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OSTEOARTHRITIS
and
CARTILAGE

Prevalence of degenerative morphological changes in the joints of the lower extremity

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Summary

Information on the prevalence and extent of degenerative morphological changes (DMC) in the joints of the lower extremity, including foot joints is sparse. In the present study, the first and fifth metatarsalphalangeal (MTP), transverse tarsal, subtalar, talocrural, knee and hip joints of 50 cadavers were examined grossly and graded on a five-point scale for signs of DMC Selected samples were examined histologically. Our results confirm clinical findings that severe DMC in foot joints are uncommon except in the first MTP joint where the plantar aspect is most affected. The knee joint displayed the most numerous and severe signs of DMC followed by the first MTP joint. The hip, talocrural, subtalar and transverse tarsal joints displayed comparatively moderate levels of DMC while the fifth MTP was rarely affected The only joint to display significantly greater levels of DMC on the distal side of the joint as compared with the proximal side, when a difference was present, was the hip. There were significantly greater levels of DMC on the medial aspect of two or more joints within an extremity than on the lateral aspect. Radiographs often showed few or no signs of DMC even when erosion down to subchondral bone was observed upon gross examination.

Key words: Human, Osteoarthritis, Cartilage, Foot joints

Introduction

Numerous studies have documented the prevalence and/or extent of degenerative morphological change (DMC) in both surgical and post-mortem specimens of hip [1–4], knee [5–12] and ankle [13, 14] joints. Heine [15] has probably recorded the most extensive study on the prevalence of DMC comparing acromioclavicular, sternoclavicular, shoulder, elbow, hip, knee and great toe joints in autopsy specimens. He found that the great toe was second only to the knee in incidence of extensive DMC with the conditions progressively increasing with age.

Historically, the foot has been ignored in studies of individual and comparative DMC in joints. Though the ankle and foot are subjected to as much as one and a half times body weight during walking they are actually not nearly as prone to clinically detectable DMC, including osteoarthritis (OA), as are hip and knee joints. Primary OA is uncommon in the subtalar, talonavicular, calcaneocuboid, transverse tarsal and interphalangeal joints. However, it is the first metatarsal phalangeal (MTP) joint that is a common site of primary OA, its progression leading to hallux limitus and ultimately hallux rigidus.

There is limited information on the extent and location of DMC in the joints of the foot particularly in relationship to other joints of the lower extremity. In this study we compare selected foot joints as well as ankle, knee and hip joints for the incidence of DMC in both lower extremities of cadaveric specimens. The joints of the foot were chosen based on weight bearing and range of motion during gait [16]. They include the subtalar, transverse tarsal (talonavicular and calcaneocuboid), first MTP and fifth MTP joints.

Materials and methods

The hip, knee, talocrural, subtalar, transverse tarsal, first MTP and fifth MTP joints of 100 lower extremities of 50 formalin-fixed cadavers were dissected and immediately inspected for signs of DMC. A total of 3200 articular surfaces were studied. The specimens were those used by medical and podiatry students in their anatomy dissection laboratories. General medical history, occupation and cause of death were available for most of the specimens. The age distribution of the 26 female and 24 male cadavers was from 36–94 years with a

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Table I
Age of cadavers

	Decade in years						
	30–39	40–49	50–59	60–69	70–79	80–89	90–99
Number of cadavers	1	1	2	10	13	17	6

mean age of 76.4 years. This age distribution is representative of that which is available to dissection laboratories. Table I indicates the ages according to decades. All cadavers were caucasian. Only specimens that had intact ligamentous components were included in the study. No specimen had apparent signs of, or had a history of, lower extremity surgery. None of the articular surfaces appeared to have undergone post-mortem degeneration.

To address the question of the integrity of the cartilage, representative samples of each grade of DMC from several specimens were prepared for histological examination. Paraffin sections were stained with Safranin 0 for sulfated glycosaminoglycans [17] and inspected for the presence of intact cartilage layers. Any cadaver that had an articular surface that had begun post-mortem degeneration to the point of affecting the grading system was eliminated from the study.

To better visualize the presence of fibrillation and fissuring, India ink was applied to the articular surfaces [9, 18]. The ink was brushed onto the surface with an artist's paint brush, and then the cartilage was lightly rinsed with distilled water and blotted to remove the excess. Signs of cartilage changes were graded on the following scale based on Collins [19] (Fig. 1): Grade 0 indicating no signs of DMC; Grade 1 indicating early fibrillation, flaking, shallow pits or grooves and/or small blisters affecting the cartilage surface in the absence of changes in articular surface geometry; Grade 2 representing deep fibrillation and fissuring, flaking, pitting and/or blistering, early

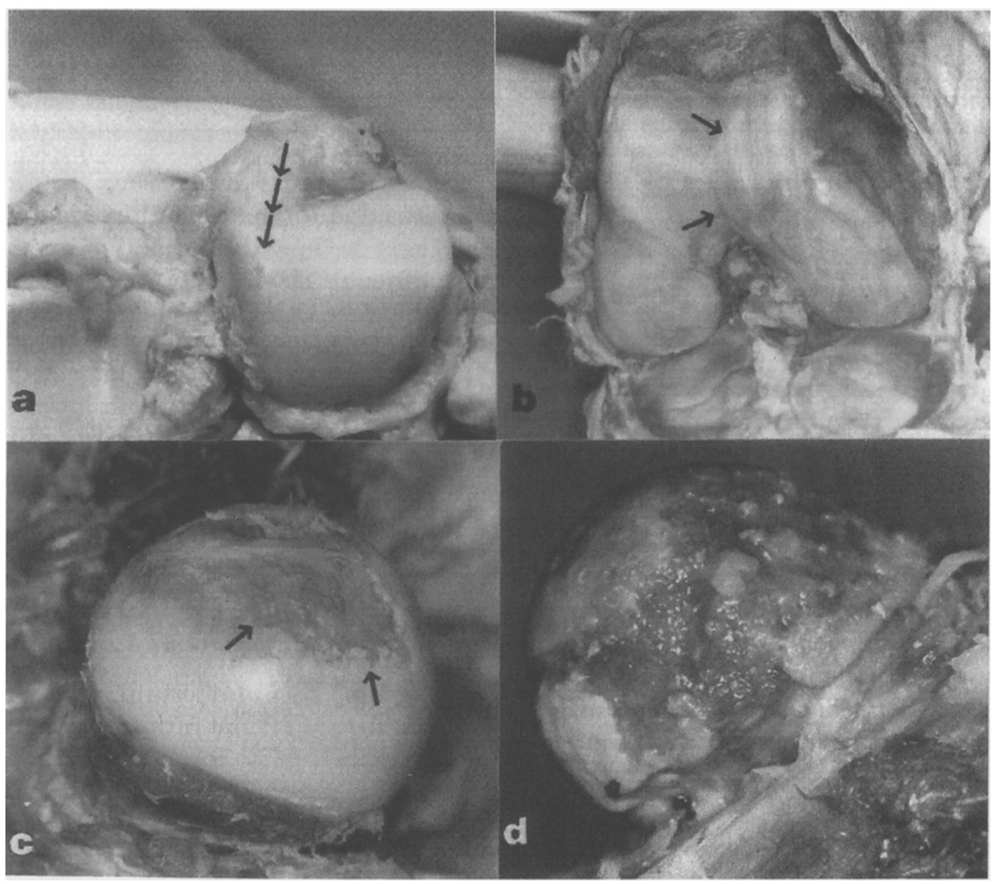


FIG. 1. Composite photograph depicting representations of the four grades of degenerative morphological changes. (a) Grade 1: fibrillation and pitting on the medial margin of the talar dome; (b) Grade 2: fibrillation and longitudinal ridges on the patellar surface of the distal femur; (c) Grade 3: erosion of less than 30% of the articular cartilage surface of the femoral head down to subchondral bone; (d) Grade 4: erosion of greater than 30% of the atticular cartilage surface of the femoral head accompanied by osteophytosis.

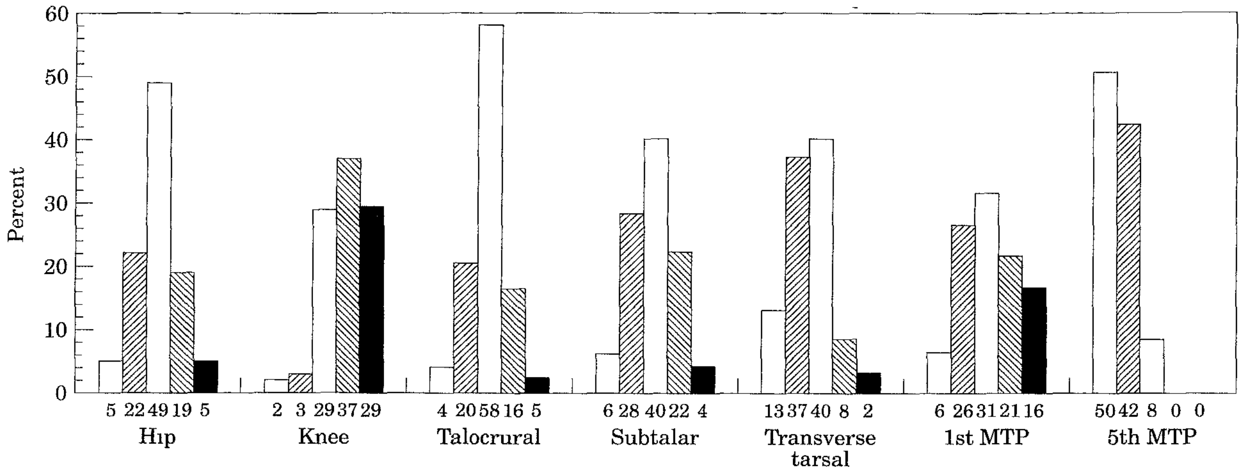


FIG. 2. Comparison of levels of degenerative changes (expressed as % out of 100 extremities) (□), Grade 0; (▨), Grade 1, (□), Grade 2; (▧), Grade 3; (■), Grade 4.

marginal hyperplasia and, possibly, small osteophytes; Grade 3 representing extensive fibrillation and fissuring, obvious osteophytes and 30% or less of the articular cartilage surface eroded down to the subchondral bone; and Grade 4 indicating prominent osteophytes, lips or shelves at the articular margin, greater than 30% of the articular surface eroded down to the subchondral bone and gross geometric changes. For consistency, one observer graded all 100 extremities Statistical significance was determined by analysis of variance where $P < 0.05$.

In addition, for comparison with gross visual inspection, radiographs were taken of the knee, talocrural, subtalar and first MTP joints from three cadavers, a 66-year-old man, a 74-year-old woman and a 77-year-old man.

Results

Fig. 2 shows the percentage of specimens observed at each grade of DMC. These grades represent the highest level of DMC observed in each of the joints indicated. Fig. 3 shows the comparison of DMC severity on the proximal side as compared with the distal side of each joint. A comparison of DMC severity on medial versus lateral columns through the lower extremity, from the knee distal, can be seen in Fig. 4.

HIP JOINT

The only significant difference in severity of DMC between the right and left hips was at Grade 4, where four of five hips were from the right. None

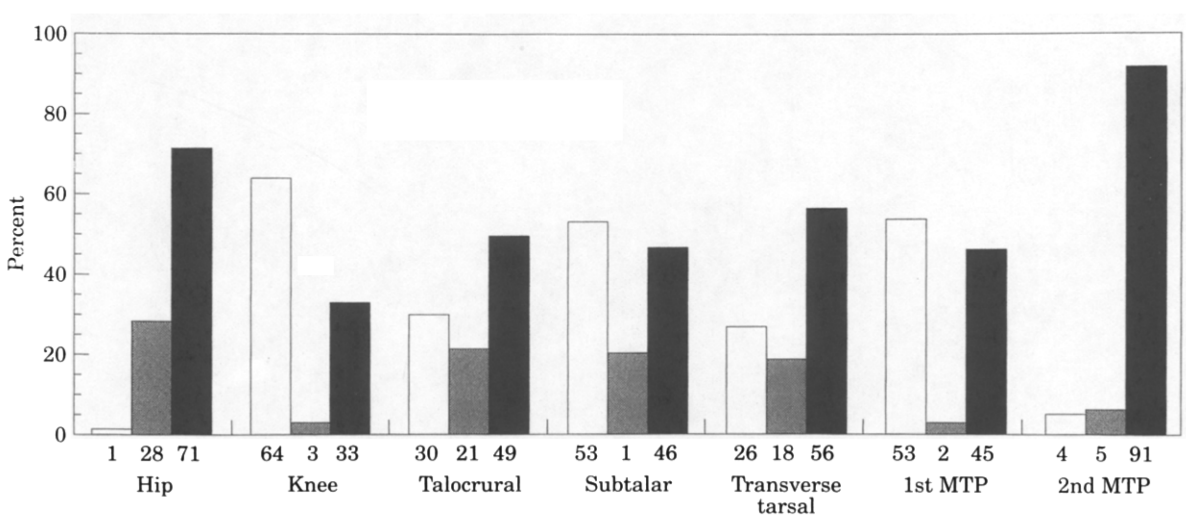


FIG. 3. Comparisn of levels of degenerative changes on proximal vs distal (expressed as % out of 100). (□), Degenerative changes > proximal side; (□), degenerative changes < distal side; (■), degenerative changes on proximal = distal side

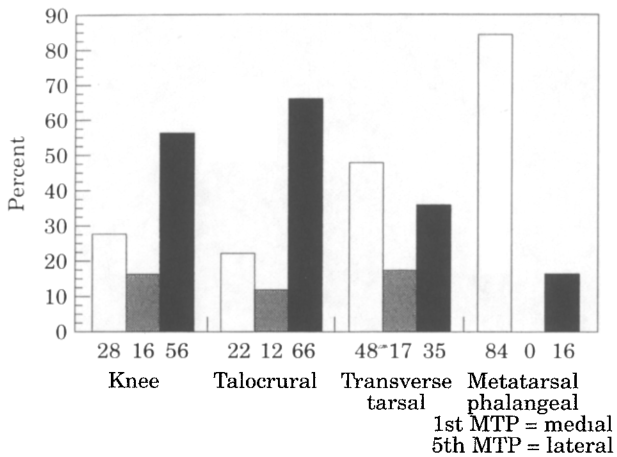


FIG. 4 Comparison of degenerative changes on medial and lateral columns through the lower extremity from the knee distal (expressed as % out of 100). (□), Degenerative changes > on medial; (□), degenerative changes > on lateral; (■), degenerative changes on medial = lateral

of the Grade 4 cadavers were bilateral conditions and their respective matches were either Grade 2 or 3. There was a modest increase in the level of DMC with advancing age. There was no significant difference between male and female distribution among any of the five grades.

On the proximal (acetabular) side of the joint, osteophyte formation occurred primarily on the lunate surface adjacent to the fossa and to a lesser extent around the outer margin. In advanced cases of DMC, osteophytes could be found extensively associated with both regions. Osteophytes were less than 5 mm in height and never extensive in breadth. Erosion of the acetabular cartilage was observed in 13% of hips, primarily around the lunate surface adjacent to the fossa and occasionally extending inferiorly. At Grade 4, erosion could also be found along the outer cartilage margin.

On the distal (femoral) side of the joint, osteophyte formation was more extensive around the anterior margin and fovea. Erosion of the cartilage was present in 24% of hips around the fovea, particularly anterosuperiorly. The most severe cases of Grade 4 affected the entire articular cartilage surface with osteophytes greater than 5 mm at the margin.

In only six of the most severely degenerated joints were there any apparent gross signs of abnormality within the surrounding soft tissue. In three of these cases, the synovial membrane displayed grossly visible thickening with the presence of small villus projections.

KNEE JOINT

Sixty-six percent of knee joints displayed Grade 3 or 4 and had the most severe signs of DMC compared with the other joints (Fig. 2). Only five knees from four cadavers displayed grades of 0 or 1 and this did not correlate with age. The youngest specimen, aged 36, displayed Grade 2 over the medial femoral condyle and the medial facet of the patella bilaterally. Grade 3 was observed in our second youngest specimen at 49 years of age. There were no significant gender differences in cases of cartilage erosion with 14 women and 14 men displaying bilateral Grades of 3 or 4. Four females and six males displayed the condition unilaterally. The three cadavers with the most severe erosive condition in the knee were obese females. The next two cases following in DMC severity were heavy males of large proportions.

Fig. 3 shows the comparison of DMC between the proximal side of the joint, as represented by the femoral condyles, and the distal side, as represented by the tibial plateaux.

Considering only the femur, in 64% of specimens, the severity of DMC was comparable on both patellar and condylar surfaces of the femur while 17% displayed more severe DMC on the patellar surface and 19% displayed more severe changes on the condylar surface.

Observations of the patellofemoral articulation showed that in 45% of the knees the severity of DMC was comparable on both patellar and femoral surfaces with 28.8% of these cases being bilateral within a cadaver. Thirty-eight percent of knees displayed more severe DMC on the patellar surface with 28.9% of these cases being bilateral. Of the 17% of knees displaying greater changes on the femoral surface, 23.5% of these were bilateral conditions.

In 65% of patellae, signs of DMC were comparable on both medial and lateral facets. Twenty-five percent of patellae displayed greater DMC on the medial facet and, of these, four (4% of total specimens) displayed the appearance of dysplasia with an accompanying lateral subluxation. Each of these four patellae displayed DMC to the degree of erosion accompanied by erosion on the lateral aspect of the patellar surface of the femur. Only 10% of patellae displayed greater DMC on the lateral facet with seven (7% of total specimens) displaying early lateral subluxation and one displaying further lateral subluxation due to patellar dysplasia. Thus a total of 11% of patellae showed dysplasia and each of these was associated with Grades of 3 or 4 on both the patellar and femoral surfaces.

Signs of DMC on the medial facet of the patella could generally be visualized most often on the most medial aspect of this facet. Four cadavers, two male and two female, exhibited genu valgum and had Grades of 3 or 4 on the medial aspect of the medial facet of their respective patellae. These patellae were not dysplastic but were subluxated laterally and articulated primarily or entirely with the lateral aspect of the femur which also exhibited Grades of 3 or 4. In one cadaver, bilateral patellae were completely eroded to subchondral bone while the articulating femurs showed only Grade 2.

Occasionally, parallel linear grooves were observed on corresponding articular surfaces of the femur and the patella. In only one knee did these grooves reach the subchondral bone. In every case when the femorotibial articulation showed DMC, the patellofemoral articulation did as well.

Osteophytes, when present, were randomly distributed around the border of the articular surface of the patella except for the inferior border where they were rarely present. On the femur, osteophytes were observed primarily at the borders of the patellar articular surface and with far less frequency around the condylar borders.

Signs of DMC on the tibial plateaux first appeared in those regions not covered by the menisci. Grades of 3 or 4 were found in 16% of the knees and were observed only on the uncovered surfaces. However, at these grades, fibrillation could often also be observed on the menisci covered surfaces. All changes occurred more frequently on the medial than on the lateral facet of the tibial plateau. Though conditions were not always bilateral, neither extremity showed a preponderance over the other for severity of DMC.

In only 11 cases of Grade 3 and 4 were there any macroscopically apparent changes in the accompanying synovial membrane which displayed a thickened and rough appearance. In eight of these specimens the synovial membrane could be found sending small villus projections into the joint space.

In none of the specimens graded 0, 1, or 2 did we observe any apparent gross abnormalities in the menisci, while 24% of the specimens at Grades 3 and 4 displayed atrophy, fraying, thinning or small tears in the menisci. No specimen, however, displayed anything that could be considered a serious change in meniscal appearance.

Upon inspection of the radiographs of the three previously specified cadavers, only a moderate level of subchondral sclerosis was noted even when full-thickness defects were visible upon gross examination.

TALOCRURAL JOINT

There was no significant difference between right and left among any of the grades, and severity was bilaterally equal in 60% of the cadavers

By the age of 66 all joints displayed at least Grade 1, a grade that could also be observed in joints from individuals in their 80s and 90s. Of the 16 joints categorized as Grade 3, five (31%) were from females and 11 (69%) were from males. The two joints in Grade 4 were those of 74- and 87-year-old females. In total, 22% of males and 14% of females displayed erosion at the level of Grades 3 or 4 in the talocrural joint.

The proximal (tibiofibular) side of the talocrural joint as compared with the distal (talar) side can be seen in Fig. 3. Fig. 4 shows a comparison of severity of DMC on the medial side of the talocrural joint as compared with the lateral side.

Cartilage defects were observed primarily at the boundaries between trochlear and malleolar regions of the talar dome. Most often these defects consisted of fibrillation and fissuring and were observed more frequently on the medial aspect of the joint. When the defects at the boundaries between trochlear and malleolar regions extended to Grade 3, the erosion was present only at the borders. This erosion gradually tapered into fibrillated cartilage and then to normal appearing cartilage on the central trochlear aspect of the talar dome. In two unrelated extremities, longitudinal grooves running anteroposteriorly through the cartilage and into the subchondral bone of the talar dome were created by osteophytes along the anterior border of the articulating tibial plafond. These grooves were remarkable in appearance and extended nearly the entire width of the articulation.

Osteophyte formation occurred principally at the anterior and medial margin of the talar dome and the anterior margin of the tibial plafond. When osteophytes were present at the anterior margin of the tibia, there were often defects in the articulating cartilage of the talus. Less often, osteophytes were observed at the posterior marginal border of the tibial plafond. In these cases no defects were observed in the talus. Pitting, a sign of osteochondrosis dissecans, was observed in five cases on the trochlear surface of the talar dome without any corresponding defects in the articulating tibial cartilage.

In cases in which erosion was present (18% of tali) it occurred most often anteriorly or anteromedially, less often anterolaterally and only in one specimen posteriorly on the medial surface of the body of the talus. This latter joint displayed rotation of the talocrural joint in the transverse plane and the lateral surface of the body of the talus showed erosion anteriorly. The corresponding articular surfaces of the tibia and fibula also showed erosion.

No apparent gross changes were observed in the surrounding soft tissues in any of the specimens.

Radiography of a Grade 2 specimen showed the presence of a grossly visible osteophyte but no subchondral bone changes beneath cartilage that was fibrillated and fissured upon gross examination. Radiography of a Grade 3 specimen failed to reveal any signs of DMC.

SUBTALAR JOINT

Severity of DMC was bilaterally equal in 56% of cadavers while 28% displayed more severe DMC in the subtalar joint of the right foot and 13% displayed more severe changes in the left. All four of the subtalar joints with Grade 4 DMC were from males while at lower grades there were no significant differences between males and females.

Age related DMC involved the lower grades more than the higher grades. With increasing age it became rarer to see an articular surface in this joint free of DMC, though these changes did not necessarily involve erosion.

In 61% of specimens the anterior facet of the head of the talus [Fig. 5(a) and (b)] exhibited Grade 2 or higher either individually or with the middle facet which exhibited Grade 2 or higher in 21% of joints. When these two facets were not fused (as is frequently the case) the border between the two frequently displayed some erosion.

Grade 4 was never observed on the calcaneus, and Grade 3 was observed on only three calcanei. In each of the three cases, a single but different facet was affected. For these three calcanei, corresponding grades of DMC were not observed in the articulating surfaces of the talus. No apparent gross changes were observed in the associated soft tissues of any of these specimens. Lateral view radiographs of the subtalar joints displaying Grades 2, 3 or 4 upon gross visual examination failed to show overt signs of degenerative changes [Figures 5(b) and (c)].

TRANSVERSE TARSAL JOINT

The transverse tarsal joint actually consists of two joints, a medial talonavicular portion and a lateral calcaneocuboid portion (Fig. 6). Results for the two portions are reported together. Severity of DMC was bilaterally equal in 70% of cadavers while 20% displayed greater DMC severity in the right foot and 10% in the left foot.

At Grades lower than 3 there were no significant differences in severity between genders. Of the eight transverse tarsal joints displaying Grade 3, seven were from female cadavers. At Grade 4, there was one from each gender.

Changes with age involved the lower grades more than the higher grades. Thinning of the articular cartilage in the absence of erosion as well as osteophyte formation were the major macroscopic age-related changes.

When the anterior articular surface of the talar head was involved, the central aspect and medial, superior and lateral peripheral articular borders were affected by fibrillation and thinning in the absence of erosion. Osteophytes were present in six cases and could be seen on the superior or lateral articular border.

Involvement of the concave articular surface at the posterior aspect of the navicular included central fibrillation, fissuring or erosion as well as thinning and erosion at the articular border.

The anterior articular surface of the calcaneus was most often involved centrally but peripheral regions could be affected as well when DMC

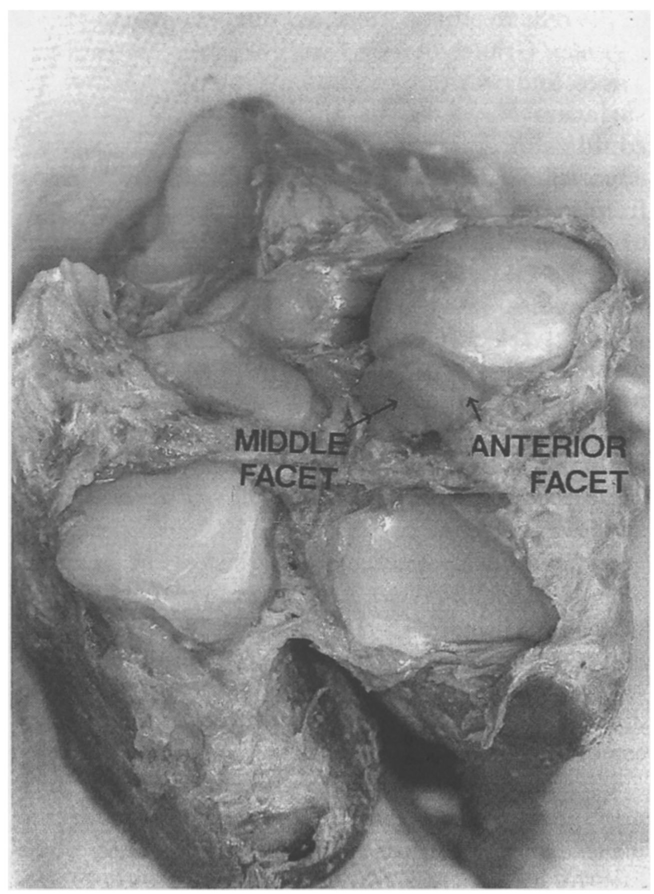
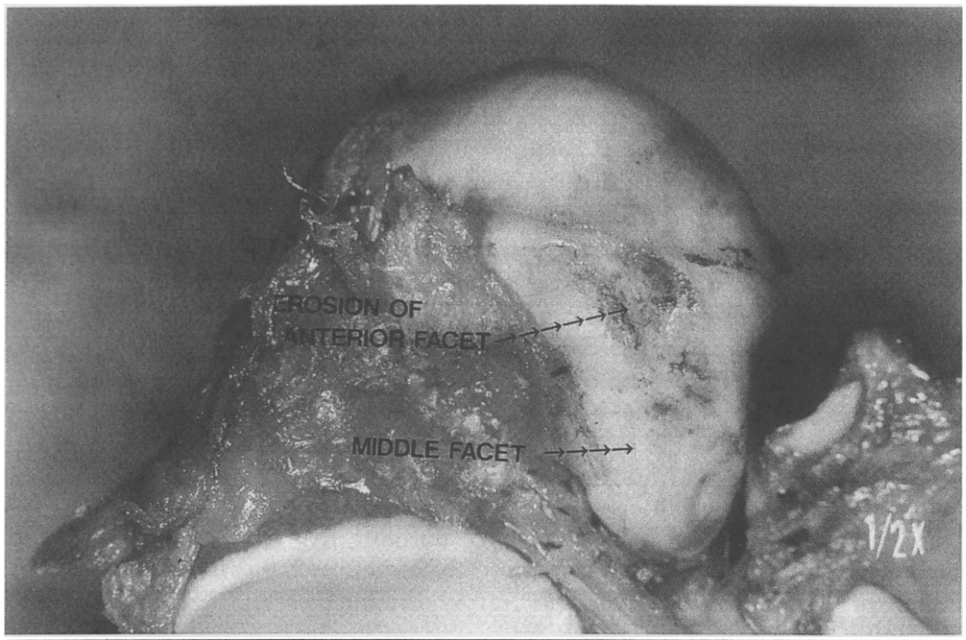


FIG. 5 (a) *(caption opposite)*.

(b)



(c)

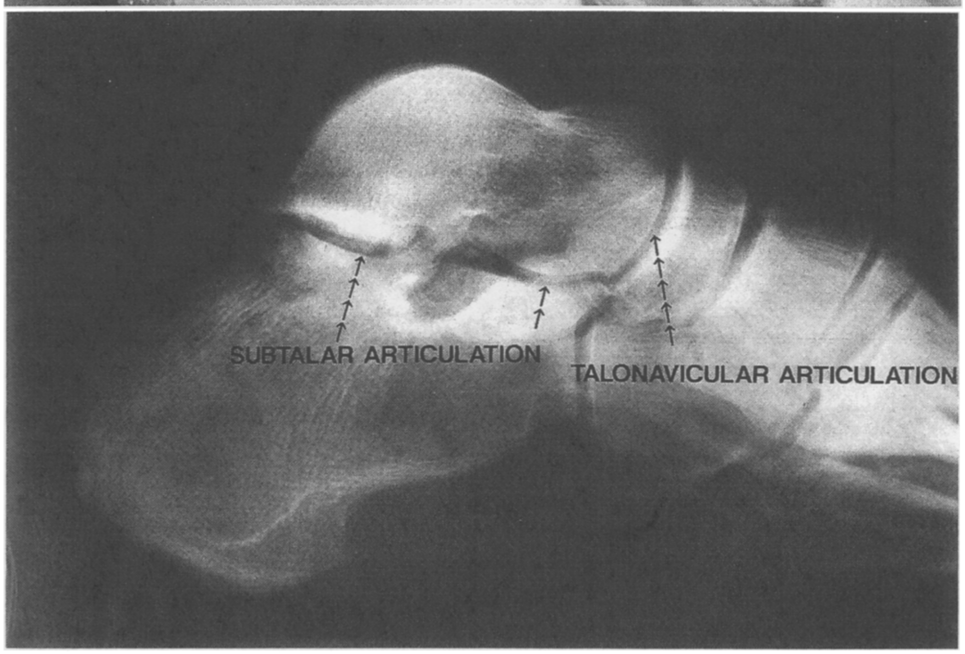


FIG. 5. (a) Talus, showing anterior and middle facets of inferior surface of the head; (b) gross anatomical view of the head of the talus of the subtalar joint showing fibrillation and fissuring particularly on the anterior/middle facet region; (c) lateral radiographic view of the specimen in (b).

became more diffuse on this surface. In only one joint was a calcaneal osteophyte observed, and this was located at the superior articular border.

The posterior surface of the cuboid displayed signs of DMC centrally and laterally with macroscopically apparent thinning in the absence of erosion being observed in 17% of specimens. Osteophytes, when present, were located on the inferior articular border.

No apparent gross changes were observed in the associated soft tissues of any of the specimens.

FIRST MTP JOINT

With 37% of specimens at Grades 3 or 4, this joint is second only to the knee in terms of severity of DMC observed (Fig. 2). There was no significant difference in severity between right and left feet, and severity was bilaterally equal in 56% of cadavers. At Grades 2 and 4 there were significant differences between gender with 21% of female and 10% of male joints at Grade 2 and 5% of female and 10% of male joints at Grade 4.

Within the first MTP joint, DMC was related more to hallux abducto valgus and body size/weight than to age.

The bars to the far right in each set in Fig. 4 show the severity of DMC on the medial side of the forefoot, as represented by the first MTP joint, compared with the lateral side of the forefoot, as represented by the fifth MTP joint.

Degenerative changes of the first metatarsal head more frequently involved the plantar aspect, which articulates with two sesamoid bones [Fig. 7(a)]. DMC was never more severe on the dorsal or anterior aspects than on the plantar aspect. In 38% of specimens the level of DMC was greater on the plantar aspect and in 62% of specimens the severity was comparable between anterior/dorsal and plantar aspects.

On the plantar aspect of the first metatarsal head, the cristae were always involved in DMC. Fibrillation, and later fissuring, began on the medial facet (which articulates with the medial sesamoid bone) progressing onto the crista and finally culminating in erosive changes on the crista. [Fig. 7(b)] Progressive DMC developed medially to laterally, most often affecting the medial facet first and only in late stages the lateral facet. In 47% of specimens, DMC were greater on the plantar aspect of the metatarsal head than on the sesamoids with which it articulates. In 7% of specimens, DMC were greater on the sesamoids than on the plantar aspect of the metatarsal head with 5% of that percentage contributed by the medial sesamoid and 2% by the lateral sesamoid. In 46% of specimens, changes were comparable on both metatarsal and sesamoid articular surfaces.

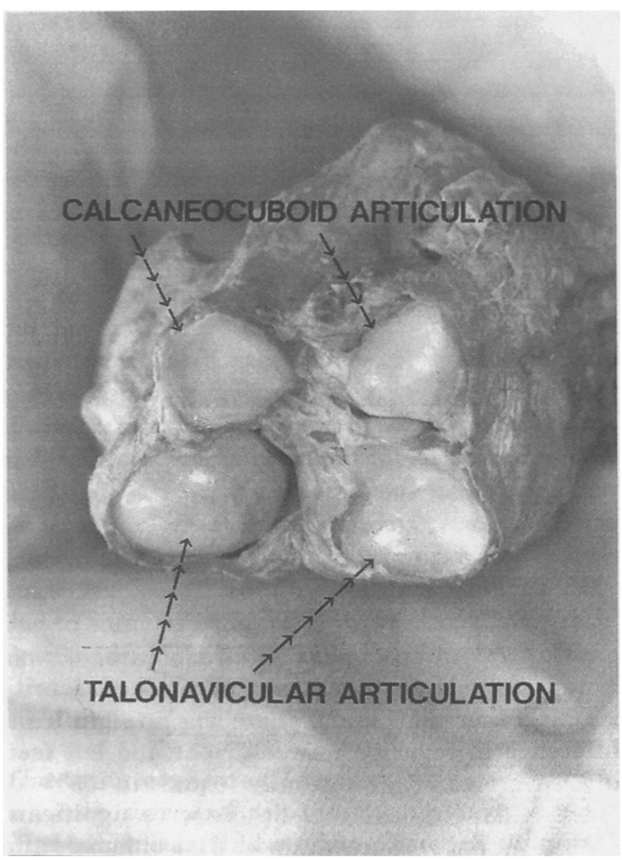


FIG. 6. Transverse tarsal joint showing talonavicular and calcaneocuboid portions

In 14% of specimens, DMC was more severe on the medial sesamoid than on the lateral while in 6% of specimens DMC was greater on the lateral sesamoid. Lesions began as fibrillations on the central region of these concave articular surfaces and later developed into erosions of the same region with lipping at the articular cartilage borders. In 80% of specimens, DMC was comparable on both medial and lateral sesamoids. The sesamoids were frequently displaced laterally, and occasionally, the lateral sesamoid extended into the intermetatarsal space. There were four male and two female cadavers with bilateral hallux abducto valgus, and one female with the condition affecting the left foot only. In each of these cases there was a Grade of 3 or 4 on at least one of the articular surfaces of the joint. Also, in each case, the plantar aspect of the metatarsal head was more severely affected than was the dorsal aspect.

In five of the joints at Grade 4, synovial membrane changes were grossly apparent. The membranes appeared rough, and in three of these specimens, small villus projections were found protruding into medial and lateral sides of the articular space. Osteophytes were observed primarily on the dorsal margin of the metatarsal head.

Radiographs of all previously specified specimens failed to show overt signs of degenerative changes [Fig. 7(c)].

FIFTH MTP JOINT

There was no significant difference between right and left feet, and severity was bilaterally equal in 95% of cadavers. Comparing males and females there was no significant difference in grades observed.

DMC was limited to fibrillation and minimal fissuring occurring in the central regions of both articular surfaces. Though osteophytes were never observed, a slight degree of lipping was occasionally seen around the articular cartilage border of the base of the proximal phalanx. The primary age related change observed in the fifth MTP was macroscopically apparent cartilage thinning.

No apparent soft tissue changes were observed in any of the specimens.

COMPARISON OF JOINTS WITHIN AN EXTREMITY

For a comparison of the presence of cartilage erosion, as represented by Grades 3 or 4, among joints within an extremity, see Table II. It should be stated that all five specimens showing severe DMC in the foot only, displayed the condition in the first MTP joint within hallux abducto valgus. No other joint of the foot exhibited Grades of 2, 3 or 4 unless the condition was also present in the hip, knee or ankle as well. Table III shows a comparison of DMC on the medial side of an extremity as compared with the lateral side.

Table IV shows the joint(s) that were the most severely affected by DMC within a single extremity. Where two or more joints are listed, these joints displayed the same grade within the extremity. The joints listed were selected on the basis of frequency of appearance. It is evident that the knee joint is the most affected joint in the lower extremity, both alone or in combination with other joints in a single extremity.

Though a history of physical activity of each of the cadavers is unknown, in our study there did not appear to be a correlation between occupation and severity of DMC. Some of the most severe cases were documented as having sedentary (clerical) occupations. It should be noted, however, that none of our cadavers had histories of extremely physically-demanding occupations whereby a true correlation could be determined.

Discussion

The objective of this study was to determine the prevalence and extent of DMC in joints of the foot in comparison with those found in other joints of the lower extremity. Many of the early morphological alterations, as represented by Grades 1 and 2 may simply be 'normal' senescent articular changes that are not symptomatic and perhaps would not degenerate further. It is, however, important that these alterations be documented and compared among joints.

The foot has largely been ignored in epidemiologic studies though Heine [15] included the first MTP joint in his comparison of seven joints in autopsy specimens. The results of the current study are in concurrence with Heine, as well as with clinical evidence, that the knee shows the most extensive DMC in the greatest number of specimens. A complete documentation of the DMC observed in this joint can be found in Bennett *et al.* [5] and Mitrovic *et al.* [11, 12]. Our data indicates that obesity and very large body size are greater determining factors in the prevalence of severe DMC in the knee than is age. This is in agreement with data reported by Felson [20–22] and Felson *et al.* [23] who found a close association between knee OA and obesity, particularly in females. Though, in a study of 300 cadaveric knees, Casscells [6] found that women had a significantly higher incidence of DMC than men, a 1990 study of symptomatic OA [24] showed similar incidence for both sexes. In the present study, though our data show no significant differences in grades of changes between sexes, females displayed the most severe cases when erosion was involved.

Concerning femoropatellar changes, our results differ somewhat from those of Kiss *et al.* [10] who found the patellar surface more frequently involved and more severely affected than the femoral surface in early stages of DMC but equally affected in later stages. In the present study the patella continues to be the more affected site throughout the development of DMC except when both surfaces were so degraded that it was impossible to make a distinction.

Our results are in close agreement with Mitrovic *et al.* [11], though a direct comparison is difficult to make due to differences in the respective grading systems. Mitrovic *et al.* [11] described cartilage changes beginning with the presence of fissures and found the vast majority of specimens displaying lesions on both patellar facets as our data shows in the present study We are also in agreement that a minority of cases involve only one of the facets with the medial facet being more frequently affected than the lateral.

In addition, our study shows that 11% of all knees displayed some degree of patellar dysplasia leading to subluxation of the patella in relation to the femur. This was always associated with articular cartilage erosion and is similar to that condition found by Mitrovic *et al.* [11] in 13% of their sample, and also associated with severe degenerative cartilage changes. This dysplasia does indeed appear to predispose the articular cartilage to morphological degeneration.

In a study of 120 autopsies, Mitrovic *et al.* [12] found that 58% of knees displaying cartilage ulcerations also exhibited atrophic or torn menisci, we found this number to be lower in our study. Indeed, we could only identify gross abnormalities of the menisci in 24% of Grade 3 or 4 specimens.

The extent and location of lesions of the hip joint are consistent with those reported in a postmortem study by Byers *et al.* [1] and others [2, 4].

We are also in agreement that there was no significant gender difference. However, in contrast to Byers' study, our data shows a significant difference between right and left hips at Grade 4 where four of five hips were from the right. In comparison with the other joints studied, the hip ranked moderately, with the knee and first MTP joints showing significantly more joints with erosion.

In our study, as in Heine's [15], the first MTP joint was second to the knee in incidence and severity of DMC. Though the second metatarsal head [16], in particular, along with the third and fourth metatarsal heads bear the highest peak pressure in the normal foot [25], the joints to which these surfaces contribute are not even remotely as prone to the clinical manifestations of OA as is the first MTP joint. While a minimum range of motion of 65–75° in the first MTP joint is necessary for normal locomotion, the lower degree of mobility and minimum range of motion necessary for the lesser MTP joints most likely contributes greatly to this situation. It is interesting that nearly all clinical symptomatology involving the first MTP joint is associated with the dorsal and medial aspects of the metatarsal head. In contrast, we found the plantar aspect to be the most affected site, always involving the crista and affecting the medial facet more frequently than the lateral. This discrepancy can be explained by the fact that

(a)

(b)

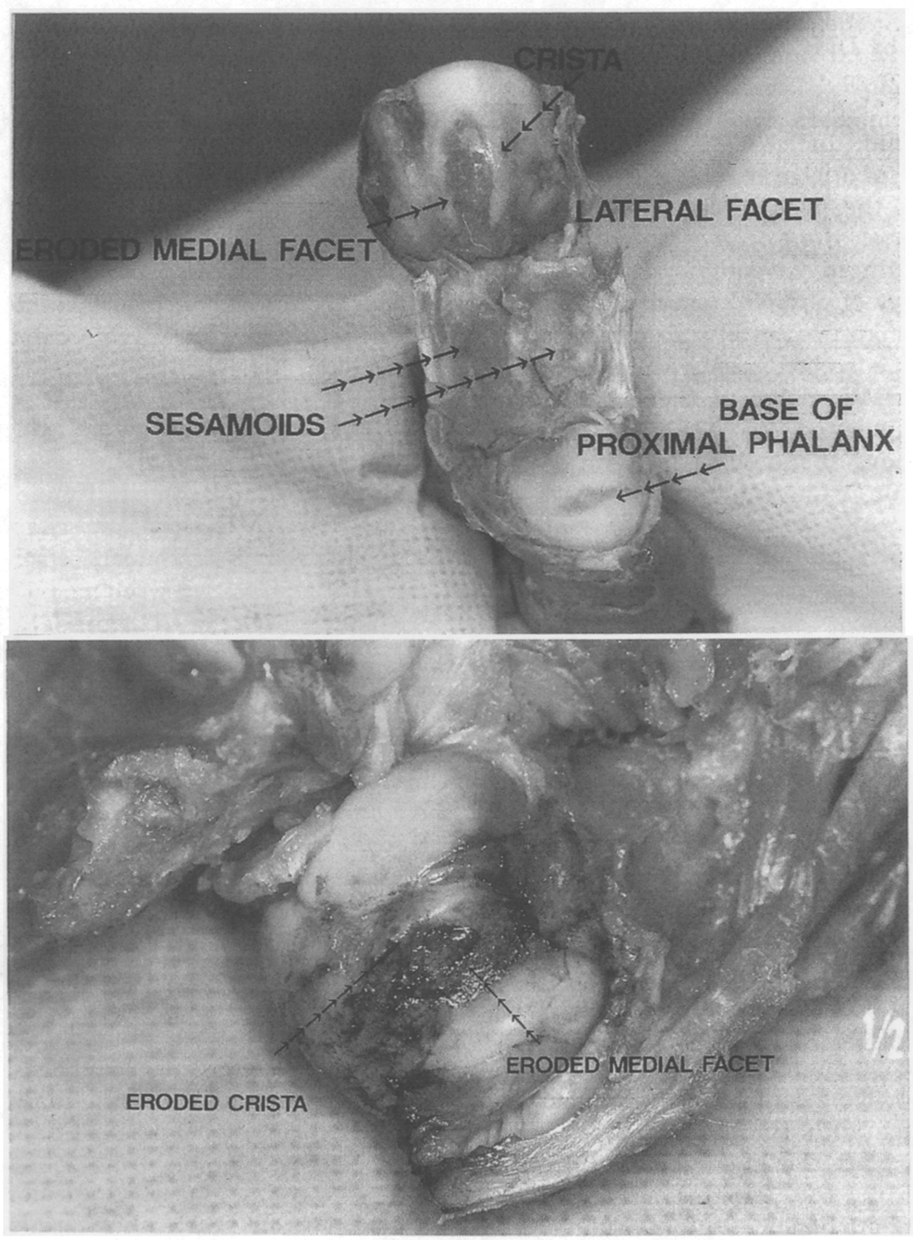


FIG 7 (a)–(b) *(caption opposite)*

(c)

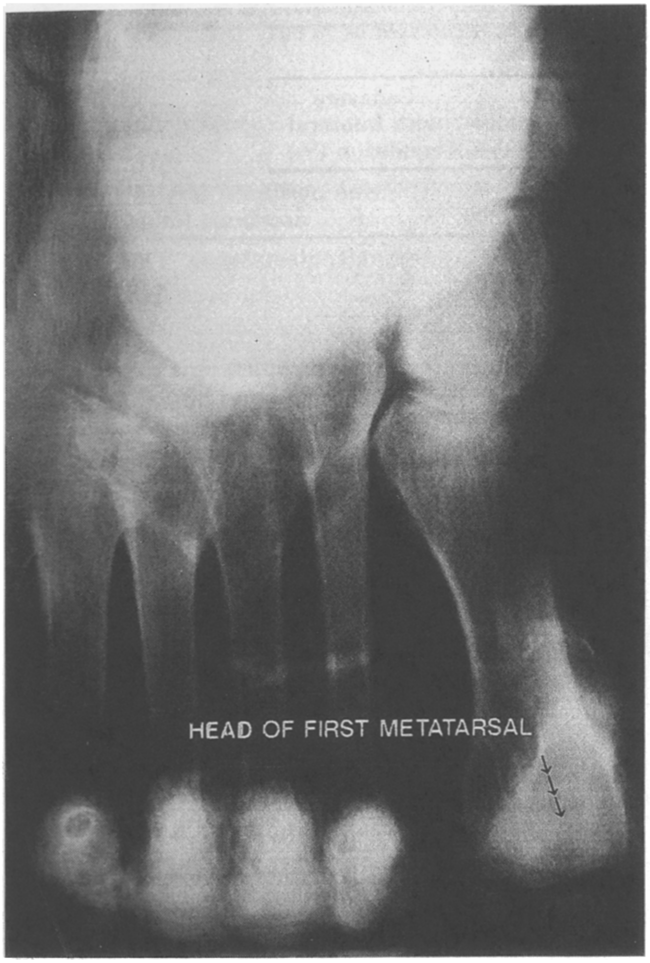


FIG. 7. (a) View of plantar surface of first metatarsal medial and lateral facets and crista, (b) gross anatomical view of the plantar aspect of the head showing head of the first metatarsal showing erosion of the cristae. (c) Axial sesamoid radiographic view of the specimen described in (a).

symptomatology consists of both pain and functional failure as a result of osteophyte formation and contour changes on the dorsal aspect rather than erosion on the plantar aspect. Enlargement of the dorsal aspect of the metatarsal head conflicts with shoewear. In addition, range of motion is limited by the formation of osteophytes at the dorsal margin and enlargement of the medial eminence of the metarsal head. Though the plantar aspect showed significantly higher levels of DMC than the dorsal aspect, the sesamoids with which it articulates displayed significantly lower levels of changes. We feel these are important findings because the plantar aspect of the first metatarsal head can not be visualized in its entirety during routine surgical procedures involving the metatarsal head, and it is nearly inaccessible via arthroscopy [26].

In a study by Bennett *et al.* [25], it was determined that the hallux was a region of greater weight bearing than the first metatarsal head. Root *et al.* [16] state that the first metatarsal head can serve as a base to stabilize the hallux for weight bearing. However, we found significantly greater levels of DMC on the metatarsal head than on the proximal phalanx. This may be due to the relative mobility of the involved bones whereby, during plantarflexion, movement of the first metatarsal head occurs while the hallux remains stable.

Though our study showed a higher prevalence of low grade DMC in the first MTP joint in females and a slightly higher prevalence of Grade 4 changes in males, clinically, severe DMC are more frequently observed in females. Though it is possible that females more frequenly seek out medical attention for this condition for cosmetic reasons or perhaps because of greater pain sensitivity, a more likely possibility is that our sample was not large enough to compare with the results of large clinical studies. That the fifth MTP joint displayed extremely low levels of DMC is not surprising in light of the fact that the fifth metatarsal head is subjected to the lowest average peak pressure of all the MTPs and, as a component of the most lateral of the MTP joints, it requires less dorsiflexion because its metartarsal lifts from the ground earlier in toe-off [16].

Though clinically and radiologically evident DMC in the talocrural joint is rare and, when present, are often due to previous trauma, our study shows that full-thickness cartilage erosions were evident in 18% of our sample. Perhaps the discrepancy between clinical prevalence and that found in post-mortem specimens reflects a difference in pain reception between the talocrural joint and more complex joints such as the knee. One must also consider the possibility that the talocrural joint has a greater potential for repair than the knee or hip, and therefore, may not deteriorate to debilitating levels. An additional possibility is that perhaps the biomechanics of the talocrural joint allows for a greater level of functioning in the presence of full-thickness defects.

Our results, however, are in concurrence with Meachim [14], Meachim *et al.* [7], Heine [15] and Huch (unpublished) that full-thickness defects occur less frequently in the talocrural joint than in the knee joint. Though our percentages are somewhat higher than theirs, this may be accounted for by the higher average age of our cadavers. Only 4% of talocrural joints in our study were free of signs of DMC which corresponds to the study by Tsukahara *et al.* [13] on paraformaldehyde

Table II
Joints graded 3 or 4 to show those individual joints, or in combination with others, most susceptible to full-thickness defects (expressed as % out of 100 extremities)

Joint(s)	Females	Males	Total males and females	Cadavers with bilateral condition (%)
Hip only	—	1	1	—
Knee only	12	10	22	5
Talocrural only	1	—	1	—
Foot only	3	2	5	1
Hip, knee only	3	1	4	—
Knee, foot only	9	7	16	2
Talocrural, foot only	2	—	2	—
Hip, knee, foot only	7	3	10	2
Hip, talocrural only	—	1	1	—
Hip, knee, talocrural only	—	1	1	—
Knee, talocrural foot only	3	5	8	—
Hip, knee, talocrural, foot	—	6	6	1
Total	40	37	77	11

fixed specimens (mean age of cadavers was 66.2 years) in which 2.4% were normal. Our study, as well as others [27], have shown that the talocrural joint is more often affected by DMC in males than in females.

The subtalar joint, which is composed of three articulations between the talus and the calcaneus, displayed a moderate level of DMC in comparison with other joints. The minimum range of motion of this joint in the frontal plane for normal locomotion is 8–12° [16]. The anterior and medial facets showed more frequent and higher levels of DMC than the posterior facet. This is not surprising in light of Wagner *et al.*'s [28] study which showed, in fresh cadaveric specimens that the anterior/medial facet region has a greater mean contact pressure although the posterior facet has a greater contact area.

The transverse tarsal joint, consisting of talonavicular and calcaneocuboid articulations, has a minimum range of motion in the longitudinal axis of about 4–6° [16]. The levels of DMC at this joint were most similar to, though a bit lower than, those found at the subtalar joint. Though the two

Table III
Number of extremities (out of 100) showing more severe signs of degenerative changes on the medial side of two or more joints (from the knee distal) as compared with the lateral side in the same extremity

	DMC medial > DMC lateral		DMC lateral > DMC medial	
	Female	Male	Female	Male
Two joints in an extremity				
No. single extremity affected	1	5	3	1
No. bilateral pairs affected	6	1	0	1
More than two joints in an extremity				
No. single extremity affected	5	8	2	2
No. bilateral pairs affected	8	7	0	0

Table IV
Joint(s) most severely affected by degenerative changes in an extremity (expressed as % out of 50 cadavers)

	Joints most severely affected				
	Knee	Knee and 1st MTP	Knee and hip	Knee, talocrural and 1st MTP	1st MTP
Unilateral condition only	30	16	10	6	6
Bilateral condition	30	0	0	0	0

MTP, metatarsalphalangeal.

portions of the transverse tarsal joint function together around two common axes of motion, more joints showed higher levels of DMC within the talonavicular portion than in the calcaneocuboid portion. This is in agreement with clinical findings [29] that primary OA of the calcaneocuboid joint is extremely rare.

The knee displayed the greatest difference between the proximal and distal sides but in the hip, talocrural, transverse tarsal and fifth MTP joints there was most often no significant difference between the two sides. However, it is interesting that in those cases in which a difference between the two sides of the joint was present, the hip was the only joint to display greater levels of DMC on the distal side as compared with the proximal side. One can only speculate as to whether or not this is related to the biomechanics of this ball and socket joint

Considering all of the joints studied within a single lower extremity there were significantly greater signs of DMC on the medial aspect of two or more joints than on the lateral aspect. Looking at joints individually, the knee, talocrural, transverse tarsal and MTP joints displayed significantly greater signs of DMC medially than laterally when there was a difference. Most often, however, there was no difference in the knee and talocrural joints.

The significance of these medial versus lateral differences is most certainly related not only to the normal biomechanics within each individual joint, but to any deviation from the normal biomechanics due to the conditions of genu varum or valgum. A varum deformity will result in greater weight bearing on the medial compartment of the knee and ankle while a valgum deformity results in greater weight bearing on the lateral compartment. Of all of the comparisons noted in this study, the medial versus lateral comparison is probably the most dependent upon slight deviation in extremity alignment. Of the four apparent genu valgum cases reported in our study, each exhibited greater DMC on the lateral femoral condyles accompanied by lateral displacement of the patella with medial facet degeneration. However, less apparent varum or valgum conditions may also have been present in our specimens, thus resulting in more severe changes either medially or laterally.

In the talocrural joint, it has been shown [30] that the contact area is primarily at anterior and lateral portions of the joint. However, Driscoll *et al.* [31] showed that in plantarflexion of the talocrural joint, contact is more anterolateral. Concerning load bearing on the talar dome, Calhoun *et al.* [32] calculated load to be greater on the medial facet than on the lateral facet during plantarflexion/inversion and dorsiflexion/eversion. Within the foot, the significance of the medial versus lateral difference may be related to the relative flexibility of the two sides of the foot. Due to the structure of the bony components of the foot, the medial portion of the longitudinal arch is considered to be the flexible component relative to the lateral portion. This flexibility, therefore, increases the level of mobility on the medial side relative to the lateral leading to more biomechanically-related pathologies, as well as greater friction between opposing articular surfaces.

When all joints of an entire extremity are considered, in 22% of extremities the knee was the only joint to display erosion and 5% of the total extremities showed this condition bilaterally. This was followed by 16% of extremities displaying erosion in the knee and foot only, with 2% of the total extremities showing this condition bilaterally. The next most common condition involved erosion in the hip, knee and foot only in 10% of extremities with 2% of all extremities showing this condition bilaterally.

Concerning radiography, although overt signs of DMC were not apparent skeletally (even in specimens with grossly visible severe DMC, this does not rule out changes in joint space. Joint space narrowing may not appear if the conditions under which the specimens were radiographed did not accurately mimic the weight bearing conditions of the live state.

It should be mentioned that, although the occupation history of our cadavers was documented, the lack of history regarding physical activity may be of some significance. Individual cases of advanced DMC in one or more of the joints may reflect extraordinary physical demands placed upon those joints. However, it is unlikely that this would be the case in a significant enough number of individuals within our sample to skew the results substantively.

In conclusion, this study has provided information on the comparison of DMC in the joints of the foot to that found in hip, knee and ankle joints. The significance is that it supplements clinical studies showing that a more generalized incidence of articular cartilage degeneration may exist and that cartilage deterioration may not necessarily lead to known symptoms or radiographic changes.

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References

1. Byers PD, Contepomi CA, Farkas TA. A post mortem study of the hip joint. Ann Rheum Dis 1970;29:15–31
2. Harrison MHM, Schajowicz F, Trueta J Osteoarthritis of the hip: a study of the nature and evolution of the disease. J Bone Joint Surg 1953;35B:598–626.
3. Meachim G Articular cartilage lesions in osteoarthritis of the femoral head. J. Pathol 1972;107.199–210.
4. Bullough P, Goodfellow J, O'Connor J. The relationship between degenerative changes and load-bearing in the human hip. J Bone Joint Surg 1973;55B.746–58.
5. Bennett GA, Waine H, Bauer W. *Changes in the Knee Joint at Various Ages*. New York: The Commonwealth Fund 1942.
6. Casscells SW. Gross pathological changes in the knee joint of the aged individual. Clin Orthop Rel Res 1978;132:225–32.
7. Meachim G, Emery IH Quantitative aspects of patello-femoral cartilage fibrillation in Liverpool necropsies. Ann Rheum Dis 1974;33:39–47.
8. Marar BC, Orth MC, Pillay UK. Chondromalacia of the patella in Chinese. J Bone Joint Surg 1975;57A:342–5.
9. Emery IH, Meachim G. Surface morphology and topography of patello-femoral cartilage fibrillation in Liverpool necropsies. J Anat 1973;116. 103–20
10. Kiss I, Morocz I, Herczeg L. Localization and frequency of degenerative changes in the knee joint: evaluation of 200 necropsies. Acta Morph Hung 1984;32(2):155–63.
11. Mitrovic D, Stankovic A, Borda-Iriarte O, Uzan M, Quintero M, Ryckewaert A Résultats de l'examen autopsique des cartilages des genoux chez 120 sujets décédés en milieu hospitalier. Articulation fémoro-patellaire Rev Rhumatol 1987;54:15–21.
12. Mitrovic D, Borda-Iriarte O, Naveau B, Stankovic A, Uzan M, Quintero M, Ryckewaert A. Resultats de l'examen autopsique des cartilages des genoux chez 120 sujets décédé en milieu hospitalier. Aticulation fémoro-tibiale. Rev Rhumatol 1989; 56:505–10.
13. Tsukahara T. Degeneration of articular cartilage of the ankle in cadavers studied by gross and radiographic examinations. J. Jap. Orthop Assoc 1990;64.1195–201.
14. Meachim G. Cartilage fibrillation at the ankle joint in Liverpool necropsies. J Anat 1975; 119:601–10
15. Heine J. Uber die arthritis deformans. Arch Path Anat Physiol 1926;260:521–663
16. Root ML, Orien WP, Weed JH. Normal and abnormal function of the foot. In *Clinical Biomechanics*, Vol. II Clinical Biomechanics Corp. 1977.
17. Rosenberg L Chemical basis for the histological use of Safranin O in the study of articular cartilage. J Bone Joint Surg 1971;53A.69–82.
18. Meachim G. Light microscopy of Indian ink preparations of fibrillated cartilage. Ann Rheum Dis 1972,31:457–64.
19. Collins DH. *The Pathology of Articular and Spinal Diseases* London· Edward Arnold and Co 1949;76–9.
20. Felson DT. Epidemiology of hip and knee osteoarthritis. Epidemiol Rev 1988,10.1–28.
21. Felson DT. The epidemiology of knee osteoarthritis. results from the Framingham Osteoarthritis Study. Semin Arthritis Rheum 1990;20:42–50
22. Felson DT. Weight and osteoarthritis. J. Rheum 1995;43(Suppl):7–9.
23. Felson DT, Zhang Y, Anthony JM, Naimark A, Anderson JJ. Weight loss reduces the risk for symptomatic knee osteoarthritis in women. Ann Intern Med 1992;116·535–9.
24. Wilson MG, Michet CJ, Ilstrup DM, Melton LJ Idiopathic symptomatic osteoarthritis of the hip and knee: a population-based incidence study. Mayo Clin Proc 1990;65.1214–21.
25. Bennett PJ, Duplock LR. Pressure distribution beneath the human foot. J Am Pod Med Assoc 1993;83:674–8.
26. Lundeen RO. *Manual of Ankle and Foot Arthroscopy*. U.S. Churchill Livingstone Inc. 1992.
27. Cushnaghan J. Dieppe P. Study of 500 patients with limb joint osteoarthritis. I. Analysis by age, sex and distribution of symptomatic joint sites. Ann Rheum Dis 1991;50:8–13.

28 Wagner UA, Sangeorzan BJ, Harrington RM, Tencer A Contact characteristics of the subtalar joint: load distribution between the anterior and posterior facets. J Orthop Res 1992;10:535–43

29 Mann RA. Oxteoarthritis of the foot and ankle In *Osteoarthritis, Diagnosis and Management* Philadelphia: WB Saunders Co 1984:397.

30 Kimizuka M, Kurosawa H, Fukubayashi T Load-bearing pattern of the ankle joint. Arch Orthop Traumatol Surg 1980;96:45–9

31. Driscoll HL, Christensen JC, Tencer AF Contact characteristics of the ankle joint. J Am Pod Med Assoc 1994;84:491–8

32 Calhoun JH, Eng M, Li F, Ledbetter BR, Viegas SF. A comprehensive study of pressure distribution in the ankle joint with inversion and eversion. Foot Ankle 1994;15·125–33.