Socket Flexion and Gait of an Above-Knee, Bilateral Amputee

EDWARD PEIZER, PH.D.[1]

M ANY factors affect the gait of an above-knee, bilateral amputee as he walks on his prostheses. Among the factors are his general health and strength, the length and condition of his stumps, the alignment of his prostheses, his comfort, and the type of knee units employed.

While some of these factors are difficult to observe accurately, others lend themselves to objective measurement and evaluation by means of current bioengineering techniques. Not long ago, the Bioengineering Laboratory of the Veterans Administration Prosthetics Center had occasion to evaluate the gait of an above-knee, bilateral amputee, and in the course of the evaluation developed records that show graphically the "before" and "after" effect of increased hip flexion of about 10 deg. in both sockets.

BACKGROUND

An above-knee, bilateral, 26-year-old, male amputee veteran, who was fitted with two suction sockets and two Hydra-Cadence knee units, was referred to the Bioengineering Laboratory for gait evaluation. The amputations resulted from an automobile accident; the patient was a vigorous young man in good health, with well-muscled, strong stumps. He weighed 158 lb. with prostheses, stood 5 ft. 8 in., had 12-in. stumps, and had worn constant-friction knee units for two years. In May 1962, he was fitted with one Hydra-Cadence unit, and approximately three months later was fitted with a second Hydra-Cadence unit.

After he had worn both units for three or four months, evaluation indicated that, although he managed two suction sockets adequately, the two Hydra-Cadence units produced a jerkiness in his gait which was tentatively attributed to the higher energy requirements of the hydraulic units.

The clinic team recommended that both Hydra-Cadence units be replaced with constant-friction units and requested the Bioengineering Laboratory to obtain photographic records of his performance on the Hydra-Cadence units for subsequent comparison with records to be obtained of his performance on the constant-friction units.

On May 15, 1963, the amputee appeared at the Bioengineering Laboratory for evaluation. Preliminary examination of the prostheses indicated only marginal—if not inadequate—initial hip flexion. Observation of the subject's gait tended to confirm this impression; he seemed exceptionally "stable" and found it necessary to jerk his knee forward to initiate the swing phase. This produced a marked lurching pattern in his gait.

The Bioengineering Laboratory recommended realignment of the prostheses, with particular emphasis on increasing initial hip flexion as a step which might improve function and obviate the necessity for refitting with constant-friction knee units. The clinic team concurred. A biomechanical analysis of the amputee's performance with his unaltered prostheses was conducted at the Laboratory on May 15. On May 24, 1963, after the amputee's prostheses were realigned by procedures which did not involve refabrication of the sockets, his performance was re-evaluated.

PROCEDURES

The purpose of the two biomechanical evaluations was to identify changes in the gait pattern of the amputee which might have

[1] Chief, Bioengineering Laboratory, Veterans Administration Prosthetics Center, 252 Seventh Ave., New York 1, N. Y.

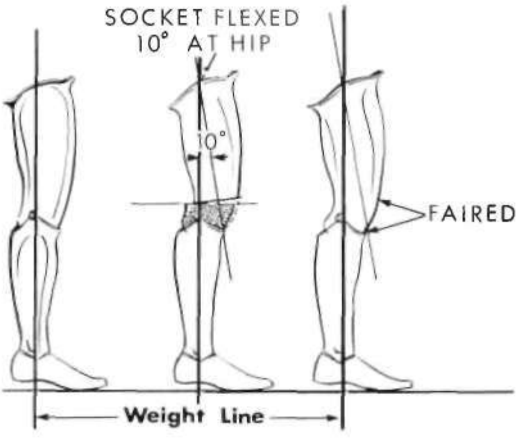

Fig. 1. Socket realignment to provide 10 deg. of initial hip flexion.

occurred as a result of changing the attitude of both sockets so as to increase initial hip flexion (Fig. 1).

Because of the length of the amputee's stumps (12 in.) and the need to maintain cosmetic acceptability, the maximum increase of hip flexion possible was from 0 deg. to 10 deg. This change in attitude was intended to increase the amputee's functional range in hip extension and thereby improve his control of knee stability during stance, with potential effects upon his speed of walking, his stride length, the smoothness of the path followed by his center of gravity, the application of his body weight to the floor, the characteristics of his push-off, and his knee flexion at toe-off. Since the change was simply an increase of flexion, and only in one plane, it was accomplished without the use of the VAPC adjustable coupling *(2).*

Although the amputee normally walked with the aid of canes, he did not use them during the two evaluations.

For each evaluation, the amputee walked along a level walkway, first in one direction and then in the other, thus making two transits of the walkway on each occasion. Run No. 1 and run No. 3 were made on May 15; run No. 4 and run No. 5 on May 24. Because of equipment failure on run No. 2, no data are shown for that run.

He was targeted with reflective tape at the head, elbow, hip, knee, ankle, and shoe for photography from the side by an interrupted-light camera during the transits. Also, as he proceeded along the walkway, he stepped on a set of force plates (thus providing a measure of the application of his body weight to the floor). Simultaneously, the tachograph (Fig. 2) measured and recorded his acceleration and velocity. Descriptions of these procedures and devices appeared in *Artificial Limbs* in 1954 *(1).*

RESULTS

AVERAGE VELOCITY

Average velocities, determined by integrating the tachograph curves, are given below in fiftieths of an inch of galvanometer deflection. An increase in velocity may reflect easier initiation of swing phase, an increased push-off force, or greater stride length.

VELOCITY IN TERMS OF GALVANOMETER DEFLECTION
(in 1/50 in.)

Run No.	Prior to Realignment of Prostheses	After Realignment of Prostheses
1	15.9	
3	21.8	
4		27.1
5		24.3

It can be noted that the patient's velocity was greater after realignment of his prostheses—substantially higher in run No. 4, and moderately higher in run No. 5. In Figure 3, the velocity curves prior to realignment fall below the zero velocity level, indicating backward movement. In order to initiate the swing phase, it was necessary for the patient to incline his torso forward, with a consequent rearward thrust of the pelvis. The tachograph recorded this rearward thrust as a backward movement.

AVERAGE STRIDE LENGTH

Stride length is the distance between consecutive heel contacts by the same leg. In this case, increased stride length may be regarded as a result of greater control and strength in hip extension, increased push-off force, and easier initiation of the swing phase.

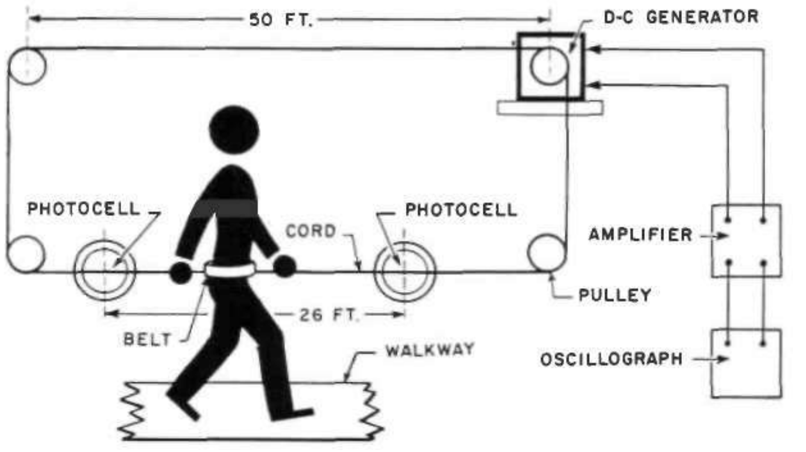

Fig. 2. Schematic diagram of the tachograph, a system for recording linear velocity. The subject wears a lightweight belt, to which is attached a fine cable that turns the rotor of a direct-current generator. Voltage produced by the generator is proportional to the velocity of the subject.

AVERAGE STRIDE LENGTH

Prior to Realignment of	Prostheses:	17.0 in.
After Realignment of	Prostheses:	19.4 in.

SMOOTHNESS OF GAIT

In addition to measuring velocity, the tachogram reflected other elements of the gait pattern. Thus the smoother wave forms recorded after realignment of the prostheses (Fig. 3) indicate less lurching and jerkiness in the gait pattern.

ANTEROPOSTERIOR AND VERTICAL DISPLACEMENTS

No significant differences were observed in the displacement of the head, elbow, hip, and knee after realignment of the sockets. However, the ankle displacement curve (Fig. 4) indicated a more rhythmic oscillation of greater amplitude after the realignment. This motion reflects more normal timing and range of knee flexion.

KNEE FLEXION

Knee flexion at toe-off and during the swing phase prior to realignment of the sockets was variable and at times very limited. After realignment of the sockets, the extent of knee flexion at toe-off and during the swing phase was more consistent and generally of more normal magnitude.

Knee Flexion at Toe-Off in Degrees	Maximum Knee Flexion during Swing Phase in Degrees
Before Realignment	
27.5	51.0
4.5	5.5
41.0	41.0
10.0	13.5
22.0	25.0
After Realignment	
30.0	30.0
38.0	44.5
33.0	39.5
44.0	47.0
43.0	51.0
31.0	31.0

FLOOR REACTION FORCES

In view of the variability of the patient's performance on the four runs, vertical load and fore-and-aft shear forces do not show consistent differences. Nevertheless, reference to Figure 5 indicates that:

The patient applied his full body weight to the prostheses faster after the sockets were realigned.

	Before Realignment *Time in Seconds*		After Realignment *Time in Seconds*
	.300		.260
	.463		.175
	2).763		2).435
Mean	.381	Mean	.218

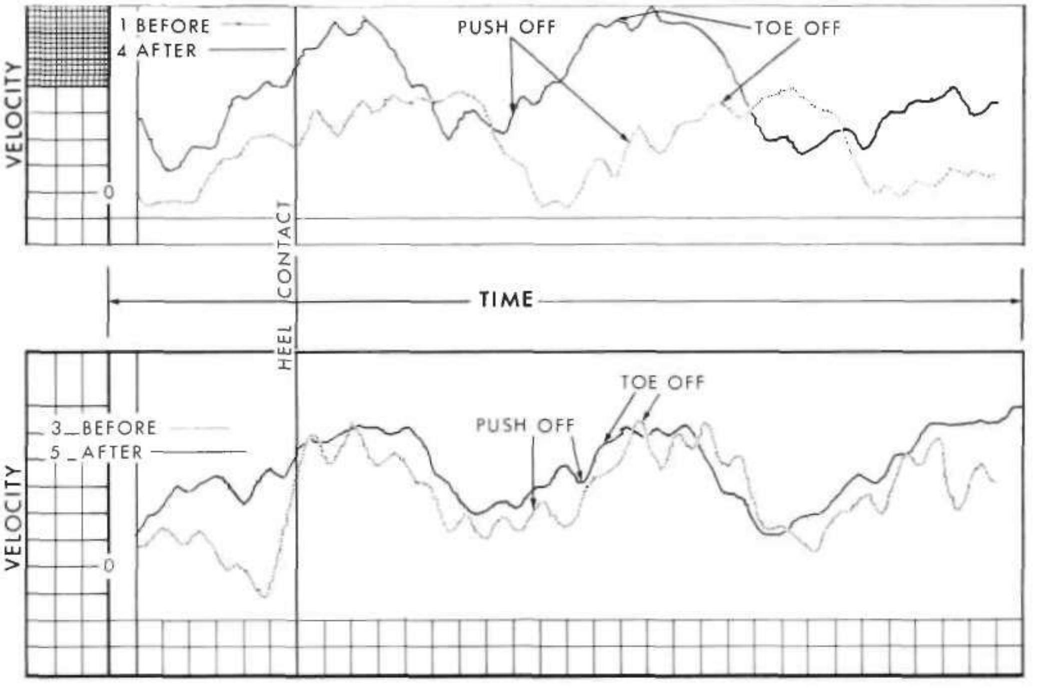

Fig. 3. Tachograph recordings. Run No. 1 and run No. 3 were recorded on May 15, 1963, prior to realignment of prostheses; run No. 4 and run No. 5 on May 24, 1963, after realignment.

Full body weight was applied to the prostheses in a smoother, less jerky fashion, as indicated by a diminution of the oscillations in the patterns representing performance after realignment.

The smaller amplitude of the oscillations in the vertical load curves after realignment indicates decreased lurching in the stance phase and perhaps a smoother initiation of the swing phase on the contralateral side.

The fore-and-aft shear load curves indicate greater horizontal forces after push-off with the realigned sockets. Moreover, the increased magnitude of the aft shear loads after toe-off before realignment indicates a greater degree of toe drag.

MOTION-PICTURE ANALYSIS

Motion pictures were made of the patient prior to and after realignment of the sockets. Analysis of the gait patterns indicated the following positive changes:

Somewhat less anteroposterior pelvic lurch,
More symmetrical arm swing.
Somewhat longer step length.
Narrower walking base.
Easier initiation of the swing phase with increased hip flexion.

Analysis of the motion pictures did not bring out any significant improvement in stability. However, this may have been masked by the obviously improved mobility.

SUMMARY

The performance of an above-knee, bilateral amputee in level walking with two suction sockets and two Hydra-Cadence knee units was compared before and after increasing initial hip flexion approximately 10 deg. Before realignment, he had worn the assembly three or four months. However, the second evaluation was conducted on the same day as the realignment; consequently, the comparison does not represent a reliable index to the significance of the change. The observations

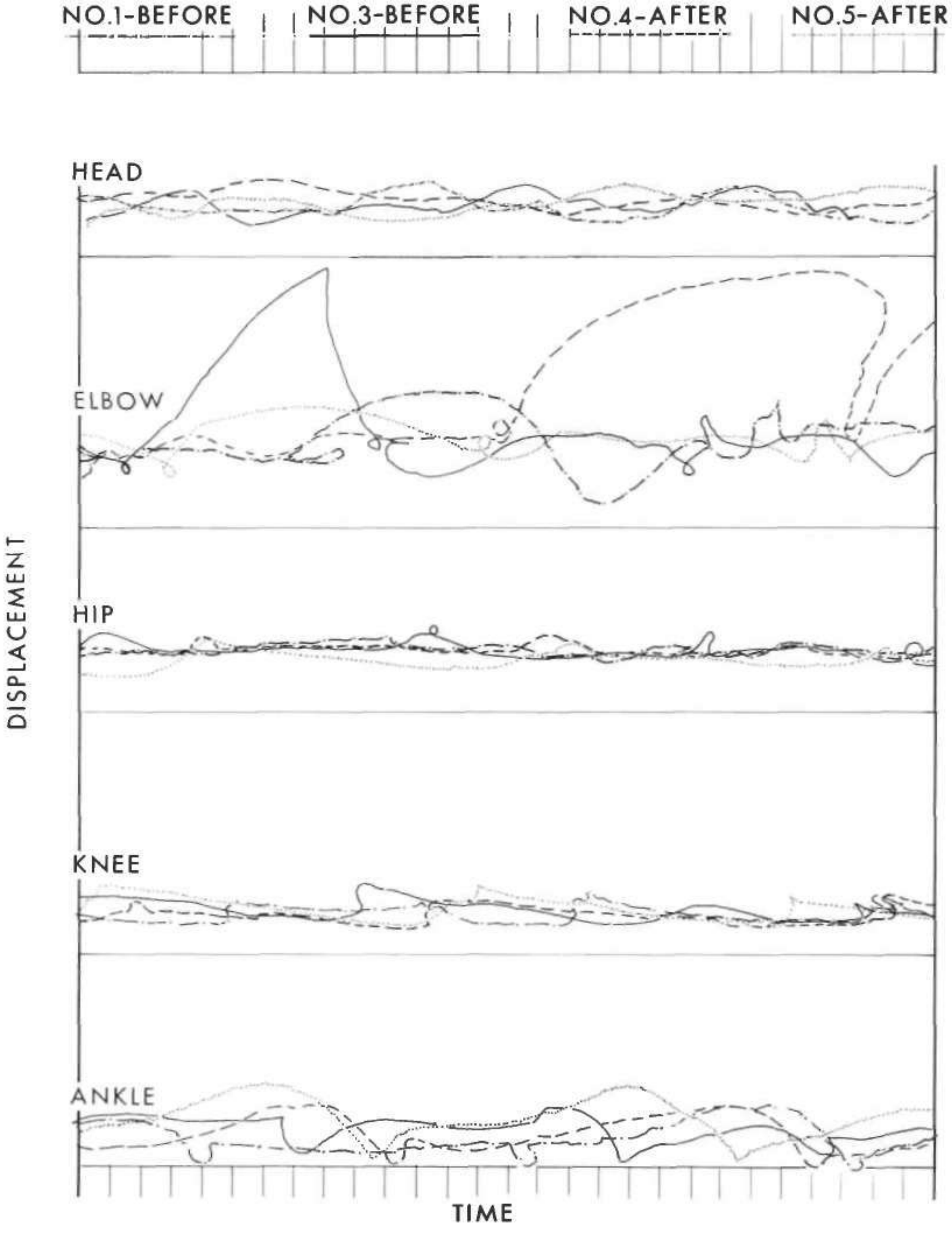

Fig. 4. Pathways of targeted points on the amputee during ambulation, as determined by interrupted-light photography.

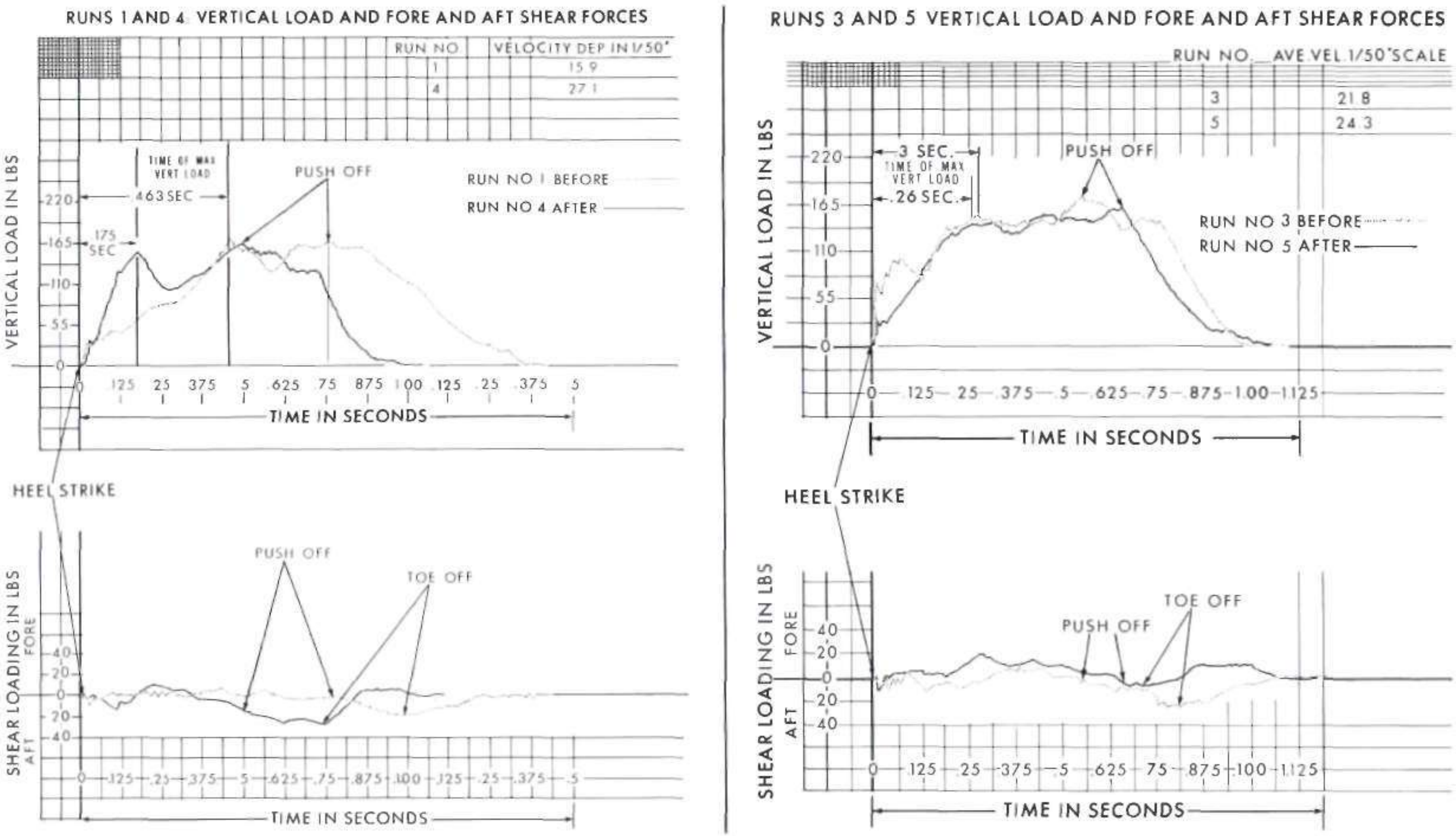

Fig. 5. Force-plate data. Vertical forces applied by the subject to the force plate during the stance phase are shown in the upper curves. Less time was required to apply the full body weight to the prosthesis after realignment. Fore-and-aft shear forces shown in the lower curves indicate the pattern of push-off and toe-off.

disclose only immediate reactions; another evaluation after at least three months of wear should provide a more conclusive analysis.

In general, the patient's performance revealed marked variations from run to run, making it difficult to select a truly representative performance for each test condition. For this reason, "before" and "after" data describing performance during the runs have been presented.

The increased initial hip flexion was undertaken to increase the amputee's range and strength in hip extension. Analysis of the data disclosed mild improvements in:

Stability.
Velocity and stride length.
Smoothness of gait pattern.
Initiating the swing phase by increased push-off forces.

The only significant change which could be identified in the symmetry of the motions of body segments was a more normal ankle displacement, reflecting improved knee flexion in the swing phase.

A follow-up inquiry on August 20, 1963, disclosed that the patient, who was employed in a summer camp, was wearing his prostheses daily. Because of the hilly terrain where he was working, he was using two crutches rather than the two canes previously used. Despite his comments that the limbs were heavy and he wanted to have the socket fit re-checked, he regularly wore the prostheses from 8:00 a.m. to 11:00 p.m. daily and did considerable walking.

This experience illustrates a tendency toward excessive concern for stability when fitting and aligning prostheses for above-knee, bilateral amputees, thereby imposing needless functional limitation.

In this particular case, more than 10 deg. of initial hip flexion could have been tolerated without significant loss of stability. However, even the increase of 10 deg., the maximum in view of stump length and cosmetic requirements, had several beneficial effects on the patient's performance.

LITERATURE CITED

1. Contini, Renato, *Prosthetics research and the engineering profession*, Artificial Limbs, September 1954, p. 47.
2. Staros, Anthony, *Dynamic alignment of artificial legs with the adjustable coupling*, Artificial Limbs, Spring 1963, p. 31.