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The Effects of Aggressive Notchplasty on the Normal Knee in Dogs*

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ABSTRACT

We assessed the possible association between an aggressive intercondylar notchplasty and histopathologic, radiographic, and gait changes to the knee. Three groups of six adult greyhounds were observed for 6 months. Group I dogs had a sham operation. Group II dogs had a 4-mm notchplasty of the lateral femoral condyle where it articulates with the lateral tibial spine. Group III dogs had a 7- to 8-mm notchplasty of the lateral femoral condyle to simulate the long-term effects of an overly aggressive notchplasty. Force plate gait analyses were not significantly different for any dogs at 3 and 6 months. Histopathologic studies (hematoxylin and eosin and safranin O stains) revealed notchplasty area remodeling with a thin layer of lamellar bone covered by fibrous connective tissue. Both Group II and III dogs had significant loss of lateral femoral condyle and trochlear groove articular surface proteoglycans. The radiographic notch width index remained unchanged throughout the study for Group I; the indexes increased immediately after surgery in Groups II and III because of the notchplasty, but after 6 months these values returned to near-preoperative measurements. An aggressive intercondylar notchplasty caused articular cartilage histopathologic changes at 6 months consistent with those found in knees with early degenerative arthritis. Significant refilling of a nonimpinged notchplasty occurred by 6 months after surgery. Our results raise concern about the effects of aggressive intercondylar notch widening in humans.

Widening the femoral intercondylar notch is currently used routinely in almost all ACL reconstructions. The intent is to prevent ACL graft impingement,[4,15,17,38] improve visualization during surgery, and allow easier passage of the ACL graft. The recommended size of a notchplasty varies from a few millimeters to up to 25% of the lateral femoral condyle.[4,17,20] Two of the authors (RFL and GCT) noted during training sessions on ACL reconstructions in cadaveric knees that some participants perform a rather aggressive widening notchplasty. Our concern about the long-term effects of these notchplasties on the knee led us to perform this study. The purpose of this study was to determine whether intercondylar widening notchplasty contributes to early degenerative arthritic or to gait pattern changes of the knee.

MATERIALS AND METHODS

Animal Model

Eighteen adult greyhounds were used as experimental subjects. Before the study, all dogs were examined for evidence of disease, with a special emphasis on knee (stifle) joint abnormalities. Sex, age (from ear tattoos), and weight were recorded. The animals' health was evaluated by a complete physical and orthopaedic examination, AP and lateral knee radiographs, complete blood count, serum chemistries, urinalysis, and *Ehrlichia canis* and *E. platus* titers.

The dogs were divided into three groups of six dogs each. The first group had a sham control surgery, consisting of a lateral parapatellar arthrotomy with eversion of the patella. The same time of exposure and technique of closure was used in all three groups. The knee joint was left open for 20 minutes, frequent irrigation was performed with normal saline at 37°C, and the ACL was retracted to simulate the manner in which it would be retracted during the notchplasty. For Group II dogs, a notchplasty was performed involving only the portion of the lateral femoral condyle that articulated with the tibial spine (Fig. 1). Before the initiation of the study, the amount of notchplasty was determined to be 4 mm by measurements performed at necropsy on six dogs and was confirmed intra-

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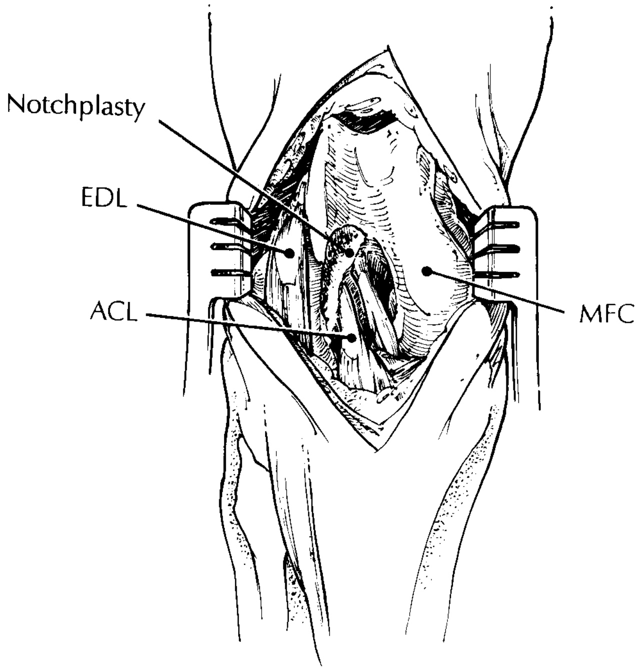

Figure 1. The notchplasty technique in Group II greyhounds. EDL, extensor digitorum longus; MFC, medial femoral condyle.

operatively in all 18 cases. A comparable notchplasty in humans, based on measurements in 50 nonpaired cadaveric knees, would be 6 to 8 mm (R. LaPrade and M. Valastro, unpublished data, 1994). Extreme care was taken during the procedure to protect the fibers of the ACL by placing a periosteal elevator between the bur and the ACL. For Group III dogs, the notchplasty involved 50% (7 to 8 mm; correlate in humans, 12 to 16 mm) of the articular surface of the medial aspect of the lateral femoral condyle, and the ACL was also protected and left intact. For each group of dogs, the contralateral limb was used as a normal control to accommodate the possible variations between individual animals. Meticulous hemostasis of the soft tissues was obtained before closure in all groups.

Animal Housing

Acclimation, cage size, feeding, and care were in accordance with policies adopted by the Auburn University Institutional Animal Care and Use Committee. Housing, feeding, and basic care were overseen and provided by the Auburn University College of Veterinary Medicine's veterinarian.

Preoperative Evaluation

The orthopaedic examination included evaluation of lameness (at rest, during activity, and after activity), range of motion of both knees, thigh circumference, any signs of swelling or tenderness, and clinical limits-of-motion testing. A baseline gait analysis was also performed using video recording and force plate analysis to compare with the postoperative condition. Each dog was videotaped for archival purposes and to ensure that only foot strikes completely on the force plate were included in the evaluation. For each limb, the mean impulse and peak vertical forces were determined from a minimum of five trials and normalized for the dog's weight.

Preparations for Surgery

Anesthesia was induced with thiopental and acepromazine maleate and was maintained with isoflurane. In addition, an epidural anesthetic (morphine, 0.2 mg/kg diluted in sterile saline) was administered to assist in postoperative pain control. After anesthetic induction, preparation of the affected knee was accomplished by random selection of the operative extremity (coin toss) and selection of the technique to be performed. A povidone-iodine preparation (Betadine, Purdue-Frederick Co., Norwalk, Connecticut) was applied after the shaving of the extremity. The surgical approach consisted of a lateral parapatellar incision and dislocation of the patella medially to gain access to the knee.

Synovial Fluid Evaluation

Synovial fluid was aspirated and analyzed before the initial surgery and at sacrifice. A slide preparation of the fluid determined the presence and type of cells. In addition, the synovial fluid was analyzed qualitatively for viscosity. Biochemical analysis of the synovial fluid is part of a separate study group and is not reported here.

Radiographic Assessment

Plain radiographs of the affected and unaffected knees were made preoperatively, immediately after surgery, and at sacrifice (6 months). Additional radiographs of the operative knee joints were obtained at the 3-month interval. Radiographs included AP, lateral, and intercondylar notch views.[26] A notch projection was used to measure the total condylar width, width of the intercondylar notch at the level of the popliteal recess, and the respective widths of the medial and lateral femoral condyles. The notch width index (NWI), a ratio measuring the width of the intercondylar notch divided by the total condylar width of the knee at the level of the popliteal groove on a notch view radiograph,[18,35,36] was recorded for each knee. Evidence of degenerative changes, including osteophytes, was recorded for each knee. An NWI was calculated on the operative limb's intercondylar notch radiograph preoperatively, immediately after surgery, at 3 months, and at sacrifice (6 months). This notch view technique for the canine knee was developed concurrently with this study and has already been reported.[26] In this technique, the canine knee is flexed to 75° and the notch view radiograph is obtained parallel to the intercondylar notch roof while the dog is anesthetized.

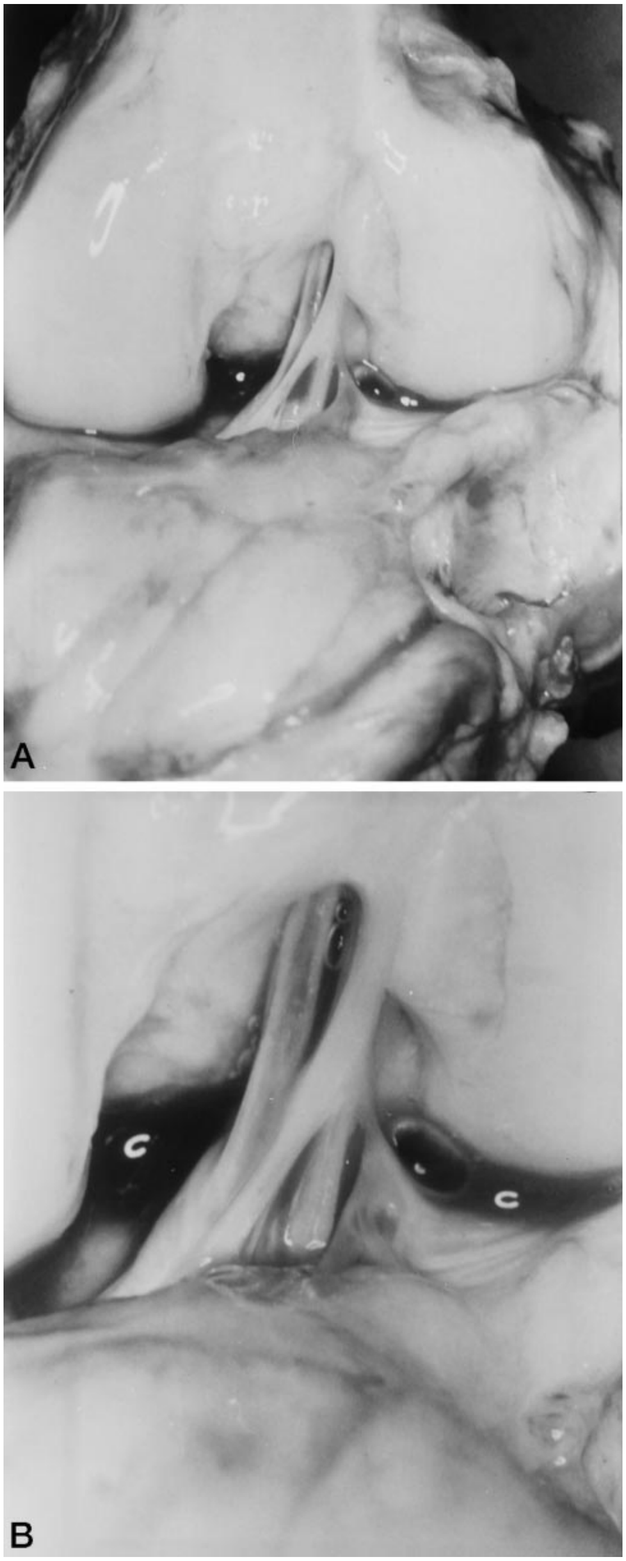

Figure 2. A, distal femur from a Group III dog at 6 months. Osteophytes had partially refilled the widened notch of the medial aspect of the lateral femoral condyle. B, close-up view of the medial aspect of the lateral femoral condyle demonstrating the osteophyte and band of scar tissue found in all Group III dogs.

Postoperative Care

After the completion of each initial operative procedure, the operative knee of each study animal was radiographed to obtain an intercondylar notch radiograph. All animals were monitored during recovery from anesthesia. After recovery, all dogs were returned to the animal housing facilities. Dogs were monitored daily for pain, infection, anorexia, or other signs of disease or distress. Ten days after surgery, the sutures were removed. From 1 month after surgery until the end of the study the dogs were walked 2.5 km on a motorized carousel 3 days a week. The dogs were housed for 180 days after surgery and were allowed unrestricted activity in their runs immediately after surgery.

Once a month, all study group dogs had orthopaedic screening evaluations that included clinical assessment of gait, range of motion, thigh circumference, lameness, and stability, and evaluation of swelling, tenderness, and general orthopaedic wellness. At 3 and 6 months postoperatively, the dogs also had gait assessment on a force plate and radiographic assessment of both the operative and the nonoperative knee joint.

Histologic Studies

All histologic analysis was performed by an experienced musculoskeletal histopathologist (DJS), who was blinded to the type of treatment group and hypothesis of the study. Histologic analysis was performed on both synovial and articular cartilage biopsies. Synovial biopsies were obtained at the time of initial surgery from the synovium over the lateral retinaculum in the lateral gutter and at the time of sacrifice from the synovium over the medial retinaculum from the medial gutter to avoid scarring from healing of the anterior lateral patellar arthrotomy. Hematoxylin and eosin staining was performed on these specimens. Mononuclear cell infiltration was graded according to the Myers classification (grade 0, no mononuclear cell infiltration; grade 1, definite mononuclear cell infiltration; grade 2, diffuse mononuclear cell infiltration).[27]

At sacrifice, a general orthopaedic assessment based on the gross evaluation of the joint structures was made and recorded. Biopsies of the lateral femoral condyle, medial femoral condyle, patellofemoral joint, lateral tibial plateau, and medial tibial plateau were obtained for histopathologic correlation by obtaining slices through the entire condyle. All specimens were fixed in neutral buffered formalin. Hematoxylin and eosin staining was performed to determine the presence of abnormal histologic changes. Safranin O staining was performed at blocks adjacent to the areas tested with hematoxylin and eosin to analyze the proteoglycan content in the specimens. Grading of safranin O staining was performed according to the Mankin scale (normal, 0; slight reduction, 1; moderate reduction, 2; severe reduction, 3; and no dye noted, 4).[22]

Statistical Analysis

Statistical analysis was performed on the data by means of PC-SAS (SAS Institute, Cary, North Carolina). Statis-

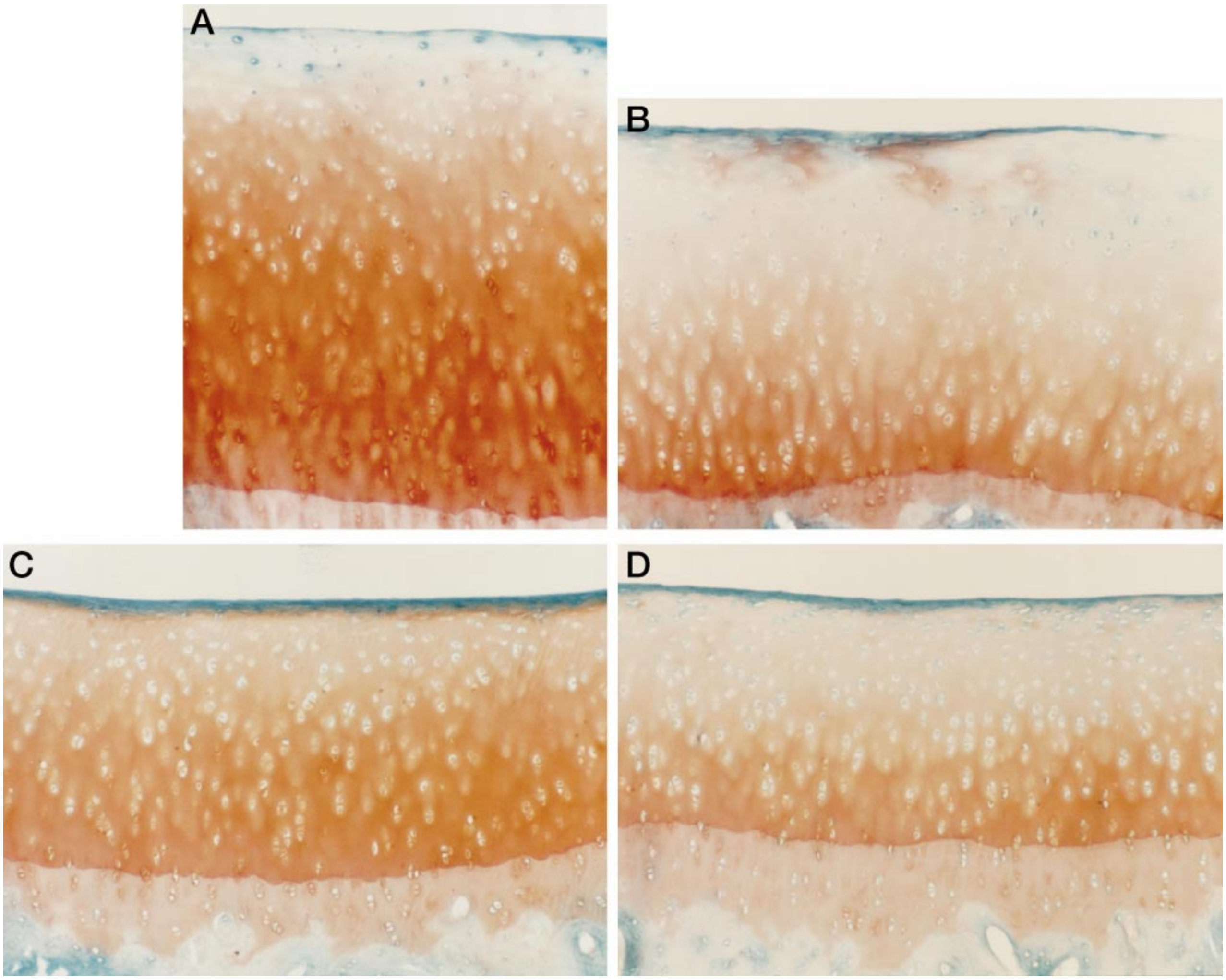

Figure 3. Photomicrographs of the articular cartilage from a greyhound 6 months after an intercondylar widening notchplasty. The thickness of the articular cartilage and the intensity of staining with safranin O are greater in the control knee. A, lateral femoral condyle from a Group III control knee (safranin O staining, magnification ×10). B, lateral femoral condyle from a Group III (extensive notchplasty) operative knee (safranin O staining, magnification ×10). C, trochlear groove from a Group III control knee (safranin O staining, magnification ×10). D, trochlear groove from a Group III operative knee (safranin O staining, magnification ×10).

tically significant differences between groups were evaluated with an analysis of variance (ANOVA). The ANOVA, using the general linear model in PC-SAS, was used to test for differences in thigh circumferences, gait parameters, NWI, and histologic grading scales. Unless explicitly stated otherwise, a P value of <0.01 was considered to be statistically significant. We chose a P value of 0.01 primarily to adjust for the (necessarily) small sample size, reducing the chance of making a type I error. The ANOVA model accounts for the repeated measures, as well as for the multiple comparisons.

RESULTS

Orthopaedic Evaluations

Orthopaedic evaluation revealed no abnormalities in knee limits-of-motion testing in any animal of any group over time. Clinical lameness was resolved by 2 months after surgery in all groups. There was no statistically significant difference in thigh circumference between the operative and nonoperative knees in any group at any time. Likewise, there was no difference in the range of motion of the operative and nonoperative limbs, either between or within groups.

Synovial Fluid Analysis

Normal cells were seen in all dogs both preoperatively and at sacrifice. There was no evidence of any inflammatory reactions or infections. All synovial fluid aspirates had normal viscosity preoperatively, at 3 months, and at sacrifice by qualitative analyses of the amount of stretch between a latex-gloved index finger and thumb. All knees were noted to have approximately 10 cm of stretch as measured by one observer (RDM).

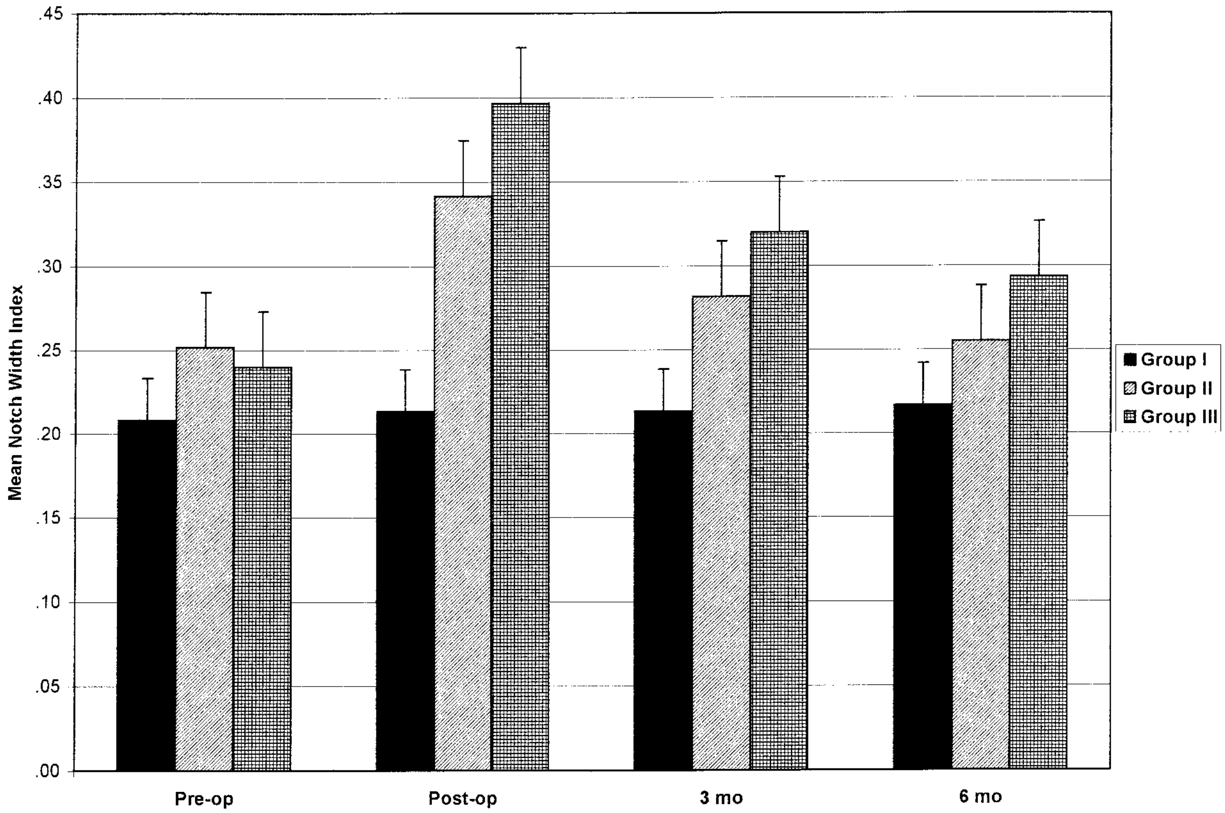

Figure 4. Changes in the measured NWI over time.

Synovial Biopsy Histologic Studies

All three groups of dogs had normal results on preoperative synovial histologic tests (Myers scale, 0.0). Postoperatively, all three groups showed evidence of mild subsynovial fibrosis consistent with surgery and injury. Group I dogs had an average Myers scale grade of 0.0 (±0.0 SD), and the average grade for Group II dogs was 0.17 (±0.41 SD). Group III dogs, with an average Myers scale grade of 0.83 (±0.41 SD), demonstrated a significant increase in subsynovial lymphocytes and plasma cells in addition to the mild subsynovial fibrosis demonstrated in the other groups ($P = 0.007$). Synovial infiltration by polymorphonuclear leukocytes was not present in any specimen.

Articular Cartilage Analysis

Macroscopic examination revealed a normal appearance (white and shiny) of all Group I and control knees. Group II knees had a mild but noticeable loss of surface luster. Group III knees demonstrated a bluish discoloration with a mild loss of surface luster. All knees had a normal-appearing ACL. All Group III dogs had a large band of fibrous scar tissue, which was not seen in Group I or II dogs, from the retropatellar fat pad to the superomedial aspect of the notchplasty. Osteophyte formation was present in all Group II and III dogs and was always in the region of the previous notchplasty (Fig. 2). No osteophytes were seen in the Group I or control knees.

Articular cartilage from Group I dogs demonstrated no changes when compared with that from control knees for both hematoxylin and eosin and safranin O staining (average Mankin scale for safranin O, grade 0.0 [±0.0 SD] for both control and Group I knees). Group II dogs demonstrated minimal loss of surface safranin O staining (basophilia) in the lateral femoral condyle and trochlear groove, with an average Mankin grade of 1.0 (±0.0 SD), and showed no changes compared with the controls for hematoxylin and eosin staining. The difference in safranin O staining on the Mankin scale was statistically significant compared with that in the control and Group I knees ($P < 0.05$). Group III dogs showed mild to moderate loss of surface basophilia, which again was located in the lateral femoral condyle and trochlear groove (Fig. 3). The average Mankin grade for Group III dogs was 1.8 (±0.41 SD). Group III dogs demonstrated a statistically significant difference in safranin O staining compared with that of Group I, Group II, and control knees ($P < 0.001$). In addition, there were mild surface fibrillations and occasional hyaline cartilage cell cloning seen with hematoxylin and eosin staining in the lateral femoral condyle and trochlear groove in this group.

Radiographic Analysis

Preoperatively, no evidence of periarticular osteophytes, subchondral sclerosis, or decreased joint space was seen in any knee of any dog. The radiographs that were obtained preoperatively, at 3 months, and just before sacrifice for the AP and lateral knee projections of the operative limb also demonstrated no periarticular osteophytes, subchondral sclerosis, or decreased joint space in any group.

Group I dogs showed no statistically significant changes in the NWI over time. For both Group II and Group III dogs, there was a statistically significant difference between the preoperative and postoperative NWIs and also significant refilling of the notchplasty areas with bone at both 3 and 6 months postoperatively ($P < 0.001$) (Fig. 4).

Gait Analysis

Gait analysis was performed preoperatively, at 3 months, and just before sacrifice (6 months).[9] No statistically significant differences were found for the normalized impulse of vertical force or the normalized peak force between any groups and controls or between any time intervals.

DISCUSSION

Intercondylar notchplasty has been used for more than a decade as an adjunct in ACL reconstructive surgery. Up to this point, however, no assessment of the potentially harmful effects of a notchplasty on the knee has been made. In addition, the recommended size of an intercondylar notchplasty area has not been well defined.

Magill,[20] in 1982, and Kieffer et al.,[17] in 1984, were among the first to report on notchplasty in the course of an ACL reconstruction. Magill recommended that up to 25% of the lateral femoral condyle be removed for the notchplasty. Tanzer and Lenczner[38] recommended that when the ACL graft is wider than 8 mm, the surgeon should perform a notchplasty to prevent impingement of the graft on the medial aspect of the lateral femoral condyle, but no specific size was recommended for a notchplasty. Berg,[4] in 1991, reported that an NWI must be greater than or equal to 0.25 to accommodate ACL reconstructive grafts at the time of surgery, and he advised that knees with an NWI less than this should have the notch widened to achieve an NWI of at least 0.25 before placing the ACL graft. In addition, Good et al.[14] noted that the medial aspect of the lateral femoral condyle forms a lip, and they recommended that this lip be removed concurrent with the ACL reconstructive notchplasty. It was this lip, also present in the canine knee, that was removed in the Group II dogs in our study. We chose a larger notchplasty area in Group III dogs to evaluate the effects of an aggressive notchplasty on the knee.

The purpose of this study was to determine whether an aggressive notchplasty contributes to harmful changes in the knee. The animal model for this study was chosen for several reasons. Greyhounds are a uniform breed, and their joints are large enough to study both topographically and morphologically. In addition, the canine knee (stifle) joint has been shown in several studies to provide histologic and radiographic changes that are indistinguishable from early osteoarthritic changes seen in human knees.[1–3,5–7,11–13,16,21,24,25,27,28,30,32–34,37,39,40] Leaving the ACL intact gave the best in vivo method of studying the isolated effects of a notchplasty in this model.

Effects of an Aggressive Notchplasty on a Knee

The early histologic changes of osteoarthritis in articular cartilage have been studied extensively.[3,5–7,16,22,27,32,33] One of the earliest detectable histologic markers of osteoarthritis is a loss of proteoglycans. Proteoglycans are responsible for the compressive stiffness of articular cartilage and also arrest the flow of interstitial water.[23] Changes in proteoglycan quality, quantity, and organization occur before other articular cartilage histologic changes, such as cell cloning or surface fibrillation. Safranin O stains are a semiquantitative measure of the amount of proteoglycans in a given specimen when graded histologically by the Mankin classification.[22] In this study, we found that Group II and Group III dogs had a statistically significant difference in safranin O staining of the lateral femoral condyle and trochlear groove compared with that in the contralateral control knees and Group I (sham) knees. This difference indicates that, at 6 months, an aggressive intercondylar notchplasty in the greyhound knee may contribute to early arthritic changes in the knee. Further study is necessary to determine whether these abnormal articular cartilage changes contribute to degenerative arthritis over time.

The sham-operated (Group I) dogs had essentially normal knees and results comparable with those of the sham-operated dogs in the literature.[8,10,24,29,30,32] They had normal force plate gait studies, mild subsynovial fibrosis on synovial biopsy, and normal articular cartilage compared with the control knee at 6 months after surgery. The mild subsynovial fibrosis that we found has been found in sham-operated dogs in the past.[31]

The notchplasty in Group II dogs attempted to more closely approximate the extent of an aggressive intercondylar notchplasty performed during some human ACL reconstructions. The notchplasties performed in this group removed the portion of the medial aspect of the lateral femoral condyle that articulates with the lateral tibial spine, which is the portion of the lateral femoral condyle that forms a small medial lip. These dogs had a mild degree of subsynovial fibrosis and a statistically significant loss of surface proteoglycans.

Group III dogs demonstrated statistically significant results with an active, low-grade synovitis on synovial biopsy. Group III dogs also had a mild but significant increase in their subsynovial lymphocytes and plasma cells, possibly indicating a reaction to degenerative chondrosis. This finding indicates that Group III dogs had an active, low-grade synovitis at 6 months after notchplasty[12,19,31] that was not present in either of the other two groups of dogs. In addition, Group III dogs had a significant mild-to-moderate loss of surface proteoglycans.

Thus, at 6 months after surgery, more early articular cartilage histopathologic changes were present in the

Group III dogs. Although Group III dogs, where 50% of the articular surface of the medial aspect of the lateral femoral condyle was removed, had more extensive notchplasties than has been recommended or reported on for human ACL reconstructions, the results could potentially represent the long-term effects of an overzealous notchplasty. The significantly abnormal articular cartilage changes that were seen in Group III dogs, as well as in Group II dogs with aggressive notchplasties similar to that performed during some human ACL reconstructions, indicate that more study is necessary to determine the long-term effects of an intercondylar notchplasty on the knee. Even though the overall effect of a notchplasty on the knee did not result in any outward clinically apparent changes (gait mechanics or thigh circumference), until further long-term study on this subject is performed we recommend that the size of the notchplasty area be limited and only that portion of the medial and superior aspect of the lateral femoral condyle that would cause impingement on the ACL graft be removed. We also suggest that notchplasty not be performed if there is no impingement.

We believe that a careful assessment of the size of the intercondylar notch should be undertaken before performing a widening intercondylar notchplasty at the time of an ACL reconstructive surgery. If there is no graft impingement, then no notchplasty is necessary. Also, one must make sure that the tunnels are in the correct location. Based on our findings, any notchplasty larger than that necessary to prevent graft impingement could potentially cause histopathologic changes in the articular cartilage and could fill in with abnormal fibrocartilage and lamellar bone (rather than normal hyaline cartilage) over time.

Although the results of this study seem to indicate that the measurable effects of a limited notchplasty are minimal, we did not specifically test for this condition. Further studies on more limited notchplasties and longer followup within groups have been planned.

The Fate of Notchplasty Areas Over Time

In this stable canine knee model, the notchplasty areas for both Group II and Group III dogs showed a statistically significant filling-in over time with lamellar bone and fibrocartilage (Fig. 4). This trend was statistically significant at both 3 and 6 months. The dogs in our study had normal ACLs both after the initial operative procedure and at the time of sacrifice. There was no evidence of instability by clinical testing in any knee of any dog. We believe the reason the notchplasty areas in this study filled in over time is that they were not impinged on. There was no detectable instability noted in our study, either clinically or via gait analysis, that could have contributed to the filling-in of the notchplasty area with osteophytes. We speculate that this may be the mechanism for osteophyte formation in the intercondylar notch of some or all ACL-deficient knees. We also recognize that instability may contribute to the formation of these osteophytes in an ACL-deficient knee.

CONCLUSIONS

This is the first study, to our knowledge, that evaluated gait and force plate studies, histologic changes, and radiographic changes concurrently to assess the effects of a surgical procedure on the knee. We found that an aggressive intercondylar notchplasty of the knee has a role in abnormal articular cartilage changes of the lateral femoral condyle and trochlear groove 6 months postoperatively in a canine model. We also found that a significant refilling of a nonimpinged notchplasty area occurs over the same time interval. We recommend that the size of the human intercondylar notchplasty be limited to that portion of the lateral femoral condyle that would cause impingement on the ACL graft at the time of reconstruction. If there is no impingement, then no notchplasty is necessary. Based on the results of this study in the greyhound dog, any notchplasty area larger than this could potentially lead to permanent articular cartilage damage and would fill in with lamellar bone and fibrocartilage. More study is necessary to assess the long-term effects of an intercondylar notchplasty on the knee.

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