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Gait Deviations in Patients with Early Osteoarthritis of the Knee

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We design a case control study to evaluate the gait deviations of patients with early osteoarthritis(OA) of the knee, which are subtle and difficult to observe clinically. Twenty-six patients with symptomatic OA were recruited from the outpatient department. The control group consisted of 20 normal subjects who were matched for age, body weight, and body height. Both the patient and control groups were subjected to a similar protocol of gait analysis with comfortable speed. The peak value of angular displacement of pelvic tilt up, pelvic tilt down, knee valgus, ankle dorsifexion, and ankle rotation were significantly lower ($p< 0.05$) in the OA group. The peak angular displacement of knee varus of the OA group was significantly higher. The OA group also had significant higher peak moment in hip flexion, hip abduction, knee extension, knee valgus and plantarflexion. However, the peak moment of knee flexion and varus were significantly lower than the control group. Patients tend to restrict the motion of ankle dorsiflexion, ankle rotation, and knee valgus to diminish pain. The decreased pelvic tilt up and down may also be due to the restricted motion of lower leg. The increased varus angular displacement is the result of varus deformity and ligamentous laxity, as a result of the long standing varus deformity of knee joint which transforms the mechanical axis of lower extremity and produces excess loading over the medial compartment. As the varus deformity increases, the valgus moment inevitably increases in order to achieve stability of knee joint during ambulation. The limited range of motion (ROM) at the end stage of knee extension may contribute to the increased extension moment of knee at stance phase to avoid buckling. This limitation of ROM also influences the ankle and hip joints, increasing the joint moment of plantarflexion, hip flexion and hip abduction. The OA group produces negative knee joint power and generate lower ankle joint power than the control group at pre-swing phase. Therefore, we can infer that the OA group can not generate power at pre-swing phase is due to poor propulsive force at pre-swing phase. In conclusion, patients with early osteoarthritis of knee joint have certain gait features during ambulation. The characteristic poor propulsion at pre-swing phase of knee and ankle joints could be an early sign of OA that may was used as a reference of clinical assessment. (Tw J Phys Med Rehabil 2005; 33(3): 123 - 130)

Key words: osteoarthritis knee, gait analysis, joint angle, moment

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INTRODUCTION

Osteoarthritis(OA) is the most common rheumatic disease and the knee is the most commonly affected weight bearing joint. [1] The critical contributions of the knee joint to lower extremity function and ambulation make OA of the knee a significant and challenging disability.

Quantitative gait analysis is essential to improve the understanding of the mechanisms underlying gait, thus enabling clinicians to adapt the rehabilitation program to the specific patient. Previous studies suggest that walking patterns are adversely affected by lower extremity joint disease. Gyory and colleagues[2] compared the knee joints of 29 able-bodied subjects to 65 patients with degenerative arthritis and 30 patients with rheumatoid arthritis. Analyzing knee kinematics and ground reaction forces, the authors found the angles of flexion and extension at stance phase were markedly reduced in the subjects with degenerative disease. Also, the peak ground-reaction forces in the subjects with degenerative disease were approximately 9% lower, with the absolute values actually falling below 100% of the subjects' body weight. In a similar study, Stauffer and associates[3] found decreased range of motion (ROM), reduced isometric knee strength, and lower peak ground-reaction forces and loading rates in subjects with OA. Brinkmann and Perry[4] also found decreased knee flexion and extension velocities and limited knee ROM in a group of 20 OA subjects. Messier and associates[5] compared 15 adults with symptomatic OA of the knee and 15 age, mass, and gender-matched control subjects. They found that patients with symptomatic OA of the knee have poorer flexibility in both the affected and unaffected legs and demonstrate significantly less knee angular velocity and, to a lesser extent, knee range of motion during gait. They have an increased loading rate in the unaffected leg after heel strike, exert less peak vertical force during push-off, and are significantly weaker in both the dominant and nondominant legs compared to adults with no lower extremity disease. Weidenhielm and colleagues[6] investigated 54 patients with moderate medial osteoarthrosis of the knee. Varus deformity of the knee was assessed from static radiographic measurements as the Hip-Knee-Ankle (HKA) angle. They found that the adduction moment in mid stance was more important than the peak adduction moment in differentiating between patients and normal controls. The amplitude of the peak adduction moment depended on the gender and body mass of the patients, while the amplitude of the mid stance adduction moment depended on body mass and the varus deformity of the knee, there was moderately high correlation with the peak adduction moment at midstance. Sharma et al. [7] also found a significant relationship between adduction moment and severity of OA disease.

The purpose of this study was to evaluate the gait deviations of patients with early OA of the knee, which are subtle and difficult to assess clinically. We believe that this evaluation could be beneficial for assessing the effectiveness of a rehabilitation program and may help clinicians make decisions.

MATERIALS AND METHODS

Subjects

Twenty-six patients (7 men and 19 women) 45 to 70 years old, with unilateral symptomatic OA of the knee were recruited from an outpatient department. All showed symptoms of pain in the affected knee while in motion or at rest plus at least one of the following: tenderness with pressure; mild swelling; crepitous while in motion; or stiffness. The findings on anterior-posterior and lateral view X ray of knee during full weight-bearing must include joint space narrowing, subchondral sclerosis, and osteophyte formation. The control group consisted of 20 (5 men and 15 women) healthy subjects (Table 1).

We used the Ahlback classification (Table 2) to classify the severity of OA, which is interpreted by the same radiologist. Only grade one OA is regarded as early degenerative change.

Instrumentation

A Vicon 370 motion analysis system (Oxford Metrics Ltd, Oxford, England) and two AMTI force plates (Advanced Mechanical Technology INC, MA, US) were used to obtain kinematic and kinetic data by using a 60 Hz sampling rate. In order to determine the spatial coordinates of each body segment, thirteen retroreflective markers were placed on selective anatomic features, including: bilateral second metatarsal head, lateral malleolus, external femoral epicondyle, lateral half of lower leg, lateral half of thigh, anterior suprior iliac spine, and sacrum.

Gait analysis procedures

Before testing, the anthropometric data were measured, included absolute leg length, ankle and knee width. in the supine position. The absolute leg length was measured from the anterior superior iliac spine to the medial malleolus.

During testing, each subject was asked to walk on a 10 meter-long walkway at a self-selected comfortable speed. Three analyzable trials were saved for further data analysis.

Data analysis

Data analysis included the temporal-stride parameters (e.g. walking speed, step length, step time, double and single support) and the angle and moment changes of hip, knee, and ankle joints at three planes. The statistical analyses were performed using SPSS 10.0 (SPSS inc., Chicago, Illinois). Differences in the age, body height, body weight, and gait parameters (e.g. kinematic and kinetic data) between OA patient and control group were compared using Student's *t* test, and differences in sex distribution were determined with the X^2 test. Pair *t* test was used to compare bilateral side difference. A value of p<0.05 was considered statistically significance.

RESULTS

No significant differences in the demographic data (e.g. sex, age, body height, and body weight) were found between OA patient and control groups.

The temporal-stride parameters expect walking speed were significant difference (p<0.05), there were no significant differences on step length, step time, single support and double support between the OA patient and the control groups (Table 3). By calculating the peak value of angular displacement of the OA and control groups, we found that pelvic tilt up, pelvic tilt down, knee valgus, ankle dorsifexion, and ankle rotation were significantly lower (p< 0.05) in the OA group, whereas in peak angular displacement of knee varus, the OA group was significantly higher than the control group (Table 4).

Table 1. Comparison of demographic data between OA patients and control groups

	OA patient (n=26)	Control group (n=20)	P value
Sex	M=7, F=19	M=5, F=15	0.884
Age (year)	65.7±8.5	63.6±11.3	0.516
Body height (cm)	155.6±7.3	159.5±9.3	0.187
Body weight (kg)	62.4±9.9	62.6±8.3	0.942

M, male; F, female.

Table 2. Classification of severity of osteoarthritis of the knee

Grade	Radiographic change
I	At most a slight reduction of the cartilage height
II	Obliteration of the joint space
III	Bone loss of ≤ 7mm measured along the medial or lateral margins of the joint from a line perpendicular to the axis of the tibia and tangential to the unaffected articular surface
IV	Bone loss > 7mm measured as above
V	Bone loss > 7 mm with subluxation, defined as lateral displacementof the tibia by at least 10 mm in relation to the femur

Table 3. Temporal-stride parameters of OA patients and control groups

Parameters	OA patients		Control group (n=20)	p value
	Sound (n=26)	Affected (n=26)		
Walking speed (%BH/sec)	48.7±11.8	52.8±11.7	59.5±10.7	0.002*
Step length (%BH)	32.0±5.2	32.9±5.4	30.8±5.3	> 0.05
Step time (step/min)	50.0±1.9	51.2±1.7	49.8±3.7	> 0.05
Single support (% GC)	35.8±2.5	30.3±10.3	35.4±3.3	> 0.05
Double support (% GC)	28.8±3.8	25.6±7.3	28.3±4.5	> 0.05

BH, body height; GC, gait cycle.

Table 4. Peak angular displacement of OA patients and control groups

Parameters	OA patients	Control group	P value
Pelvic tilt up	4.1±4.7	7.4±4.0	p=0.019*
Pelvic tilt down	-0.2±5.7	-4.4±4.4	p=0.009*
Hip flexion	27.4±14.1	29.6±6.8	NS
Hip extension	-11.8±12.9	-9.9±7.2	NS
Knee flexion	55.2±24.0	52.5±10.5	NS
Knee extension	1.5±8.8	5.5±7.5	NS
Knee varus	16.8±10.0	9.2±11.9	p=0.036*
Knee valgus	-5.6±6.0	-12.3±10.4	p=0.02*
Ankle dorsiflexion	12.8±7.8	17.5±6.7	p=0.004*
Ankle internal rotation	4.7±6.8	12.7±10.8	p=0.009*

* represent significant difference between both groups, p<0.05; NS= no significant; pelvic tilt up (+) and down (-) at sagittal plane; hip flexion (+) and extension (-) at sagittal plane; knee flexion (+) and extension (-) at sagittal plance; knee varus (+) and valgus (-) at coronal plane; and ankle internal (+) and external (-) rotation at transverse plane.

The peak vertical ground-reaction force of the sound side of the OA group was 101.96±3.7 Newton and the affected side was 101.21±3.3 Newton in average. There was no significant difference between the sound side and the affected side. The average peak vertical ground-reaction force of control group (102.65±3.7 Newton) is also no significantly different when compared to the OA group. Figure 1 demonstrates the lower limb sagittal plane moment changes during gait. We found that the OA group had significantly higher knee extension and lower ankle plantar flexion moment at stance phase and early swing phase. The OA group had significantly higher peak moment in hip flexion, hip abduction, knee extension, knee valgus and plantarflexion. However, the peak moment of knee flexion and varus were significantly lower than the control group (Table 5).

DISCUSSION

Felson et al [8] found that only 30-40% of those with radiographic changes of OA have symptoms. During walking, we found that the OA group demonstrated a symmetric characteristic between the sound side and the affected side. Even between the OA and the control group the difference of step length, step time, single support, and double support were also trivial. These results support our hypothesis that in the early stage of OA the change of gait can be subtle and difficult to observe clinically. In the peak angular displacement of pelvic tilt up, pelvic tilt down, knee valgus, ankle dorsiflexion, and ankle rotation, the OA group values were significantly lower than the control group. This may be due to patients' tendency to restrict ankle dorsiflexion, ankle rotation, and knee valgus, in order to reduce pain. The decreased pelvic tilt up and down may also be due to the restricted motion of lower leg. On the other hand, the increased varus angular displacement may be the result of varus deformity and ligamentous laxity, as up to 70% of patients of OA of knee exhibit varus deformity. [9]

The peak vertical ground-reaction forces were similar between the sound side and affected side, and also similar between the OA and control group. Therefore, the early degenerative change of the joint does not seem to influence the impact force of lower extremity. The peak moments of hip flexion, knee extension, knee valgus and ankle plantar flexion of the OA group are higher than control group, whereas knee flexion and varus are lower. As the result of the long standing varus deformity of knee joint which transform the mechanical axis of the lower extremity and produce excess loading over the medial compartment. As the varus deformity increases, the valgus moment inevitably increases to achieve stability of the knee joint during ambulation. The limited ROM in the end stage of knee extension may possible contribute to the increased extension moment of the knee at stance phase to avoid buckling (figure 1). This limitation of ROM also influence the ankle and hip joint to increase the joint moment of plantar flexion, hip flexion and hip abduction, which can be a result of compensatory mechanism. In our previous serious studies, the OA patients have poor second peak ground reaction forces. [10] Therefore, we can infer that the OA group can not generate power at pre-swing phase is due to poor propulsive force at pre-swing phase.

The results of this study could be a baseline of clinical treatment protocols such as lateral wedged insoles, intra-articular hyaluronate injections, [11] analgesic drugs and physical therapy. The weakness of this study is lack of the functional evaluations. Therefore, the kinematics and kinetics data cannot correlate with the function outcome of patents. As a result, we can only propose some possible mechanism to explain the kinetics and kinematics data of the OA patients.

CONCLUSION

Our results showed that patients with early OA of the knee have significantly characteristic gait patterns that are significantly different from their matched controls. The characteristic poor power production at pre-swing phase of knee and ankle joints could be an early sign of OA which may use as a reference of clinical assessment.

Table 5. The peak moment of each joint of OA patients and control groups

Parameters	OA patients	Control group	p value
Hip flexion moment	0.60±0.26	0.40±0.31	p=0.026*
Hip abductor moment	0.98±0.20	0.66±0.44	p=0.002*
Hip internal rotation moment	0.14±0.07	0.18±0.10	NS
Knee flexion moment	0.30±0.18	0.42±0.30	p=0.05*
Knee extension moment	0.67±0.60	0.26±0.20	p=0.009*
Knee valgus moment	0.49±0.27	0.30±0.20	p=0.018*
Knee internal rotation moment	0.18±0.05	0.14±0.06	NS
Ankle plantarflexion moment	0.89±0.52	1.17±0.17	p=0.013*
Ankle internal rotation moment	0.23±0.18	0.19±0.12	NS

* represent significant difference between both groups, $p<0.05$; NS= no significant.

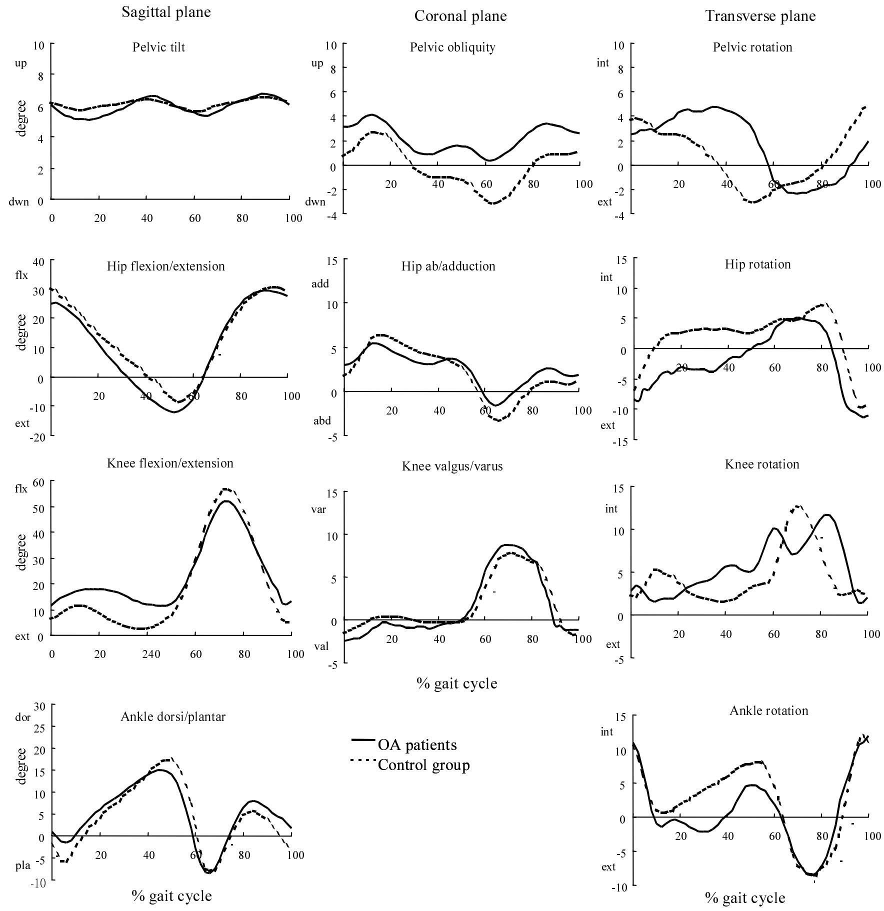

Figure 1. Lower limb joint angles.

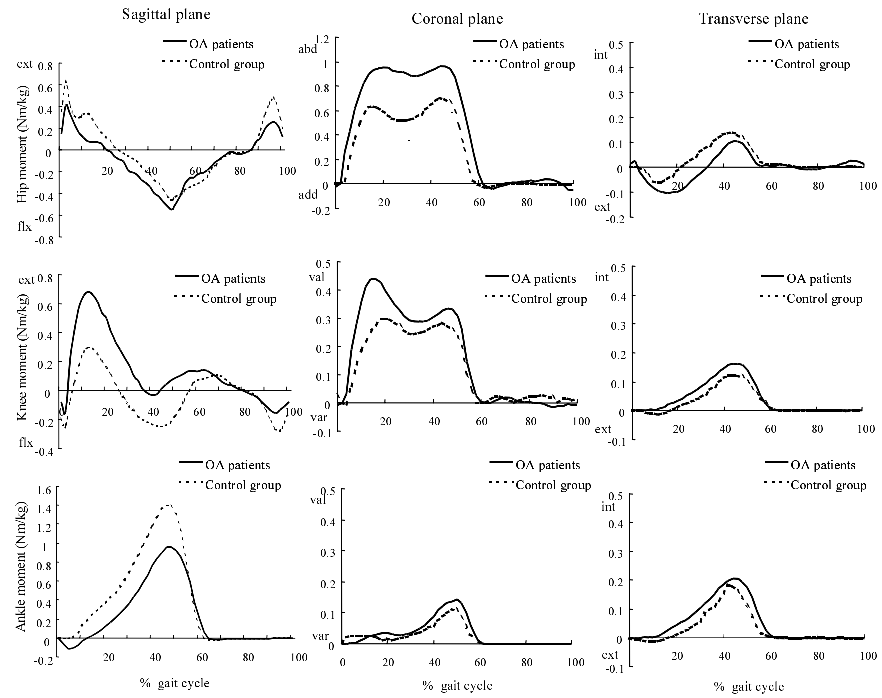

Figure 2. Lower limb joint moments.

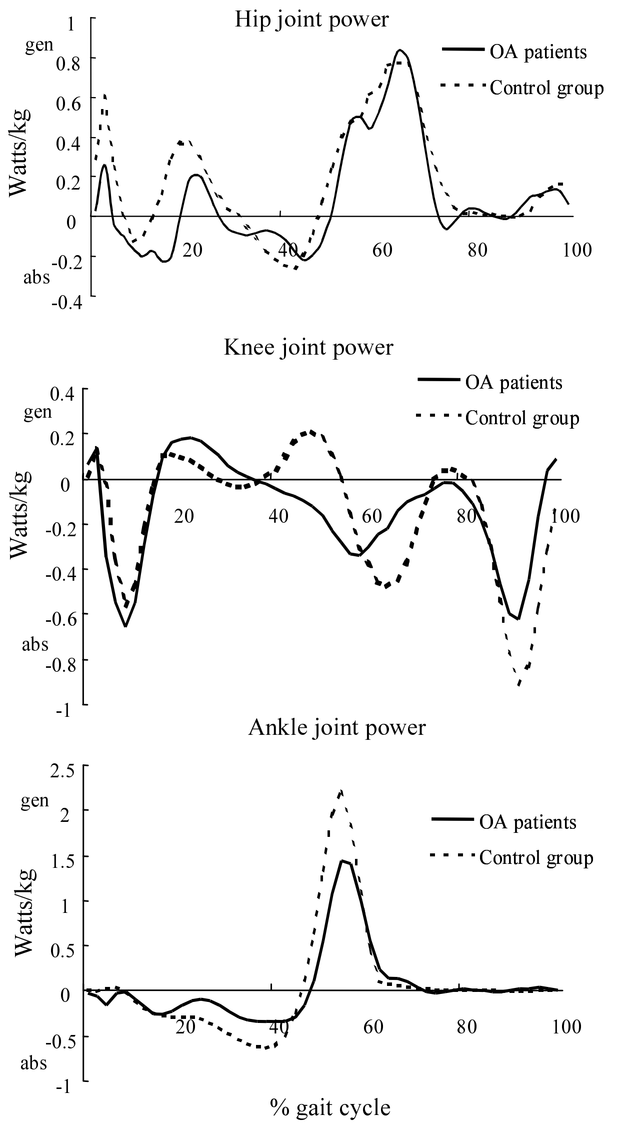

Figure 3. Lower limb joint powers.

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退化性膝關節炎早期之步態變化

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本研究是希望藉由步態分析來評估早期退化性膝關節炎患者細微且臨床不易觀察的步態變化。共收集有 26 位單側有症狀之退化性膝關節炎症狀的門診病患及 20 位年齡、體重、身高相當的正常對照組，進行舒適步行速度的步態分析。結果患者的骨盆上傾、骨盆下傾、膝關節外翻、足踝背屈及旋轉的角度位移峰值明顯低於對照組。患者的膝關節內翻角度位移峰值則明顯高於對照組。患者的髖關節屈曲、髖關節外展、膝關節伸展、膝關節外翻及足踝蹠曲的力矩峰值明顯優於控制組。而患者膝關節屈曲及內翻的力矩峰值明顯低於控制組。步態表現顯示患者是藉限制足踝背屈、足踝旋轉及膝外翻以減輕疼痛。而減少骨盆的上傾及下傾則可限制下肢的活動。膝內翻角度增加則是因爲關節內翻變形及韌帶鬆弛所造成。進而導致下肢承重的力線內移而將過多的壓力集中在關節內側。隨著內翻變形的加劇，爲了要維持步行中的膝關節穩定度，外翻力矩勢必要增加。膝關節伸展末段的角度些微受限可使伸展力矩增加，以避免支撐期突發性的膝關節屈曲，如此也導致了足踝蹠曲、髖關節屈曲及外展的力矩增加。擺動前期膝關節及踝關節的功率減低，代表退化性膝關節炎的患者缺乏推進的力量。早期退化性膝關節炎的患者具有特定的步態，尤其是關節角度位移及關節力矩的峰值變化更是明顯。此等變化臨床不易發現及作量化紀錄，步態分析則可提供精確數據描繪其變化，對量化評估扮演重要角色。（台灣復健醫誌 2005; 33(3): 123 - 130）

關鍵詞：退化性膝關節炎(osteoarthritis knee)，步態分析(gait analysis)，關節角度(joint angle)，力矩(moment)

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