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A COMPARISON OF SOME GAIT CHARACTERISTICS WITH SIX KNEE JOINTS[1]

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Patients with above-knee amputations are provided empirically with various types of knee joints. Factors which may be considered are the stability of the knee in stance phase, maintenance problems, and cost of the prosthesis. Little consideration has been given to the effect on gait of different knee joints. Various claims are advanced by manufacturers for different brands of knee joints but little evidence is available from dynamic studies to support such claims.

The present investigation involved seven male above-knee amputees who were fitted serially with six types of knee joints. Gait characteristics of the subjects were analyzed with each device to ascertain any differences that resulted as the joints were used. The fittings were carried out by a well-qualified prosthetist who fabricated a lightweight plastic socket which permitted the substitution of various knees. This, and suitable attention paid to alignment, allowed reproducible study of the gait variables of each knee.

METHODS

The knees used in the study were:

Dyna-Flex Hydraulic Knee	[38]
Hosmer Pneumatic Knee	[39]
Bock 3P23 Knee	[45]
Kolman Safety Knee	[49]
Mauch S-N-S Knee	[59]
Blatchford Stabilized Knee with Pneumatic Swing Control	[61]

as catalogued in the United States Veterans Administration publication entitled *Selection and Application of Knee Mechanisms* (*5*). The numbers in the brackets indicate the page number in the VA publication.

Each subject was fitted with the knee joint and given an opportunity to practice during morning hours. In the afternoon of the same day he was observed in our laboratory and, after satisfying himself of his best gait, recording of gait variables was made. The next day the same procedure was carried out with a different knee joint. Gait characteristics of the intact leg and prosthesis were determined by direct measurement of knee angle, heel strike to toe-off interval, and average stride length.

A goniometer was mounted concentrically on the knee joint. A 10kΩ Ohmite potentiometer was attached to the arms of the goniometer (Figs. 1 and 2). Suitable resistances were placed in series with the potentiometer to give an output of approximately 0–5 volts within 0–100 degrees of knee flexion. Repeatability and accuracy of the goniometer angle measurement were about 2 percent.

A miniature spring-loaded push-button foot switch was attached to the heel and another to the toe of the shoe to indicate the time of heel strike and toe-off. The output from these devices was fed by lightweight twisted-pair wire to a miniature chassis box mounted on the subject's belt. A heavier gauge cable fed the signal away to a tape recorder. An assistant walked beside the patient to prevent the cable from interfering with freedom of movement.

A Crown 700 Series, MOD IM 7 tape transport allowed the standard tape recording of DC signals. Two channels of the FM section were used to record the knee-angle and foot-switch contact times. Another channel recorded the observers' comments from start to finish of the walk.

The data from the tape recorder were displayed

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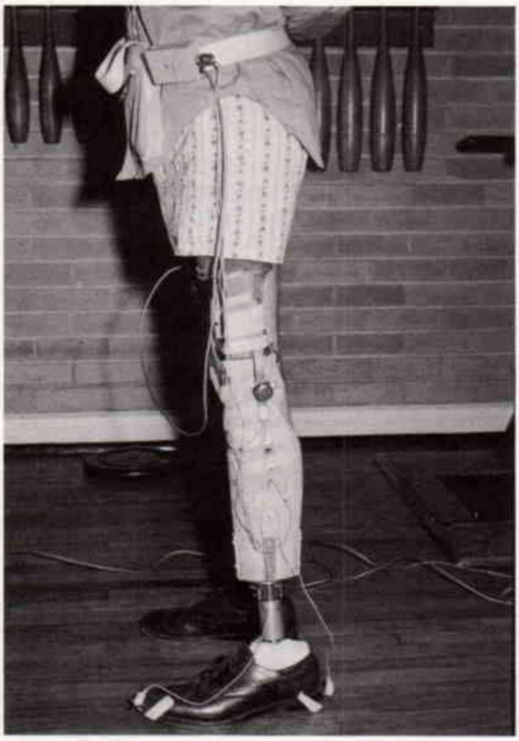

Fig. 1. Instrumented prosthesis for measuring characteristics of gait of above-knee amputees.

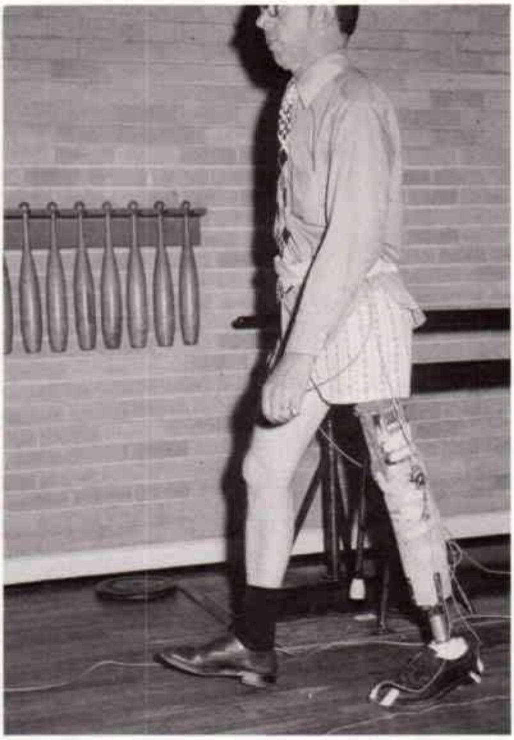

Fig. 2. Above-knee amputee subject walking while using instrumented prosthesis to record gait characteristics.

on a Tectronic Oscilloscope, Model 564, which allowed monitoring and rapid analysis of gait pattern. The oscilloscope has a split-screen storage capability which permits the signal to be viewed at various speeds and amplitudes. Each flexion cycle was superimposed onto previous ones to determine average times during a walk.

The measurements were made on a level walkway 15 meters long. The first and last three meters were used to stabilize gait and permit deceleration. Three walks were performed with each prosthetic knee and the results were examined for repeatability before being retained. In the statistical analysis the arithmetical mean value and standard deviation were calculated.

The variation around the mean values for each subject for the cycles during which measurements were made was very small for all variables. This was considered to mean that during the recordings, the patient walked naturally and attained steady state as regards his gait. None of the subjects used a cane or other support while the recordings were being made.

Mean age of the subjects was 41 years (range 22–56), body height 179 cm (range 165–188), and body weight 71 kg (range 64–77). The mean stump length was 31 cm (range 25–39) corresponding to about 65 percent of the length of the intact femur.

A prosthesis-evaluation questionnaire was given to each subject and to a trained observer to provide additional information on the amputee's walking pattern. The factors investigated included pain, fatigue, cosmesis, gait rhythms, and specific complaints.

As a comparison point for this group of amputees, studies reported by James *et al* (*1*) and Murray *et al* (*4*) were chosen. In those studies, gait characteristics at a normal walking speed were studied in 34 male unilateral above-knee amputees wearing various knee joints and 30 normal male subjects, respectively.

RESULTS AND DISCUSSION

Table 1 gives the mean value, standard deviation, and range for normal walking speed and the corresponding values for walking cycle duration, step frequency, and stride length in the group of amputees. Comparative data reported by James *et al* (AK amputees) and Murray *et al* (normal subjects) are also given.

Table 2 presents the mean values and standard deviations for duration of stance and swing phase, the step-length difference between prosthesis and intact leg, and heel rise. Comparative data, as in Table 1, are also given.

Table 3 and Table 4 summarize patients' and observers' comments, respectively. McAndrew was selected as being representative of patients whose experience was of free-swinging knees. Reid had used the Hosmer pneumatic prosthesis for four years prior to the study.

The characteristics that were measured directly are knee angle, heel strike and toe-off time, stride length, and walking cycle. From these data one can calculate accurately walking speed,

TABLE 1. VALUES FOR GAIT VARIABLES OF SIX PROSTHESES AT NORMAL WALKING SPEED
(Standard deviation and range are given in parentheses.)

	Kolman Bock Blatchford	Mauch S-N-S	Dyna-Flex Hosmer	James (*1*)	Murray (*4*)
Walking Speed (cm/sec)	85 (18) (55–115)	83 (16) (59–104)	92 (15) (56–113)	94 (15) (63–123)	151 (20)
Stride Length (cm)	119 (20) (75–150)	120 (20) (89–147)	125 (20) (86–135)	129 (17) (95–162)	156 (13)
Step Frequency (steps/min)	82(10) (63–94)	84 (7) (74–93)	87 (4) (79–94)	85 (72–105)	113
Walking Cycle (sec)	1.50(0.24) (1.26–2.01)	1.44(0.19) (1.26–1.82)	1.47(0.15) (1.26–1.87)	1.41(0.12) (1.14–1.67)	1.06 (0.09)

TABLE 2. VALUES FOR WALKING CYCLE COMPONENTS AT NORMAL WALKING SPEED
(Standard deviations are given in parentheses.)

	Kolman Bock Blatchford	Mauch S-N-S	Dyna-Flex Hosmer	James (*1*)	Murray (*4*)
Stance Phase (sec) Percent of Cycle	0.087 (0.03) 58	0.92 (0.03) 59	0.93 (0.02) 59	0.80 (0.08) 57	0.65 (0.07) 61
Swing Phase (Sec) Percent of Cycle	0.63 (0.031) 42	0.52 (0.03) 41	0.54 (0.02) 41	0.61 (0.05) 43	0.41 (0.04) 39
Step Length Difference Prosthesis—Intact leg (cm)	1.0 (0.10)	0.0 (0.12)	1.0 (0.09)	5.8 (0.10)	0.0 (0.09)
Heel Rise (cm)	20 (10)	16 (10)	12 (6)	------	------

TABLE 3. SUMMARY—SIX KNEES—PATIENTS' COMMENTS

Knee	McAndrew	Reid
Own	—Thinks it's OK, although he knows it's not very good and that better units are available (free swing—no resistance).	See Hosmer (suction pneumatic)
Bock	—Much better than his own, likes security. Terminal impact, medial whip and vaulting present.	—Felt flexion was less than it actually was. Likes it better than Kolman.
Kolman	—As Otto Bock, but more security.	Good stability—not as smooth as his own (i.e., terminal impact objectionable).
Dyna-Flex	Stable upon heel strike—thought flexion was less than it actually was—Kolman better.	Didn't like it at all—worked opposite to his own (pneumatic).
Mauch S-N-S	—Felt heavy. Likes ease of adjustment. Feels there is almost no flexion even though it may be 50 percent.	Very smooth walk—the only one we tested that he would like to wear.
Hosmer	—Very smooth walk; he said it's a "rolling" type of walk (after proper adjustment).	He is happy with it—except slight abduction makes him "pull in" the prosthesis to get it "under him." (Fitting problem.)
Blatchford	—As Hosmer—more "safety" upon heel strike with this one.	Not as good as his own—likes Mauch S-N-S better—stance not smooth and even.

step frequency, stance- and swing-phase duration, heel rise, and the difference in stride length between prosthesis and intact leg.

The knee-flexion angle was studied throughout each angle to calculate the time interval between the start of flexion and toe-off and the degree of heel rise. The interval between the start of flexion and toe-off was constant to within 0.03 second for each subject and did not vary with the type of prosthesis. However, subjects with longer time intervals, *e.g.*, Reid, exhibited a better quality gait in the opinion of the observer.

Heel rise was assumed to be a function of knee angle only, and was calculated as the distance between heel and floor at maximum knee angle. Hip rotation and vertical hip motion [4 cm. for normals according to Lamoreux (*3*)] were assumed to be constant at a normal walking speed. This was observed to be especially valid for the cadence responsive knees. Table 2 indicates the large variation in heel rise for all subjects wearing the same prosthesis. The pendulum effect was pronounced since the time interval from toe-off to maximum flexion tended towards a constant value of 0.25 second.

The most significant conclusion from the data of Table 1 is that cadence-responsive knees allow significantly greater walking speed with a minimum of effort. Further confirmation is found in the comments of Tables 3 and 4. As expected, the stance- and swing-phase intervals decrease in proportion to walking speed. The patients with the greatest body height walked with a longer step, and had a somewhat shorter walking-cycle

TABLE 4. BASIC SUMMARY—SIX KNEES—OBSERVERS' COMMENTS OF PATIENTS' GAIT

Knee	McAndrew	Reid
Own	Very bad—vaulting, terminal impact excessive, medial whip, excessive heel rise.	See Hosmer
Bock	Some improvement only, over his own.	As Kolman, but somewhat better.
Kolman	Walks better than with his own but still with same gait problems (terminal impact).	Very irregular, jerky walk. Terminal impact.
Dyna-Flex	Kicked his stump to overcome knee's resistance with success, resulting in a bad walk (excessive terminal impact).	A poor walk—pneumatic resistance of his own worked opposite to this one. (Prosthesis poorly built—terminal impact and resistance in swing phase high.)
Mauch S-N-S	Too dramatic change from his own. Even at minimum resistance is too much. Ext. resistance stops stump kicking—good stability.	Very smooth walk—no problems.
Hosmer	Very good—smooth and easy.	This is his own—a very good walker prosthesis, has slight abduction.
Blatchford	Same as Hosmer—it seems the hydraulic knees are too "stiff" for him. The lower resistance of the pneumatics (Hosmer and Blatchford) seems ideal for him.	Walks better with his own—the stance control was jerky (seemed to take too much effort to get knee extended).

duration than those with the lowest body height. They had, furthermore, higher maximal and normal walking speeds.

With few exceptions, the material of James *et al* indicates that the subjects took longer steps with the prosthesis than with the intact leg. They believe that the full extension of the hip on the prosthesis side was prevented by pressure of the prosthetic socket against the ischial tuberosity. This limitation can also contribute to making the stance phase of the prosthesis shorter than that of the intact leg. The data from our Table 2 show that the stride length of the intact leg follows closely that set by the prosthetic limb as first reported by Karpovitch (*2*). This is most likely a result of the close attention paid to alignment and construction of a comfortable socket for this study. None of the subjects experienced any great discomfort or pain with any of the interchangeable knee joints.

The values of gait variables for each subject were usually clustered within a narrow range regardless of the prosthesis. This may indicate the influence of a stable, well-fitted socket with the prosthetic knee joints. It appears that the subject walks with a characteristic gait pattern of his own on any stable prosthesis.

All units tested were stable on heel strike. As expected, the Kolman and Bock units had to be readjusted constantly as a result of wear on the braking surfaces.

The knees with mechanical friction exhibit excessive heel rise and terminal impact of the prosthesis as it goes into full extension.

MAIN CONCLUSION

In spite of the claims of manufactuers, it appears that on flat level surfaces it is the patient who walks the prosthesis and controls gait variables. The more complicated designs seem to have no great advantages over the simpler ones for walking on flat level surfaces.

Stability at the beginning of stance (heel strike) and mid-stance is common to all these knee joints when properly fitted and aligned. Complex units do not necessarily give a better gait.

This study was confined to straight walking on a flat level surface and the number of subjects was limited because of a lack of funds. It is suggested that the study be expanded to include more subjects on varied terrains.

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