LABORATORY FOR KINESIOLOGIC ANALYSIS [a b]

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INTRODUCTION

Twenty years ago investigators at the University of California at Berkeley defined the biomechanical basis of human locomotion (1). Their kinetic and kinematic description contributed significantly to the knowledge of normal gait and allowed extrapolation into the area of pathological gait. These studies have been the classical reference for prosthetics-orthotics design, evaluation, and teaching. The value of the knowledge of the normal in understanding the pathological is obvious, and this has been the considerable contribution of the California studies.

Techniques not available 20 years ago now exist, making it possible to extend biomechanics knowledge in a manner which is important to continue prosthetic-orthotic improvements and to evaluate such devices regarding their overall usefulness. The significant limitation in earlier study pursuits was the arduous requirements of manual reduction and treatment of data which seriously affected study design. Since it was not convenient to handle large amounts of data, it followed that volume sampling and data replication were not used to any extent consistent with requirements to differentiate systematic variance from chance error. As a consequence, little reliable information is available today to describe the extent of normal variance or to describe the relation between gait factors under a variety of walking conditions. For instance, little is known about the relation between knee forces and changes in step length, speed of walking, or cadence.

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The poor reliability in measurement is particularly critical where the evaluation of an appliance component or item is of concern relative to its effect on function. Judgments have been rendered on the basis of information which is very little better than observation unaided by objective measurement, since it has not been possible to acquire adequate or sufficient information conveniently. Consequently, the value of newly developed appliances and sometimes even those already in common use is not known truly on a biomechanical basis. Without such basic knowledge improvement of appliances or innovative concepts occurs too frequently on a costly, gadgeteering basis.

RATIONALE

To establish a sound basis for evaluation and the design and development of prosthetic-orthotic appliances, attention was given to the construction of special equipment and instrumentation features embodied within systems approach to kinesiologic measurement. The outstanding characteristic of the system is the convenience of data reduction and treatment by modern electronic data processing means. This processing makes it possible to obtain reliable measures and thereby provide the sound basis required for biomechanics analysis. Moreover, the system was designed with consideration for special requirements in the testing of physically disabled subjects. Therefore, approaches were employed to permit the acquisition of data without imposing undue physical demands on the patient who may be the subject under study. In this regard, the equipment design reflects the need to acquire maximum information during a minimum number of test trials required of each subject. To effect such design there are important departures from similar equipment in use elsewhere. The new departures are the configuration and placement of the force plates used to measure ground reaction forces during walking, and an entirely new technique to measure body position with reference to orientation planes.

KINEMATIC MEASUREMENTS

To measure body position with reference to the orientation planes, five potentiometers, each actuated by retractable cords, are used (Fig. 1 and 2). Three of the cords converge and attach at the subject's right hip, and two converge at the left. The potentiometers are arranged in a fixed geometry on a structure supported by an overhead trolley to the rear of the subject. Owing to the constant dimensional relation of their points of origin, measurement of the lengths of each cord at any instance permits calculation of the spatial coordinates of each hip. This system of measurement is significant to maximum data gathering because all steps during a single test trial are recorded, and also the

position of the leg joints can be measured for both extremities simultaneously.

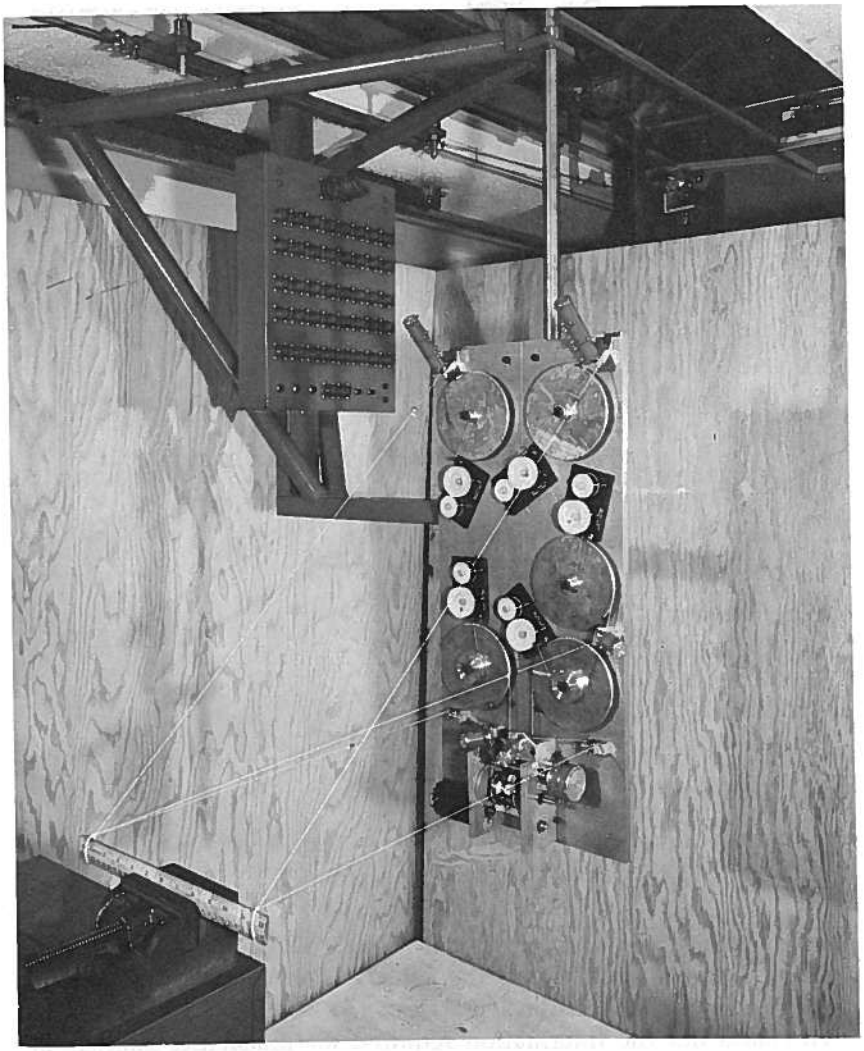

FIGURE 1.—Partial assembly of instrumentation on overhead trolley to measure hip position during walking.

The importance of this feature may be readily appreciated in that the patient is not required to make repeated trials in order to acquire records of both extremities, since by the usual photographic means only one side at a time is recorded. Furthermore, the unacceptable method of superimposing translatory position curves from different trials to attempt kinematic analysis is eliminated. This method is unsatisfactory

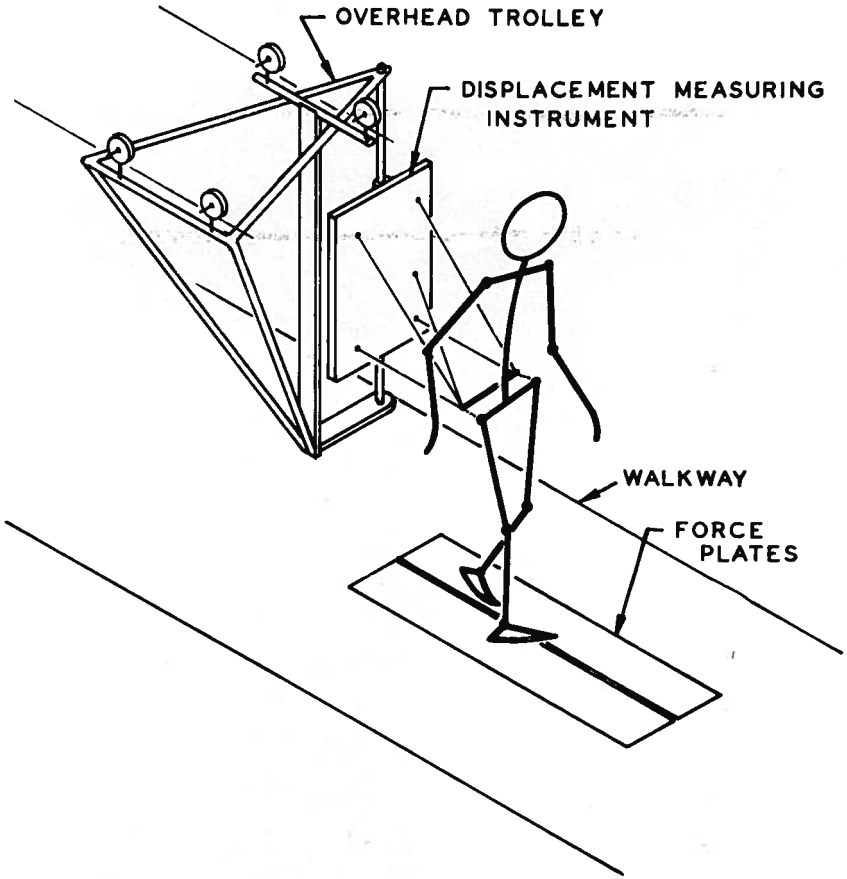

FIGURE 2.—Instrumentation and technique to measure the hip position during walking (see text).

because velocity and step length can scarcely be counted on to be the same in different trials unless the subject is so constrained, and this constraint also is an equivocal practice.

To round out the information required for kinematics analysis the rotatory positions of the hip, knee, ankle, and subtalus are recorded, using electrogoniometer assemblies. Foot switches are used to reference the data to the subdivisions of the gait cycle.

A trolley, motor driven on tracks over the walkway, supports the instrumentation to record displacement of both hip joints and also supports the cable which transmits signals from the various transducers on the patient to the recording console. The speed of the trolley is self-regulating since it derives its control signals automatically from the subject. A junction box provides a jack panel to connect leads from

instruments attached to the patient (e.g., electrogoniometers, foot switches, and myoelectric detectors).

KINETIC MEASUREMENTS

Two force plates installed in the 40-ft.-long walkway are used to measure forces acting upon the body during walking. The plates, each 12 in. by 60 in. mounted side by side ¼ in. apart, measure the vertical, longitudinal, and lateral components of floor reaction forces and the location of the center of pressure. Their length permits three or more consecutive steps to be sampled when walking on the plates. Their close side-by-side positioning permits force measurements without the need to alter the natural width of the subject's walking base. While the latter aspect is vulnerable to data contamination if foot contact is made simultaneously with both plates, it is considered more desirable than a wider separation of the plates. Both of these geometric considerations are important when measuring pathologic gait. First, the patient need not be forced into any particular cadence, step length, or velocity, and second, effects of pain or fatigue are minimized by reducing the total number of passes over the plates needed to obtain adequate data.

Techniques developed during the past years have resulted in a variety of plate suspension and force measurement methods. The strain gage suspension for the force plates was based upon concepts used at the Case-Western Reserve University Biomechanics Laboratory. The elements of the force plate assembly are presented schematically in Figures 3 and 4. The gages of the force plate system are used in tension only, and the vertical and longitudinal loads are registered on a different structural member from that which receives the lateral load.

The tops of the force plates are removable to permit the use of transparent plates when the foot-substrate phenomena are to be observed from below. A barograph, similar in design to the one at the Veterans Administration Prosthetics Center in New York, may also be used to study foot pressure patterns during walking.

DATA RECORDING AND PROCESSING

The measures directly acquired from the total of the instrumentation include the translatory position and velocity of the hip joints, the rotatory position of the hip, knee, and ankle and the vertical, longitudinal, and lateral floor reaction forces. These measures will permit the calculation of the knee and ankle translatory positions, the floor reaction resolution vectors, and the moments about the hip, knee, and ankle in the X, Y, and Z planes.

All measures are recorded using the Datak previously described (2). This system provides multiple recording media including an oscillo-

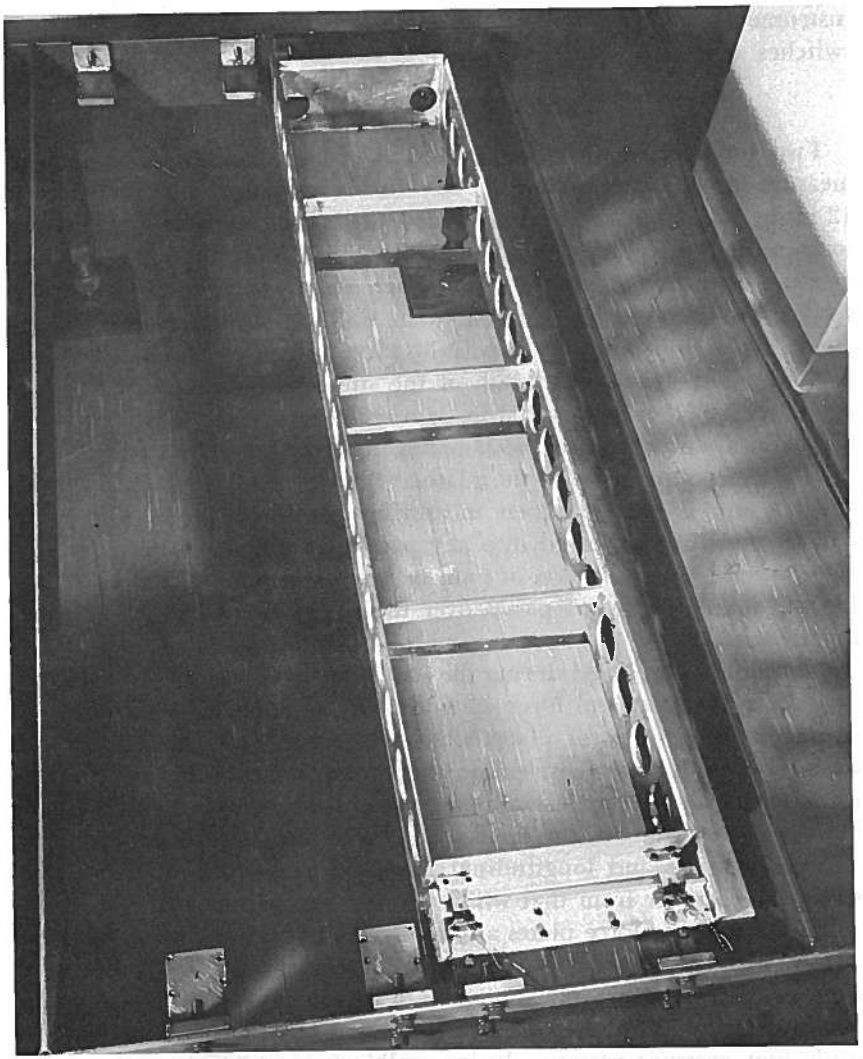

FIGURE 3.—The force plates, partially assembled.

scope used primarily for pretest calibration, an oscillogram useful for quick visual inspection to check on the performance of all systems during testing, and a magnetic tape which is the key to automatic data reduction.

Time signals provided by a timing generator within the Datak are selectable within a periodicity ranging from 1 to 100 per second and are automatically recorded on the oscillogram and the magnetic tape. These are used to trigger the data reduction functions provided by Biocoder (2). In addition to timing signals, the option is provided to

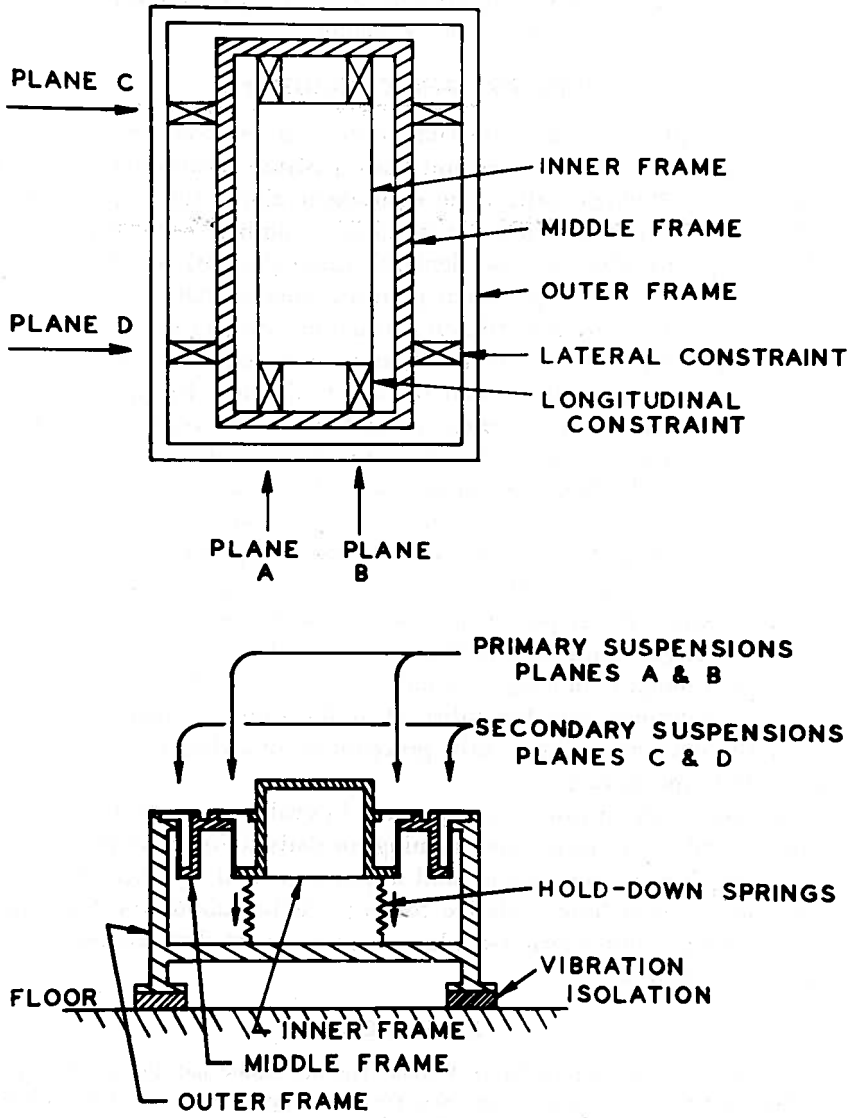

FIGURE 4.—Mechanical schematic of the force plate suspension in top and cross-section views.

use an event-marking signal (i.e., arising from an elgon or foot switch, etc.) to trigger data reduction.

The automatic data reduction through replay of the magnetic tape is the function of the Biocoder. The data are converted from analog-to-digital form and automatically key-punched onto cards. Computer processing of the data on the cards includes the calculation of mo-

ments about the anatomic joints and also the spatial position of the joints referenced to the X, Y, and Z planes.

SUMMARY AND CONCLUSIONS

Special equipment and instrumentation have been developed to obtain ground reaction forces and body position measurements in the analysis of pathologic gait. The equipment allows the acquisition of maximum information during a minimum number of test trials so as not to impose undue physical demands upon the patient under study. Special features of the equipment permit automatic data recording and reduction to eliminate the arduous manual process employed heretofore. By rendering the data automatically onto punched cards, modern electronic data processing means may be used to develop descriptions of the gait and to calculate the kinematics and kinetics of locomotion.

Information gained from the above measures is of inestimable value in many ways. In bioengineering design the information is critical to the development of bracing and artificial limb configurational concepts specifically related to such factors as points of application of force, the areas of stress and strain, the areas and location of pressures transmitted to body tissues, the requirements for permitting or restricting motion and the strength requirements of materials used. Where mechanical or electrophysiological bracing is under consideration the information is useful to determine the feasibility of applications in their conceptual stage, thereby precluding costly procedures involving trial and error fabrication and testing.

The use of the measures is important in evaluating orthopedic treatment procedures in functional training for daily living activities, and in the evaluation of components and appliances used by patients. The information contributed relative to forces acting about the leg joints in the frontal and transverse planes permits new dimensions to biomechanics analysis.

REFERENCES

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