Scand J Rehab Med 22: 45–50, 1990

ASSESSMENT OF WALKING BEFORE AND AFTER UNICOMPARTMENTAL KNEE ARTHROPLASTY

A Comparison of Different Methods

Eva Mattsson,[1] Elisabeth Olsson[2] and Lars-Åke Broström[2]

From the Departments of [1]Physical Therapy and [2]Orthopaedics, Karolinska Institute, S-104 01 Stockholm, Sweden

ABSTRACT. Walking ability was assessed in twenty patients before and one year after knee replacement with a cemented unicompartmental, Brigham prosthesis (mean age 63.4 years, nine women). All patients had moderate medial gonarthrosis. One year after surgery, knee function, assessed by the BOA score, self-selected and maximal walking speed as well as single limb support of the involved leg were increased. Pain and exertion during walking and oxygen cost of level walking were decreased at all measured speeds. Individual improvement in self-selected walking speed was correlated to improvement in maximal walking speed. Individual decrease of oxygen cost of level walking was correlated to decrease of perceived pain and exertion during walking. For clinical routine purpose clinical assessment, especially of pain, supplemented with measurement of self-selected walking speed were found to be sufficient for assessing effects of treatment such as unicompartmental prosthetic knee replacement.

Key words: gait, knee replacement, oxygen consumption, pain, correlations.

Pain is the main indication for knee arthroplasty. Pain alleviation in combination with replacement of the articulating surfaces implies a possibility for an improved range of knee motion and for better utilization of available muscle strength. From a functional point of view, assessment of walking capacity can be used to evaluate the effects of endoprosthetic knee replacement.

Usually the results after joint replacement are rated with clinical scores with only rough consideration of walking. Furthermore it has been shown that assessment, using such scores, depends on which score system is used. Andersson (3) compared the results in 77 patients, all tested with nine different scores before and after hip replacement, and found great variations in the results.

Average free walking speed and duration of single limb support to identify weight bearing capability have been pointed out as particularly noteworthy indicators of a patient's walking ability after total knee replacement (TKR) (7, 9, 15, 16). As many gait parameters are velocity dependent, it is important to clarify whether a change of a gait parameter is due to the change in walking speed or to a change of gait pattern. This is achieved by evaluating the gait variables at a constant walking speed (4).

A different method to evaluate walking ability is to study the energy cost of level walking. It has been shown that measurements of both walking speed and oxygen cost of walking are valuable parameters in the assessment of walking both in normal subjects and in patients with walking disorders (6, 8, 10, 11, 12, 13, 20).

Knee arthroplasty has become a common operation and the number of operated patients is increasing every year. To be able to supplement the clinical examinations with tests of walking ability for routine purpose, we have to find simple tests of walking with high correlations to objective, reliable measurements of walking ability. We have not found any report of results after joint replacement in which different methods to study walking capacity have been compared or related to clinical scoring.

The aim of this study was (*a*) to evaluate individual changes in clinical parameters, assessed by a clinical score, gait parameters and walking efficiency after knee arthroplasty in patients with moderate gonarthrosis and (*b*) to compare the results from simple walking tests with those from advanced gait analyses.

SUBJECTS AND METHODS

Twenty patients (eleven men and nine women) with moderate osteoarthrosis of one knee, grade 2–3 according to

Ahlbäck's classification (1), were tested before and one year after medial unicompartmental knee replacement. Mean age was 63±4.5 (mean ± SD) years and mean weight was 82±13.5 kg.

All patients were free from symptoms from other joints in the lower extremities and no patient had cardiorespiratory symptoms. None of the patients required any assistive devices for walking.

A unicompartmental endoprosthesis, Brigham model, was used to replace the medial knee compartment (19). A parapatellar retinacular incision was used. Femoral and tibial components were cemented in position with soft tissue tightening and any varus deformity was corrected. Weight bearing and exercises were started on the first postoperative day and after discharge all patients had the same physiotherapy postoperatively twice a week, in all ten times.

Clinical assessment

All patients were clinically and radiographically examined before and one year after surgery. Clinical results were assessed using the British Orthopaedic Association (BOA) knee function chart (2).

The questions in the BOA chart on gait, the patients' own opinion, and the extension lag were excluded giving a maximal score of 39 points. The excluded variables were more thoroughly assessed with other tests in this study.

One year after surgery the patients graded their opinion of treatment effects, using a six-graded scale (6=very satisfied, 5=satisfied, 4=relatively satisfied, 3=neither better nor worse, 2=worse and 1=very bad).

Radiographic examination included measurements of leg alignment, the Hip-knee-ankle (HKA) angle, from long X-ray films in the frontal plane of the whole leg at full weight bearing.

Prosthetic positioning and radiolucent zones around the components or the cement were determined from plain films in the frontal and the sagittal planes.

Walking tests

The walking tests described below were all performed during the same day, with a rest between the tests. The first series of tests was performed one day before surgery and the second series one year after surgery.

Simple tests of walking ability

Measurements of walking speed, pain and exertion during walking was used as simple tests of walking ability. The patients were asked to walk for four minutes in a corridor of 75 m, first at a self-selected, comfortable walking speed and after a rest, at their maximal walking speed. Walking speed was determined by a speedometer (in $m \cdot min^{-1}$) (11). At the end of every walking test the patients were asked to grade their pain and exertion during walking using a ten graded scale (5).

Advanced tests of walking ability

Gait analysis. Gait analysis was performed on a force plate walkway consisting of two five meter long, force measuring platforms recording several consecutive steps from both feet during level walking (17).

The following parameters were measured:

- self-selected walking speed ($m \cdot min^{-1}$)
- step frequency, F ($steps \cdot s^{-1}$)
- stride length/lower extremity length, LEL
- single limb support, SLS, % gait cycle for each leg
- maximal vertical force, MVF, % body weight for each leg
- MVF ratio (involved/uninvolved leg)
- vertical force impulse, VFI (involved/uninvolved leg).

The patients were instructed to walk with ordinary shoes first in their own freely chosen walking speed and then three times in slower and three times in faster speeds. The mean of each parameter was based on altogether 12 gait runs, approximately 33 gait cycles. As these were performed over a range of walking speeds, it was assumed that a few gait runs would be performed in the same walking speed on the two occasions.

Walking efficiency. Energy cost of level walking was measured according to a previously described method by which oxygen cost and speed can be measured with high accuracy (11).

During the walking test the patients wore a light-weight box (3.5 kg, volume 10 liters) on their back. They also wore a nose clip and breathed through a mouth piece connected to the mixing box by a flexible low-resistance hose. The gas mixture was subsequently analysed by means of a respiratory mass spectrometer (MGA 200, Centronics, Croydon, UK). Ventilation and gas exchange were computed as described by Linnarsson et al. (11).

The oxygen cost was measured during walking at both self-selected and maximal walking speeds. One year after surgery, oxygen cost was also measured at the speed that was self-selected and comfortable preoperatively. To achieve this predetermined walking speed the patients were guided by a test leader, who walked alongside pushing the speedometer (11).

Statistical methods

Student's *t*-statistic was used to test individual differences in the various parameters pre- and postoperatively and to test correlations. Pearson's or Spearman's correlation coefficient was used to identify the relationship between variables.

RESULTS

Clinical assessment

One year after surgery all knees were clinically stable. Leg alignment was corrected to an HKA angle less than 5 degrees of varus or valgus in all knees. Prosthetic positioning was considered satisfactory in all knees and one year after surgery there were no signs of prosthetic loosening.

The BOA score increased in all patients, as a mean from 30 points before surgery to 38 points after one year (Table I).

All patients stated significant pain relief after surgery. After one year 15 patients were very satisfied, four patients satisfied and one neither better nor worse. The patient, who did not experience improvement, had an injury nine months after surgery causing pain in the calf muscle during walking one year after surgery.

Table I. *Clinical scoring and simple tests of walking ability*

	Before surgery	One year after surgery	
BOA score (points)	30.4 ± 1.9	38.1 ± 1.1	***
Self-selected walking speed ($m \cdot min^{-1}$)	62.3 ± 8.3	74.2 ± 5.9	***
Maximal walking speed ($m \cdot min^{-1}$)	85.1 ± 3.9	93.9 ± 9.6	***
Pain (1–10) during walking at			
Maximal speed	4.4 ± 2.6	0.8 ± 1.4	***
Speed = preoperative self-selected speed	3.3 ± 2.3	0.4 ± 0.9	***
Exertion (1–10) during walking at			
Maximal speed	4.4 ± 2.5	1.8 ± 1.3	***
Speed = preoperative self-selected speed	3.0 ± 2.2	0.9 ± 1.3	***

*** $p < 0.001$.

Walking tests

Twelve months postoperatively no patient used walking aids. Mean values for the different gait parameters are presented in Tables I, II and III.

Simple tests of walking ability. Self-selected walking speed was preoperatively 62.3 $m \cdot min^{-1}$ and after one year 74.2 $m \cdot min^{-1}$. Seven patients had the same self-selected walking speed as normal subjects, 75 $m \cdot min^{-1}$ (18), or even faster one year after surgery. There was a mean increase in self-selected walking speed of 11.9 $m \cdot min^{-1}$ in 19 out of the 20 patients. The patient who had an injury, as described above, did not improve.

Maximal walking speed is presented in Table I. Two patients decreased their maximal walking speed. One of them, the patient who reported the injury, decreased 2.8 $m \cdot min^{-1}$. The other patient decreased 4.8 $m \cdot min^{-1}$ but he could already walk very fast preoperatively (109.2 $m \cdot min^{-1}$).

One year after surgery all patients experienced decreased pain during walking at the speed that was self-selected preoperatively ($p < 0.001$) and 16 patients walked without any pain.

Pain during maximal speed walking was decreased in 19 patients ($p < 0.001$) and 12 patients walked without any pain.

One year after surgery all patients walked at the preoperative self-selected speed with decreased exertion ($p < 0.001$). At maximal speed eighteen patients experienced decrease of exertion during walking ($p < 0.001$).

Advanced tests of walking ability

Gait analysis. One year after surgery the patients had improved their average self-selected walking speed with 9.8 ± 7.0 $m \cdot min^{-1}$ ($p < 0.001$). The ratio between the involved and uninvolved leg in single limb support and vertical force impulse had increased towards normal value (=1) (Table II). In all patients it was possible to find one gait run performed in the same walking speed on both occasions. When walking speed was thus treated as an independent variable, only duration of single limb support demonstrated a significant increase (Table III).

Walking efficiency. One year after surgery all patients decreased their oxygen cost of walking ($p < 0.001$) during both self-selected and maximal walking speed. Oxygen cost of walking at self-selected walking speed was postoperatively decreased to the same level as that for normal subjects at the same speed.

Relationship

Clinical assessment. Individual improvement in BOA score was correlated with decrease of pain ($r = 0.44$, $p < 0.05$) and with decrease of exertion ($r = 0.46$, $p < 0.05$) during preoperative self-selected walking speed and with decrease of exertion ($r = 0.49$, $p < 0.05$) during maximal walking speed. There was no correlation between the individual improvement of the BOA score and the change of walking speeds, energy cost of walking or stride characteristics.

Table II. *Gait analysis*

Ratio between involved and uninvolved leg. Variables were determined at an average speed of 62.6 m·min^{-1} before surgery and 72.3 m·min^{-1} one year after surgery

	Before surgery	One year after surgery	
Single limb support (% gait cycle)	0.94±0.05	0.99±0.04	**
Maximal vertical force (% body weight)	0.98±0.02	0.96±0.05	NS
Vertical force impulse	0.94±0.09	0.99±0.06	NS

** $p<0.01$, NS = no significance.

The patients' opinion of treatment effects was not correlated with individual changes in measured parameters. However, correlations were found between rated own opinion and graded pain during walking at predetermined speed ($r=-0.68$, $p<0.001$) and maximal speed ($r=-0.58$, $p<0.01$) one year after surgery.

Individual change of self-selected walking speed was correlated with individual change of maximal walking speed and change of single limb support (involved/uninvolved leg), measured at different speeds pre- and postoperatively. Patients with the greatest increase of self-selected walking speed also had the greatest increase of maximal walking speed ($r=0.64$, $p<0.01$).

Decrease of pain during walking at self-selected speed was correlated with decrease of pain during walking at maximal walking speed ($r=0.77$, $p<0.001$). Decrease of pain was also correlated with decrease of exertion during walking at the maximal speed ($r=0.55$, $p<0.01$).

Individual decrease of oxygen cost of level walking was found to be correlated with decrease of pain ($r=0.42$, $p<0.05$) and exertion ($r=0.45$, $p<0.05$) determined at the same walking speed. There were no other correlations found between changes in oxygen cost and other measured parameters.

Individual changes in the parameters from the advanced gait analysis, measured at different speeds pre- and postoperatively, were only correlated with improvements in self-selected and maximal walking speed. Individual changes in the parameters from the advanced gait analysis, measured at the same speed, did not show any correlation with any other measured parameters.

Table III. *Advanced tests of walking ability*

Variables from gait analysis were determined at the same walking speed before and after surgery. Oxygen cost of walking were determined before surgery both at self-selected and maximal walking speed and after surgery both at maximal speed and at the speed that was self-selected as comfortable preoperatively

	Before surgery	One year after surgery	
Step frequency (step·s^{-1})	1.7±0.1	1.7±0.2	NS
Stride length/lower extremity length	1.4±0.2	1.4±0.2	NS
Single limb support (% gait cycle, involved leg)	34.3±3.0	35.7±2.3	*
Maximal vertical force (%) body weight, involved leg)	105.7±7.6	105.1±4.8	NS
Oxygen cost of walking (ml·kg^{-1}·m^{-1}) at speed = preoperative self-selected speed	0.191±0.024	0.159±0.015	***
Oxygen cost of walking at maximal speed	0.195±0.022	0.165±0.017	***

* $p<0.05$, *** $p<0.001$, NS = no significance.

DISCUSSION

In this study, walking capacity in patients with osteoarthrosis of the knee has been assessed before and one year after unicompartmental knee replacement. Only patients with symptoms from one knee with moderate medial osteoarthrosis were selected in order to constitute a uniform group of patients in whom the main obstacle for walking was knee pain.

After prosthetic replacement most patients are reported to be painfree and satisfied with the treatment. However, very little attention is usually paid to their walking capacity. One important aim of this study was to focus more interest on the functional outcome after knee replacement and to correlate such treatment evaluation to ordinary clinical scoring.

Advanced tests of walking such as gait analysis with measurements of stride characteristics and oxygen cost of walking provided objective values of walking capacity and reliable information of the surgical treatment effects. Some patients improved to test values which were equal to those of normal subjects (18). However, in our patients, in whom the main obstacle for walking was knee pain, simple walking tests such as measurements of comfortable and maximal walking speed were found to reflect satisfactorily walking ability and knee function.

One year after surgery all patients had improved in clinical scoring and in walking ability but the assessment of walking revealed that one patient who had sustained an injury to his calf muscles had not improved as much as the others.

Pain relief is an important goal in the treatment of patients with osteoarthrosis. The results from this study demonstrated that in spite of radiographically moderate signs of osteoarthrosis of the knee, patients experienced a lot of pain during walking. In comparison to results from a previous study, the average score for pain was higher than that for patients with severe osteoarthrosis of the hip (13). This difference might be explained by the fact that patients with osteoarthrosis of the hip can choose a more pain alleviating walking pattern. However, this chosen walking pattern has been found to require a higher oxygen cost of walking at corresponding walking speeds (12, 13, 14, 20).

The results from this study showed that patients with moderate osteoarthrosis of the knee also have a changed walking pattern but not to the same extent as the patients with osteoarthrosis of the hip.

In some previous studies the maximal walking speed has been proposed as a useful parameter to assess treatment effects (12, 13). Patients with osteoarthrosis of the hip and knee joints are often elderly and are not accustomed to using their maximal walking speed and therefore the self-selected comfortable speed is more appropriate.

There was a high correlation between individual changes in maximal walking speed and self-selected walking speed; thus in our patients, any of these speeds could be used for assessment of treatment effects.

The self-selected walking speed in normal subjects has been shown to be the most efficient speed (18) but the patients in this study choose the walking speed that gave less pain.

CONCLUSION

For routine purpose clinical assessment, especially of pain, and measurement of self-selected walking speed have been found to properly reflect knee function in patients with moderate osteoarthrosis of the knee, and can be recommended as adequate parameters to assess treatment effects such as unicompartmental prosthetic knee replacement.

ACKNOWLEDGEMENT

This study was supported by grants from the Karolinska Institute research funds.

REFERENCES

1. Ahlbäck, S.: Osteoarthrosis of the knee, a radiographic investigation. Acta Radiol (Suppl 227) 1968.
2. Aichroth, P., Freeman, M., Smillie, I. & Souter, W.: A knee function assessment chart. J Bone Joint Surg *60-B:* 308–309, 1978.
3. Andersson, G.: Hip assessment, a comparison of nine different methods. J Bone Joint Surg *54-B:* 621–625, 1972.
4. Andriacchi, T. P., Ogle, J. A. & Galante, J. O.: Walking speed as a basis for normal and abnormal gait measurements. J Biomechanics *10:* 261–268, 1977.
5. Borg, G.: Psychophysical bases of perceived exertion. Med Sci Sport Exercise *5:* 377–381, 1982.
6. Brown, M., Hislop, H., Waters, R. & Porell, B.: Walking efficiency before and after total hip replacement. Phys Ther *60:* 1259–1263, 1980.
7. Chao, E. Y., Laughman, R. K. & Stauffer, R. N.: Biomechanical gait evaluation of pre- and postoperative total knee replacement patients. Arch Orthop Traumat Surg *97:* 309–317, 1980.
8. Grimby, G.: On the energy cost of achieving mobility. Scand J Rehab Med *9:* 49–54, 1983.

9. Gronley, J. K. & Perry, J.: Gait analysis techniques. Rancho Los Amigos Hospital Gait Laboratory. Phys Ther *64:* 1831, 1984.
10. Inman, V., Ralston, H. & Todd, F.: Human Walking. Williams & Wilkins, Baltimore, 1984.
11. Linnarsson, D., Mattsson, E., Eklöf, L., Broman, L., Broman, M. & Broström, L.-Å.: Determination of the oxygen cost of level walking. Clin Physiol *9:* 1–10, 1989.
12. Mattsson, E., Broström, L.-Å. & Linnarsson, D.: Change in walking capacity after uni- and bicompartmental prosthetic replacement of the knee. Inter Orthop 1989. In press.
13. Mattsson, E., Broström, L.-Å. & Linnarsson, D.: Walking efficiency after total hip arthroplasty. Clin Orthop 1989. In press.
14. McBeath, A., Bahrke, M. & Balke, B.: Walking efficiency before and after total hip replacement as determined by oxygen consumption. J Bone Joint Surg *62-A:* 807–810, 1980.
15. Murray, M. P.: Gait as a total pattern of movement. Am J Phys Med *46:* 290–333, 1967.
16. Olsson, E. & Barck, A.: Correlation between clinical examination and quantitative gait analysis in patients operated upon with the Gunston-Hult knee prosthesis. Scand J Rehab Med *18:* 101–106, 1986.
17. 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:* 93–99, 1986.
18. Ralston, H.: Energy–speed relation and optimal speed during level walking. Int Z Angew Physiol Arbeitsphysiol *17:* 277–283, 1958.
19. Thornhill, T.: Unicompartmental knee arthroplasty. Clin Orthop *205:* 121–131, 1986.
20. Waters, R., Perry, J., Conaty, P., Lunsford, B. & O'Meara, P.: The energy cost of walking with arthritis of the hip and knee. Clin Orthop *214:* 278–284, 1987.

Address for offprints:

Eva Mattsson, RPT, Dr Med. Sc.
Dept. of Physical Therapy
Karolinska Institute
S-10401 Stockholm
Sweden