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Implications of a polymer meniscus implant on knee tribology

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BIBLIOGRAPHY

- [1] Dowson, D., Bio-tribology. *Faraday Discussions*. **2012**, *156*, 9–30.
- [2] Lee, S.; Spencer, N. D., Sweet, hairy, soft, and slippery. *Science*. **2008**, *319*, 575–576.
- [3] Dejak, B.; Młotkowski, A.; Romanowicz, M., Finite element analysis of stresses in molars during clenching and mastication. *The Journal of Prosthetic Dentistry*. **2003**, *90*, 591–597.
- [4] Trutoiu, L. C.; Carter, E. J.; Matthews, I.; Hodgins, J. K., Modeling and animating eye blinks. *ACM Transactions on Applied Perception*. **2011**, *8*, 1–17.
- [5] Charnley, J., The lubrication of animal joints in relation to surgical reconstruction by arthroplasty. *Annals of the Rheumatic Diseases*. **1960**, *19*, 10–19.
- [6] Klein, T. J.; Schumacher, B. L.; Blewis, M. E.; Schmidt, T. A.; Voegtline, M. S.; Thonar, E. J.; Masuda, K.; Sah, R. L., Tailoring secretion of proteoglycan 4 (PRG4) in tissue-engineered cartilage. *Tissue Engineering*. **2006**, *12*, 1429–1439.
- [7] Dédinaite, A., Biomimetic lubrication. *Soft Matter*. **2012**, *8*, 273–284.
- [8] Han, L.; Grodzinsky, A. J.; Ortiz, C., Nanomechanics of the Cartilage Extracellular Matrix. *Annual Review of Materials Research*. **2011**, *41*, 133–168.
- [9] Athanasiou, K. A.; Darling, E. M.; Hu, J. C.; DuRaine, G. D.; Reddi, A. H., *Articular Cartilage*. CRC Press, **2013**.
- [10] Ng, L.; Grodzinsky, A. J.; Patwari, P.; Sandy, J.; Plaas, A.; Ortiz, C., Individual cartilage aggrecan macromolecules and their constituent glycosaminoglycans visualized via atomic force microscopy. *Journal of Structural Biology*. **2003**, *143*, 242–257.
- [11] Peters, T. J., *All About Albumin: Biochemistry, Genetics, and Medical Applications*. Academic Press, **1995**.
- [12] Greene, G. W.; Banquy, X.; Lee, D. W.; Lowrey, D. D.; Yu, J.; Israelachvili, J. N., Adaptive mechanically controlled lubrication mechanism found in articular joints. *Proceedings of the National Academy of Sciences of the United States of America*. **2011**, *108*, 5255–5259.
- [13] Dahl, L. B.; Dahl, I. M. S.; Engstrom-Laurent, A.; Granath, K., Concentration and molecular weight of sodium hyaluronate in synovial fluid from patients with rheumatoid arthritis and other arthropathies. *Annals of the Rheumatic Diseases*. **1985**, *44*, 817–822.

- [14] Slack, S. M., Appendix A—Properties of Biological Fluids. In *Biomaterials Science: An Introduction to Materials in Medicine*, Ratner, B. D.; Hoffman, A. S.; Schoen, F. J.; Lemons, J. E., eds., 3rd ed., Elsevier, **2013**, p. 1479–1482.
- [15] Jay, G. D., Lubricin and surfacing of articular joints. *Current Opinion in Orthopaedics*. **2004**, *15*, 355–359.
- [16] Steele, B. L.; Alvarez-Veronesi, M. C.; Schmidt, T. A., Molecular weight characterization of PRG4 proteins using multi-angle laser light scattering (MALLS). *Osteoarthritis and Cartilage*. **2013**, *21*, 498–504.
- [17] Yu, J.; Banquy, X.; Greene, G. W.; Lowrey, D. D.; Israelachvili, J. N., The boundary lubrication of chemically grafted and cross-linked hyaluronic acid in phosphate buffered saline and lipid solutions measured by the surface forces apparatus. *Langmuir*. **2012**, *28*, 2244–2250.
- [18] Hills, B.; Crawford, R., Normal and prosthetic synovial joints are lubricated by surface-active phospholipid A Hypothesis. *The Journal of Arthroplasty*. **2003**, *18*, 499–505.
- [19] Wise, C. M.; White, R. E.; Agudelo, C. A., Synovial fluid lipid abnormalities in various disease states: review and classification. *Seminars in Arthritis and Rheumatism*. **1987**, *16*, 222–230.
- [20] Dumbleton, J., *Tribology of Natural and Artificial Joints*. Elsevier, **1981**.
- [21] Makris, E. A.; Hadidi, P.; Athanasiou, K. A., The knee meniscus: structure-function, pathophysiology, current repair techniques, and prospects for regeneration. *Biomaterials*. **2011**, *32*, 7411–7431.
- [22] Proctor, C. S.; Schmidt, M. B.; Whipple, R. R.; Kelly, M. A.; Mow, V. C., Material properties of the normal medial bovine meniscus. *Journal of Orthopaedic Research*. **1989**, *7*, 771–782.
- [23] Gupte, C. M.; Bull, A. M. j.; Thomas, R. D.; Amis, A. A., A review of the function and biomechanics of the meniscofemoral ligaments. *Arthroscopy*. **2003**, *19*, 161–171.
- [24] Arnoczky, S. P.; Warren, R. F., Microvasculature of the human meniscus. *The American Journal of Sports Medicine*. **1982**, *10*, 90–95.
- [25] Seror, J.; Merkher, Y.; Kampf, N.; Collinson, L.; Day, A. J.; Maroudas, A.; Klein, J., Articular cartilage proteoglycans as boundary lubricants: structure and frictional interaction of surface-attached hyaluronan and hyaluronan-aggregrecan complexes. *Biomacromolecules*. **2011**, *12*, 3432–3443.

- [26] Schmidt, T. A.; Gastelum, N. S.; Nguyen, Q. T.; Schumacher, B. L.; Sah, R. L., Boundary lubrication of articular cartilage: role of synovial fluid constituents. *Arthritis and Rheumatism*. **2007**, *56*, 882–891.
- [27] Katta, J.; Jin, Z.; Ingham, E.; Fisher, J., Biotribology of articular cartilage-A review of the recent advances. *Medical Engineering & Physics*. **2008**, *30*, 1349–1363.
- [28] MacConaill, M. A., The function of intra-articular fibrocartilages, with special reference to the knee and inferior radio-ulnar joints. *Journal of Anatomy*. **1932**, *66*, 210–227.
- [29] Jones, E., Joint lubrication. *The Lancet*. **1936**, *227*, 1043–1045.
- [30] Dowson, D., Modes of lubrication in human joints. *Proceedings of the Institution of Mechanical Engineers, Conference Proceedings*. **1966**, *181*, 45–54.
- [31] Gleghorn, J. P.; Bonassar, L. J., Lubrication mode analysis of articular cartilage using Stribeck surfaces. *Journal of Biomechanics*. **2008**, *41*, 1910–1918.
- [32] L. Dintenfuss, Lubrication in synovial joints: A theoretical analysis. *The Journal of Bone & Joint Surgery*. **1963**, *45*, 1241–1256.
- [33] Zhu, D., *Encyclopedia of Tribology*. Springer US, Boston, MA, **2013**.
- [34] McCutchen, C. W., The frictional properties of animal joints. *Wear*. **1962**, *5*, 1–17.
- [35] Forster, H.; Fisher, J., The influence of loading time and lubricant on the friction of articular cartilage. *Proceedings of the Institution of Mechanical Engineers, Part H: Journal of Engineering in Medicine*. **1996**, *210*, 109–119.
- [36] Ateshian, G. A.; Lai, W. M.; Zhu, W. B.; Mow, V. C., An asymptotic solution for the contact of two biphasic cartilage layers. *Journal of Biomechanics*. **1994**, *27*, 1347–1360.
- [37] Caligaris, M.; Ateshian, G. A., Effects of sustained interstitial fluid pressurization under migrating contact area, and boundary lubrication by synovial fluid, on cartilage friction. *Osteoarthritis and Cartilage*. **2008**, *16*, 1220–7.
- [38] Swann, D. A.; Radin, E. L., The Molecular Basis of Articular Lubrication. I. Purification and Properties of a Lubricating Fraction from Bovine Synovial Fluid. *Journal of Biological Chemistry*. **1972**, *247*, 8069–8073.

-
- [39] Hills, B. A.; Butler, B. D., Surfactants identified in synovial fluid and their ability to act as boundary lubricants. *Annals of the Rheumatic Diseases*. **1984**, *43*, 641–648.
- [40] Ateshian, G. A., A Theoretical Formulation for Boundary Friction in Articular Cartilage. *Journal of Biomechanical Engineering*. **1997**, *119*, 81–86.
- [41] Hills, B. A., Boundary lubrication in vivo. *Proceedings of the Institution of Mechanical Engineers, Part H: Journal of Engineering in Medicine*. **2000**, *214*, 83–94.
- [42] Unsworth, A., Tribology of human and artificial joints. *Proceedings of the Institution of Mechanical Engineers, Part H: Journal of Engineering in Medicine*. **1991**, *205*, 163–172.
- [43] Maroudas, A., Hyaluronic acid films. *Proceedings of the Institution of Mechanical Engineers, Conference Proceedings*. **1966**, *181*, 122–124.
- [44] Walker, P. S.; Dowson, D.; Longfield, M. D.; Wright, V., "Boosted lubrication" in synovial joints by fluid entrapment and enrichment. *Annals of the Rheumatic Diseases*. **1968**, *27*, 512–520.
- [45] Fein, R. S., Are synovial joints squeeze-film lubricated? *Proceedings of the Institution of Mechanical Engineers, Conference Proceedings*. **1966**, *181*, 125–128.
- [46] Higginson, G. R.; Norman, R., A model investigation of squeeze-film lubrication in animal joints. *Physics in Medicine and Biology*. **1974**, *19*, 785–792.
- [47] Dowson, D.; Jin, Z. M., Micro-elastohydrodynamic lubrication of synovial joints. *Engineering in Medicine*. **1986**, *15*, 63–65.
- [48] Murakami, T.; Higaki, H.; Sawae, Y.; Ohtsuki, N.; Moriyama, S.; Nakanishi, Y., Adaptive multimode lubrication in natural synovial joints and artificial joints. *Proceedings of the Institution of Mechanical Engineers, Part H: Journal of Engineering in Medicine*. **1998**, *212*, 23–35.
- [49] Chan, S. M. T.; Neu, C. P.; DuRaine, G.; Komvopoulos, K.; Reddi, A. H., Atomic force microscope investigation of the boundary-lubricant layer in articular cartilage. *Osteoarthritis and Cartilage*. **2010**, *18*, 956–963.
- [50] Schumacher, B.; Block, J.; Schmid, T.; Aydelotte, M.; Kuettner, K., A novel proteoglycan synthesized and secreted by chondrocytes of the superficial zone of articular cartilage. *Archives of Biochemistry and Biophysics*. **1994**, *311*, 144–152.

- [51] Seror, J.; Sorkin, R.; Klein, J., Boundary lubrication by macromolecular layers and its relevance to synovial joints. *Polymers for Advanced Technologies*. **2014**, *25*, 468–477.
- [52] McDermott, I. D.; Amis, A. A., The consequences of meniscectomy. *The Journal of Bone & Joint Surgery (British Volume)*. **2006**, *88-B*, 1549–1556.
- [53] Andrews, S.; Shrive, N.; Ronsky, J., The shocking truth about meniscus. *Journal of Biomechanics*. **2011**, *44*, 2737–2740.
- [54] Vrancken, A. C. T.; Buma, P.; van Tienen, T. G., Synthetic meniscus replacement: a review. *International Orthopaedics*. **2013**, *37*, 291–299.
- [55] Baker, B. E.; Peckham, A. C.; Pupparo, F.; Sanborn, J. C., Review of meniscal injury and associated sports. *The American Journal of Sports Medicine*. **1985**, *13*, 1–4.
- [56] Keene, G. C. R.; Bickerstaff, D.; Rae, P. J.; Paterson, R. S., The natural history of meniscal tears in anterior cruciate ligament insufficiency. *The American Journal of Sports Medicine*. **1993**, *21*, 672–679.
- [57] Allen, P. R.; Denham, R. A.; Swan, A. V., Late degenerative changes after meniscectomy. Factors affecting the knee after operation. *The Journal of Bone & Joint Surgery (British Volume)*. **1984**, *66-B*, 666–671.
- [58] Englund, M.; Lohmander, L. S., Risk factors for symptomatic knee osteoarthritis fifteen to twenty-two years after meniscectomy. *Arthritis and Rheumatism*. **2004**, *50*, 2811–2819.
- [59] Fairbank, T. J., Knee joint changes after meniscectomy. *The Journal of Bone & Joint Surgery (British Volume)*. **1948**, *30-B*, 664–670.
- [60] Zur, G.; Linder-Ganz, E.; Elsner, J. J.; Shani, J.; Brenner, O.; Agar, G.; Hershman, E. B.; Arnoczky, S. P.; Guilak, F.; Shterling, A., Chondroprotective effects of a polycarbonate-urethane meniscal implant: histopathological results in a sheep model. *Knee Surgery, Sports Traumatology, Arthroscopy*. **2011**, *19*, 255–263.
- [61] Verdonk, P. C. M.; Demurie, A.; Almqvist, K. F.; Veys, E. M.; Verbruggen, G.; Verdonk, R., Transplantation of viable meniscal allograft. Survivorship analysis and clinical outcome of one hundred cases. *The Journal of Bone & Joint Surgery*. **2005**, *87*, 715–724.

- [62] Verdonk, P. C. M.; Demurie, A.; Almqvist, K. F.; Veys, E. M.; Verbruggen, G.; Verdonk, R., Transplantation of viable meniscal allograft. Surgical technique. *The Journal of Bone & Joint Surgery*. **2006**, *88*, 109–118.
- [63] Milachowski, K.; Weismeier, K.; Wirth, C., Homologous meniscus transplantation. *International Orthopaedics*. **1989**, *13*, 1–11.
- [64] Cole, B. J.; Carter, T. R.; Rodeo, S. A., Allograft Meniscal Transplantation. *The Journal of Bone & Joint Surgery*. **2002**, *84*, 1236–1250.
- [65] Stone, K. R.; Rodkey, W. G.; Webber, R.; McKinney, L.; Steadman, J. R., Meniscal regeneration with copolymeric collagen scaffolds. In vitro and in vivo studies evaluated clinically, histologically, and biochemically. *The American Journal of Sports Medicine*. **1992**, *20*, 104–111.
- [66] Klompmaker, J.; Veth, R.; Jansen, H.; Nielsen, H.; De Groot, J.; Pennings, A., Meniscal replacement using a porous polymer prosthesis: a preliminary study in the dog. *Biomaterials*. **1996**, *17*, 1169–1175.
- [67] Tienen, T. G.; Heijkants, R. G. J. C.; de Groot, J. H.; Pennings, A. J.; Schouten, A. J.; Veth, R. P. H.; Buma, P., Replacement of the knee meniscus by a porous polymer implant. A study in dogs. *The American Journal of Sports Medicine*. **2006**, *34*, 64–71.
- [68] Kang, S.-W.; Son, S.-M.; Lee, J.-S.; Lee, E.-S.; Lee, K.-Y.; Park, S.-G.; Park, J.-H.; Kim, B.-S., Regeneration of whole meniscus using meniscal cells and polymer scaffolds in a rabbit total meniscectomy model. *Journal of Biomedical Materials Research. Part A*. **2006**, *77A*, 659–671.
- [69] Mandal, B. B.; Park, S.-H.; Gil, E. S.; Kaplan, D. L., Multilayered silk scaffolds for meniscus tissue engineering. *Biomaterials*. **2011**, *32*, 639–651.
- [70] Balint, E.; Gatt, C. J.; Dunn, M. G., Design and mechanical evaluation of a novel fiber-reinforced scaffold for meniscus replacement. *Journal of Biomedical Materials Research. Part A*. **2012**, *100A*, 195–202.
- [71] Kon, E.; Filardo, G.; Tschon, M.; Fini, M.; Giavaresi, G.; Reggiani, L. M.; Chiari, C.; Nehrer, S.; Martin, I.; Salter, D. M.; Ambrosio, L.; Marcacci, M., Tissue Engineering for Total Meniscal Substitution: Animal Study in Sheep Model—Results at 12 Months. *Tissue Engineering. Part A*. **2012**, *18*, 1573–1582.
- [72] Toyonaga, T.; Uezaki, N.; Chikama, H., Substitute Meniscus of Teflon-net for the Knee Joint of Dogs. *Clinical Orthopaedics and Related Research*. **1983**, *179*, 291–297.

- [73] Sommerlath, K.; Gallino, M.; Gillquist, J., Biomechanical characteristics of different artificial substitutes for rabbit medial meniscus and effect of prosthesis size on knee cartilage. *Clinical Biomechanics*. **1992**, *7*, 97–103.
- [74] Messner, K., Meniscal substitution with a Teflon-periosteal composite graft: a rabbit experiment. *Biomaterials*. **1994**, *15*, 223–230.
- [75] Kobayashi, M.; Chang, Y.-S.; Oka, M., A two year in vivo study of polyvinyl alcohol-hydrogel (PVA-H) artificial meniscus. *Biomaterials*. **2005**, *26*, 3243–3248.
- [76] Elsner, J. J.; Portnoy, S.; Zur, G.; Guilak, F.; Shterling, A.; Linder-Ganz, E., Design of a free-floating polycarbonate-urethane meniscal implant using finite element modeling and experimental validation. *Journal of Biomechanical Engineering*. **2010**, *132*, 095001.
- [77] De Coninck, T.; Elsner, J. J.; Linder-Ganz, E.; Cromheecke, M.; Shemesh, M.; Huysse, W.; Verdonk, R.; Verstraete, K.; Verdonk, P., In-vivo evaluation of the kinematic behavior of an artificial medial meniscus implant: A pilot study using open-MRI. *Clinical Biomechanics*. **2014**, *29*, 898–905.
- [78] Condello, V.; Arbel, R.; Agar, G.; Rozen, N.; Angele, P.; Victor, J.; Brittberg, M.; Verdonk, P., A novel synthetic meniscus implant for the treatment of middle aged patients: results of 118 patients in a prospective, multi-center study. In *European Federation of National Associations of Orthopaedics and Traumatology Meeting*, London, United Kingdom, **2014**.
- [79] Condello, V.; Ronga, M.; Linder-Ganz, E.; Zorzi, C., Alternatives to Meniscus Transplantation Outside the United States. In *Cartilage Restoration*, Farr, J.; Gomoll, A. H., eds., chap. 19, Springer New York, New York, NY, **2013**, p. 223–249.
- [80] Rongen, J. J.; van Tienen, T. G.; van Bochove, B.; Grijpma, D. W.; Buma, P., Biomaterials in search of a meniscus substitute. *Biomaterials*. **2014**, *35*, 3527–3540.
- [81] Klein, J., Molecular mechanisms of synovial joint lubrication. *Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology*. **2006**, *220*, 691–710.
- [82] Dowson, D., Elastohydrodynamic and micro-elastohydrodynamic lubrication. *Wear*. **1995**, *190*, 125–138.

- [83] Jay, G. D.; Tantravahi, U.; Britt, D. E.; Barrach, H. J.; Cha, C.-J., Homology of lubricin and superficial zone protein (SZP): products of megakaryocyte stimulating factor (MSF) gene expression by human synovial fibroblasts and articular chondrocytes localized to chromosome 1q25. *Journal of Orthopaedic Research*. **2001**, *19*, 677–687.
- [84] McNary, S. M.; Athanasiou, K. A.; Reddi, A. H., Engineering Lubrication in Articular Cartilage. *Tissue Engineering: Part B*. **2012**, *18*, 1–13.
- [85] Das, S.; Banquy, X.; Zappone, B.; Greene, G. W.; Jay, G. D.; Israelachvili, J. N., Synergistic interactions between grafted hyaluronic acid and lubricin provide enhanced wear protection and lubrication. *Biomacromolecules*. **2013**, *14*, 1669–1677.
- [86] Kuijjer, R.; Van De Stadt, R. J.; De Koning, M. H. M. T.; Van Der Korst, J. K., Influence of Constituents of Proteoglycans on Type II Collagen Fibrillogenesis. *Collagen and Related Research*. **1985**, *5*, 379–391.
- [87] Köwitsch, A.; Yang, Y.; Ma, N.; Kuntsche, J.; Mäder, K.; Groth, T., Bioactivity of immobilized hyaluronic acid derivatives regarding protein adsorption and cell adhesion. *Biotechnology and Applied Biochemistry*. **2011**, *58*, 376–389.
- [88] Ludwig, T. E.; McAllister, J. R.; Lun, V.; Wiley, J. P.; Schmidt, T. A., Diminished cartilage-lubricating ability of human osteoarthritic synovial fluid deficient in proteoglycan 4: Restoration through proteoglycan 4 supplementation. *Arthritis and Rheumatism*. **2012**, *64*, 3963–3971.
- [89] Höök, F.; Rodahl, M.; Brzezinski, P.; Kasemo, B., Energy dissipation kinetics for protein and antibody–antigen adsorption under shear oscillation on a quartz crystal microbalance. *Langmuir*. **1998**, *14*, 729–734.
- [90] Veeregowda, D. H.; Kolbe, A.; van der Mei, H. C.; Busscher, H. J.; Herrmann, A.; Sharma, P. K., Recombinant supercharged polypeptides restore and improve biolubrication. *Advanced Materials*. **2013**, *25*, 3426–3431.
- [91] Veeregowda, D. H.; van der Mei, H. C.; de Vries, J.; Rutland, M. W.; Valledelgado, J. J.; Sharma, P. K.; Busscher, H. J., Boundary lubrication by brushed salivary conditioning films and their degree of glycosylation. *Clinical Oral Investigations*. **2012**, *16*, 1499–1506.
- [92] Ducker, W. A.; Senden, T. J.; Pashley, R. M., Direct measurement of colloidal forces using an atomic force microscope. *Nature*. **1991**, *353*, 239–241.

- [93] Ralston, J.; Larson, I.; Rutland, M. W.; Feiler, A. A.; Kleijn, M., Atomic force microscopy and direct surface force measurements (IUPAC Technical Report). *Pure and Applied Chemistry*. **2005**, *77*, 2149–2170.
- [94] Pettersson, T.; Nordgren, N.; Rutland, M. W.; Feiler, A., Comparison of different methods to calibrate torsional spring constant and photodetector for atomic force microscopy friction measurements in air and liquid. *The Review of Scientific Instruments*. **2007**, *78*, 093702(1–8).
- [95] Jay, G. D.; Torres, J. R.; Warman, M. L.; Laderer, M. C.; Breuer, K. S., The role of lubricin in the mechanical behavior of synovial fluid. *Proceedings of the National Academy of Sciences of the United States of America*. **2007**, *104*, 6194–6199.
- [96] Chang, D. P.; Guilak, F.; Jay, G. D.; Zauscher, S., Interaction of lubricin with type II collagen surfaces: adsorption, friction, and normal forces. *Journal of Biomechanics*. **2014**, *47*, 659–666.
- [97] Chang, D. P.; Abu-Lail, N. I.; Coles, J. M.; Guilak, F.; Jay, G. D.; Zauscher, S., Friction force microscopy of lubricin and hyaluronic acid between hydrophobic and hydrophilic surfaces. *Soft Matter*. **2009**, *5*, 3438–3445.
- [98] Zappone, B.; Ruths, M.; Greene, G. W.; Jay, G. D.; Israelachvili, J. N., Adsorption, lubrication, and wear of lubricin on model surfaces: polymer brush-like behavior of a glycoprotein. *Biophysical Journal*. **2007**, *92*, 1693–1708.
- [99] Dumont, G. D.; Hogue, G. D.; Padalecki, J. R.; Okoro, N.; Wilson, P. L., Meniscal and chondral injuries associated with pediatric anterior cruciate ligament tears: relationship of treatment time and patient-specific factors. *The American Journal of Sports Medicine*. **2012**, *40*, 2128–2133.
- [100] Jacobson, A., Biotribology: the tribology of living tissues. *Tribology & Lubrication Technology*. **2003**, *59*, 32–38.
- [101] Zreiqat, H.; Dunstan, C. R.; Rosen, V., *A Tissue Regeneration Approach to Bone and Cartilage Repair*. Mechanical Engineering Series, Springer, Cham, **2015**.
- [102] Buma, P.; van Tienen, T.; Veth, R., The collagen meniscus implant. *Expert Review of Medical Devices*. **2007**, *4*, 507–516.
- [103] Chiari, C.; Koller, U.; Dorotka, R.; Eder, C.; Plasenzotti, R.; Lang, S.; Ambrosio, L.; Tognana, E.; Kon, E.; Salter, D.; Nehrer, S., A tissue engineering approach to meniscus regeneration in a sheep model. *Osteoarthritis and Cartilage*. **2006**, *14*, 1056–1065.

- [104] Kobayashi, M.; Toguchida, J.; Oka, M., Preliminary study of polyvinyl alcohol-hydrogel (PVA-H) artificial meniscus. *Biomaterials*. **2003**, *24*, 639–647.
- [105] Majd, S. E.; Kuijjer, R.; Köwitsch, A.; Groth, T.; Schmidt, T. A.; Sharma, P. K., Both Hyaluronan and Collagen Type II Keep Proteoglycan 4 (Lubricin) at the Cartilage Surface in a Condition That Provides Low Friction during Boundary Lubrication. *Langmuir*. **2014**, *30*, 14566–14572.
- [106] Wang, A.; Essner, A.; Schmidig, G., The effects of lubricant composition on in vitro wear testing of polymeric acetabular components. *Journal of Biomedical Materials Research. Part B, Applied Biomaterials*. **2004**, *68*, 45–52.
- [107] Blewis, M. E.; Nugent-Derfus, G. E.; Schmidt, T. A.; Schumacher, B. L.; Sah, R. L., A model of synovial fluid lubricant composition in normal and injured joints. *European Cells & Materials*. **2007**, *13*, 26–39.
- [108] Harsha, A. P.; Joyce, T. J., Challenges associated with using bovine serum in wear testing orthopaedic biopolymers. *Journal of Engineering in Medicine*. **2011**, *225*, 948–958.
- [109] Feiler, A. A.; Sahlholm, A.; Sandberg, T.; Caldwell, K. D., Adsorption and viscoelastic properties of fractionated mucin (BSM) and bovine serum albumin (BSA) studied with quartz crystal microbalance (QCM-D). *Journal of Colloid and Interface Science*. **2007**, *315*, 475–481.
- [110] Chang, D. P.; Abu-Lail, N. I.; Guilak, F.; Jay, G. D.; Zauscher, S., Conformational mechanics, adsorption, and normal force interactions of lubricin and hyaluronic acid on model surfaces. *Langmuir*. **2008**, *24*, 1183–1193.
- [111] Indest, T.; Laine, J.; Kleinschek, K. S.; Zemljič, L. F., Adsorption of human serum albumin (HSA) on modified PET films monitored by QCM-D, XPS and AFM. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*. **2010**, *360*, 210–219.
- [112] Mate, C. M., *Tribology on the Small Scale: A Bottom Up Approach to Friction, Lubrication, and Wear*. Oxford University Press, **2008**.
- [113] Coles, J. M.; Chang, D. P.; Zauscher, S., Molecular mechanisms of aqueous boundary lubrication by mucinous glycoproteins. *Current Opinion in Colloid & Interface Science*. **2010**, *15*, 406–416.
- [114] Nejadnik, M. R.; Olsson, A. L. J.; Sharma, P. K.; van der Mei, H. C.; Norde, W.; Busscher, H. J., Adsorption of pluronic F-127 on surfaces with different hydrophobicities probed by quartz crystal microbalance with dissipation. *Langmuir*. **2009**, *25*, 6245–62459.

- [115] Pettersson, T.; Naderi, A.; Makuska, R.; Claesson, P. M., Lubrication properties of bottle-brush polyelectrolytes: an AFM study on the effect of side chain and charge density. *Langmuir*. **2008**, *24*, 3336–3347.
- [116] Veeregowda, D. H.; Busscher, H. J.; Vissink, A.; Jager, D.-J.; Sharma, P. K.; van der Mei, H. C., Role of structure and glycosylation of adsorbed protein films in biolubrication. *PLoS ONE*. **2012**, *7*, e42600.
- [117] Venus Trial. <https://www.meniscus-study.com/home>. **2016**. Accessed: April 2016.
- [118] Hirsh, S. L.; McKenzie, D. R.; Nosworthy, N. J.; Denman, J. A.; Sezerman, O. U.; Bilek, M. M. M., The Vroman effect: competitive protein exchange with dynamic multilayer protein aggregates. *Colloids and Surfaces B: Biointerfaces*. **2013**, *103*, 395–404.
- [119] Bionate® Thermoplastic Polycarbonate Polyurethane (PCU). [http://www.dsm.com/content/dam/dsm/medical/en_US/documents/bionate\(r\)-pcu-product-sheet.pdf](http://www.dsm.com/content/dam/dsm/medical/en_US/documents/bionate(r)-pcu-product-sheet.pdf). **2012**. Accessed: April 2016.
- [120] Moazzez, B.; O'Brien, S. M.; Merschrod S, E. F., Improved adhesion of gold thin films evaporated on polymer resin: applications for sensing surfaces and MEMS. *Sensors*. **2013**, *13*, 7021–7032.
- [121] Nakanishi, K.; Sakiyama, T.; Imamura, K., On the adsorption of proteins on solid surfaces, a common but very complicated phenomenon. *Journal of Bioscience and Bioengineering*. **2001**, *91*, 233–244.
- [122] McClellan, S. J.; Franses, E. I., Adsorption of bovine serum albumin at solid/aqueous interfaces. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*. **2005**, *260*, 265–275.
- [123] Shiboski, S. C.; Shiboski, C. H.; Criswell, L. A.; Baer, A. N.; Challacombe, S.; Lanfranchi, H.; Schiødt, M.; Umehara, H.; Vivino, F.; Zhao, Y.; Dong, Y.; Greenspan, D.; Heidenreich, A. M.; Helin, P.; Kirkham, B.; Kitagawa, K.; Larkin, G.; Li, M.; Lietman, T.; Lindegaard, J.; McNamara, N.; Sack, K.; Shirlaw, P.; Sugai, S.; Vollenweider, C.; Witcher, J.; Wu, A.; Zhang, S.; Zhang, W.; Greenspan, J. S.; Daniels, T. E., American College of Rheumatology classification criteria for Sjögren's syndrome: A data-driven, expert consensus approach in the Sjögren's International Collaborative Clinical Alliance Cohort. *Arthritis Care & Research*. **2012**, *64*, 475–487.
- [124] Manson, T. T.; Cosgarea, A. J., Meniscal injuries in active patients. *Advanced Studies in Medicine*. **2004**, *4*, 545–552.

- [125] Jones, J. C.; Burks, R.; Owens, B. D.; Sturdivant, R. X.; Svoboda, S. J.; Cameron, K. L., Incidence and risk factors associated with meniscal injuries among active-duty US military service members. *Journal of Athletic Training*. **2012**, *47*, 67–73.
- [126] Majewski, M.; Susanne, H.; Klaus, S., Epidemiology of athletic knee injuries: A 10-year study. *The Knee*. **2006**, *13*, 184–188.
- [127] Verdonk, P. C. M.; Forsyth, R. G.; Wang, J.; Almqvist, K. F.; Verdonk, R.; Veys, E. M.; Verbruggen, G., Characterisation of human knee meniscus cell phenotype. *Osteoarthritis and Cartilage*. **2005**, *13*, 548–60.
- [128] Ateshian, G. A., The role of interstitial fluid pressurization in articular cartilage lubrication. *Journal of Biomechanics*. **2009**, *42*, 1163–1176.
- [129] Abraham, G.; Frank, R.; Gupta, A.; Harris, J.; McCormick, F.; Cole, B., Trends in Meniscus Repair and Meniscectomy in the United States, 2005–2011. *American Journal of Sports Medicine*. **2013**, *41*, 2333–2339.
- [130] Vrancken, A. C. T.; Madej, W.; Hannink, G.; Verdonschot, N.; van Tienen, T. G.; Buma, P., Short Term Evaluation of an Anatomically Shaped Polycarbonate Urethane Total Meniscus Replacement in a Goat Model. *PLoS ONE*. **2015**, *10*, e0133138.
- [131] Majd, S. E.; Kuijer, R.; Schmidt, T. A.; Sharma, P. K., Role of hydrophobicity on the adsorption of synovial fluid proteins and biolubrication of polycarbonate urethanes: Materials for permanent meniscus implants. *Materials & Design*. **2015**, *83*, 514–521.
- [132] Zhu, T. F.; Budin, I.; Szostak, J. W., Vesicle extrusion through polycarbonate track-etched membranes using a hand-held mini-extruder. *Methods in Enzymology*. **2013**, *533*, 275–282.
- [133] Horvath, S. M.; Hollander, J. L., Intra-articular temperature as a measure of joint reaction. *The Journal of Clinical Investigation*. **1949**, *28*, 469–473.
- [134] Khoshgoftar, M.; Vrancken, A. C. T.; van Tienen, T. G.; Buma, P.; Janssen, D.; Verdonschot, N., The sensitivity of cartilage contact pressures in the knee joint to the size and shape of an anatomically shaped meniscal implant. *Journal of Biomechanics*. **2015**, *48*, 1427–1435.

