate the movement of the body similarly to the CNS. More complex artificial intelligence systems are under development which contribute technology to advance this area tremendously.

Collaborative Research:

The key factor in the transmittal of basic research to the clinical domain is the facilitation of communication between engineers, doctors, and rehabilitation professionals. This communication is optimized by daily contact which requires that patient care facilities employ technical staff. Continued support of collaborative research efforts enhances opportunities for transferring technology. Communication at scientific meetings is essential and should be promoted whenever possible.

Howard J. Hillstrom, Ph.D.

It is my contention that the objective role of the foot and ankle in the lower extremity biomechanics of posture and locomotion has all but been overlooked. Clearly the 26 bones, 33 joints, and over 100 tendons, ligaments, and muscles of this complex structure can no longer be regarded as a rigid body with a simple hinge across the transmalleolar axis. Not only is the function of the foot and ankle poorly understood in individuals with neuromusculoskeletal pathology but in asymptomatic healthy individuals as well. The use of realigning conservative treatment strategies such as custom molded neutral position foot orthoses has increased in the popularity but the foundational research is lagging the application. Gait analysis is considered to have an important role in exploring etiology details, differential diagnosis, prognosis, and demonstrating treatment effectiveness in patients with foot and ankle pathologies. It is possible that pathologies up the kinetic chain (i.e., at the knee, hip, and pelvis) may be related to aberrant alignment of the foot and ankle as well. An outline of the major issues is presented.

1. To investigate the role of foot architecture (i.e., foot type) in lower extremity biomechanics and pathologies of the feet that effect a patients ability to stand and walk in a comfortable (i.e., pain free) and safe (i.e., without falling) manner.
    - A. Objectively measure the differences in biomechanical foot function during upright posture and locomotion of individuals with different foot types (i.e., pes planus, rectus, pes casus, etc.).
    - B. Determine how these different foot types effect the function of the knee, hip, and pelvis during posture and comfortable cadence locomotion.
    - C. Examine the role of the foot, it's aberrant alignment, and supporting devices (i.e., MAFIAS, in shoe foot orthoses, splints, etc.) in geriatric postural stability.
    - D. Determine the effectiveness of foot and ankle, as well as knee, realigning devices for the treatment of osteoarthritis (OA).
        a. Examine the clinical outcomes of these concepts applied to other forms of rheumatic disease.
    - E. Develop cost effective alternatives to the custom molded shoe for minimizing the chances of re-ulcerating as well as preventing the initial development of plantar ulcers in the diabetic foot.
2. To develop and validate quantitative tools to assist in discovering the detailed function of the foot and ankle.
    - A. Develop six degree of freedom (DF) hindfoot (i.e., ankle and subtalor joint complex) kinematics that is anatomically and hence clinically relevant for describing foot function.
    - B. Develop six (DF) based on hindfoot kinetics as well.
    - C. Extend the six DF kinematics and kinetics to the midfoot and forefoot.
    - D. Assess the static and dynamic validity of plantar pressure platform and

in shoe plantar pressure measurements.

E. Establish new reliable parameters (i.e., from 3D kinematics, 3D kinetics, plantar pressures, MRI/CT, accelerometery, etc.), to objectively define foot and ankle function during posture and locomotion (e.g., pronation, supination, internal tibial torsion, etc.).

F. Establish normative databases of these parameters and explore the potential differences offered by foot types, age and sex.

3. To determine the efficacy and effectiveness for in shoe foot orthoses to assist in the management and/or prevention of the following clinical concerns.
   A. Hallux-Abducto Valgus (HAV) - bunion deformity.
   B. Hallux-Limitus/Rigidus - first metatarsal phalangeal degenerative joint disease.
   C. Osteoarthritis (OA) and rheumatoid arthritis (RA) - foot pain, malignant and functional deficits.
   D. Plantar Faciitis/Heel Spur Syndrome.
   E. Amputation resulting ultimately from Diabetic neuropathy and/or Charcot arthropathy.
   F. Significant flat foot deformity.
   G. Lower extremity torsional deformities (e.g., foot, malleolar, tibial, and femoral).

4. Determine efficacy and effectiveness for surgical management of the aforementioned problems in their severe forms (e.g., the Evans calcaneal osteotomy for treating significant flatfoot deformity).

5. Develop improved forward dynamic foot and ankle models for computer based simulation of healthy and pathological gait.
   A. Utilize a given patients anthropometric values and gait parameters to fit the model with their data.
   B. Simulate conservative treatment of that patient with the computer based model.
   C. Make teaching versions of these models available via the Internet for general educational purposes.

John P. Holden, Ph.D.

The techniques used in gait analysis provide powerful tools to address many of the areas recently identified[1] as needing increased research in rehabilitation medicine: improving functional mobility; assessing the efficacy and outcomes of medical rehabilitation therapies and practices; developing improved assistive technology; understanding whole body system responses to physical impairments and functional changes; and developing more precise methods of measuring impairments, disabilities, and societal and functional limitations. There is justified optimism about the expanding role that movement analysis can play in rehabilitation medicine. To advance this role most effectively, progress is necessary in several key areas, including: basic research and technological developments; standardization; clinical research applications; and education and training. The six criteria suggested fifteen years ago[2] as necessary for the usefulness and widespread acceptance of any patient evaluation tool remain relevant to movement analysis today, and they can assist in motivating the formation of current recommendations. Among the many worthwhile actions that can be taken, the following are offered for particular consideration by the National Center for Medical Rehabilitation Research (NCMRR) and other agencies and organizations with an interest in movement analysis and rehabilitation medicine.

1. Recent advances in instrumentation and computer technology have greatly increased the accuracy and precision of the fundamental data collected in movement analysis, as well as the speed with which these data are processed and transformed into the information used by clinicians. Surprisingly few studies, however, have examined the effects of measurement errors, model assumptions, and data processing methods on the accuracy and precision of the eventual output variables upon which research conclusions and clinical decisions are based. As a result, researchers and clinical groups must qualify their conclusions and recommendations due to a lack of confidence in certain elements of the data. It is recommended that NCMRR and other agencies support research to document the limitations and uncertainties associated with data acquisition protocols and analysis techniques, assess their effects on the information made available for clinical interpretation, and develop new approaches that enhance the quality of movement analysis information with respect to accuracy, precision, and sensitivity.

2. Gait analysis is often used for patient assessment by comparing a patient's gait patterns with a database from able-bodied subjects, in an attempt to discriminate between "normal" and abnormal function. The normal limits defined in these databases must be sensitive enough to identify gait deviations, and to distinguish deviations which are due to primary pathological deviations, secondary compensatory phenomena, or other factors which can affect gait measures (e.g., age, gender, size, walking speed). The development of large databases from multiple centers is complicated not only by variability in subject performance, but also by variation among laboratories in how data are collected, processed, and reported. It is recommended that NCMRR and other organizations support the development of data collection

and processing standards, detailed databases that account for additional variables that affect interpretation, and data scaling techniques and statistical models that will improve the ability to accurately distinguish normal and abnormal patterns and to discriminate between possible causes of gait pattern deviations.

3. Movement analysis can provide quantitative measures of numerous parameters that cannot be assessed by other means, and these data are combined with clinical information to plan and evaluate rehabilitation interventions. Research is needed, however, to determine which variables are most important in determining a person's ability to safely and efficiently execute functional tasks. Investigations in this area should be based on a theoretical framework, or model, that will allow the results to be applied to as many activities and situations as possible. It is recommended that NCMRR support the use of movement analysis techniques for (a) basic scientific research on the roles of the various systems (e.g., sensory, cognitive, neuromuscular, musculoskeletal) that affect mobility, (b) multidisciplinary, multivariate research to measure and explain the relationships among pathologies, impairments, functional limitations, and disabilities, and (c) clinical research to validate current clinical practices, develop new tests for direct use in patient care, and test the efficacy of interventions when movement analysis is included as part of the patient assessment and/or treatment plan.

4. The full use of movement analysis to help people with locomotion disabilities requires the integration of knowledge and skills in a variety of areas, including medicine, engineering, and kinesiology. Optimal integration across these disciplines can occur when all of the people involved in the process have a basic understanding of the capabilities, benefits, and limitations of movement analysis technology. It is important that there be adequate opportunities for interdisciplinary training, as well as improved tools for efficient communication of movement analysis concepts and data. It is recommended that NCMRR and other organizations support development of new educational opportunities and approaches, including computer-based teaching tools, research training fellowships, instructional workshops in conjunction with major meetings or through tele-conferencing, and new course programs that will facilitate understanding and application of the latest information in movement analysis.

The widespread acceptance of clinical movement analysis in rehabilitation medicine may require large-scale controlled clinical trials to test the efficacy of current techniques in direct patient care. At the same time, efforts must continue in the areas of basic research, technological development, and standardization, in order to improve the quality and versatility of movement analysis as a research and clinical tool. Indeed, advances in techniques and in our basic understanding of the rehabilitation process will likely lead to more efficacious application of movement analysis in the direct clinical care of persons with locomotion disabilities.

1. *Research Plan for the National Center for Medical Rehabilitation Research*, 1993.
2. Brand R.A. & Crowninshield R.D. Comment on criteria for patient evaluation tools. *J. Biomechanics* 14(9):655, 1981.

Thomas M. Kepple, M.A.

Background:
I have worked for the last 10 years at the National Institutes of Health (NIH) Biomechanics Lab. (The NIH biomechanics lab is a part of the NIH Rehabilitation Medicine Department.) From my experience at NIH, I firmly believe that gait analysis can provide information that can be extremely valuable to the treatment of the rehabilitation patient. If this statement is true, then why are gait analysis labs rarely found in rehabilitation clinics? The failure of this potentially valuable tool to make a significant impact throughout the field of rehabilitation medicine has been the largest disappointment in my time at NIH. I believe one reason for the failure of gait analysis to make significant rehabilitation impact is that it is not cost effective to build and staff a clinical gait analysis lab. For this reason I have confined my position paper to a single issue.

Issue:
What can be done so that gait analysis can provide clinically important rehabilitation information in a cost effective manner?

Recommendations:
1) Bring down the cost of purchasing and maintaining a clinical gait analysis laboratory.

Prices of computers and technology have been dropping steadily over the past 10 years; however, these price reductions have not been reflected in the cost of the data collection systems. In addition, most gait analysis systems still require at least two full-time staff members for operation, maintenance and analysis of the data. Funding should be provided to aid in the development of high quality low cost data collection systems.

2) Improved education for rehabilitation clinicians in the area of gait analysis.

Although gait analysis provides valuable clinical information, the significance of the information is often lost in the translation between laboratory staff and practicing clinician. Improved education for the clinician will result in both better use of gait analysis data and significant savings due to the reduction of laboratory staffing.

3) Demonstrate that gait analysis can produce long-term cost benefits for the Insurance Industry.

Third party reimbursement is a major obstacle to the goal of making gait analysis commonplace in rehabilitation settings. Research must be funded to determine the areas in which gait analysis can be used to produce long-term savings for insurers.

Casey Kerrigan, M.D.

Gait laboratory analysis has not yet been recognized by third party payors as an essential tool in rehabilitation practice although there is great potential for gait laboratory analysis to become this. It is already recognized for orthopedic surgical planning in patients with cerebral palsy affecting their gait. For the same reasons that gait laboratory analysis is useful in surgical planning, it could also be extremely useful for routine rehabilitation practice. It can be used to evaluate from a dynamic perspective which particular muscle group is weak or overly active or which muscle tendon group is tight. Traditional static evaluation of muscle weakness, spasticity, and tightness is often not adequate insofar as the findings on static evaluation commonly do not correspond to findings obtained from gait laboratory analysis. This point is important since most of our rehabilitation interventions are based on accurately determining which muscle/tendon groups are functionally weak, overly active or tight. For instance, strengthening functional electrical stimulation, or bracing are prescribed to improve or substitute for strength and stretching, modalities, or nerve or motor point blocks with localized medications are prescribed to improve overactive muscle activity or range of motion. Gait laboratory analysis thus can be an essential tool in evaluating and providing recommendations for treatment in gait disability secondary not only to cerebral palsy, but to any upper motor neuron diagnosis.

Gait laboratory analysis could be useful not only for rehabilitation management, but for further rehabilitation treatment development as well. It is difficult to evaluate the effect of a particular rehabilitation intervention if the problem is not adequately assessed at the beginning and evaluated at follow-up. For instance, the effect of a functional electrical stimulation program or of a particular brace may be impossible to evaluate if the underlying weakness is not adequately assessed. Additionally, information can be obtained about the mechanism of the electrical stimulation program if gait laboratory analysis is used as an evaluation tool at follow-up. In some instances, gait laboratory evaluation may be the only manner in which to assess an impairment. For example, individuals with gait disability often have different patterns of muscle activity which can be assessed only with dynamic electromyographic evaluation. A gait laboratory evaluation may show inappropriate timing of muscle activity which can be treated with electromyographic biofeedback. Electromyographic biofeedback as a potential treatment is optimally evaluated using gait laboratory evaluations. Essentially, any treatment which aims to improve walking through improving strength, range of motion, spasticity, or timing of muscle activity is best assessed with gait laboratory evaluation. Thus, gait laboratory assessment can be an important tool in evaluating the effects of current commonly prescribed rehabilitation interventions as well as in evaluating and developing possible new interventions.

Research Recommendations:

1. There needs to be a demonstration of the benefits of gait laboratory evaluation improving rehabilitation management.

2. It needs to be shown that gait laboratory analysis provides useful clinical information which is not present per routine clinical evaluation, in particular, research demonstrating the discrepancy between static and dynamic findings is important.

3. Research is needed which develops gait laboratory analysis as an evaluation tool to assess the dynamic relevance of impairments such as strength, spasticity, range of motion, etc.

David E. Krebs, P.T., Ph.D.

Before computer aided locomotion analysis (CALA) can be accepted as a routine clinical tool, several important problems must be resolved.

Technical. There are no published studies comparing *in vivo* joints torques and forces from instrumented tendons, or joints, collected simultaneously with "gait lab" estimates of these same variable. Because power, forces and emg cannot be directly observed, CALA is attractive as a means of estimating kinetics. These estimated kinetics, however, may err in magnitude and in direction; power calculations derived from them will err as well. In contrast, modern kinematic estimates have greater validity, since at least at the gross level, they have survived repeated scrutiny by clinicians and engineers. At higher levels of precision, however, the exact joint center locations, skin movement artifacts and other errors contaminate gait analysis kinematic data, which in turn also corrupt kinetic estimates. Appropriate standards of *in vivo* precision, accuracy and validity of gait lab estimates will permit clinicians to judge the limits of CALA, much as clinicians know the resolution and limits of MRI data.

Clinical. Most rehab and surgical interventions are targeted at changing impairments. There are only 2 or 3 published articles relating gait, as a functional limitation improvement, to impairment improvement, and these gait articles used only temporodistance gait measurements. Establishment of appropriate individual, functional and normative standards must precede the widespread acceptance of, and reimbursement for, computer aided gait analysis. Most importantly, large sample intervention outcome studies are needed, to permit scientific assessment of benefits, and cost-benefits, of routine CALA. Ending the vicious cycle in which insurers under-reimburse CALA, therefore no outcomes data are produced, and therefore no reimbursement is offered -- must be a top goal.

Karen Ksiazek, M.D.

Motion analysis has most commonly been utilized kinematically document normal patterns of movement and deviations there from in individuals with disabilities. It has attempted to objectively delineate the differences invoked by treatment intervention be it surgical or fine tuning of assistive technological interfaces yet it has not been able to tell us why one form of intervention works better than another. Thus as an individual assessment tool it is unable to answer the questions of function. If incorporated with measurements directed toward kinetic and endurance evaluation, it then has the potential to impact the dynamic picture of function as it relates to functional efficiency. The parameters of kinetic assessment and ultimate workload need to be standardized before adequate valid intervention can be engendered. If kinetic approaches could be enhanced, then the change in any gait with fatigue may be explored more intensively. Resulting torque curve characteristics overtime may then shed light on the prediction of loads across muscles and the ultimate tolerable work for a given energy expenditure. In disease states this may assist treating teams to better design appropriate rehabilitative schedules and predict functional capacity for transition into the community. It could then provide a physiologic justification for varying the level of rehabilitative involvement.

Another area of great potential is in the learning of new motor control patterns those with acquired or evolving disabilities. We often find variability in learning curves and acceptance in new amputees with regards to their prostheses. Some have difficulty incorporating the prosthesis into their daily activity patterns despite extensive therapeutic intervention. If the efficiency and pattern of their motor planning could be assessed, then alterations in the interface between user and technology could be more readily directed towards the individuals needs.

Quantification of the extent of deviation from normal patterns of movement in these individuals be it gaining with a prosthesis or utilizing an artificial implant may then shed insight into the risk of developing secondary disabilities such as arthritis and scoliosis which may in the long run limit the potential gains of such prosthetic restoration. As changes may evolve overtime in functional ability or strength, motion analysis could potentially be used to assess these changes and direct updates in the prosthetic prescription to avert such secondary complications and maintain function efficiently.

Robert McAnelly, M.D.

PROBLEMS	CURRENTLY REIMBURSED GAIT ANALYSIS	REHABILITATION ISSUES FOR GAIT ANALYSIS
DIAGNOSTIC		
Number of Diagnoses	Cerebral palsy and spina bifida	CP, spina bifida, spinal cord injury, joint replacement, stroke, amputation, brain, injury, etc.
THERAPEUTIC		
Number of Interventions	Tendon and osteotomy procedures	Stretching, strengthening, neuromuscular facilitation, coordination and balance training, orthotics, prosthetics, motor point blocks, etc.
NUMBERS NEEDED		
Number of laboratories needed	One for every major metropolitan area	One for every rehabilitation unit
PERSONNEL		
Personnel available per laboratory	5-6	2-3
Level of education of laboratory personnel	Physical Therapist, MD, Ph.D. Gait Engineer, Kinesiologist	Physical Therapist, MD
FUNDING		
Funding per subject	Thousands billed for preoperative gait analysis	Hundreds billed for medical consultation and physical therapy time
Financial effect of managed care	Significant	More significant

Rehabilitation faces diverse problems. One can classify three ways to solve rehabilitation issues:

Top-down: major cerebral palsy laboratories will develop generalized gait analysis programs that will be used to analyze gait problems of multiple diagnoses. These programs will be passed down to smaller rehabilitation laboratories.

Bottom-up: individual smaller research laboratories will develop protocols for each individual rehabilitation diagnosis. A multiplicity of programs will then slowly disseminate across all laboratories.

Collaborative: Multi-laboratory studies involving small and large laboratories to share data and tackle large problems in a consistent manner. Collaborative studies are best because it draws on talent from everywhere, but laboratory standardization is an involved process.

Some solutions will evolve with better technology. Markerless systems will simplify data gathering. Expert systems will simplify analysis. Establishing therapeutic protocols will allow us to simplify marker sets. We still need to prove which diagnoses will benefit from gait analysis.

RECOMMENDATIONS

1. Help develop interlab standardization to encourage collaborative research and rapid dissemination of programming. This should include standardization of 2-dimensional gait analysis. Contact gait analysis manufactures to include them in your discussions.

2. Encourage development of movement analysis programs for upper extremity rehabilitation, back rehabilitation, and wheelchair propulsion.

Irene McClay, Ph.D., P.T.

Gait analysis has gained a healthy respect from the research arena. However, there are still many medical professionals (and insurance companies) who question the clinical merit of this tool. One argument is that it does not assist in diagnosing a condition. However, I contend that we might be able to "diagnose" the mechanics related to the condition, such as asymmetry of joint excursion. Another tenet is that gait analysis is only useful if it provides information that assists with clinical decision making. I believe that if we can gain insight into the mechanical cause of an injury, then we will be better equipped to make clinical decisions regarding optimal treatment interventions.

Therefore, I strongly believe that gait analysis could play a strong role in the clinical area. However, we need to address the following issues in order for gait analysis to be accepted as a clinical tool.

RECOMMENDATION 1

Establish normative three-dimensional biomechanical data for all forms of locomotion (i.e., walking, running, stair ascent/decent) along with the expected variability of each parameter.

The literature is generally lacking substantial normative three-dimensional data of the lower extremity during various forms of locomotion. This makes it particularly difficult to establish the presence of an abnormality in one's mechanics. Once these abnormalities are determined, relationships between structure, mechanics and injury can be established.

RECOMMENDATION 2

Establish which gait parameters are most revealing with regards to understanding a gait-related injury.

For example, angular velocities may lend more insight into a gait-related problem than peak angular values. Loading rates of ground reaction forces may be more critical than the peak values. Additionally, since joints move in concert with each other, development of new parameters describing the interaction between joints is needed. Focusing on the most critical parameters will enhance the understanding of injuries and facilitate the development of optimal treatment interventions. These critical parameters should be ones that are not readily apparent with visual gait analysis in order to justify the need for an instrumented analysis.

RECOMMENDATION 3

Investigate the effect of alteration of abnormal gait through treatment intervention.

If relationships between mechanics and injury are established, then the effect of altering those mechanics can be pursued. These interventions can take on many forms. One area of involves the active alteration of one's base of gait during running or contracting a muscle sooner during stair descent. Increasing one's available range of motion through stretching could also improve the manner in which they move. Also, the effect of orthotic intervention on gait mechanics needs further investigation. There are numerous studies on the effect of foot orthotics on foot and ankle motion. However, these orthotics are often prescribed for knee pain and their effects at this joint are still unknown. This information is helpful, not only to the clinician, but also to insurance companies who need objective outcome measures to establish the efficacy of the treatments for which they are reimbursing.

In summary, I believe the time has come to provide evidence of the merit of gait analysis in the clinical arena. Its utility in assisting in clinical decision-making and determining efficacy of treatments through outcome measures must be proven. Cost-benefit analyses must be performed. These steps are needed before it will become accepted by the medical and the insurance communities. The working conference on gait is the first step in this process and I look forward to the opportunity to participate in this important meeting.

Ellen H. Melis, M.Sc.

My experience in gait analysis stems from my Master's training in Rehabilitation Sciences at McGill University, where I worked with spinal cord injured subjects receiving FES-assisted gait training. I have also worked in the area of elderly gait and am presently involved with spinal cord injured subjects walking with ambulatory assistive devices. My affiliation with the Rehabilitation Institute and their Gait and Motion Analysis Laboratory puts me in contact with the clinical setting as well as the research environment.

I believe that many clinicians presently do not have access to gait analysis, partly due to the fact that many of the gait analyses are expensive. I also believe that many clinicians do not receive the proper training to interpret the data one would be able to obtain from a proper gait analysis. The education of clinicians is an area which should be addressed. The proper interpretation of data is highly important if the use of gait analysis is to be meaningful. Furthermore, I think there should be normative data to which slow gait patterns (as often seen in rehabilitation candidates) can be compared. We are in the final stages of preparation of such a study. I also feel that the reporting of gait analysis should be standardized so that clinicians can communicate in the same language. EMG data for example is often normalized to peak EMG, but other times to average EMG level. These issues should be addressed if gait analyses in rehabilitation are to be meaningful.

In order to advance the area therefore, I would suggest that the following topics be addressed:

1) The training of clinicians at the professional level as well as the undergraduate and graduate level.

2) The availability of EMG analysis systems and access to these systems from the clinician's point of view.

3) General guidelines for the normalization of gait data.

4) Normative data should be collected for comparative speeds for subjects without disabilities.

Freeman Miller, M.D.

The current definition of the application of gait analysis to clinical medicine should be clarified by a position statement with respect to what people are doing and what parts of clinical medicine gait analysis is currently accepted clinical practice. I think there are specifically some areas that are fairly clear, such as in the treatment of cerebral palsy. There are other areas where there is come what less experimental applications in clinical medicine. Getting some definition of where gait analysis is in its current application to clinical medicine would be a useful statement for people planning the formation of laboratories at the level of hospitals.

There is a need for research agencies especially funding agencies such as the NIH and private funding agencies to have a sense of where in the area of development gait analysis laboratories currently are. Again, in this area it is my feeling that gait analysis development is far enough advanced that this is really in the realm of the commercial state and that commercial companies should be encouraged to continue this development. Except for some rare exceptions, this should not be a current area of federally funded research. Also there is such a wide clinical application that gait laboratories should largely be planned and funded by hospitals and other care providers as a part of their provisions of clinical services with those services being paid for by the patient or their third party payers. This kind of infrastructure spending I also do not feel should be part of federal funding.

There clearly are areas of research which would encourage gait analysis to grow and encourage its more rational application. Specifically, I feel that some federal funding directed at understanding how to use gait analysis for outcome research and funding directed at fostering communication and developing ways for data sharing so that larger groups of patients can be identified to evaluate outcome research is something that should be encouraged. The understanding of how technical outcomes as measured by gait analysis are reflected in the patient's overall functional outcome also needs to be evaluated.

We need to define a list of problems that are currently addressed by clinical gait laboratories in the area of what is preventing them from functioning best for patients. Some of these which I have experienced are a lack of trained personnel which is especially true of physicians understanding gait analysis techniques, a lack of standardization in gait analysis and gait analysis laboratories, still the continuing struggle to obtain funding from third party payers because they do not understand the technology, and the reluctance for investment by hospitals and other clinical care providers into this technology.

Don W. Morgan, Ph.D.

A major issue in gait analyses in rehabilitation medicine is the use of exercise as a tool in the assessment and management of gait-related disorders in children with neuromuscular disease (NMD). Issues deserving of further attention include the development and refinement of testing protocols to assess muscle strength and function, quantifying the relationship between changes in muscle strength and function and gait parameters, and determining the extent to which various exercise training stimuli improve locomotor efficiency and performance.

With respect to exercise testing of children with NMD, variables which have clinical and functional importance include muscle strength and power. Muscle strength is often reduced in pediatric NMD and may progressively decrease with physical growth. Since certain disease conditions feature joint contractures and varying rates of strength decrements, modifications in muscle strength testing protocols may be required. Levels of muscle endurance, peak mechanical power, and total mechanical work are also lower in children with NMD compared to age-matched controls. Interestingly, few studies have been conducted examining the association between muscle strength improvements and gait function in the child with NMD.

Another physiological variable that has clinical relevance for the child with NMD is the energy cost of locomotion. Limited data in children suggest that the aerobic cost of transport is substantially higher in children with cerebral palsy (CP) compared to normals. While the factors explaining this phenomenon remain obscure, it is likely that specific temporal, kinematic, and kinetic features of gait may contribute to energy-inefficient locomotion. From a practical standpoint, a wasteful gait pattern may restrict the functional and physical capabilities of young CP children to varying degrees, thus limiting their physical independence and their integration into school, recreational, and family activities.

Based on the aforementioned discussion, a number of future research directions emerge that would have meaningful implications for clinicians. Alternative exercise testing protocols for children may need to be developed to assess levels of muscle strength and locomotor efficiency in NMD children and of muscle strength and locomotor efficiency in NMD children and to track the relationship between changes in these variables and alterations in gait. The development of age-appropriate databases on normal children can also serve as a benchmark in establishing realistic goals for locomotor energy demands and gait performance in young CP children and provide an informed basis for the early evaluation and rehabilitation of this cohort. Such an approach might be expected to increase the likelihood of achieving near-normal or satisfactory levels of functioning in children with CP, while minimizing the long-term physical and economical consequences associated with this health condition. Lastly, more research is needed to assess the neuromuscular trainability of the child with NMD. While it has been suggested that exercise training can enhance motor independence and walking performance in NMD children, experimental support across a wide variety of NMD conditions is sparse. Along these lines,

additional study should be conducted to document the therapeutic use of strength training and augmented gait and EMG biofeedback to drive specific features of the gait pattern toward more optimal conditions. Although speculative, such an approach might improve locomotor efficiency and reduce the need for surgical intervention.

Michael J. Mueller, Ph.D., P.T.

There are many areas where research is needed to improve the effectiveness of Gait Analyses in Rehabilitation Medicine. I believe the following recommendations are some of the most important.

1. Research is needed to determine how to use gait analysis to help make clinical decisions and guide treatment. To achieve this goal, we need to understand better the relationships between measures of impairment, function, and disability as they relate to walking. For example, the traditional rehabilitation model has assumed that reductions in muscle strength and range of motion (ROM) can cause deficits in walking resulting in reduced mobility in the patient's given environment. Treatment is directed at improving the impairments, i.e., increasing the strength and ROM, to improve the patient's ability to walk. Research is needed to clarify these relationships and determine optimal methods to improve walking and related disability.

2. Research is needed to understand Fitness better the strategies that patients use to walk given various musculoskeletal and neurological impairments. Musculoskeletal and neurological impairments can be thought of as various constraints that the patient must work under. A greater understanding of optimal strategies for specific impairments would help the rehabilitation team to treat patients to overcome or compensate for any given impairment. Treatment may include exercise, gait training, surgery, or adaptive equipment.

In regard to determining these optimal "strategies," theories from Motor Control and Biomechanics should be integrated and applied to gait analysis and training. Kinetic gait analysis variables, such as joint movements and power, should be characterized further in various patient populations to identify common patterns. The kinetic variables may provide further insights to the causes of movement patterns and implications for most effective treatment interventions.

3. Research is needed to identify how technology can benefit gait analysis and treatment. Further work is needed to clarify how technology, such as imaging (i.e., CT scans), pressure sensors, finite element analysis, and gait analysis, can be integrated in the design and fabrication of orthotic, prosthetic, and other assistive devices to enhance walking.

Sara Mulroy, Ph.D., P.T.

All aspects of health care are facing a similar challenge: to substantiate, using outcomes and cost data, that the services provided are not only effective but also cost efficient. Rehabilitation medicine has the additional handicap of not providing an immediate, life-saving service. The benefits of rehabilitation therefore, are harder to quantify than those of acute care or emergency medicine and often are judged to be a luxury.

Gait analysis traditionally has been labor intensive and expensive. To survive in the current climate of minimalist health care, gait analysis laboratories must identify the information that they provide that impacts both cost and patient outcomes. The most common clinical use of a gait analysis laboratory is a pre-surgical evaluation. If a gait evaluation can identify which surgeries are most likely to be successful and which ones are not appropriate, those patients who do have surgeries should have better outcomes and those who do not should have avoided the unnecessary medical expenses.

The interpretation of the data and the decision-making process, however, are not standardized across laboratories. There are two major approaches to surgical recommendations based on gait analysis data. Both methods use motion analysis data to pinpoint the primary gait deviations, but one approach identifies the muscular causes and contributors with EMG data (indwelling, fine-wire, electrodes) and a second approach uses kinetic analysis to document the net internal moment required to meet the demands at each joint. In the second example EMG data typically are collected with surface electrodes and are used only as secondary, supporting information.

A multi-center study is needed to evaluate patient outcomes and cost data of post-surgical patients who had their surgical decision based on fine wire EMG data and those based on joint kinetics with supporting surface EMG data compared to the outcomes of patients who have surgery without a pre-operative gait analysis. Laboratories representing both perspectives should collaborate on the project. A cost-benefit analysis could identify a minimal data set necessary for accurate pre-operative assessment and allow patients and providers to select a level of pre-surgical evaluation based on the knowledge of predicted outcomes gained with each additional procedure or piece of information. This study should focus on a variety of patient populations, both pediatric and adult.

The second role of gait analysis laboratories in rehabilitation medicine is to provide information that directs patient treatment and identifies the optimal use of scarce rehabilitation resources. This can take three forms: testing of individual patients under several treatment conditions, comparing therapeutic approaches for groups of patients using and experimental design and identifying gait variables that when measured on an individual predict whether a particular treatment would be appropriate.

Gait analysis laboratories also are uniquely equipped to evaluate the biomechanics of functional activities other than walking such as wheelchair propulsion, transfers and upper extremity activities of daily living. Documentation of suboptimal movement or patterns of muscle use could extend the scope of gait analysis laboratories' contribution to patient care.

My recommendations to advance the role of gait analysis in rehabilitation medicine are:

1. Conduct a multi-center study to document cost and post-surgical outcomes with and without pre-operative gait analysis for a variety of patient populations.

2. Compare the outcomes of surgeries in which the plan was based primarily on EMG data with those based on joint kinetics.

3. Delineate the accuracy and reliability of surface and fine wire EMG in pre-surgical decision-making.

4. Support therapeutic intervention studies designed to identify factors that predict successful outcomes or which therapeutic approach would be most appropriate.

5. Collaborate with clinicians to investigate pathological biomechanics in upper-extremity functions and activities other than ambulation.

Jennifer Nymark, M.Sc.

Gait and motion analysis facility has the potential to be a strong evaluative tool in clinical rehabilitation to identify, classify and monitor outcome of functional movement limitations due to a variety of impairments. However, the gap between academic laboratory research and clinical practice continues to exist. Consequently, the Gait and Motion Analysis Laboratory was developed at our adult rehabilitation center and supported as an integral part of clinical service to foster evidence-based clinical decision-making in addition to its research mandate. The team is comprised of physical therapists, rehabilitation engineers, research kinesiologist, electronic and mechanical technologists and physiatrists. All personnel have a proportion of their positions dedicated to the Laboratory in addition to their other clinical and research activities. Clinical referrals representing a wide variety of impairments, diagnoses and age groups are received from internal staff and external clinicians.

Major Issues: The following issues are drawn from our experience and communication network of peers and are highlighted under 3 main categories: 1) Administrative and Academic Support 2) Standardization and 3) Quality and Cost of Health Care.

Administrative Support
Dedicated physical space and trained human resources are still a rarity in clinical institutions. A comprehensive resource list of all clinical service laboratories world-wide, within or close to clinical settings, would be of great benefit for information sharing and added evidence for continued support from hospital administrators. Formal joint-university appointments and academic collaborators are essential to the development of our clinical facility.

Standards of Procedures and Interpretation of Data
More formal training and support is required to standardize measurement procedures and interpretation of results particularly in the area of 3 D kinematics, kinetics and EMG processing and quantification. Normal or appropriate data bases are still limited and need to be developed further in order to assist in our interpretation of data particularly in the older and the substantially slower walking clients. Laboratory reports need to clearly indicate the specific deficits in order that meaningful information will answer the questions posed by the referrants.

Quality and Cost of Health Care
Clinical gait and movement analyses are often time-intensive and require specialized training of personnel. The challenges to the emerging technologies are to improve the user-friendliness and turn-around time for data display. Clients, referrants and evaluators would all benefit from less complex systems. At present, it would seem critical to have all clinical laboratories document and share findings with their peers on concrete examples of cost-benefit analyses related to the delivery of rehabilitation care.

SUGGESTED GOALS OF THE CONFERENCE

1) Generate a mechanism for a world-wide network communication of a) clinical and b) research, gait and motion analysis laboratories for sharing and comparing information

2) Obtain agreement on the need and mechanism to initiate standardization of evaluation procedures and interpretation of results

3) Gain support on the need for more published investigations on cost-benefit analyses of clinical gait and motion analysis service in rehabilitation

4) Profile the need for more formally recognized post-graduate education programs in this field

5) Gain support on the need for the formation of guidelines to assist referrants to gain the most useful information from a referral to a gait and motion analysis facility.

Carol A. Oatis, P.T., Ph.D.

The central issue in gait analysis in rehabilitation medicine is the question of clinical relevance. As we all know gait analysis fell into disrepute in the late seventies because there was little apparent clinical benefit from the elaborate analyses performed on patients. While there was some benefit in situations where EMG was used to help guide surgical decisions, most clinical decisions were unaffected by the gait analysis. In fact, the gait data frequently arrived at the clinician's desk weeks after the patient was gone.

Gait data are now more quickly available to the clinician, but I still believe that we must more clearly identify the benefits of sophisticated gait analysis to the patient and clinician. Will the assessment provide data otherwise unavailable and, more importantly, will these data affect the way the patient is treated. The rapidly changing health care environment demands that there be a better accounting of the application of costly evaluations. One of the ways to answer these questions is to ask more questions relating gait data to more relevant functional activities and to the patient's self perceived function. The ability to walk in a well-lit laboratory may not correlate with an individual's ability to walk at home or in the community.

Another related issue is the accessibility of gait analysis to the patient population. Clearly the vast majority of patients do not have access to sophisticated gait analysis. However one might ask whether all patients need this detailed evaluation. As the question of clinical relevance is better understood, a clearer image of what types of patients will benefit should also emerge. Classification of gait disabilities may lead to a better use of gait analysis technology.

In summary, I believe that the primary issues related to gait analysis and rehabilitation medicine are those addressing the medical gains and the economic costs of this approach for the majority of patients.

Susan Rethlefsen, P.T.

Gait analysis has made great strides in recent years in terms of the equipment and software used, increases in the types of information which can be obtained (i.e., kinetic data), as well as improved education for clinicians interpreting gait analysis data. However, as our skills and technology have advanced, new problems and issues have arisen. Some of these relate to gait analysis models and methodology, others deal with the interpretation of data as well as expanding the application of motion analysis technology.

1. One technical problem involves the limited applicability of some kinematic models to subjects with certain types of bony deformities, such as pelvic obliquity, subluxed or dislocated hips, extreme equinovarus or Plano-valgus deformities at the ankle, as well as torsional problems in the femur or tibia. The models used in data processing software are developed based on subjects with normal anatomy, and can yield inaccurate information in some types of patients.
Recommendation: Continue refinements in existing models so that they can be applied to subjects with the above problems.

2. It is a goal of many gait laboratories throughout the country to conduct multi-center research. Yet inconsistencies exist in the equipment and methodology (such as marker placement, EMG normalization techniques and software used to process the data) employed by different laboratories, making this impossible.
Recommendation: Standardization of procedures and methodology among gait labs, as well as studies to determine ways to improve reliability and validity of data collected both within and among different laboratories so that data can be shared.

3. Gait analysis is most often used in pre-surgical planning, and to assess the outcome of surgical procedures. There is a limited amount of research in the literature regarding the outcome of other interventions to improve function, such as serial casting, functional electrical stimulation, strengthening programs, etc. on gait and function. Gait analysis is an excellent tool for examining the impact of these alternative treatments.
Recommendation: Research on the outcome of alternative therapeutic treatments on gait and function.

4. Surgeries done based on gait analysis data lead to a more "normal" looking gait pattern on the data plots and graphs. However, walking velocity often decreases after surgery, and other functional skills sometimes become impaired (such as sitting on the floor, getting up from the floor, getting in and out of the bath tub). Gait is only one aspect of gross motor function, and information regarding the effect of surgical intervention on other functional activities is needed.
Recommendation: Encourage study of gross motor functional skills (in addition to gait) in patients before and after treatment intervention.

Cheryl Riegger-Krugh, ScD, P.T.

Gait analysis adds a great deal to the evaluation of movement ability for patients with neuromusculoskeletal dysfunction. Gait analysis includes a wide-range of visual of observational gait analysis to very instrumented measurement of a person's gait. The term "clinical gait analysis" has different operational definitions for different people.

Recommendations of high priority for gait analysis:

1) Clarify the term "clinical gait analysis."

2) Develop gait outcome measures that are predictive of future functional mobility status.

3) Determine the meaningful gait outcomes measures that are able to be identified with visual gait analysis. These measures may require validation with instrumentation.

Mary Rodgers, Ph.D., P.T.

A number of issues have prevented the wide-spread acceptance of gait analysis results in Rehabilitation Medicine. The usefulness of gait analysis assessments in treatment planning and/or treatment implementation is dependent upon having timely and accurate results which are presented in a summarized and understandable fashion. The technologies involved are relatively new and varied, so that research work going into gait is ongoing. This presents difficulty with normative comparisons because of lack of large data collections and inconsistency of instrumentation. Also, the compensations required by some individuals who have pathologies may allow a functional, although not normal, gait. So another issue becomes what the desired outcome is for the wide variety of pathological gaits, especially if "normal" gait is not the target.

Katherine Rudolph, M.S., P.T.

Computerized Clinical Movement Analysis Position Statement

Computerized movement analysis is currently being used by a wide variety of individuals and institutions for anything from research to clinical decision-making. Some laboratories serve both functions. In the current health care environment, technologies are being developed in order to provide more appropriate and effective treatments. Movement analysis laboratories are growing in numbers and the information they provide can be a valuable complement to other medical information, however, I feel that as a profession we need to consider the future very carefully.

One prominent problem that needs to be addressed is that of third party payer reimbursement of computerized movement analysis. Anyone who has seen a child with cerebral palsy, who is unable to walk following many inappropriate surgeries can attest to the need for gait analysis in surgical planning in individuals with cerebral palsy. However, many third party payers are unaware of the efficacy of such testing because the literature is lacking in well-designed studies which show its benefit. I feel that research funds should be provided to perform prospective studies in the field of gait analysis in people with cerebral palsy as well as the use of movement analysis in other populations. Once this is done, computerized movement analysis in populations where its value is well established will be covered by third party payers and movement analysis laboratories can begin to move into other areas in which its use could be vital, such as analysis of movement for treatment planning in physical or occupational therapy.

Another important aspect of movement analysis is the lack of clearly defined guidelines for the proper use of motion analysis technology. Laboratories may have different measurement techniques which provide similar information, for example, the use of three dimensional electrogoniometers for recording joint kinematics as opposed to three dimensional video based movement analysis systems. Some of the technology is appropriate, others may not be. Until the efficacy of one technique over another, or proof that two techniques are equivalent, is shown it will be difficult to ask third party payers to reimburse for computerized gait analysis. This would also aid in assigning standardized movement analysis codes for reimbursement.

Clinical movement analysis laboratories are typically staffed by individuals from diverse backgrounds, including medicine, physical therapy, biomechanics, and engineering. These individuals are often trained under “experts” in the field, through on the job training or continuing education courses. While this type of training can be very extensive, it is not standardized in any way. The multi-disciplinary aspect of this type of team provides a wide-range of input into the day-to-day functions of the lab. However, because of the diversity of training it is of the utmost importance that we show the public and third party payers that every lab is qualified to perform computerized movement analysis. This does not preclude others from performing movement

analysis for research purposes, it merely ensures that the public is getting a clinically useful and appropriate test.

To further this cause, I feel that a minimum level of competency should be demonstrated, through licensing, by all individuals involved in the *analysis* of gait data, including therapists, physicians and others who would be interpreting motion data. Training should be performed by laboratories, designated as being training centers. This licensure would ensure that the personnel are qualified to chose and perform appropriate tests and that they are qualified to make appropriate interpretations of the information. I also feel that each clinical motion analysis laboratory should also be licensed. This licensure would include demonstration of a standard level of accuracy, reliability and validity with their measurement systems.

Finally, I feel that although the issues facing the movement analysis community are numerous many of them impact each other. I feel that we are all committed to furthering the advancement of clinical movement analysis and I feel that this working conference has allowed many individuals, from different disciplines, to define a direction for the near future of this clinical tool. I propose that conferences such as this be repeated periodically, to set goals and assess the progress of our mission.

Lisa M. Schutte, Ph.D.

Major issues facing the field of gait analysis include ensuring that the best possible quality of data comes out of the clinical gait analysis labs and that the treatment decisions made using the data have scientific basis whenever possible. The discussions concerning standards and accreditation started by groups such as the American Academy of Cerebral Palsy and Developmental Medicine and North American Society of Gait and Clinical Movement Analysis are an important step in addressing both issues. In addition, the current accepted practices of clinical labs can always be improved upon. Future methodological and technical advances should be aimed specifically at increasing the reliability of the data generated by the clinical labs. For example, data quality can be improved by methodological improvements that decrease the dependence of data quality on precise marker placement and technological advancements that decrease the encumbrance of patients during data collection may allow the patients walking pattern in the lab to more closely match their functional abilities in the community.

Ensuring that good clinical decisions are made based on the gait data is difficult. A great deal of information is gathered in a typical gait analysis. How that information is interpreted depends heavily on the experience and intuition of the clinicians looking at the data. In general, gait analysis provides a good assessment of what a particular patient's gait looks like and how it differs from normal but still does not necessarily provide much direct information about why the gait is abnormal. Answers to questions such as: What underlying pathologies are causing the gait deviations? Which gait deviations are compensatory mechanisms and which are directly causes by pathology? Are not always obvious. Consider, for example, crouch gait (i.e., excessive knee flexion throughout stance) a common gait pathology in children with cerebral palsy. Many different factors are thought to contribute to crouch gait (i.e., hamstrings tightness, hip flexion contractures, weak ankle plantarflexors, poor balance). Gait analysis not only provides a way to quantify the amount of excess knee flexion but also provides a way to tell if the hip is flexed, internally rotated or abducted more than normal, if the pelvis is tilted forward or backwards or if the EMG of any muscles is abnormal. All this information may impact treatment decisions. However, there remains no consensus on how to distinguish between the various potential causes of crouch gait. Additional research aimed at increasing our understanding of the relationship between specific gait deviations and the causative pathologies is necessary in order to adequately address such issues. In my opinion this research should be a combination of well-designed clinical studies and more basic research into the mechanics of normal and pathological gait.

The lack of universal acceptance of gait analysis is a major factor that prevents people with locomotion disabilities from accessing gait analysis. Although gait analysis has many strong advocates and acceptance has increased in recent years, many third party payers and potential referring physicians remain skeptical. For gait analysis to be widely accepted additional outcomes based research is needed to establish the utility and reliability of gait analysis in

identifying when specific pathologies are contributing to a patient's gait abnormalities. That is studies must demonstrate that for specific groups of patients gait analysis provides a reliable means to choose between two or more potential treatments and properly choosing between these treatment results in improved outcome.

Acceptance of gait analysis is also limited by the complexity of the information that is collected in a typical gait analysis and by the difficulties associated with communicating this complex information to nonexperts. Technological advances in telecommunications, computer graphics, multi-media have great potential to impact how gait analysis data is stored, communicated, and shared, and how individuals are educated about gait. These technological advances should be utilized intelligently by people working in the field of gait analysis to make gait analysis information more accessible.

In summary, my specific recommendations for the field of clinical gait analysis are to:

1. Continue efforts to establish a formal accreditation process for clinical labs.

2. Continue to develop more reliable and less cumbersome methodologies and tools for data collection.

3. Conduct both clinical and basic research aimed at increasing our understanding of the relationship between specific pathologies and observed gait abnormalities.

4. Conduct clinical, outcomes based research to establish utility of gait analysis in selecting appropriate treatment for individual patients.

5. Effectively utilize technological advances in telecommunication, multi-media, computer graphics to better communicate information about gait to non-experts.

Karen Lohmann Siegel, M.A., P.T.

Issue #1: Identify critical impairments that lead to locomotion disability.

Background: Rehabilitation clinicians frequently need to develop treatment plans for individuals with locomotion disabilities who have numerous physical impairments and functional limitations. As a result, rehabilitation goals must be prioritized, along with the treatment approaches designed to meet those goals. Rehabilitation treatment plans often focus on physical impairments, with the hope that minimizing impairments will minimize locomotion disability. Prioritization often assigns greater importance to treatments designed to ameliorate the most severe impairments, but there is no certainty that the greatest impairment is the greatest contributor to a locomotion disability. A casual relationship between specific physical impairments and locomotion disabilities has not been well established. If thresholds for levels of impairment could be identified that predict a greater likelihood of locomotion disability, it would provide clinicians with objective information on which to develop goals with their clients and prioritize treatment plans. In the case of chronic progressive disorders with increasing severity and number of impairments over time, these thresholds could help to identify critical periods when rehabilitation intervention is essential to maintain ambulation ability.

Recommendation: Research employing gait analysis methodologies is needed to identify the critical impairments that are most likely to result in functional gait limitations (so that clinicians can appropriately prioritize rehabilitation treatment plans) and should answer the following questions:

a) What is the relationship between typical physical impairments, functional gait limitations, and locomotion disabilities?

b) Specifically, what is the critical location and severity of pain, excursion of each lower extremity joint, strength of each lower extremity muscle, coordination, proprioception, metabolic capacity, and other abilities that are needed to prevent functional gait limitations and locomotion disability?

Issue #2: Develop criteria for ideal compensatory gait patterns for a given set of impairments.

Background: Normal gait patterns are the current "gold standard" to judge success in the rehabilitation of people with locomotion disabilities. However, symptoms of overuse are common in relatively unimpaired structures that attempt to compensate for impaired structures. As a result, "normal" gait patterns may not be optimal for many individuals with functional limitations in gait. Rehabilitation clinicians need guidelines to determine what is an optimal compensatory gait pattern for a given set of impairments to assist in goal setting with their clients and in developing treatment plans.

Recommendation: Research employing gait analysis methodologies is needed to identify the best goal of rehabilitation for locomotion disabilities by answering the following questions:

a) What are the compensatory gait strategies utilized by people with locomotion disabilities for a given set of impairments (such as those commonly associated with amputation, hemiparesis, spastic diplegia cerebral palsy, neuropathy associated with a specific peripheral nerve or spinal level, muscle disorders affecting specific muscle groups, and others)?

b) Do some compensatory strategies result in better gait function than others (such as fewer falls, faster walking speed, increased walking endurance, and other measures) for a given set of impairments?

c) Are some compensatory gait strategies more likely to produce symptoms of overuse (such as pain, muscle strain, joint instability, or other symptoms) than other compensatory gait strategies for a given set of impairments?

d) Based on the answers to the above questions, what is the optimal compensatory strategy in gait for a person with locomotion disability associated with a given set of impairments?

Issue #3: Establish how the results of gait analysis can be used to develop rehabilitation treatment recommendations.

Background: The results of gait analysis have been used to assist in the development of rehabilitation treatment recommendations for individuals with locomotion disabilities. The indicators for various rehabilitation treatment components and the mechanisms by which the treatment affect gait have not been well documented through research. As a result, the interpretation of gait analysis data and the process by which recommendations are developed is heavily dependent upon the professionals performing the gait evaluation.

Recommendation: Research is needed to establish the indications for rehabilitation treatment recommendations from the results of gait analysis based on an individual's existing physical impairments, functional gait limitations, and locomotion, and locomotion disability by answering the following questions:

a) In the area of exercise:
What are the indications for various types of exercise and for which muscles should they be prescribed?

b) In the area of gait training:

What gait devices (if any) should be prescribed and how should they be utilized? What compensatory gait strategies should be encouraged, and what compensatory strategies discouraged? What is the best way to teach an individual to utilize the desired compensation?

c) In the area of footwear:
What is the optimal shoe design? What shoe modifications are indicated and how should they be designed?

d) In the area of orthosis prescription:
What type of orthosis is indicated (foot, ankle-foot, knee-ankle-foot, etc)? What are the best characteristics for the orthosis components (flexible or rigid; articulated or locked joints, etc.)?

e) In the area of prosthesis prescription:
What are the best characteristics for the prosthesis components (type of foot, type of knee joint, alignment, etc.)?

Issue #4: Document the role of gait analysis in rehabilitation treatment.

Background: There is an anecdotal case evidence to suggest that the results of a gait analysis can be used to guide rehabilitation treatment planning and improve walking ability of people with locomotion disabilities. However, the contribution of gait analysis to the rehabilitation process and its potential benefit has not been systematically documented in an adequate number of research studies.

Recommendation: Controlled randomized research studies are needed to document the potential impact of gait analysis on the rehabilitation process of people with locomotion disabilities to answer the following questions:

a) Do the results and conclusions of gait analysis change rehabilitation treatment plans?

b) Is functional level at discharge from rehabilitation treatment greater in individuals who have undergone gait analysis for the purpose of making rehabilitation treatment recommendations when those treatment recommendations have been implemented?

c) If rehabilitation treatment plans developed from gait analysis provide individuals with a higher functional level than rehabilitation without gait analysis, what is the impact of the higher functional level on the health, productivity, independence, and quality of life of the person?

Lisa Selby-Silverstein, Ph.D., P.T., NCS

The following are my recommendations with respect to advancing the field of Gait and Motion Analysis in Rehabilitation Medicine:
1) Clinicians need to be educated as to strengths, limitations, and utility of various components of gait and motion analysis and *the variety of populations* which might benefit from their utility.

2) Manufacturers need to be held accountable to have their systems attain a particular level of performance and they should disclose all strengths *and limitations* of their systems in a clear format in the sales literature.

3) Billing and reimbursement needs to be available for subjects with a variety of diagnostic codes. Billing should be based on what is done (not just "gait analysis" but rather 4 channels of EMG, 2D or 3D motion analysis - possibly by number of frames?) and depth of the analysis. Payment should be approved or disapproved based on impairment *NOT DIAGNOSIS*. For example, this type of analysis should be reimbursable for any patient with a balance, gait, or movement impairment which needs to be understood, documented or tracked by quantitative means. Reimbursement should not be just for children with cerebral palsy before and after surgery. Perhaps with more detailed understanding and tracking of movement disorders, recommendations for treatment interventions such as physical therapy or pharmacological management could be based on more objective findings. In addition, their efficacy could also be monitored.

4) We must assure that standardization does not limit use and/or growth of the field of motion analysis (or reimbursement thereof). Use of quantitative measures should be encouraged by all groups of clinicians treating movement dysfunction.

5) Any type of clinician licensed to evaluate and treat movement dysfunction should be encouraged and reimbursed for the use of quantitative measures to assist in this process. This should include any of the measures used in motion analysis. Collaboration with technical personnel should be required for laboratory development, up keep, and data interpretation. In addition, since I believe that any one clinician will tend to make recommendations biased toward treatments they know best, teams of clinicians probably would make the best recommendations. I believe that when clinicians make treatment recommendations, they should only make them within their licensure pervue and expertise as aneurologist, physiatrist, orthopaedist or physical therapist. Hence, particular situations might warrant interpretation and recommendations be made by teams of clinicians and technical personnel familiar with motion analysis *as well as management options* for the pathology of interest. Unlicensed or unregistered technical personnel should definitely assist in understanding and interpreting gait data, but should not make specific treatment recommendations.

Guy Simoneau, Ph.D., P.T.

My particular interest in gait analysis revolves around its use in the rehabilitation of older individuals who have ambulation and/or balance disorders. The major issue is determining whether gait analysis can in fact provide objective information, not available through a typical physical examination, that would influence the treatment procedures and ultimately the rehabilitation outcome of these individuals. This evidence (perhaps) with the exception of gait analysis in the pediatric population) is currently lacking in the literature.

Recommendations:

1) To develop a body of literature demonstrating the usefulness of gait analysis for clinical decision-making in adult patients with orthopedic/balance disorders. For example: produce controlled studies comparing rehabilitation recommendations made based on the physical examination alone compared to the treatment recommendations made from the physical examination supplemented by the biomechanical evaluation. Ultimately, these studies would help determine whether these differences in recommendations (assuming there would be differences) actually have a positive effect in rehabilitation outcome.

2) Based on the above studies, identify the components of the biomechanical evaluation that are useful: kinematics, kinetics, GRF, momentum, EMG, etc.

3) Develop consistency across labs for the evaluation procedure, the interpretation of data, the generation of reports and cost.

Jean L. Stout, MS, P.T.

The ability to regain or retain walking ability after the onset or diagnosis of a motor impairment is a major goal of the rehabilitation process. In gait analysis we have technology that can describe, quantify, and advance the understanding of how walking occurs, what happens when walking is disrupted, and in some cases, what treatment is needed for walking to be restored for optimal function. Clinically, gait analysis can provide an objective measure to assist in treatment planning, and provide and objective measure of the outcome of the treatment and the rehabilitation process involved in that treatment. And yet, during a time when outcome data and research is encouraged and sometimes demanded by payors of treatment, the use of gait analysis is not considered a necessity for determination of treatment planning to treatment success in the improvement of walking.

The issues which inhibit the use of gait analysis in rehabilitation medicine as the powerful tool I believe it is, come from a variety of sources. These include:

- Lack of access of Patients with Locomotor disabilities to Gait Analysis: This occurs by lack of reimbursement of third party payors who consider gait analysis to be experimental and by professional colleagues who treat gait disorders but consider gait analysis to be unnecessary. Education of both professionals, third party payors and the health care consumer falls into this category.

-An Under developed Potential of Gait Analysis as a Diagnostic and Prognostic Tool: Lack of and appropriate neurophysiology ---> engineering interface underlies this problem. Improved correlations between basic science knowledge of the pathophysiology of the disorders and the effects on the motor output need to be established. Current engineering models fail to adequately incorporate pathologic neurophysiology. Characteristics of the locomotor disabilities need to be better understood.

- Limitations Imposed by Current Technology and Instrumentation: Improvements would enhance the usefulness of gait analysis information in rehabilitation therapy programs. Functional measures of muscle strength, dynamic balance, and energy sources are examples.

-Lack of Standardization Among Existing Laboratories: When a health care professional recommends or orders an MRI or a diagnostic EMG and Nerve Conduction studies, results are typically reported in a standardized fashion that is not dependent upon where the study was conducted. This, unfortunately, is not the case in the area of gait analysis. Standardization of protocols and output need to be established. Just as MRI scans are read by specialists with certain qualifications for understanding the output from the study, the field of gait analysis also needs to develop qualification standards for those who interpret data.

- Lack of Correlation of Gait Analysis Information and Current Rehabilitation Procedures: This broad area incorporates rehab therapy protocols for treatment, standard diagnostic EMG, prosthetic designs at various levels of amputation, orthotics, etc.

I believe that the NCMRR model of outcome research can be applied to the area of locomotor disorders and the enhancement of function through the use of gait analysis. Understanding the pathophysiology, impairment, functional limitations, disability, and societal limitations are all vital. Recommendations related to the above problem areas would be as follows (these are not listed by priority):

1) Promotion of studies to Document the Effectiveness of Gait Analysis as a Clinical Outcome Tool. These studies should emphasize the correlation of the results of functional activities of locomotion including balance, speed , energy expenditure, etc.

2) Develop a Stronger Neurophysiology ---> Engineering Interface to understand the role of neuropathology and/or muscle pathology to the effects on gait and gait analysis information. This should include but not be limited to areas of pattern recognition, improved neuropathological engineering models of gait, defining standard patterns of pathology for particular disorders, and models to restore function in lower motor neuron injury.

3) Promote research to define the prognostic indicators within gait analysis data for potential functional improvement after surgical intervention.

4) Promote advancement of current instrumentation to assess more aspects of gait.

5) Develop guidelines or definition of required or desired areas of assessment by clinical gait analysis to be as inclusive as possible to all aspects that define dysfunction.

6) Promote the development of medical education models that incorporate gait analysis as the definitive procedure for identification, definition, and treatment planning of all locomotor impairments. These education models should include health care professionals, third party payors, and health care consumers.

Duk Hyun Sung, M.D. and Jongmin Lee, M.D.

First of all, there is no established standard methodology to run gait analysis system. For example,
-What is the normal reference data? (The kinematic data vary greatly according to gait speed)
-Should the several gait cycles be averaged or not?
-If several cycles should be averaged for the interpretation, How many gait cycles should be averaged to analyze of patients' gait?
-The position of passive marker on skin surface can not be put on exactly same site before and after the certain treatment in spite of every efforts.
-Is the data from the one gait analysis system comparable to that another gait analysis system?

Because there will be many experts in gait at the meeting, I want to know the current knowledge about above several questions in the workshop. We should establish the methodology to run the gait analysis system to make an objective, reproducible data for clinical purpose and research design.

Secondly, my Lab. does not have a biomedical engineer. (The National Insurance system in my country does not reimburse the high cost of the gait analysis, so we cannot charge the appropriate price to insurance company or patients).

Thirdly, is there a specific recommendation which can not be made if the gait analysis is not performed in the management of spastic patients. The orthopedic surgeon in my institute uses the gait analysis data mainly for the evaluation of the surgical effect. He is reluctant to depend on gait analysis data in his surgical planning. In my experience, there are multi-joint problems in spastic patients which can't be evaluated exactly in observational gait analysis and the orthopedic management is the last procedure when there is no effect in spite of the various non-orthopedic procedures on the soft tissue. Thus I have tried to use phenol black or Botox injection, intrathecal baclofen. So we must develop the treatment strategy according to the data of the gait analysis (define characteristic gait patterns to make a guideline for treatment procedure like the nerve block or Botox injection, intrathecal baclofen, and surgery. (Adult cases as well as children).

Fourthly, although the gait analyses have used mainly for the spastic cerebral palsy children, I think it can be more applicable to adult spastic patients or amputee than children. In my country, the percentage of the geriatric population grows up in contrast to the lowering percentages of the children, we must apply this test to adult geriatric patients and there should be an advantage in clinical practice or research area.

Fifthly, I do not use much of the gait analysis for the evaluation of the L/E orthosis and prosthesis because there is not many cases of amputee in my country compared to the United States, and a lot of patients refuse to use orthosis. But the gait analysis can be a useful to develop or evaluate new prosthetic and orthotic designs (for example, the articulated plastic AFO, floor reaction AFO are really superior to the conventional plastic AFO).

Susan Sienko Thomas, M.A.

Gait analysis as a patient assessment tool.

Computerized gait analysis has been used for many years as a method to document both normal and pathological movement. The necessity for quantitative assessment of pathological movement is the complex three dimensional interactions between joints and the subsequent response from the muscles. Visual and clinical assessment alone make it difficult to determine the primary and secondary compensations found in pathological gait. Therefore, the use of three dimensional gait analysis provides a mechanism from which all planes of motion at several joints can be evaluated simultaneously, thus allowing closer evaluation and interpretation of the abnormal motion. In addition, gait analysis provides the documentation necessary to assess treatment outcome whether it be surgery, orthotic/prosthetic management or therapy.

The use of gait analysis as a patient assessment tool is limited by the following: the lack of link segment model standardization and marker placement between different systems and different laboratories; the lack of an accurate model which demonstrates the complex motion which occurs at the foot; the lack of consistency in the processing methods used in data analysis which may modify or change the clinical interpretation; the lack of normal age matched databases available to compare abnormal gait patterns; the lack of trained individuals to perform and interpret the gait analysis assessments; and the exorbitant cost of the gait analysis systems.

Gait analysis could be improved by the development and implementation of a standardized model which would be utilized by all motion measurement systems. The development of this model would dictate the processing techniques thus providing a basis for patient comparison and data sharing between labs. The use of a standard model would also allow for data sharing between all systems thus providing a mechanism for which norms from various labs around the country could be combined for a large variable age database.

Use of gait analysis assessments in treatment planning and/or treatment implementation. The information gained from the gait analysis can be effectively used in the determination of various treatment plans. Gait analysis can provide a quantitative assessment of the pathological gait pattern compared to normal and/or to their pre-treatment movement pattern. The use of gait analysis can determine primary and secondary gait deviations which allow for treatment options to be directed toward the primary problems.

The use of gait analysis as a tool in the treatment planning is limited by: the lack of standardization between centers in the interpretation of the data, specifically in the more complex areas of moments, and powers; recommendations from the gait analysis appear to be based more on the experience level of the physician than solely the information gained from the gait analysis; the poor understanding by clinicians of the relationship between

electromyographic (EMG) patterns and the pathological gait pattern; the lack of understanding by the referring physicians and therapists of the data and subsequent recommendations resulting from the gait analysis. Although gait analysis is extremely good at providing quantitative documentation from which the results from the treatment interaction can be measured, it has not yet been proven that the recommendations that result from the use of gait analysis provide better treatment recommendations than they would have if gait analysis were not used. Gait analysis has not been shown to reduce the number of surgical interventions and subsequently the cost of treatment for individuals with movement pathology.

Gait analysis could be improved through continuing education courses at minimal cost provided to personnel involved in gait analysis to share ideas, discuss interpretation of data in an open, non-threatening format. Continuing education courses could benefit both physicians directly involved in the interpretation and physicians referring the patients, as well as all individuals including the engineers and gait lab clinicians. Greater emphasis should be placed on research aimed at determining whether the use of gait analysis influences treatment decisions, improves the quality of care and reduces the cost of treatment.

Factors which prevent the people with locomotion disabilities from accessing gait analysis.

Although the availability of gait analysis is increasing, gait analysis still remains a restricted resource for many individuals most specifically adults with pathological gait. Due to the significant amount of research on the benefit of using gait analysis with children with cerebral palsy, many of the laboratories are established at pediatric facilities under the direction of physicians who are most familiar with pediatric neuromuscular disorders. This restricted use is only one reason that access to gait analysis is limited.

Access to gait analysis still remains a major problem for the following reasons: cost of the service and subsequent reimbursement for services by the insurance companies; distance required for travel to the closest laboratory and lack of knowledge on the part of physicians and therapists that this technology is available and the benefit of the information received from an assessment.

A significant emphasis needs to be placed on educating the insurance companies about the benefits of gait analysis including the increased understanding of the pathological gait pattern which will improve treatment recommendations and possibly the cost of the overall treatment plan. Improved advertising abilities and education of referring physicians and therapists should be made available in regions which gait analysis services are readily available. A central database should be made available so that should a physician want a gait analysis for their patient, they may be able to determine the laboratory which is closest to the patient.

James C. Wall, Ph.D.

In the report of the NIH Gait Research Workshop, which was published in 1977, many issues were raised which are still pertinent today. One of these was raised by Dr. Burstein who stated that "*... right now we have almost no clinically useful diagnostic tools that can be taken outside of the heavily-financed research laboratory.*" If I am reading this comment correctly, a plea is being made for objective gait measurements that can be obtained by clinicians faced with the day to day task of assessing, treating and monitoring patients with gait abnormalities. This situation remains today with the result that the vast majority of the decisions about treatment of gait abnormalities are based on subjective assessments. For all the advances that have been made in measurement of gait and in the number of advanced, well equipped clinical gait laboratories that now exist, there has been a failure on the part of the gait analysis community to address the needs of the therapist or clinician that is daily involved in assessing, treating and monitoring patients with gait problems. This is compounded by the fact that the majority of therapists are much less interested in assessment, particularly objective measurement, than treatment, even though they will agree that treatment decisions must be made in the light of an assessment and that numerical data would certainly help. It is quite the paradox but points out that it is not simply the lack of practical objective measurement systems for them to use, but that objective gait analysis is also not perceived as a priority.

The truth is that there are simple objective measures which could be used clinically, particularly for obtaining outcome measures. For example, walking speed and stride time could be measured using a simple stopwatch and from these stride length could be calculated. So with minimum equipment the basic temporal/distance parameters could be measured. If they did nothing else they would greatly improve upon what is now being done.

I think that part of the problem in getting clinicians to use objective gait measurements is their lack of knowledge about gait, both normal and pathological, particularly with respect to the interpretation of gait data. Perhaps this is where we need to start. There then needs to be a concerted effort to provide them with tools that will aid their subjective assessment by providing objective measurements. The clinical gait analysis community should be involved in this process since they are in the best position to advise clinicians on these measurements and how and when they should be used. For example, some guidelines might be provided on the measurements that should be taken before a referral is made for a more comprehensive gait analysis. Once we know which measurements should be made and under what conditions, we should then develop clinically practical techniques for their determination.

In the light of these comments I would like to make the following recommendations:

Recommendation #1.

Develop educational materials which will promote an understanding of normal and pathological gait, with particular emphasis on interpreting the results from gait analyses.

Recommendation #2.

Develop practical objective gait measurement techniques that are valid and reliable and which can be used by clinicians involved in assessing, treating and monitoring patients with gait problems.

Kimberly A. Wesdock, P.T.

The major issues in gait analysis in rehabilitation are multi-faceted and relate to evaluation procedures, interpreting the data, using the data for research purposes, and accessing gait analysis. Different laboratories across the country use different gait analysis systems to evaluate similar patient problems in individual ways. That is, everybody is "doing their own thing" and typically billing for these services to third-party payers. All gait laboratories must be held accountable for their actions, and therefore guidelines and standards must be established. This standardization procedure has been initiated by the North American Society of Gait and Clinical Movement Analysis (NASGCMA), but this endeavor is in the early stages. Additional groundwork must be laid to assure that all issues - clinical, research, and access to care - are addressed. Specific issues of concern include:

I. Assessment

A. Standardizing ***Clinical Evaluation*** procedures, including nomenclature.

B. Standardizing ***Marker Placements*** - What is the reliability within and among laboratories?

C. Standardizing ***Equipment*** - Presently, gait laboratories are using different software and camera systems. Are these systems equally accurate and produce comparable data?

D. ***EMG*** Analysis: Fine wire vs. surface - When to use and why?

E. ***Energy Expenditure***: Oxygen Consumption vs. Mechanical Energy vs. Physiologic Cost Index - Are these measures of energy expenditure valid and reliable? How are different laboratories using this information? Can laboratories use this information in a standardized way? Which diagnoses can specifically benefit from this evaluation (in addition to cerebral palsy)?

F. ***Functional Assessments*** - Are laboratories using evaluation tools such as the Gross Motor Function Measure (GMFM) to correlate functional gross motor skills with gait? Are laboratories routinely performing motion analysis during functional activities other than gait such as stair-climbing, upper extremity reaching tasks, trunk movements, etc.? (For research or clinical use?)

II. Interpretation of the Data

A. ***Joint Powers*** - Are laboratories using this information in a standardized way when analyzing gait and making treatment recommendations?

B. ***Diagnosis-Specific Testing*** - Do gait laboratories evaluate and interpret the data differently, for specific diagnoses? What are the inherent physical and functional problems specific to each diagnosis that gait analysis can evaluate and longitudinally document? Given the natural history of progression of individual diagnoses, can gait laboratories provide useful information upon which to base treatment decisions? (e.g., cerebral palsy vs. juvenile arthritis vs. myelomeningocele vs. dystonia).

C. ***EMGs*** - Do gait laboratories interpret EMG findings in a standardized way?

D. ***Reporting the Data*** - Standardization of report formats among gait laboratories will assist in collaborative research endeavors, education and training, and third party reimbursement.

III. Clinical Recommendations

A. ***Surgical vs. Non-Surgical Recommendations*** - Many laboratories are primarily evaluating children pre- and post-op orthopaedic surgery. Other physicians who may benefit from gait analysis include: physiatrists, rheumatologists, neurologists, etc. How can gait laboratories best serve these other specialties as well as individuals with various movement disorders?

B. ***Physical Therapy Recommendations*** - Multiple physical therapy recommendations can be made after gait analysis. With collaborative research efforts, the efficacy of many treatment techniques can begin to be evaluated. However, follow-up gait analysis studies are necessary to accomplish this goal, and third party reimbursement is often difficult to obtain, as are physician referrals for repeat testing.

C. ***Bracing Decisions*** - Do gait laboratories make recommendations for orthoses in a standardized way? What patient populations would benefit from these analyses?

D. ***Follow-Up*** - Are repeat gait analyses routinely performed to document the effects of all therapeutic interventions (surgical and non-surgical) after the initial analysis? Gait laboratories need a standardized way of documenting functional outcomes, such as a national database, so that information can be used for education and research purposes.

IV. Research

A. ***Accessing Funds*** - Clinical laboratories housed in hospitals that are not university-affiliated (and do not have Ph.D. personnel on staff) often wish to participate in research efforts. These gait laboratories must be made aware of available research funding for specific projects.

B. ***Research Design and Priorities*** - What are the pertinent research questions to answer? How can laboratories design studies to best utilize staff time and effort? How can individual laboratories initiate and/or coordinate multi-center collaborative studies? Which diagnoses

should be targeted?

C. ***Statistical Analysis*** - Workshops at national gait conferences are imperative in assisting new researchers in the field to statistically analyze gait data.

D. ***Outcomes Database*** - The establishment of a national diagnosis-specific database will assist all laboratories in documenting the natural progression of different disorders as well as functional outcomes. Additionally, this information will be necessary for third-party payers to justify services.

V. Accessing Gait Analysis

A. ***Barriers*** - preventing access to gait analysis include demographics, prohibitive cost, lack of knowledge by potential referring sources, and questionable benefits. These barriers must be investigated and prioritized, and action plans implemented to reduce or eliminate the barriers.

B. ***Age Discrimination*** - Many gait laboratories (including some "centers of excellence") are located within childrens' hospitals which often do not serve individuals over the age of 21. This issue must be addressed to improve access to gait analysis centers for all individuals with movement disorders, regardless of age.

C. ***Funding*** - should be allocated to ensure that all U.S. consumers have equal access to gait analysis, regardless of demographics and ability to pay. For example, a plan should be established for individuals in the Midwest states (many of which do not have laboratories) to access gait analysis. Even if insurance companies or non-profit organizations agree to pay for testing, how can assistance be obtained for families to travel out-of-state to existing laboratories, and who assists with lodging and miscellaneous costs?

Recommendations Needed for Advancement in Gait Analysis

1. Standardization of nomenclature, methodology, equipment, interpretation, and reporting used in gait analysis.

2. The establishment of diagnosis-related guidelines for evaluation and testing.

3. The establishment of a national database to document the longitudinal progression of different diagnoses before and after therapeutic intervention.

4. Collaboration among different laboratories to initiate multi-center studies investigating clinical questions and documenting functional outcomes.