Relationships among measurements obtained by use of computed tomography and radiography and scores of cartilage microdamage in hip joints with moderate to severe joint laxity of adult dogs

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Objective—To evaluate correlations among measurements on radiographic and computed tomography (CT) images with articular cartilage microdamage in lax hip joints of dogs.

Animals—12 adult mixed-breed hounds.

Procedures—Pelvic CT and radiography were performed. Hip joints were harvested following euthanasia. Orthopedic Foundation for Animals (OFA) and PennHIP radiograph reports were obtained. Norberg angle (NA) and radiographic percentage femoral head coverage (RPC) were determined. Center-edge angle (CEA), horizontal toit externe angle (HTEA), ventral acetabular sector angle (VASA), dorsal acetabular sector angle (DASA), horizontal acetabular sector angle (HASA), acetabular index (AI), and CT percentage femoral head coverage (CPC) were measured on 2-dimensional CT images. Femoral head-acetabular shelf posterior百分比 was measured on sagittal 3-dimensional CT (SCT) and transverse 3-dimensional CT (TCT) images. Light microscopy was used to score joint cartilage. Relationships of OFA confirmation and PennHIP osteoarthritis scores with radiography, CT, and cartilage variables and relationships of cartilage scores with radiography and CT measurements were evaluated with Spearman rank correlations. Pearson correlation was used for relationships of distraction index (DI) with radiography, CT, and cartilage variables.

Results—Significant relationships included PennHIP osteoarthritis score with cartilage score, CEA, HTEA, DASA, AI, CPC, and TCT; OFA confirmation score with cartilage score, NA, RPC, CEA, HTEA, DASA, AI, CPC, and TCT; cartilage score with NA, RPC, CEA, HTEA, DASA, HASA, AI, and TCT; and DI with cartilage score, CEA, HTEA, DASA, AI, and CPC.


**Abbreviations**

<table>
<thead>
<tr>
<th>HD</th>
<th>Hip dysplasia</th>
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<tr>
<td>DDH</td>
<td>Developmental dysplasia of the hip</td>
</tr>
<tr>
<td>2-D</td>
<td>Two-dimensional</td>
</tr>
<tr>
<td>3-D</td>
<td>Three-dimensional</td>
</tr>
<tr>
<td>CT</td>
<td>Computed tomography</td>
</tr>
<tr>
<td>DI</td>
<td>Distraction index</td>
</tr>
<tr>
<td>NA</td>
<td>Norberg angle</td>
</tr>
<tr>
<td>RPC</td>
<td>Radiographic percentage of femoral head coverage</td>
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<tr>
<td>OFA</td>
<td>Orthopedic Foundation for Animals</td>
</tr>
<tr>
<td>CEA</td>
<td>Center-edge angle</td>
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<tr>
<td>VASA</td>
<td>Ventral acetabular sector angle</td>
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<tr>
<td>DASA</td>
<td>Dorsal acetabular sector angle</td>
</tr>
<tr>
<td>HASA</td>
<td>Horizontal acetabular sector angle</td>
</tr>
<tr>
<td>HTEA</td>
<td>Horizontal toit externe angle</td>
</tr>
<tr>
<td>AI</td>
<td>Acetabular index</td>
</tr>
<tr>
<td>SCT</td>
<td>Sagittal 3-dimensional computed tomography</td>
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<tr>
<td>TCT</td>
<td>Transverse 3-dimensional computed tomography</td>
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<td>CPC</td>
<td>Computed tomography percentage femoral head coverage</td>
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Hip dysplasia is a leading cause of disease in the hip joints of dogs and humans, and HD in dogs is an accepted condition used to study DDH in humans. The precise pathophysiologic processes by which apparently normal neonatal hip joints become malformed, osteoarthritic joints by the time of adulthood have not been determined in dogs or humans. However, a valuable imaging modality used to diagnose HD in dogs.
Computed tomography is routinely used to image hip joints of immature and mature humans for diagnostic purposes, surgical planning, and evaluation of therapeutic interventions. The use of 2-D and 3-D CT imaging has substantially advanced detection of minor conformational abnormalities of the hip joints associated with the initiation and progression of DDH-associated osteoarthritis. Computed tomography of the hip joints of dogs has been used to assess joint changes mediated by surgical treatment and to detect joint laxity and dorsolateral femoral subluxation for diagnosis of HD in dogs. Pelvic limbs are typically abducted or subjected to simulated weight bearing during CT, and measurements are performed on images for comparative purposes. Computed tomography is not routinely used on dogs to assess degenerative joint changes.

Hip joint articulation can be quantified with standard measures on radiographic and CT images. The DI is a measure of passive laxity in the hip joints of dogs determined by use of a distraction radiographic technique. The NA is used to measure femoral head subluxation, and RPC is a measure of the percentage of femoral head covered by the acetabulum on standard ventrodorsal joint-extended radiographs of dogs. Personnel at PennHIP and the OFA use numeric scores for hip joint confirmation and degenerative joint disease of dogs by use of independent standardized systems. The CEA, VASA, DASA, HASA, HTEA, and AI are standard measures used to evaluate human 2-D CT hip joint images. Similarly, femoral head- to-acetabulum ratios are measured on SCT and TCT images of hip joints in humans. To our knowledge, these CT measures have not been routinely used in canine patients.

The study reported here was designed to test the hypothesis that measures obtained from CT images have stronger correlations with articular cartilage microstructural changes than with measures obtained from radiographs. The hypothesis was tested by evaluating relationships among established canine radiographic measures and standard human CT measures with microstructural cartilage changes in canine hip joints with moderate to severe joint laxity characteristic of HD. The objective was to determine a combination of imaging modalities and measures that reflect microstructural changes in canine hip joints with the highest accuracy.

**Materials and Methods**

**Animals**—Twelve 30-month-old mixed-breed hounds (progeny of 2 dams and 1 sire) were used for the study. There were 5 males and 7 females with a mean ± SEM body weight of 25.6 ± 1.38 kg (range, 20.0 to 35.0 kg). For inclusion in the study, the DI of both hip joints of each dog had to be ≥ 0.45. One hip joint from each dog was selected for evaluation in accordance with a randomized block design. The study was performed in accordance with institutional and National Institutes of Health regulations governing the treatment of vertebrate animals. Procedures were initiated after approval by a university animal care committee.

**Radiography**—Each dog was anesthetized, and hip extended and distraction radiographs were obtained via established techniques. Radiographs were submitted to PennHIP and the OFA for objective evaluation. For purposes of statistical evaluation, the numeric PennHIP DI score was used as reported, and the degenerative joint disease classification was assigned a numeric score (none = 0; mild = 1; moderate = 2; and severe = 3). Numeric scores were similarly assigned to OFA grades (excellent, good, fair, or borderline = 0; mild = 1; moderate = 2; and severe = 3).

**CT evaluation**—Immediately after radiography, CT images of the pelvis were obtained. Dogs were placed in dorsal recumbency with the hip joints extended, in accordance with established standards. Positioning was maintained by the use of tape and sandbags and confirmed with a survey scan. Transverse pelvic imaging was performed by use of 1.5-mm slice widths. Images were stored on optical disks and transferred to a computer workstation where 3-D images were reconstructed in both transverse and sagittal planes. Both 2-D and 3-D images were printed on radiographic film.

**Radiography and CT measurements**—Radiographic and CT images were digitized at 400 × 400 dots/inch and an 8-bit depth of gray scale by means of a transpar-
ent scan bed of a high-resolution scanner at full size. Images were exported as uncompressed tagged-image file format files and implemented in a graphics software program. The software measuring tool was used to obtain all measurements.

The NA and RPC were measured 3 times for the selected hip joint of each dog (Figure 1). Computed tomography measurements were obtained from 3 contiguous slices, which were selected on the basis that each image contained a clearly defined acetabular fossa, sourcil, fovea capitis, and round femoral heads.

The mean of all measurements was used for statistical analysis.

The center of the femoral head on 2-D CT images was assumed to be the midpoint of a line drawn perpendicular to a straight line that connected the caudal articular cartilage margins on the dorsal and ventral articular surfaces (Figure 2). All measurements were performed in accordance with methods routinely used for images obtained from human patients.

CEA—The CEA is used to assess dorsolateral coverage of the femoral head by the bony acetabulum. It was measured between a line that extended from the center of the femoral head to the dorsolateral point of the labrum and a line perpendicular to the horizontal axis of the pelvis that extended dorsally from the center of the femoral head to the lateral edge of the acetabular rim. The DASA was measured between a line that extended dorsally from the center of the femoral head to the lateral edge of the acetabular rim and horizontal pelvic axis. The HASA was measured between the ventral line of the VASA and dorsal line of the DASA.

HTEA—The HTEA is used to evaluate the lateral slope of the acetabular roof. The angle was measured between a line that extended from the medial edge of the sourcil to the lateral edge of the dorsal acetabular rim and a line that extended laterally from the medial edge of the sourcil parallel to the horizontal pelvic axis (Figure 4). The sourcil is a curved area of dense bone on the weight-bearing surface of the acetabulum, and it is recognized by its sclerotic, arched appearance that resembles an eyebrow.

AI—The AI is the ratio of acetabular depth to acetabular width multiplied by 100. The width was quantified by use of the VASA, DASA, and HASA, respectively.

VASA, DASA, and HASA—Ventral, dorsal, and global acetabular coverage of the femoral head is quantified with the VASA, DASA, and HASA, respectively.

Figure 2—Representative 2-D CT image obtained from a dog indicating the center of the femoral head (X), which was assumed to be the midpoint of a line drawn perpendicular to a straight line that connected the caudal margins of the articular cartilage on the dorsal and ventral articular surfaces.

Figure 3—Representative 2-D CT image obtained from a dog indicating ventral, dorsal, and global acetabular coverage of the femoral head, which was quantified by use of the VASA, DASA, and HASA, respectively. The VASA was measured between the horizontal pelvic axis and a line that extended from the center of the femoral head (X) to the ventrolateral acetabular rim. The DASA was measured between a line that extended from the center of the femoral head to the dorsolateral edge of the acetabular rim and the horizontal pelvic axis. The HASA was measured between the ventral line of the VASA and dorsal line of the DASA. The CEA was used to assess dorsolateral coverage of the femoral head by the bony acetabulum. It was measured between a line that extended from the center of the femoral head to the dorsolateral point of the labrum and a line perpendicular to the horizontal axis of the pelvis that extended dorsally through the labrum from the center of the femoral head.
measured on a line drawn between the dorsolateral and ventrolateral points of the acetabulum, and the depth was measured from the medial edge of the sourcil to the width line (Figure 4).

CPC—The CPC is the ratio of width of the dorso-acetabular shelf to width of the femoral head. It was measured on 2-D CT images, with 3 vertical lines drawn perpendicular to the horizontal pelvic axis (Figure 4). The first line passed along the medial edge of the acetabulum, the second along the lateral edge of the acetabulum, and the third along the lateral edge of the femoral head. The ratio of the distance between the first and second and first and third lines was multiplied by 100 to yield the CPC.

3-D CT images—Measurements were performed on SCT and TCT images to assess the ratio of the exposed femoral head to the acetabular shelf (Figure 5). The distance between the dorsolateral edge of the acetabulum to the most lateral edge of the femoral head was divided by the distance between the ilium and dorsolateral edge of the acetabulum at the same level. Ratios were multiplied by 100 to yield femoral head–acetabular shelf percentages for the SCT and TCT.

Histologic examination—Dogs were euthanized immediately after radiography and CT by IV administration of sodium pentobarbital (200 mg/kg). Hip joints were harvested from each dog, and sections for light microscopy were prepared from the joint used for the radiography and CT measurements. Femoral heads and corresponding acetabulae were sectioned in a coronal plane at the level of the ligamentum teres by use of a precision saw with a diamond wafering blade (Figure 6). Sections were fixed in neutral-buffered 10% formalin and decalcified in citric-buffered formic acid. Sections were embedded in paraffin, and 6-µm-thick sections were then stained with H&E and safranin-O. Stained sections were viewed with light microscopy and graded by use of a revised Mankin scoring method. Evaluations were based on histologic changes in 6 categories (structure of articular cartilage, uptake of fibrocartilage, number of chondrocyte clones, extent of fibrocartilage, number of osteophytes, and condition of subchondral bone). Investigators were not aware of radiographic or CT measurements. Mean scores for each femoral head and corresponding acetabulum were used for statistical analyses. Acetabular and femoral

![Image](https://example.com/image.jpg)

Figure 4—Representative 2-D CT image obtained from a dog indicating the HTEA, which was measured between a line from the medial edge of the sourcil (the dorsum of the sourcil is outlined by white arrows) to the lateral edge of the dorsal acetabular rim (a) and a line that extended laterally from the medial edge of the sourcil parallel to the horizontal pelvic axis. To determine AI, the acetabular width was measured on the line drawn between the dorsolateral and ventrolateral points of the acetabulum, and depth was measured on a perpendicular line from the medial edge of the sourcil to the width line (b). The AI was calculated as b/a X 100. For CPC measurements, a line (line 1) was drawn perpendicular to the horizontal pelvic axis along the medial edge of the acetabulum, a second line (line 2) was drawn along the lateral edge of the acetabulum, and a third line (line 3) was drawn along the lateral edge of the femoral head. The CPC was calculated as (A/B) X 100. See Figure 1 for remainder of key.

![Image](https://example.com/image.jpg)

Figure 5—Representative 3-D SCT (A) and TCT (B) images obtained from a dog, which were used to assess the ratio of exposed femoral head to acetabular shelf. The distance between the dorsolateral edge of the acetabulum to the most lateral edge of the femoral head (a) was divided by the distance between the ilium and dorsolateral edge of the acetabulum (b) at the same level.
head scores were combined to yield a single score for each hip joint.

Statistical analysis—The mean, SEM, median, and range for all measurements were calculated. Relationships of OFA confirmation and PennHIP osteoarthritis scores with radiography, CT, and cartilage variables were evaluated with Spearman rank correlations. Relationships of cartilage scores with radiography and CT measurements were also evaluated with Spearman rank correlations. The Pearson correlation was used to assess relationships of DI with radiography, CT, and cartilage variables. Histologic scores for the femoral head and acetabulum were compared by use of least-squares linear regression.

Analyses were performed with commercially available software programs. For all analyses, values of \( P < 0.05 \) were considered significant. Results were reported as mean ± SEM.

Results

Twelve hip joints were included in the study. Five joints had no osteoarthritis, 2 had mild osteoarthritis, 2 had moderate osteoarthritis, and 3 had severe osteoarthritis on the basis of PennHIP osteoarthritis scores. Four joints had no disease, 3 joints had mild disease, 3 joints had moderate disease, and 2 joints had severe disease on the basis of OFA grades. Mean ± SEM DI score for all hip joints was 0.75 ± 0.09 (range, 0.48 to 1.25; Table 1). Ranges for CT and radiography measurements for each dog were consistent with ranges for DI and radiographically evident joint disease scores.

A strong linear correlation \((r^2 = 0.73; P < 0.001)\) was detected between femoral and acetabular cartilage.

Table 1—Mean ± SEM values for radiographic and microstructural osteoarthritis scores as well as radiography and CT measurements in adult mixed-breed hounds with laxity of the hip joints.

Table 2—Correlation coefficients of osteoarthritis and DI scores with cartilage scores as well as with CT and radiography measurements in adult mixed-breed hounds with laxity of the hip joints.

Figure 6—Photograph of a hip joint of a dog. The region where each femoral head (F) and acetabulum (A) was sectioned is indicated between the parallel black lines. The ligamentum teres (L) is indicated (gray arrow).
scores. The PennHIP osteoarthritis score had significant positive correlations with cartilage score, HTEA, and femoral head–acetabular shelf percentage on TCT (r = 0.70 to 0.92), whereas it had significant negative correlations with CEA, DASA, AI, and CPC (r = –0.71 to –0.92; Table 2). The OFA confirmation score had significant positive correlations with cartilage score, HTEA, and femoral head–acetabular shelf percentage on TCT (r = 0.79 to 0.97) and significant negative correlations with NA, RPC, CEA, DASA, AI, and CPC (r = –0.60 to –0.88). Significant positive correlations were evident between cartilage score, HTEA, and femoral head–acetabular shelf percentage on TCT (r = 0.76 to 0.92), whereas significant negative correlations were evident between cartilage score and NA, RPC, CEA, DASA, HASA, HASA, and AI (r = –0.73 to –0.91). The DI was significantly and positively correlated with cartilage score and HTEA (r = 0.65 to 0.81), whereas it was significantly and negatively correlated with CEA, DASA, HASA, HASA, AI, and CPC (r = –0.72 to –0.81).

**Discussion**

Hip dysplasia in dogs has been a focus of research in pelvic imaging for a number of years. Computed tomography of the pelvis is routinely used for diagnosis, prognosis, and treatment of DDH in humans, but it has had limited application in dogs for the same purposes with regard to HD. Results of studies support the advantages of CT over standard radiography to assess early joint conformational changes characteristic of DDH in humans and HD in dogs. Although major technologic advances, assessment of joint surface changes remains limited with either modality. Therefore, standardized measurements designed to quantify conformational changes are used to predict whether there is disease of the hip joints and progression of disease characteristic of HD on radiographic and CT images. Results of the study reported here supported the use of measurements obtained from both 2- and 3-D CT images of canine hip joints in a standard extended-hip position in combination with established procedures to predict microstructural changes in articular cartilage characteristic of HD.

The acetabular labrum plays an important role in mechanical stability and lubrication of the hip joint. There is a high frequency of acetabular labral tears in the period preceding disease or the early stages of osteoarthritis in humans with HD. Cartilage degeneration generally originates in the dorsocranial weight-bearing region of the femoral head and acetabulum in dogs. Measurements that correlated most highly with cartilage degeneration in the study reported here were the CEA, HTEA, and DASA, which is consistent with information known about progression of hip joint disease. The range of CEA values in this study reflected the laxity of the hip joints in the dogs; the value for CEA was negative when the femoral head was lateral to the bony acetabulum, whereas it was positive when the femoral head was within the acetabulum. The CEA is a fairly sensitive indicator of DDH, and it decreases drastically as disease progresses. Humans whose hip joints are affected by DDH have higher HTEA values than do humans with normal hip joints because of insufficient coverage of the femoral head by the acetabulum, which is similar to the degenerative changes characteristic of HD in dogs illustrated by the results of our investigation. Similarly, DASA and AI values are decreased relative to reference values in human patients with HD, which are also consistent with the findings for the dogs reported here. The significant but less pronounced correlation between HASA and cartilage score was likely attributable to the poor correlation of the VASA with cartilage damage because HASA is the sum of both angles. The strong correlation between 2-D measurements with the PennHIP osteoarthritis score, OFA confirmation score, and DI further indicated their potential to provide an additional amount of information about health of hip joints in dogs.

The PennHIP osteoarthritis score had the strongest correlation with cartilage score of the radiographic scoring systems, with a correlation coefficient within the top 3 of all outcome measures evaluated. Notably, both radiographic scoring systems evaluated in this study had good correlations with cartilage changes. This was not surprising because both systems are designed to detect subtle joint changes characteristic of osteoarthritis through comprehensive evaluations of joint congruity and conformation as well as bony changes. Results of another report support a combination of radiographic measures to predict macroscopic cartilage lesions in young dogs. In the study reported here, CEA, HTEA, and DASA measurements on 2-D CT images and PennHIP radiographic osteoarthritis score were the best predictors of cartilage degeneration. It is possible that a combination of measurements may provide the best representation of the condition of the articular surface in the hip joints of dogs.

The fact that lower NA and RPC corresponded strongly with poorer OFA confirmation and greater microstructural changes in this study is consistent with results of other reports, although microstructural changes were not included in those earlier investigations. An NA ≥ 105º and RPC ≥ 50% are considered to indicate normal hip joint confirmation, but the cutoff values are not applicable to all breeds of dogs. The wide range of NA and RPC values in our study included values within and outside of the reference ranges for most midsize dog breeds. Lack of correlation of the RPC with DI in our study was not necessarily unexpected because DI was measured on distraction radiographs, whereas RPC was not. Lack of correlation between NA measurements with DI and PennHIP osteoarthritis scores contrasts with results of another study in which there was a good correlation in similarly aged dogs. Differences in study populations and designs as well as the methods used complicate direct comparisons among studies.

Measurements on 3-D CT images to evaluate hip joints of dogs is a relatively new concept, although it is established for use in human patients. Three-dimensional imaging provides information that is unavailable on 2-D images, including, but not limited to joint congruency as well as acetabular and femoral shape. The femoral head–acetabular shelf percentage for TCT had strong positive correlations with articular cartilage...
damage, PennHIP osteoarthritis scores, and OFA confirmation scores in the study reported here. Given that the femoral head–acetabular shelf percentage for TCT is a measurement of dorsal femoral head coverage similar to the CEA, HTEA, and DASA, this result was not surprising. The advantages of 3-D imaging for purposes of preoperative planning and assessment of complex DDH have been established, and it is possible that the same may be true for canine patients. The strong correlation of the femoral head–acetabular shelf percentage for TCT with articular cartilage damage supports the use of this measure to predict arthritic cartilage damage; however, the additional step necessary to generate and measure the femoral head–acetabular shelf percentage for TCT may not necessarily be warranted in all cases.

A homogenous canine population was selected for this study to assess the relationship between the outcome measures selected. The DI range included was consistent with a moderate to high likelihood that the dogs would have degenerative joint changes characteristic of HD. Images were obtained from dogs of the same age to limit potential age effects and to increase the potential that dogs in the study population would have a wide range of degenerative changes, rather than advanced disease in all joints. Fulfillment of this objective was supported by the fact that radiographic and microstructural evidence of joint disease ranged from unaffected to severely affected. Although the study population was selected for purposes of specific evaluation, it was not necessarily representative of all dog breeds. Additionally, prognostic value of specific radiographic measurements varies among breeds of dog and on the basis of age. It is possible that the correlations between the measurements used in this study and microstructural articular cartilage changes may vary among dog breeds. Validation steps will be necessary to confirm the relationships in a heterogenous population of dogs.

Computed tomography for evaluation of hip joints in dogs has been reported, with images obtained with the hind limbs in a typical standing position with or without weight-bearing forces. Dogs were placed in a standard hip-extended position for the study reported here to permit measurements routinely performed on CT images of hip joints of humans. Extensive research within the field of CT imaging of human hip joints has permitted the determination of sex-specific cutoff values for the measurements described for the dogs of our study. Additional studies will be necessary to determine similar values for dogs with consideration given to sex- and breed-specific differences.

A number of techniques to assess the condition of articular cartilage have been described for dogs and humans. Arthroscopy, magnetic resonance imaging, and synovial fluid markers of osteoarthritis reportedly are potential diagnostic tools with which to assess early degenerative joint disease that is not radiographically evident. In 1 study, moderate articular cartilage lesions were detected during arthroscopy in hip joints without radiographic evidence of joint disease. Synovial fluid markers of osteoarthritis have been used in dogs and humans as a fairly sensitive mechanism by which to assess changes in articular cartilage. Magnetic resonance imaging is considered an accurate method to assess pathologic changes within the acetabular labrum and adjacent articular cartilage in humans with HD. It is possible that this imaging modality will be useful for the same application in canine patients. Advances in imaging and molecular methods to assess joint disease continue to provide additional information about a condition shared by numerous species.

Osteoarthritis of the hip joints is chronic and progressive, and it is typically diagnosed in relatively advanced stages when clinical and radiographic signs become evident. Methods to predict the condition of articular cartilage and disease progression will substantially enhance therapeutic options for affected animals by permitting early initiation of treatment. For research purposes, accurate methods to monitor disease progression at the microstructural level may reduce the number of required tissue harvests and facilitate assessment of therapeutic interventions. Additionally, the measurements assessed in the study reported here may provide an additional mechanism to elucidate the complex pathophysiological processes of HD in dogs. Computed tomographic imaging is an imaging modality that may result in new standards by which hip joints of dogs are evaluated.

References

## Appendix

Scoring system used for histologic examination of articular cartilage.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Score</th>
<th>Description</th>
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<td>Structure of cartilage</td>
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<tr>
<td>0</td>
<td>No abnormalities</td>
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</tr>
<tr>
<td>1</td>
<td>Surface irregularities</td>
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<tr>
<td>2</td>
<td>Pannus and surface irregularities</td>
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<tr>
<td>3</td>
<td>Clefts from surface to transitional zone and superficial disorganization; loss of boundary between tangential and transitional zones</td>
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<tr>
<td>4</td>
<td>Clefts from surface to radial zone with or without disorganization of radial zone and with or without loss of superficial layers</td>
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<tr>
<td>5</td>
<td>Progression of loss of cartilage into radial zone with or without clefts to radial zone or the mineralized zone</td>
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<tr>
<td>6</td>
<td>Cartilage eroded down to the mineralized zone</td>
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<tr>
<td>Cells</td>
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<td>0</td>
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<td>Diffuse hypercellularity</td>
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<td>Hypocellularity</td>
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<td>4</td>
<td>Severe hypocellularity and cartilage loss</td>
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<tr>
<td>Staining</td>
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<td>Slight reduction in staining with or without reduction of staining in radial zone</td>
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<td>Integrity of mineralized zone</td>
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