SECTION II
METHODS

2. OVERVIEW

The Workshop design consisted of three distinct phases. The first focused on orienting co-chairs and participants to the task of developing recommendations. This phase began the evening prior to participant involvement with an orientation session for co-chairs. The goal of this meeting was to introduce co-chairs to the concept of team facilitation and overview detailed instructions pertaining to the recommendation development process. Co-chairs were provided an opportunity to review guiding philosophies and important definitions, practice warm-up activities, and discuss outlines describing the preferred recommendation development process. On the first day of the Workshop, participants received background material and a glimpse of the future of gait analysis by prominent speakers in the field of gait and human movement analysis.

The second phase was focused on recommendation development. One and a half days were spent in smaller working groups directed to develop recommendations for the future of gait analysis. Each of the three work groups were facilitated by co-chairs as they worked on one of the three topic areas. Work groups were subdivided into teams and groups were asked to develop concise recommendations using a model recommendation as a guide. On the last day of the meeting, verbal summaries of all of the recommendations were presented to the group at large.

Finally, after having an opportunity to review and briefly clarify each of the recommendations, each workshop participant was asked to assign a priority score to each recommendation (third phase, priority scoring), including those developed by other work groups. The recommendation scoring session could best be described as a scripted directed activity during which participants were instructed to score recommendations sequentially.

Immediately after scoring the recommendations, a team of Workshop participants entered the raw scores into a computer generated spreadsheet. While this was occurring, the Workshop coordinators and co-chairs met in an executive session to create a plan for the development of this document.

The following sections contain essential details related to the goals and principal phases of the Workshop.

2.1 Guiding Philosophies

The following is a list of guiding philosophies that was used to orient co-chairs during the co-chair orientation session.

1) We wish to capture all recommendation ideas, however unusual they might seem.
2) Participants, should be encouraged to be bold! There are no bad recommendations.
3) A comprehensive list of recommendations that covers many categories is best.
4) A large total number of recommendations is better than a few.
5) The basic philosophy of recommendation development is to strengthen all recommendations.
6) Duplication of effort between work groups is acceptable, encouraged, and an expected outcome of this meeting.
7) Sole authorship of recommendations is acceptable however discouraged. Co-chairs, should attempt to maintain a team format.
8) All participants will judge (be given an opportunity to score) all recommendations.
9) Recommendations will not be prioritized using coercion or undesired ejection from the pool of recommendations.
10) To score well (receive a low score), a recommendation must be clearly written, contain a compelling argument, and pertain to an important cross cutting issue.

2.2 Important Definitions and Rules

1) A work group consists of a group of participants that has been assigned one of the conference topics.
2) A team is a subset of a working group and should contain no greater than five participants.
3) A participant's assigned position is defined by their assigned work group, team, and seat. Co-chairs may request participants to return to their assigned position at any time.
4) Participants may not enter the assigned room of other working groups.
5) Subject to co-chair approval, team membership can change as recommendations develop.
6) Each team member should be prepared to act as a recorder or spokesperson.
7) A team must have a spokesperson at all times.

2.3 Workshop Agenda

<u>Thursday, September 26th - Morning</u>

Milestones for this Day: Provide overview of task and background information. Formulate teams and strategies for report generation.

7:30-8:30 **Registration**

8:30-8:45 Greetings: *Marcus Fuhrer, Ph.D., Louis A. Quatrano, Ph.D.*

8:45-9:00 Overview of meeting: What the next three days will be like.
Steven J. Stanhope, Ph.D.

9:00-9:15 **Topic I: The use of gait analysis as a patient assessment tool.**
Introduction and overview
Chairs: Peter Cavanagh, Ph.D. and Casey Kerrigan, M.D.

9:15- 9:45 Presentation 1:
Melanie Brown, M.D.

9:45-10:15 Presentation 2:
Kenton Kaufman, Ph.D.

10:15-10:45 **Break**

10:45-11:00 **Topic II: The use of gait analysis assessments in treatment planning and/or treatment implementation.**
Introduction and overview
Chairs: Jerry Harris, Ph.D. and Alberto Esquenazi, M.D.

11:00-11:30 Presentation 1:
Sandra Olney, P.T., Ph.D.

11:30-12:00 Presentation 2:
Felix Zajac, Ph.D.

12:00-1:30 **Lunch**

1:30-1:45 **Topic III: Factors which prevent the people with locomotion disabilities from accessing gait analysis.**
Introduction and overview
Chairs: Jack Winters, Ph.D. and Freeman Miller, M.D.

1:45-2:15 Presentation 1:
James R. Gage, M.D.

2:15-2:45 Presentation 2:
Edmund Y.S. Chao, Ph.D.

2:45-3:00 Working group assignments and directives: Conference attendees will be divided into three independent working groups. Each working group will be asked to formulate recommendations related to one conference topic.
Steven J. Stanhope, Ph.D.

3:00-3:30 **Break**

3:30-5:30 Breakout: Conference participants convene in working group areas. Review strategy for reaching conference goal. Subdivide into teams and select team leaders.

<u>Friday, September 27th - Morning</u>

Milestones for this Day: Develop team recommendations. Formulate working group reports. Distribute draft working group reports to conference participants.

8:30 Reconvene working groups: Develop recommendations.

11:30-1:30 **Buffet lunch**

5:00-5:30 Working group Co-chairs submit draft reports to Conference Coordinators.

5:30-7:00 **Dinner:** Distribute draft reports to all conference participants

<u>Saturday September 28th, - Morning</u>

Milestones for this Day: Present and discuss working group recommendations. Score all recommendations. Generate final report development plan. Present report development plan to NCMRR representative.

8:30-8:45 **Greeting:**
Rory A. Cooper, Ph.D.

8:45-9:15 Presentation of Recommendations: Working Group (Topic) I
Co-chairs

9:15-9:30 Discussion

9:30-10:00 Presentation of Recommendations: Working Group (Topic) II
Co-chairs

10:00-10:15 Discussion

10:15-10:30 **Break**

10:30-11:00 Presentation of Recommendations: Working Group (Topic) III
Co-chairs

11:00-12:00 Discussion

12:00-12:15 Priority voting/scoring: Conference participants score recommendations
Conference Coordinators

12:15-12:30 Closing remarks
Marcus Fuhrer, Ph.D., Louis Quatrano, Ph.D.

12:30-1:30 **Lunch**

12:30 - 5:00 **Executive Session:**
Co-chairs of the three working groups, and conference coordinators for the three working groups meet and formulate development plan for the conference report to be presented to the NCMRR.

2.4 Overview of Speaker Abstracts

The following abstracts were provided by speakers in advance of the conference. Each invited speaker was instructed to develop a presentation based on a predetermined topic or theme. Session co-chairs were invited to provide an overview of the session's topic as an introduction to main speakers. These presentations and associated materials were designed to stimulate participant interactions regarding fundamental issues pertaining to the use of gait analysis in Rehabilitation Medicine in the hope that this would facilitate the development of recommendations. We are grateful to the authors who have summarized their materials and made them available in a timely manner.

2.4.1 TOPIC I The use of gait analysis as a patient assessment tool.

Gait Analysis in Rehabilitation

Peter R. Cavanagh, Ph.D.

The field of clinical gait analysis still needs to respond to the challenges that have been posed by Brand and his associates (Brand 1992, Brand and Crowninshield 1981). Among the most important of the several criteria that these authors have proposed is the question: "Does gait analysis change the course of treatment and the outcome for the patient?" If this question cannot be answered affirmatively by carefully controlled, prospective, randomized, clinical trials, then the motivation for treating physicians and surgeons to order gait analysis will be significantly reduced.

There is also a need to define the scope of gait analysis in rehabilitation somewhat more broadly than has been done in the past. In addition to the conventional tools of electromyography and movement analysis, the measurement of such quantities as plantar pressure between the foot and the shoe, force between a walking aid and the hand, long term measurement of load bearing during activities of daily living all deserve consideration as valid components of gait analysis in a rehabilitation setting. While level straight line walking has been the paradigm of choice in most previous studies, renewed emphasis on other more demanding tasks of daily life should be given consideration.

It is critical that the technology of the information age be applied to the interpretation and management of clinical gait analysis data. With appropriate standardization of methodology, there should be no need for each laboratory to collect their own normative data. Such databases should be readily available electronically and the professional organizations should be taking a leadership role in the creation, distribution, and maintenance of such resources.

Brand, R.A. and Crowninshield, R.D. (1981) Comments on criteria for patient evaluation tools. Journal of Biomechanics, 114:655.

Brand R.A. (1992) Assessing gait analysis for clinical decisions. Proceedings of the VII Meeting of the European Society of Biomechanics, Rome. 256-259.

A Framework for the Use of Biomechanical Gait and Movement Analysis as an Assessment Tool in Rehabilitation Medicine

Melanie Brown, M.D.

Thirteen of the twenty-nine research priorities identified in the 1993 “Research Plan for the National Center for Medical Rehabilitation Research” require or would benefit from the use of biomechanical gait and movement analysis as an assessment tool. These research priorities involve the measurement of pathophysiology, impairment, functional limitation, disability, and societal limitation. The National Center for Medical Rehabilitation Research (NCMRR) defines pathophysiology as the interruption of, or interference with, normal physiological and developmental processes or structures. Impairment is a loss or abnormality at the organ or organ system level of the body. Functional limitation is the 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. Disability is a limitation in performing tasks, activities, and roles to levels expected within physical and social contexts. Lastly, societal limitations are restrictions attributable to social policy or barriers which limit fulfillment of roles or deny access to services and opportunities associated with full participation in society. Among the various measurement tools that are currently used in rehabilitation medicine, biomechanical gait movement analysis is one of the few assessment tools (if not the only one) that quantifies the functional limitations associated with pathophysiologies and impairments of the neuromusculoskeletal system.

Biomechanical gait and movement analysis is an assessment tool which is used to identify and measure biomechanical strategies. If the parts of the body are defined as segments (e.g., foot, shank, thigh, pelvis, trunk, etc.), then a biomechanical strategy is the series of segment positions and intersegmental moments (rotational forces) that is coordinated by the central nervous system in order to allow individuals to perform functional tasks. Each biomechanical strategy has a kinematic component (segment positions) and a kinetic component (intersegmental moments). Although the kinematic strategy may be readily observable, accurate identification of the kinetic strategy through visual inspection is rare. Zajac (1993) has described skeletal muscles as the active moment generators within the human body. He has pointed out that because the segments of the body are linked by joints (e.g., ankle, knee, hip, etc.), each muscle in the body has the capacity to apply a moment to any segment of the body; even segments to which the muscle does not directly attach. This implies that there are numerous kinetic strategies for executing any given functional task. There is mounting evidence that this redundancy in the neuromusculoskeletal system allows individuals with functional limitations to compensate through the use of adaptive biomechanical strategies (e.g., Siegal 1993). This is extremely important in rehabilitation medicine where a major focus is the prevention of disability and societal limitation through the use of assistive devices, exercise and other modalities which help patients compensate for functional limitations associated with neuromusculoskeletal abnormalities.

According to data from the 1989 National Health Interview Survey Supplement, there are at least 7.7 million American Adults (18 years or older) living in the community with disabilities. Within this disabled population it is estimated that 760 thousand individuals have difficulty getting out of a bed or chair, 2.4 million individuals have difficulty walking, and 2.2 million have difficulty going outside, presumably due to obstacles such as stairs. It is imperative that rehabilitation scientists and health care providers find better and more efficient ways of compensating for functional limitations in order to decrease the prevalence of disability and societal limitation in this population. Biomechanical gait and movement analysis has contributed to our understanding of functional limitations and how they relate to pathophysiology, impairment, disability, and societal limitation. Its continued use as an assessment tool in rehabilitation medicine is essential to accomplishing the research priorities outlined by the NCMRR and to enhancing the quality of life for people with disabilities.

RECOMMENDATIONS:

1. Perform randomized controlled studies in which a traditional rehabilitation intervention program is compared to a program designed using biomechanical movement analysis.
2. Compare rehabilitation outcomes in similar patient populations with and without the use of biomechanical movement analysis (blinded, randomized, controlled trials).
3. Decrease or subsidize the cost of the necessary equipment (force plates, cameras, computer software, and hardware).
4. Minimize the time it takes to collect, reduce, and analyze data.
5. Determine which scaling and statistical methods are most appropriate for reporting biomechanical movement analysis data.

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Future Directions of Gait Analysis as a Patient Assessment Tool

Kenton R. Kaufman, Ph.D.

During the past decade health care delivery systems have evolved at a pace that few expected. The most visible change is the development of managed care delivery systems. Managed care makes fixed payments per subscriber for all services, creating the incentive to attract a higher number of subscribers but provide the fewest number of services to each subscriber. Gait laboratories can play a key role in managed care scenarios. Future challenges exist to further evolve the science of clinical gait analysis to make it effective as a patient assessment tool. The future of gait analysis will depend upon advances made in experimental, analytical, and interpretation techniques for gait studies.

Experimental Techniques: Interest in gait analysis is emerging. Despite the growing availability of technology, gait analysis has not yet become a common tool for the clinician. The future of gait analysis lies in the ability to process data quickly and identify the functional problems of a patient's gait. Currently, the manual labor required to sort and identify the trajectories which describe the patient's motion for each individual trial is time consuming, driving the cost of the analysis up and slowing down the turnaround time for clinical decision-making. Future work needs to be undertaken to develop intelligent tracking systems of multiple markers which will provide measurements in real time within the constraints of accuracy, resolution and high scan rates required for clinical analysis without constricting the already limited function of a severely disabled child or adult.

The results of the gait study must be presented in a form which is readily comprehensible. Currently the clinical interpretation of pathological gait requires holding in human memory a large number of graphs, numbers, and clinical tests from data presented on hardcopy charts, radiological x-rays, video, and computerized graphs which are compared to data from a normal population. The referring physician, who is not an expert in gait analysis, is overwhelmed by the portfolio of measurements in a clinical report. Recent developments in computer animation make it possible to apply advanced methods to visualize human movements a scientific computing environment is needed which will allow the rapid transmission, archival, retrieval, and manipulation of images within a system which is intuitive to a clinician.

Analytical Techniques: During a gait study, a large number of measurements are obtained. The experimental data are entered into an analytical model to obtain values of variables not directly measurable. The body is modeled as a system of articulated, rigid links. The joint rotation is based on the determination of Eulerian angles or the screw displacement axis. The joint motion is combined with the ground reaction force, body segment mass and body segment inertia to compute the intersegmental joint kinetics using Newton's second law. These body segment estimates are a big source of error in biomechanical models. Future work should be aimed at obtaining inexpensive, fast, non-invasive, individualized estimates of the inertial properties of body segments. In addition, realistically developed, theoretical models of the musculoskeletal system are needed to quantitate biomechanical changes which may occur in patients as a result of surgery prior to the performance of the surgery. Currently, state of the art mathematical models of the musculoskeletal system are being developed to predict gait patterns. Future models should include the 3-D characteristics of the musculoskeletal geometry as well as the subject-specific parameters. The musculotendinous aspects of the model need to be scaled to the individual being studied. The biomechanical consequences of modifying muscles or bones needs to be estimated in a computer environment and presented to the clinician to actually see the results of the proposed surgical intervention.

Muscle forces reflect the underlying neurological control processes responsible for observed movement patterns and play a major role in determining stress in bones and joints. Thus, a knowledge of muscle forces is fundamental for improving the diagnosis and treatment of individuals. Currently, information on muscle function is routinely obtained by acquiring electromyographic data. However, the integrated electromyogram does not account for the passive stretch of muscle. Further, there is a significant delay between the maximal electrical activity in the muscles and maximal tension. An attractive alternative for quantification of muscle function is the measurement of intramuscular pressure which is a mechanical variable that is proportional to muscle tension. Further, estimation of muscle force from intramuscular pressure is not affected by changes in signal due to muscle fatigue. However, currently available transducers for measurement of intramuscular pressure are too large for clinical applications. Recent improvements in micro sensor technology will make it possible to develop much smaller, minimally invasive devices.

Interpretation Techniques: Methods are needed to characterize a patient's gait and direct the clinician reading the gait study to the movement abnormalities. A person's gait is classified as abnormal when the person's gait parameters deviate excessively from normal. One of the main obstacles to automated gait analysis is the difficulty of distinguishing between normal and abnormal. Robust analysis of these data require consideration of interactions among a large number of highly coupled variables and the time dependence of these variables. Statistical techniques and artificial intelligence techniques have been utilized for recognizing gait abnormalities. Each of these methods offers advantages and disadvantages. Additional development of these techniques is needed.

Summary: The ultimate goal of clinical gait analysis is to provide reliable, objective data upon which to base clinical decisions. Real-time measurement technology, biomechanical modeling, computer animation, and gait classification techniques are needed to shape our future. It is increasingly important that we consider the effectiveness of what we do and the role it plays in shaping outcome of medical care. The future of gait analysis will require the ability to identify the critical tests, obtain and interpret data more quickly, predict the outcome of various clinical procedures and quantify the outcome. Reforms in health care require that we be able to manage costs while providing an important diagnostic service.

2.4.2 TOPIC II The use of gait analysis assessments in treatment planning and/or treatment implementation.

Summary to Introduction and Overview for "The Use of Gait Analysis Assessments in Treatment Planning and/or Treatment Implementation."

Jerry Harris, Ph.D.

The purpose of this introduction is to provide a brief overview of gait analysis applications as they apply to treatment planning and implementation. Gait analysis has proven useful for the study of neuromuscular disorders, the evaluation of prosthetic joint replacement, and the study of athletic injuries, amputee gait, orthotics, and assistive devices. The most prevalent of applications is in the field of pediatric orthopaedics where gait analysis is used for pre-surgical planning, post-surgical follow-up, evaluation of surgical and non-surgical interventions, resident training and research.

This introduction will focus on the use of quantitative gait analysis methods for treatment planning and implementation. The recognized prerequisites of normal gait will be defined and used to examine the advantages and limitations of current gait analysis methods. Several clinical illustrations that require the identification of multiple bone and soft tissue abnormalities for proper treatment will be highlighted. Examples of clinical conditions requiring an ability to examine multi-level, simultaneous events in three dimensions in order to differentiate between primary deviations and coping responses will be presented. The use of joint kinetics (moments and powers) to assist in treatment planning and orthotic evaluation will also be included. Finally, the importance of a combined clinical approach which includes kinematic and kinetic gait analysis, dynamic electromyography and clinical examination will be summarized.

Gait Analysis in Treatment Planning and Implementation: Good, Bad and Indifferent, but Which are Which?

Sandra J. Olney, P.T., Ph.D.

Gait assessment over the past several decades has contributed greatly to our knowledge about walking but a great deal has been written about its failure to be an essential tool in treatment planning and implementation in rehabilitation. I am not going to complain about high costs of unreliable equipment, unwilling health care providers, the failure of clinicians to understand biomechanics, and the failure of engineers to ask the right questions. Instead, there are good, bad, and indifferent applications, and I will provide my assessments for discussion.

Of **spatial-temporal measures**, walking velocity is arguably the single most important outcome measure of walking, and relates significantly to most functional measures. It has not been used directly in treatment planning. Many other measures, such as temporal and spatial symmetry, have been expressed in a number of ways, and some evidence suggests symmetry is not very important (Griffin et al., 1995). In summary, such measures document the status of a subject and offer little for treatment planning. The applications of spatial-temporal measures have been of indifferent merit at best.

Treatment planning has frequently focused on obtaining more normal joint kinematics, such as increasing dorsiflexion of the ankle during swing phase or avoiding genu recurvatum. In general, if the desirability of specific joint patterns is self-evident, as in preventing tripping, or avoiding genu recurvatum, kinematic assessment has proved to be very useful both in planning and evaluating treatments. However, altering the kinematics in the direction of normal without a specific reason may be deleterious, for example, by preventing a positive adaptation (Winter et al., 1990). In summary some applications of kinematic measures from gait analysis are good, but many have been of indifferent merit, or even bad.

The evaluation of **kinetic information** is most difficult as it is the latest reported, a fact that may be attributable to the sophistication and expense of the analysis systems required. Overall, measures of movements have rarely been used to plan treatment. The muscle powers across major joints have been reported for a few conditions and some theoretically-founded recommendations for treatment planning have been offered (Olney and Colborne, 1991). The use of emerging general principles, such as attempting to augment the power generation of the ankle plantarflexors at push-off (Mandel et al., 1990) have generally given positive outcomes, though the failure to report kinetic details limits the ability to make full use of the studies. In summary, general principles of treatment are being put forward for some pathologies, but much more work is needed; applications of kinetic measures to treatment have generally been absent , though their potential appears good.

What is needed to make gait analysis useful for treatment planning and

implementation?

Stop making assumptions about the desirability of normal patterns of any measures. Offering information that is indifferent or bad is worse than offering no information, and only damages the credibility of that method.

Use more kinetic analysis. It is logical to target the source of the problems.

Establish sound biomechanical principles of treatment applying to particular pathologies.

Verify the principles of treatment and determine the extent of their generalizability. Only the most obvious of principles have been identified and even these have not been thoroughly studied.

Relate outcome measures such as gait velocity to specific kinetic changes. Failure to do so impairs our ability to target specific kinetic variables in treatment and to use them to develop innovative therapy.

Develop power, work and efficiency measures for use in meaningful ways. Energy is a paramount concern, and our tools are seriously deficient.

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Using Musculoskeletal Models, Forward Dynamics, and Computer Simulations to Analyze Gait, Interpret Gait Data, and Plan Treatment

Felix E. Zajac, Ph.D.

The following is what is needed at a basic level to make gait analysis a highly productive tool:
-Development of a conceptual basis for how muscles coordinate the body segments
-Development of methods to measure muscle/tendon force or muscle/tendon motion during gait
-Development of a conceptual framework for sensorimotor control of muscle coordination

Human gait demands that the nervous system (because of its role in coordinating muscles) and the musculoskeletal system (because of its role in producing muscle forces, body acceleration, and movement) interact effectively, not only amongst themselves, but with the environment. That is, the nervous system has the role of being the sensorimotor controller, the musculoskeletal system the role of transforming neural output signals from the controller into forces, and the environment the role of resisting gait propulsion (e.g., wind resistance) or assisting propulsion (e.g., the ground from which reaction forces propel the body). Pathology in either the neural or musculoskeletal system can cause gait impairment, which may or may not be a disability.

The primary obstacle to effective utilization of current gait measurements in the diagnosis, treatment, and assessment of gait disorders (especially those from neural pathology) is the absence of a theoretical foundation from which basic concepts of sensorimotor control and muscle coordination can evolve. Minimally, the fundamental unitary element of these concepts must be at the muscle level (cf. Joint level). Other obstacles are experimental in nature; the inability to record data at the muscle level (e.g., muscle forces; difficulty of recording from individual muscles with surface electrodes; technical expertise of using fine-wire electrodes) and to design experiments from which sensorimotor control principles can be elucidated.

The current conceptual framework of muscle coordination in human gait is, in a large part, not based on the integrative action of individual muscles to coordinate individual body segments, but rather on knowledge of how each musculoskeletal component functions alone. For example, basic concepts of how muscles develop force and interact with loads exist (though they may not be the loads encountered during locomotion). Concepts of how tendons stretch when loaded and how the musculotendon path around the joint affects the transmission of muscle force into joint torque (or moments of muscle force about the joint) also exist. We even know how the body segments interact in the swing leg and how legs (if considered to act like springs) can propel animals and can account for the kinetic and potential energy flow of the whole body. But we know very little about how the properties of these individual elements of the musculoskeletal system coordinate body motion to produce gait. The integrative action of muscles in coordinating movement of the body segments is critical to the understanding of gait since a muscle can accelerate body segments (or accelerate joints into rotation) far removed from those to which it attaches (or spans). Furthermore, body inertia acts to filter the internal and external forces acting on the body such that the movement of the body segments can be a consequence long after they occur.

The current conceptual framework of sensorimotor control in human gait is at an even earlier stage of scientific development. One primary reason is concepts for sensorimotor control of motor tasks hardly exist in general, much less for human gait specifically. For example, some investigators advocate that the nervous system can construct internal models of the musculoskeletal system from which sensorimotor control can emerge; others that the nervous system acts to excite muscles to establish limb mechanical impedance to ensure limb and body stability; and others a combination of these two principles. Perhaps the concept most relevant to human gait, one would think, is pattern-generator neural circuits (presumably in the spinal cord). Though this concept is under intense development in non-primate vertebrates, its usefulness to delineating concepts of sensorimotor control at the muscle level in humans during gait will remain low probably into the distant future.

Gait measurement techniques now provide volumes of kinematic data (e.g., position of the segments), kinetic data (e.g., ground reaction forces), and neural output data (e.g., EMGs). This information in the hands of experts (e.g., clinicians or engineers in a clinical environment) can be an asset to diagnosis, treatment, and assessment. However, the effective utilization of this data is based on hands on experience. The clinician or engineer is, in effect, an "expert system" and, as such, the level of expertise is significantly influenced by the number of observations (i.e., the clinical experience).

Current gait analysis techniques have evolved to "massage" the gait data (e.g., to produce net joint movement and net joint power); and the technique of "massaging" has indeed progressed to an advanced state. However, these inverse dynamics methods have severe limitations in their ability to elucidate muscle coordination concepts because, fundamentally, they are not muscle based.

What is needed for basic concepts of muscle coordination to evolve? I submit that a muscle-based computer model and how the musculoskeletal system interacts with the environment (e.g., ground) during gait must become an integral part of the R&D effort. Computer models are the cornerstones to the understanding of the control and the dynamics of any large scale system, such as aircraft control and satellite control system design. The complexity of the computer model used to describe the musculoskeletal system depends, of course, on the specific intent (clinical objective) of the R&D project and our conceptual understanding of muscle coordination of gait. What makes a model critical to the advancement of a scientific discipline is that the assumptions an investigator makes must be explicitly defined. Such precise clarification of the assumptions provides others with the ability to criticize the conceptual framework being assumed. Computer simulations of gait, the outcome from these forward dynamic models, provide data to refute or support these criticisms. Thus, systematic scientific progress can be made regarding our understanding of muscle coordination of gait.

The generation of computer simulations of gait from musculoskeletal models is, however, challenging because determining the excitation pattern of the many muscles involved in gait is non-trivial. Nevertheless, computer algorithms exist which can find the muscle coordination pattern most consistent with the kinematic, kinetic, and EMG measurements, and /or other assumption. In this scenario, we have created an "*in vitro* tester," whereby it is conceivable that simulations could be created for various proposed surgical and rehabilitation musculoskeletal interventions, and potential functional (gait) outcomes predicted. Futuristically, such a testbed could be created for each patient from a generic model. Thus, the computer simulation testbed for gait would serve as a tool to design and plan surgical and rehabilitation strategies for individuals with not only similar musculoskeletal pathologies but unique ones as well.

Of course, in reality, it is the nervous system with its biologically-based sensorimotor-control algorithm that dictates the muscle coordination pattern, not the artificial computer algorithm, regardless how closely the simulation data generated from the computer algorithm agrees with the measurements. Unfortunately, computer models of the sensorimotor control system are really in their infancy and highly speculative. It will probably require quite ingenious experiments on gait or other locomotor tasks to postulate a credible 1st-generation structure for sensorimotor control. Sensorimotor control data is incredibly sparse. Nevertheless, computer models of the musculoskeletal system could be combined with models of sensorimotor control to generate gait simulations. These neuro-musculo-skeletal computer models would then serve as testbeds for studying gait disturbances whose etiology could be not only musculoskeletal but neural as well.

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

Gait Analysis in Cerebral Palsy: Why isn't it Routinely Used?

James R. Gage, M.D.

I. Gait Analysis

A. What is it ?

1. Gait analysis could be considered to be a continuum ranging from simple observation of gait at one extreme in which no technological aids are used to the use of complicated and expensive equipment at the other.

2. Components of a typical modern system include:

a. video system

b. motion measurement system

c. dynamic electromyography

d. one or more force plates

B. How did it begin ?

1. Edward Muybridge

a. could be considered the father of motion analysis as well as the movie industry.

b. over the period of 1872-1888, Muybridge managed to obtain clear, still pictures of Leland Stanford's horse accident trotting. When projected rapidly through a device known as a zoopraxiscope, an observer would get the impression of seeing the animal in motion.

II. Is Gait Analysis Useful?

A. Some of the questions required to answer this are:

1. Is there a problem with traditional methods of treatment ?

2. What does motion analysis offer us that we don't already have ?

3. Does gait analysis necessitate a large, highly trained staff ?

4. Is it cost effective ?

B. Is there a problem with traditional methods of treatment ?

1. Without objective analysis of outcome, how can you tell ? It is my personal opinion that the "state of the art" in the treatment of cerebral palsy consists of:

a. poor understanding of the pathophysiology of the condition

b. a lack of knowledge of the principles of normal gait

c. little or no understanding of pathological gait

d. "surgery by eye" as opposed to objective measurement parameters

e. a tendency to do staged corrections of one muscle group at a time followed by long periods of immobilization after each intervention

2. After becoming Director of the C.P. Service at NCH, I turned to gait analysis because of:

   a. poor patient outcomes
   b. inconsistent results of treatment
   c. dissatisfaction on the part of parents, therapists, and patients

3. As a result of this approach, the childhood of a patient with cerebral palsy becomes a series of surgeries and recoveries, and if one looks at critical parameters of evaluation such as oxygen consumption, most of these children have not been helped by the interventions.

C. What does motion analysis offer us that we don't already have ?

1. Objective assessment and documentation of:
   a. pre-operative pathology
   b. post-operative outcome

2 It really allows practical application of the scientific method which is:
   a. the accumulation of facts
   b. organization of these facts into principles or laws
   c. postulation of hypotheses to account for the facts and laws

3. Before we had this tool to assist us with treatment of cerebral palsy, we would start with a spastic child who walked abnormally and end with a spastic child who walked differently, but it was difficult to tell exactly what surgery had accomplished.
4. Accurate critique of surgical outcome prevents the perpetuation of errors into the future.
5. Results of treatment become much more predictable.

D. Does gait analysis necessitate a large, highly trained staff?

1. Current commercial systems run on a desktop computer.
2. Commercial software is friendly; usually in a “windows” or Macintosh format.
3. A minimum clinical laboratory staff would probably consist of a computer technician, physical therapist, secretary, and a physician who is able to interpret the data.

E. Is it cost effective ?

1. In our laboratory gait analysis which includes video, kinematics, kinetics, EMG, and oxygen consumption and cost runs about $2000.
   a. this is roughly the cost of a CT or MRI scan
   b. it enables multiple lower extremity procedures with predictable outcomes
   c. what is the cost of a treatment error in a child with a 60 to 70 year life expectancy?

III. If gait analysis is so useful, why isn't it in wide use?

A. Physician attitudes

1. Training generally does not include gait analysis and/or engineering mechanics.
   a. absence of engineering in training means fear or reluctance to use engineering principles in practice

2. Orthopaedic residency is basically an apprenticeship and gait is not understood or taught by the student's preceptor.
   a. earlier generations of orthopaedist's who worked with polio actually had a better understanding of gait than those of the present day
   b. the Orthopaedic In-Training Examination generally includes traditional questions on cerebral palsy and few if any questions on cerebral palsy gait and/or gait analysis

3. The necessity of laying down previous practice and accepting a different way is difficult since the implicit implication is that previous practice was incorrect.

4. This is a technology with a price in terms of utilization.
   a. MRI's and CT scans are useful without any background knowledge beyond anatomy
   b. a great deal of time and study is required to master the principles of normal and pathological gait and gait analysis

B. The laboratory itself

1. Although the cost of gait analysis has come down, the price of a reasonably equipped modern laboratory is still about $250,000.
2. A gait analysis laboratory requires a lot of space.
3. Funding must be found for at least three full-time employees.
4. All of the successful clinical laboratories of which I am aware have an associated physician to provide an interpretation of the data.
5. There is a lack of standardization among existing laboratories which acts to confuse physicians and payers.

C. Refusal of third party payers to recognize value and/or assume cost

1. Centers of excellence have difficulty because:
   a. the surgeon to patient ratio is high and hence surgeons are reluctant to refer away patients -- even those with conditions they don't understand
   b. managed care programs usually make it very difficult to access to physicians who are "out of plan"
   c. gatekeepers and capitation both act to ration or restrict treatment

2. Although most managed care systems talk of "quality and cost," to date the emphasis has been entirely on the latter.

3. As long as gait analysis is not commonly accepted medical practice, third party payers will continue to resist it.

a. in general, any new or non-traditional practice of medicine is labeled "experimental" and payment is denied.

4. Managed care seeks to minimize costs of expensive individuals and get them out of their network as soon as possible. Currently, there is no incentive to optimize the function of these individuals -- in fact the converse is present.

To summarize, in gait analysis we have a technology which can describe, quantify, and elucidate the mechanisms by which walking occurs; reveal what has happened when walking is disrupted, and in some cases indicate which treatments are most likely to restore function to an optimal level. The technology has evolved to the point where it is reliable, easy to use and, compared to ten years ago, relatively cheap, and yet physicians, hospitals and payers are all resisting its use.

IV. Remedies

A. If gait analysis is to come into widespread use we need to:

1. Enlarge the scope of gait analysis, particularly into elite performance where it will be readily embraced by both the athletes and the public.

2. See that individuals who treat these patients receive active instruction in gait and gait related topics.

3. Demand objective outcome studies in all papers relating to treatment of these individuals.

4. Overhaul payment system so that there is incentive in producing an optimal outcome as opposed to minimizing treatment.

5. The benefits of gait analysis in the treatment of locomotor disabilities must be proven to colleagues, patients, and payers.

V. What is the Status of Gait Analysis Today?

A. Good commercial hardware & software systems are available at about 1/6 the price of the system built at Newington Children's Hospital in 1980.

B. Outcome studies are beginning to be published.

C. Acceptance is growing for gait analysis in the treatment of neuromuscular conditions.

D. A new journal entitled *Gait & Posture* is now being published.

E. Motion analysis is beginning in prosthetics, sport's medicine, and other performance related activities.

F. A few final thoughts:

1. As stated earlier, before we had this tool we would start with a spastic child who walked abnormally and end with a spastic child who walked differently, but it was difficult to tell exactly what the surgery had accomplished. Now, however, we have a tool by which we can accurately critique our surgery.

2. The technology of gait analysis is moving rapidly, but physician attitudes need to change:

a. There is a wide spread perception among orthopaedic surgeons that clinical examination and observational gait analysis are adequate to determine treatment. I hope I have succeeded in proving to you that this is not the case.

3. If we as physicians and therapists wish to treat human gait problems of any type, we must be:

a. willing to commit the time and effort necessary to master the principles of normal and pathological gait. A. Bruce Gill said it best, "Study principles not methods; if one understands the principle he can devise his own methods."

b. familiar with the technology used to measure gait and the basic principles of biomechanics.

c. willing to participate as a member of a team which includes members from other disciplines such as engineering, kinesiology, and physical therapy.

4. Nothing in life can be consistently improved or optimized unless it can be subjected to objective analysis and its governing principles and/or mechanisms are well understood --- Cerebral Palsy is no exception!

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Factors which prevent the people with locomotor disabilities from accessing gait analysis

Edmund Y. S. Chao, Ph.D.

Routine access of gait analysis as a tool for clinical application has not been extended to patients without locomotor disabilities. It is, therefore, not surprising to find that such methodology is grossly overlooked on its value in studying individuals who have different degrees of locomotor disabilities. To review the factors which prevent patients from accessing gait analysis will be helpful to lay the background to discuss similar issues concerning people with locomotor disabilities. Cost, reliability, accuracy, and clinical relevance have been the four main factors preventing routine access to gait analysis in patients with locomotor problems. Additional research and development must be devoted to this field in order to overcome these barriers. Gait analysis is one of the earliest biomechanical techniques applied to both basic research and clinical application but many of the past efforts were devoted to measuring instruments and data capturing methodologies. Data analysis and establishment of a reliable database on both normal and patients with locomotor abnormalities have not received adequate attention and emphasis in the past. There is also a lack of appreciation of how complex bipedal locomotion actually is and how one may reach inappropriate conclusions based on very limited data. Additional barriers exist when such technology is being considered for individuals with locomotor disabilities. First, the definition of gait must be redefined by expanding its scope. Second, the outcome of such analysis should include locomotion efficiency, comfort, exercise and rehabilitation values, and prevention of secondary injuries. Improvement of assistive tools and equipment including locomotor robots must be part of such effort. Third, reliable and effective indices reflecting an overall rating of gait (or locomotor) performance must be developed for easy reporting of analysis results and data documentation. Finally, gait should not be limited to the functional contributions of the lower limb alone. The trunk and upper extremity do play a significant role in the efficiency and the compensatory effect of human mobility. With a combined effort by the bioengineers, therapist, rehabilitation physicians, gait analysis will remain a mainstay in medical rehabilitation research and in the management of patients with locomotor disabilities.

2.5 Breakout session: Day 1

2.5.1 Goals

The goals of the first breakout session were to develop a comprehensive list of recommendation concepts under each category heading and assign recommendation development responsibility to individuals or teams. Specifically, participants were asked to first develop a comprehensive set of recommendation categories. Then potential recommendation topics (titles or themes) were generated and placed under appropriate categories. Finally, the session ended with teams selecting recommendation topics on which they will develop recommendations during the second breakout session.

The focus of each working group related to one of the following questions.

What needs to be done to:

Group 1) improve the use of gait analysis as a patient assessment tool?

Group 2) better the treatment planning and/or treatment implementation uses of gait analysis?

Group 3) increase the accessibility of gait analysis for people with locomotion disabilities?

2.5.2 Team decision-making process:

Co-chairs were instructed to implement a team decision making process. This process began with a silent individual generation of ideas. Next, participants were asked to present their ideas without discussion. During this phase, team members were encouraged to listen and take notes. Once all participant ideas were presented, an open discussion of individual ideas took place. Final decisions were then enacted.

2.5.3 Team Warm-up: Day 1

Co-chairs were instructed on importance of team warm-up activities. These activities were designed to prepare participants for the rigors of team work. Co-chairs were strongly encouraged to begin the first breakout session with the following warm-up activity:

Warm-up
Day 1

We make the assumption that you come to this meeting bearing a lot of distractions. Just as it is important to stretch muscles prior to exercise, we would like you to stretch your mind each day prior to your participation in this group. The following warm-up activity is designed to help you leave behind concerns and ease into the meeting, to gradually focus on the task of developing recommendations.

We would like you to introduce yourself to the other members of your table. Please address each of the following questions during your introduction.

1) What is your name?
2) Where do you work?
3) What did you want to be when you were a child?
4) What is your favorite weekend recreation?

2.5.4 Team Leader/Spokesperson Selection Process

Workshop coordinators wished to create an atmosphere in which participant ideas were assumed to have equal weight. To facilitate this idea, a lottery technique was used to select team spokespersons. These individuals were required to periodically provide oral reports to the working group regarding the status of recommendation development. The process by which these individuals were selected is described in the following five steps.

1) All participants write a number between 1 and 100 on a piece of paper
2) Pass paper to the person on your right
3) Chairs call out one number between 1 and 100
4) Person holding closest number is elected
5) For ties, the process was quickly repeated

2.5.5 Breakout session tasks: Day 1

The primary goal of breakout session one was to prepare participants for the task of recommendation development. During this session participants were systematically lead through the following list of activities.

1) Review and discuss the sample recommendation.
   a) Silent review (5 min.)
   b) Team discussion
   c) Question and answer period at the working group level

2) Generate a list of recommendation categories.
   a) Within teams, start with silent generation of ideas (5-10 minutes)
   b) Each team creates a written list of ideas (without discussion)
   c) Within teams, discuss and clarify team list of ideas
   d) Team spokesperson reports list to co-chairs
   e) Co-chairs develop and post a master list of recommendation categories.

Display each category heading at the top of a large sheet of paper.

3) Generate a list of potential recommendation titles within each category.
   a) Start with silent generation of ideas (5-10 minutes)
   b) Each team creates a list of ideas (without discussion)
   c) Within teams, discuss and clarify team list of ideas
   e) Team spokesperson reports draft titles to chairs without discussion
   f) Chairs write each title and team (table) number under the category heading
   g) Working group, discuss like titles and combine when appropriate

4) Assign individual titles and associated categories to teams.
   a) Redistribution of team participation at this time is acceptable
   b) Select new team leaders/spokespersons if necessary

5) Teams create strategy for developing draft recommendations.

2.6 Breakout session: Day 2

The goal of the second breakout session was to develop a set of completed recommendations. Participants were given the entire day to accomplish this task. Following a brief warm-up activity, participants began the arduous task of recommendation development. During this session, team spokespersons were periodically asked to provide verbal reports to the working group. When deemed necessary by participants, adjustments to work assignments were implemented. While co-chairs circulated amongst working groups, conference coordinators maintained a vigil over the three working groups, periodically facilitating the process of recommendation development.

2.6.1 Warm-up activity Day 2

Warm-up
day 2

Today's warm-up is called Superlatives. Take a minute to study the composition of the group and silently decide on a superlative adjective (youngest, tallest, baldest...) that describes yourself in contrast to the other members of group. When everyone has selected their superlative go around the table sharing adjectives and testing the accuracy of your perceptions.

2.7 Recommendation Development Materials

Workshop participants were provided the following reference materials, including the sample recommendation, to assist them during the recommendation development process.

Working Group Report Guidelines

The completed conference report will contain recommendations created during the meeting. It is anticipated that each of these conference recommendations will contain elements of attendees' initial position statements and new material introduced during the conference. In order to facilitate the development of conference recommendations, participants are strongly encouraged to further research topics and prepare written materials in advance of the conference using the following format and draft recommendation as guides.

Recommendation Title: (Developed by working group)

Recommendation Code: (Assigned by Co-chairs)

Category: (Assigned by working group)

All recommendations will be categorized according to the general nature of the specific actions being recommended. The following list of categories can be used as a guide: (research, education, training, standardization, policy, technological development, other).

Recommendation

Background

This section should contain the background/rationale for the issue/problem/question for which research, development, or policy/program changes are being recommended. (Typically, this will consist of one or more affirmative statements indicating what has been achieved and what remains to be achieved in a given area.)

Objectives

List the specific objectives that should be pursued. (These statements should characterize the desired resolution of the issue/problem/question described in the background section.)

Recommended Actions

This section should contain the specific recommended action(s) to achieve the objective(s) specified in the objectives section. (These are the research questions, developments, or policy/program actions that should be pursued to achieve the objective(s) specified above.)

2.7.1 Sample Recommendation

(EXAMPLE RECOMMENDATION)

Recommendation Title: Training Fellowships for Physical Therapists

Recommendation Code: Z1

Category: Training

Recommendation

Background

A major barrier to the clinical implementation of gait analysis technologies in rehabilitation settings, and therefore access to these technologies, is the excessive resources required to purchase, maintain, and implement a modern motion analysis laboratory. The initial cost of equipment and space allocation are important contributing factors which require a significant initial institutional commitment. However, these initial investments pale in comparison to the annual salary and benefit expenditures required to maintain laboratory staff. Historically, the operating complexity and immaturity of gait analysis technologies have demanded gait laboratory staffing trends to include a senior technical director (often a Ph.D.), technical assistance (engineering staff), and a clinical coordinator who is responsible for patient testing and report generation (typically a physical therapist or kinesiologist). Recent advancements in motion analysis technologies provide a level of automation and sophistication such that a clinician who obtains sufficient training and experience with gait analysis technologies is capable of independently executing the wide range of tasks associated with modern gait analysis.

Objectives

Decrease the annual cost of supporting a clinical gait analysis laboratory by replacing the present day multi-staff model with a single staff model consisting of a hybrid cross-trained licensed physical therapist.

Recommended Actions

Develop fellowship training programs at centers of excellence that will provide licensed physical therapists extensive training and experience in modern gait analysis technologies and the integration of these technologies into the patient care setting.

2.8 Priority Scoring of Recommendations

The recommendation scoring session was preceded by a recommendation review session. While participants received the recommendations the evening prior to the scoring session, it was felt that a group review session would improve participant focus. During the review session, co-chairs summarized the list of recommendations that were generated within their respective working groups. An attempt was made to minimize discussion that would result in the development of participant interpretations that extended beyond recommendation text. The recommendation priority ranking process occurred in a group setting. Participants were instructed to use the full range of scores provided by the priority scoring system and were lead through the scoring process by a workshop coordinator. Participants were provided ample time to reflect on each recommendation prior to the recording of their score. Score sheets were collected prior to closing statements from the conference coordinators and participant dismissal. The following recommendation scoring system was used in conjunction with scoring sheet depicted in the following section.

100-200	Highest Priority
200-300	Moderate Priority
300-400	Average Priority
400-500	Low Priority
500-600	Lowest Priority

2.8.1 Sample Scoring Sheet

<u>RECOMMENDATION SCORING SHEET</u>

Circle Your Working Group Number I II III

When instructed to do so, please score each of the following recommendations using the NIH scoring system. All recommendations <u>must</u> receive a numerical score.

100-200 Highest Priority
200-300 Moderate Priority
300-400 Average Priority
400-500 Low Priority
500-600 Lowest Priority

#	Code	Recommendation Title	Score
1	A1	Gait Assessment and Clinical Decision Making	
2	A2	Gait Assessment and Functional Outcomes	
3	A3	Is Gait Analysis Efficacious in Improving Treatment Outcomes?	
4	A4	Accuracy, Precision and Validity of Movement Analysis Techniques	
5	A5	Evaluation of Clinical Interventions Using Functional Movement Analysis and…	
6	A6	Development of Standards for Management of Clinical Movement Analysis Data	
7	A7	Development of Timely and Objective Methods of Acquisition, Reduction and…	
8	A8	Development of a System Network for Sharing Movement Analysis Data Files	
9	A9	Education and Training of Personnel Involved in Gait Analysis	
10	A10	Determinants of Gait Related Pathology	
11	A11	Development of Models to Study the Relationship Between the Observed…	
12	A12	The Scope of Movement Analysis	
13	B1	Expand the Clinical Application of Gait Analysis	
14	B2	Gait Analysis as a Cost Effective Patient Management Tool	
15	B3	Use of Gait Analysis Technology as Treatment	
16	B4	Clinical Motion Analysis Databank with Patient Profiles	
17	B5	Standards for Reporting the Results of Clinical Gait Analysis	
18	B6	Collaboration via Telecommunications / Telemedicine	
19	B7	Improved Sensors of Neuromusculoskeletal Activity in Gait Analysis	
20	B8	Automated Protocol for Determining Joint Centers	
21	B9	Identify the Relationship Between Impairments, Functional Gait Limitations, and…	
22	B10	Toward Routine Utilization of Gait Analysis	
23	B11	Educate Clinicians in the use of Gait Analysis in Treatment Planning and…	
24	B12	Effectiveness of Gait Analysis	
25	C1	Advance Research Evidence for the Clinical Utility of Movement Analysis Across…	
26	C2	Scope and Availability of Gait Analysis Facilities	
27	C3	Establish Comprehensive Gait Analysis (GA) as a Standard of Care in…	
28	C4	Role of Three-Dimensional Computerized Gait Analysis in Treatment…	
29	C5	Time/Distance Analysis for use in Group/Multicenter Outcome Studies	
30	C6	Define the Components of Gait Analysis	
31	C7	The Development of Interactive Software to Assist Professionals in the…	
32	C8	Standardization of Gait Analysis	
33	C9	Accreditation of Diagnostic Clinical Gait Laboratories	
34	C10	Medical Education Models for Health Care Professionals	
35	C11	Consumer and Patient Education	
36	C12	Universal Access to Gait Analysis Services	
37	C13	The Development of Information Resources Which Will Help New Gait…	

2.9 Workshop Evaluation

This Workshop was an unusual design since the purpose was to develop, over a relatively short period of time, an extensive set of prioritized recommendations for future directions in gait analysis. This was the first opportunity to implement this workshop model. Therefore, a high evaluation participation rate was desired. To accomplish this goal, workshop evaluation forms were attached as a face sheet to the list of recommendations that was distributed the evening prior to the recommendation review and priority scoring sessions. On the final morning of the Workshop, a completed evaluation form served as the ticket with which participants could obtain a recommendation scoring form. Participants, working group chairpersons and observers were allowed to evaluate the Workshop.

2.9.1 Workshop Evaluation Form

Participant Evaluation for
Gait Analysis in Rehabilitation Medicine
September 26-28, 1996

1. Usefulness of the Meeting (and topics discussed):
   ___ Extremely useful
   ___ Very useful
   ___ Somewhat useful
   ___ Not useful

2. Organization and structure of the Meeting:
   ___ Excellent
   ___ Good
   ___ Average
   ___ Poor

3. Presentation of materials, (including handouts, slides, etc.):
   ___ Excellent
   ___ Good
   ___ Average
   ___ Poor

4. What was the best part of the meeting for you?

5. What was the weakest part of the meeting?

6. What improvements would you make if any?

7. Do you have any specific preferences for future Meeting topics?

8. Comments:

Please fill this out and return for a score sheet in the morning