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Subchondral bone of the human knee joint in aging and osteoarthritis

K. Yamada*, R. Healey*, D. Amiel*, M. Lotz† and R. Coutts*
**Department of Orthopaedics, University of California, San Diego, 9500 Gilman Dr. 0630, La Jolla, California 92093-0630, U.S.A.*
†Division of Arthritis, The Scripps Research Institute

Summary

Objective: Although most research investigating the pathogenesis of osteoarthritis (OA) has focused on cartilage, it has been suggested that the subchondral bone (SCB) plays an important role in the development of OA. The relationships between aging, severity of OA change and the SCB thickness and density in the human knee joint specimens from a wide range of ages were examined.

Methods: One hundred forty knee joints from 72 individuals (25 females, 45 males and 2 unknowns; average age 54.8 years, range 17 to 91 years) were obtained. The surface of the articular cartilage of both the femur and tibia was evaluated for gross morphological changes with a 4-point grading scale. The lateral and medial femoral condyles were cut along a sagittal plane and the tibia along a coronal plane to make bone and cartilage strip specimens. The strips were X-rayed onto mammography film and then scanned into a computer for assessment of SCB thickness and density using image analysis software.

Results: Medial tibial SCB thickness was significantly lower among the elderly (age>69 years) than among the young (age<40) or the middle-aged (40 to 69) (P<0.001 via ANOVA). Lateral tibial SCB thickness also showed the same trend of decreasing thickness with increasing age, but differences between age groups were not statistically significant. Tibial SCB thicknesses were significantly lower in arthritic grades compared to normal grades (P=0.008 in lateral and 0.017 in medial via ANOVA); in contrast, no significant differences between normal and arthritic were found in femoral SCB thicknesses. The arthritic group tended to have lower SCB densities than the normal group, but this was statistically significant in only the lateral femoral condyle.

Conclusions: The results obtained in the present study are not consistent with generally accepted notions of the relationship between subchondral bone thickness or density and OA. Subchondral bone changes are not etiologic for OA but, more likely, are secondary to loss of articular cartilage which precedes the appearance of subchondral sclerosis. © 2002 Published by Elsevier Science Ltd on behalf of OsteoArthritis Research Society International.

Introduction

Osteoarthritis (OA) is among the most prevalent disorders in the elderly population, and because of this prevalence, much research has been carried out to clarify the pathogenesis of OA. Although it is well known that various joint tissues, including articular cartilage, synovium, subchondral bone and ligaments may be implicated, the major focus for human OA research has remained primarily on the articular cartilage. However, bony changes surrounding the OA joint are frequently seen in X-ray images of OA patients, and the sclerosis of the subchondral bone, in particular, is regarded as one of the primary radiologic features of OA[1]. Investigators have suggested for many years the relevance of studying the role of the subchondral bone in the development of OA[2–5]. Those investigators who have reported on the subchondral bone in OA reported conflicting observations. In studying OA in the macaque, Carlson *et al*. observed thickening of the subchondral bone to precede fibrillation of the cartilage[6]. However, Dedrick *et al*. in a canine model, suggested that thickening of the subchondral bone was not required to initiate cartilage fibrillation[7]. The question of whether the subchondral bone changes occur before cartilage deterioration or subsequent to these changes still seems to remain unanswered[8].

Although the epidemiologic studies have shown that there was a clear relationship between aging and the incidence of OA[9,10], the relationship between age and function has proved to be extremely complex. While cartilage cellularity reportedly decreases and age-related changes in chondrocyte function have been observed prior to the manifestation of changes in the very early stage of OA[11–13], there has been a limited volume of research to clarify the differences between age-related and OA-related changes in human joint tissues.

A major difficulty of investigating the pathogenesis of OA in humans is that joint specimens available for this purpose are removed from patients undergoing arthroplastic surgeries. These patients are typically elderly and in an advanced stage of OA, resulting in a disproportionate age and severity distribution[14–16]. There is a clear need to characterize OA utilizing a substantial number of human subjects with a broad range of age, and the full spectrum of disease severity.

The purpose of the present study is to examine the subchondral thickness and the density in human knee joints, particularly the femorotibial joint, from both genders with a broad range of age to clarify the significance of the subchondral bone in both aging and OA development. The

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Address correspondence to: Richard Coutts M.D., Department of Orthopaedics, University of California, San Diego, 9500 Gilman Dr. 0630, La Jolla, California 92093-0630, U.S.A. Tel: (858) 534-2676; Fax: (858) 534-5304; E-mail: rcoutts@ucsd.edu

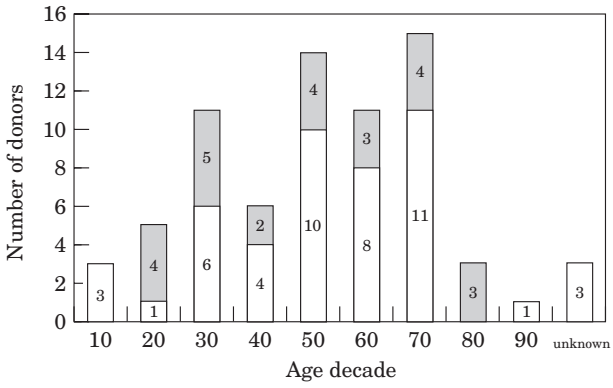

Fig. 1. Histogram of age by decade.

specific questions to be addressed are: (1) are there any relationships between aging and the thickness or density of the subchondral bone? (2) are there any relationships between deterioration of the cartilage surface and the thickness or density of the subchondral bone? and (3) are there any other factors that influence the subchondral bone?

Materials and methods

ACQUISITION OF DONORS

From March 1998 to December 1999, 140 knee blocks were obtained from 72 donors. Both right and left knee joints were harvested from all donors except four. Donors consisted of 25 females, 44 males and 3 unknowns with an average age of 54.8 years (range 17 to 91). Figure 1 represents the distribution of donors' age and gender. Most knee blocks were provided from tissue banks while some were taken after autopsy at local hospitals. Demographic and medical information of the donors (e.g. age, gender, race, height, weight, cause of death and history of joint diseases) were obtained from the donor tissue banks or hospital records. The knee blocks were refrigerated until processed at an average period of 2.7 days (post death or post harvest).

GROSS OBSERVATION OF FIBRILLATION OF ARTICULAR CARTILAGE

The knee block was dissected and soft tissues surrounding the knee joint were removed. The surface appearance of the knee joint was studied for fibrillation and/or erosion of articular cartilage. Normal cartilage surface had a smooth and glossy appearance and was easily distinguishable from a fibrillated surface. The lesions of cartilage erosion and defects could be seen easily. For cartilage surfaces that showed fibrillation, india ink, which highlighted the cartilage fibrillation, was used to determine the severity of surface damage of the articular cartilage. The cartilage surface appearance was graded according to the following scale: Grade 1—Normal, Grade 2—Minimal fibrillation, Grade 3—Overt fibrillation, Grade 4—Erosion. Grade 4 was subclassified further, based on the size of the area of involvement (Table I).

SPECIMEN PREPARATION

The femur and tibia were cut using a handheld saw to make bone and cartilage strip samples approximately

Table I
Grading scale used for gross morphological assessment

Grade 1: (Intact surface)	Surface normal in appearance and does not retain India ink.
Grade 2: (Minimal fibrillation)	Surface retains India ink as elongated specks or light gray patches.
Grade 3: (Overt fibrillation)	Areas which are velvety in appearance and retain India ink as intense black patches.
Grade 4: (Erosion)	Loss of cartilage exposing the underlying bone.
Grade 4a: 0 mm<Erosion≤5 mm	
Grade 4b: 5 mm<Erosion≤15 mm	
Grade 4c: 15 mm<Erosion	

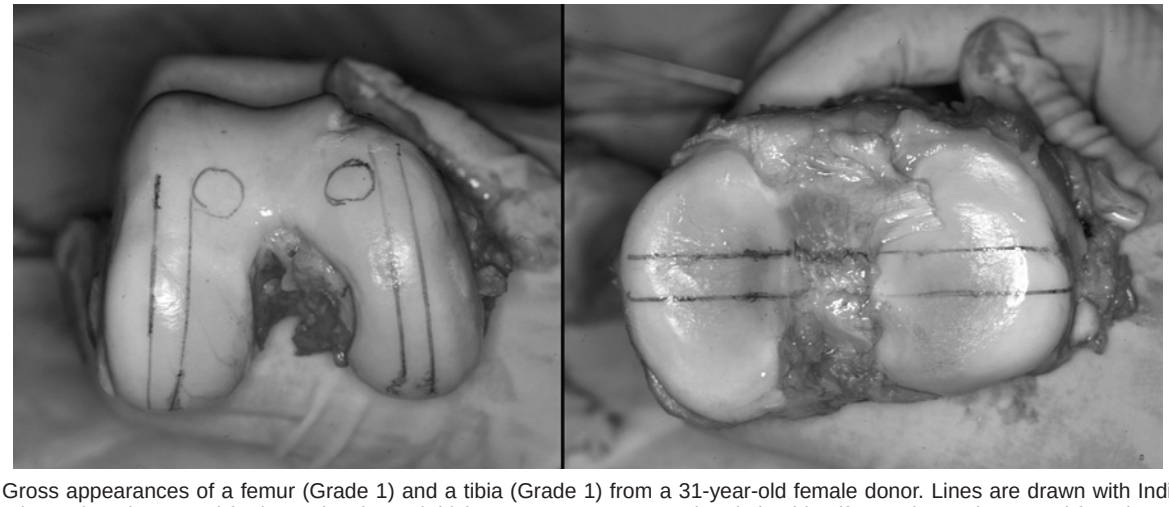

Fig. 2. Gross appearances of a femur (Grade 1) and a tibia (Grade 1) from a 31-year-old female donor. Lines are drawn with India ink to identify the regions harvested for bone density and thickness measurements. The circles identify specimens harvested for other studies.

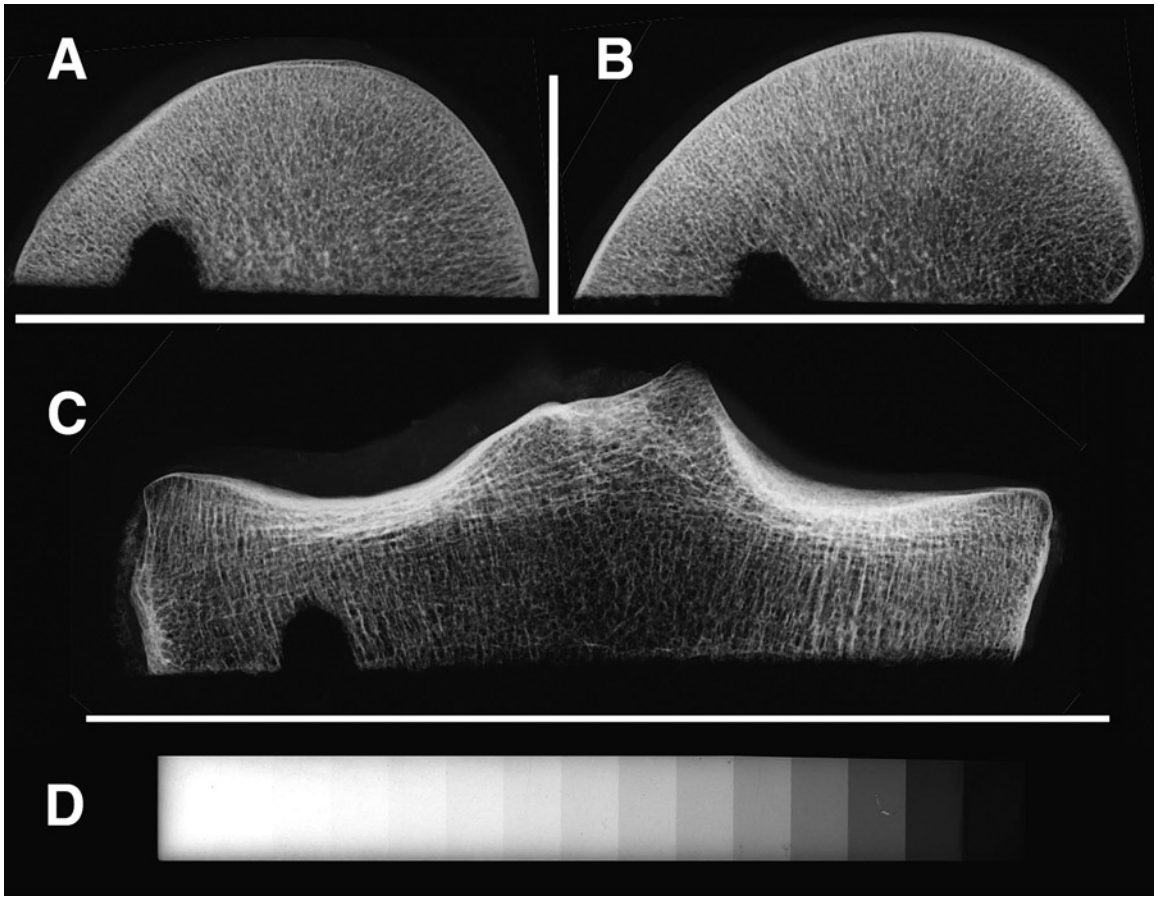

Fig. 3. X-ray images of the strip specimens from a 31-year-old female donor. (a) Lateral femur, (b) medial femur, (c) tibia, (d) aluminum stepwedge.

10 mm in thickness. The lateral and medial femoral condyle were cut along a sagittal plane and the tibia along a coronal plane so that the strip specimen included the cartilage subject to the most constant mechanical stress loads on the joint[29] (Fig. 2). Specimen gross thickness was measured using digital calipers. The strip specimens were fixed and kept in 10% formalin until X-ray photographs were taken on mammography film using a Faxitron X-ray device. Radiographs were taken with an aluminum step wedge control alongside the specimens in order to quantitate the bone density (Fig. 3).

RADIOGRAPHIC ASSESSMENTS

Measurements of thickness and density of the subchondral bone were performed using commonly available image analysis software (NIH Image 1.62). After scanning the X-ray images into a computer (Macintosh G3), the central one-third of each side (lateral and medial) of the tibial condyle was selected as the region of interest (ROI). The average gray scale density (on a scale of 256 gray levels) was measured for each row of pixels within this region of interest across the edge of the bone deep enough to cover the sclerotic area beneath the cartilage on the tibial plateau. For the femoral condyles, a ROI of 0.5 inches in width was selected. The smaller region more accurately identified the cartilage edge of the femoral condyle that had a rounder contour than the tibia. The region of interest enclosed the distal pole of the femoral condyle so that the plotting profile was perpendicular to the bone surfaces as much as possible.

A plot of the average gray scale profile within each ROI provided a graphical image of both the subchondral thickness and uncalibrated gray scale density (Fig. 4). The thickness of the subchondral bone was defined as the distance between the edge of the bone/cartilage junction and the end of high intensity pixels on the X-ray image. The density of the subchondral bone was calculated by matching the measured gray scale density to the corresponding gray scale of the aluminum step wedge, which was correlated to a known density. The gross thickness of the specimen for each corresponding ROI was then divided into the unit calibrated density to calculate the radiographic density. The analyses were performed five times and the average value recorded for each specimen.

STATISTICAL ANALYSIS

All the data was compiled and analysed using a statistics software package (StatView) to detect statistical significances. All results were expressed as mean±1 S.D. The nominal significance level was set at 0.05.

To detect the effects of aging on the subchondral bone, subjects were categorized into four age groups; youngest (under 40 years old), younger (40–54), older (55–70) and oldest (over 70). The Kruskal–Wallis test was used to determine significant differences in the relationship between either subchondral bone thickness or density and

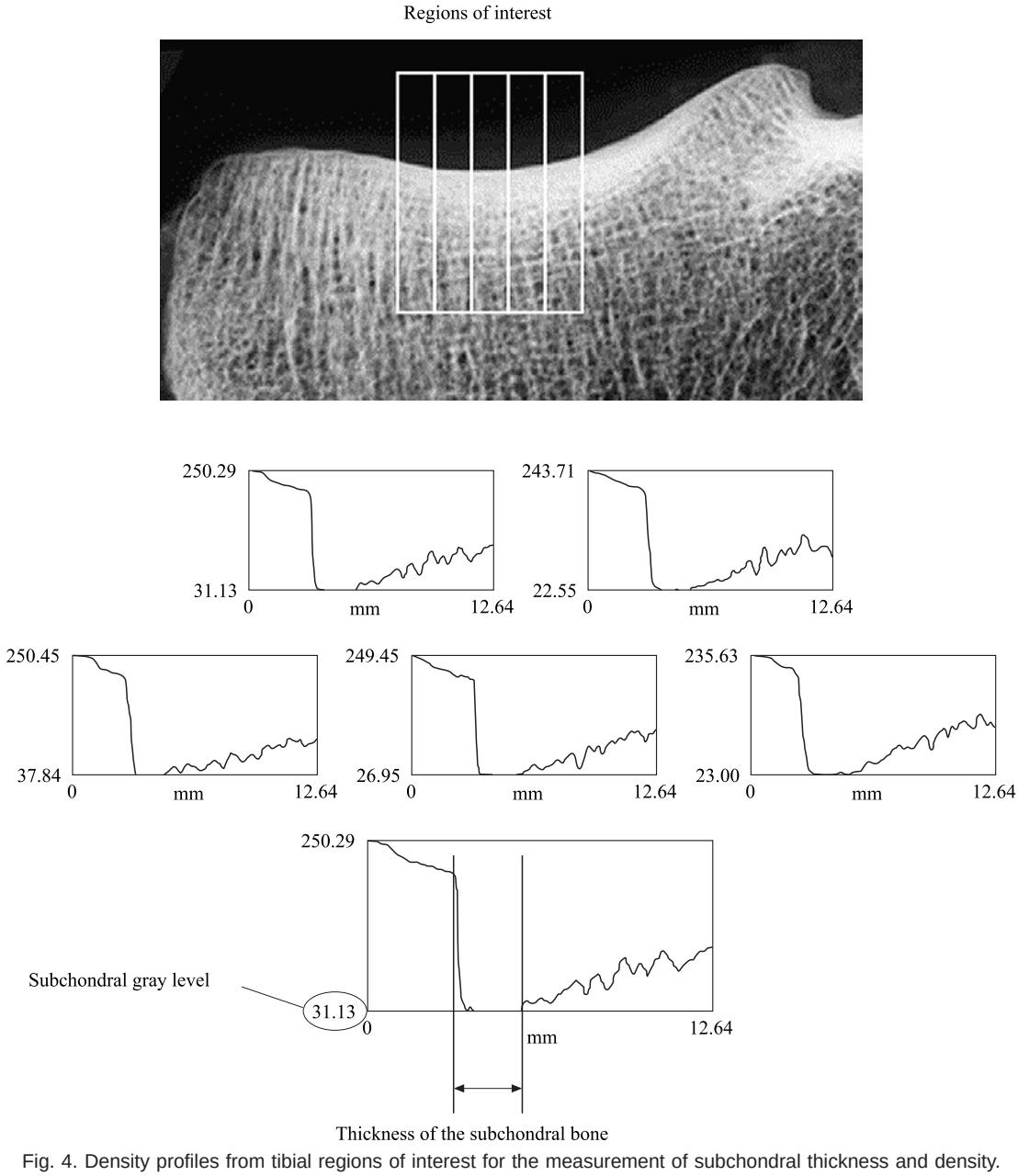

Fig. 4. Density profiles from tibial regions of interest for the measurement of subchondral thickness and density.

the four age groups as well as cartilage surface grades (Grades 1–4). Once differences were detected, group comparison was performed by the Scheffe's post-hoc test. The Mann–Whitney test was used to determine significance in a pair-wise comparison.

Multiple regression analyses were also performed with either the thickness or density of the subchondral bone as dependent variables and age, sex, femoral gross grade, tibial gross grade, presence of OA history, height, body weight and body mass index (BMI) as independent variables.

Results

One hundred and thirty lateral and medial femoral condyles and 134 tibial plateaus were obtained. Two tibial plateaus were cut too close to the joint surfaces to be measured and were excluded from the study. Thus, 132 tibial plateaus were available for X-ray assessments in the present study.

The physical information of the donors and the results of the gross assessments of the knee joints are listed in Table II.

EFFECT OF AGE ON THE JOINT SURFACE APPEARANCE

The average age of donors was 34.1±10.7 years old in Grade 1, 56.9±14.0 in Grade 2, 65.2±12.2 in Grade 3 and 69.2±13.6 in Grade 4 in the femoral condyles, while for the tibial side 35.9±17.6 in Grade 1, 51.3±17.38 in Grade 2, 62.23±12.3 in Grade 3 and 69.1±16.2 in Grade 4 (Fig. 5). There were statistically significant positive correlations observed between grade and age both in the femoral condyles and tibial plateaus (P<0.001, Kruskal–Wallis

Table II
Demographic variables of the donors and cartilage surface grading in the specimens measured

Variable	Value
Age, years	54.2±19.1
Gender, % (*N*=72)	
Male	61.1
Female	34.7
Unknown	4.2
Height, cm (mean±S.D.)	173.9±9.3
Body weight, kg (mean±S.D.)	77.1±23.7
BMI, kg/m^2 (mean±S.D.)	25.2±7.0
OA history, % (*N*=72)	
Yes	18
No	82
Femur grade, % (*N*=130)	
Grade 1	26.2
Grade 2	28.5
Grade 3	16.2
Grade 4	29.2
Tibia grade, % (*N*=134)	
Grade 1	23.1
Grade 2	26.2
Grade 3	38.5
Grade 4	16.9

BMI=body mass index.

test). Group comparisons revealed that Grade 1 group was significantly younger than any other group in both the femur and tibia (P<0.001, Scheffe's post hoc test).

EFFECT OF AGE ON THE SUBCHONDRAL BONE

The subchondral bone thickness of the tibial plateaus was 2.90±1.21 mm, 2.84±1.20 mm, 2.33±0.80 mm and 2.25±1.17 mm on the lateral side and 3.49±1.12 mm, 3.59±1.04 mm, 3.03±1.29mm and 2.36±1.12 mm on the medial side in the youngest (under 40), the younger (40–54), the older (55–70) and the oldest (over 70) age groups, respectively (Fig. 6). These values show significant negative correlation with advancing age (P=0.03 in lateral and P=0.0001 in medial; Kruskal–Wallis test). Group comparisons reveal that the oldest age group had significantly lower thickness in the medial tibial subchondral bone compared to both the youngest and the younger age groups (P=0.0013 and 0.0017, Sheffe's post hoc test). The thickness of the subchondral bone in the femoral condyles revealed neither significant constant correlations with age nor any differences among the age groups.

The density of the subchondral bone showed negative trends with advancing age in both the femoral condyles and tibial plateaus (Fig. 7). Only in the lateral tibial plateau was a significant negative correlation with age observed (P=0.002; Kruskal–Wallis test).

EFFECT OF CARTILAGE GRADING ON THE SUBCHONDRAL BONE

The thickness of the tibial subchondral bone showed negative trends with the cartilage surface grading in both the lateral and medial tibial plateaus, though no statistical significance was detected. The thickness in the femoral condyles seemed to show no trends with the cartilage grading (Fig. 8).

The density of the subchondral bone showed negative trends with the cartilage grading in both the femur and tibia (Fig. 9). Only in the lateral tibial plateau was a significant negative correlation observed (P=0.03; Kruskal–Wallis test).

EFFECT OF GENDER ON THE SUBCHONDRAL BONE

Table III shows the comparison between male and female thickness and density of the subchondral bone wherein females demonstrated some areas of greater density but less thickness. The subchondral bone thickness was lower in females than in males in every region assessed in the present study with statistically significant differences seen in the lateral femoral condyles and the medial tibial plateaus (P=0.02 and<0.01, respectively; Mann–Whitney test). However, the subchondral bone density was higher in females than in males. Statistically significant differences were seen in both the lateral and medial tibial plateaus (P<0.01; the Mann-Whitney test).

EFFECT OF OBESITY ON THE SUBCHONDRAL BONE

There was no significant correlation observed between either body weight or BMI and the subchondral bone

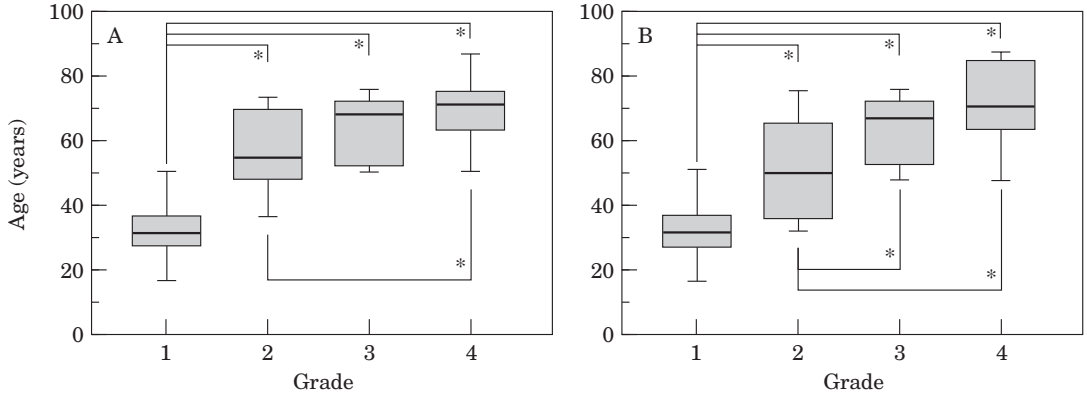

Fig. 5. Cartilage surface grade vs age in years. Significant positive correlations were observed for both the femoral ((a) tied P value by the Kruskal–Wallis test=0.031) and tibial ((b) tied P value by the Kruskal–Wallis test=0.001) surfaces with increasing age. Median values are shown. Shaded bars represent 25% and 75% and the error bars represent 5% and 95% confidence intervals. *P<0.01 by the Scheffe's post hoc test.

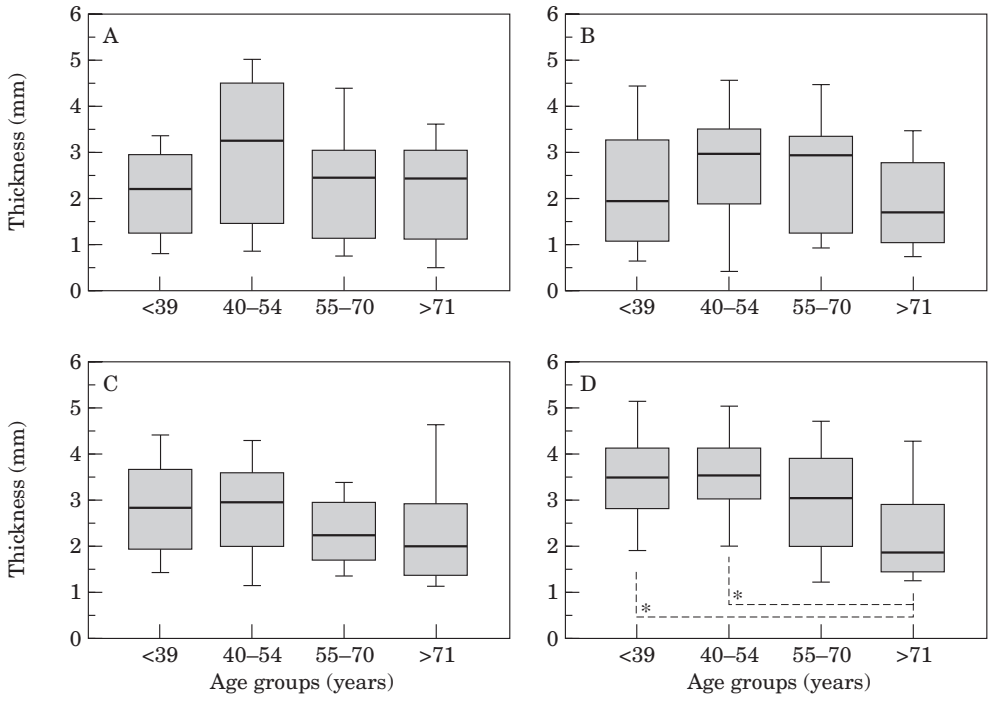

Fig. 6. Subchondral bone thickness (mm) vs age groups. A statistically significant decrease in thickness was seen between age groups under the medial tibia ((d) tied *P* value by the Kruskal–Wallis test=0.001). (a), lateral femur, tied *P* value by the Kruskal–Wallis test=0.166; (b), medial femur, tied *P* value by the Kruskal–Wallis test=0.170; (c), lateral tibia, tied *P* value by the Kruskal–Wallis test=0.031. Median values are shown. Shaded bars represent 25% and 75% and the error bars represent 5% and 95% confidence intervals. **P*<0.01 by the Scheffe's post hoc test.

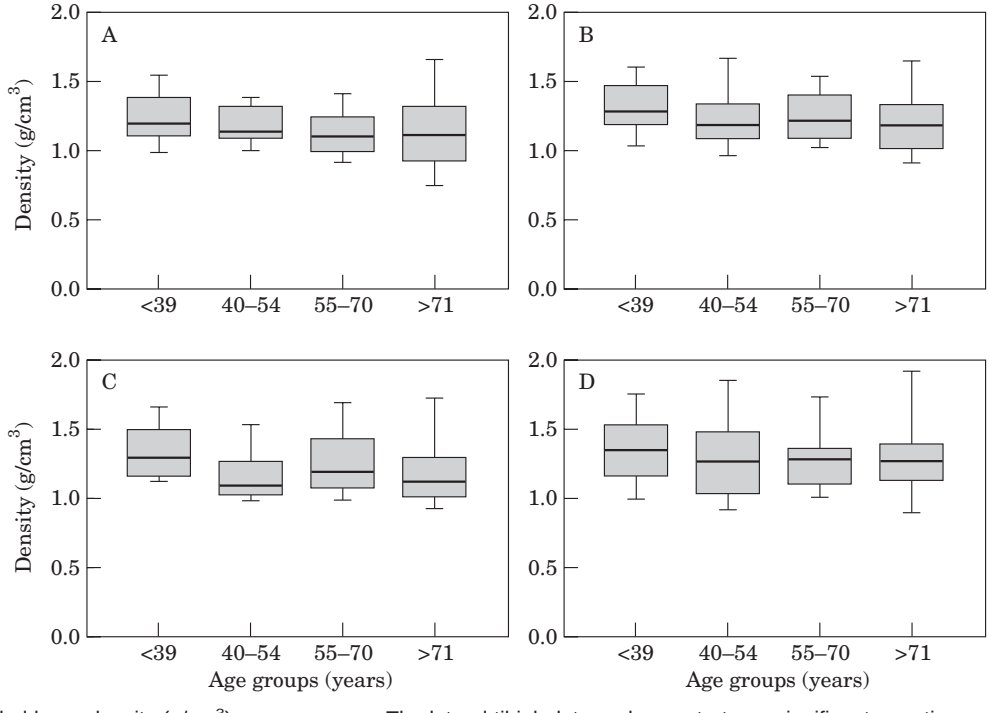

Fig. 7. Subchondral bone density (g/cm^3) vs age groups. The lateral tibial plateau demonstrates a significant negative correlation between density and age ((c) tied *P* value by the Kruskal–Wallis test=0.002). (a), lateral femur, tied *P* value by the Kruskal–Wallis test=0.188; (b), medial femur, tied *P* value by the Kruskal–Wallis test=0.095; (d), medial tibia, tied *P* value by the Kruskal–Wallis test=0.634. Median values are shown. Shaded bars represent 25% and 75% and the error bars represent 5% and 95% confidence intervals.

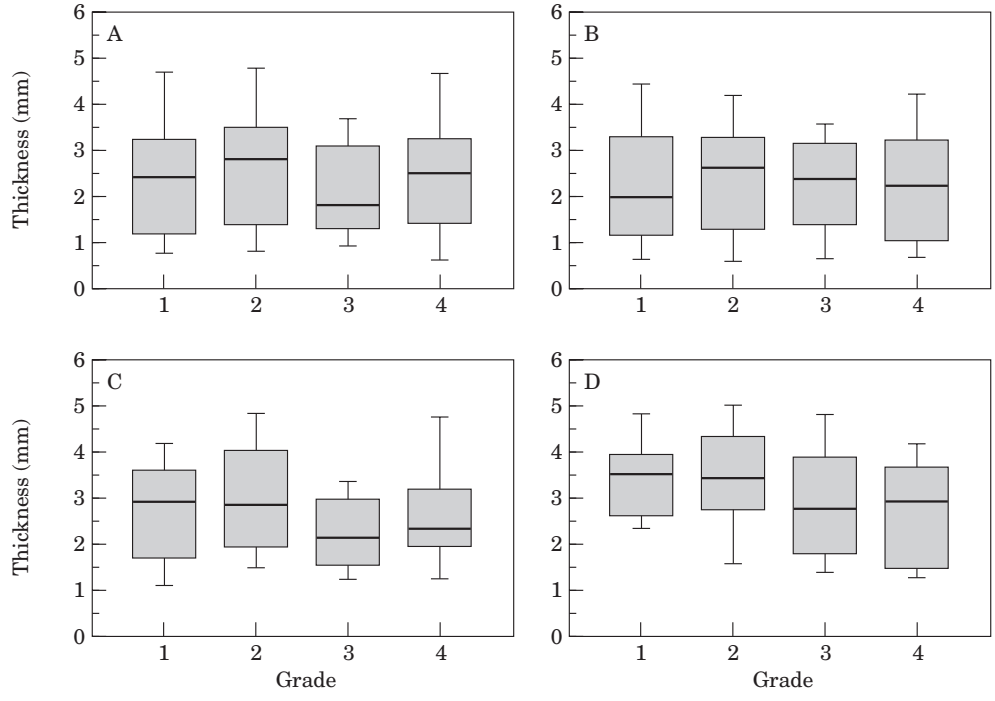

Fig. 8. Subchondral bone thickness (mm) vs cartilage surface grade. No statistically significant differences were seen between groups. (a), lateral femur, tied *P* value by the Kruskal–Wallis test=0.687; (b), medial femur, tied *P* value by the Kruskal–Wallis test=0.854; (c), lateral tibia, tied *P* value by the Kruskal–Wallis test=0.071; (d), medial tibia, tied *P* value by the Kruskal–Wallis test=0.122. Median values are shown. Shaded bars represent 25% and 75% and the error bars represent 5% and 95% confidence intervals.

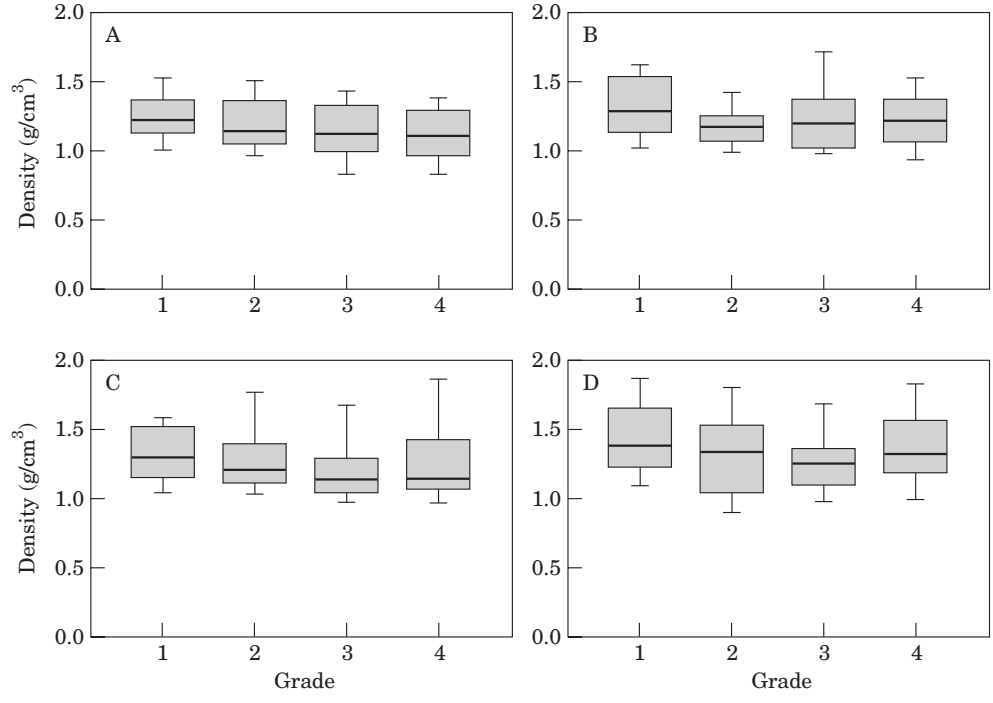

Fig. 9. Subchondral bone density (cm^3) vs cartilage surface grading. The lateral tibial plateaus (c) demonstrate a significant negative correlation (*P*=0.030) with cartilage grade by the Kruskal–Wallis test. (a), lateral femur, tied *P* value by the Kruskal–Wallis test=0.646; (b), medial femur, tied *P* value by the Kruskal–Wallis test=0.126; D, medial tibia, tied *P* value by the Kruskal–Wallis test=0.122. Median values are shown. Shaded bars represent 25% and 75% and the error bars represent 5% and 95% confidence intervals.

parameters. Grouping the population by BMI above and below the median values, the groups with higher BMI showed a trend towards higher subchondral bone thickness and density (Table IV). However, this was statistically significant for only the density measurements of the lateral and medial femurs.

Table III
Comparisons of subchondral bone thickness and density between males and females

	Male	Female	*P* value[1]
Thickness (mm)			
Lateral femur	2.69±1.45	2.11±1.25	0.020[2]
Medial femur	2.48±1.31	2.12±1.27	0.155
Lateral tibia	2.65±1.20	2.46±1.01	0.509
Medial tibia	3.32±1.28	2.74±1.07	0.007*
Density (g/cm^3)			
Lateral femur	1.17±0.26	1.19±0.22	0.310
Medial femur	1.22±0.22	1.28±0.23	0.109
Lateral tibia	1.21±0.24	1.36±0.31	0.003[2]
Medial tibia	1.26±0.28	1.45±0.36	0.002[2]

[1]Mann–Whitney U-test.
[2]Statistically significant difference.
Females show less thickness of the subchondral bone in the lateral femur and medial tibia but greater density under both the lateral and medial tibial plateaus.

Table IV
Subchondral bone thickness and density compared to Body Mass Index (BMI) (above and below median BMI)

	Body Mass Index (BMI)		
	≤25.1	>25.1	*P* value[1]
Thickness (mm)			
Lateral femur	2.28±1.44	2.57±1.59	0.120
Medial femur	2.18±1.29	2.50±1.34	0.204
Lateral tibia	2.47±1.06	2.51±1.13	0.974
Medial tibia	2.89±1.16	3.19±1.26	0.214
Density (g/cm^3)			
Lateral femur	1.12±0.25	1.21±0.22	0.037[2]
Medial femur	1.18±0.20	1.29±0.22	0.008[2]
Lateral tibia	1.24±0.26	1.28±0.24	0.298
Medial tibia	1.31±0.35	1.35±0.24	0.135

BMI=body mass index.
[1]Mann–Whitney U-test.
[2]Statistically significant difference.
There is a trend towards higher thickness and density for individuals with a BMI greater than the median of 25.1.

MULTIPLE REGRESSION

The variables listed in Table II were statistically tested in a linear regression model as independent predictors of the subchondral bone thickness and density. Age was identified as a statistically significant predictor of both the subchondral bone thickness in the lateral and medial tibial plateaus. Gender was identified as a statistically significant predictor of the subchondral bone density in the lateral and medial plateaus. Height, body weight and BMI were identified as significant predictors of the subchondral thickness in the lateral femoral condyles.

Discussion

With regard to the selection of specimens, it is important to consider how far the donor population was biased from the normal population. The tissue providers were not asked to pre-select donors because we sought to obtain specimens with as broad and similar a distribution of age and pathology as the normal population. However, the majority of the specimens in this study were provided by tissue banks, which may be obligated to provide healthy specimens for allograft surgeries. Thus, there may have been a predisposition in obtaining donor specimens. This may lead to a bias in the distribution of this study and it could be argued that the data does not represent the normal population. One should be careful to interpret the results described in this paper. Despite this limitation, the large number of specimens (72 donors, 130 femurs and 132 tibias) analysed in this study is large by comparison with other reported studies and the results drawn from the data are felt to be reliable.

The subchondral bone thickness and density were measured on high-resolution radiologic images. Subchondral bone was defined as the sclerotic area directly below the cartilage. Occasionally, trabecular bone beneath a joint surface was observed showing sclerosis for a variable distance. Such sclerotic trabecular bone was not included in the measurement of the subchondral bone because it was considered that such underlying trabecular bone was influenced by the systematic state of the skeleton, aging, and the extent of remodeling activities[18].

It is essential to clarify the degree to which the human specimens are affected by the pathological condition of OA in order to distinguish between the normal aging process and pathological arthritic effects. Disparities between clinical symptoms, radiographic changes and arthroscopic findings have been previously identified[19,20]. For this study, a gross morphological assessment was employed to grade the pathological changes of OA.

Gross morphological assessment revealed that the surface appearance of the articular cartilage deteriorated significantly with advancing age on both the femoral and tibial surfaces. This finding is in agreement with the generally accepted observation that the articular cartilage undergoes notable age-related changes that may lead to degeneration of the tissue[21]. Epidemiologic studies have revealed that an age-related predisposition to OA appears to increase after the age of 50 or 60 years[22]. In this study, there were very few specimens graded 1 (normal) from donors over the age of 50 years.

Comparing age with the thickness and density of the subchondral bone, age appeared to have statistically significant negative associations with the subchondral bone thickness in both the lateral and medial tibiae, but only in the lateral side was there a statistically significant negative association with the subchondral bone density. No such associations were found with the femoral subchondral bone. On the other hand, when comparing the cartilage surface grading and the thickness or density of the subchondral bone, no statistically significant association between thickness and density with either the femurs or tibias was observed. There was however a relatively weak negative association with the subchondral bone density between the lateral tibial plateau and the gross grading. It should be noted that advancing age clearly revealed negative associations with both the thickness and density of the subchondral bone, while no such association was observed with the cartilage surface grading.

Previous studies investigating the subchondral bone in human knees have focused primarily on the tibia and not the femur[23–25]. Both the femur and tibia were investigated in this study; however, neither the subchondral thickness nor density of the femur demonstrated any significant changes over time. It is thought that this is related, at least in part, to the difference in the way mechanical stresses are applied to the bone beneath the articular cartilage.

Because the femur moves upon the tibial plateau in a combination of rolling and sliding, and has a wider contact area compared to the tibia, tibias presumably sustain constant mechanical stresses and, therefore, reflect the influence of mechanical stresses more than do femurs.

The prevalence of cartilage changes appeared to increase with advancing age in this study cohort. Associations between age and the cartilage surface grading observed in the present study were highly significant, indicating a worsening of cartilage grade with age. The subchondral bone thickness and density, however, showed only mild correlations with age and cartilage surface grading, and these changes were a decrease in both density and thickness. Age showed relatively strong associations with the subchondral bone thickness when compared among age groups, and furthermore was identified as a predictor of a decreasing subchondral bone thickness in the tibial plateaus using multiple regression analysis. The cartilage surface grading showed hardly any trends in relationship to either the thickness or density of the subchondral bone. When the subcategories of the grade 4 knees were evaluated in relationship to subchondral bone density and thickness, the same lack of trends was observed. However, the numbers were small and it was not felt to be appropriate to break this data out. Rather, the grade 4 subcategories were lumped together for the purposes of this analysis. Once the numbers of specimens have been increased, this analysis may prove more fruitful.

It should be pointed out that the measurements of subchondral bone thickness and density that were performed in this study were made on slices of bone taken from the femoral condyles and tibial plateaus. This potentially could introduce a sampling error, and it could be that other regions of the joint might show different degrees of subchondral bone thickening and density. The histology that is being performed on these slices may provide further insights into how important an issue this may be.

There have been a number of reports emphasizing the importance of the subchondral bone thickness in the development of OA, although most of the reports have dealt with either animal models[5–7,26] or aged human populations[14,27]. The validity of our study, compared to previous studies, lies in the large number of human knee specimens obtained from donors over a wide distribution of age.

It is a recognized fact that patients presenting with late stage OA demonstrate sclerotic changes in the subchondral bone. There appears to be an inconsistency between this observation and the findings of decreasing bone density and thickness with age and with loss of articular cartilage. At this point in time, the authors feel that the sclerotic changes associated with late stage OA are a late manifestation of the disease. Sclerotic changes probably reflect a response of the subchondral bone to the increased load bearing and friction that occurs after the loss of the articular cartilage. This theory will need to be studied further.

It appears that females have thinner and denser subchondral bone compared with males. Considering the fact that osteoporosis is more common in females, this finding seems contradictory. However, the subchondral bone measured in the present study was defined as the radiographic high intensity area beneath the cartilage, and did not include the underlying trabecular bone that may be more involved in osteoporotic changes than the subchondral bone. It is important to separate these two when discussing the pathophysiology of the disease[28].

Obesity has been implicated as a risk factor for knee OA by a number of population based studies[29]. Obesity increases the mechanical stress applied to the joint surface in the lower extremity. As the subchondral bone thickness and density are considered to be influenced by the mechanical stress, it is noteworthy that there were associations detected between the subchondral bone parameters and the body weight as well as the BMI.

Conclusion

From the results observed in this study, it may be concluded that the subchondral bone changes are not as significant to osteoarthritic changes in human joints as previously suggested. Rather, density and thickness may be influenced more by the normal aging process or may be a late manifestation of an arthritic process.

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