The rotational angle in osteoarthritic knees

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Summary. *The angle of rotation of the knee joint during weight-bearing in osteoarthritic knees has not been fully determined. The authors aimed to examine the nature and extent of rotation during weight-bearing by means of ultrasonic investigation. There was a highly significant correlation between the rotational angle measured by ultrasound and that determined by CT. The dynamic rotatory movement during weight-bearing was measured in 107 osteoarthritic and 40 control knees. At 20° of flexion the internal rotation of the early grade I osteoarthritic knees (−1.6°) was significantly less than that of the control knees (−4.8°, $P=0.004$). This abnormality was the initial pathological rotational change in osteoarthritis of the knee joint. The external rotation at maximal extension and the rotation of the screw-home movement proportionately decreased with progression of medial compartment osteoarthritis. By virtue of these observations we have clarified the dynamic rotatory movement in osteoarthritic knees during weight-bearing.*

Résumé. *L'angle de rotation du genou arthrosique pendant l'appui pas été entièrement expliqué. Les auteurs ont étudié la rotation de l'articulation du genou par ultrasons. Il existe une corrélation très significative entre l'angle de rotation mesuré aux ultrasons et par tomodensitométrie. Le mouvement rotatoire dynamique pendant l'appui fut mesuré dans 107 gonarthroses et 40 genoux témoins. A une flexion de 20°, la rotation interne des genoux souffrant d'une arthrose de la classe I initiale fut significativement plus faible que celle des genoux témoins (−4.8°, $P=0.004$). Cette anomalie de rotation était la modification pathologique initiale. La rotation externe lors d'une extension maximale et la rotation du mouvement vissé a proportionnellement diminué avec la*

progression de l'arthrose du compartiment interne. Nous avons donc éclairci le mouvement de rotation dynamique des genoux arthrosiques pendant l'appui.

Introduction

A greater understanding of the rotational alignment of the knee joint is necessary for clarification of the pathogenesis of osteoarthritis in this joint. Computed tomography (CT) is effective in the measurement of rotational abnormalities of the lower limb in prone osteoarthritic patients [1, 8, 10, 12, 15] but it cannot be employed for scanning during weight-bearing. Moulton et al. [7] used ultrasound for the measurement of femoral anteversion and reports followed of ultrasonic measurement of tibial torsion [3, 5] and femoral anteversion [13].

The knee joint is designed to be loaded and measurements of rotation during physiological weight-bearing would probably provide a useful insight into the normal function and pathological derangements of the joint. As yet, however, there have been no direct measurements of rotation of the proximal tibial condyle relative to the distal femoral condyle during weight-bearing.

We aimed to establish a reliable method of measuring knee rotation during weight-bearing using ultrasound, and then use this information to clarify the rotational abnormalities in osteoarthritic knees. In the first phase of the study we confirmed that knee rotation could be accurately measured by ultrasound, after which we measured the dynamic rotatory movement in osteoarthritic knees. The results were compared to those obtained in a control group.

Materials and methods

Method of measuring knee rotation by ultrasound

Measurements were undertaken using a real-time ultrasound apparatus with a 3.5 MHz linear probe (Yokogawa Medical Systems, Model RT 3000). Skin contact was made with an ultrasound conductor and gel. Rotation of the knee joint was defined as the rotation of the tibia relative to the femur in the plane perpendicular to the long axis of the leg. The rotation of the knee was measured as the angular difference between the line connecting the posterior surface of the femoral condyles and the posterior surface of the tibial condyles (Fig. 1). The same investigator performed all the ultrasonic measurements in the prone and weight-bearing positions.

1. Technique of prone rotational measurement (Fig. 2). The patients were laid in the prone position and the popliteal space was scanned transversely. The distal femoral condyle was scanned at the level between the mid-point of the patella and its apex. The proximal tibia was scanned between the level of the articular surface and the head of the fibula. The probe was tilted in the plane of the ultrasound beam until the line connecting the posterior surface of the femoral condyles and a second line connecting the posterior surface of the tibial condyles was horizontal on the monitor screen. A clinometer adjacent to the ultrasound probe indicated the femoral and tibial tilting angles. The rotation of the knee joint was expressed as the angular difference between the tilting angles.

2. Technique of weight-bearing rotational measurement. Weight-bearing measurements were made with the patient standing on both legs and positioned on a frame which had been designed by the authors (Fig. 3A). It had a horizontal bar which could be moved up and down. The horizontal bar was positioned along the lateral aspect of the knee, perpendicular to the long axis of the leg. The vertical position of the horizontal bar was aligned with the joint line, as determined by ultrasound.

The popliteal space was scanned transversely in an identical fashion to that described for the prone measurements. The ultrasound probe with the base line was manipulated at the popliteal space, visualizing the posterior femoral condyles. The probe was moved until the line connecting the posterior surface of the femoral condyles appeared horizontal on the monitor screen. The angle formed between the posterior femoral base line and the adjustable horizontal bar was measured with a protractor (Fig. 3B). This angle was designated as the "femoral angle" (F-angle). A similar ultrasonic technique was used to measure the tibial angle (T-angle).

The patient remained standing in the frame with the adjustable horizontal bar positioned lateral to the knee at the level of the joint line. The ultrasound probe was manipulated until the line connecting the posterior surface of the tibial condyles appeared horizontal on the monitor screen. The angle formed between the tibial base line and the adjustable horizontal bar (T-angle) was measured with a protractor (Fig. 3B). The angular difference between the F-angle and the T-angle represented the rotation of the knee joint during weight-bearing (Fig. 3C).

Confirmation of the accuracy of knee rotation measured by ultrasound

The authors compared the results using ultrasonic technique with those obtained by CT with patients in the prone position. Fifteen knees in 8 normal volunteers and 14 knees in 8 patients with osteoarthritis or rheumatoid arthritis were assessed by ultrasound. All 29 knees had identical measurements of ro-

Fig. 1A, B. Transverse ultrasonic scan of the popliteal space (right knee): (A) The line connecting the posterior surface of the femoral condyles. (B) The line connecting the posterior surface of the tibial condyles

Fig. 2. Technique of prone rotational measurements

tation to those obtained by CT scan in patients positioned similarly. The knees were scanned and measured at identical levels with the CT scanner, in accordance with the technique described by Takai et al. [12]. The CT measurements were performed with a Toshiba X-force apparatus. All ultrasonic and CT measurements were performed without the examiner knowing the results of the other method. The ultrasound results were compared for accuracy with the CT scan results using the Pearson test.

Fig. 3A–C. Technique of weight-bearing rotational measurements: (A) The frame designed by the authors. (B) Technique of weight-bearing rotation measurements. (C) The angular difference between the F-angle and the T-angle represents the rotation of the knee joint during weight-bearing

Measurement of knee rotation in patients with osteoarthritis

The rotation of the knee joint was measured by ultrasound in both the prone position and during weight-bearing in 107 knees in 69 patients with medial osteoarthritis (OA group) and in 40 knees in 20 normal adults (control group). Rotation was considered to be positive when the tibia was externally rotated in comparison to the femur, and negative when the tibia was internally rotated.

The osteoarthritis patients were divided into three radiographic grades (Table 1): Grade I; 45 knees with minimal degenerative findings and well maintained joint spaces. Grade II; 38 knees with degenerative changes and medial joint spaces narrowed to a thickness no greater than 3 mm. Grade III; 24 knees with advanced degenerative changes and absent medial joint spaces.

The degree of terminal knee extension in all osteoarthritic patients ($-5.1 \pm 3.9^\circ$) was significantly less than in the control group ($0.9 \pm 1.9^\circ$) ($P=0.0001$, Mann-Whitney U-Test). There were no significant differences in the measurements of terminal knee extension among the three osteoarthritic groups ($P=0.25$, ANOVA) (Table 1). The rotation at maximal extension (a mean of 5.1° of flexion) in the osteoarthritis group was therefore comparable with the rotation at 5° of flexion in the control group.

In normal knee-joints rotation automatically occurs at final extension and when the tibia rotates externally on the femur. This automatic rotation is conventionally termed "screw-home movement" (SHM). Previous measurements of the degree of SHM and the range of extension at which automatic rotation occurs have yielded variable results [2, 6, 9, 14]. In this study, rotation during weight-bearing was measured with the knee joints extended and in 20° of flexion. The screw-home move-

Table 1. Data for control and osteoarthritic patients in the second study

Grade	Number of knees	Age (years)	FTA	Degree of terminal knee extension
Control	40	27.2±4.5°	176.8±1.6°	0.9±1.9°
Grade I	45	72.6±7.0°	177.3±3.5°	-4.4±4.3°
Grade II	38	73.3±6.8°	179.7±4.2°	-5.3±3.5°
Grade III	24	76.8±6.4°	186.3±4.5°	-6.0±3.6°

(mean±S.D.) S.D.=standard deviation; FTA=Femoral-Tibial Angle; N.S.=not significant; * $P<0.05$; ** $P<0.01$

ment was defined as the difference between the rotation at maximal extension in the osteoarthritis group, and 5° of flexion in the control group and 20° of flexion. All prone measurements of rotation in both control and arthritic knees were made with the knee extended. The one-factor ANOVA technique was used for statistical analysis and post-hoc analysis was performed using Scheffe's F Test. A p-value of less than 0.05 was considered to be significant.

Results

Correlation of ultrasound with CT

There was a highly significant correlation between the rotational angle measured by ultrasound and that determined by CT ($r=0.991$, $P=0.0001$) (Fig. 4). This observation indicates that the rotation of the knee joint can be measured as accurately by ultrasound as with a CT scan.

Comparison of osteoarthritic knees with normal joints

1. Measurement of knee rotation during weight-bearing. Comparisons of rotation and dynamic rotatory movement among the control group and the three osteoarthritic groups are presented in Table 2 and in Fig. 5.

The control group had 3.5° of external rotation at extension (5° of simulated flexion contracture), and 4.8° of internal rotation at 20° of flexion. The screw home movement of the control group was 8.3° of external rotation.

In the grade I group the measurements at maximal extension did not differ significantly from those of the control group ($P=0.99$) although the internal rotation at 20° of flexion for the grade I group was significantly less than that of the control group ($P=0.004$). On this basis, there was a significant difference between the extent of external rotation of SHM in the control patients ($8.3\pm3.2^\circ$) and the grade I patients ($4.9\pm4.3^\circ$, $P=0.0005$).

Fig. 4. Comparison between the rotational angle measured by ultrasound and by CT

Fig. 5. Change in the dynamic rotatory movement with the progress of osteoarthritis of the knee joint

Table 2. Rotational angle during weight-bearing

Grade	20° of flexion	5° of flexion for control group maximal extension for OA groups	SHM
Control (n=40)	-4.8±2.9° **	3.5±2.5° N.S.	8.3±3.2° **
Grade I (n=45)	-1.6±4.5° N.S.	3.3±3.7° **	4.9±4.3° **
Grade II (n=38)	-2.4±4.6° N.S.	0.1±4.9° **	2.5±3.2° N.S.
Grade III (n=24)	-4.4±3.7°	-3.9±3.7°	0.5±3.6°

(mean±S.D.) S.D.=standard deviation; SHM=screw home movement; N.S.=not significant; * $P<0.05$; ** $P<0.01$

Table 3. Rotational angle in the prone position

	Control group (5° of flexion) (n=40)		OA group		
			Grade I (n=45)	Grade II (n=38)	Grade III (n=24)
Rotational angle	2.7±1.9°	N.S.	3.6±4.9°	N.S.	1.6±5.5°
			N.S.		
				**	
				*	

(mean±S.D.) S.D.=standard deviation; N.S.=not significant; * $P<0.05$; ** $P<0.01$

The external rotation at maximal extension and the rotation of the screw-home movement proportionately decreased with progression of medial compartment osteoarthritis.

2. Measurement of knee rotation in the prone position (Table 3). In the grade III group, internal rotation of the tibia was significantly greater than in the control group and the grade I group. Nevertheless, there was no proportionate change with progressive of osteoarthritis, as shown by the measurements obtained during weight-bearing.

Discussion

Ultrasonic scans, which can reliably produce accurate measurements of knee joint rotation during physiological weight-bearing, have a significant advantage over CT scanning techniques. In particular, ultrasound is non-invasive and does not use radiation.

In our second study there were no significant differences between the groups when the measurements were made at maximal extension with the subjects in the prone position (grade I and grade II, grade II and grade III, control and grade II). However, measure-

ments obtained at maximal extension during weight-bearing showed significant differences.

In patients with medial compartment osteoarthritis the medial joint space was much more narrow in weight-bearing radiographs than in those obtained with the patient lying prone. This indicates that the knee is a load-bearing joint and that measurements performed when the knee is not loaded may be more subject to error and less valid.

Using CT scans, Eckhoff et al. [1] reported a significant difference between the external rotation of an osteoarthritic knee ($4\pm1^\circ$) and a normal knee ($0\pm0^\circ$). Conversely, Moussa [8] and Yagi [15] found no difference between osteoarthritic and normal knees. Sasaki [10] determined that external rotation of the knee decreased in the early stages of osteoarthritis, but increased with advanced osteoarthritis. There is little agreement between the results of studies of rotation in osteoarthritic knees measured by CT, possibly because the measurements were made in the prone position.

The change in the dynamic rotatory movement with progression of osteoarthritis is shown in Fig. 5. In the early grade I group, external rotation at maximal extension was intact but internal rotation of the tibia at 20° of flexion was diminished. The SHM was

already disturbed in the earliest grade I knees. Progression of the osteoarthritis produced proportionate changes in the pathological rotation of the tibia and external rotation at maximal extension gradually diminished. Additionally, the rotation of SHM continued to decrease with progression of the osteoarthritis and the knee joint then moved more like a simple hinge joint.

The precise determination of the SHM in osteoarthritic knees has not been clearly defined. Kettelkamp et al. [4] measured leg rotation during walking by means of an electrogoniometer. They found that the patterns in osteoarthritic patients resembled those of normal persons. Smillie [11] termed the abnormal rotatory action of the osteoarthritic knee "reverse of the screw-home movement". Kuriwaka [6] found that the SHM was disturbed in the early stages of osteoarthritis and that pathological rotatory movement occurred with progression of the osteoarthritis.

The rotation of the knee at 20° of flexion during weight-bearing has not been previously measured or reported. There was no significant difference between grade I and the control group at maximal extension, but the internal rotation of grade I was significantly less than that of the normal group at 20° of flexion. This rotational abnormality was the initial pathological rotational change in knee osteoarthritis. In the walking cycle the range of motion of the knee during the stance phase is from 5° through 20° of flexion. The flexion angle of the knee during flat foot and mid-stance, when the load increases, is from 15° to 20°. This observation indicates that the determination of a rotational deformity at 20° of flexion is important in the elucidation of the pathogenesis of osteoarthritis of the knees. We have shown that ultrasound is useful as a method of measuring knee joint rotation during weight-bearing and we have clarified the dynamic rotatory movement in osteoarthritic knees.

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