NORMATIVE DATA COLLECTION IN ADULTS AND EVALUATION OF HIP AND KNEE PROSTHETIC REPLACEMENTS*

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Originally the author's primary interests were to study, in depth, the gait of patients with selected neuro-musculo-skeletal disabilities and to evaluate the effect of various treatment procedures on walking performance. Ranges of variability for the walking patterns of normal subjects were not available, however, and this baseline information was essential for meaningful comparisons of the walking disorders of disabled patients. Accordingly, evaluations of disabled patients were temporarily delayed so that normal baselines could be obtained. The first normative study posed questions which triggered the necessity for additional studies of different aspects of normal gait.

A simple, inexpensive and reliable photographic method to record the simultaneous displacement patterns of walking in two planes of space was developed (Fig. 1). Silver Scotch-Lite targets were fixed to specific anatomic landmarks of the patients, and the patients were photographed as they walked beneath a mirror mounted to the ceiling. The target images which projected in the overhead view and the targets on the medial and lateral aspects of the body were registered on the same film. In our original study we applied this method to establish the ranges of normal variability for the displacement patterns of 16 body segments during free speed walking of 60 normal men, divided equally into five age groups from 20 to 65 years, with equal numbers of men in three height categories from 61 to 74 inches in each age group (1). This study identified the effect of age and height on the free-speed walking patterns, and also assessed the reproducibility of the measurements through repeated trials. A diagram of the experimental design is shown in Figure 2.

The findings from this original study of free speed walking suggested that the walking speed selected by individual men influenced the amplitude of certain movement patterns. Therefore, the next study was undertaken to identify the means by which normal men increase their walking speed (2). We learned that one of the many mechanisms of increasing speed is increasing the amount of transverse pelvis rotation used during walking, as shown in Figure 3. This study provided information which is particularly useful in understanding the deficits in walking speed which are characteristic of a wide variety of disabled patients and which limit the rehabilitation potential and employment possibilities of many patients.

In our original gait study we also noted that several gait components of the men in the 60-year age group differed significantly from those of the younger men, suggesting a "subclinical" presenile walking pattern. The term "subclinical" is used because all of the test subjects had physical

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examinations prior to the gait study and all were normal except for a few who had diminished vibratory sensation. Accordingly, in a separate gait study of 64 normal men divided evenly into eight age groups, the upper age limit was extended to 87 years to determine if the previously suggested presenile patterns were consistent and progressive with advanced age (3). The subjects were of medium or short height. This study demonstrated that the amplitudes of many of the gait components of normal elderly men did indeed differ characteristically from those of normal younger men. For example, walking speed decreased with advanced age, and this decrease resulted more from taking shorter strides than from slower cadences (Fig. 4). This study provided realistic baselines for comparing the disordered gait patterns of disabled men of advanced age.

As we began to record the gait of above-knee amputees and patients with Parkinson's disease, we noted peculiarities in the vertical pathways of the heel and toe and also in their arm swing patterns. Since normal standards for these gait components were not available, these additional normal gait studies were undertaken (4-6).

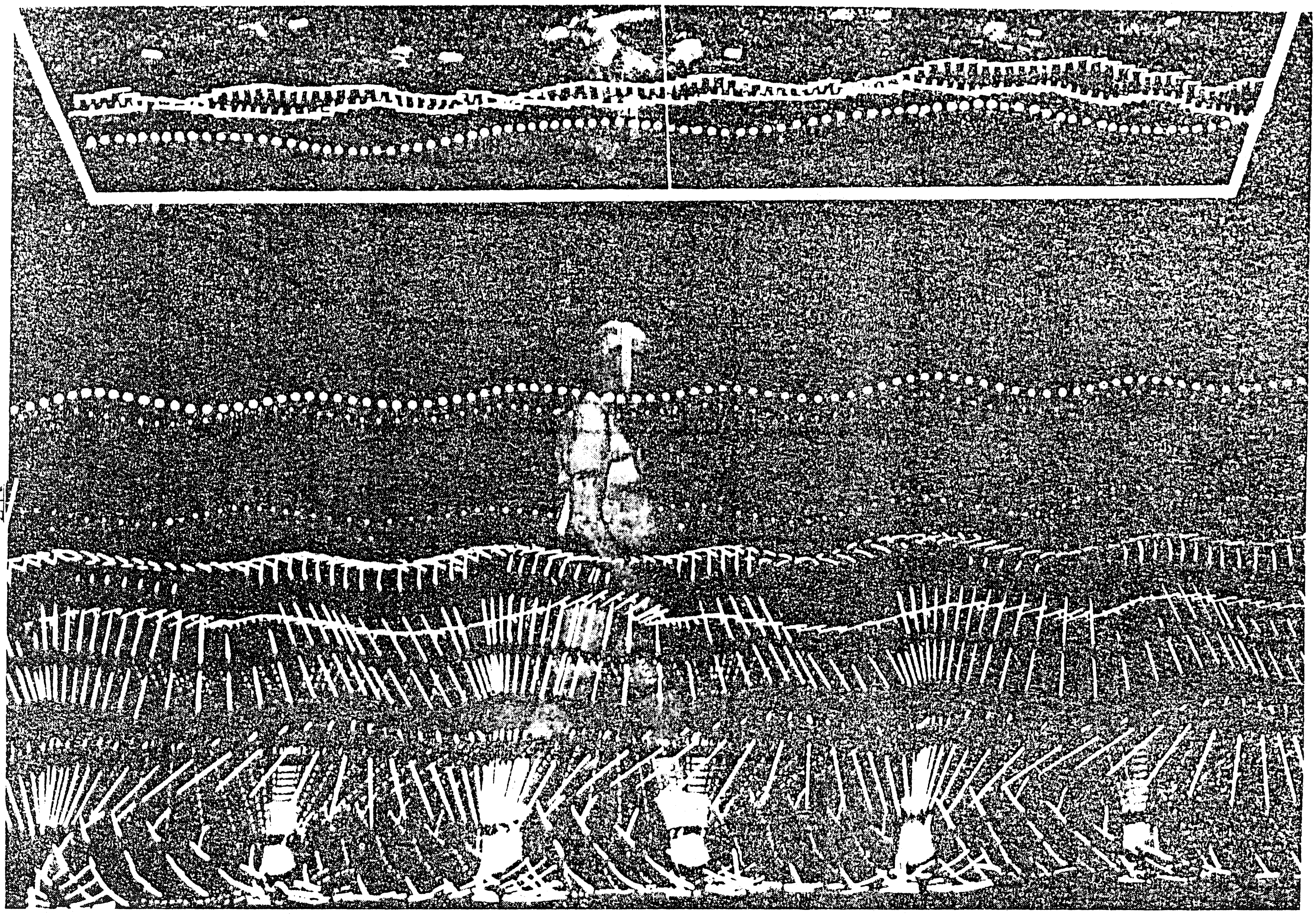
As our standards became available, we received referrals for gait evaluations of disabled women as well as men. It was necessary, therefore, to establish standards of normality for the gait components of women and to identify the effect of age, height, walking speed and heel heights on their walking patterns (7). We measured pronounced differences in the amplitudes of most of the displacement patterns of women as compared to those of normal men and also measured pronounced differences in the displacement patterns when the women walked with different heel heights. This comprehensive study provided necessary baselines since many women with orthopaedic or neurological disabilities require shoes with a specific heel height in order to walk comfortably. An example of the effect of heel height on one of the components of walking is shown in Figure 5.

We believe that this series of normative studies has contributed to a deeper understanding of the walking act and that we have established adequate standards of normal variability which can serve as baselines for comparing the gait of disabled men and women in wide ranges of height and age, under various conditions of walking, and with various types of shoes.

<u>Examples of the Application of Normal Standards to Evaluate the Functional Performance of Patients with Hip and Knee Joint Disabilities</u>

Before we started evaluating the effect of different types of total hip replacement on walking performance, we knew it would be prohibitive, if not useless, to analyze all of the gait components we were capable of recording. Accordingly, we expedited two separate studies to give us insight into the most sensitive gait components to be assessed in patients with hip disease. One study identified the common pain-avoidance maneuvers in the gait of patients with hip arthritis,(8) and the other identified the mechanism by which patients with surgical fusion of the hip compensate for absence of hip joint motion during walking (9). In the presence of hip

FIGURE 1



FACTORIAL DESIGN

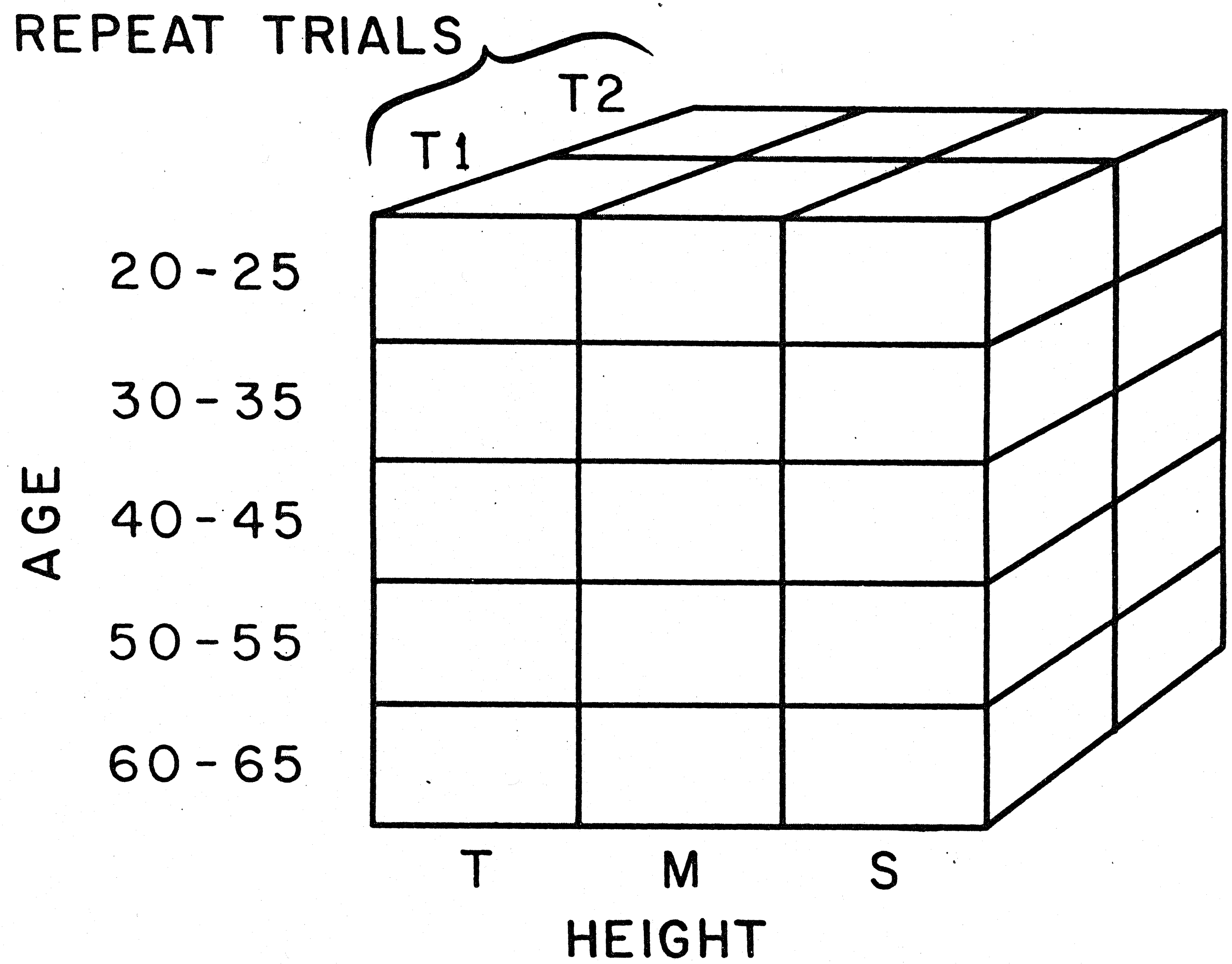
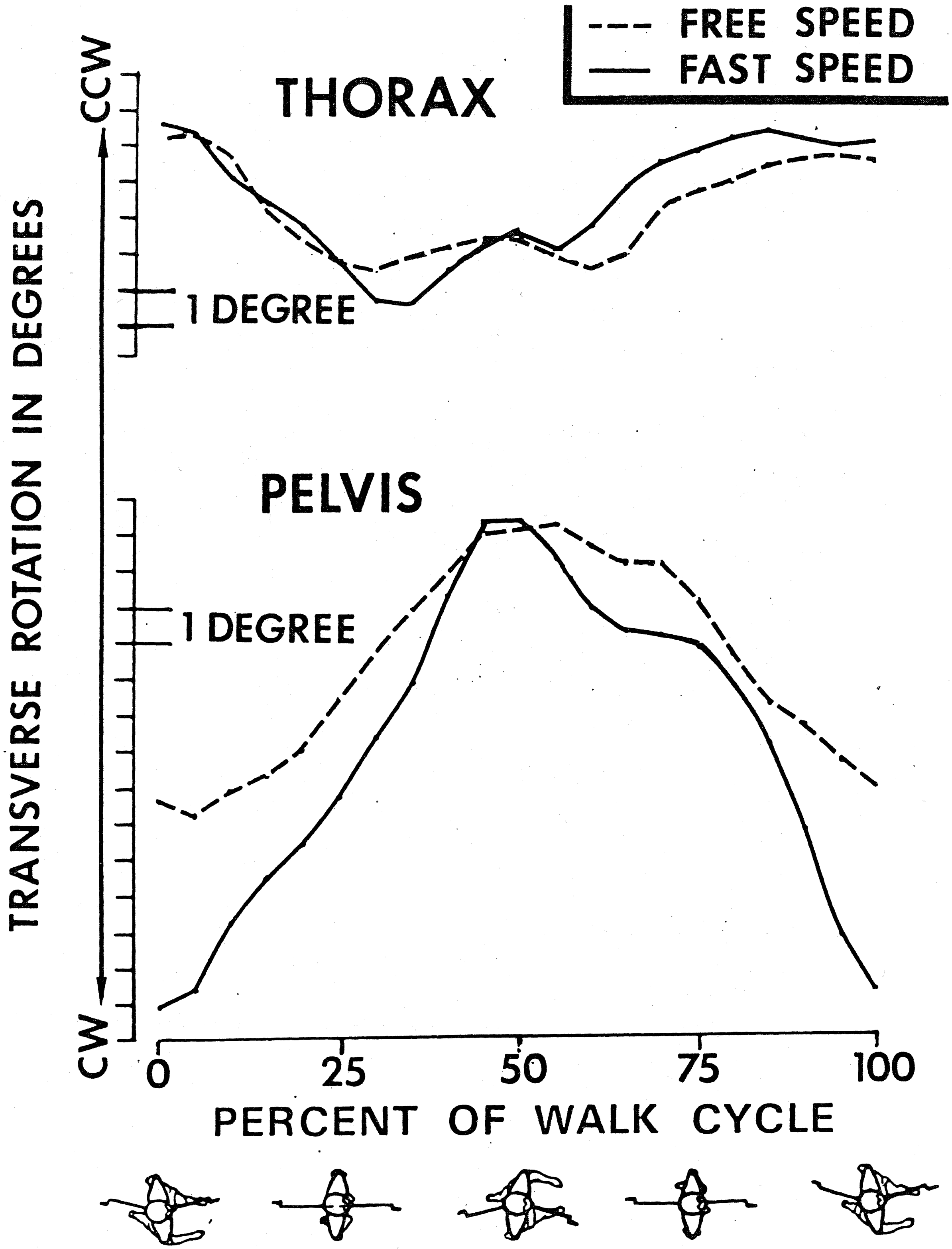
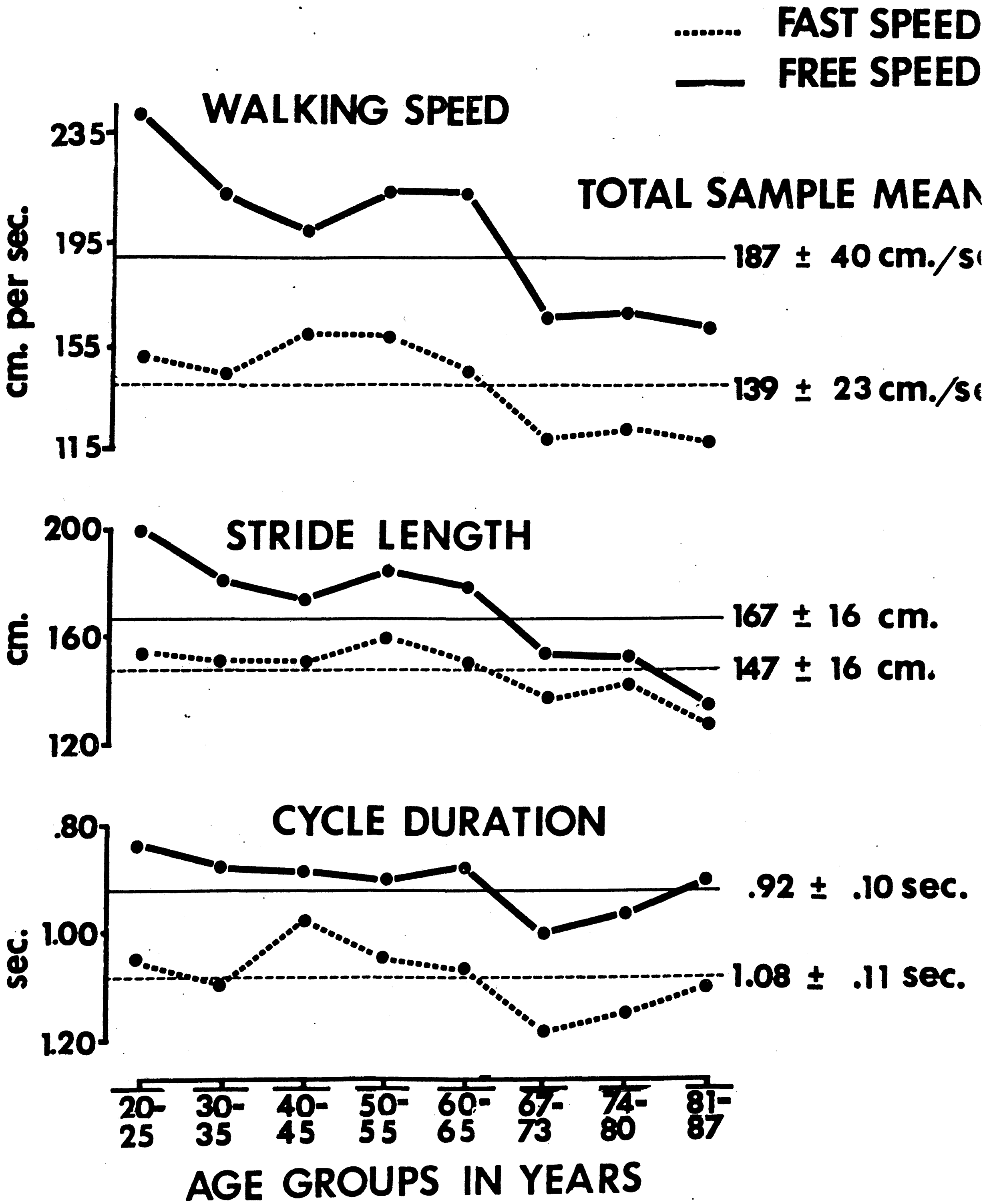


FIGURE 3



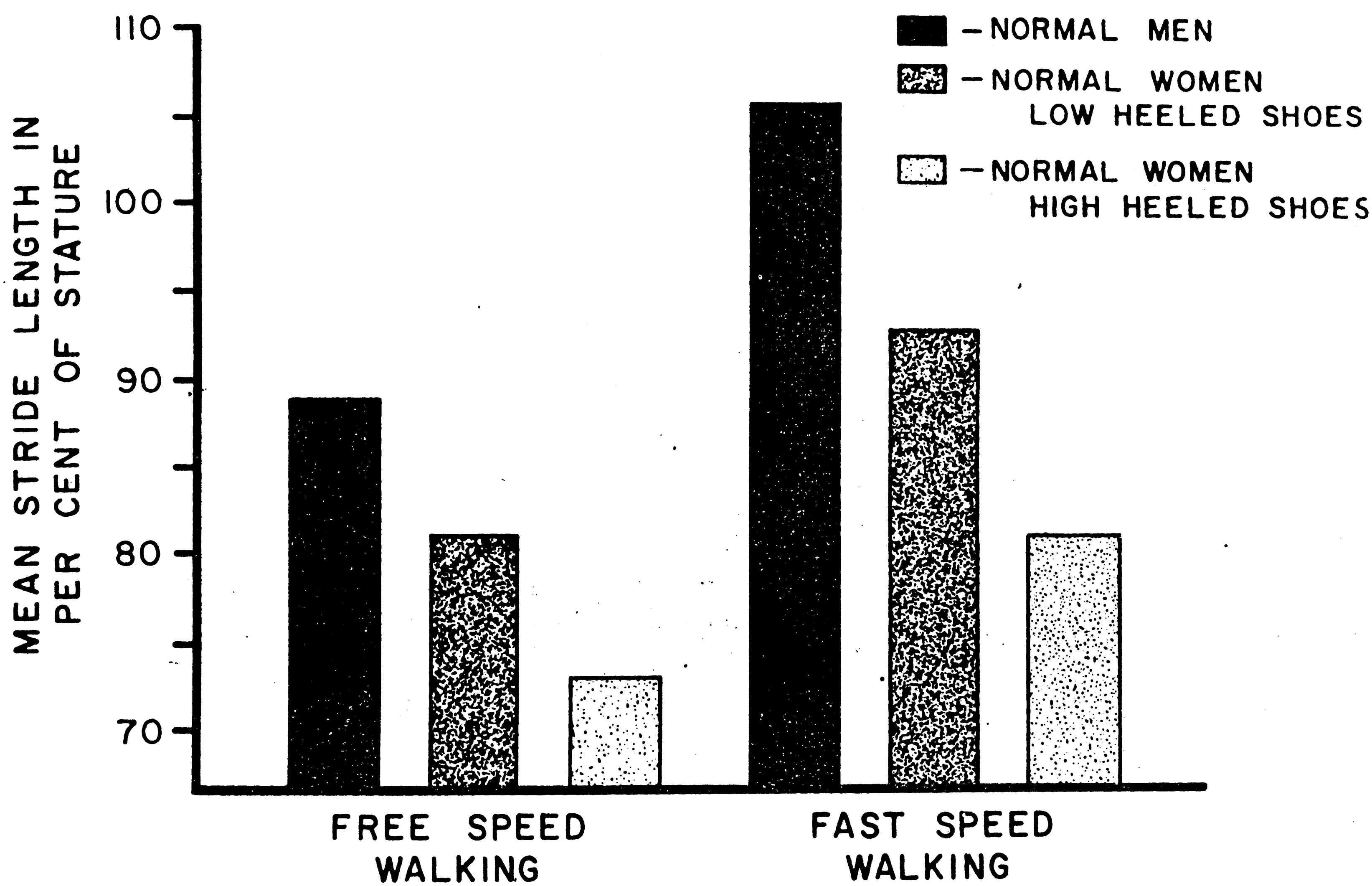
FREE SPEED
FAST SPEED
THORAX
1 DEGREE
PELVIS
1 DEGREE
TRANSVERSE ROTATION IN DEGREES
CCW
CW
0
25
50
75
100
PERCENT OF WALK CYCLE

FIGURE 4



FAST SPEED
FREE SPEED
WALKING SPEED
TOTAL SAMPLE MEAN
235
195
155
115
cm. per sec.
187 ± 40 cm./s
139 ± 23 cm./s
STRIDE LENGTH
200
160
120
cm.
167 ± 16 cm.
147 ± 16 cm.
CYCLE DURATION
.80
1.00
1.20
sec.
.92 ± .10 sec.
1.08 ± .11 sec.
20-25
30-35
40-45
50-55
60-65
67-73
74-80
81-87
AGE GROUPS IN YEARS

FIGURE 5


MEAN STRIDE LENGTH IN
PER CENT OF STATURE
110
100
90
80
70
— NORMAL MEN
— NORMAL WOMEN
LOW HEELED SHOES
— NORMAL WOMEN
HIGH HEELED SHOES
FREE SPEED
WALKING
FAST SPEED
WALKING

pain, patients show many characteristic gait abnormalities. Their excessive lateral lurching of the head as compared to normal subjects is illustrated in Figure 6. Figure 7 demonstrates another characteristic of patients with hip pain: they use less than normal hip flexion-extension on the painful side during walking, particularly less hip extension. Even though many of the patients had hip flexion contractures before surgery, there was no correlation between the amount of hip extension they had, as measured by standard methods, and the amount of extension they used during walking.

Figure 8 shows clippings of gait photographs of a patient before and after total hip replacement and of a normal woman of similar age and height. Preoperatively, the patient had restricted excursions of the joints of the lower limb, particularly the hip, during walking. Her excessive and irregular lateral lurching of the head can be seen in the overhead mirror, and the side view of the neck target indicates the slow, stop-start type of forward progression before surgery. Postoperatively, it can be seen that she walked faster, had more joint mobility and had smoother forward and lateral motion of the trunk.

Figure 9 shows the average amount of lateral lurching before and six and twenty-four months after surgery for 100 patients with uncomplicated McKee-Farrar total hip replacement. Although the amount of lateral lurching was definitely decreased after surgery, the patient groups did not reach the limits of normal variability by the second postoperative year. The greatest improvement was made during the first six months after surgery, with lesser but continued improvement between the sixth and twenty-fourth postoperative months. These statements apply not only to lateral lurching, but to most of the measurements of walking performance which we made during this study (10).

In contrast, Figure 10 shows examples of declines in functional performance which were measured in this same study in seven patients who had operative or postoperative complications, mainly infection or prosthetic component loosening. Here the declining performance of the patients with complications is compared to the average improvement of the group without complications.

Our normal studies have also been used to provide standards in studies comparing groups with different types of total hip replacement (11). For example, Figure 11 shows the average improvement in the amount of hip flexion-extension used during walking by three groups of men before and six months after different types of hip replacement as compared to normal men. The average measurements were similar for the three groups six months after operation; however, we found that the patients with bilateral disability improved much more than those with unilateral disability in this particular component of function. Whether these trends will persist or change with time is the subject of a future longitudinal study.

Improvement toward a more normal gait has also been measured in patients with Geometric knee replacement (12). Figure 12 shows average patterns of knee flexion-extension throughout the walking cycle for patients before and three, six and twelve months after knee replacement as compared

FIGURE 6

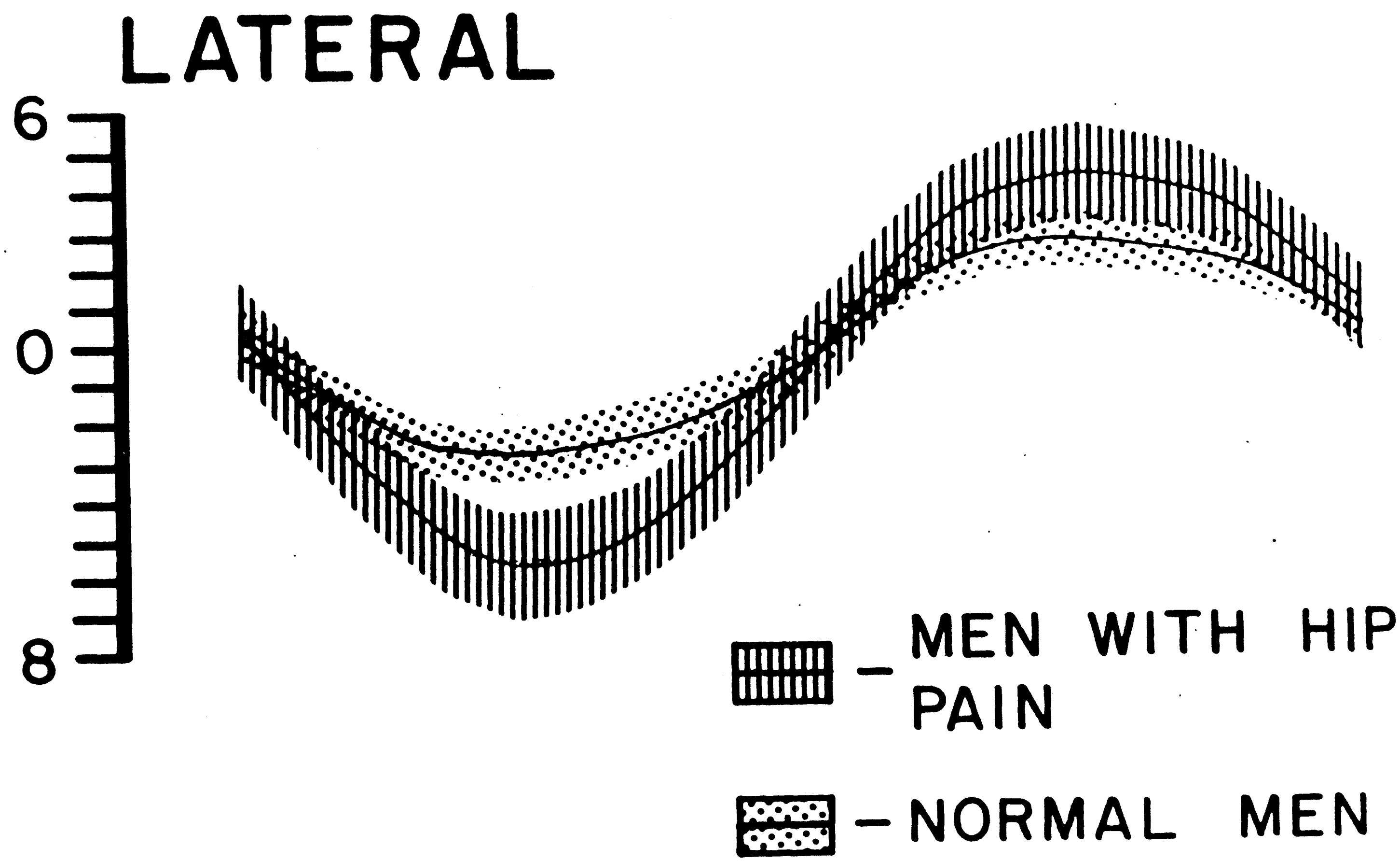
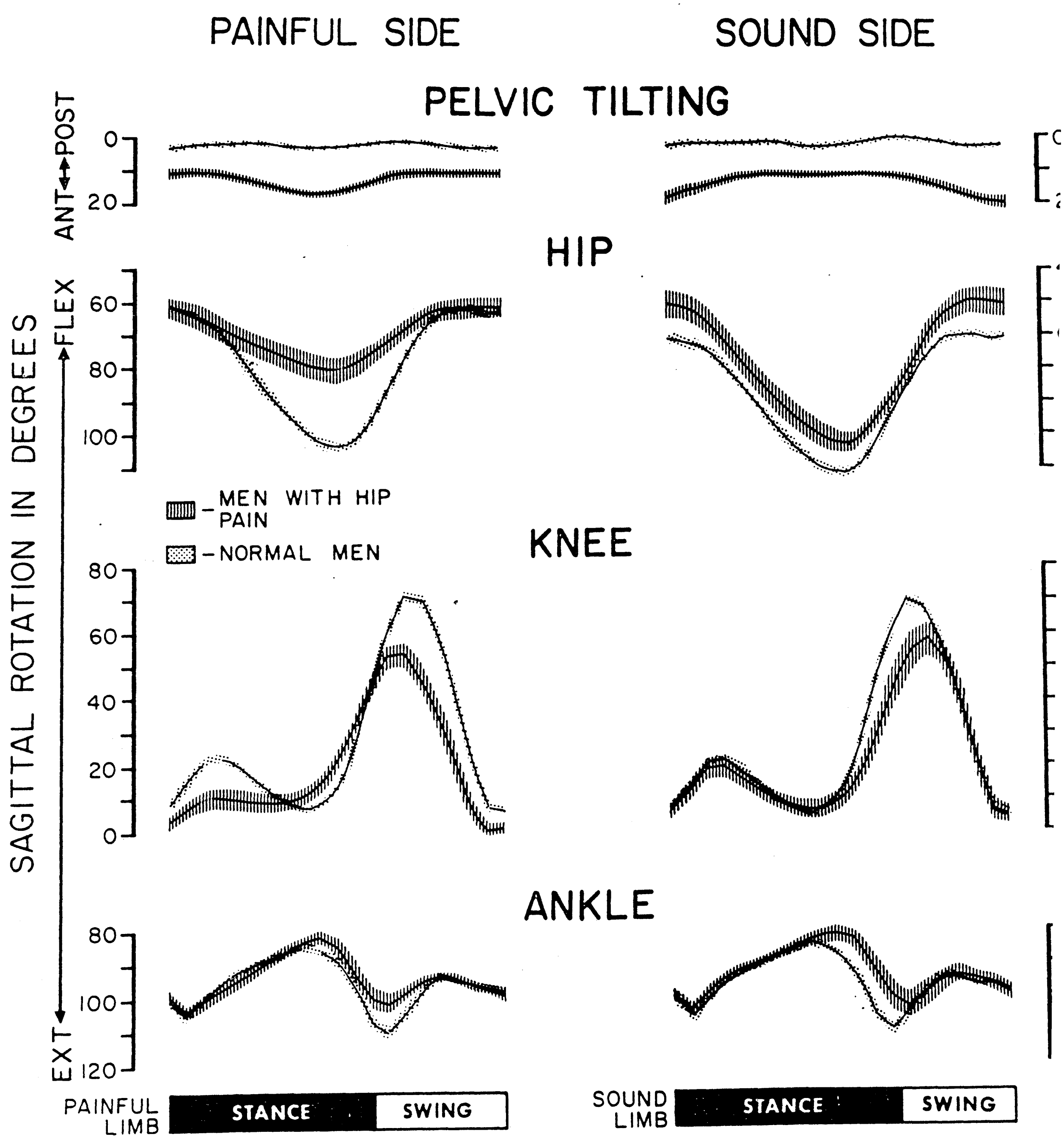


FIGURE 7


PAINFUL SIDE
SOUND SIDE
PELVIC TILTING
ANT ↔ POST
0
20
HIP
FLEX
60
80
100
MEN WITH HIP PAIN
NORMAL MEN
KNEE
80
60
40
20
0
ANKLE
80
100
120
EXT
SAGITTAL ROTATION IN DEGREES
PAINFUL LIMB
STANCE
SWING
SOUND LIMB
STANCE
SWING

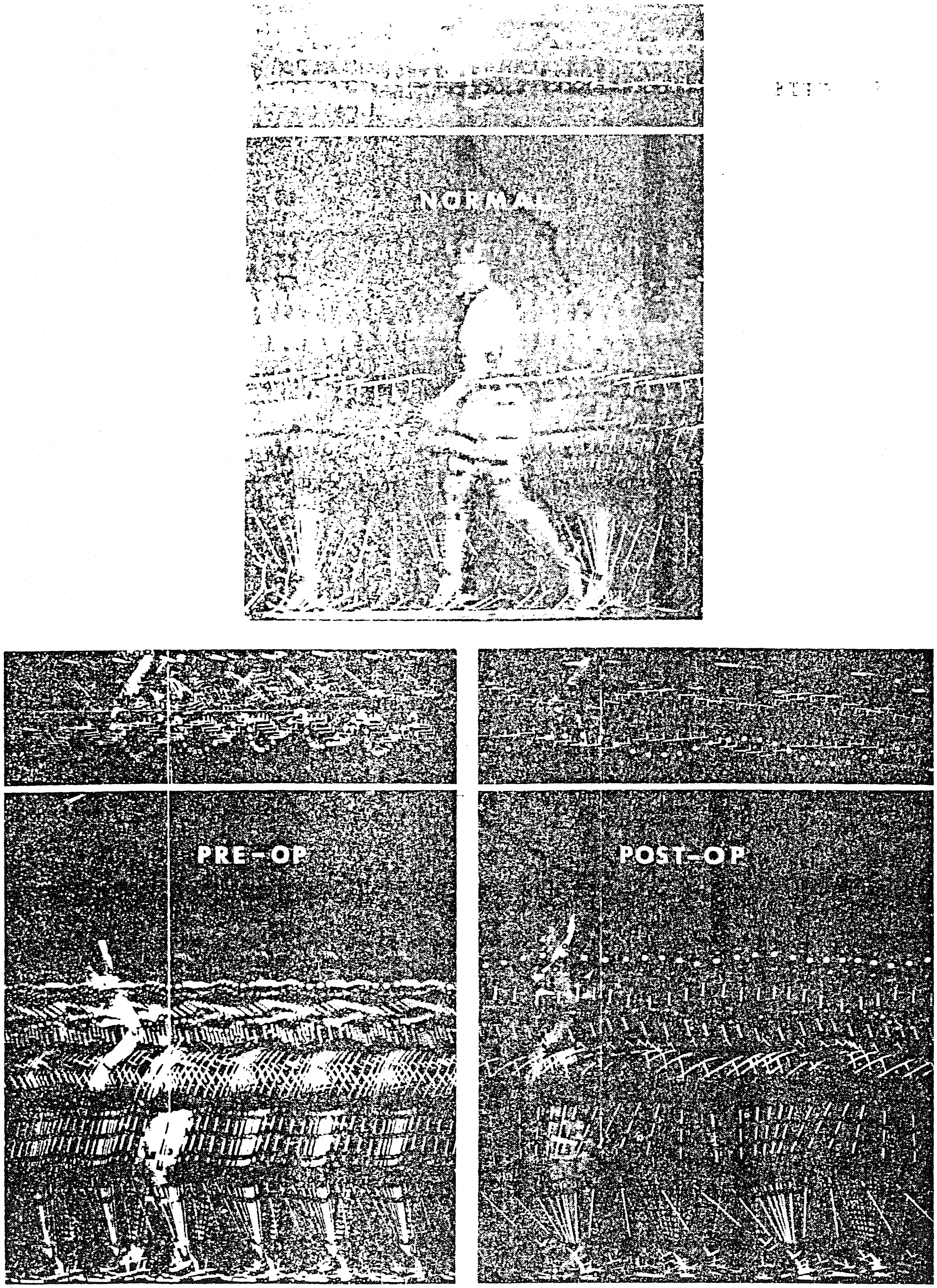

NORMAL
PRE-OP
POST-OP

FIGURE 9

LATERAL MOTION OF THE HEAD (CM)

McKEE-FARRAR

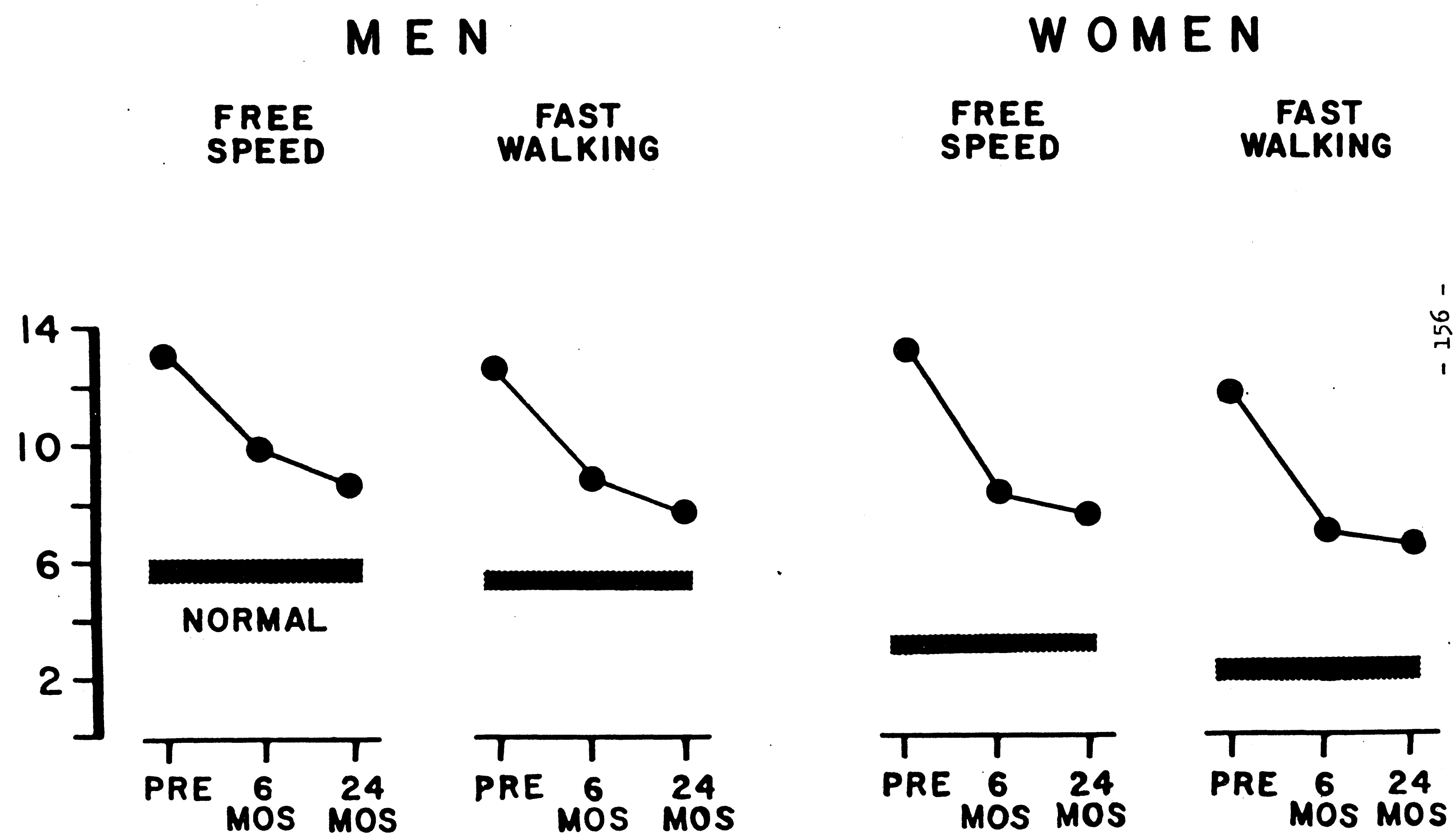


FIGURE 10

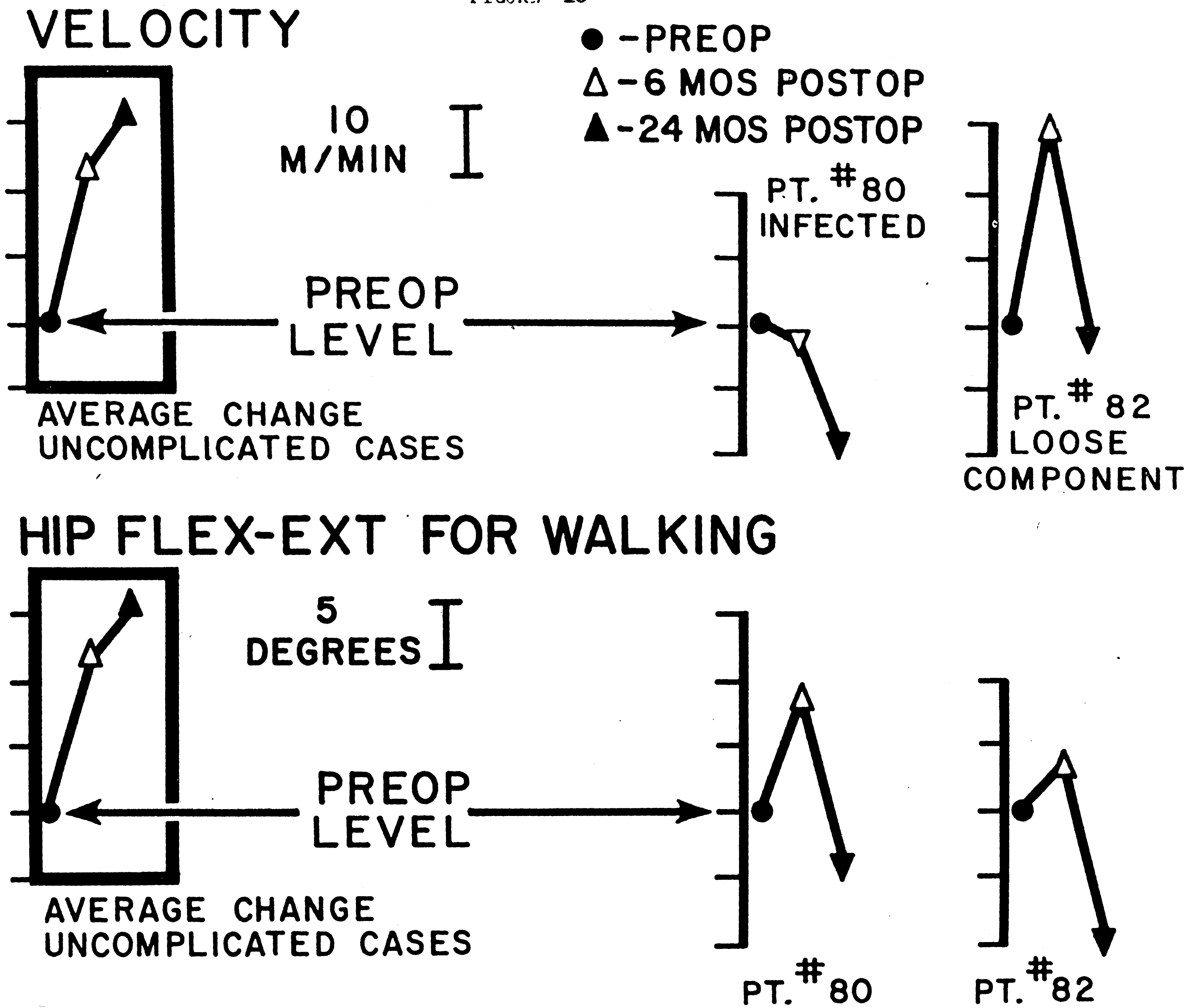

VELOCITY
● -PREOP
Δ -6 MOS POSTOP
▲ -24 MOS POSTOP
10
M/MIN
PREOP
LEVEL
AVERAGE CHANGE
UNCOMPLICATED CASES
PT. #80
INFECTED
PT. # 82
LOOSE
COMPONENT
HIP FLEX-EXT FOR WALKING
5
DEGREES
PREOP
LEVEL
AVERAGE CHANGE
UNCOMPLICATED CASES
PT. #80
PT. #82

FIGURE 11

TOTAL EXCURSION OF HIP FLEXION-EXTENSION

MEN — FREE SPEED WALKING

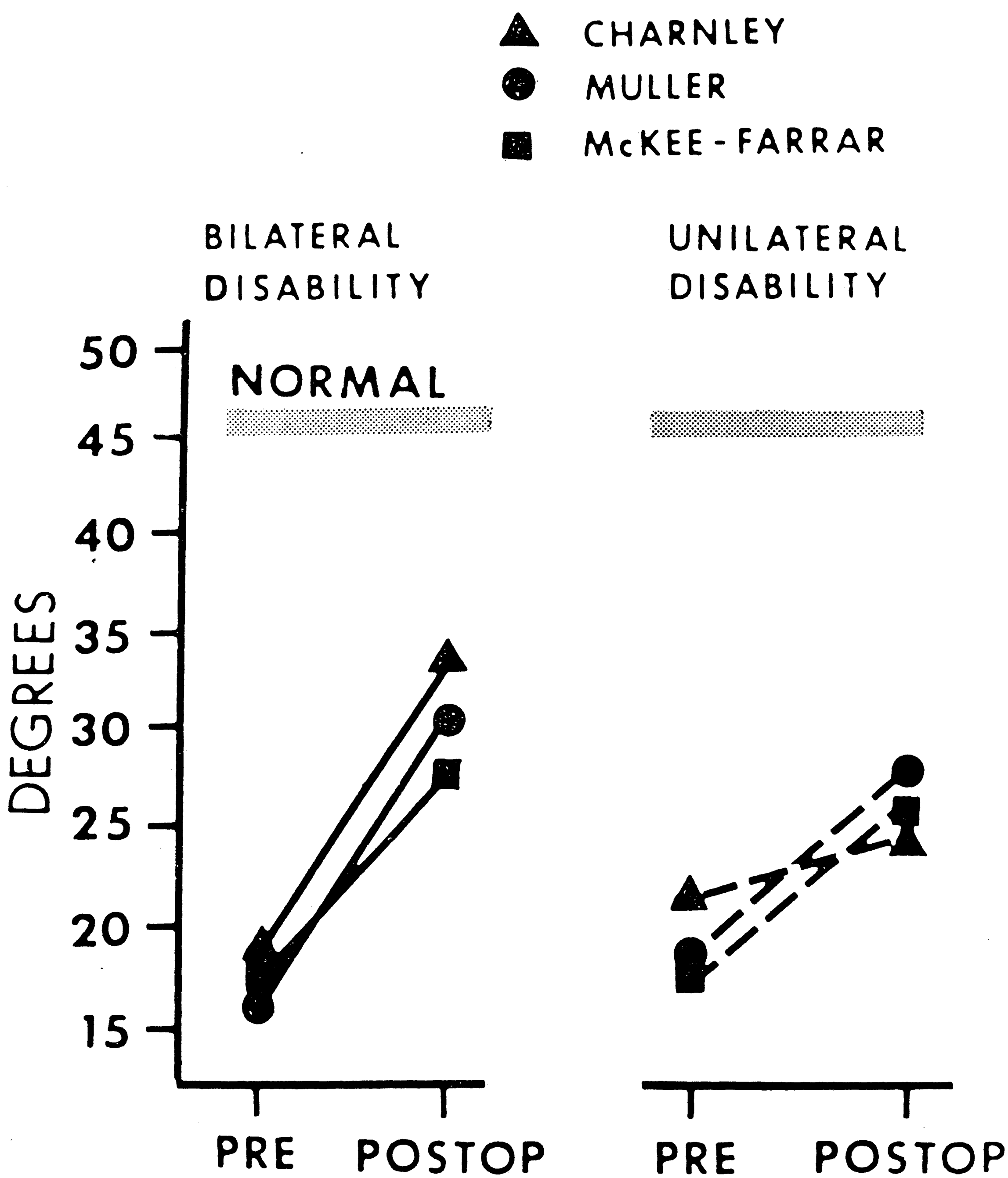
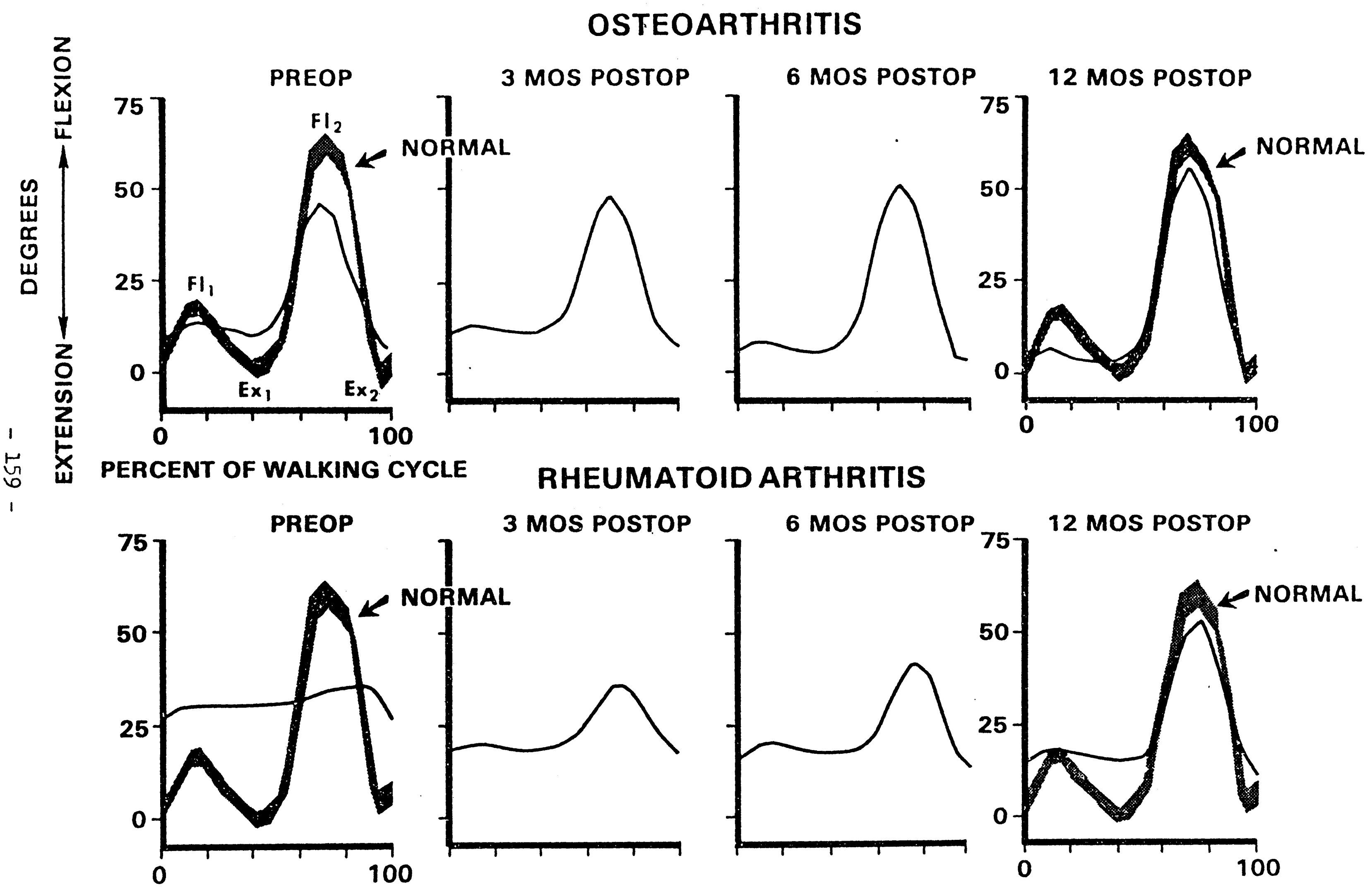


FIGURE 12

KNEE FLEXION-EXTENSION DURING WALKING



to normal. The knee motion of the patient groups was strikingly different from normal before surgery, particularly for the group with rheumatoid arthritis. Although the group with rheumatoid arthritis improved considerably, their average knee pattern was still more abnormal than that of the group with osteoarthritis one year after operation.

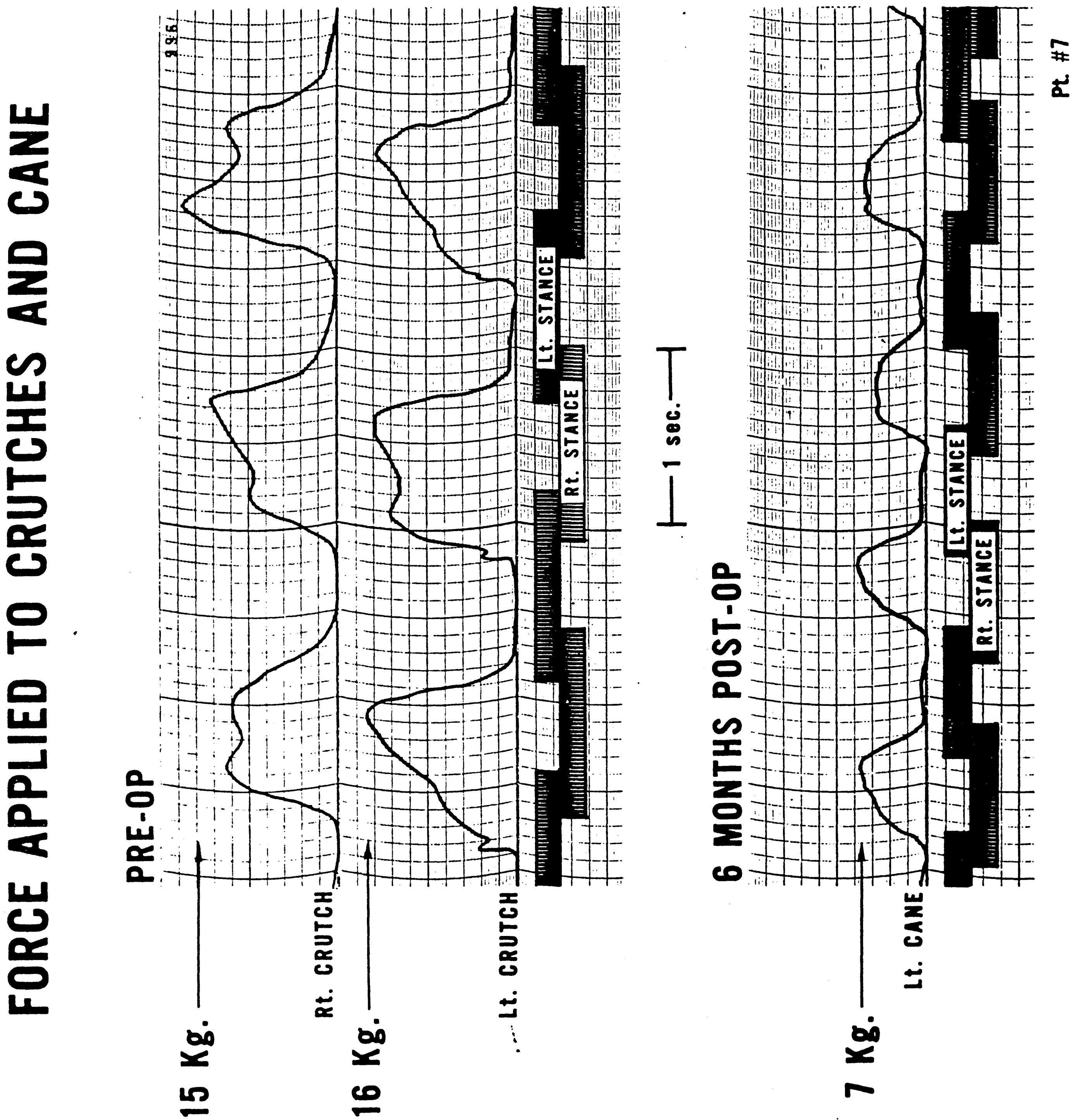
Although this paper was to address itself to gait, it is important to note that we take a multifaceted approach and measure various components of function in the different joint replacement studies. As an example, if the patient uses an assistive device during walking, we monitor the thrust force applied to the canes or crutches simultaneously with foot-floor contact times from our electronic walkway (13-15). Portions of the records of a patient before and after total hip replacement are shown in Figure 13. The dark horizontal bars under the force pattern indicate the durations of the right and left stance phases. For joint replacement studies, we have chosen to report the mean integrated area under the force curve which occurred during the stance phase of the operative limb, and we believe that this provides an additional sensitive measure of change in functional performance.

We also measure strength of particular muscles which span the joint to be replaced. In Figure 14, average gains in strength of the hip adductor muscles from before to six months after surgery are shown for groups of men and women with three different types of hip replacement. The standards for normal subjects were obtained prior to beginning the hip replacement studies (16). While these preliminary findings of differences among the groups are fascinating, they should not be regarded as conclusive since our previous studies have demonstrated that further improvement in functional performance occurs in many patients after the sixth postoperative month.

As a final example, we also measure weight distribution between the feet during one-minute periods of comfortable standing. Figure 15 shows patients with hip and ankle disabilities standing on the platform (17). These platform measurements are also extremely useful in our pre- and postoperative studies of functional performance of patients with hip and knee disabilities.

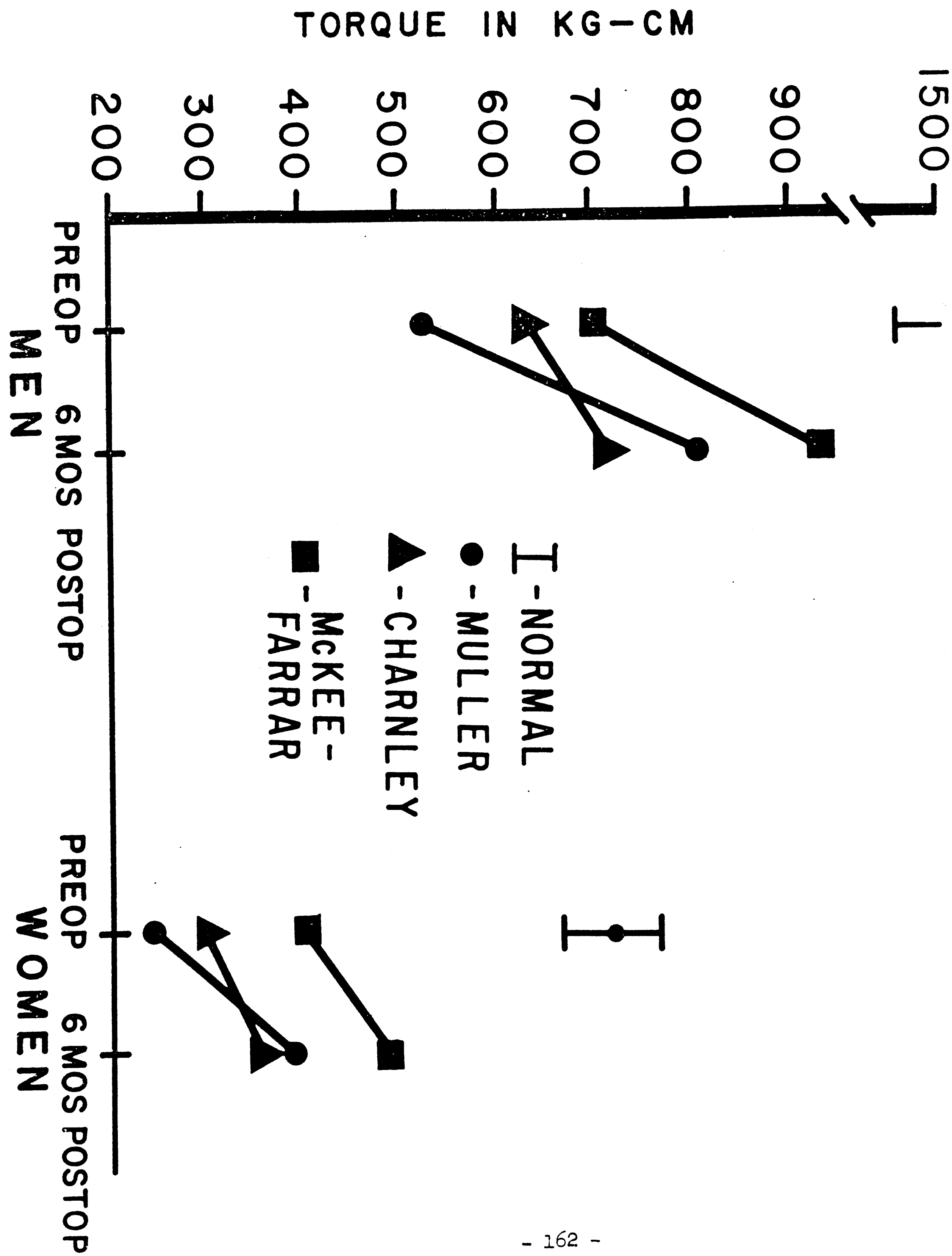
Although patients' subjective impressions are important, they are of little value in a critical evaluation of a given procedure or in comparing the results following different types of procedures. It is hoped that this type of quantitative information will lead to a deeper understanding of the manifestations of the various disease processes and to optimal therapeutic efforts directed toward restoring functional performance.

FIGURE 13

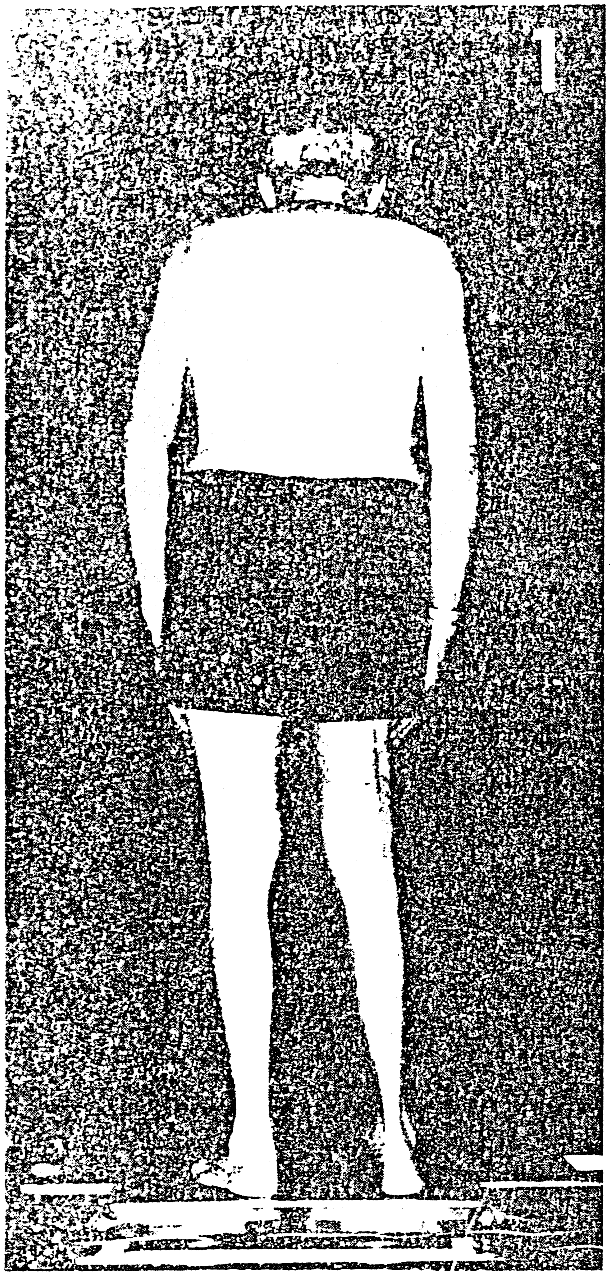


FORCE APPLIED TO CRUTCHES AND CANE
PRE-OP
15 Kg.
Rt. CRUTCH
16 Kg.
Lt. CRUTCH
Lt. STANCE
Rt. STANCE
1 sec.
6 MONTHS POST-OP
7 Kg.
Lt. CANE
Lt. STANCE
Rt. STANCE
Pt. #7

FIGURF 14

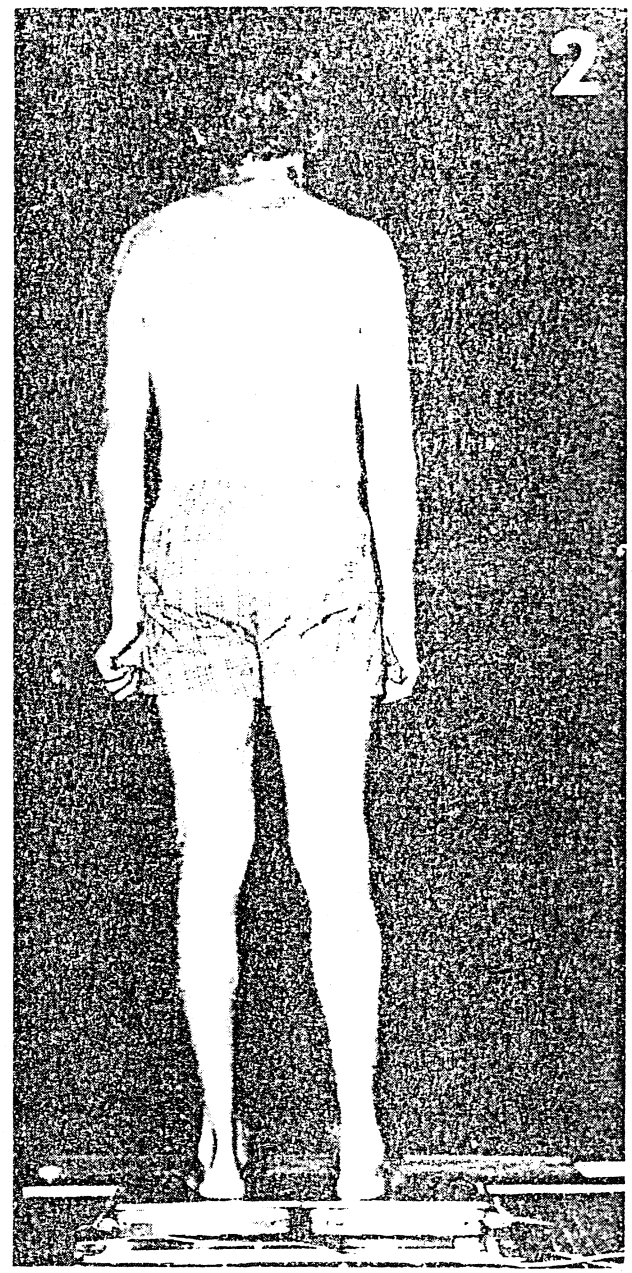


TORQUE IN KG-CM
1500
900
800
700
600
500
400
300
200
PREOP
6 MOS POSTOP
MEN
PREOP
6 MOS POSTOP
WOMEN
- NORMAL
- MULLER
- CHARNLEY
- McKEE-FARRAR



LT.= 41 kg RT.= 28 kg

Solid Union, Rt. Intertroch. Fracture



LT.= 46 kg RT.= 24 kg

Acute Sprain, Rt. Ankle

Figure 12. Mean patterns of knee flexion-extension throughout the walking cycle for patients with rheumatoid and osteoarthritis before and at intervals after Geometric knee replacement. The shaded area represents the mean pattern and two standard errors above and below the mean for normal men of similar age and height.

Figure 13. Polygraph records showing forces a patient applied to axillary crutches before hip replacement and to a cane six months after hip replacement. Foot-floor contact times are indicated by the dark bars below.

Figure 14. Mean maximum isometric torque of the hip adductor muscles before and at six months after surgery for groups of men and women with Muller, Charnley and McKee-Farrar total hip replacement. The dots and vertical bars indicate the means and two standard errors above and below the means for normal men and women.

Figure 15. Photographs of disabled patients on a force platform device as weight distribution was being monitored.

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