Acta orthop. scand. 46, 123–134, 1975

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PERFORMANCE OF BK AMPUTEES USING PTB PROSTHESES

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Accepted 21.viii.74

It is generally claimed that the patellar tendon-bearing (PTB) prosthesis, which is now in widespread use, enables the below-knee amputee to achieve a near-normal performance level by virtue of its certain distinct biomechanical advantages when compared to other conventional types of below-knee prostheses. In view of the paucity of any objective studies supporting such a claim, a systematic investigation was undertaken to assess ergonomically the performance level or, in other words, the degree of functional restoration in a group of below-knee amputees using PTB prostheses.

MATERIAL

The investigation material consisted of 10 adult male below-knee amputees, all wearing PTB prostheses fabricated at the Artificial Limb Centre, Department of Orthopaedics, University College of Medicine (Goenka Hospital), University of Calcutta. The brief case histories of these subjects are presented in Table 1.

The amputation in each of the 10 test cases was traumatic. At the time of reporting to the O.P.D. of the Department of Orthopaedics, five of the subjects complained of loss of limb and desired to be fitted with suitable prostheses, whereas the other five demanded replacement of the conventional BK prostheses which they had been using for quite some time.

The side of amputation was left in seven out of the 10 cases studied. The stump length, measured from the knee joint line to the distal end of the stump ranged between 9 and 22 cm (arithmetic mean, 15 cm). All stumps were conical in shape and the power of the flexors and extensors was observed to be good in each case.

The design of the PTB prosthesis was kept identical in each case and it generally conformed to the standards laid down by Radcliffe & Foort (1961), the only variation being in the modified S.A.C.H. footpiece (that is, with solid ankle,

Table 1. Brief case histories

Case no.	Name	Age (years)	Height (cm)	Body weight without prosthesis (kg)	Year of amputation & means of ambulation on first visit to UCMGH* O.P.D.	Side of amputation	Stump length (cm)
1	BKD	17	161	36.0	1968 Axillary crutches	Left	13
2	AKM	47	161	47.1	1930 Conventional BK prosthesis	Right	13
3	AKS	35	160	54.1	1962 Conventional BK prosthesis	Left	14
4	PG I	27	164	43.2	1961 Conventional BK prosthesis	Right	20
5	DPP	20	148	37.9	1968 Not ambulatory	Left	9
6	SSM	40	167.6	40.5	1961 Conventional BK prosthesis	Left	17
7	PG II	24	163	44.0	1967 Axillary crutches	Left	16
8	BRA	45	163	42.0	1966 Conventional BK prosthesis	Left	22
9	SD	20	178.2	67.9	1970 Axillary crutches	Left	13
10	AM	24	158	48.5	1971 Axillary crutches	Left	15

* UCMGH: University College of Medicine (Goenka Hospital), University of Calcutta, Calcutta, India.

spongy heel and a spongy toe-break at the middle-third of the foot). The weight of the prosthesis ranged between 1.7 and 2.7 kg (arithmetic mean, 2.1 kg), that is, proportionately it varied between 3 and 6 per cent (arithmetic mean, 4.5 per cent) of the total body weight of the rehabilitee, including shoes and prosthesis.

Each rehabilitee member of the test group, before being selected for the present *of the test group subjects.*

Preparation for prosthetic fitting	Date of final fitting & delivery of prosthesis	Body weight with prosthesis (kg)	Weight of prosthesis (with shoe) (kg)	Date of testing
Stump exercise; gradual stretching of 20° flexion contracture in knee; quadriceps resistance exercises for 1 month.	24.5.69	37.8	1.8	27.2.71
Quadriceps drill for 1 month.	20.6.69	49.0	1.9	1.3.71
Quadriceps drill for 1 month.	15.7.70	56.0	1.9	2.3.71
Quadriceps drill for 1 month.	15.7.70	45.5	2.3	23.3.71
Quadriceps drill for 1 month.	7.5.69	39.6	1.7	26.4.71
Quadriceps drill for 1 month.	3.6.69	43.0	2.5	28.4.71
Quadriceps and stump exercises for 2 months.	2.7.70	46.5	2.5	27.5.71
Quadriceps drill for 1 month.	17.7.70	44.7	2.7	2.6.71
Quadriceps drill for 2 months.	24.10.70	70.0	2.1	9.6.71
Quadriceps drill for 1 month.	21.6.72	50.5	2.0	3.3.72

investigation, had been finally checked by a clinical team consisting of an orthopaedic surgeon, a bioengineer and a prosthetist, employing a subjective procedure (Ganguli et al. 1972), and discharged to resume his normal activities.

Although the principal aim of this investigation was to derive standards of optimum performance for below-knee amputees wearing PTB prostheses, departure

Table 2. Personal data of control and test group subjects: means and standard deviations.

	Age (years)	Height (cm)	Body weight (kg)	Body surface area (m^2)
Control group (n = 16)				
Mean	28.4	164.3	51.0	1.54
S.D. (±)	7.05	7.12	6.56	0.10
Test group (n = 10)				
Mean	29.9	163.1	48.3	1.47
S.D. (±)	11.00	7.95	9.33	0.156

Note: In the above Table, body weights of the test group subjects are the total body weights including the weights of the prostheses and shoes.

from normal in the test group was studied as a matter of interest. For this purpose, a control group consisting of 16 normal, healthy, sedentary adult males was formed. The means and standard deviations of the control group subjects' personal data are presented in Table 2 along with those of the test group subjects.

METHODS

For the assessment of the degree of functional normality restored in the test group subjects, an objective testing procedure, using the ergonomic approach (Datta et al. 1972, Ganguli et al. 1971, Ganguli et al. 1973) was adopted. The battery of tests consisted of two *static performance tests:* (i) sitting upright in a chair, and (ii) standing erect from the sitting position and maintaining the standing posture for 2 minutes; two *dynamic performance tests:* (i) walking a distance of 1 km on level ground, at a speed of 3 km/h, for a period of 20 minutes at a stretch, and (ii) ascending 127 steps of a staircase, each step of which was 14.2 cm high and the total height climbed being 18 m, at a rate of 7.48 m/min and 7.37 m/min for the control group and the test group subjects, respectively; and a *step test* for measuring exercise tolerance, during which the subject was made to step on and off a 20 cm high stool, at the rate of 15 steps/min, for a period of 10 minutes. The *static and dynamic* tests were chosen so as to represent the basic body postures and acts that are necessary for leading a normal life. The control group subjects also were administered with the same set of tests. As a typical example of the tests, the walking test is illustrated in Figure 1.

While the *dynamic* tests were being performed, the speeds were kept uniform by having an investigator to closely accompany the subject with a stopwatch in hand, for timing the rate of motion over measured distances. For the *step test*, the rate was maintained approximately constant with the help of a metronome.

During each test, the physiological factors studied were: energy cost and the corresponding cardio-respiratory responses (namely, oxygen consumption, pulmonary ventilation and peak heart rate) of the subject.

Figure 1. A test group subject performing the walking test.

RESULTS

The means and standard deviations of all the parameters observed, namely, energy expenditure (Kcal/min/kg), oxygen consumption (L/min, STPD/kg), pulmonary ventilation (L/min, BTPS/kg) and peak heart rate (beats/min) for both the groups are presented in Table 3. The percentage increases in the test group over the control group subjects for all the said parameters, are shown in Figure 2. The means and standard deviations as well as the percentage increases for the first three of the above-mentioned four physiological parameters were calculated from the respective net values, that is, per unit body weight (kg) in order to eliminate the influences of difference in body build among the subjects.

Table 3. Physiological parameters observed: means and standard deviations.

Description of parameters	Control group					Test group				
	Sitting	Standing	Walking	Ascend-ing	Step test	Sitting	Standing	Walking	Ascend-ing	Step test
Energy expenditure (Kcal/min/kg body wt*)										
Mean	0.0208	0.0256	0.0444	0.0776	0.0790	0.0203	0.0300	0.0591	0.0934	0.0815
S.D. (±)	0.00401	0.00649	0.00874	0.01107	0.01206	0.00464	0.00366	0.01069	0.01300	0.01804
Oxygen consumption (L/min STPD/kg body wt*)										
Mean	0.0044	0.0055	0.0094	0.0166	0.0159	0.0043	0.0065	0.0124	0.0197	0.0170
S.D. (±)	0.00089	0.00138	0.00186	0.00242	0.00251	0.00103	0.00140	0.00221	0.00292	0.00368
Pulmonary ventilation (L/min BTPS/kg body wt*)										
Mean	0.134	0.155	0.249	0.369	0.389	0.140	0.190	0.327	0.491	0.447
S.D. (±)	0.0277	0.0411	0.0621	0.0475	0.0607	0.0342	0.0367	0.0762	0.0901	0.1159
Peak heart rate (Beats/min)										
Mean	83.2	89.6	94.2	125.0	115.2	82.8	89.8	114.0	136.4	124.4
S.D. (±)	8.60	9.79	11.94	3.93	4.76	7.73	12.59	16.64	12.88	12.86

* For the test group subjects, body weight has been considered without the weight of the prosthesis and shoes.

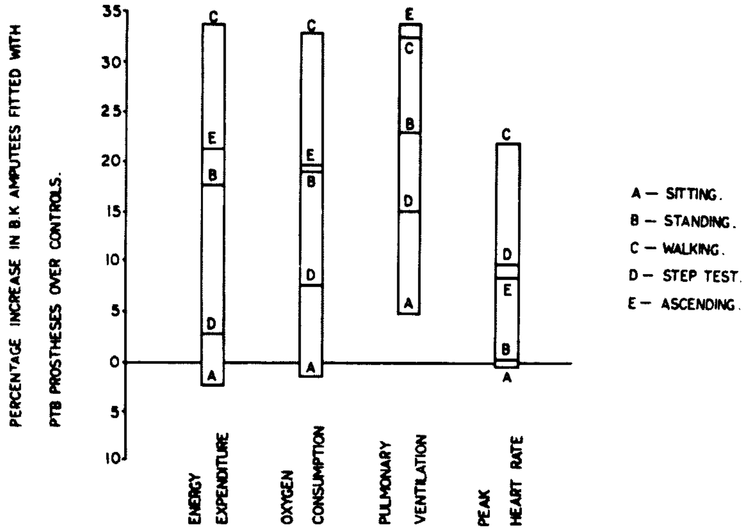

Figure 2. Percentage increases in the values recorded for the test group over those for the control group subjects.

DISCUSSION

Possible sources of discomfort in the below-knee amputee fitted with a PTB prosthesis and adopting a sitting posture are 'inadequate hamstring channels, an unduly high posterior brim, impingement of the higher medial and lateral walls onto the back of the prosthesis, or unduly anterior or distal placement of the tabs of the cuff'. None of the test group subjects of the present investigation, however, complained of any discomfort during the sitting test and this was also confirmed from the energy expenditure values and the cardiorespiratory responses recorded. As a matter of fact, since this test does not involve total weightbearing by the lower extremities, contrary to the standing activity, no increase over the control group values was expected in the test group results. The results, on the other hand, showed slightly lower values in the case of the rehabilitees which might be due to the loss of a tangible portion of the metabolically active tissues of one lower limb.

In the standing position, the test group subjects were observed to spend 17.2 per cent more energy than the control group subjects. This increase can be attributed to the special demand placed on the amputated leg by the built-in design provisions of the PTB prosthesis, for fulfilment of the weightbearing function. The surfaces of the PTB socket which support the body weight are sloped, thus requiring a much larger total force than half the body's weight to be applied at right angles to the weightbearing regions of the stump, in order to give adequate support. The observed increase in the test group values over the control group values, for all the physiological parameters recorded, thus should be deemed as natural in the BK amputee-PTB prosthesis combination. That this observed rise was not partly due to any defect in fitting, alignment and length of the prosthetic leg, was confirmed by the fact that the stump in each case was free from abrasions which are likely to result from such defects. Weightbearing appeared to be distributed over the proper areas of the stump, as indicated by inspection of the stumps and noting the imprints of the stump socks on the skin of the stump.

Although during the final subjective check-out examination at the clinic the departure from the normal walking performance in the test group subjects was hardly noticeable, the present ergonomic investigation revealed a 33 per cent increase of energy expenditure (converting the gross energy expenditure values per unit body weight) when compared to the controls. Out of the two basic energy-consuming functional components of walking on the level, that is, the static one manifested in the supportive function and the dynamic one responsible for the locomotion, the demand due to the former has already been seen to be 17.2 per cent more than the value for the control group subjects from the results of the 'standing test'. That the remaining increase of 15.8 per cent over the normal subjects was due to the dynamic component (that is, for accelerating and decelerating the prosthetic leg by exerting extra motive force and power through the thigh and stump muscles, which also involved abnormal displacements and high instantaneous velocity changes of the body's centre of gravity, thereby requiring more energy to be spent than under normal circumstances) alone was evident because of the absence of other factors contributing to a rise in energy expenditure, such as, poor fit and alignment which would have shown up in several forms of stump damage. Only one study on the energy expended during walking in below-knee amputees wearing prostheses has been reported in the scientific literature (Durnin & Passmore 1967) but that cannot be used for comparison because there the walking speeds were 4.2 and 5.0 km/h as against the 3.0 km/h speed chosen in the present investigation. Furthermore, Durnin & Passmore's report did not mention anything about the type of prosthesis used by their test subjects.

During the stair ascending test, the below-knee prosthetic rehabilitees were not found to be inconvenienced by adopting the normal alternating (that is, step-over-step) method of climbing a staircase and none of them had any difficulty such as catching the toe against the riser of the stairs. Their control of knee stability was also found to be satisfactory. The percentage increase in their energy expenditure over that of the control group subjects was observed to be 20.5. In a study carried out by Hirschberg & Ralston (1964), the energy expenditure per step for stair climbing was seen to be 40 to 50 per cent higher in handicapped hemiplegic subjects when compared with normal, healthy subjects. The 20.5 per cent increase over the normal value in below-knee amputees fitted with PTB prostheses, therefore, seems to be reasonable as this extra energy demand may be attributed to carrying the extra load of the prosthesis, which expends extra energy. A question which may pertinently be raised here is why the increase in energy expenditure of the test group subjects over the control group subjects was proportionately lower for the activity of stair ascending than it was for walking on level ground. This may be explained in the following way. While the level walking speed for both groups of subjects was kept at the same (that is, 3.0 km/h), the rate of stair ascent of the normal group was 7.48 m/min as against 7.37 m/min in the amputees, to suit their comfort and convenience. Furthermore, although stair climbing involves more active positive (that is, anti-gravity) work on the part of the muscles, the accelerations and decelerations are less vigorous as compared to walking on the level.

The step test proved to be of least use and it could not furnish any interesting information since the test group subjects could not always maintain the rate of stepping as regularly and precisely as the control group subjects. They were also found to be at a disadvantage in stepping off the stool backwards, due to the absence of kinesthetic and tactile senses in the prosthetic leg.

CONCLUSION

Owing to the dearth of published data on the optimum performance standards of the below-knee amputee–PTB prosthesis system, the test group results had to be compared with the normal performance standards. Rationally speaking, each category of rehabilitee has its own optimum performance standard and, therefore, comparison with the normal may often be misleading. However, the information generated by the present investigation, regarding the performance of the below-knee amputees fitted with PTB prostheses, can be used as a standard for comparison, for future research work in this field.

The ergonomic observations have provided some very valuable information regarding the fitness level of the below-knee rehabilitees. The evaluative techniques usually employed in orthopaedic and rehabilitation clinics are not capable of yielding such information. The importance of ergonomic studies on the physically handicapped and the rehabilitees has been emphasized (Inman et al. 1961), not only because they generate useful data about the efficacy of the assistive devices they use, but also because they enable the clinician and the rehabilitation worker to assess the possible occupations that such persons can take up as a livelihood. The data available from the present investigation can be used to define the criteria whereby one could avoid imposing hazardous work loads on below-knee amputees wearing PTB prostheses.

From the expenditure point of view, the heaviest natural activity studied was stair ascending. For this activity, the average gross energy expenditure of the test group subjects was found to be 4.25 Kcal/min (range: 3.04–6.96 Kcal/min), and they performed it without any undue excess expenditure of energy or undue discomfort, as compared to the control group subjects. This value of energy expenditure falls within the group of 'moderate' exertion, in some cases falling under the 'heavy' exertion group, according to the classifications made by Turner (1955), Patwardhan (1960), Malhotra and his co-workers (1966) and Ramanathan and his co-workers (1967). It can, therefore, be easily concluded that the below-knee amputees fitted with PTB prostheses should be able to meet the demands of industrial occupations up to the moderately heavy grade, particularly in view of the fact in such industrial occupations, the high demands are likely to be of an intermittent nature.

SUMMARY

A below-knee amputee is generally known to achieve a close-to-normal performance level, with the patellar-tendon-bearing method of stump fitting. This was confirmed by an ergonomic investigation on ten below-knee amputees, fitted with PTB prostheses. The test group subjects were given two static tests, two dynamic tests and one exercise tolerance test, during which their oxygen consumptions, pulmonary

ventilations, energy expenditures and peak heart rates were measured. The performance of the test subjects were compared with that of a control group consisting of sixteen normal, healthy, individuals.

The percentage increases in the values of the biomechanical parameters of the test subjects, over those of the control group, were found to be justified and thus natural to the below-knee amputee–PTB prosthesis system.

The ergonomic study has not only yielded information regarding the biomechanical efficacy of the PTB prosthesis, but it has also shown that the amputees fitted with such prostheses can take up, without any undue extra effort and metabolic cost, industrial occupations of the moderately heavy kind.

ACKNOWLEDGEMENTS

The authors are indebted to Dr. S. N. Sen, Vice-Chancellor, University of Calcutta, for his constant interest and encouragement. Thanks are due to Dr. B. B. Chatterjee, Mr. B. N. Roy and other members of the Department of Physiological and Industrial Hygiene, All India Institute of Hygiene and Public Health, Calcutta and also to the medical and paramedical staff of the Department of Orthopaedics, University College of Medicine (Goenka Hospital), University of Calcutta, for their active help and valuable suggestions.

REFERENCES

Datta, S. R., Ganguli, S., Chatterjee, B. B. & Roy, B. N. (1972) Biomechanics in the assessment of rehabilitation of below-knee amputees fitted with PTB prostheses. Paper presented at the Seminar on Ergonomics, Life Science Centre, University of Calcutta.

Durnin, J. V. G. A. & Passmore, R. (1967) *Energy, work and leisure.* 1st ed. p. 111, Heinemann, London.

Ganguli, S., Datta, S. R., Chatterjee, B. B. & Mukherjee, P. (1971) Rehabilitation effectiveness assessment through biomechanics. Digest, 9th I.C.M.B.E., 164.

Ganguli, S., Banerjee, S. & Bose, K. S. (1972) A preliminary communication of fitting below-knee amputees with patellar-tendon-bearing prostheses. *J. Ind. med. Ass.* **59**, 145–151.

Ganguli, S., Datta, S. R., Chatterjee, B. B. & Roy, B. N. (1973) Performance evaluation of an amputee–prosthesis system in below-knee amputees. *Ergonomics* **16**, 797.

Hirschberg, G. G. & Ralston, H. J. (1964) Energy cost of stair climbing in normal and hemiplegic subjects. *Amer. J. Phys. Med.* **44**, 165–168.

Inman, V. T., Barnes, G. H., Levy, S. W., Loon, H. E. & Ralston, H. J. (1961) Medical problems af amputees. *Calif. Med.* **94**, 132–138.

Malhotra, M. S., Ramaswamy, S. S. & Sengupta, J. (1966) Caloric and fluid requirements at high altitude. *Human adaptability to environments and physical* *fitness*. p. 180. Defence Institute of Physiological and Allied Sciences, Madras, India.

Patwardhan, V. N. (1960) *Dietary allowances for Indians*. Special Report No. 35, Indian Council of Medical Research.

Radcliffe, C. W. & Foort, J. (1961) *The patellar-tendon-bearing below-knee prosthesis*. University of California Biomechanics Laboratory, San Francisco and Berkeley.

Ramanathan, N. L., Datta, S. R., Roy, B. N., Chatterjee, A. & Mullick, L. N. (1967) Energy cost of different muscular exercise tests performed by Indian subjects. *Ind. J. occup. Hlth.* **10**, 253–261.

Turner, D. (1955) The energy cost of some industrial occupations. *Brit. J. industr. Med.* **12**, 237–239.

Key words: amputees; prosthesis

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