The Lack of Correlation Between Radiographic Findings and Cartilage Integrity

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Abstract: Total knee arthroplasty is a common treatment of osteoarthritis, although unicompartmental knee arthroplasties are frequently used to retain unaffected compartments. Joint space width (JSW) is a major factor in determining treatment. We examined the relationship between JSW and cartilage quality in 60 patients undergoing total knee arthroplasty to assess its accuracy in representing cartilage degradation. Radiographic JSW was recorded, whereas the unaffected compartment of each tibial plateau was examined postoperatively using Collins, Mankin, and Kellgren and Lawrence scores. No correlation was seen between visual or histologic grading and JSW. Histology more accurately represented cartilage quality, yet it is impractical to obtain preoperatively; thus, JSW is the main mode of assessment. However, using JSW solely to indicate unicompartmental knee arthroplasty may overlook disease in apparently unaffected compartments. **Keywords:** unicompartmental, knee, joint space width, osteoarthritis, cartilage.

Total knee arthroplasty (TKA) surgery has been proven to relieve the pain and functional impairment associated with osteoarthritis (OA) and is thus the most common surgical treatment of the disease [1]. With the progressive advent of minimally invasive techniques and improvements in prosthetic design [2,3], there has been a notable increase in the use of unicompartmental knee arthroplasty (UKA) in the last decade particularly. Furthermore, advances and refinements to operative technique have led multiple groups to publish mid- to long-term survival results equivalent to those for TKA [4-7].

With up to 6% of all knee arthroplasties in 2000 being unicondylar [8], the remaining controversy remains in whom and when a UKA should be performed [3,9]. Measurement of joint space width (JSW) from radiographs is a major factor in monitoring the progression and disease state as well as determining treatment [10]. Thus, the use of radiographic analysis and JSW correlation to cartilage distribution is pivotal to the diagnosis of unicompartmental disease.

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In this study, we investigated the relationship between JSW and cartilage quality to determine how accurately radiographic JSW represents the status of the cartilage. To our knowledge, no group has explored this relationship in relation to its application in identifying unicondylar arthroplasty candidates.

Our hypothesis is that JSW is not an accurate indicator of the severity of cartilage damage in cases of OA of the knee.

Materials and Methods

Sixty male and female human subjects were randomly selected from patients undergoing TKA surgery for idiopathic OA by one orthopedic surgeon over 2 years in an institutional review board–approved study. The subjects ranged in age from 48 to 87 years; the average age at time of measurement was 69 years; no patient had undergone previous arthroscopic procedure. There were 45 cases of reduced medial joint space (varus) and 15 cases of reduced lateral joint space (valgus). All subjects received a unilateral primary TKA. Of the 60 cases, there were 35 left knees and 25 right knees. Anterior-posterior view and lateral view radiographs of the knee joint were obtained before surgery using a standardized protocol with a 20% magnification.

Collins Grading

The gross tibial plateau only was obtained during the TKA procedure. Digital images were taken immediately after resection, with one investigator grading all samples according to the Collins visual grading scale. This

Table 1. Collins Score

Score	Definition
1	Normal cartilage
2	Swelling and softening, slight degradation and tangential flaking, shallow pits and grooves
3	Slight fibrillation, obvious degradation of cartilage, significant loss of cartilage substance
4	Serious fibrillation, minimal presence of cartilage with eburnation of exposed bone

recognized scoring gradient from 1 to 4 corresponds to cartilage morphology that displayed normal, swelling/softening, slight superficial fibrillation, and deep or serious fibrillation [11,12] (Table 1).

Mankin Grading

Fresh core samples of 5-mm diameter were obtained from various locations of the tibial plateau and prepared for Mankin grading. Samples were collected using the Osteochondral Autograft Transfer System, OATS [Arthrex, Naples, Fla], autograft diameter 5 mm manufactured by Arthrex. All samples were decalcified and embedded in paraffin. The Mankin grading system is a standard for cartilage assessment and incorporates grading of the structural integrity, cell density, tidemark integrity, and loss of proteoglycan in the sample [13]. The composite score ranges from 0, representing normal and unaltered tissue, to 12, representing severely damaged tissue (Table 2). Two investigators (MB and XY) evaluated randomized and blind-coded samples. The final Mankin score was the mean of their individual evaluations.

JSW Measurement

Radiographs of the anterior-posterior weight-bearing view were examined and the joint space was measured using a calibrated scale in ImageJ software (NIH, Bethesda, MD). All radiograph images were digitalized and calibrated in ImageJ according to a scale on the original radiograph. Measurements of medial and lateral sides correspond to a vertical line drawn parallel to the long axis of the tibia, from the midpoint of the medial/lateral femoral condyle to the tibial plateau. The *JSW* was defined as the distance between the condyle surface and tibial plateau surface along this line. Generally, JSW of 5 mm and greater is considered normal; subjects were thus divided into 2 groups based on their JSWs accordingly [11].

Radiographs were also graded according to the Kellgren and Lawrence grading system, which has proven to be an effective way to examine the state of OA [14]. This grading scale indicates the severity of OA, ranging in value from 1, with the presence of insignificant osteophyte and unimpaired joint space, to a score of 4, with greatly impaired joint space with sclerosis of the subchondral bone [15].

Ultimately, to examine how cell visual appearance relates to tissue integrity, 60 cored samples were taken from distinct locations on each tibial plateau; and their respective Collins and Mankin grades were compared.

In establishing a correlation between cartilage quality in the Collins grade and the component cell integrity of the Mankin score, we hoped to explore the histologic component of tibial plateau cartilage on the nonaffected side. Core samples were taken from the lateral side in the varus cases and from the medial side in valgus cases to avoid areas where cartilage had been completely degraded.

Statistical Methods

χ^2 was used to analyze the distribution of JSW within respective Collins grades using SigmaStat 2.0 (SPSS Inc, Chicago, IL) software. The null hypothesis of no relationship between row and column frequencies was stated. The χ^2 analysis of a contingency table comparing Collins grades II and III to JSW less 5 and greater than or

Table 2. Modified Mankin Grading System

Aspect	Stain Method	Description	Grade
Structure integrity	Alcian blue	Normal	0
		Surface irregularity	1
		Clefts to transitional zone	2
		Clefts to radial zone	3
		Clefts to calcified zone	4
		Complete disorganization	5
Cell density	Alcian blue	Normal	0
		Diffused hypercellularity	1
		Cloning	2
Tidemark integrity	H & E	Normal	0
		Duplicated tidemark	1
		Vessel penetration through 1st tidemark	2
		Vessel penetration through 2nd tidemark	3
Proteoglycan staining	Safranin O	Whole thickness stained	0
		Distal two third stained	1
		Distal one third stained	2

H & E indicates hematoxylin and eosin.

equal to 5 was performed; similarly, analysis was made between Kellgren and Lawrence scores to Collins grades II and III. In another test, the Mankin histology grade was correlated with the Collins grade using the Spearman rank order correlation. In both cases, $P < .05$ was considered statistically significant.

Results

Of the 60 cases examined, 29 (48%) were found to have JSW greater than or equal to 5 mm on the less affected side. Of valgus cases, 3 (20%) of 15 had JSW greater than or equal to 5 mm on the medial side; and of varus cases, 26 (58%) of 45 had measured JSW greater than 5 mm on the lateral side. Overall, the JSW measured on the less affected side of the femoral-tibial joint ranged from 0 to 8.3 mm (Fig. 1A, B).

There were 17 cases displaying Collins grade III cartilage on the less affected side of the knee, and all cases displayed areas of Collins grades I and II on the less affected side. Of the valgus cases, 5 (33%) of 15 displayed Collins grade III on the medial tibial plateau. The average medial JSW of the grade III valgus cases was 3.1 mm (0.6-5.3, SD = 1.74), and the average medial JSW of grade II cases was 4.0 mm (2.8-6.0, SD = 1.24). In varus cases, 12 (27%) of 45 displayed areas of Collins grade III on the lateral tibial plateau, with an average lateral JSW of 5.3 mm (0-7.9 mm, SD = 1.89). All varus samples presented area of Collins grades I and II, and the

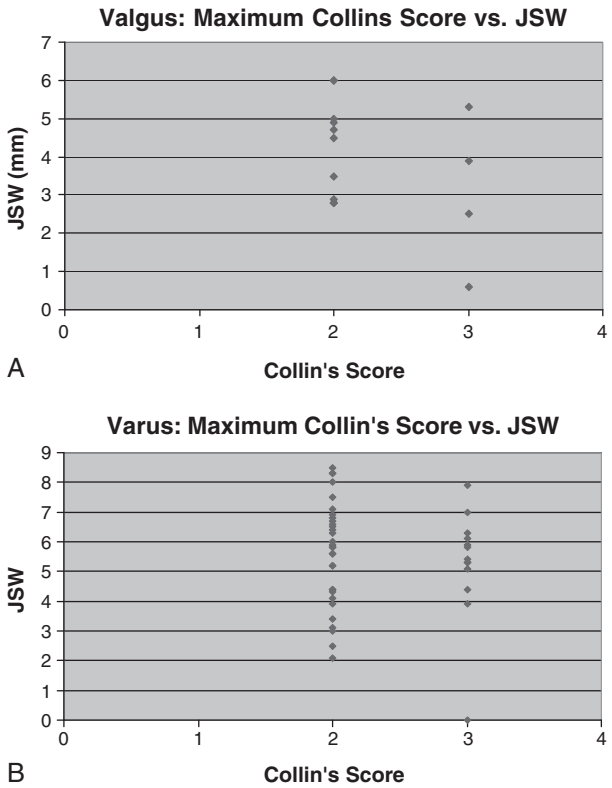

Fig. 1. (A) Distribution of results, varus and valgus. (B) Distribution of results.

Table 3. Collins Grade and Corresponding JSW

	Smaller Lateral JSW (Valgus) (n = 15)	Smaller Medial JSW (Varus) (n = 45)	Total (n = 60)
Collins grade II	10	32	42
JSW >5 mm	3	22	25
JSW <5 mm	7	10	17
Collins grade III	5	13	18
JSW >5 mm	1	10	11
JSW <5 mm	4	3	7

average lateral JSW of cases with grade II cartilage was 5.5 mm (2.1-8.5, SD = 1.72) (Table 3).

No significant statistical correlation was found between JSW and Collins grade ($P = .863$). In addition, neither the valgus nor varus subgroup showed significant statistical correlation between JSW and Collins grade ($P = .836$ and $P = .853$, respectively).

Of the 5 valgus cases with Collins grade III degeneration, the average corresponding Kellgren and Lawrence score was 2.4 (range, 1-4), correlating to "minimal" arthritis with retained joint space, although with definite osteophytes, whereas the average scores for grade II cases were 2.2, again with range from 1 to 4. In the 12 varus cases with Collins grade III, the average Kellgren and Lawrence score was 1.4 (range, 1-2), correlating to a "doubtful" presence of arthritis with insignificant osteophyte, whereas grade II corresponded to a score of 3.4 (range, 1-4). No significant correlation was noted between Kellgren and Lawrence score and Collins grade.

There was no statistically significant difference in cartilage quality in "unaffected" compartments when comparing varus or valgus knees, yet varus knees with degraded contralateral compartments significantly maintained JSW more so than valgus knees; Collins grade 3 varus knees had a JSW of 5.3 mm compared with the 3.1 mm in valgus knees.

Comparing the Collins grade to the histologic Mankin grading system yielded a statistically significant relationship. The Spearman rank order correlation of 3 groups of Mankin grades, defined by the sample's Collins grade, proved that the Collins grade is correlated with the Mankin grade with a correlation coefficient of 0.885 ($P < .01$) (Fig. 1). A summary of the data reveals that poor cartilage quality can be found in subjects with normal JSW (Fig. 2).

Discussion

The results indicate that radiographic JSW is not an accurate indicator of knee joint articular cartilage quality, as seen in visual grading of gross samples and histologic measurements (Fig. 3A, B). These findings are clinically relevant because JSW is one of the major factors, along with patient symptoms and physical examination, in assessing the status and progression of OA. Although the gross visual grading and histologic grading are more accurate, they are difficult or even

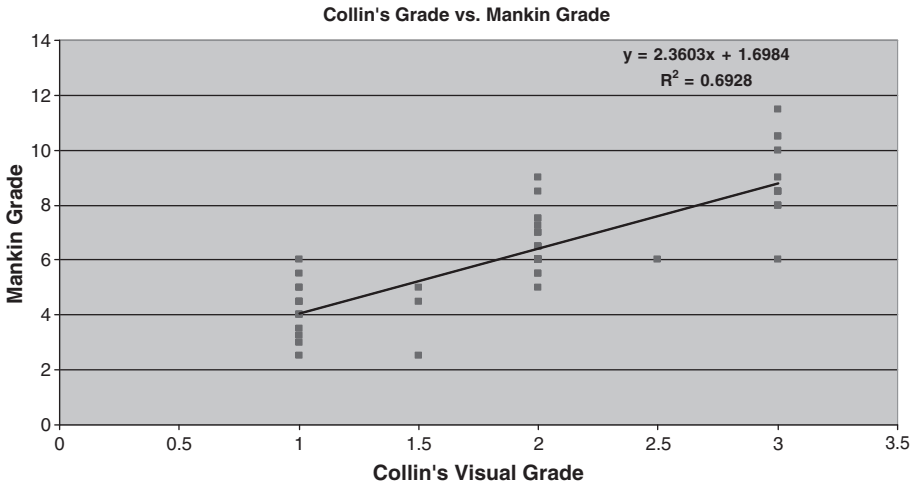

Fig. 2. Linear regression of Collins and Mankin grades.

impossible to obtain preoperatively, whereas intraoperatively, it still remains unusual for the nonoperated compartment to be directly inspected.

Importantly, cell integrity as seen by the Mankin grade is correlated with the Collins score, thus emphasizing that degeneration at a macroscopic and microscopic level cannot be observed radiographically. There are clinical implications pertaining to the factors assessed when deciding if UKA is an appropriate procedure to treat cases of OA. If cartilage exists in a moderately to severely damaged state on the side of the knee that appears unaffected, one may surmise that there will be more future revisions or conversions due to the persistence/recurrence of knee pain.

The literature on UKA states conflicting ranges of appropriate patient age. Some authors address that middle-aged patients with OA often require different care and procedures than their older counterparts [16]. However, other findings state that the ideal candidate for UKA is someone older than 60 years [9]. The most recent works advocate UKA for middle-aged and younger patients [16]; if one uses the US census criteria of 35 to 54 years for middle aged [17], our average of 69 years falls outside this, although our patients' age ranged from 46 to 87 years.

To this end, the findings illustrate that older patients with longer and more sustained arthritic progression are likely to be at increased risk of cartilage damage in every compartment of the knee regardless of apparent radiographic findings. Indeed, further analysis of the data showed that patients younger than 65 years had a significantly more degraded contralateral compartment with Mankin score of 8.7 (12-5.5), compared with 4.4 (2-9.5) in participants older than 65 years. Such findings further add to the debate of which group of patients is most suited to UKA.

Another factor to consider is the angle at which the radiographs were taken. Various studies have found that nonstandard procedures in taking x-ray films such as internal or external rotation of the limb as well as the degree of the x-ray beam influence the appearance of joint space. One finding indicates that a 5° or 10° downward

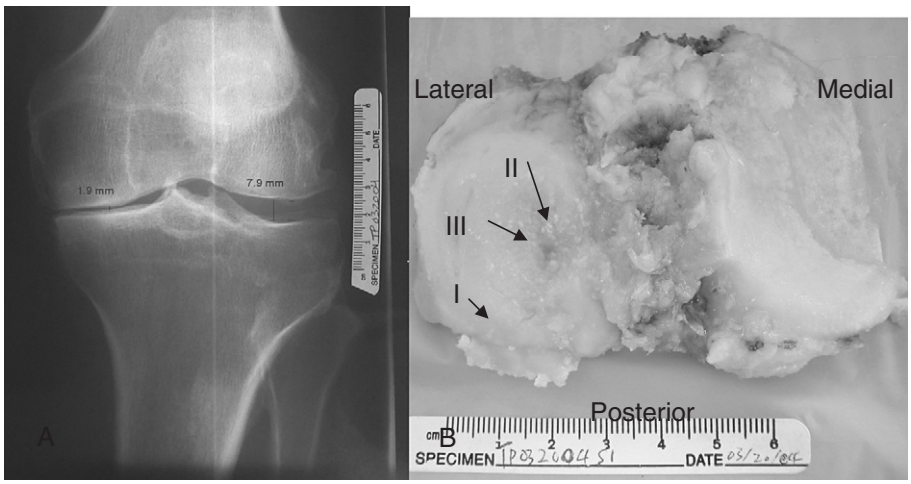

Fig. 3. (A) Left varus radiograph with lateral JSW 7.9 mm. (B) Corresponding gross sample, Mankin grades 5.5, 9, and 8.5, for Collins grades I, II, and III, respectively.

inclination of the x-ray beam and a 15° to 30° external rotation of the foot significantly reduce the JSW in subsequent radiographs [16]. We assumed standard procedure and proper beam alignment when addressing the anterior-posterior view radiographs as per the institution's standard protocol. Furthermore, one wonders if the increasing frequency of the 45° posterior-anterior flexion radiograph as part of basic surgical planning [18,19] may more effectively indicate any disruption to the contralateral compartment, thus better correlating JSW with cartilage quality, although this is not currently standard preoperative protocol for all UKA procedures. Further studies investigating the role of flexed posterior-anterior films and the correlation of femoral cartilage with JSW are warranted to fully elucidate the relationship between radiographic views and cartilage integrity.

There is also the question of how the nonoperated side will be affected by the unicompartmental procedure. Studies have raised the question of OA on the nonoperated side being worsened after the procedure [20], yet conflicting investigators have noted no change or accelerated progression in the contralateral compartment post-UKA [21,22]. This study's result is of importance to all patient groups; normal JSW between the femur and tibia is generally accepted as being 5 to 6 mm [23]. Yet, within this range, a number of patient factors prevail. Sex is thought to affect JSW, with men having a slightly wider space [23]. Studies of the knee and hip suggest that, with increasing age, joint space may decrease, with the most significant reductions seen in perimenopausal women [24]. Height and weight are also thought to negatively correlate with JSW particularly in valgus knees [25], although recent studies suggest that, although there is a higher incidence of OA in obese patients, joint space narrowing is not completely proportionate to weight gain [26]. These findings may have influence on the radiographic measurement of OA particularly if race is taken into account; studies suggest that African Americans have more severe OA and JSW reduction than their white counterparts [27]. Although we found no significant difference between radiographic findings, cartilage conditions, and patient sex, such questions do warrant further investigation in relation to the outcomes of UKAs in different patient groups. Our findings with regard to radiographic findings and actual cartilage integrity are also applicable to TKA procedure. Yet the significance is not as marked in this group, for if a patient presents with a unilaterally well-preserved joint space and is symptomatic in only one compartment, then it is feasible that he or she will go on to have a unicondylar procedure. Yet we have shown that advanced degenerative changes may be present in other compartments that may later go on to create functional difficulties. This conclusion may be applicable to tibial osteotomy; our study suggests that radiographs may be misleading regarding the severity of cartilage damage, particularly in varus knees, as the abnormal alignment can increase JSW of the lateral compartment even if the cartilage has already been seriously damaged. Thus, there is a possibility that symptoms and signs of OA will be present in the compartment with wider JSW after tibial osteotomy. Surgeons should carefully evaluate the condition of both compartments to decide the angle of the osteotomy.

Ultimately, there are clear clinical indications and benefits for the use of UKAs; yet this study has noted finite discrepancies in radiographic JSW and actual articular cartilage quality, as a result of which one may predict a rise in the number of UKA revisions or conversions over the next decade. To this end, a noninvasive method to examine cartilage preoperatively may be helpful. Histologic examination of all compartments before UKA is not feasible without arthroscopic biopsy, which is accompanied by increased cost and morbidity. Thus, analysis with magnetic resonance imaging may prove beneficial. Although this modality would avoid patient radiation, the inherent cost implications are not lost on the authors. As a result, it would be difficult to advocate the routine use of magnetic resonance imaging preoperatively in all prospective UKA patients; yet our study suggests that those younger than 65 years with varus knees may have a markedly more degraded cartilage than JSW would indicate. This study aims to elucidate the efficacy of adjunctive diagnostic modalities aside from clinical history and examination. The study identifies the poor correlation between JSW and cartilage quality; although nearly half of all subjects maintained a normal joint space radiographically, analysis showed 62% of these patients had significant, though asymptomatic, cartilage damage. One wonders if the presence of considerable cartilage damage may increase the likelihood of developing symptomatic disease in the future and thus render these patients unsuitable for unicompartmental procedures. Ultimately, this study adds to the debate of who is suitable for UKA procedures and outlines the poor correlation between true cartilage integrity and radiographic findings.

References

1. Nunez M, Nuñez E, Segur JM, et al. Health-related quality of life in patients with osteoarthritis after total knee replacement: factors influencing outcome at 36 months of follow-up. Osteoarthritis Cartilage 2007;15:1001.
2. Hamilton WG, Ammeen D, Engh Jr CA, et al. Learning curve with minimally invasive unicompartmental knee arthroplasty. J Arthroplasty 2010;25:735.
3. Vince KG, Cyran LT. Unicompartmental knee arthroplasty: new indications, more complications? J Arthroplasty 2004;19:9.
4. SooHoo NF, Kominski G. Cost-effectiveness analysis of total ankle arthroplasty. J Bone Joint Surg Am 2004;86:2446.
5. Newman JH, Ackroyd CE, Shah NA. Unicompartmental or total knee replacement? Five-year results of a prospective,

randomised trial of 102 osteoarthritic knees with unicompartmental arthritis. J Bone Joint Surg Br 1998;80:862.
6. Khan O, Davies H, Newman J, et al. Radiological changes ten years after St. Georg Sled unicompartmental knee replacement. Knee 2004;11:403.
7. Berger RA, Meneghini RM, Jacobs JJ. Results of unicompartmental knee arthroplasty at a minimum of ten years of follow-up. J Bone Joint Surg Am 2005;875:999.
8. Hussey M. US markets for reconstructive devices 2002. Toronto (Ontario, Canada): Millennium Research Group; 2003.
9. Dennis MG, Di Cesare PE. Surgical management for the middle aged arthritic knee. Hosp Jt Dis 2004;3,4: 172.
10. Hellio Le Graverand MP, Mazzuca S, Duryea J, et al. Radiographic-based grading methods and radiographic measurement of joint space width in osteoarthritis. Radiol Clin North Am 2009;47:567.
11. Collins DH. The pathology of articular and spinal diseases. London: Edward Arnold Co.; 1949.
12. Li G, Thomson M, Dicarlo E, et al. A chemometric analysis for evaluation of early-stage cartilage degradation by infrared fiber-optic probe spectroscopy. Appl Spectrosc 2005;12:1527.
13. Mankin HJ, Dorfman H, Lippiello L, et al. Biochemical and metabolic abnormalities in articular cartilage from osteoarthritic human hips. J Bone Joint Surg Am 1971;535:23.
14. Spector TD, Hart DJ. Definition of osteoarthritis of the knee for epidemiological studies. Ann Rheum Dis 1993;790.
15. Petersson IF. Radiographic osteoarthritis of the knee classified by the Ahlback and Kellgren & Lawrence systems for the tibiofemoral joint in people aged 35-54 years with chronic knee pain. Ann Rheum Dis 1997;56:493.
16. Murphy TP, Brubaker SM, Mihalko WM, et al. Review of unicompartmental knee arthroplasty in younger patients. Semin Arthroplasty 2007;18:162.
17. Cheeseman Day J, National Population Projections. United States Census Bureau. 2008. www.census.gov/population/www/pop-profile/profile.html.
18. Kotani H, Ishisaka N, Furu M, et al. A new plain radiography method using the optimal angle of knee flexion for assessing early degeneration of the knee joint. J Arthroplasty 2005;20:614.
19. Mason RB, Horne JG. The posteroanterior 45° flexion weight-bearing radiograph of the knee. J Arthroplasty 1995;10:790.
20. Froimson MI, Bloomfield MR, Sherman RA. Revision of the failed unicompartmental knee arthroplasty. Semin Arthroplasty 2009;20:23.
21. Walton MJ, Weale AE, Newman JH. The progression of arthritis following lateral unicompartmental knee replacement. Knee 2006;13:374.
22. Newman J, Pydisetty RV, Ackroyd C. Unicompartmental or total knee replacement: the 15-year results of a prospective randomised controlled trial. J Bone Joint Surg Br 2009;91:52.
23. Lanyon P, O'Reilly S, Jones A, et al. Radiographic assessment of symptomatic knee osteoarthritis in the community: definitions and normal joint space. Ann Rheum Dis 1998;57:595.
24. Lanyon P, Muir K, Doherty S, et al. Age and sex differences in hip joint space among asymptomatic subjects without structural change: implications for epidemiologic studies. Arthritis Rheum 2003;48:1041.
25. Niu J, Zhang YQ, Torner J, et al. Is obesity a risk factor for progressive radiographic knee osteoarthritis? Arthritis Rheum 2009;61:329.
26. Le Graverand MP, Brandt K, Mazzuca SA, et al. Progressive increase in body mass index is not associated with a progressive increase in joint space narrowing in obese women with osteoarthritis of the knee. Ann Rheum Dis 2009;68:1734 [Epub 2008 Dec 5].
27. Braga L, Renner JB, Schwartz TA, et al. Differences in radiographic features of knee osteoarthritis in African-Americans and Caucasians: the Johnston county osteoarthritis project. Osteoarthritis Cartilage 2009;17:1554 [Epub 2009 Sep 1].