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Preliminary study on static weight distribution under the human foot as a measure of lower extremity disability

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Abstract—*Only a few methods have been reported in the recent literature for measuring the forces under human feet in normal and abnormal cases. The purpose of the present investigation was to study whether the static weight distribution under feet on the parafrontal plane can be used as a measure of lower extremity disability by using a system of load cells as transducers. Three postpolio cases, three lower extremity amputees and three Perthes disease victims constituted the test group and five normal healthy adult males with sedentary habits formed the control group in this preliminary study. Normalised weight distribution under the right and left foot of each test group subject has been compared with the mean and s.d. of the control group. The test group subjects showed different degrees of variation from the control group in the static-weight-distribution pattern according to their disability.*

Keywords—*Foot forces, Lower extremity disability, Static weight distribution*

1 Introduction

STATIC weight distribution under the human feet in the erect standing posture is of utmost importance to the understanding of foot function in normal and orthopaedically handicapped persons. Several workers have attempted in several ways to study the distribution of pressure under the human foot in static as well as dynamic conditions in normal and pathological cases (ELFTMAN, 1934; MORTON, 1930; HUTTON *et al.*, 1972; STOTT *et al.*, 1973; STOKES *et al.*, 1974; VENKATAPPAIAH and RAMANATHAN, 1976, 1978; MIYAZAKI and IWAKURA, 1978.) The first attempt in this regard was made by BEELY in 1882, where he used a thin sack filled with plaster of paris that gave the footprint of the subject on walking (ELFTMAN, 1934). Morton was the first investigator who used a kinetograph consisting of a rubber mat bearing longitudinal ridges in contact with inked ribbon and paper (MORTON, 1930), whereas Elftman employed a cinematic technique (ELFTMAN, 1934) with a black rubber mat on the top while the upper surface of the rubber mat was flat the lower surface had pyramidal projections which helped the changes in area of rubber in contact with glass to be easily observed and photographed. This technique was obviously unwieldy and generated only qualitative information.

Among the recent investigators, STOKES *et al.* (1974), STOTT *et al.* (1973) and HUTTON *et al.* (1972) used a 12-channel transducer-amplifier-recorder system to measure the vertical loads borne by different areas of the foot in dynamic condition. More recently, MIYAZAKI and IWAKURA (1978) proposed a portable device consisting of two pairs of force transducers, an amplifier-transmitter unit and a receiver-processor unit. However, this method may not be suitable in the case of patients with haemiplegia, cerebral palsy, drop foot, valgus foot, varus foot etc. The Barograph method proposed by VENKATAPPAIAH and RAMANATHAN (1976, 1978) needs standardisation of the light source because the linearity between the foot pressure in a particular region and the amount of light reflected from that region is not obvious, as assumed by the authors.

With the advancement of medical science it is becoming increasingly necessary to measure as many relevant parameters as possible in the clinical setting itself so that the clinician can base his recommendations on sound scientific data and does not have to depend entirely on his knowledge and expensive. In the context of foot-pressure distribution, which is emerging as a valuable source of information in orthopaedic practice, none of the above techniques possesses the required qualities for ready clinical application.

The purpose of the present investigation was, therefore, to explore whether a clinically suitable

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method could be devised for studying the static weight distribution under the feet as a measure of lower extremity disability.

2 Methodology

The ideal way to record the distribution of any weight is to have a continuous variation along two perpendicular axes. Owing to the limitations imposed by budget constraints and data-reduction problems, it was decided to divide the foot into six parallel segments, all the segments being parallel to the frontal plane.

The measuring system thus developed could be described as a combination of

(*a*) the transducers

(*b*) the interface system

(*c*) the indicator.

Six strain-gauge load cells were used as the transducers. These were fixed on a wooden platform and each had a thin aluminium strip covered with rubber padding at the top. The rectangular area thus formed by six parallel strips constituted the support for the foot under investigation, while the other foot was supported by a dummy platform of matching area and height.

The interface system, called the 'bridge-balancing unit', provided a voltage signal proportional to the load on a particular strain-gauge transducer, and this voltage was displayed on the indicator dial that was calibrated directly in kilogrammes. Initial zero adjustment facility was available in the bridge-balancing unit. The system is shown in Fig. 1.

Each load cell with its corresponding part of the bridge-balancing unit is termed as one channel. Thus, there were six channels numbered 1, 2, 3, 4, 5 and 6 for the purpose of identification. The dummy platform and the load cell system were placed side by side (as shown in Fig. 2) so that the subject could stand with one foot on the dummy platform and the other on the load cell system with toes placed towards channel 1 and heels towards channel 6. The selector switch was turned from 1 to 6 and the corresponding load displayed on the indicator was noted. The process was repeated three times and the average load on each channel determined. Then the position of the dummy platform and the load cell system was interchanged and the whole process repeated to obtain the average weight distribution under one foot.

The weight supported by a particular channel depends on the weight of the subject together with the weight-distribution pattern. Therefore, it is necessary to normalise the data before any comparison is made. The weight of the subject seems to be a fair normalising factor, but it was observed that the foot under investigation always carried more than half of the total body weight due to conscious attention of the test subject in general and/or due to some disability or deformity in special cases. Therefore, the load supported by a particular foot (i.e. the sum total of the readings on all the channels) is taken as the normalising factor and the weight distribution data so normalised is used for interpretation.

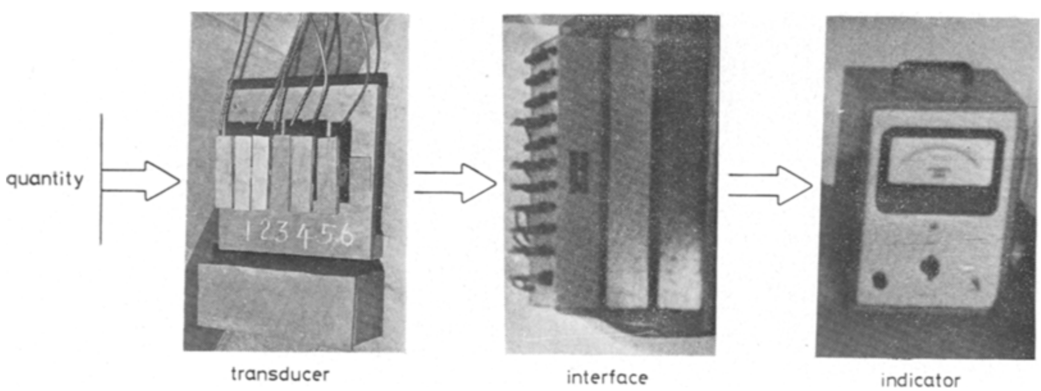

Fig. 1 Measuring sytem for static weight distribution

Fig. 2 Foot under study

3 Materials

Three postpolio subjects, one bilateral below-knee amputee, one unilateral below-knee right-leg amputee, one unilateral above-knee left-leg amputee and three Perthes disease victims constituted the test group of the study. Their personal data are given in Table 1. Table 2 represents the personal data of five matching normal healthy adult male subjects. The test group was selected considering the relative occurrence of the diseases and ready availability of the patients.

4 Results and discussion

Figs. 3 and 4 represent the histograms of normalised weight distribution under right and left

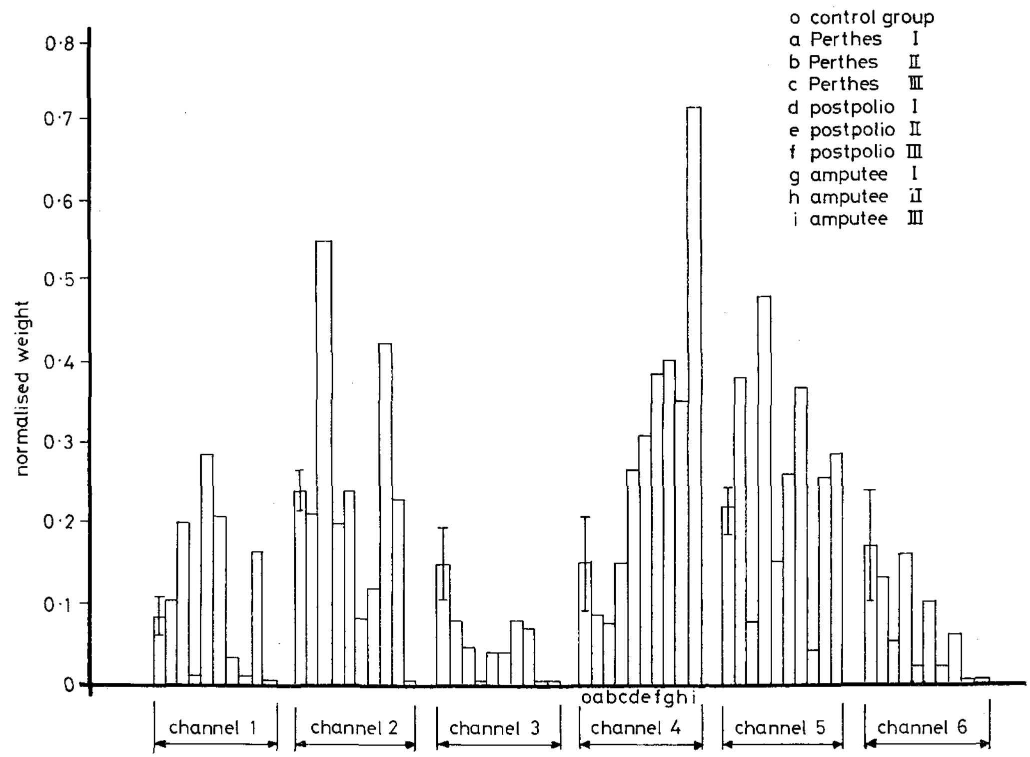

Fig. 3 Normalised weight under right foot

Table 1. Personal data of the test subjects

Sl number	Identification mark as in Figs. 3 and 4	Sex	Age years	Height cm	Weight with prosthesis kg	Weight without prosthesis* kg	Medical history	Remarks
1	*a*	m	15	156·5	—	37·9	Perthes-I	right hip
2	*b*	m	17	165·5	—	46·75	Perthes-II	left hip
3	*c*	m	12	137·5	—	26·0	Perthes-III	bilateral
4	*d*	f	13	132·0	27·0	26·2	Postpolio-I	fixed flexion deformity at right knee and at left ankle: uses caliper
5	*e*	m	15	130·0	—	24·4	Postpolio-II	full length caliper was given, not used for last 5 years
6		m	13	129·0	—	22·5	Postpolio-III	same as patient *e*
7	*g*	m	12	154·0	35·1	30·8	Amputee-I	below-knee bilateral
8	*h*	m	33	155·0	38·5	34·0	Amputee-II	above-knee unilateral (left leg)
9	*i*	m	23	161·5	49·4	46·6	Amputee-III	below-knee unilateral (right leg)
		Mean:	17·44	146·78	37·5	32·79		
		S.D.±	6·5	13·65	8·04	8·73		

*With shoes (total weight in case of nonamputees) feet, respectively. In each Figure the data corresponding to a particular channel are grouped together with the control group data leading. The error in the Figures represent the standard deviation observed among the subjects for the same foot. This investigation did not include a study of the variability between the two feet of the same subject in the control group.

In Figs. 3 and 4, *a*, *b* and *c* constitute Perthes disease of right, left and bilateral victims, respectively. In Perthes case *a* (right hip affected), a variation of weight distribution from the control group results has been found under the right leg. The maximum weight (150% more than the control) was recorded under channel 5, which corresponded to the subject's heel. The variation was observed to be within the normal range as far as the left leg was concerned.

Table 2. Personal data of normal subjects

Number	Name	Sex	Age years	Height cm	Weight kg
1	S.S.	m	25	172·0	51·5
2	S.C.	m	22	167·0	51·5
3	D.T.	m	28	165·0	51·0
4	S.B.	m	28	160·0	72·0
5	A.G.	m	28	170·0	48·3
		Mean	26·2	166·8	54·86
		S.D.±	2·399	4·17	8·65

In Perthes case *b* (left hip affected), the variation of weight distribution from the control was found under the right foot instead of the left foot. This might have been due to the shortening present in the left leg (measured from the anterior superior illiac spine to medial malleolus). For this leg, 100 and 300% more weight than the control group subjects was transmitted through channels 1 and 2, which corresponded to the toe and metatarsal regions, respectively. 100 and 40% less weight was observed under channels 5 and 6, which represented the heel area.

In Perthes case *c* (both hips affected) the weight distribution was below the normal range on channels 1 to 3 for both legs. Only channel 5 of the right leg showed about a 250% increase in load transmission compared with the control group.

The postpolio cases are represented by *d*, *e* and *f*. Only patient *d* (leg affected) had on a caliper. Patients *e* and *f* had been given calipers but were not using them because they had been damaged after some use.

In the right leg of patient *d*, the maximum weight distribution (about 150% greater than the normal range) occurred through channel 1, and this might have very well been due to the fixed flexion deformity of the right knee (flexion 30°). In the case of the left

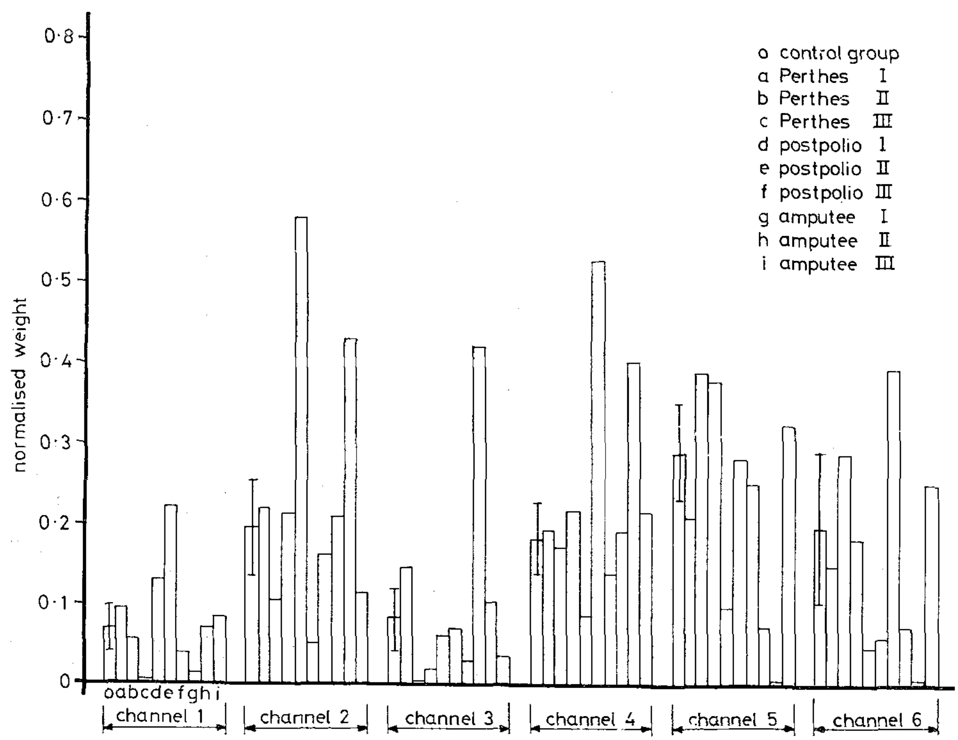

Fig. 4 Normalised weight under left foot

leg, the maximum weight distribution (about 300% more than the normal range) occurred through channel 2, which could be attributed to the fixed flexion deformity of the left ankle (plantar flexion 50°).

Patients *e* and *f* each had a minute shortening of the left leg of about 1·5 cm. Probably because of this they both showed a 200% greater variation through channel 4 of the right foot.

The below-knee bilateral, above-knee unilateral (left leg) and below-knee unilateral (right leg) amputees are represented by *g*, *h* and *i*, respectively. They all showed a maximum concentrated distribution of weight through one or two channels of the amputated leg, e.g. patient *g* showed a 150% greater variation through channel 4 of the right foot and 250% through channel 3 of the left foot. Case *h* showed a 150% greater variation through channel 4 of both feet. On the other hand, case *i* showed a 500% greater variation than the normal range through channel 4 of the affected leg.

The above investigation was a preliminary study and therefore it was restricted to only a few subjects taken from different types of lower extremity disabled persons. More conclusive findings would be desired subsequent to the study of a large number of groups of patients representing different types of lower extremity disability.

5 Conclusion

The static-weight-distribution test as described may be used extensively in hospitals and clinics to study objectively the lower extremity disability of human subjects for

(*a*) detection of pressure points/zones, including ulceration caused by diabetes as reported by STOKES *et al.* (1974)

(*b*) design effectiveness assessment of different types of corrective shoes prescribed for lower extremity orthopaedic disorders

(*c*) assessment of length as well as alignment of prostheses, the role of which is to keep the patient in correct functional position, i.e. keeping the pelvis horizontal

(*d*) assessment of congenital disclocation of hip or any paralytic weakness of the gluteus maximus and gluteus minimus where a clinician has to depend on the Trendelenburg test or any other subjective type of test to study the stability of the hip or hip abductors.

The method as stated above, with or without some modifications, may be useful in the field of industrial ergonomics. The man/machine system may be redesigned to avoid any shifting of the c.g. in different working postures, causing unbalanced loading of the lower extremities, which causes excessive energy to be expended (GANGULI, 1977). Similarly, it may be applicable in the design of footwear on the basis of sound bioengineering and ergonomic principles.

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