Walking activities and wear of prostheses

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SUMMARY A study of the walking activities of 243 individuals was carried out. The individuals came from four different occupations and had an age range of 17-83 years. The survey carried out in this investigation showed surprisingly little correlation between variables such as age, height, and weight of individuals and their speed of walking, length of stride, or distance walked. Correlation matrices were obtained for the whole sample and then for each sex, showing similar trends. The most significant correlation was between the height of an individual and the length of the stride, and there was a lesser correlation between age and the number of steps walked by an individual per day. Further statistical analyses showed that males in manual occupations walked most and those in sedentary occupations walked least. On the other hand, in the female groups housewives seemed to walk least and those in technical occupations walked most. The average number of steps walked per day by a male individual for the whole sample was 9537; that for females was 9839. The corresponding distances walked per day were 6.7 and 6.5 km. The differences were not statistically significant. Predictions of wear of prosthetic components made of ultrahigh molecular weight polyethylene were made on the basis of the above data and other variables affecting wear, such as the weight of the subject and the area available for contact during walking. Charts have been constructed of the penetration of the metallic component into the plastic one for both hip and knee prostheses, thus enabling predictions of the wear of the plastic components of these two most widely used prostheses. Owing to the wide ranging values of the variables used in making the predictions of wear, these latter should be regarded only as 'safe' first estimates.

Key words: daily walking distance, wear, prosthetic hips and knees.

Walking is the most predominant of the locomotive activities of humans and perhaps the most predominant of Western man's activities. Much fewer cycles of sitting, kneeling, or squatting occur in Western Societies than in the Eastern. Walking is therefore the most important activity from the point of view of wear of lower limb prosthetic joints. During this process removal of particles from the articulating surfaces of the prosthesis occurs, and if the amount of debris removed is large tissue reaction may result. Or else, as a consequence of excessive wear the mechanical strength of the prosthetic component in question may be significantly reduced such that it will fail under the large loads arising in the joint during walking.

It is interesting that relatively few data are

published on the subject of walking activities. This is perhaps due to the difficulty of obtaining measurements from a large number of individuals and partly due to popular assumptions concerning this matter. It is a popular view that certain correlations exist; for instance that the shorter a person the faster the pace, and the shorter the stride will be; or, the heavier or older an individual, the slower will be the pace of walking etc.

This communication is concerned with a survey of a number of the above mentioned variables in a relatively large sample of individuals from different occupations and with the effect of some of these variables on the wear of two of the most implanted prostheses, the hip and the knee.

Materials and methods

Two hundred and forty-three subjects were studied. Their age, sex, and occupation were noted. The

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height and body mass were recorded. Their normal cadence of walking was measured by noting how many paces they took in a minute. Then measurements took place in the street or in corridors in work places, such as hospitals, factories, or schools. The stride length was measured by dividing the distance walked by the corresponding number of paces taken. A pedometer was attached to the subject to record the number of steps they walked a day. The subject was asked to wear this pedometer for 24 hours beginning at whatever time the pedometer was given to him. The measurements were made during a normal working day from Monday to Friday.

The data were subjected to statistical analysis to obtain the means and standard deviations and to investigate further: (a) if correlations existed between some of the measured quantities and (b) if there were significant differences between the sexes and groups within the different occupations. The yearly wear rate of hip acetabular cups and knee tibial components commonly made of ultrahigh molecular weight polyethylene (UHMWPE) was predicted on the basis of the relevant data obtained.

Table 1 Classification of participants according to sex and occupation

Occupation	Male	Female
Sedentary	53	22
Technical	35	27
Manual	56	19
Housewives	—	31
Total	144	99

Table 2 Age, height, and body mass distribution in all participants

	Male			Female		
	Mean	SD	Range	Mean	SD	Range
Age (years)	44.9	15.7	17–78	40.7	15.8	17–83
Height (cm)	174.5	7.5	157–193	161.7	5.4	150–178
Body mass (kg)	72	8.8	49.3–103.5	63.2	8.5	41–96

Table 3 Distribution of cadence, stride length, number of steps and distance walked/day

	Male (n=144)			Female (n=99)		
	Mean	SD	Range	Mean	SD	Range
Cadence (strides/min)	63.7	11	31–89	63	11.31	21–91
Stride length (cm)	71.3	6.9	41–97	65	7.8	46–81
No of steps/day	9537	4761	1600–35 500	9839	5706	1200–32 600
Distance walked/day (km)	6.7	3.2	1–19.6	6.5	4.1	0.6–19.8

Results and discussion

Of the participants, 144 were male and 99 were female. The classification of occupations is shown in Table 1.

The means, standard deviations, and ranges of age (years), height (centimetres), and body mass (kilograms) are shown in Table 2. The means, standard deviations, and ranges of cadence (strides/minute), stride length (cm), number of steps per day, and the corresponding distance walked per day are shown in Table 3. The data in Tables 1–3 are for the male and female sample from all occupations. Similar data have been obtained for each occupation group for both sexes. These are presented in Tables 4–7.

Table 4 Statistical data on persons in sedentary occupations

		Male (n=53)	Female (n=22)
		Mean	SD
Cadence (strides/min)	Mean	62.3	63.7
	SD	10.8	12.8
Stride length (cm)	Mean	71.4	62.9
	SD	5.5	4.7
No of steps/day	Mean	8241	7954
	SD	3911	5997
Distance walked/day (km)	Mean	5.93	5.10
	SD	3.09	3.74

Table 5 Statistical data on persons in technical occupations

		Male (n=35)	Female (n=27)
		Mean	SD
Cadence (strides/min)	Mean	65.5	58.5
	SD	10.6	6.3
Stride length (cm)	Mean	71.2	70.0
	SD	9.8	8.3
No of steps/day	Mean	10 338	15 433
	SD	4587	5353
Distance walked/day (km)	Mean	7.36	10.58
	SD	3.3	4.4

Table 6 Statistical data on persons doing manual work

		Male (n=56)	Female (n=19)
Cadence (strides/min)	Mean	64.1	66.0
	SD	11.6	13.1
Stride length (cm)	Mean	71.2	63.5
	SD	5.8	7.6
No of steps/day	Mean	10 248	9242
	SD	5270	3217
Distance walked/day (km)	Mean	7.11	5.79
	SD	2.92	1.95

Table 7 Statistical data on housewives (n=31)

Cadence (strides/min)	Mean	64.7
	SD	11.2
Stride length (cm)	Mean	63.3
	SD	7.3
No of steps/day	Mean	6922
	SD	2867
Distance walked/day (km)	Mean	4.34
	SD	1.84

The matrix of the correlation coefficient was computed for all the subjects, and the data are presented in Table 8. The same was done for all male and female subjects within each sex group, and since the data were quite similar it was deemed unnecessary to include two more such large tables in this paper.

From Table 3 it can be seen that there are no significant differences between sexes so far as the speed of walking or distance walked, but there seems to be a slight difference between the males and females so far as the stride length and number of steps are concerned; males have a longer stride and females take more steps per day.

The analysis of variance (ANOVA) was carried out on all the groups within both sexes to establish if there were significant differences between these groups. The analysis showed that for all male groups there were significant differences ($p < 0.05$) in the number of steps and distance walked per day.

Table 8 Correlation coefficients

	Age	Height	Weight	Cadence	Stride	Number	Distance
Age	1	-0.16	0.17	-0.11	-0.29	-0.42	-0.44
Height	-0.16	1	0.45	-0.02	0.60	0.10	0.20
Weight	0.17	0.45	1	-0.04	0.16	-0.16	-0.12
Cadence	-0.11	-0.02	-0.04	1	0.02	0.01	-0.01
Stride	-0.29	0.60	0.16	0.02	1	0.16	0.37
Number	-0.42	0.10	-0.16	0.01	0.16	1	0.92
Distance	-0.44	0.20	-0.12	-0.01	0.37	0.92	1

Similar results were obtained for all female groups, with a higher significance ($p < 0.01$). Further tests were then carried out showing that males in manual occupations walked the most and, as would be expected, those in sedentary activities walked least. On the other hand, in the female groups housewives seemed to walk least and those in technical occupations walked most. Table 8 is interesting in that it shows the difference between reality and popular views concerning correlations between age or height or weight and the speed of walking. Although there is a correlation between height and the stride length, it is not large. A lesser degree of correlation exists also between age and the number of steps made per day. The high correlation between the number of steps made and the distance walked is not surprising, since the distance walked is the product of the number of steps made by the length of stride.

WEAR OF PROSTHETIC COMPONENTS

The wear rate of a plastic prosthetic component is similar to some extent to that of a stick of chalk. The wear characteristic of chalk is dependent on how hard it is pressed against the blackboard and how far it is drawn. The wear rate of a plastic prosthetic component is similarly dependent on a wear coefficient, which is characteristic of the component material rubbing against the metallic (or ceramic) component. It is also dependent on the force acting on the joint and the distance through which the components slide on each other. A simple relationship governs the volume of debris removed from the plastic component such that:

$$V = kPL$$

where V = the volume of debris removed, k = the wear coefficient characteristic of the plastic sliding on metal (or from whatever material the component is made of), P = the force acting on the two components, and L = the sliding distance.

Methods of obtaining the coefficient of wear experimentally have been described, and different values for k have been obtained by various authors for UHMWPE sliding on stainless steel, cobalt chrome alloy, and ceramic surfaces.

The value of PL, the product of the joint force and the sliding distance, represents the intensity of use of the prosthesis. Since walking is the activity through which a prosthesis is most used, the value of PL is calculated by integration from the load and speed variations with time during one complete walking cycle. The volume of wear debris in a walking cycle can then be calculated. Since a mean value for the number of walking cycles per day taken by various groups is known, the daily volume of wear debris and hence the yearly wear rate of a plastic prosthetic component can be estimated.

It is important to recognise that the calculated yearly wear rate, in terms of the penetration of the metallic component of the prosthesis into the polymeric component, does not take account of the additional contribution to this penetration that might be made by creep of the polymer. Recent estimates of the penetration due to creep and the correlation between these calculated wear and creep penetration rates with in-vivo data for hip joints have been discussed by Downson *et al.*^{2a 2b}

It must be noted that the product PL is a function of the weight of the individual, and the heavier the latter, the larger will be the volume of the wear debris. It was interesting to make some theoretical predictions of the wear of different hip and knee prostheses. These predictions, however, were made on the basis of the values of the wear coefficient k and the product PL calculated from published and/or communicated data by Paul¹ and Morrison.² The following values for the above have been assumed.

1. Wear coefficient values (k) for UHMWPE sliding on stainless steel $6.8 \times 10^{-7} \text{ mm}^3/\text{Nm}$. This value is quoted from Dowson *et al.*,³ and results from laboratory wear tests under wet conditions with load, speed, and surface finish similar to the use found in prostheses. For UHMWPE, which has been solid phase formed sliding on cobalt chrome alloy the values of k between 0.86 and $5.9 \times 10^{-7} \text{ mm}^3/\text{Nm}$ obtained by Seedhom *et al.*⁴ will be used here.
2. The load and sliding distance product PL. (a) For a natural hip of diameter 45 mm and patient of weight 620 N (63 kg) PL was found to be approximately 50 Nm.⁴ Thus for any artificial hip of radius, R and patient weight, B :

$$PL = \frac{50}{620 \times 45} \times 2RB \text{ Nm}$$

(b) For a natural knee of an average size and patient of weight 620 N (63 kg) PL is approximately 60 Nm.⁴

For different knee prostheses the value of PL must be calculated (as in the case of the hip

prostheses) for the specific geometry and patient weight. Many of knees in current use are of approximately the same radii as those of the natural knee, for example Kinematic, the Freeman Samuelson, the Coutalier, the Leeds, the Geomedic, and others. For these the following relationship is used:

$$PL = \frac{60B}{620} \text{ Nm}$$

For other knee prostheses whose femoral and tibial components are much smaller than those of the natural knee, e.g., the Sheehan, a smaller value of PL is assumed:

$$PL = \frac{55B}{620} \text{ Nm}$$

The wear rate in the form of penetration of the metallic component into the plastic one in mm/year is calculated. It is assumed that the wear is uniform on the whole of the contact surface of the plastic component. This is not strictly the case, but it is adopted here as a basis for comparison. Clearly, the approximations used in these calculations limit the accuracy of the results, but some indication of the relative magnitudes of prosthesis wear is obtained.

Fig. 1 represents the wear of hip prostheses

Fig. 1 Wear of hip prosthesis of different diameters, and for individuals of different weights, based on 10 000 steps walked by the individual each day.

expressed as predicted penetration of the femoral component into the acetabular cup in mm/year. This is calculated for different diameters of the prosthetic femoral heads and also for individuals of body mass between 60 and 85 kg. Fig. 2 represents a different exercise whereby the wear of one hip prosthesis is calculated for individuals within the same weight range and for a range of walking activity between 2000 and 10 000 steps per day. As these charts show the predicted penetration of the femoral head in the acetabular cup decreases as the diameter of the femoral head increases. Also, for the same prosthesis, the lighter the patient and the fewer the steps made per day, the lower the year's wear.

The same applies in the case of knee prostheses. The larger the articular area of the prosthesis available for transmitting the loads, the lower the yearly wear, as shown in Fig. 3. The extremes of wear occur in the Sheehan knee, which is typical of a prosthesis with a small contact area, and a prosthesis of the surface replacement type of which the Leeds knee, the Kinematic, the Freeman Samuelson, the Oxford, and others are typical, and all of which have a much larger contact area. These wear rates are plotted for individuals of different weights and for the same range of walking activities, i.e., 2000–10 000 steps per day (Fig. 4).

The above predictions are based on assumptions which the authors wish to discuss.

The pedometers used could conceivably give false/positive registrations corresponding to non-routine (mainly 'jerky') movements of the leg.

Fig. 2 Wear of Charnley hip prosthesis, for individuals with different body masses and varying walking activities.

These are likely to have only a small effect on the pedometer reading, which can be reasonably assumed to be representative of the daily number of steps taken by the subject.

Fig. 3 Wear of knee prosthesis with different areas of the tibial component for individuals with different body masses.

Fig. 4 Wear of knee prosthesis, with varying load bearing areas and patient weights, against patient activity.

Perhaps the more controversial of the assumptions are those regarding the magnitude of joint forces and number of steps taken per day. Both quantities are expected to be smaller in patients with prosthetic joints than in normals. The predictions of wear have been made on the basis of the larger forces, which may be justified in younger patients whose muscles would still be somewhat vigorous and who may be surprisingly active!

The predictions of wear of the polyethylene prosthetic component must therefore be regarded as 'safe' first estimates, taking into account the wide ranging values of the variables used in the calculations.

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