Ground Reaction Measuring Shoes as an Aid in the Clinical Assesment of Pathological Gait

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Abstract

Few systems for measuring and adequate presentation of relevant gait parameters have been developed so far. When a system is to be used routinely in a clinical environment with paretic or plegic patients, designers face additional problems.

In this paper a system built around ground reaction measuring shoes and optional to a minicomputer is described. An extensive software package for data processing and presentation was developed.

Normal gait patterns are compared to those of hemiplegic patients. Illustrative examples of the changes in pathological gait patterns during therapy or the changes due to orthotic devices are given.

The system has been extensively used for two years with a group of hemiplegic patients during their therapy to record the process of rehabilitation. Experiences obtained with the system and the results are briefly discussed.

Introduction

In clinical environments several methods are used for the evaluation of gait of motorically disabled persons. The majority of them are qualitative, based on observations of gait and related motor functions. Evaluation is performed on-line (during walking), or alternatively video-recordings or films can be analysed later. Each of these approaches has some advantages over the other. The first method is faster and cheaper, but requires a more skilled observer, and the possibilities of an inadequate evaluation of anomalies are not negligible. The drawbacks of such methods originate from the fact that no unique and precise selection and definition of the observed anomalies has been adopted worldwile and therefore the results obtained at different "schools" can hardly be compared. Also, the results are likely to be biased by the observer, because the attributes such as "high", "medium", "low", etc., according to which the anomalies are scored, are not always equally interpreted by different people, or even by the same person on different occasions.

Therefore, several efforts have been made to evaluate the anomalies quantitatively. There is a tendency, not merely to copy the quantitative clinical observations and replace them by measurable quantities, but to develop a new approach based on the biomechanical and control principles of locomotion. First, it must be said that the set of parameters which is suitable for qualitative observation does not coincide with the parameters that can be measured quantitatively, and is not necessarily the set that quantifies gait the best. Therefore, the importance of the individual parameters for the evaluation of gait is to be judged thoroughly by the criteria based on the cited principles.

Owing to the requirements that must be met in the clinical environment few of the measurements that can be adequately performed in the laboratory can be directly transferred to clinical use, yet each clinical measurement has to meet the basic principles of objectiveness. In short, clinical evaluation of gait should give results of acceptable accuracy after a time interval comparable to the duration of measurement. The measuring equipment and method must be adapted to the patients' status. Few systems that meet all these requirements have been developed so far.

A system for the measurement of ground reaction forces during gait implemented with some other measuring equipment, that approximately satisfies the above requirements is described here.

Instrumentation

Four pairs of measuring shoes of different sizes and light to wear have been constructed (Fig.1). The sole of each shoe is equipped with 8 transducers. Semiconductive strain gauges are stuck to the supporting metal construction to which force is exerted during gait, and connected to a bridge circuit./1/. The output voltage is approximately proportional to the vertical component of the ground reaction force. A simple proportional relation $F_z = k \cdot U$, where F_z is the vertical component, k the calibration coefficient , and U the measured voltage, is sufficiently accurate for a limited range of measuring conditions. There are three factors making k an in exact constant: the component of ground reaction in the direction of walking, the angle of contact between the sole of the shoe and the ground, and a slightly variable distribution of the ground reaction over the active area of the transducer. These influences can be compensated for and diminished to a certain extent by a proper orientation of the transducers in the sole and by minimizing the support area of the trans ducers.

Fig.1

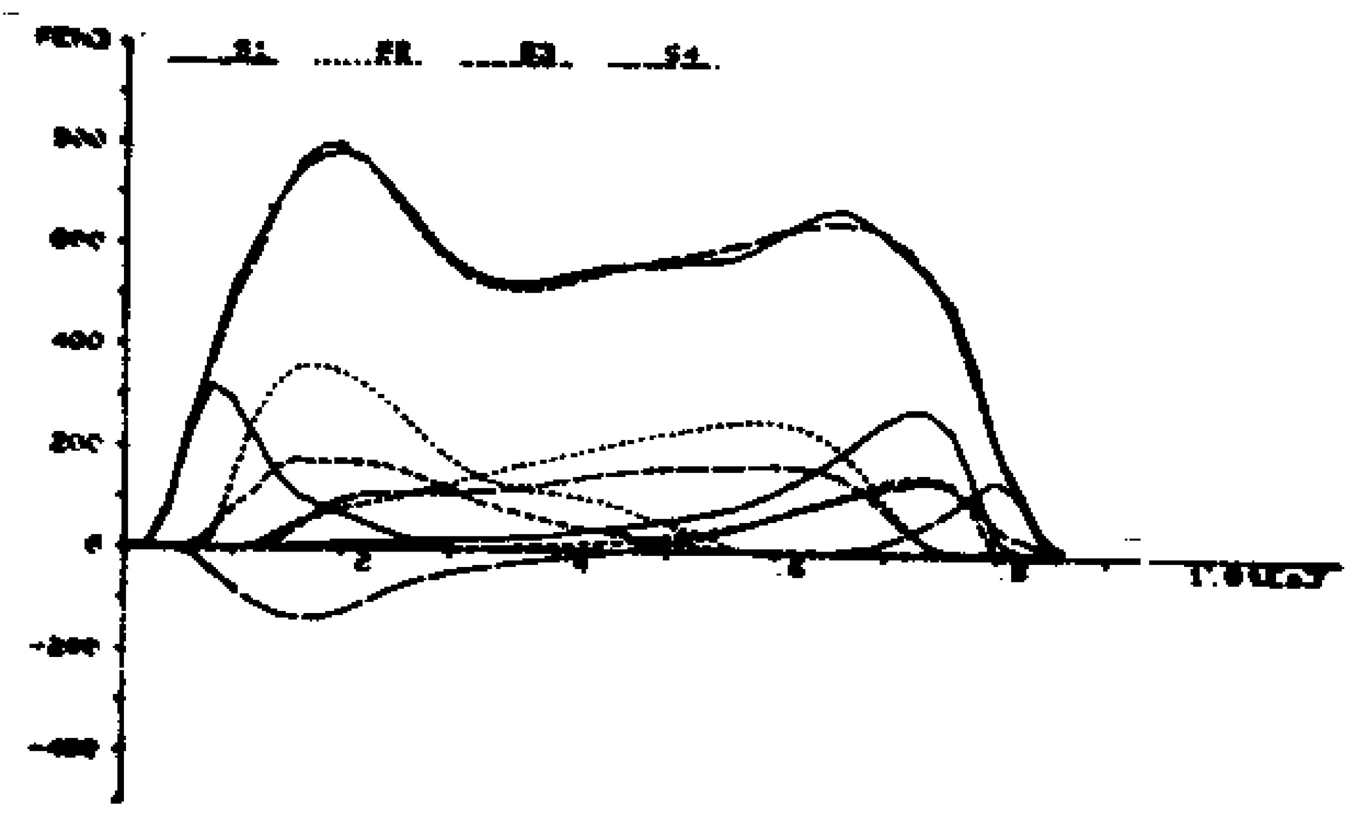


Fig. 2

The results of gait measurements by the measuring shoes were compared to those obtained by a force-plate. An exaple of a normal gait is shown in Fig.2. The upper two curves represent the vertical component of force measured by the shoe (full line), and by the force-plate (dashed line), while the curves beneath represent the components corresponding to particular transducers in the shoe, and to the longitudinal component of the ground reaction. The error of measurements is estimated to be far below 10% through the entire stance phase and for rather different gait paterns.

Ground reaction measuring shoes have some advantages over the fixed force-plate. All steps of a particular walking sequence can be measured, and therefore data on the necessary number of steps can be collected very quickly. In contrast, with common force-plates only one step per run can be measured. Saving of time and energy is rather important, especially with severely disabled persons. Also, the measurements are not limited to one site only. However, the data obtained by the shoes are measured in the coordinate system moving with them, and therefore for several purposes of gait analysis the motion of this system relative to the fixed laboratory coordinate system must be known.

A simple goniometric system /2/ is normally used for measurement of rotations in the hip, knee, and ankle joints of both legs. The axis of rotation is defined for each joint separately by the attachment of the system, andby the positions of the corresponding segments of the legs in space. With persons standing in an erect position these axes are perpendicular to the sagittal plane of walking. Here also, several factors influence the reliability and the accurycy of measurements. Motion of the skin relative to the underlying bone structure, imprecise positioning of the system , and translation of the axix of rotation during gait are some examples . Zero positions of separate potentiometers are defined by their readings when the measured person is standing in an erect position. However, these are not always zero with respect to a common fixed laboratory coordinate system. Thus only relative rotations (flexion - extension) can be measured satisfactorily. The accuracy of these measurements is further influenced by abduction-adduction movements and by axial rotations in the joints. These influences cannot be avoided, or corrected for if not measured. They are conditioned by the construction and the mode of attachment of the goniometric system. When rotations in planes other than sagittal one are relatively small, the accuracy of the system is estimated to be 5%.

A ground reaction measuring crutch is designed to measure the axial force in the crutch during walking. A strain gauge, connected to a bridge circuit is used here, too.

Signals from all the transducers are transfered to amplifiers via cable conections and the amplified signals to a HP 2100 minicomputer. The frequency of data sampling can be selected by the operator, the maximal being 50Hz. Also, the number of data channels (up to 24) and the duration of sampling can be selected at will. Normally, approximately 30 steps are recorded. In our site conditions this requires 2 - 3 runs.

After each succesful measurement, data are strored on magnetic media for later processing. Putting-on the measuring shoes, zero adjustment and connecting cables doesn't take more than 5 minutes, while the attachment and adjustment of the goniometric system requires up to 20 minutes. Another 20 minutes are spent in fixing the electrodes and selecting the stimulation sequences, when the stimulated gait is measured. Thus the perosn measured is engaged for 40 - 90 minutes, depending on the type and the extent of the measurements.

Data processing and presentation

An extensive software package has been developed for processing and graphical presentation of the measured data. The data collected by the measuring shoes can be presented in several ways. In Fig. 3 the

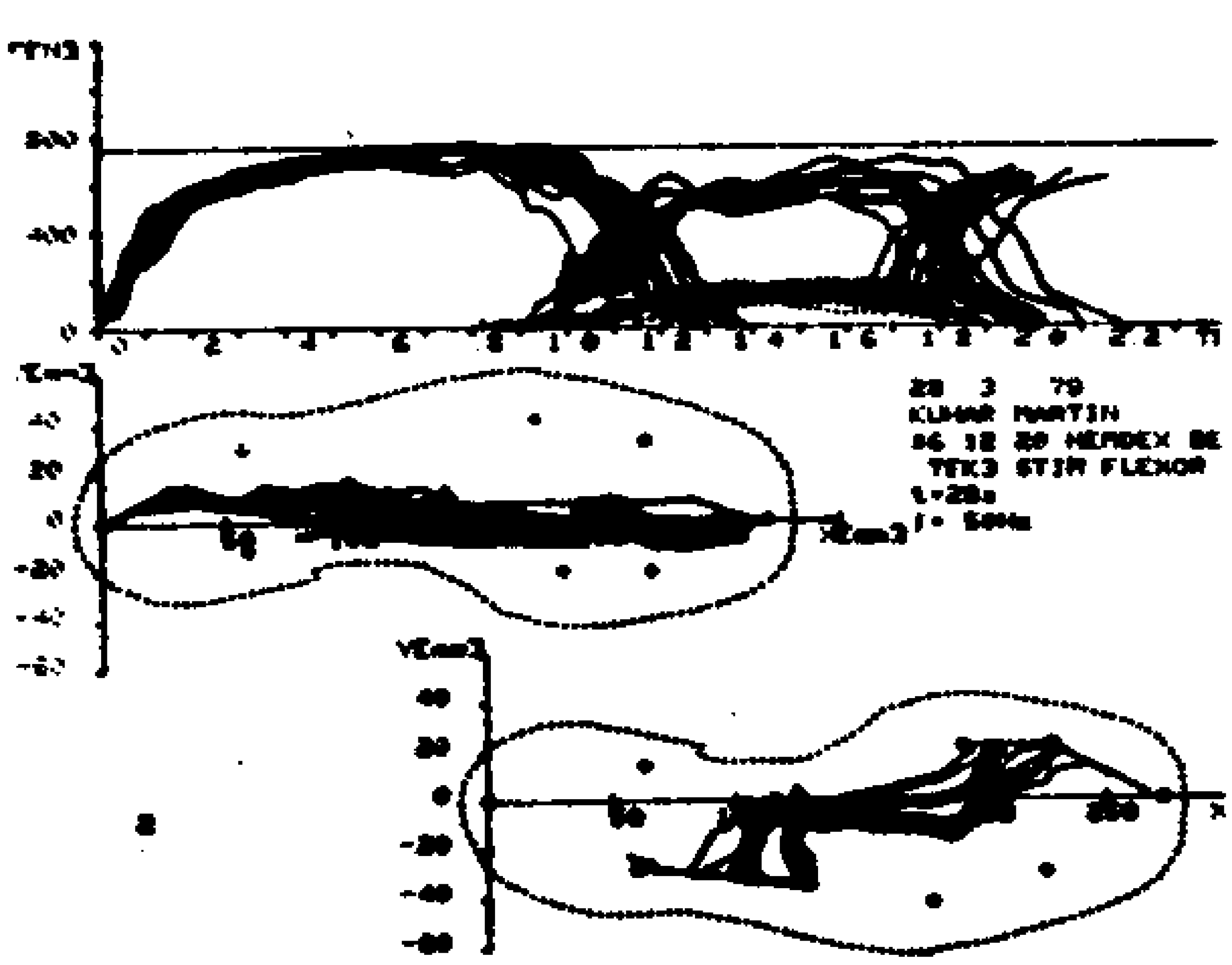


Fig.3

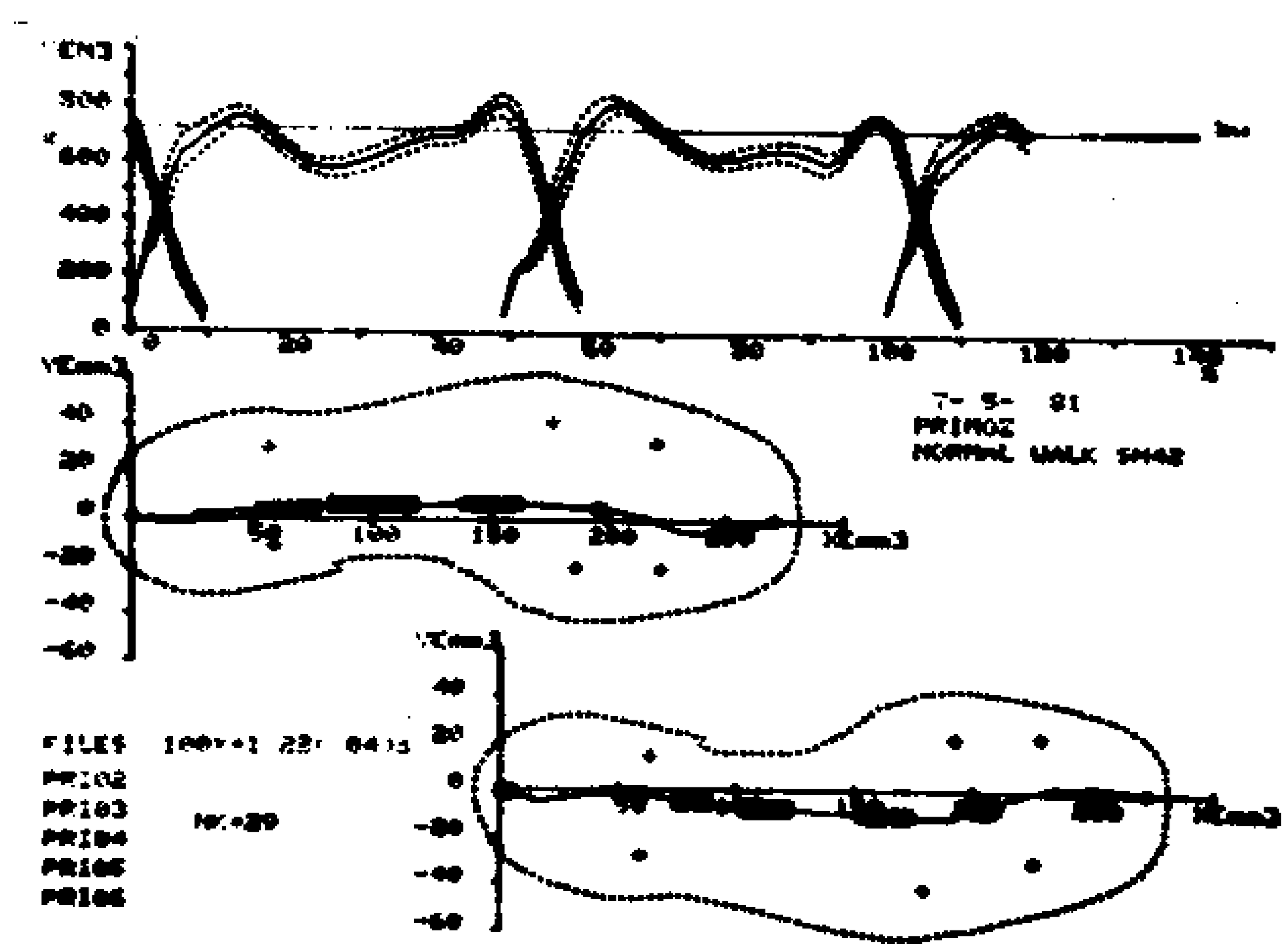


Fig.4

time dependence of the vertical component of the ground reaction for one run, for both feet, and for each step separately are plotted. The origin of the time axis is defined by the moment the left foot touches the ground. When the crutch is used, its axial force also can be shown (dotted lines).

A line parallel to the time axis, denoted by "bw" at its end, represents the weight of the measured person. The spatial distribution of the centre of pressure is plotted inside the outline of the shoe soles, shown schematically.

Another way of presenting the same quantities averaged over up to 80 steps is possible (Fig.4). The time axis is given as a percentage of the average stride duration. The numerical value of this time interval, together with its standard deviation, and the number of steps considered in the average are given in the text attached to the figure. Standard deviations of the spatial distribution of the centre of pressure under the feet are plotted at preselected intervals, and represented by rectangles giving standard deviations of both coordinates for the point of the trajectory lying in the centre of the rectangle.

An alternative method of presenting the time dependence of the averaged coordinates (X, Y) of the centre of pressure for both feet, together with their standard deviations is also available (Fig.5).

The time dependence of the force exerted on each of 8 transducers of the selected shoe during walking, can be presented by another program. It plots the corresponding time dependence of the averaged output voltages together with their standard deviations for several steps, for 8 transducers (Fig.6), or alternatively the voltages for each step separately. The origins of the time axis are defined by the moment of foot touch-down by a preselected tranducers.

Some other presentations are also possible, but those described above are the most often used in the evaluation of the rehabilitation process.

The data obtained by the goniometric system also can be presented in some different ways. In all of them the vertical component of the ground reaction is shown instead of the vertical component of the ground reaction is shown instead of the commonly used basograms of heel-switches. Goniograms are normalized to the average stride duration. The time axis is given as a persent age of this time interval. Its origin is defined by the touch down of the corresponding foot. Two methods of presentation are normally used. In the first (Fig.7), goniograms and ground reactions are plotted for each step separately. An alternative program plots the averaged goniograms for several runs and for up to 80 steps (Fig.8). Standard deviations and normal values of the joint angles, as given in the literature /3/, can be also presented. Beside information about the occurrence of heel-on, heel-off, and toe-off, indicated by vertical lines, the time dependence of the averaged ground reaction is given, too.

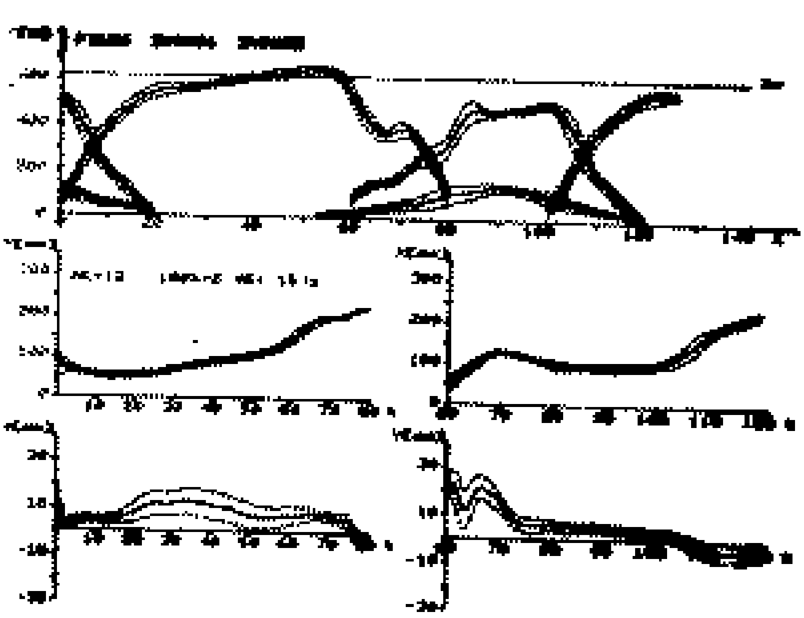


Fig.5

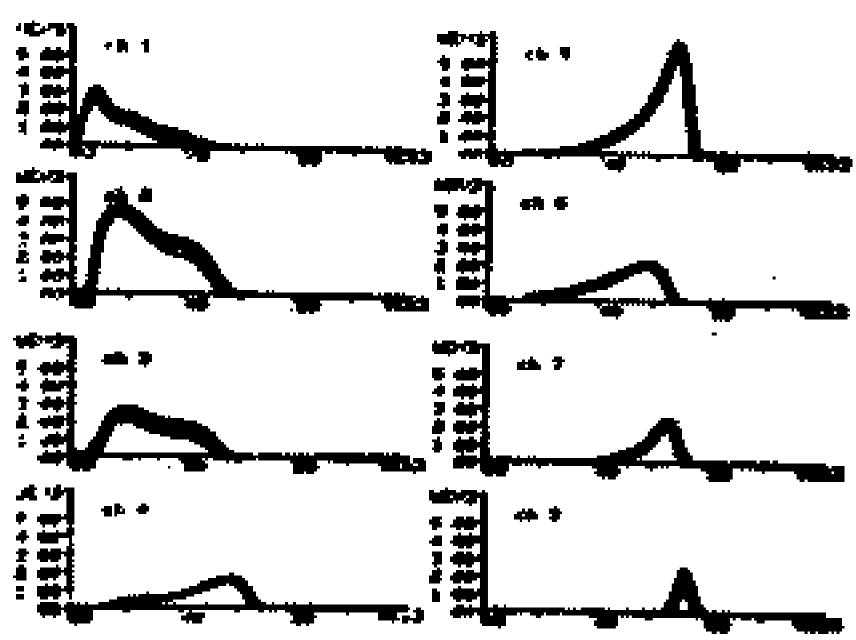


Fig.6

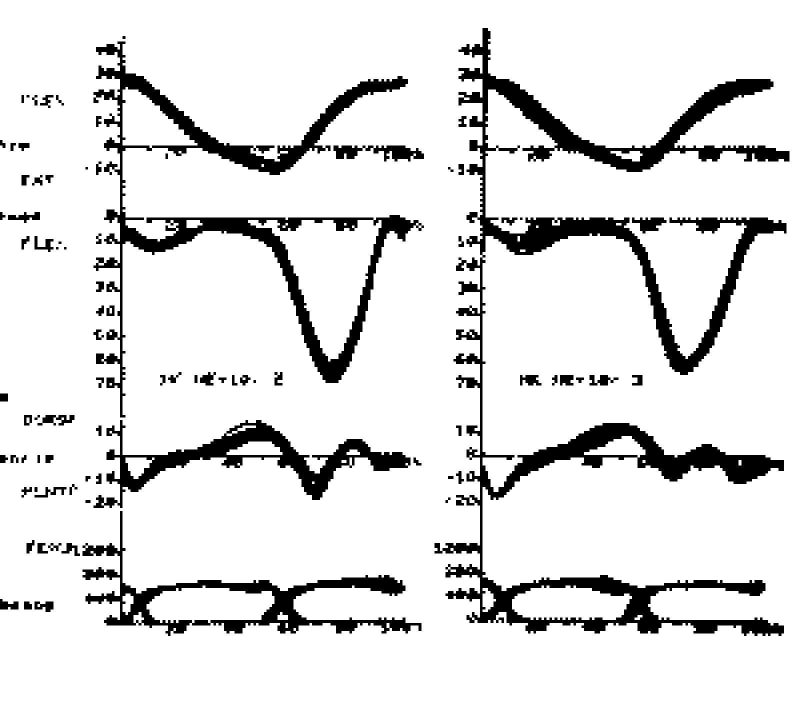


Fig.7

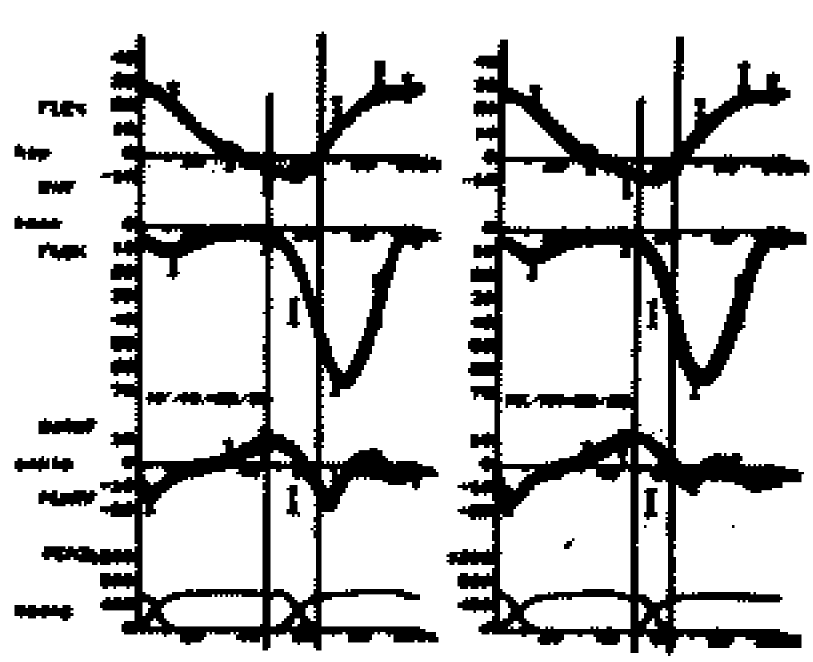


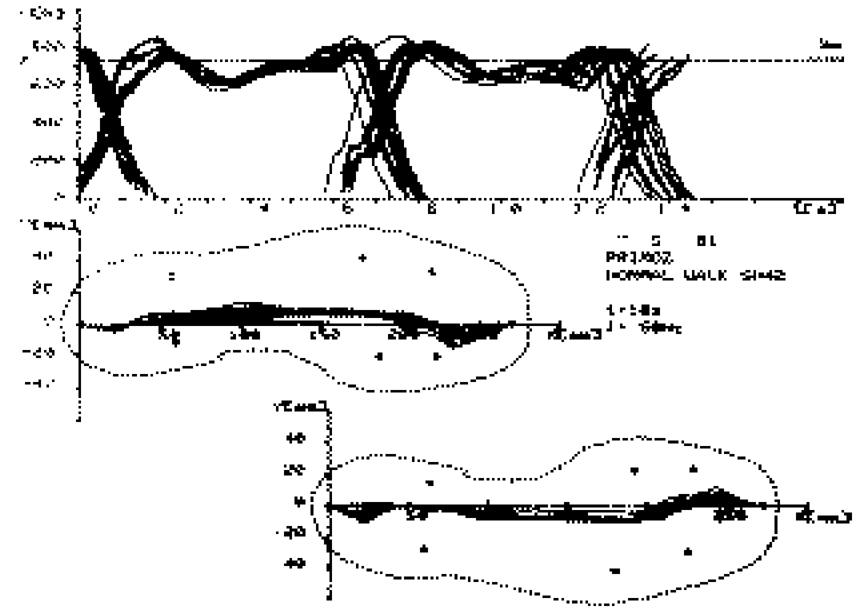
Fig.8

Discussion

Ground reaction measuring shoes combined with force measuring crutch and a goniometric system were extensively used in the study of therapeutic and orthotic effects of multichannel electrical stimulation of lower extremities in hemiplegic patients. The rehabilitation process in over 20 patients was evaluated by these measuring techniques. In general, they are complementary to the standard qualitative evaluations, such as the kinesiological analysis of gait /3/, test of motor functions, and evaluation of daily activities. Meanwhile, some observations from kinesiological analysis can be compared to the corresponding measurements (e.g. flexion - extension movements of the hip, knee, and ankle; the anomalies at foot contact with the ground and at the push-off moment, etc.). Normally, the qualitative assesment of anomalies agrees satisfactorily with the measurements. But exceptions can also be found. They can probably be ascribed to the "subjective factor" of the qualitative methods.

The extent of the anomalies can be best estimated by comparing normal and pathological gait patterns. Figs. 4,6,7,8,9 are examples of normal gait, while Figs. 3,5,10,11,12,13, and 14 represent different pathological gaits. The explanation of particular figures can be found in the preceding paragraph.

The orthotic effects of six-channel electrical stimulation applied to a right-side hemiplegic patient can be seen from Figs. 11 to 14. Figures 11 and 12 represent the non-stimulated, and figures 13 and 14 the stimulated gait. Differences can be seen in the ground reaction force and its distribution under the impaired foot, as well as in the goniograms of the right leg. We believe that quantitative measurements of gait are a prerequisite for an objective assesment of anomalies and the degree of their correction. This is the only way that different therapies and orthotic devices can be objectively evaluated.



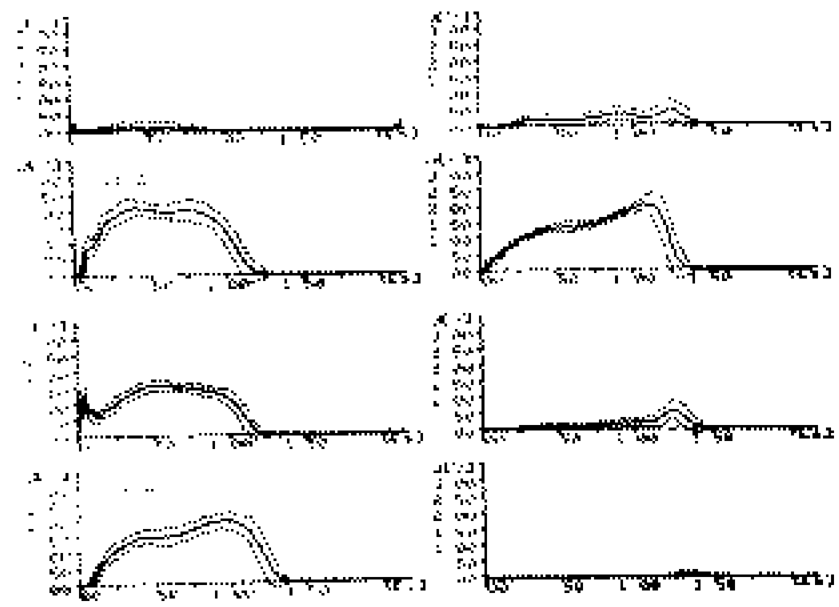
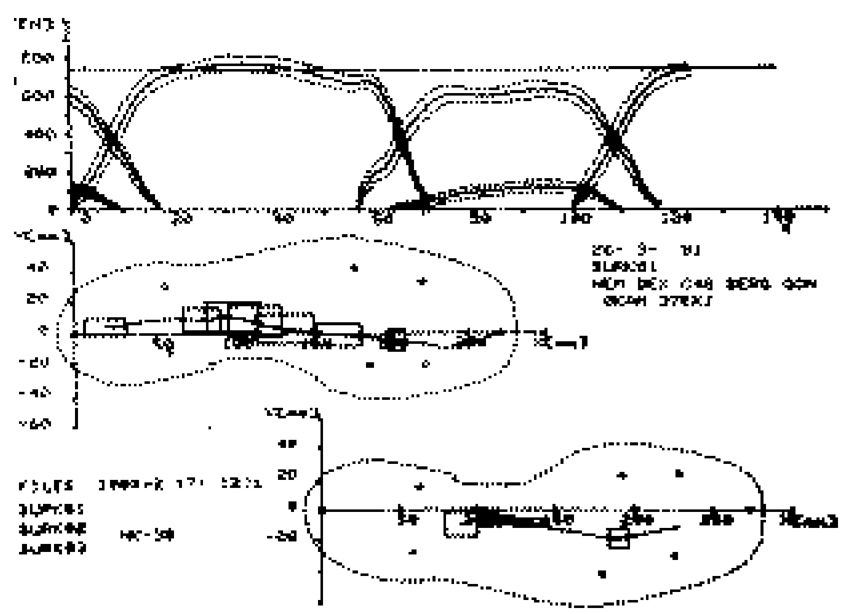


Fig.9



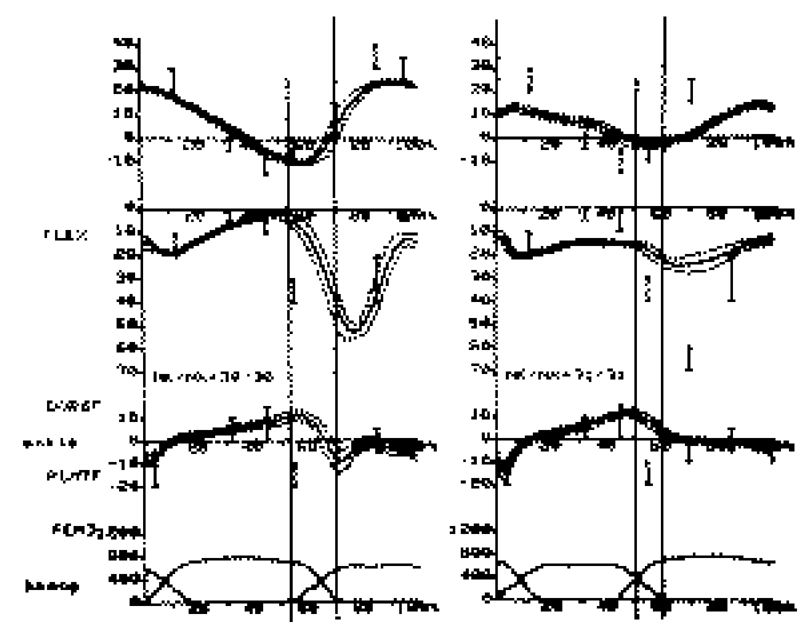
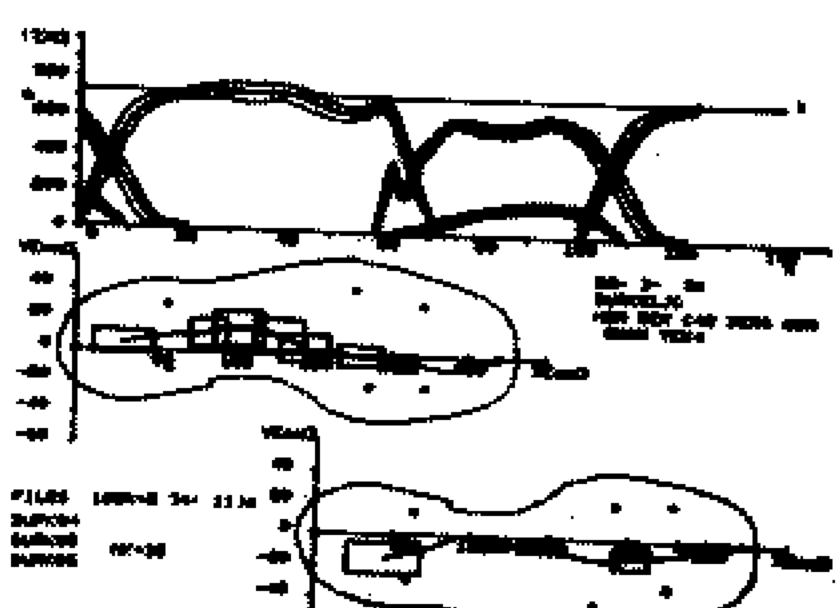
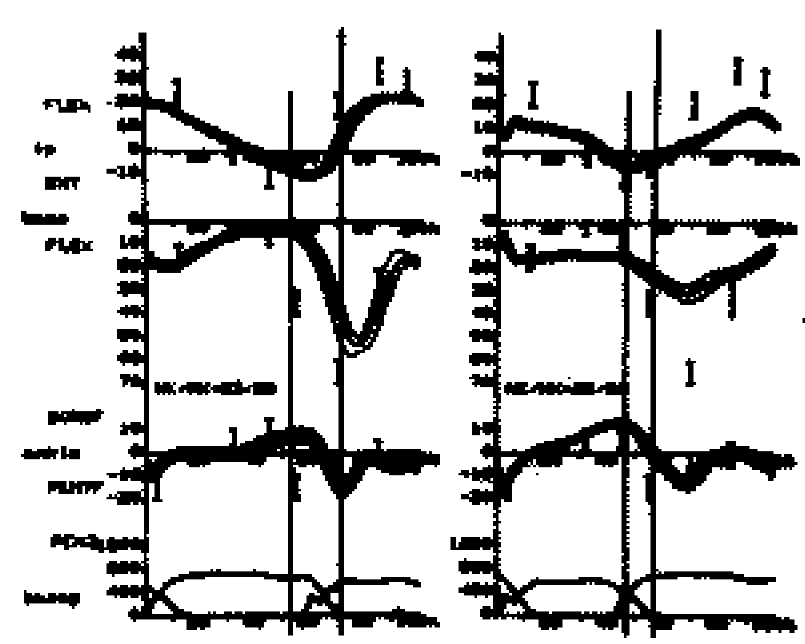


Fig.11





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