Kinetic and kinematic characteristics of gait in patients with medial knee arthrosis

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ABSTRACT – We compared the mechanics of gait in 13 patients with early medial arthrosis (OA) of the knee and 13 normal controls, by measuring gait events, kinematic and kinetic parameters. In the OA group, walking velocity, cadence and stride length were reduced and stride time and double support time accordingly increased on both sides, the overall stance phase was prolonged in the OA group, but the stance phase and swing phase peak flexion were reduced. The varus in the stance phase and the valgus in the swing phase were increased. The extensor moment in the loading response was increased and the flexor moment at late stance reduced in the OA group. Patients with OA had a greater valgus (abductor) and internal rotation moment during the stance phase. The times to second vertical force peak (VFP) were similar in the two groups. Values of VFP1 and VFP2 were lower in the OA group. Our findings indicate that computerized gait analysis can be used to reveal various mechanical abnormalities accompanying arthrosis of the knee joint at an early stage. Some of these abnormalities may have etiologic implications, but others may represent secondary changes developed in part as a compensatory mechanism in knee OA.

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Normal walking patterns are adversely affected by lower extremity joint disease. The knee is the joint most frequently associated with disability in OA (Guccione et al. 1994). Several parameters related to gait have been studied in patients with normal and arthrotic knees (Stauffer et al. 1977, Brinkmann et al. 1985). However, only a few authors have controlled such parameters as age, sex, weight and dominant side, or studied the spatiotemporal parameters (Györy et al. 1976, Messier et al.1992). Moreover, they have concentrated on patients having severe OA and analyzed specific gait parameters with various definitions in a single joint.

In medial OA of the knee, temporal and distance gait factors (velocity, cadence and stride length) are frequently reduced (Györy et al. 1976). Furthermore, stance phase flexion-extension, peak vertical ground-reaction forces (VF) and loading rates are markedly reduced (Stauffer et al. 1977, Brinkmann et al. 1985, Messier et al. 1992). Patients with varus deformity of the knee walk with a gait that is higher than the normal external adduction moment (Schnitzer et al. 1993). The adduction moment at the knee is the primary determinant of medial-lateral load distribution. Sharma et al. (1998) found a relationship between the adduction moment and the severity of OA disease. These mechanical changes in OA of the knee may play an etiologic role or develop during the course of the disease.

We report changes in gait parameters in patients with early medial OA of the knee joint, compare the findings with those in healthy controls and assess the relationship with the course of the disease.

Methods

Subjects

We selected 13 female patients with early medial arthrosis in both knees, between the ages of 46 and 60 years. To minimize the possible effects of sex on gait parameters, men were not included in the study. Patients with OA were compared to 13 healthy female controls.

Table 1. Demographic characteristics of patients and control subjects

Parameter	Normal group Mean (SD)	Patient group Mean (SD)
Age (yr)	58 (11)	57 (8)
Weight (kg)	72 (12)	77 (12)
Height (cm)	157 (4.7)	157 (7.2)

The diagnosis of OA was based on radiographic evidence of medial joint narrowing, osteophyte formation, subchondral sclerosis and knee pain for more than 6 months as well as at least one of the following: mild swelling, tenderness on palpation, crepitus on motion or stiffness in the morning or after long periods of inactivity. All patients met the ACR (American College of Rheumatology) criteria for OA of the knee (Altman et al. 1986). Among the patients diagnosed as having medial OA, those with medial narrowing on a long-leg radiograph, ability to perform gait analysis procedures, radiographic evidence of stage 0.5 or 1 OA in both knees were admited to the study (Ahlbäck 1968).

Control subjects were recruited from relatives of inpatients and the outpatient clinic. Those with evidence of rheumatoid or any other type of arthritis, a history of injury to the lower extremity, or of prolonged knee pain that required medication and knee surgery were excluded. The patients and subjects in both groups were of similar gender, age, weight and height (Table 1) and their right side was dominant.

Gait analysis

Before gait analysis, all subjects gave informed consent as advised by the Ethics Committee. Both groups underwent gait analysis with the same protocol by one and the same physician. Spatiotemporal and kinematic data were obtained from the Vicon 370 Motion Measurement and Analysis System. This system consisted of 5 video cameras, a computer system for data acquisition, processing and analysis and a datastation. The experimental model idealized the lower extremity as a system of rigid links with spherical joints. The joints were assumed to have a fixed axis of rotation. Skeletal movement can be described using surface markers placed in precise anatomical positions.

All subjects were instructed to walk at a self-selected speed along the walkway and to practice until they could consistently and naturally make contact with both of the force plates. Three acceptable trials were obtained for each foot and averaged to yield representative values. In the kinematic and kinetic analyses, both limbs of the OA cases were matched with their respective control subject's ipsilateral limbs (i.e., the either left or right).

External retro-reflective markers, used for computer digitization, were placed on each of the following anatomic locations: anterior superior iliac spine (ASIS), sacrum, lateral thigh, joint line of the knee, lateral shank, calcaneus, lateral malleolus and second metatarsal head. The 3-dimensional position of each reflective marker was sampled 60 times a second. Markers were placed on the bony prominences to minimize artifacts due to skin movement. On the other hand, these locations provided anatomic reference points to locate internally the joint center position of the hip, knee and ankle. The hip joint center was detrmined using leg length, inter-ASIS distance and ASIS-greater trochanter distance calculated by Vicon Clinical Manager (VCM) (Bell and Brand 1990). The knee center was located at one-half the knee width medially along the knee flexion axis. The ankle joint center was located at one-half the ankle medially along the ankle flexion axis. The kinematic variables included maximum knee flexion, varus at stance phase and flexion, valgus at swing phase.

Ground reaction forces (GRF) were collected using 2 force plates (Bertec, Columbus, OH). GRF measurements were acquired simultaneously with a measurement of the limb position. Time-to-second vertical force peak and values of first and second vertical force peaks were determined. To calculate the moments, each segment of the limb (thigh, shank and foot) was assumed to be a rigid body with a coordinate system chosen to coincide with the anatomic axes. Moments producing flexion-extension, abduction-adduction and internal-external rotation at the knee joint were calculated. Angular velocity and acceleration around the longitudinal axis were assumed to be negligible. All moments and ground reaction forces were normalized to body weight and height permitting comparison with other results in the literature.

Statistics

The Statistical Package for the Social Sciences (SPSS for Windows v.901) was used for the statistical analyses. All parameters of gait were compared between patients and normal controls with the Mann-Whitney U-test, since the number of subjects was limited and the data considerably skewed. Power analysis was not done.

Results

Spatiotemporal analysis

Since the walking velocity, cadence and stride length were reduced, the stride time and double support time were increased on both sides in patients with OA of the knee. The overall stance phase time (% gait cycle) was longer in the OA group (Table 2).

Kinematic analysis

Maximum knee flexion during the stance phase and maximum knee flexion during the swing phase were reduced on the right side. In the frontal plane, maximum knee varus in the stance phase and valgus in the swing phase were increased on both sides (Table 3).

Kinetic analysis

Extensor moment, seen in the loading response during the early stance phase was longer in the OA group than in the controls. Flexor moment, seen at late stance, was decreased. Patients with OA had a greater valgus (abductor) and internal rotation moment during the stance phase than normal subjects. However, we found no increase in valgus moment in the left knee. On analysis of ground reaction forces, the times-to-second vertical force peak (VFP2) were similar in the groups. When the two peak force values were compared, the OA group had lower peak values (Table 4). Moreover, the curve patterns of GRFs were asymmetric and showed a plateau instead of the usual pattern of two peaks in normal controls.

Table 2. Changes in spatiotemporal parameters

Parameter	Side	Normal group Mean (SD)	Patient group Mean (SD)	P-value
Cadence (steps/min)	L	112 (14)	102 (10)	0.03
	R	113 (13)	101 (11)	0.05
Walking velocity (m/s)	L	1.0 (0.1)	0.9 (0.1)	0.01
	R	1.0 (0.1)	0.9 (0.1)	0.01
Stride time (s)	L	1.1 (0.2)	1.2 (0.1)	0.03
	R	1.1 (0.1)	1.2 (0.1)	0.03
Double support time (s)	L	0.30 (0.02)	0.3 (0.1)	0.01
	R	0.30 (0.02)	0.3 (0.1)	0.03
Stride length (m)	L	1.1 (0.1)	1.1 (0.1)	0.03
	R	1.1 (0.1)	1.1 (0.1)	0.03
Stance phase (%)	L	63 (1.1)	64 (0.9)	0.01
	R	62 (1.9)	64 (0.7)	0.01

Table 3. Changes in kinematic parameters

Parameter	Side	Normal group Mean (SD)	Patient group Mean (SD)	P-value
Knee flexion (stance)	L	16 (6.8)	11 (5.3)	0.3
(degrees)	R	15 (4.9)	11 (4.8)	0.03
Knee flexion (swing)	L	55 (4.0)	50 (7.0)	0.6
(degrees)	R	56 (7.4)	47 (7.8)	0.02
Knee varus (stance)	L	–1.2 (5.4)	3.1 (4.3)	0.02
(degrees)	R	–1.7 (3.0)	2.4 (4.7)	0.01
Knee valgus (swing)	L	15 (7.7)	22 (5.9)	0.02
(degrees)	R	16 (8.8)	21 (8.5)	0.01

Table 4. Changes in kinetic parameters

Parameter	Side	Normal group Mean (SD)	Patient group Mean (SD)	P-value
Knee flexion moment	L	0.22 (0.18)	0.10 (0.09)	0.04
(Nm/kg)	R	0.17 (0.16)	0.06 (0.08)	0.04
Knee extension moment	L	0.40 (0.12)	0.52 (0.12)	0.03
(Nm/kg)	R	0.41 (0.20)	0.62 (0.25)	0.02
Knee valgus moment	L	0.39 (0.10)	0.44 (0.16)	0.5
(Nm/kg)	R	0.33 (0.05)	0.45 (0.11)	0.01
Knee rotation moment	L	0.18 (0.01)	0.20 (0.05)	0.04
(Nm/kg)	R	0.17 (0.05)	0.22 (0.05)	0.04
Time to VFP2	L	70 (1.9)	70 (3.0)	0.50
(% stance)	R	69 (1.0)	70 (2.3)	0.1
Vertical force peak 1	L	97 (7.2)	91 (2.2)	0.01
(% BW)	R	95 (3.1)	92 (3.7)	0.01
Vertical force peak 2	L	100 (5.6)	95 (2.6)	0.01
(% BW)	R	100 (5.2)	95 (3.6)	0.02

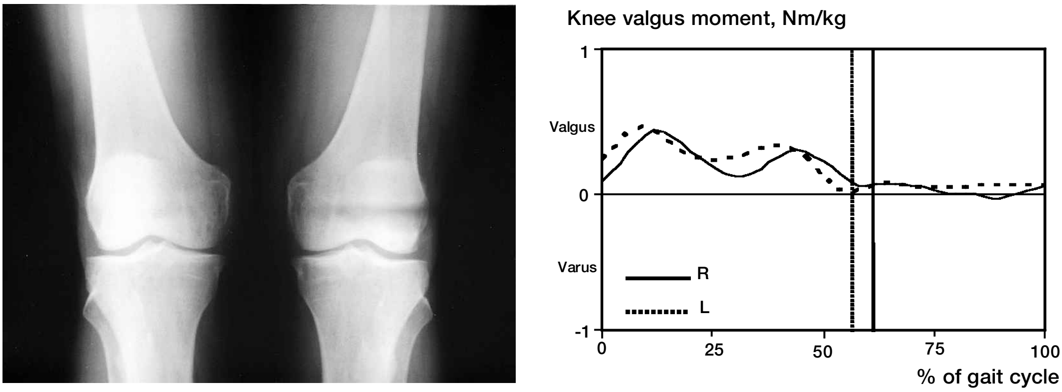

Figure 1. Anteroposterior radiograph and gait curve of valgus moment of the OA case with least affected knees.

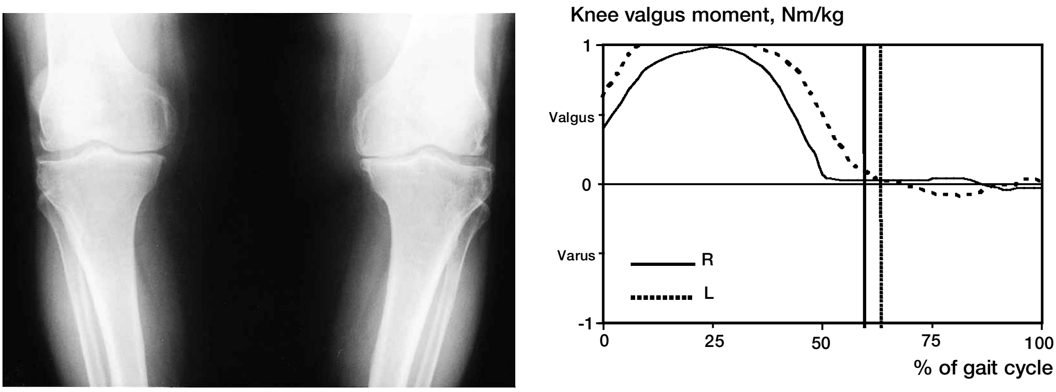

Figure 2. Anteroposterior radiograph and gait curve of valgus moment of the OA case with most affected knees.

Discussion

Assessment of gait changes at an early stage of knee arthrosis should be helpful in distinguishing between abnormalities causing progression of the disease and occurring as part of the compensatory mechanism during the course of the disease.

Spatiotemporal parameters and knee joint angles are considered to be important parameters of gait in knee OA. These may be good predictors of disability (Györy et al. 1976). In our study, walking velocity, cadence and stride length were reduced and, accordingly, stride time and double support time were increased in patients with OA. Similarly, Györy et al. (1976) found reduction in velocity, cadence and stride length in their study. They confirmed the relationship between these parameters and disability. According to Andriacchi et al. (1982), reduced walking speed and stride length were part of the adaptive mechanism to reduce pain by decreasing knee moments.

These adaptive changes occurred relatively early in the course of the disease. However, their clinical significance was not clear since we did not assess the severity of disability and pain, or their relationship with mechanical changes.

Overall stance phase time (% gait cycle) was longer in the OA group. The delay in early loading response, push off and reduction of walking velocity apparently contributed to this prolongation as part of the adaptive mechanism.

The results of the joint angle measurements indicated that maximum knee flexion during the stance phase and during the swing phase were reduced on both sides, as compared to the control group. However, the changes on the left side were not significant. Possible mechanisms for this may have been the small number of subjects in the patient and control groups, or the fact that the dominant side may have been affected more than the other side. Messier et al. (1992), found similar changes in joint angle measurements. However, they evaluated gait parameters in the affected and unaffected knees in patients with OA. OA of the knee causes the subjects to limit their activity level, which results in an overall reduction in flexibility and dynamic range of motion (Messier et al. 1992). Therefore, the abnormalities observed in measurements of joint angles seem to reflect mechanical changes secondary to osteoarthrosis rather than underlying factors involved in the pathogenesis.

In the frontal plane, maximum knee varus during the stance phase and valgus during the swing phase were increased. Since all cases in the OA group had narrowing of the medial joint space and opening of the lateral space in various degrees, the maximum varus angle was expected to increase to a certain extent at the stance phase. However, in the cases with an excessively high varus angle, another reason could be the experimental error produced by placement of stick markers on the unintentionally internally rotated thigh, a situation which is commonly seen in studies of gait analysis. An increase in valgus in the swing phase may have been due to the increase in lateral soft tissue pretension, unresisted by external adductor moment and axial loading or simply due to internal rotation of the limb.

Patients with OA had greater intrinsic abduction (valgus) and internal rotation moments during the stance phase than normal subjects. In the normal state, 60–80% of total intrinsic compressive load transmitted across the knee is on the medial compartment (Andriacchi 1994). Since all cases in the OA group had narrowing of the medial joint space, total compressive load transmitted across the medial compartment was expected to increase in the stance phase. External adduction moment is strongly related to the magnitude of the total intrinsic compressive load on the medial compartment (Schipplein and Andriacchi 1991). A greater magnitude of this moment may contribute to the development and progression of medial tibiofemoral OA (Schnitzer et al. 1993, Sharma et al. 1998). Normally, antagonistic muscle (knee flexors) force, axial load and lateral soft tissue tension are needed to maintain dynamic joint stability during walking.

Interestingly, an increase in abduction (valgus) moment was seen during the stance phase in patients in the OA group despite the increase in the varus angle. This seemed to reflect an increase in lateral soft tissue tension as a part of the adaptive mechanism to resist external adductor moment and maintain stability. Although the etiological and prognostic role of the external adductor moment has been documented clearly in many studies, it is uncertain whether the intrinsic abductor (valgus) moment plays a similar role (Schnitzer et al. 1993, Sharma et al. 1998).

According to Prodromos et al. (1985), a shorter than normal stride length and higher than normal abduction moment suggest an unloading mechanism during gait which appears to be beneficial in patients with medial OA of the knee joint. Since our patients were in an early stage of osteoarthrosis, an increase in the abductor moment could be a protective mechanism against further progression of the disease by resisting the external adductor moment. Hence, either an increase or decrease in this moment would be a prognostic or etiological factor useful in clinical practice, if shown in future longitudinal studies.

Patients with knee OA, varus alignment and lateral laxity generate greater flexion-extension moments to increase stability by minimizing lateral joint opening and improving joint surface load distribution (Noyes et al. 1992). According to Schipplein et al. (1991), at each instant of stance phase, the moment resulting from the sum of the axial load and either the flexor or extensor muscle force acting around the medial joint contact, viewed from the frontal plane, must resist the adductor moment to prevent lateral joint opening. They found that the external flexion moment was higher in patients with knee OA and they were using more net quadriceps effort than normal subjects to balance this moment. Similarly, the extensor moment seen on loading response during the early stance phase was longer in the OA group than in controls in our study. However, during late stance, the OA group had a lower flexion moment. Since maximum knee flexion during the swing phase was reduced, the degree of force necessary to produce flexion by the hamstring group would be expected to decrease, adn this would cause a low flexor moment.

When ground reaction forces were analyzed, we found no difference in the normalized time to the second vertical force peak (VFP2) between the two groups (Table 4). Unlike Messier et al. (1992), we observed no earlier unloading of the knee during the stance phase. When the two peak force values were compared, the OA group had significantly smaller and more asymmetric peak values. Moreover, the curve pattern of ground reaction forces showed a plateau instead of the usual pattern with two peaks. These results are consistent with the data reported by Györy et al. (1976) and Stauffer et al. (1977). Messier et al. (1992) also found a reduction in the value of VFP1, but not VFP3. They reported more asymmetric peak values, in accord with our results, and attributed these changes to a lower loading rate and shortening of the push off phase due to osteoarthrotic pain.

Our findings indicate that mechanical gait changes may occur in patients with early medial OA of the knee. Computerized gait analysis can detect these changes at an early stage. However, the interpretation of causes and compensatory effects in various moment patterns is difficult because there are complex interrelations. Although the results of this study are encouraging, too few patients were evaluated to serve as a basis for broad clinical conclusions at this time. Therefore, longitudinal studies with larger groups are needed to distinguish between pathogenetic and compansatory factors in OA of the knee joint.

Ahlbäck S. Osteoarthrosis of the knee: a radiographic investigation. Acta Radiol (Suppl 277) 1968: 7-72.

Altman R, Asch E, Bloch D, et al. Development criteria for the classification and reporting of osteoarthrosis : classification of the osteoarthrosis of the knee. Arthritis Rheum 1986; 29: 1039-49.

Andriacchi T P. Dynamics of knee malalignment. Orthop Clin North Am 1994; 25: 395-403.

Andriacchi T P, Galante J O, Fermier R W. The influence of total knee replacement design on walking and stair-climbing. J Bone Joint Surg (Am)1982; 64: 1328-35.

Bell A L, Brand R A. A comparison of the accuracy of several hip center location prediction methods. J Biomechanics 1990; 23: 617-21.

Brinkmann J R, Perry J. Rate and change of knee motion during ambulation in healthy and arthritic subjects. Phys Therapy 1985; 65: 1055-60.

Guccione A A, Felson D T, Anderson J J, et al. The effects of specific medical conditions on the functional limitations of elders in the Framingham study. Am J Public Health 1994; 84: 351-7.

Györy A N, Chao E Y S, Stauffer R N. Functional evaluation of normal and pathologic knees during gait. Arch Phys Med Rehabil 1976; 57: 571-7.

Messier S P, Loeser R F, Hoover J L, et al. Osteoarthrosis of the knee: effects on gait, strength and flexibility. Arch Phys Med Rehabil 1992; 73: 29-36.

Noyes F R, Schipplein O D, Andriacchi T P, et al. The anterior cruciate ligament-deficient knee with varus alignment; an analysis of gait adaptations and dynamic joint loadings. Am J Sports Med 1992; 20: 707-16.

Prodromos C C, Andriacchi T P, Galante J O. A relationship between gait and clinical changes following high tibial osteotomy. J Bone Joint Surg 1(Am) 1985; 67 (8): 1188-94.

Schipplein O D, Andriacchi T P. Interaction between active and passive knee stabilizers during level walking. J Orthop Res 1991; 9: 113-9.

Schnitzer T J, Popovich J M, Anderson G B J, Andriacchi T P. Effect of piroxicam on gait in patients with osteoarthritis of the knee. Arthritis Rheum 1993; 36 (9): 1207-13.

Sharma L, Hurwitz D E, Thonar E A, et al. Knee adduction moment, serum hyaluronan level and disease severity in medial tibiofemoral osteoarthrosis. Arthritis Rheum 1998; 41 (7): 1233-40.

Stauffer R N, Chao E Y S, Györy A N. Biomechanical gait analysis of the diseased knee joint. Clin Orthop 1977; 126: 246-55.