Scand J Rehab Med, 18: 101–106, 1986

CORRELATION BETWEEN CLINICAL EXAMINATION AND QUANTITATIVE GAIT ANALYSIS IN PATIENTS OPERATED UPON WITH THE GUNSTON-HULT KNEE PROSTHESIS

Elisabeth Olsson and Anders Barck

From the Department of Orthopaedic Surgery, Karolinska Hospital, Stockholm, Sweden

ABSTRACT. A group of 21 patients with total knee joint replacement was followed-up ten years after the operation. The clinical assessment including pain, range of motion, muscle strength and knee function was related to an objective gait analysis which included ground reaction force patterns and joint angular motion. This method of gait analysis not only confirmed in an objective way the impression from the clinical assessment but also provided a more accurate gradation of the results. The method is applicable to patients with weight bearing problems.

Key words: gait analysis, total knee replacement, clinical examination, correlations

An accurate assessment of the postoperative function is necessary for the evaluation of joint replacement, in particular the knee joint. This is most frequently done by clinical examination at which the impression of the investigator and the method he uses inadequately may influence the results as described by Andersson (1). There has been a longstanding call for an objective analysis of the function of replaced joints. By evaluating a patient's stride characteristics, the combination of muscle strength and mobility can indirectly be assessed in an objective way. Quantitative gait analysis offers a definite means of interpreting the patient's subjective opinion and the information gathered on routine clinical examinations.

In this study a correlation has been made between time/distance, kinetic, and kinematic gait variables, and the results of a clinical examination of patients operated upon with a unicompartmental replacement of the knee joint according to Gunston-Hult. This is a slight modification of the original Gunston prosthesis, the tibial component having been transformed into a flat plateau.

MATERIAL

All patients in this study had osteoarthritis of the knee. They were treated from 1973 and onwards with a follow-up time between 12 and 2 years, with a mean time of 9 years. All patients received a unicompartmental Gunston-Hult prosthesis as described by Barck (3). Of the 72 patients 22 fulfilled the criteria required for the test on the force plate walkway. The criteria were that the patients could walk 40 m without a rest and 200 m with a rest. The reason for this was that the walking test included approximately the latter length of walking. One of the tested patients was excluded. She could walk, but her usual way of walking was so influenced by a recent femoral fracture, that the knee surgery was not regarded as possible to evaluate. Thus, 21 patients remained for evaluation, representing 30 Gunston-Hult prostheses, of which 25 were operated with a medial compartment replacement and the remaining five with a lateral. One patient had the other knee replaced with a Blacina prosthesis and one had the other knee osteotomized. Mean age was 72 years (62–86), mean weight for the 8 men was 88 kg and for the 13 women 77 kg, mean height was 178 and 163 cm, respectively. No patient used a walking aid indoors.

METHOD

Clinical assessment

The clinical examination was performed by an orthopaedic surgeon (A.B.) after the gait analysis of which the surgeon had no information. The clinical assessment was based on 243 variables of which 20, regarding pain, range of motion, strength and knee function, were considered suitable for correlation with the objective assessment shown in Table I.

Pain. Eight questions on pain at rest, during and after activities, were asked for each leg including Binary (Yes/No) and Visual Analogue Scale questions (VAS).

Range of motion. Passive extension and active flexion were measured with the patient in a supine position. The coronal tibiofemoral angle was measured with the knee in maximal passive extension and the tibia stressed both laterally and medially. The knee was considered unstable if motion in the frontal plane exceeded 10 degrees.

Strength. Strength was graded as 1–3 depending on the amount of the examiner's resistance which the patient could overcome on extending the knee.

Knee function. For the assessment of knee function a method according to Waugh et al. (10) was chosen, as this more than other accepted clinical evaluation methods stresses the importance of isolating the contribution of the actual knee to mobility and function. Waugh stated, that

Table I. *Reported significant correlations ($p<0.05$) between biomechanical gait variables and clinical findings in different studies*

DJD = degenerative joint disease, RA = rheumatoid arthritis, ROM = range of motion, — = inverse correlation

Biomechanical gait variable	Stauffer, Chao & Györy (9) 65 DJD 30 RA patients preop.	Kettelkamp et al. (6) 41 RA patients	Present material 21 DJD patients postop.	*p*
Velocity	Pain on weight bearing		ROM	
	Pain at rest		Function (—)	
	ROM		Walking distance	
	Total flexion		Maximum walking speed	<0.01
	Strength		Stairs	
	Walking distance			
	Stairs			
	Sit down and rise from chair			
	Limp (—)			
	Instability			
Gait cycle duration			Pain	<0.001
			Pain after walking	<0.001
			Flexion contracture >5° (—)	<0.01
			Function	<0.001
			Walking distance (—)	
			Maximum walking speed (—)	
Step rate	Walking pain (—)	Pain	Pain (—)	<0.001
	Total flexion		Pain after walking (—)	<0.001
	Walking distance		Pain at rest (—)	
	Limp (—)		Flexion contracture >5°	
	Stance flexion (—)		Function (—)	<0.001
			Instability (—)	
			Walking distance	
Stride length/Lower extremity length	Strength	Pain	ROM	
	Total flexion	ROM	Maximum walking speed	
	Instability (—)	Standing flexion		
	Walking distance			
	Limp (—)			
	Rise from chair			
Weight acceptance time, % gc			Pain after walking	
			Strength (—)	
			Function	<0.01
			Walking distance (—)	
			Stairs up (—)	
Stance phase, % gc	Rise from chair		Pain after walking	
			ROM (—)	
			Function	<0.01
			Walking distance (—)	
			Stairs up (—)	<0.01
Maximal vertical force, % body weight	Rise from chair		Pain after walking (—)	<0.01
			Function (—)	
			Walking distance	<0.01
			Maximum walking speed	
Stance flexion of knee	Pain	Pain	Stairs up	
	Pain on weight bearing	ROM	Total flexion	
	ROM			
	Total flexion ($p<0.01$)			
Total flexion of knee	ROM	Pain	ROM	<0.001
	Strength	ROM	Stairs down	<0.01
	Stance flexion	Flexion contracture	Sit down	<0.01
	Stride length/LEL	Standing flexion		
	Step rate			

for proper comparison the performance of the same activity by each patient should be measured by the same standards on each occasion. Such requirements cannot be met by asking the patient how well he performs certain activities, because circumstances are different in each case and some patients are better in compensating for disability.

The ability of standing on one leg, sitting down and rising from a 41 cm high chair as well as climbing and descending stairs was assessed according to a 5 grade scale. In a test, the stair test, the patient was asked to mount and descend platforms of varying heights. The affected leg should lead when climbing and follow when descending. There was one VAS question concerning overall function. All questions were asked and tests were done for each leg. Information was also gathered regarding maximal walking distance.

Maximal walking speed. The average velocity was calculated when the patient walked for 3 min as fast as he could back and forth in an 80 m long corridor accompanied by the investigator (E. O.).

Gait analysis

The gait analysis was performed by a physiotherapist (E. O.). The method involved walking on a 5 m walkway with on line registration of time/distance factors, ground reaction force patterns, and sagittal angular motion of both knees and hips as described by Olsson et al. (7).

Time/distance factors. Data were recorded from two 5 m long force plates. Ample space at both ends gave the patient a chance to adjust his (her) walk on the walkway to an almost constant speed. Optical switches at either end of the walkway measured average velocity and triggered the measuring procedure. Attempts were made to obtain the greatest possible variation in each subject's walking speed. Most of the variables were seen in relation to walking speed. The means of 12 gait runs and 43 gait cycles per patient were used for evaluation. The phases of the gait cycle were measured for each leg for comparison of sides (symmetry). In addition to the variables shown in Table I, step lengths and duration of single support for each leg were measured.

Ground reaction force patterns. The maximal vertical force for each leg was measured in every gait run.

Sagittal angular motion. A modification of the self-aligning goniometer described by Öberg & Lamoreux (11) was used. The kinematic test was made immediately after the first twelve runs in order to see whether the goniometer interfered with the patient's usual gait pattern. Before tests were performed the patients walked for some five minutes with the goniometer mounted in order to get acquainted with it. Knee flexion in stance and swing phase of both legs was tested in slow, normal and fast speed respectively. (Hip flexion registrations were not part of the study.) Velocity, step rate, and mean step length were also tested for these runs. Hence, 12 gait variables were recorded for each patient in the kinematic test.

Ten minutes after completing the gait test a protocol was presented with the mean value of each gait variable for each gait run. The mean values of all gait variables for all gait runs in different walking speeds were analyzed statistically.

Statistical methods

Student's t-test was used for differences between means and correlation coefficients. When the number of cases in any subgroup was considered to be too small for the t-test the Mann Whitney U-test was used.

Approximately 250 correlation coefficients were computed and tested. At the 5% risk level this gave ($250 \times 0.05 = 12.5$) 12 or 13 "significant" coefficients generated at random. If the risk level was lowered to 1% the number of randomly generated significances was reduced to only 2 or 3.

RESULTS

All specified correlations represent the worse leg and if not differently stated $p<0,05$. They are presented in Table I together with correlations found by Stauffer, Chao & György (9), whose patients were tested prior to surgery, and Kettelkamp (6), who studied patients with rheumatoid arthritis.

The distribution of patients into groups according to pain in one knee, both knees, or no pain at all as well as mean values of the gait tests are shown in Table II. Significant differences were found between the group with no pain and the two other groups. The group with no pain and the group with bilateral pain demonstrated the greatest differences however. There was a significant difference in range of walking speed between the group without pain and the one with two painful knees.

Time/distance factors

Average walking speed showed a strong ($p<0.01$) correlation to maximal walking speed and also to overall function (inversely), walking distance, range of motion (ROM) and stair climbing. Mean gait cycle duration, which was another measure of velocity, showed here a very strong correlation ($p<0.001$) to pain and inversely to flexion contracture >5° ($p<0.01$). It correlated more strongly than average walking speed to function ($p<0.001$) as measured in this study. There was a significant difference ($p<0.001$) in gait cycle duration between the eleven patients with pain ($\bar{x}=1.336$, $SD=0.932$) and the ten patients without pain ($\bar{x}=1.150$, $SD=0.108$).

Step rate. A strong inverse correlation was found between step rate and all questions on pain ($p<0.001$). The difference in mean step rate between the eleven patients with pain in the knee ($\bar{x}=1.528$, $SD=0.11$) and the ten patients without pain ($\bar{x}=1.783$, $SD=0.12$) was well stated ($p<0.001$). Step rate was also strongly inversely correlated to function ($p<0.001$).

Table II. *Means and tests of differences in patients with and without pain*

VAS = Visual Analogue Scale

Variable	Group I: no pain	Group II: pain one knee	Group III: pain both knees	Diff. between groups	
				I–II	I–III
Number of patients	10	5	6		
Both knees Gunston-Hult prosthesis	5	1	3		
Average velocity (cm/s)	111	91	66		**
Step rate (steps/s)	1.78	1.51	1.49		**
Gait cycle duration (s)	1.13	1.37	1.38	**	**
Single limb support (% gait cycle)	35	35	31		*
Weight acceptance time (% gait cycle)	15	15	20		*
Max.vertical force (% body weight)	109	104	101		**
Pain after walking (VAS)	35	81	88		***
Function (VAS)	29	40	55	*	**
Max.walking speed (cm/s)	157	144	113		*

* $p<0.05$, ** $p<0.01$, *** $p<0.001$.

Time of support. The difference between the two legs in duration of single support and stance phase was not significant. Positive correlations to climbing stairs were found for single support time and stance time ($p<0.01$). In this study stance phase time demonstrated more correlations to the clinical examination than did time of single support.

Weight acceptance time. Weight acceptance time (from ipsilateral heel strike to toe off of the opposite side) of the worse leg ($\bar{x}=14.2$, SD $=2.38$) was significantly longer than that of the better leg ($\bar{x}=13.6$, SD $=2.3$). A difference in weight acceptance time between the legs correlated to standing on one leg ($p<0.01$).

The strongest correlation was found between weight acceptance time and function ($p<0.01$). It was also associated with walking pain and inversely with strength, walking distance, and ability to climb stairs.

Step length. A difference in step length between the legs was correlated to flexion contracture ($p<0.01$) and also inversely to function, resting pain and climbing stairs.

All different measurements of step length were positively correlated to active flexion of the knee.

Ground reaction force patterns

Maximal vertical force showed strong correlations ($p<0.01$) to walking distance and inversely to walking pain ($p<0.01$) and function.

The vertical force under the worse leg ($\bar{x}=104.5$, SD $=4.9$) was less than under the better leg ($\bar{x}=106.7$, SD $=6.6$).

The difference in maximal vertical force between the two legs was correlated to weight bearing pain ($p<0.01$).

Sagittal angular motion

Stance flexion. In 20 patients stance flexion was found to be less ($p<0.01$) in the worse leg ($\bar{x}=10.5$, SD $=3.22$) as compared with that of the better leg ($\bar{x}=13.25$, SD $=5.21$). Stance flexion was associated with climbing stairs as represented by the score used in this study. Stance flexion of the better knee was positively correlated to velocity. No such correlation was found for the worse knee.

Total sagittal motion. The mean of total flexion of the worse knee during walking ($\bar{x}=48$, SD $=8.7$) was less than that of the better knee ($\bar{x}=51$, SD $=10.3$). There was a strong positive correlation ($p<0.001$) between total flexion and range of motion.

Positive correlations were also found ($p<0.01$) to descending stairs and sitting down. All variables of sagittal angular motion were correlated to climbing and descending stairs.

DISCUSSION

In a study like this the problem of "many significant tests" should be considered. The risk of presenting false significant correlations is, however, in

Table III. *Comparison of gait variables between patients with no pain and normal population groups from Chao (4)*

The values for the mean and standard deviation are presented

	Present material ($n=10$)[a] Mean age 70 (range 62–86)		Chao et al. (4) Mean age 58 (range 32–85)			
			Men $n = 32$		Women $n = 37$	
Variables	X	SD	X	SD	X	SD
Step rate (steps/s)	1.79	0.10	1.73	0.16	1.87	0.16
Stride length/Lower extr. length	1.31	0.20	1.56	0.15	1.40	0.14
Average velocity (cm/s)	104	18	127	21	116	18
Step length (cm)	57	12	73	8	61	8
Stance phase (% gait cycle)	64	2	59	2	60	2
Single limb support (% gait cycle)	35	2	41	2	40	2
Double support (% gait cycle)	15	1	9	1.9	10	6
Max.vertical (% body weight)	108	4	114	9	110	6
Stance knee flexion	11	2	17	5	15	6
Total sagittal motion	52	7	72	6	66	9

[a] 3 men, 7 women.

this case minimal. No correlation considered as unreasonable has been presented, nor has anything been dealt with that did not show significance in almost all variables measuring the same parameter in different ways.

The result indicates that the measured gait variables correlate well to patients' functional performance. The measured gait factors represent a quantification of the patient's subjective opinion and the information gathered at very thorough clinical evaluation. Hence, pain can be measured in quantitative values by step rate and gait cycle duration as estimated here. Function can be measured by step rate, duration of gait cycle, weight acceptance and stance. Pain after walking is reflected by all the above mentioned variables and also by maximal vertical force.

The patients were all considered as having a good or excellent result from the operation. Patients are often divided into groups with uni- and bilateral surgery but in this case they were grouped according to presence of pain in one, both or no legs. These groups showed very strong correlations to the walkway registrations.

Stance and total flexion and maximal vertical force were less and weight acceptance time longer for the worse leg implying that the variables indicating weight bearing capacity could discriminate well between the legs. This is noteworthy as the better leg in more than half the material had a diseased knee, which however had been operated upon. A difference in duration of stance, single support or step length might have been found in the material as a whole if the number of patients had been larger.

A common finding is that patients with knee joint replacement have an abnormal gait pattern despite being clinically asymptomatic. The ten painfree patients were compared with a group of normal individuals from Chao's et al. work on normative data of the knee joint (4) as shown in Table III. Average walking speed was slower, duration of stance and weight acceptance longer, and single support shorter, and total flexion was less in the patient group. Velocity was a good measure of overall function but if separated into its constituents step rate and step length the correlations were stronger.

There was a consistency with other authors (6, 9) especially concerning step rate and stance flexion and their correlations to clinical findings, but the different authors focussed their attention on or measured different variables. Stauffer's (9) material consisted of patients tested before surgery indicating more pronounced disabilities than in this material, and Kettelkamp (6) studied rheumatoid knees. Though the way of estimating quadriceps strength was very elementary in this study, correlations were found to stride length/lower extremity length and velocity but also to maximal vertical force and stance duration.

Significant correlations were found in the better leg between velocity and both stance flexion and maximal vertical force. No such correlations were found for the worse leg. This material was too small to allow conclusions as to significant biomechanical variables but the tendency was consistent with the findings of Andriachi et al. (2), Chao et al. (5) and Simon et al. (8).

Conclusion. This investigation has proved that this method of gait analysis not only confirms the result from a thorough clinical examination, but also provides additional and objective information impossible to measure by clinical observation. The method enables a more accurate gradation of locomotor function especially in patients with weight bearing problems.

REFERENCES

1. Andersson, G.: Hip assessment: A comparison of nine different methods. J Bone Jt Surg *54-B*: 621, 1972.
2. Andriacchi, T. P., Galante, J. O. & Fermier, R. W.: The influence of total knee replacement design on walking and stair climbing. J Bone Jt Surg *64-A*: 1328, 1982.
3. Barck, A. L.: Compartmental knee arthroplasty with the Gunston-Hult prosthesis. (Unpublished data.)
4. Chao, E. Y., Laughman, R. K., Schneider, E. & Stauffer, R. N.: Normative data of knee joint motion and ground reaction forces in adult level walking. J. Biomech *16*:219, 1983.
5. Chao, E. Y., Laughman, R. K. & Stauffer, R. N.: Biomechanical gait evaluation of pre- and postoperative total knee replacement patients. Arch Orth Traum Surg *97*: 309, 1980.
6. Kettelkamp, D. B., Leaverton, P. E. & Misol, S.: Gait characteristics of the rheumatoid knee. Arch Surg *104*: 30, 1972.
7. Olsson, E., Öberg, K. & Ribbe, T.: A computerized method for clinical gait analysis of floor reaction forces and joint angular motion. Scand J Rehab Med *18*: 93, 1986.
8. Simon, S. R., Trieshmann, H. W., Burdett, R. G., Ewald, F. C. & Sledge, C. B.: Quantitative gait analysis after total knee arthroplasty for monarticular degenerative arthritis. J Bone Jt Surg *65-A*: 605, 1983
9. Stauffer, R. N., Chao, E. Y. & Györy, A. N.: Biomechanical gait analysis of the diseased knee joint. Clin Orth Rel Res *126*: 246, 1977.
10. Waugh, W., Tew, M. & Johnson, F.: Methods of evaluating the result of operations for chronic arthritis of the knee. J Roy Soc Med *74*: 343, 1981.
11. Öberg, K. & Lamoreux, L. W.: Gait assessment of total joint replacement patients by means of step parameters and hip-knee angle diagrams. *In* Disability (ed. R. M. Kenedi, J. P. Paul & J. Hughes). The Macmillan Press Ltd, London, 1979.

Address for offprints:

Elisabeth Olsson
Department of Orthopaedic Surgery
Karolinska Hospital
S-104 01 Stockholm
Sweden