Preventing Friction-induced Chondrocyte Apoptosis: Comparison of Human Synovial Fluid and Hylan G-F 20

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ABSTRACT. ***Objective.*** Symptomatic osteoarthritis (OA) is a common painful disease with limited treatment options. A rising number of patients with OA have been treated with intraarticular injections of hyaluronic acid, including the high-molecular-weight hylan G-F 20, which is injected following arthrocentesis. We investigated the effectiveness of hylan G-F 20 to lower coefficient of friction (COF) and prevent chondrocyte apoptosis *in vitro*.

Methods. A disc-on-disc bovine cartilage bearing was used to measure the static and kinetic COF when lubricated with hylan G-F 20, human synovial fluid (HSF), and phosphate buffered saline (PBS). Following friction testing, we stained paraffin-embedded sections of these cartilage bearings for activated caspase-3, a marker of apoptosis.

Results. Bearings lubricated with hylan G-F 20 had kinetic COF values that were similar to bearings lubricated with PBS, but significantly higher than those lubricated with HSF. There were no significant differences in static COF values in bearings lubricated with hylan G-F 20 as compared to PBS or HSF. However, bearings lubricated with HSF had significantly lower static COF values compared to bearings lubricated with PBS. The mean percentage of caspase-3-positive chondrocytes in the superficial and upper intermediate zones of bearings lubricated with hylan G-F 20 was significantly higher compared to that of bearings lubricated with HSF or unloaded controls, but significantly lower than in those lubricated with PBS.

Conclusion. These findings indicate that joint lubrication may prevent chondrocyte apoptosis by lowering the COF. Further, removal of synovial fluid prior to hylan G-F 20 injection may be detrimental to cartilage health. (First Release June 1 2012; J Rheumatol 2012;39:1473–80; doi:10.3899/jrheum.111427)

Key Indexing Terms:
ARTICULAR CARTILAGE CHONDROCYTE APOPTOSIS SYNOVIAL FLUID HYLAN

Osteoarthritis (OA) is a painful, debilitating disease in articular joints, with large societal implications[1,2]. Currently, treatment options for patients with OA are severely limited, and no disease-modifying treatments, apart from total joint replacement, are available. Most patients are treated with nonsteroidal antiinflammatory drugs or corticosteroid injections to relieve pain. Viscosupplementation is becoming a popular alternative. In it, various forms of hyaluronic acid (HA), including hylan G-F 20 (Synvisc®, Genzyme Corp., Cambridge, MA, USA), are administered by intraarticular injection.

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Synovial fluid is a blood plasma dialysate that contains lubricating components, including HA and lubricin, which are important to joint lubrication and hence chondroprotection to articular joints. HA is thought to play a number of roles in synovial fluid, including shock absorption and lubrication, and is responsible for the viscoelastic behavior of synovial fluid[3]. Joint lubrication occurs in both hydrodynamic and boundary modes[4]. HA is vital to hydrodynamic joint lubrication, which occurs when the fluid layer is wider than the surface asperities and is dominated by fluid mechanics, including viscosity[4]. During periods of high load and low velocity, lubricin serves as the primary boundary lubricant in joints, particularly when cartilage is pressurized during gait. However, HA has also been shown to contribute to lubrication in the boundary mode, particularly in combination with lubricin[5,6,7,8,9].

Healthy articular cartilage is smooth and void of fissures or attachments[10]. In addition to surface fibrillation and ultimately full-thickness cartilage loss, osteoarthritic cartilage loses chondrocytes through apoptosis[10,11,12]. It is important to note that chondrocytes maintain various metabolic functions in articular cartilage, including the maintenance of the extracellular matrix[13,14], and that OA pathogenesis is mediated in part by apoptotic mechanisms[15,16,17]. Cartilage wear leading to OA and precocious joint failure has been reported in the absence of adequate joint lubrication *in vivo*[18,19,20], but the biological underpinnings of wear in response to mechanical mechanisms have not been established. Since articular cartilage has little capacity for renewal, preventing apoptosis by supplemental lubrication may be key to counteract the onset of OA and vital to cartilage preservation[21].

We investigated the effectiveness of using hylan G-F 20 for lubricating cartilage bearings in the boundary mode to prevent chondrocyte apoptosis, using a bovine *in vitro* disc-on-disc cartilage bearing[9,22]. We hypothesized that the coefficient of friction (COF) using hylan G-F 20 would be less than that of phosphate buffered saline (PBS) and equal to that of human synovial fluid (HSF). We also hypothesized that the percentage of cells stained for activated caspase-3, a marker of chondrocyte apoptosis, of the bearing lubricated with hylan G-F 20 will be less than that of PBS and equal to that of HSF.

MATERIALS AND METHODS

Bovine cartilage preparation. Full-thickness cartilage plug bearings 6 mm (small disc) and 12 mm (large disc) in diameter were cored from the approximate load-bearing regions of femoral condyle of bovine stifle joints (n = 5) collected within 2 hours of slaughter. Following harvest, the bearings were rinsed 3 times with cell culture media (Dulbecco modified Eagle's medium/5% fetal bovine serum) and cultured for 24 hours at 37°C. Testing was performed on the cultured plugs at room temperature (RT).

Test lubricants. Hylan G-F 20 was kept at RT and away from light until testing. During testing, it was directly applied to cartilage-bearing surfaces from the product packaging using a 22-gauge needle. HSF was aspirated from knee joints of post-mortem donors with no history of joint disease within 12 hours of death (3 male donors, ages 25–39 yrs), or aspirated from patients undergoing total joint replacement. Both types of HSF were collected in the operating room and pooled together (n = 12). All HSF was frozen and stored at –80°C until analysis and testing. Plasma protein levels in the synovial fluids were not measured[23], but synovial fluids visibly contaminated with blood were not used. PBS served as a negative control. All lubricants were tested at RT.

ELISA of HSF. An ELISA using anti-lubricin monoclonal antibody 9G3 was designed and validated. High-binding 96-well plates were coated overnight with purified human lubricin in 0.1 M NaH_2PO_4, Na_2HPO_4 buffer, pH 6.5, at a final concentration of 10 μg/ml. The plates were washed and blocked with 5% milk in PBS and Tween 20 (PBST) for 2 h at RT. The plate was subsequently washed with PBST. HSF test samples were added to the plate at 1:50 dilution, then 9G3 was subsequently added at 1:5000 dilution, and the plate was incubated 1 h at RT. After a wash with PBST, goat anti-mouse IgG was added to the plate at 1:2000 dilution and incubated 1 h at RT. The plate was then washed, and tetramethylbenzidine single solution (Invitrogen) was added. Thirty minutes later, 1 M hydrochloric acid was added to stop the reaction, which was read at 450 nm.

Friction and wear testing in bovine bearings. Prior to testing, the average total cartilage thickness for each bearing pair was calculated (2.84 ± 0.38 mm) from caliper measurements at 4 regions around the circumference of both the small and large cartilage bearings. Small bearing diameters (5.45 ± 0.28 mm) were also measured using calipers.

Cartilage bearings were loaded in a disc-on-disc configuration using a material testing system (EnduraTEC 3200; Bose Corp., Eden Prairie, MN, USA), which was programmed to apply an axial strain while axial rotations were prescribed to the bearing (Figure 1). This testing paradigm was adapted from Schmidt and Sah to accommodate cell culture following friction and wear testing[22]. The maximum ranges of the load, torque, and displacement transducers of the test system were ± 22 N, ± 0.7 Nmm, and ± 6.5 mm, respectively. The cartilage bearings were fixed to the testing platform with cyanoacrylate glue, which was applied to the bony surface of the bearing plugs and allowed to dry completely before testing. During this time, cell culture media was added between the joint surfaces to prevent cartilage desiccation. Prior to testing, cell culture media was then rinsed off the cartilage-bearing surfaces 3 times with PBS. Test lubricant, either PBS, hylan G-F 20, or HSF, was applied between the bearing surfaces (n = 8 for all groups). The bearings were axially loaded to 18% of the mean total cartilage thickness, and held at that displacement for 8 min to allow fluid depressurization[9,22,24]. The large disc was then rotated in torsion +2 revolutions and reset –2 revolutions at an effective velocity of 0.3 mm/s[9] for 12 continuous cycles. Unloaded control discs, 12 mm in diameter, were kept in cell culture media during testing. All tests were performed between 48 and 72 h of harvest; individual bearings were tested only with a single lubricant; and bearings taken from each knee were tested using each test lubricant.

COF determination. The static COF (a measure of the stick-slip condition) and the kinetic COF (a measure of the equilibrium COF) were calculated using Equation 1[22].

$$\text{COF} = \text{torque absolute value}/(1/3 \times \text{small disc diameter} \times \text{axial force})^1$$

To calculate the static COF, the absolute maximum torque that occurred within the first 10° of rotation and the equilibrium axial force following the 8-min depressurization period were substituted into Equation 1. To calculate the kinetic COF, the average torque observed during the last 720° of rotation and the equilibrium axial force were used.

Activated caspase-3 staining and quantification. To test the efficacy of each lubricant in providing chondroprotection during frictional testing, we stained paraffin-embedded sections of each large cartilage-bearing disc with an antibody specific for activated caspase-3, which stains chondrocytes primed for apoptosis. Immediately following testing, cartilage discs were fixed in 10% buffered formalin. The unloaded control discs were also fixed in formalin at the time of testing. The discs were paraffin-embedded and cut vertically at the center of the disc into thin sections of full cartilage thickness (250 μm). Sections were heated to 60°C for 30 min, deparaffinized, and hydrated in xylene and alcohol. Rabbit polyclonal antibody against active caspase-3 (cat. no. ab13847, Abcam, Cambridge, MA, USA) at 1:50 dilution was added to slides at 40°C overnight according to VectaStain procedures. Following the addition of biotinylated secondary antibody solution and 3,3'-diaminobenzidine, slides were counterstained with 0.5% methyl green and coverslip slides fixed with Permount mounting media (Fisher Scientific, Waltham, MA, USA). Apoptosis quantification was performed at 20× magnification for cells in the superficial and intermediate zones along the articular surface, where loading occurred at 3 areas of interest. Images were captured at 20× with Image-Pro Plus software (Media Cyberkinetics, Bethesda, MD, USA). The percentage of apoptotic cells was determined by counting the number of cells positive for activated caspase-3 and the total number of cells for 3 distinct 100-μm zones representing areas of the superficial and upper intermediate zones: Zone A (articular surface 100 μm deep), Zone B (100–200 μm deep), and Zone C (200–300 μm deep). Total percentage of apoptotic cells refers to the mean across all 3 zones.

Terminal deoxynucleotidyl transferase dUTP nick end-labeling (TUNEL) staining. To confirm apoptosis in the bovine cartilage discs, we performed a TUNEL assay on the large bovine cartilage disc sections using an ApopTag Plus Peroxidase In Situ Apoptosis Kit (Millipore, Billerica, MA, USA). Sections were heated at 60°C for 30 min, deparaffinized in 3 changes of xylene and serial ethanol, then pretreated with proteinase K (20 μg/ml) for 15 min at room temperature, endogenous peroxidase was quenched in 3% hydrogen peroxide for 5 min, and incubated with equilibration buffer for 30 s. Excess liquid was tapped off and the sections were incubated with terminal deoxynucleotidyl transferase enzyme at 37°C for 1 h in a humidified chamber. After the reaction was stopped, sections were washed 3 times in PBS, and incubated with antidigoxigenin conjugate for 30 min at room temperature and washed again in PBS. Peroxidase substrate was applied to sections, which were stained for 4 min, washed in deionized H_2O, and counterstained with 0.5% methyl green. Sections were washed in deionized H_2O again, dehydrat-

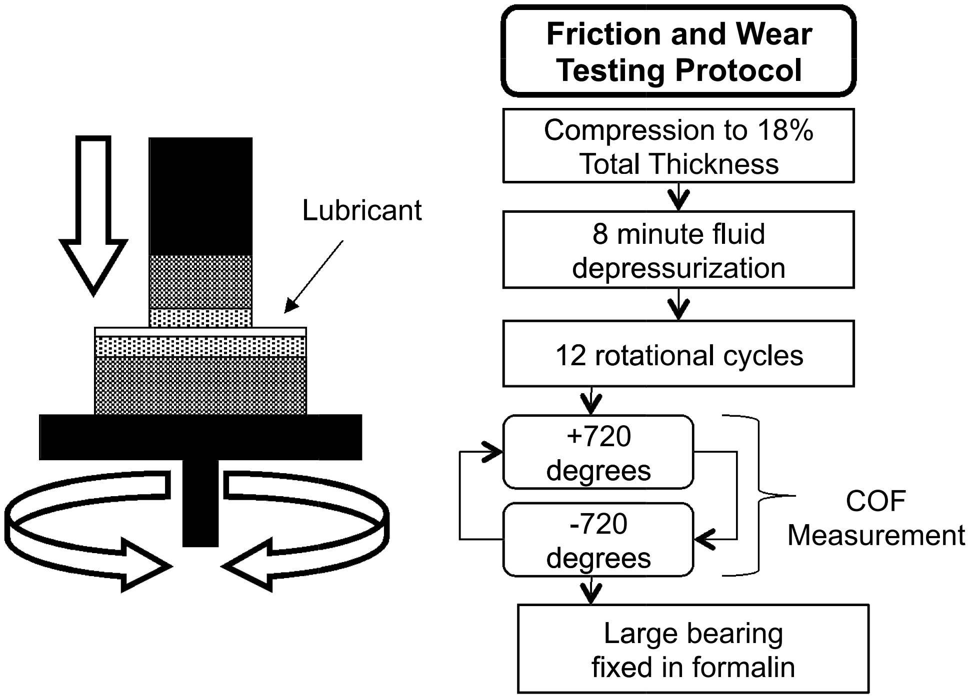

Figure 1. Schematic diagram of friction and wear testing system and the experimental protocol. Test lubricant was applied between the bearing surfaces, and the bearings were axially loaded to 18% of the mean total cartilage thickness, and held at that displacement for 8 min to allow for fluid depressurization. The large disc was then rotated in torsion +2 revolutions and reset –2 revolutions at an effective velocity of 0.3 mm/s for 12 continuous cycles. Axial load and torque were measured throughout the testing protocol.

ed in xylene 3 times, and then mounted with Permount. Images were captured at 20× with Image-Pro Plus software.

Statistical analysis. Comparisons were made between the COF values for the different test lubricants (PBS, hylan G-F 20, HSF) and unloaded control specimens using Kruskal-Wallis 1-way ANOVA on ranks with Dunn's multiple comparison post hoc tests using the Unistat Statistical Package (Unistat Ltd., London, England). The tests were run separately for the static and kinetic COF values. The percentages of apoptotic cells measured in Zone A, Zone B, and Zone C of histological sections were compared using a repeated measures 2-way ANOVA with Holm-Sidak multiple comparison post hoc tests using Sigmaplot software (Systat Software Inc., Chicago, IL, USA). Pearson correlation coefficients between the static COF and the percentage of apoptotic cells in Zone A and correlations between kinetic COF and the percentage of apoptotic cells in Zone A were performed, and a linear regression was fitted to each plot, using Sigmaplot software. Goodness of fit and significance of the correlation are reported. For all analyses, statistical significance was set at $\alpha = 0.05$ *a priori* and the 2-tailed p value is reported. All values are presented as the mean ± SD.

RESULTS

COF. The mean static COF was significantly lower for HSF-lubricated bearings compared to PBS-lubricated bearings ($p = 0.006$; Figure 2). Hylan G-F 20-lubricated bearings had a mean static COF that was not significantly lower than PBS ($p = 0.18$) or significantly higher than HSF ($p = 0.67$). However, the mean kinetic COF values were significantly lower for the bearings lubricated with HSF compared to those lubricated with hylan G-F 20 ($p = 0.022$) or PBS ($p = 0.003$). There was no difference between hylan G-F 20 and PBS. There was no difference between COF from sources of HSF (static COF $p = 0.070$ and kinetic COF $p = 0.086$), and lubricin concentrations were similar (288 ± 77.7 μg/ml for post-mortem HSF and 416 μg/ml for pooled total joint replacement HSF). The equilibrium axial load was 2.11 ± 0.92 N, which corresponds to 0.09 ± 0.03 MPa, and the maximum load applied to the bearings was 13.51 ± 5.3 N, which corresponds to 0.58 ± 0.23 MPa.

Caspase-3 and TUNEL. A significant interaction ($p < 0.001$) was observed between the lubricant treatment group and zone. Hylan G-F 20-lubricated bearings had significantly higher mean percentages of apoptotic cells in Zone A and Zone B, and when pooled over all 3 zones as compared to HSF-lubricated bearings (Zone A, $p < 0.001$; Zone B, $p = 0.006$; total, $p < 0.001$) and unloaded controls (Zone A, $p < 0.001$; Zone B, $p = 0.004$; total, $p < 0.001$), but there was no difference between the groups in Zone C (Figure 3). A significant increase in the mean percentage of cells staining positive for activated caspase-3 was observed in bearings lubricated with PBS compared to bearings lubricated with HSF (Zone A, $p < 0.001$; Zone B, $p < 0.001$; Zone C, $p = 0.003$; total, $p < 0.001$), hylan G-F 20 (Zone A, $p < 0.001$; Zone B, $p = 0.005$; total, $p = 0.001$), and unloaded bearings (Zone A, $p < 0.001$; Zone B, $p < 0.001$; Zone C, $p = 0.005$; total, $p < 0.001$). We also observed significant differences between the zones in bearings lubricated with PBS and hylan G-F 20. For those bearings,

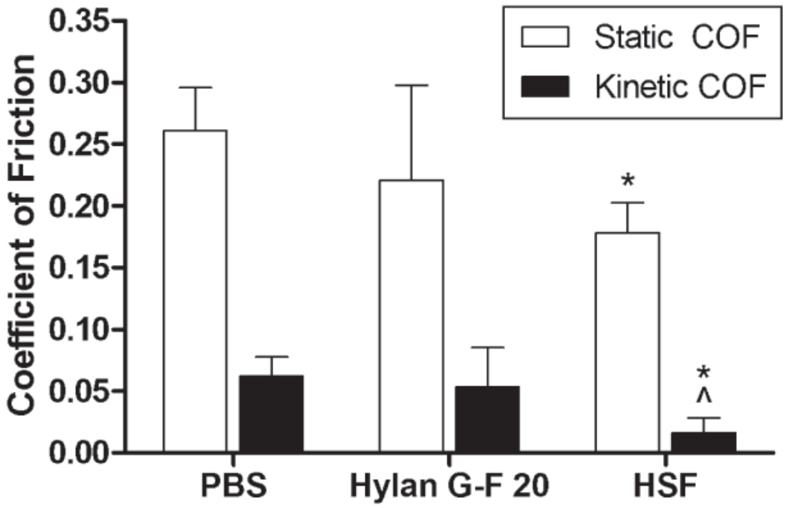

Figure 2. Coefficient of friction (COF) of bovine osteochondral bearings. Bearings were tested with test lubricants, either phosphate buffered saline (PBS), hylan G-F 20, or human synovial fluid (HSF), following the protocol outlined in Figure 1. Lubrication with HSF had the lowest mean static and kinetic COF values. Bearings lubricated with hylan G-F 20 had no significant difference compared to either group in static COF, but had a significantly higher kinetic COF compared to HSF. *Significant compared to PBS; $p < 0.05$. ^Significant compared to hylan G-F 20; $p < 0.05$.

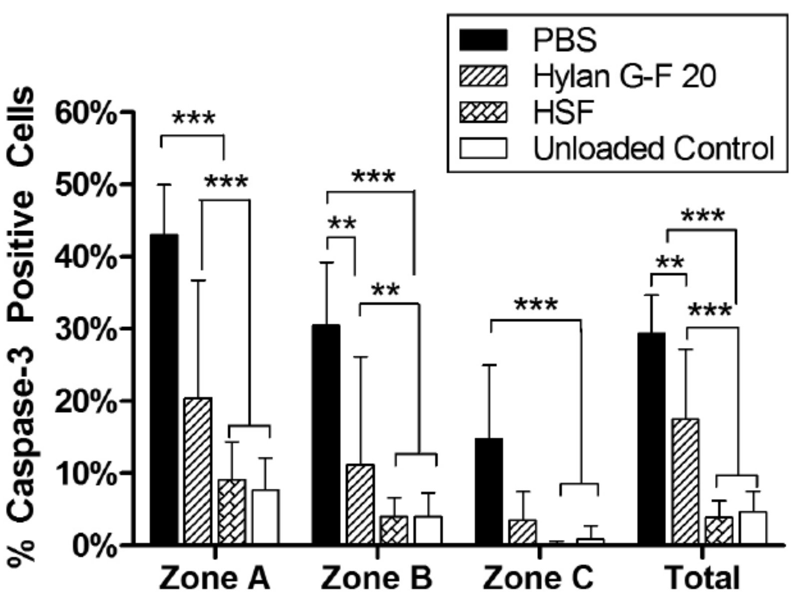

Figure 3. Activated caspase-3 in superficial and upper intermediate zone chondrocytes. Bearings lubricated with hylan G-F 20 had a significantly higher percentage of cells positive for activated caspase-3 in Zone A, Zone B, and across all zones compared to unloaded control bearings or bearings lubricated with human synovial fluid (HSF), indicating that hylan GF-20 is less chondroprotective than HSF. Bearings lubricated with phosphate buffered saline (PBS) had a significantly higher percentage of apoptotic cells in all zones compared to all other groups. **$p < 0.01$; ***$p < 0.001$.

Zone A had a significantly higher mean percentage of apoptotic cells compared to Zone B (PBS, $p < 0.001$; hylan G-F 20, $p = 0.004$), and in Zone B compared to Zone C (PBS, $p < 0.001$; hylan G-F 20, $p = 0.009$). HSF also showed a significant difference between Zone A and Zone C ($p = 0.028$). Cells in representative osteochondral plugs staining positive for activated caspase-3 were also TUNEL-positive (Figure 4).

Correlation between static and kinetic COF and percentage

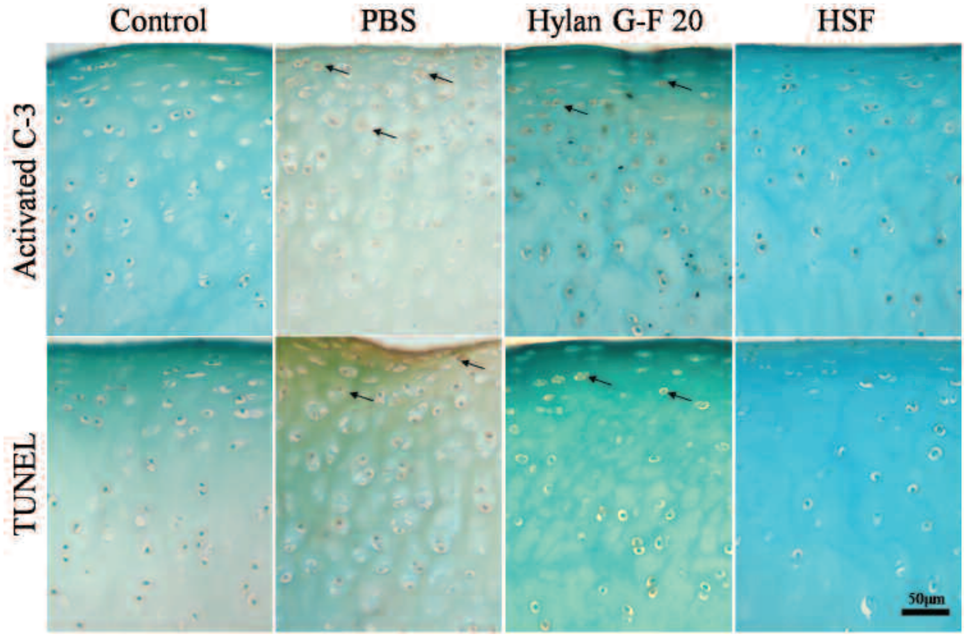

Figure 4. Bovine osteochondral bearings stained for activated caspase-3 (top) and TUNEL (bottom). Cells positive for activated caspase-3 and TUNEL are brown. Negative cells are stained blue. We observed more apoptotic cells in the phosphate buffered saline (PBS) and hylan G-F 20-lubricated bearings compared to human synovial fluid (HSF)-lubricated bearings and unloaded controls.

of apoptotic cells. We observed a positive correlation between static COF values and the percentage of apoptotic cells (p = 0.007) and between kinetic COF values and the percentage of apoptotic cells (p = 0.015). Figure 5 shows HSF data points clustered near the origin, indicating that low COF values correspond with a low percentage of apoptotic cells. In contrast, the PBS data points clustered further up the regression line, indicating that high COF values correspond with a high percentage of apoptotic cells. The data points for the bearings lubricated with hylan G-F 20 fell between the high and low clusters, indicating that hylan G-F 20 possesses better chondroprotective and lubricating ability as compared to PBS.

DISCUSSION

We observed a significantly higher mean percentage of caspase-3-positive and a significantly higher mean kinetic COF in bearings lubricated with hylan G-F 20 compared to those lubricated with HSF. While these findings suggest that hylan G-F 20 was able to prevent apoptosis with more efficiency than PBS, apoptosis was more prevalent compared to the HSF-treated bearings. Further, hylan G-F 20 was unable to

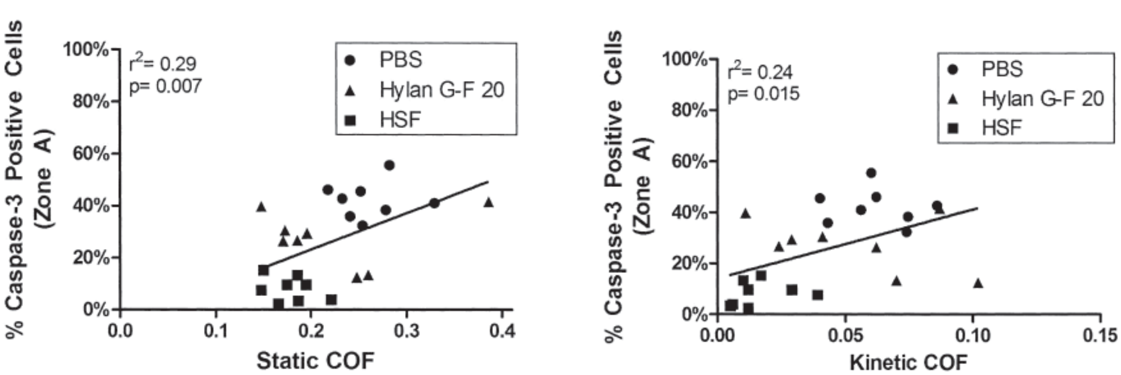

Figure 5. Correlation between static coefficient of friction (COF; left) and kinetic COF (right) and percentage of activated caspase-3-positive cells in Zone A of the superficial zone. We observed a significant correlation between COF and percentage of apoptotic cells in Zone A of the cartilage bearings. We observed trends for each lubricant, with the human synovial fluid (HSF)-lubricated bearings showing clustering toward the origin, indicating low COF and low percentage of apoptotic cells. In contrast, phosphate buffered saline (PBS)-lubricated bearings clustered in the upper right section of the plot, indicating high COF and high percentage of apoptotic cells. Hylan G-F 20-lubricated bearings fell between the 2 extremes, showing that it has some lubricating and chondroprotective abilities compared to PBS. Note that the X axis differs between graphs for better visualization of data points.

significantly lower static or kinetic COF values compared to PBS under these testing conditions. These results suggest that hylan G-F 20 itself may be insufficient as a boundary lubricant in joints, and that this viscosupplement does not provide the same degree of chondroprotection to superficial zone and upper middle zone chondrocytes as native human synovial fluid under these boundary lubrication conditions. The significant correlations between static and kinetic COF and the percentage of apoptotic cells provide further evidence that elevated friction in this bearing system results in an increase in the percentage of apoptotic cells in the superficial 100 μm of the bovine cartilage explant bearing.

Apoptotic cell death *in vivo* is mediated by cell-matrix interactions[25,26], growth factor and cytokine signaling[27], and tissue injury. Cartilage explants and cultured chondrocytes have been used to study apoptosis in response to hydrostatic pressure[28], shear stress and strain[29,30], and mechanical injury[31,32]. In our study, the elevated friction leading to apoptosis is likely due to an increase in shear stress. Currently, the mechanopathway relating to mechanical stress of friction and apoptosis in chondrocytes has not been established but is under investigation.

We observed a zonal dependence on the mean percentage of apoptotic cells, especially in bearings lubricated with PBS and hylan G-F 20, which exhibited higher percentages of apoptosis compared to bearings lubricated with HSF and unloaded control bearings. These findings indicate that the bulk of the apoptotic response occurs in the uppermost 300 μm of the cartilage, where the shear forces and deformation are greatest[30,33], and the significant correlation between COF and apoptosis indicates that an increase in friction is associated with apoptosis. The zonal differences also suggest that the collagen architecture in the superficial zone can absorb most of the shear stress and protect the deeper zones from deformation, and thus protect the deeper chondrocytes from apoptosis in the early stages.

Hylan G-F 20 is administered to patients with OA who do not respond well to nonpharmacological treatments, such as weight loss and physical therapy, or simple analgesics. Hylan G-F 20 is a high-molecular-weight (average 6000 kDa) hyaluronan product with 2 cross-linked components that originate from chicken combs[34]. It is approved by the US Food and Drug Administration for treatment of OA. Either 3 weekly doses of 2 ml or a single 6-ml dose is administered to patients diagnosed with OA[34,35]. Prior to injection, arthrocentesis is advised by the manufacturer, but may remove important components of the synovial fluid, including lubricin, vital to boundary lubrication[19,21,36]. Therefore, replacement of native synovial fluid with hylan G-F 20 alone could have proximal detrimental effects on cell survival.

There are a number of limitations associated with this model of evaluating the efficacy of hylan G-F 20 to prevent friction and apoptosis. The viscosity of hylan G-F 20 is much higher than that of synovial fluid, causing interstitial fluid depressurization of cartilage to occur at a lower rate than when the bearings are lubricated with HSF or PBS. Hylan G-F 20 is an elastoviscous fluid with elasticity (storage modulus G') of 111 ± 13 Pa at 2.5 Hz and a viscosity (loss modulus G") of 25 ± 2 Pa[34]. Normal synovial fluid exhibits a storage modulus (G') of about 19.3 ± 3 Pa and a loss modulus of 10 ± 1 Pa[37,38]. This thixotropic behavior may be preventing the cartilage bearings from achieving proper asperity contact with one another by creating a thick fluid layer and not allowing lubrication to occur truly in the boundary mode, and by deflating static COF. After the large disc is rotated, significantly more fluid is displaced by motion and kinetic COF than by hylan G-F 20-lubricated bearings, compared to HSF-lubricated bearings.

Further, the test protocol used in our study was adapted from the methods cited[9]. However, the technique was modified to permit subsequent culture of cartilage explant bearings. A disc of articular cartilage was used, in lieu of an annulus, as the upper bearing surface to prevent additional mechanical disruption during osteochondral plug harvest[9,22]. The cited methods require cartilage explants to be held while mechanically stressed without culture medium for about 2.5 h[9,22]. By shortening the testing procedure to about 20 min, we were able to collect data about boundary lubrication, because the entraining velocity and load are similar to these previous methods[9,22], while preserving the cellular viability. While the duration of loading was shorter in our method, it still approximates zero-interstitial pore pressure at the beginning of oscillation. Previous studies have shown that after 8 min, 85% of pore pressure was likely dissipated and the bearing surfaces were close to the equilibrium COF. It is also important to note that each measurement represents an independent pair of cartilage bearings, because each was tested only a single time to observe histological data linked to particular lubricants. The wear protocol following the decompression period was also extended to 12 cycles, as opposed to 2[6,22].

Numerous studies have tested the outcome of hylan G-F 20 injection compared to other intraarticular HA treatments, including nonsteroidal antiinflammatory drugs and corticosteroid therapies[39]. The mode of action of hyaluronan injection in decreasing joint pain in OA-affected joints remains unclear. Some studies have reported that loss of viscosity because of HA depletion may play a role in OA progression, although that finding has been challenged[40,41]. Adding a cross-linked HA such as hylan G-F 20 to synovial fluid reinforces non-Newtonian behavior, which is characteristic of healthy synovial fluid[42]. Alternative hypotheses have been proposed, including biosynthetic-chondroprotective effects, antiinflammatory effects, and analgesic effects due to protective action on nociceptive nerve endings[41].

In spite of studies showing safety and efficacy in treating OA pain as a clinical endpoint, the prevention of further cartilage damage following HA injection has not been established, although a delay of total knee replacement has been demonstrated in some patients with severe OA[43]. Joint lubrication is a complex phenomenon and chondroprotection requires more than a low COF. Chondroprotection is also related to the prevention of chondrocyte apoptosis. Our results suggest that the resident normal synovial fluid of a weight-bearing joint should not be removed in the evaluation and treatment of the symptomatic large joint.

Many studies have indicated a possible synergistic effect of combining HA and lubricin in the prevention of secondary OA in animal studies[44], as well as in decreases in the COF in *in vitro* cartilage bearings[6,9] and latex-on-glass bearings[8]. HA of various lower molecular weights and concentrations has been shown to lower static and kinetic COF in uncultured bearings[6,9], but the ability of these molecules to prevent chondrocyte apoptosis was not investigated. Based on the ability of these molecules to lower COF in these studies, there may be value in combining HA and lubricin to develop a therapy for patients with OA or other degenerative joint diseases[6,9].

Our study suggests that the use of hylan G-F 20 following arthrocentesis may not adequately protect cartilage from mechanical wear due to increased friction or biological wear that occurs because of chondrocyte apoptosis. We also determined that an increase in the COF of articular cartilage is correlated with an increase in chondrocyte apoptosis.

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