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CORRELATIONS BETWEEN CHANGES IN GAIT AND IN CLINICAL STATUS AFTER KNEE ARTHROPLASTY

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Twenty-six knee arthroplasties in 22 subjects were studied clinically and in a gait laboratory before and on one or more occasions after surgery. The purpose was to identify changes in gait characteristics and relate them to changes in the clinical situation of the patients.

The gait patterns of the patients changed following surgery mainly with respect to their time-distance characteristics; stride length, cadence, time of swing, and time of support. Positive correlations were noted between these gait changes and the patient's pain, his limp, and his walking distance. It is concluded that the information obtained in a sophisticated gait laboratory is of limited value to the surgeon in his clinical assessment.

Key words: biomechanical analysis; clinical assessment; gait; gait analysis; knee arthroplasty

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While the main indication for knee arthroplasty is pain, a further objective is to improve the patient's functional ability, and more specifically, his gait. This is achieved in part by pain alleviation, in part by correction of deformities, and in part by replacement of the articulating surfaces.

In addition to qualitative observations and clinical evaluations, quantitative biomechanical measurements have been used to describe changes in the function of subjects with knee disabilities before and after surgery of the knee (Andriacchi et al. 1977, Arborelius et al. 1976, Chao 1975, Chao & Stauffer 1975, Collopy et al. 1977, Kettelkamp et al. 1972, Stauffer et al. 1977, Stauffer et al. 1975).

Gait can be characterized quantitatively by time-distance measurements, such as cadence, step-length, time of support and time of swing, and by ground-force measurements. As these gait parameters are known to change with a change in walking speed, both in normal and gait-impaired subjects, gait information is useful only when considered in relation to walking speed (Andriacchi et al. 1977, Cavanagh & Gregory 1975, Grieve & Gear 1966, Jacobs et al. 1972, Lamoreux 1971, Murray et al. 1966).

Only a few studies exist in which quantitative changes in gait are related to the patient's clinical assessment (Kettelkamp et al. 1972, Stauffer et al. 1975). Kettelkamp et al. (1972) studied 41 rheumatoid knees, and found that cadence was significantly related to pain, and that the stride length increased when the range of flexion of the knee increased. Stauffer et al. (1977) studied 37 knee patients before and after a MacIntosh hemiarthroplasty. Overall, the preoperative and postoperative gait characteristics were not related significantly to clinically evaluated results. In none of these studies was walking speed documented, so it is difficult to assess the reported results.

The purpose of this investigation was to study

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changes in gait characteristics following surgery, and to relate them to changes in the clinical status of the patients. The paper does not attempt to describe in detail the clinical results of the knee arthroplasties.

PATIENTS AND METHODS

The study included 26 knee arthroplasties in 22 subjects, 14 females and 8 males. The mean age of the subjects was 60 years (range 30–79 years). Weights ranged from 50 to 101 kg (mean weight 77 kg) and heights from 154 cm to 193 cm (mean height 166.5 cm).

The clinical diagnosis was primary osteoarthritis in 15 knees, rheumatoid arthritis in 9 and in one each post traumatic osteoarthritis and avascular necrosis. Three different types of prostheses were used; 10 Polycentric, 10 Gunston, and 6 Geomedic, i.e. 20 unconstrained prostheses and 6 partially constrained. Simultaneous involvement of one or more other joints was present in 22 subjects; 17 had knee involvement, one hip involvement, and 3 both knee and hip involvement.

Gait measurements were made on all subjects just before surgery and at one or more of the following periods postoperatively; 3 to 6 months, 15 knees; 7 to 12 months, 18 knees; and 13 to 36 months, 10 knees. Eighteen knees were seen in the gait laboratory more than once postoperatively (Table 1).

A clinical evaluation was made each time gait was quantitatively evaluated. The clinical data were noted using a 133 item form previously published (Freeman et al. 1977), to assess pain and functional activities and to record the physical findings.

The instrumentation used included photocells, foot switches, and a multicomponent force plate. The data was acquired and processed using a minicomputer.

Average velocity was derived from the on-off closure of a series of five photocells placed at 2.5 meter intervals along the walkway. Velocity was computed at each interval.

Cadence, time of support and time of swing were measured using instrumented foot pads placed inside the subject's shoes. The foot pad consisted of an insole with four pressure sensitive transducers located at the heel, the heads of the fifth and first metatarsal bones and the big toe. The on-off closure patterns of the transducers were transmitted through a cable attached to an overhead trolley which trailed the subject while walking.

The information from the foot switches and the photo cells was combined into 13-bit digital words and sampled at the rate of 100 Hz. Each bit was decoded in the computer to provide times of switch closures and openings.

Time of swing, and time of support were derived for each limb independently. Time of swing was defined as the amount of time during which all switches were open and time of support as the amount of time any switch was closed.

Table 1. Number of subjects and arthroplasties studied at each time of observation

Time of observation (months)	# Knees	# Patients
Pre-op	26	22
3–6	16	16
7–12	19	15
13+	10	10

The Kristal piezoelectric force plate (Kistler, Switzerland, 40 × 60 cm) was mounted inconspicuously in the center of the walkway and used to measure dynamically the three components of foot-ground reaction force; medio-lateral (X), antero-posterior (Y), and vertical (Z). The analog signals from the force plate were digitized at a sample rate of 200 Hz and processed.

Each gait measurement included 20 traverses of a ten-meter walkway. The subject was asked to walk a prescribed number of times at his normal walking speed, at fast walking speed and at slow walking speed. No specific instructions were given to the subjects to step on the force plate to avoid alterations in normal walking patterns. A typical test, therefore, did not produce 20, but only 10 steps on the measuring surface suitable for analysis. Ground reaction force measurements were recorded along with the temporal measurements on magnetic tape for further processing.

Data analysis

The times were averaged over one traverse of the walkway (usually about 5 strides) while the subject was walking at uniform velocity. Thus, 20 traverses of the walkway yielded 20 measurements of swing, and support for the left and right limbs, over a wide range of walking speeds. Average cadence and stride length were derived from the foot switch and photo cell measurements.

Temporal and force plate data were interpreted and compared by observing each parameter plotted against walking speed. A least square regression analysis was used to fit linear, quadratic, and cubic polynomials to each data set.

Each traverse of the walkway produced a single data point for each of the temporal and ground reaction force parameters. All data points obtained in one measurement were plotted against velocity. Data for each gait parameter obtained in the knee patients were then compared to those previously obtained for normal subjects of the same stature (Andriacchi et al. 1977) by

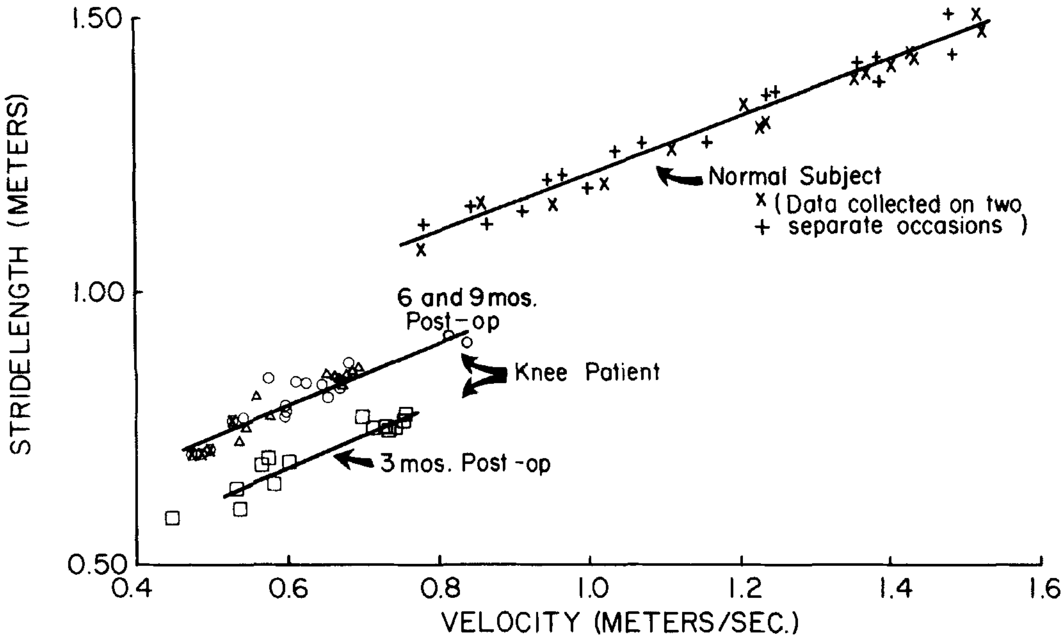

Figure 1. An illustration of the stride-length-velocity relationships for a normal subject, and a patient with a total knee replacement observed 3, 6 and 9 months postoperatively.

plotting corresponding curves on the same graph, as illustrated in Figure 1. Then, the entire curve rather than each single measurement was considered.

The clinical data was entered into the computer and correlations established with the gait data. Changes in gait and in clinical data were compared individually as well as in combinations.

RESULTS

Clinical results

When comparing the history of the patients before and after surgery the important clinical changes were a decrease in pain, which occurred in all subjects, and an increase in walking distance, which occurred in all but 3 patients. Other functional abilities, such as stair climbing and rising from a chair without the use of arm rests, improved in 11 and 9 patients, respectively. The physical examination revealed a better alignment of the leg in all knees with a preoperative varus or valgus deformity, and stability improved in all unstable knees. A less severe limp was noted in 19 of the patients. The range of motion improved by an average of 10 degrees in 9 knees, decreased by an average of 10 degrees in 7, and was unchanged in the remainder.

Gait analysis

Because of the purpose of the present paper absolute values of the gait parameters are not given. They can be obtained on request from the authors. The gait parameters of each knee patient were compared to the gait measurements obtained from a healthy subject of the same stature and sex. These subjects have been described in a previous study (Andriacchi et al. 1977). The measurements were compared over a range of walking speeds as illustrated for stride length in Figure 1. The measurement from a patient was considered normal only if the entire velocity-relationship of a particular gait parameter was the same as for that of the healthy subject. A more complete description of the approach was given in a previous publication (Andriacchi et al. 1977).

An increase in the range of voluntary walking speed was found in 18 of the 22 subjects. In 3 patients walking speed range remained unchanged, and in one it decreased. The increase in walking speed range was, as a rule, continuous up to 1 year after surgery; only minor changes occurred thereafter.

Of the gait characteristics observed, four were found to be particularly indicative of changes in gait; stride length, time of swing, time of support and degree of gait asymmetry.

The preoperative stride length was below normal in 19 subjects (22 knees), and normal in 3 (4 knees). Postoperatively, improvement was found in 11 patients (14 knees), and deterioration in 3 (3 knees). The time of swing preoperatively was below normal in all but 2 patients (2 knees). Postoperatively, changes were found in 17 patients (17 knees); 12 improved, and 5 deteriorated. Time of support postoperatively was below normal in 12 patients (14 knees), and normal in 10 (12 knees). In 8 patients (8 knees) improvement was noted, in 2 (2 knees) deterioration occurred, and the remainder were unchanged. Asymmetry during stance and swing phase changed in 9 subjects; 6 improved, and 3 deteriorated.

The ground-reaction force amplitudes also changed, but in general were not as sensitive to gait changes as were the temporal measurements. Changes in medio-lateral and antero-posterior forces occurred in 3 patients only, while changes in the vertical forces occurred in 4.

Correlation between clinical data and gait observations

The change in gait velocity was closely related to changes in pain. In the 4 subjects in whom the range of walking speed was unchanged or decreased, there was no relief or incomplete relief of day pain and walking pain in 3, while the fourth was considered to have a normal walking speed range even before surgery. A further indication of the relationship of range of walking speed to pain was that these sometimes changed between different periods of observations, but always in tandem. Similar positive correlations were found between walking speed range and both the degree of limp, evaluated clinically, and the maximum walking distance.

The temporal changes in gait related primarily to the changes in pain and in walking distance. They also related to simultaneous involvement of one or more other joints which was present in 22 subjects; 17 with knee involvement, one with hip involvement and 3 with both hip and knee involvement.

All patients who showed, postoperatively, an increase in ground-reaction force amplitudes also reported less pain postoperatively.

DISCUSSION

Following knee arthroplasty the gait patterns of patients with knee disabilities changed mainly with respect to time-distance characteristics; stride length, cadence, time of swing, time of support. Since these characteristics are all velocity dependent, it would be possible that the change resulted only from the postoperative increase in average walking speed. But, the temporal gait characteristics changed even when they were compared at the same walking speed as before surgery. It seems, therefore, that the change was due also to other factors. Such factors could be the decrease in pain when walking, and the less severe limp. Another explanation might be the change in stride length. Preoperatively, the subjects used short rapid steps requiring little single support time. Postoperatively the step length increased which influenced the other gait parameters. The velocity dependence of the temporal gait characteristics is so marked, however, that gait observations which do not take walking speed into account can arrive at wrong conclusions.

In a second study it was shown that the shorter than normal stride length found in patients was associated with a less than normal knee flexion during stance phase and an abnormal use of the extensor and flexor muscles of the knee (Andriacchi et al. 1980).

It was gratifying to note that gait became more normal after surgery. Even so, the gait did not become completely normal. This was in part due to the fact that all but one subject had multiple joint involvement. The findings, however, emphasize that normal gait cannot be expected in patients following today's knee joint replacement surgery. The design of the implant, the operative technique, and the difficulties obtaining stability can all be factors of importance in this respect.

The information obtained in a sophisticated gait laboratory appears to be of limited value to the surgeon in this clinical assessment. Such measurements are time-consuming and expensive and can perhaps be replaced by questions about the walking distance, observations of the patient's limp, and measurements of his maximum walking speed in a simple laboratory environment since these three factors relate directly to gait. The usefulness of gait observations in the laboratory lies more in the classification of particular gait abnormalities associated with joint pathologies and neuromuscular disorders and in the study of forces and moment acting at the joints for purposes of the design of artificial joints.

CONCLUSIONS

The study shows that measurements of temporal and ground reaction forces can be used to indicate gait changes following knee arthroplasties. Changes were found primarily in the temporal measurements which were clearly velocity dependent. Positive correlations were noted between these temporal gait changes and the patient's pain, his limp and his walking distance.

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