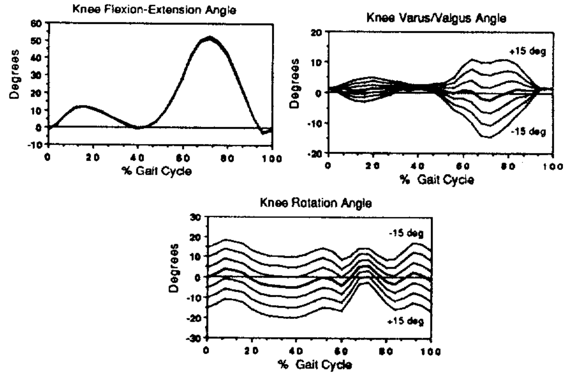

Figure 1: Effect of variabilities in the definition of KNEE flexion axis (-15 to +15 in steps of 5 from the reference position) on KNEE joint angles.

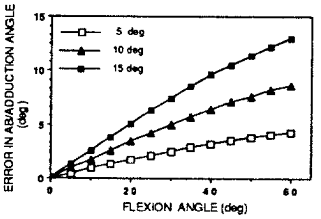

Figure 2: Error in ab/adduction angle as a function of flexion angle for different levels of error in the definition of flexion axis.

RESULTS: The effect of errors in the definition of flexion-extension axis on the knee angles are shown in Figure 1. The flexion extension angles were relatively unaffected, while the effects on varus/valgus and rotation angles were significant, particularly during the swing phase of the gait cycle where the knee flexion angle is large. The errors in knee varus-valgus angle are shown (Figure 2) as a function of knee flexion angle for different magnitudes of error in the definition of flexion axis. The error was a non-linear function of joint motion in the flexion-extension plane and increased with increasing knee flexion angle. The magnitude of the error increased with increasing errors in the alignment of flexion-extension axis. Similar results were obtained for the hip and ankle joints.

CONCLUSIONS:

1. Error in joint angle pattern is a function of both the error in orientation of flexion axis and the magnitude of flexion/extension angle.
2. Error in the definition of flexion axis has:
   a) a small effect on the pattern of flexion/extension angles.
   b) introduces non uniform errors in ab/adduction and axial rotation angles. In view of this, corrections to joint angle patterns using a constant offset may be inappropriate.
3. The large dispersion reported in the literature for certain patterns of joint angular motion (eg. knee varus/valgus) may be due to the errors in the definition of flexion axis. This type of uncertainty exists in both direct (goniometers) and indirect (video motion analysis) measurement systems.

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DR. GAIT: AN EXPERT SYSTEM FOR GAIT ANALYSIS.

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Introduction: Gait analysis is a complex task involving the identification of gait pathology from data produced by gait analysis laboratories. Having an objective, computerized system for interpreting gait laboratory data will ensure a standardized, high quality level of analysis, decrease the time involved in doing an analysis, and be a tool for the instruction of gait analysis.

Purpose: Using artificial intelligence techniques, the goal of this project is to a) design, build and evaluate an expert system for analyzing the gait of patients with cerebral palsy, b) design a qualitative model of the interacting torque-producing forces in human gait, c) prescribe a therapy based on the interpretation of the gait data, d) have the system learn from experience, and e) provide a model of problem solving for the extension of system capabilities to include patients with other gait pathologies.

Method: This project has involved the design and implementation of three generations of knowledge based systems. The first program, Dr. Gait-1, was built to mimic the reasoning of a gait expert as closely as possible in order to identify his knowledge. This system is built using GENIE, a rule based interpreter. The approach used in this system matched patterns of symptoms to causes, and did not deal with gait deviations and causes individually. This system takes as input motion data obtained from the gait study as well as the data normally used by clinicians and physical therapists. The output of the system is a report detailing the problems identified in the case and the reasons why this determination was made.

Gait-2 involved the redesign of the first system to be a more generic prototype describing the physiologic principles of gait. It still used the GENIE inference engine, but organizes its knowledge differently. Patient data is stored in frames, medical knowledge is represented in a knowledge base, and a set of data preprocessing analysis modules have been added. Dr. Gait-2 fully automates the interpretation of the motion data gathered from the gait study.

Dr. Gait-2 also incorporates an underlying model of gait into the explanations the system produces instead of simply citing a rule from its knowledge base. To do this, Dr. Gait-2 employs a qualitative physical model of the interacting torque-producing forces in human gait and compiled knowledge of how various forces in human gait are affected by changes in body conditions from the norm because of a particular disease. This model allows the effects of individual faults to be determined and also explicity captures the interaction between various faults. The system also prescribes therapies in response to the faults it identifies, and the relative merits of each therapy. One limitation of this system is it is restricted to considering sagittal plane motions.

Results: Dr. Gait-1's performance, particularly in cases involving multiple deviations, is limited because a new rule is required to be included in the rule base each time a new situation is presented. Over 500 rules were generated, making the rule base extremely large and unwieldy.

The Dr. Gait-2 system was successfully designed and implemented. It was evaluated on 40 cases ranging over different types of CP ambulatory patients by comparing it to the report previously written by the expert. For the set of test cases, the system correctly identified 89% of the specific gait deviations (151 of 170). Dr. Gait-2 also identified 46 deviations not mentioned in the case reports. Most of these additional identification deviations are minor. Of the 196 deviations the system identified, it found the correct cause 96% of the time (187 of 196). Dr. Gait-2 recommended the correct therapy 45% of the time, partially correct therapies at a rate of 51%, and incorrect therapies 4% of the time.

Conclusions: As the evaluation indicates, Dr. Gait-2 is able to correctly diagnose and treat most of the abnormal gait motions it is intended to handle. The program still suffers from several limitations that need to be overcome. First, the program's representation of time is very elementary; the gait cycle is divided into a fixed number of phases and each phase is treated as an atomic unit of time. Second, the system's qualitative model of muscle and body torques is functionally limited because it does not describe the torques within a normal gait cycle; but only tries to explain deviations from normal. Third, the program is limited in its domain; viz. analyzing motions of one leg in the sagittal plane during a single gait study of a patient with CP. The program does not use its experience to enhance itself, and as a result, the system is brittle.

The next generation of gait analysis expert system is currently under development. This system, QUAWDS, includes the knowledge used to construct Dr. Gait-2. It is more robust with respect to the domain and more extensible. This system uses Generic Task theory for structuring the knowledge base. QUAWDS will use data of both legs, all three planes, and the patient's past visits. The project is also investigating a learning strategy for identifying and correcting flaws in the system using the expert's interpretation of a case.

ASSESSMENT OF THE SUBTALAR JOINT FUNCTION AFTER FRACTURE BY ANALYSIS OF THE DYNAMIC FOOT TO GROUND PRESSURE DISTRIBUTION

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Introduction: A fracture involving the subtalar joint usually results in a substantial loss of gait function. Since questionnaire methods, physical examination and radiological analysis alone do not allow an objective description of a specific locomotion disturbance gait analysis was performed in a prospective study comprising 28 patients after surgical and conservative treatment of calcaneal fracture in order to evaluate the hindfoot function and the effectiveness of therapy.

Material and Methods: An analysis of the dynamic plantar pressure distribution was performed employing a measuring mat with a total of 1,344 capacitive transducers in a matrix arrangement. The system has 2 calibrated sensors/cm^2 and a resolution of the measured force of 1 N at a chosen measuring rate of 20 Hz. On-line data processing allows an analysis of the standard parameters time,area, force and maximum pressure (EMED-F-system). The measuring unit is integrated into the center of a walk-way which can be passed by 4 to 5 strides. The contact area of the foot was divided into 4 regions of interest. In order to eliminate interindividual differences the measured forces were standardized to body weight, the contact times were related to the actual time of loading. Combining the basic parameters the pressure time integral, the regional vertical impulse and the center of pressure line were determined. Comparing the formerly injured and the contralateral intact foot in the same individual a performance index was generated from a set of 5 parameters. The results were compared with the findings of clinical and morphological assessment performed by a second independent research group.

Results: Results of force, maximum pressure and vertical impulse proved sufficiently reliable in repetitive measurements. Uniformely, patients after conservative treatment or surgically treated patients with a poor result presented a significantly increased and prolonged loading of the hindfoot area coinciding with a diminished and delayed impulse transfer to the forefoot region (p less 0.05). Left-right asymmetry of the normalized impulse transferred to the ground is discernible favouring an unloading effect of the injured foot, in particular, after conservative treatment. A shift in the center of pressure line can usually be detected in the injured foot; in less favourable results, the typical shape of the center of pressure line gets lost. No statistically significant difference in the total loaded area of the injured and the intact foot can be detected by dynamic measurement in contrary to static podometry. The performance index closely correlates with the clinical rating score employed (Merle d'Aubigné, p less 0.005), while a connection of the performance index and the radiological evidence of joint incongruity in conventional radiography and computed tomography can not be detected.

Discussion: Apparently, the employed method represents a reliable tool for the registration of the dynamic plantar pressure distribution after a severe hindfoot injury. A higher maximum pressure and an increased impulse at the heel area may be related to a loss of the normal impact absorbing hindfoot eversion at the early stance phase. This is supported by the evidence of a shift of the center of pressure line and resembles to the gait behaviour after subtalar arthrodesis. The diminished loading of the forefoot and the toes after fracture treatment can be attributed to a decreased supination at the end of the stance phase which normally lets the lateral metatarsals participate in the push-off phase and can not be achieved if the subtalar motion is limited.

A markedly better subtalar joint function can be expected after surgical reconstruction of the calcaneus than after conservative treatment.

CHARACTERIZATION OF THE SURFACE STRAIN APPLIED TO CYCLICALLY STRETCHED CELLS IN VITRO.

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A new concept in cell culture has been developed to allow for the application of mechanical deformation in defined regimens to cultured cells. The novel cell culture system is based on flexible-bottomed, 6-well cell culture plates. The purpose of this study was to characterize the strain profile developed on the surface of a rubber-bottomed culture plate during a given deformation event and to obtain preliminary data on cellular response.

For this experiment Falcon 6-well plates with 35 mm diameter wells were used. Each well had a 27 mm hole in the well bottom. Silicone rubber membranes were cast into the bottom of each well. The surface of the silicone rubber was chemically treated to make it compatible with cellular attachment and growth. Vacuum pressures up to 17 kPa were applied to the bottom of the membrane, thus stretching it downward.

To assess the amount of strain on the surfaces of the flexible plate, a finite element model of the silicone membrane was developed using ANSYS finite element analysis software. An axisymmetric model of the plate with 112 isoparametric elements was developed and large deformation analysis was performed using an iterative approach.

In order to assess cell alignment in response to mechanical strain, avian tendon cells were plated on the flexible plate surface, and subjected to mechanical deformation by the application of 17 kPa of vacuum at 10 deformations/minute for 24 hrs. After 24 hrs, the cell alignment was analyzed under the microscope using a video analysis system.

The finite element analysis (FEA) yielded a near hemispherical membrane shape. The maximum deflection was 6.5 mm at the plate center; this matched the actual measured deflection. The FEA of the flexible culture plate surface revealed that a maximum radial strain of approximately 30% occurred on the plate at a location of 13.7 mm from the well center (3.8 mm from plate edge). The strain profile was confirmed by measurements made with the microscope/video analysis system.

The tendon cells responded by exhibiting various degrees of alignment. In the zone of maximum strain, a majority of the cells aligned circumferentially, i.e. the long axis perpendicular to the radial strain. In the zone of minimum strain there was random cell alignment.

In conclusion, this new cell culture system is an effective means of mechanically deforming cells *in*