RESULTS FROM GAIT ANALYSIS PERFORMED ROUTINELY ON PATIENTS HAVING A WIDE RANGE OF DISORDERS OF THE KNEE

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Abstract

If gait analysis can be performed routinely on patients before and after knee joint surgery, then a number of studies may be performed. This paper describes how a simplified method of gait analysis has been used to facilitate data acquisition from a large number of patients. The short term results (150 cases in nine months) have indicated the diversity of force patterns to be expected from arthritic patients. Evidence has been seen for compensatory gait, whereby the line of force in the joint does not fall through the axis predicted from long-leg x-ray films. Long-term follow-up of knee surgery patients will provide data which can be correlated with results from concurrent studies on ambulatory monitoring and prosthesis wear measurment in order to improve our understanding of the bio-engineering problems of knee joint replacement.

Introduction

In the period of four years ending in February, 1978, 412 knee arthroplasties were used at the Harlow Wood Orthopaedic Hospital (Mansfield, Notts.) Of these replacements, 25 revision operations were made in which the original prosthesis had to be replaced, or the knee arthrodesed. Two of the revision operations were necessary because of late infection following the original operation. In the remainder, revision had to be performed because of mechanical disruption causing pain or lack of function. It has long been recognised that restoration of the balance of forces within the knee is important in any surgical intervention (1). We considered that a study of the knee joint forces in patients would be of value, both in increasing understanding of the factors which influence the joint forces, and in decreasing the incidence of prosthesis failure attributable to mechanical reasons.

Estimating joint forces during walking has been possible for over ten years, following the methods described by Morrison (2). We have described a method which combines a polarized light goniometer with a force platform, using an on-line computer to estimate joint forces from the measured data (3).

For the present study, we have considered that the mechanical parameters of particular interst in the knee are those which are indicated by the moments about the two horizontal axes (figure 1). The distribution of forces between the medial and lateral condyles may be computed from these moments, and is a valuable measure of the alignment of the knee joint in the coronal plane.

Details of the method

In order to estimate the forces on the knee joint it is necessary to measure the forces at the foot-ground interface together with the location of the lower limb in space. Since the forces during the stance phase are necessarily greater, we limit measurement to that time and do not consider the swing phase. Following Bressler and Frankel (4), we have chosen to ignore components of force attributable to accelaration. At the speeds attained by most of our patients it is unlikely that the acceleration components are larger than 10% of the total (5).

The ground-foot reaction was measured by a 9261A force plate (Kistler instruments). The position of the limb in space was found by measuring the location of a talcum powder imprint of the foot left on the force plate surface. In this way the complete set of data could be obtained at low cost, using only commercially available equipment. No special interface for the computer (Digital Equipment Corporation PDP11/10) was needed since all of the data were compatible with the standard analogue inputs.

The computer programmes were written in Fortran, and use 24K of memory. Patient data files were stored on removable disc, in duplicate for security.

The protocol for collection of data was as follows: First the patient was asked to walk along the walkway over the platform using his regular gait. The starting place of the walk was adjusted so that one foot landed in the centre area of the force plate. This was not always possible and with many patients judgement was needed to decide when optimum was achieved since the distance patients can walk may be severely limited. Three recordings were made for each leg and the results compared to measure regularity of gait.

After preliminary analysis designed to ensure validity of the data, a composite picture is produced of the forces on the knee. Figure 2 illustrates a typical result. Each graph is plotted against time. Only results from the stance phase are shown.

In order to summarize the data for inclusion in patient notes, the following parameters are computed: mean total joint force; percentage medial plateau load; mean collateral ligament force. These results are then entered into the patient notes as shown in Table 1. Each figure represents the mean value, integrated over the stance phase.

Accuracy and precision of results

The validity of this method of force analysis has been discussed elsewhere (3). It was estimated that the location of the line of action of the resultant force in the knee could be determined to within 1.7 cm. The principle source of error lies in the measurement of the frontal tibial angle. By comparing the goniometer output with selected frames of a simultaneous television recording the angle could be measured to within 1^{o} during the stance phase. The video film provides a useful record of each patient, and is also stored for reference.

Results

There are several areas in which results from this kind of analysis are useful. The long-term goal is to examine the correlation between knee joint loading and prognosis for knee replacement. Since the average life of a knee prosthesis is currently some 3 - 4 years, we shall have to continue this work until at least 1981 before any major findings of such a serial study can be reported.

In addition to the long-term goal of the research it has already been possible to examine other issues. The relationship between the knee coronal angle and the load on the knee has been analysed for a group of 80 patients (6,7). A summary of these results for 172 knees is given in figure 3. This illustrates that the balance of forces in the coronal plane do not correlate in a linear way to the knee coronal angle. In particular it was found that a valgus deformity did not necessarily produce increasing load on the lateral condyle.

This ability to compensate for valgus knee deformity by modification of gait has been subject to detailed analysis. We have reported that the ability does not depend upon the range of hip movement, nor on the contralateral knee angle (6). Direct observation of the video tapes from these patients showed that either a small amount of hip adduction during swing phase, or a lateral thrust developed at the floor during stance phase, could produce greater loading of the medial condyle (7). Studies using photoelastic stress models are now being pursued to verify these findings.

Improvement in gait, and in the balance of forces on the knee have been shown in the eight patients who have been examined before and after operation. Each case demands consideration separately, and to do so in this review would be out of place. It is reassuring, however, to be able to report a consistent improvement in the balance of knee joint forces following joint replacement. Whether the improvement persists or not will only be revealed in due course. Measurements on these and other patients with knee arthroplasty will continue at intervals of one year.

In patients where the gait has been analysed prior to revision, we are able to correlate the wear of the original prosthesis with the knee joint forces observed (8). Only two cases of this nature have been recorded so far. It is hoped that here again a long-term study will reveal realistic measures of causes for prosthesis failure. In the two cases seen the wear was principally caused by bone cement debris, and took place in the area predicted by the gait analysis. An extension of this work may enable prediction of wear rates from a knowledge of the gait and joint forces of the patient.

All of the work described so far relies upon measures taken for just two seconds during six walking cycles. It is well known that considerable variation exists diurnally and seasonally with arthritic patients. For this reason it is important to consider long-term monitoring of gait, using miniature tape recorders (9). Methods for recording posture, cardiac function and overall activity have been developed locally (10), (11). We are applying these methods to some of the patients reviewed by the gait analysis clinic in an attempt to assess the benefits of knee replacement to patient mobility.

Conclusions

Consistent use of gait analysis enables a serial study of patients having knee prostheses. Results from the first year of operation have indicated that the dynamic balance of forces within the knee can only be predicted by gait analysis techniques, and is more complex than examination of static x-ray measurements would suggest. The existance of a "compensatory" mechanism in patients having a valgus knee deformity, is important for rehabilitation. If "compensation" persists after an operation which corrects the deformity, then excessive medial compartment loads may be observed.

Adjunctive studies of wear of prostheses and using ambulatory monitoring are being carried out. These facets combine with the gait analysis to provide a set of data which will be of value in determining the prognosis for knee joint replacements. An improvement in technique and success rate may justifiably be hoped for from work of this kind.

Acknowledgement

We are indepted to Professor P.H. Fenten, Department of Physiology, for his valuable assistance with ambulatory monitoring. The studies of prosthesis wear are part of collaborative work with Dr. E. Smethurst of the Metallurgy and Materials Science Department.

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TABLE 1

Results of Gait Analysis as Entered in Clinical Notes
(Typical data given as an example)

Knee Parameter	Right	Left
Weight bearing angle	7^{o} VL.	6^{o} VR
Total joint load*	2.63	2.31
Medial plateau load	61%	89%
Collateral ligament load*	0.01	0.18

*These figures are expressed as multiples of body weight.

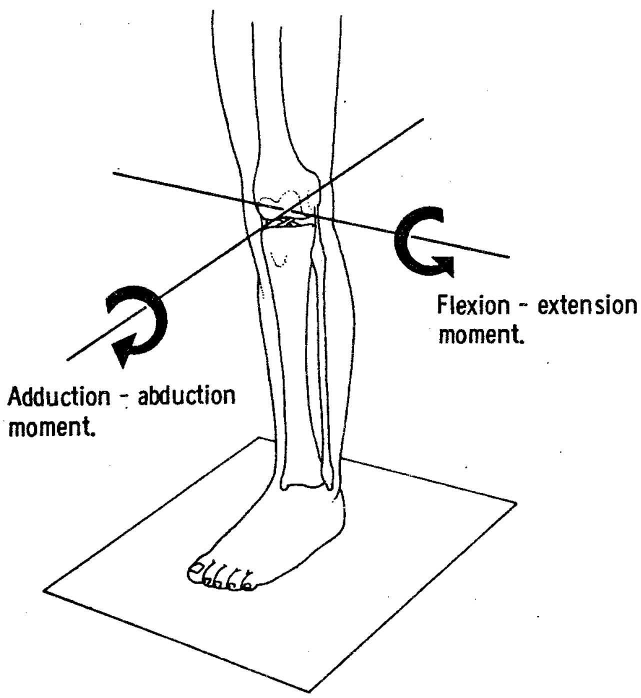

Figure 1.

To define the moments about the knee computed by the metbod described in this paper

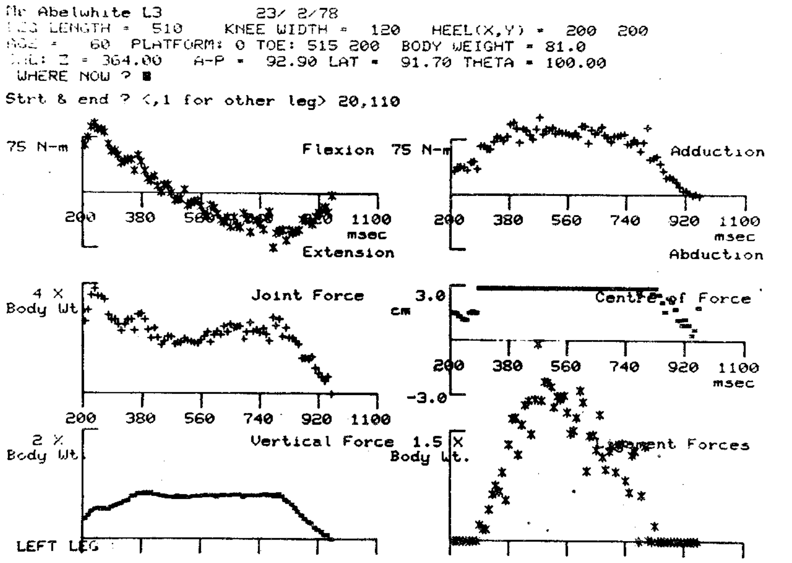

Figure 2 Typical results. A copy of the computer printout.

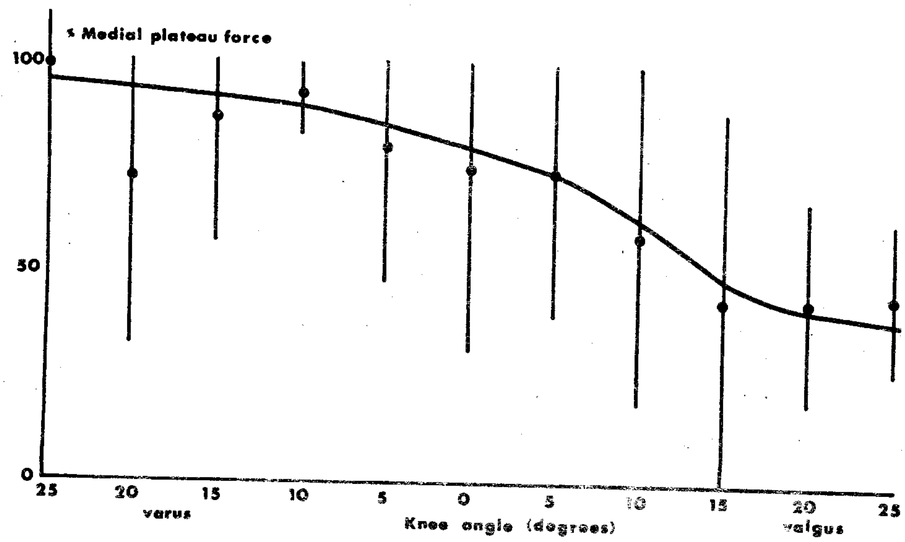

Figure 3 Percentage medial plateau force plotted against knee angle. The vertical lines indicate one standard deviation from the mean.