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IMPROVEMENT IN GAIT ONE YEAR AFTER SURGERY FOR KNEE OSTEOARTHROSIS: A COMPARISON BETWEEN HIGH TIBIAL OSTEOTOMY AND PROSTHETIC REPLACEMENT IN A PROSPECTIVE RANDOMIZED STUDY

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ABSTRACT. The aim of this study was to analyse gait improvement one year after high tibial osteotomy and unicompartmental knee arthroplasty in patients with strictly unilateral osteoarthrosis of the medial compartment of the knee. Thirty-six patients, 18 men and 18 women, received a unicompartmental Brigham knee prosthesis and 23 patients, 10 men and 13 women, were operated on with a high tibial osteotomy. Clinical and radiographical assessments were supplemented by a functional test, measurements of thigh muscle torque with a Cybex II dynamometer and analysis on a force plate walkway with electrogoniometers. All patients were assessed prior to, and one year after surgery. Both groups showed overall clinical improvement, as assessed by the British Orthopaedic Association (BOA) score. Pain during walking decreased. The range of knee flexion remained unchanged. The ability to ascend and descend steps improved. The isokinetic thigh muscle torque remained unchanged. In the prosthetic group free walking speed increased from 1.03 to 1.09 m/s ($p<0.001$). Step frequency and step length increased ($p<0.001$). Single stance phase ratio increased from 0.96 to 0.99 ($p<0.01$), indicating a more symmetrical gait. Double stance phase (% gait cycle) of both legs decreased ($p<0.001$), indicating a faster transfer of weight during walking. In the osteotomy group, free walking speed did not increase. Step length of the uninvolved leg increased ($p<0.01$). Double stance phase of the involved leg decreased ($p<0.001$) and double stance phase of the uninvolved leg decreased ($p<0.01$). Both groups improved after surgery and there was no difference between the groups. The different walking tests of this study indicated greater improvement after unicompartmental prosthetic replacement one year after surgery. Gait analysis was found to be useful by supplying important data on the functional outcome after knee surgery.

Key words: gait, high tibial osteotomy, osteoarthrosis, total knee replacement.

The choice of surgical treatment in patients with moderate osteoarthrosis of the medial compartment of the knee in the age groups around 60 years is controversial. High tibial osteotomy or unicompartmental knee replacement are the two main alternatives. In a previous retrospective study comparing clinical results after high tibial osteotomy and unicompartmental prosthetic replacement the authors found superior clinical results after prosthetic replacement (5). Usually the results of surgical treatment of osteoarthrosis of the knee have been assessed by clinical scores which give only a crude estimate of walking ability. Although reduction of pain is the main object of the surgical treatment, the ability to walk and obtain good knee function are also important. Gait analysis has been used in some previous studies to present the results of both prosthetic knee replacements and tibial osteotomy. These studies have shown that walking ability will improve after surgery, but the postoperative walking pattern will not be totally normal. In general, the patients will walk more slowly after surgery and take shorter steps than normal subjects. The single stance phase will still remain shorter on the operated side, resulting in asymmetrical weightbearing typical of antalgic gait (6, 10, 11, 16, 17, 20). Quadriceps normally allows the knee to yield in flexion about 20° early in the stance phase and then extends the knee behind the forwardly moving body. This stance knee flexion-extension will

Table I. *Patient data. Mean values ± SD*

	Unicompartmental knee replacement ($n=36$)	High tibial osteotomy ($n=23$)
Op. side (left/right)	16/20	10/13
Sex (male/female)	18/18	10/13
Age (years)	64 ± 5	65 ± 4
Height (m)	1.74 ± 0.07	1.69 ± 0.09
Body weight (kg)	85 ± 14	80 ± 10
BOA-score (points)		
Before surgery	30 ± 2	30 ± 2
After surgery	37 ± 2	38 ± 2
Pain during walking (Borg-scale)		
Before surgery	3.3 ± 1.8	3.5 ± 1.7
After surgery	0.5 ± 0.9	1.0 ± 1.4
Knee flexion arc (degrees)		
Before surgery	118 ± 14	116 ± 14
After surgery	119 ± 14	121 ± 9

remain subnormal after surgery on the painful side. The total range of knee flexion and extension during gait, known as swing flexion, will increase after surgery but will not attain normal values (6, 11, 17). A prospective randomized study comparing the functional outcome of high tibial osteotomy and unicompartmental knee replacement has to our knowledge not yet been published.

The aim of this study was to use a prospective randomized study to see whether there was any difference in the improvement of gait in patients operated on by high tibial osteotomy or unicompartmental prosthetic knee replacement. Clinical and radiographical scoring was supplemented with assessment of walking, step test, and thigh muscle performance one year after surgery.

MATERIAL AND METHODS

The patients in this study were part of an ongoing prospective randomized study aiming at evaluating the results after high tibial osteotomy or unicompartmental knee replacement with the Brigham prosthesis in patients, 55 to 70 years old, with a medial osteoarthrosis of knee grades I–III, according to Ahlbäck's classification (1). All patients had knee symptoms, mainly pain, that justified surgical treatment. No patient had impairment of their hips or ankle joints, but patients with bilateral knee symptoms with slight pain from the other knee were included. Before surgery, 50 patients were randomly selected to unicompartmental knee replacement and 50 to high tibial osteotomy. The present study group consisted of the first consecutive 59 patients with strictly unilateral knee symptoms. Thirty-six patients, 18 men and 18 women, mean age 64 years and mean body-weight 85 kg, had a unicompartmental prosthetic replacement (prosthetic group). Twenty-three patients, 10 men and 13 women, mean age 65 years and mean body-weight 80 kg, had a high tibial osteotomy (osteotomy group) (Table I). The patients were tested before and one year after surgery. The patients entered the study during two years and were operated on by three experienced orthopaedic surgeons, involved in both treatment groups. Clinical and radiographical assessments were supplemented with functional tests, i.e. step tests (23), measurements of thigh muscle torque with a Cybex II dynamometer (8), and analysis of a force plate walkway (18) with electrogoniometers (13).

Surgery

Unicompartmental prosthetic replacement: A parapatellar medial skin and retinacular incision was used. Bony cuts and insertion of the prosthetic components were made as shown in the manual for the Brigham prosthesis. Femoral and tibial components were cemented in position, and the soft tissue was tightened. Varus deformity was corrected but overcorrection to valgus was avoided according to previous recommendations (21). Full weight bearing and active exercises were allowed on the first postoperative day.

There was one case of deep vein thrombosis and one of pneumonia that complicated surgery. Aseptic loosening of the tibial plateau was seen in one case 6 months after surgery. This patient was reoperated on and a new tibial plateau was cemented in good position.

High tibial osteotomy: We performed Coventry closing wedge osteotomies (7). The aim was to achieve an overcorrection of the Hip- Knee- Ankle angle (HKA-angle) to 4° of valgus after surgery as suggested by Tjörnstrand et al. (22). Postoperatively the limb was immobilised in a whole-leg plaster cast from groin to ankle for 6 weeks, with full weight-bearing permitted from the first postoperative day.

There was one superficial wound infection which healed after treatment with antibiotics.

Clinical examination

BOA-score: The BOA (British Orthopaedic Association) score with a maximum of 39 points was used for clinical evaluation (2).

Patients' opinion: The patients' opinion of the result one year after surgery was assessed as improved, unchanged or worse.

Pain during walking: Pain during walking in self-selected walking speed was assessed using a 10-grade category scale (4).

Passive range of motion: Passive range of knee flexion and extension was assessed with a long arm goniometer to the nearest 5°.

Ability to step up and down: The ability to flex and extend the knee joint while bearing weight was tested with a step test according to Waugh (23). The patients were asked to step on to and down from a set of platforms respectively 5, 10, 15, 20, 25, 30, 35, 40, 45 and 50 cm high, with the affected leg leading up and following down. The grade was determined by the height at which the knee could do this without support, except for balance. The results were judged as improved if a higher platform could be reached one year after surgery.

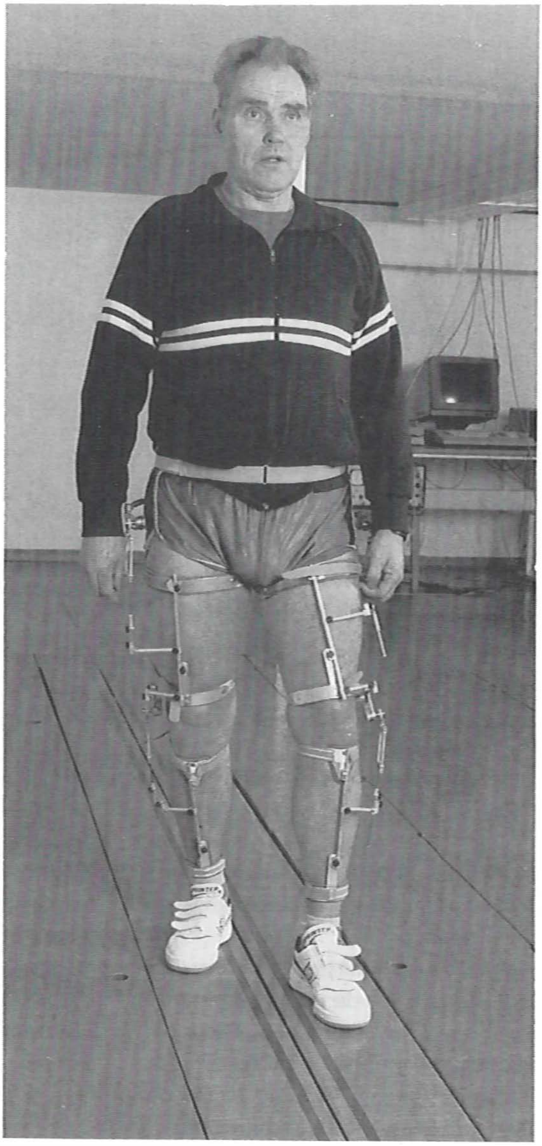

Fig. 1. A patient on the force plate walkway with the electrogoniometer mounted on the legs.

Radiography

Whole-leg weightbearing radiographs were taken before, and one year after surgery. The HKA-angle was measured in order to assess the leg alignment in the coronal plane, i.e. the varus or valgus deformity of the knee, before surgery and after surgical correction (22).

Force plate walkway with electrogoniometers

An electronic walkway was used for gait analysis (18) (Fig. 1). It consists of two 5-m long force measuring platforms. These long force plates provide a continuous record of a sequence of several steps taken by both feet thus avoiding the problem

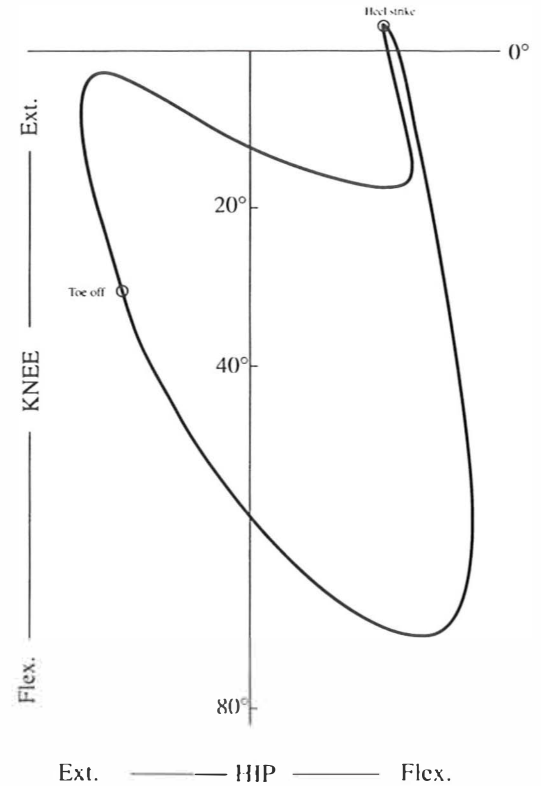

Fig. 2. A normal hip-knee angle diagram.

connected with the usual small force plate. The walkway was used for evaluation of the following parameters: Free walking speed (m/s), step frequency (steps/s) and the step length (m), maximal vertical ground reaction force (% body weight), single stance phase (% gait cycle) and double stance phas (% gait cycle) of each leg. The time when both feet were in contact with the ground with the involved leg forward was referred to as double stance phase of the involved leg. These tests were based on approximately 35 gait cycles. Measurements were made for each leg and the ratio between the involved and uninvolved leg was used as a measure of asymmetry.

Hip and knee joint mobility during walking was measured with an electrogoniometer (13, 18) (Fig. 2) and plotted as a hip-knee angle diagram for each leg (9) (Fig. 3). These tests were based on approximately ten gait cycles. The stance knee flexion-extension pattern was judged from the shape of the diagram with respect to knee flexion and extension during the stance phase (9, 13).

Muscle performance

Muscle strength was measured isokinetically at 30°/s with a Cybex II dynamometer (Cybex Div. of Lumex Inc. 2100 Smithtown Ave, Ronkonkoma, NY 11779) modified according to Gransberg & Knutsson (8). The torque, as a measure of muscle force, of the knee extensor and flexor muscles was recorded in the limb planned for surgery. The patients were instructed to extend or flex the knee as fast as possible. The

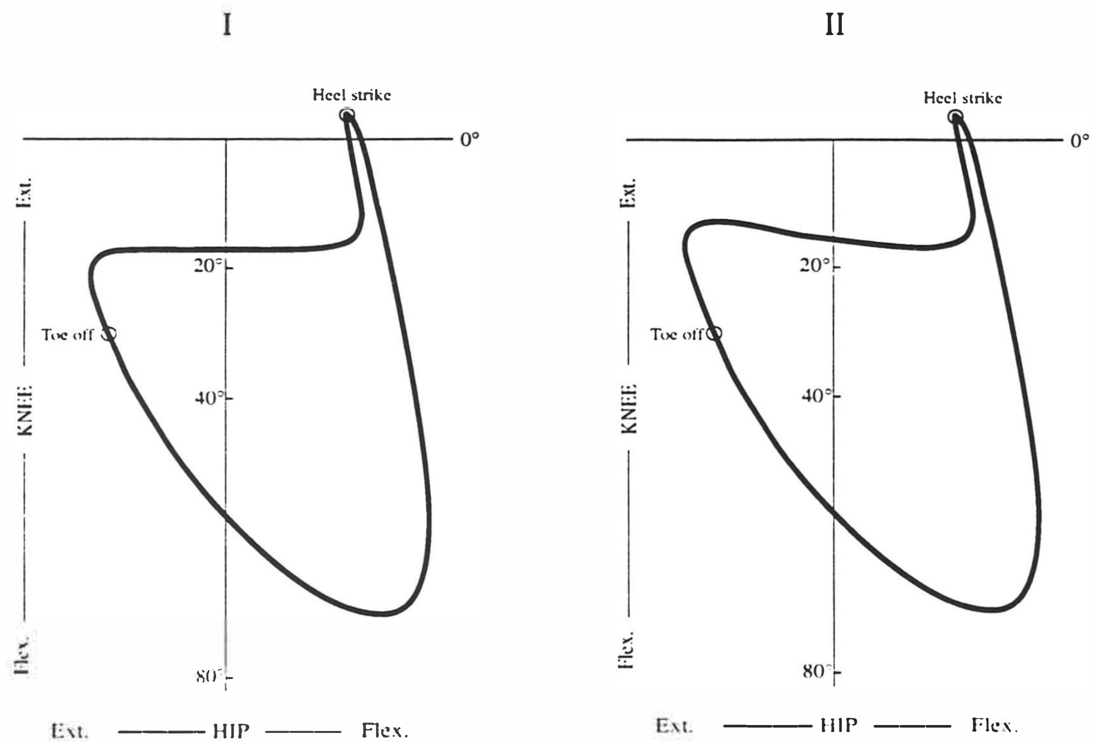

Fig. 3. Hip-knee angle diagrams with abnormal pattern. I: No knee extension during stance phase. II. Reduced knee extension during stance phase.

tests were repeated and torque curves were accepted only when three repeated tests gave similar results. The peak torque value was calculated as an average value of the three highest of the 18 recorded values of each torque curve.

Statistics

Individual differences after surgery were tested using a paired two-tailed Students t-test for the parametric parameters and Wilcoxon's matched-pairs signed-ranks test or sign test for the nonparametric parameters. Differences between the groups were tested using a two-tailed Students t-test for the parametric parameters and Mann-Whitneys U-test or chi-square test for the nonparametric parameters. The level of significance was chosen as $p < 0.01$.

RESULTS

Clinical examination

BOA-score: There was an improvement from 30 to 37 points in the prosthetic group and from 30 to 38 points in the osteotomy group. There was no difference between the groups (Table I).

Patients' opinion: Both groups improved after surgery, there being no difference between the groups. In the prosthetic group 32 patients improved, 3 were unchanged and one was worse (reoperated on at 6 months because of prosthetic loosening). In the osteotomy group, 20 patients improved and 3 remained unchanged.

Pain during walking: There was an improvement from 3.3 to 0.5 in the prosthetic group and from 3.5 to 1.0 in the osteotomy group. There was no difference between the groups (Table I).

Passive range of motion: In the prosthetic group there was a mean flexion contracture which was 5°(SD 6°) before surgery and 4°(SD 6°) after surgery. The mean range of flexion was 118°(SD 14°) before surgery and 119°(SD 14°) after surgery (Table I).

In the osteotomy group there was a mean flexion contracture of 5°(SD 7°) before surgery, which fell to 1°(SD 5°) after surgery. The mean range of flexion was 116°(SD 17°) and 121°(SD 9°) after surgery (Table I). There was no difference between the groups.

Ability to step up and down: Both groups improved after surgery. There was no difference between the groups. In the prosthetic group 17 patients were improved, 16 were unchanged and three deteriorated. In the osteotomy group 14 were improved, 6 were unchanged and 3 deteriorated.

Table II. *Results from force plate walkway. Mean values* ± *SD.* P-*value refers to individual differences after surgery*

	Unicompartmental knee replacement ($n = 36$)			High tibial osteotomy ($n = 23$)		
	Preop.	p	Postop.	Preop.	p	Postop.
Walking speed (m/s)	1.03 ± 0.18	***	1.19 ± 0.19	1.03 ± 0.19	n.s.	1.09 ± 0.15
Step frequency (steps/s)	1.65 ± 0.14	***	1.78 ± 0.13	1.68 ± 0.2	n.s.	1.75 ± 0.14
Step length						
involved leg (m)	0.61 ± 0.08	***	0.66 ± 0.09	0.61 ± 0.08	n.s.	0.62 ± 0.09
uninvolved leg (m)	0.60 ± 0.08	***	0.66 ± 0.09	0.59 ± 0.09	**	0.61 ± 0.08
Single stance phase						
involved/uninvolved	0.96 ± 0.06	**	0.99 ± 0.04	0.97 ± 0.04	n.s.	0.97 ± 0.04
Double stance phase (% gait cycle)						
involved leg	15.6 ± 2.3	***	14.3 ± 2.0	15.3 ± 2.3	***	14.0 ± 1.5
uninvolved leg	15.0 ± 1.8	***	13.8 ± 2.0	14.6 ± 1.7	**	14.0 ± 1.2
Max. vertical ground reaction force						
involved/uninvolved	0.98 ± 0.02	n.s.	0.97 ± 0.04	0.96 ± 0.08	n.s.	0.97 ± 0.04

** denotes $p < 0.01$.
*** denotes $p < 0.001$.

Radiography

After prosthetic replacement the mean HKA-angle changed from 9° of varus to 3° of varus. After high tibial osteotomy the mean HKA-angle changed from 9° of varus to 3° of valgus.

Force plate walkway with electrogoniometers

In the prosthetic group free walking speed, step frequency, step length of both legs and the single stance ratio increased. The double stance phases decreased and the maximal vertical ground reaction force ratio remained unchanged after surgery (Table II).

In the osteotomy group step length of the uninvolved leg increased. Double stance phase of both legs decreased. Asymmetry between the legs remained after surgery. All the other parameters remained unchanged (Table II). There were no differences between the groups.

ELECTROGONIOMETRY

Range of stance phase flexion: A stance knee flexion-extension of the involved knee that remained in flexion during the entire stance phase gave a false high value in degrees on the angle diagram (Fig. 3). These diagrams were excluded when the range of stance knee flexion-extension was calculated. The range of stance and swing knee flexion-extension was unchanged in both groups after surgery with a mean value of 13° and about 55°, respectively. There was no difference between the groups (Table III).

Stance knee flexion-extension pattern: In the prosthetic group 26 patients improved, one remained unchanged and 7 deteriorated after surgery. The improvement of stance knee flexion-extension pattern after surgery was significant.

In the osteotomy group 13 patients improved, one remained unchanged and 8 deteriorated after surgery. There was no significant change in stance knee flexion-extension pattern in this group after surgery. Two patients, one in each group, were not tested because of technical failures (Table III).

Muscle performance

The mean peak torque values for the knee extensor and flexor muscles before and after surgery are given in Table IV.

There were no differences in either group after surgery and no difference between the groups.

DISCUSSION

Only patients with strictly unilateral knee symptoms were included in this study. Two groups were selected before surgery with no major differences between them. From a clinical point of view all patients improved after surgery and the mean BOA-score showed that excellent results were achieved in both

Table III. *Results from electrogoniometer tests. Mean values ± SD.* P-*value refers to individual differences*

	Unicompartmental knee replacement ($n=28$)			High tibial osteotomy ($n=17$)		
	Preop.	*p*	Postop.	Preop.	*p*	Postop.
Stance phase flexion (degrees)						
involved	11 ± 4.4	n.s.	13 ± 3.3	12 ± 5.3	n.s.	12 ± 3.6
uninvolved	16 ± 6	n.s.	17 ± 5	17 ± 6	n.s.	17 ± 6
Swing phase flexion (degrees)						
involved	52 ± 9	n.s.	56 ± 9	53 ± 9	n.s.	55 ± 8
uninvolved	59 ± 9	n.s.	61 ± 7	58 ± 6	n.s.	60 ± 6

groups. Improvement after surgery according to the patients' own opinion did not disclose any differences in results between the groups. Radiographic examination showed that the desired surgical correction of leg alignment was achieved in both groups. Pain during walking was also equally reduced in both groups. The passive range of knee flexion remained unchanged in both groups. We believe that it was difficult to increase this range, mainly because there was a good range of motion prior to surgery. Interestingly the flexion contracture observed in both groups before surgery decreased in the osteotomy group, while it remained unchanged in the knee replacement group. An explanation for this might be that the tension in capsular structures and the lateral collateral ligament decreases when the fibula slides in a cranial direction as the osteotomy gap closes. Unlike Kolstad et al. we did not find a bony impediment of the anterior part of the tibial plateau causing an extension deficit of the knee (12). Furthermore, the amount of flexion deformity and the maximum possible flexion of the knee after surgery have not been found to relate to the clinical result (11). It has been claimed that it is more appropriate to measure knee function by observing the patients carrying out relevant tasks under standard conditions than by questions (23). The most demanding function of the knee joint is to flex and extend while bearing weight (23). In the present study the ability to ascend and descend steps was used to assess this function. Tests were performed one year after surgery when the patients were considered fully rehabilitated. Most patients improved but the step tests did not discriminate between the two operations with respect to knee function. Similarily, the muscle performance tests did not differ after the two operations. The isokinetic torque of the thigh muscles remained unchanged in both groups. This is in accordance with other authors, who found no correlation between isokinetic thigh muscle performance and knee function during walking (14, 19).

Table IV. *Results from the Cybex II isokinetic dynamometer tests. Peak torque in the knee extensor and flexor muscles. Mean values ± SD.* P-*value refers to individual differences*

	Unicompartmental knee replacement ($n=34$)			High tibial osteotomy ($n=21$)		
	Preop.	*p*	Postop.	Preop.	*p*	Postop.
Knee extensors (Nm)	101 ± 39	n.s.	82 ± 56	92 ± 31	n.s.	87 ± 29
Knee flexors (Nm)	68 ± 31	n.s.	65 ± 41	55 ± 24	n.s.	56 ± 25

Several studies have shown that free walking speed is a valid measure of limb impairment (3, 15, 17). Walking speed increased numerically in both groups but a significant increase was found only in the knee replacement group. Although there was no significant difference between the group means, the groups could be separated by individual improvement after surgery. The patients in the knee replacement group increased their walking speed in the same way as healthy subjects do, i.e. by increasing both step frequency and step length (3). It has been shown that patients with knee pain increase their walking speed by increasing the step frequency and not the step length (3). In the osteotomy group, walking speed increased numerically and this increase was due mainly to an increase in step length of the uninvolved leg. We cannot explain this interesting way of increasing the walking speed, but we believe that knee pain was not the only factor limiting walking speed in these patients. It would be interesting to analyse the gait pattern in these patients at the same speed before and after surgery. After prosthetic replacement gait became more symmetrical as expressed by an improvement in single stance ratio. In the osteotomy group the asymmetry in single stance ratio, i.e. the limp remained, implying that weight bearing time on each leg was not equal. The double stance phase of the involved leg improved in both groups thus allowing a faster transfer of weight onto the operated leg after surgery. An increased stance knee flexion-extension after high tibial osteotomy was found by Kettelkamp (11) and by Chao after total knee replacement (6), and they interpreted this as an improvement in walking ability. However, the patients in these studies only improved their stance knee flexion-extension from 7° to 9°. We did not find any increase in stance knee flexion-extension in our patients after surgery. They had an average stance knee flexion-extension of 11° even prior to surgery. The potential for improvement was thus less in our patients, and even in patients with an excellent clinical result the stance knee flexion-extension of the involved leg was less than normal following surgery. We also studied the stance knee flexion-extension pattern using the angle diagram (9). The pattern improved after prosthetic replacement which we interpreted as an improvement in knee function.

Both groups improved after surgery and there was no difference between the groups. The different walking tests of this study indicated a greater improvement after unicompartmental prosthetic replacement one year after surgery. Gait analysis was found to be useful by supplying important data on the functional outcome after knee surgery.

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