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The Role of Mechanical Forces in the Initiation and Progression of Osteoarthritis

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Introduction

Excessive joint loadings, either single (acute contact stress caused, for example, by blunt trauma) or repetitive (cumulative contact stress caused by cyclic loading of the joint), cause progressive joint degeneration and subsequent development of the clinical syndrome of osteoarthritis (OA) [3, 4, 6, 7, 10, 13, 15, 21]. Joint injuries causing acute excessive contact stress are common and often affect young adults. Each year, one in 12 people between the ages of 18 and 44 seeks medical attention for treatment of joint injury, and more than 12% of all lower limb OA is caused by joint trauma [5]. Despite advances in surgical treatment and rehabilitation of injured joints, the risk of OA following joint fractures has not decreased in the last 50 years [3]. Recent evidence [21] shows that intraarticular fractures are accompanied by acute, rapid chondrocyte death along fracture lines in the tissue (Fig. 1). This progressive cell damage may be an effective target for therapeutic treatment to preserve cartilage metabolism and thus, reduce the risk of subsequent posttraumatic OA.

Excessive Loading and Articular Cartilage Damage

Cumulative excessive contact stress at the articular surface that leads to OA can be exacerbated by joint dysplasia, incongruity, and instability [3, 4, 10, 15–18, 22], but also may cause OA in patients without known joint abnormalities [2, 20]. Advances in understanding of the thresholds for mechanical damage to articular cartilage and of the biologic mediators that cause progressive loss of articular cartilage due to excessive mechanical stress, will lead to better treatments of joint injuries and improved strategies for restoration of damaged joint surfaces [1, 3].

New Biologic and Mechanical Approaches to the Prevention and Treatment of OA

Recent in vitro investigations show that reactive oxygen species (ROS) released from mitochondria following excessive articular cartilage loading can cause chondrocyte death and matrix degradation [9, 14, 19]. Preventing the release of ROS or inhibiting their effects preserves chondrocytes and their matrix [9, 14]. Fibronectin fragments released from articular cartilage subjected to excessive loads also stimulate matrix degradation; inhibition of the molecular pathways initiated by these fragments prevents this effect [8].

Distraction and motion of osteoarthritic articular surfaces can promote joint remodeling, decrease pain, and improve joint function in patients with end-stage posttraumatic OA [11]. This result, combined with the observation that chondroprogenitor cells are active in osteoarthritic joints [12], suggests that altered loading creates an environment that promotes beneficial joint remodeling.

Summary

Taken together, these recent advances in understanding of how mechanical forces cause loss of articular cartilage including identification of mechanically induced mediators of cartilage loss and of how changing joint loading can promote joint remodeling provide the basis for new biologic and mechanical approaches to the prevention and treatment of OA.

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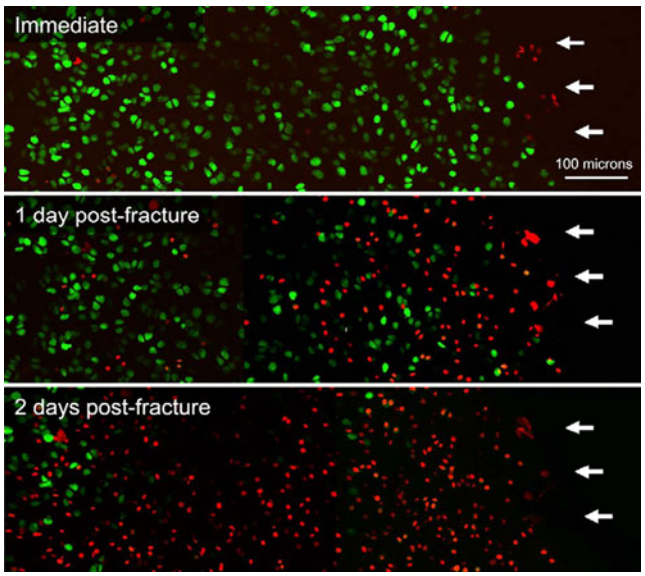

Fig. 1. Confocal microscope images of human superficial chondrocyte viability at a representative fracture edge scan site, at the immediate, 1-day, and 2-day postfracture time points. Live cells are labeled by *green fluorescence*, while dead cells are labeled by *red fluorescence*. *White arrows* indicate the edge of cartilage on the fracture line. Reprinted from Tochigi Y., Buckwalter J.A., Martin J.A., Hillis S.L., Zhang P., Vaseenon T., Lehman A.D., Brown T.D.. 2011. Distribution and progression of chondrocyte damage in a whole organ model of human ankle intraarticular fracture,93(6):533–539 copyright 2011 with permission from J Bone Joint Surg Am

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References

1. Adkisson HDt, Martin JA, Amendola RL, Milliman C, Mauch KA, Katwal AB, Seyedin M, Amendola A, Streeter PR, Buckwalter JA. 2010. The potential of human allogeneic juvenile chondrocytes for restoration of articular cartilage. Am J Sports Med 38:1324–1333.
2. Anderson DD, Iyer KS, Segal NA, Lynch JA, Brown TD. 2010. Implementation of discrete element analysis for subject-specific, population-wide investigations of habitual contact stress exposure. J Appl Biomech 26:215–223.
3. Anderson DD, Chubinskaya S, Guilak F, Martin JA, Oegema TR, Olson SA, Buckwalter JA. 2011. Post-traumatic osteoarthritis: Improved understanding and opportunities for early intervention. J Orthop Res 29:802–809.
4. Anderson DD, Van Hofwegen C, Marsh JL, Brown TD. 2011. Is elevated contact stress predictive of post-traumatic osteoarthritis for imprecisely reduced tibial plafond fractures? J Orthop Res 29:33–39.
5. Brown TD, Johnston JC, Saltzman CL, Marsh JL, Buckwalter JA. 2006. Posttraumatic osteoarthritis: a first estimate of incidence, prevalence, and burden of disease. J Orthop Trauma 20:739–744.
6. Buckwalter JA. 1992. Mechanical Injuries of Articular Cartilage. In: Finerman, G. editor, Biology and Biomechanics of the Traumatized Synovial Joint. Park Ridge IL: American Academy of Orthopaedic Surgeons, pp. 83–96.
7. Buckwalter JA, Martin JA, Brown TD. 2006. Perspectives on chondrocyte mechanobiology and osteoarthritis. Biorheology 43:603–609.
8. Ding L, Heying E, Nicholson N, Stroud NJ, Homandberg GA, Buckwalter JA, Guo D, Martin JA. 2010. Mechanical impact induces cartilage degradation via mitogen activated protein kinases. Osteoarthritis Cartilage 18:1509–1517.
9. Goodwin W, McCabe D, Sauter E, Reese E, Walter M, Buckwalter JA, Martin JA. 2010. Rotenone prevents impact-induced chondrocyte death. J Orthop Res 28:1057–1063.
10. Hadley NA, Brown TD, Weinstein SL. 1990. The effects of contact pressure elevations and aseptic necrosis on the long-term outcome of congenital hip dislocation. J Ortho Res 8:504–513.
11. Intema F, Thomas TP, Anderson DD, Elkins JM, Brown TD, Amendola A, Lafeber FP, Saltzman CL. 2011. Subchondral bone remodeling is related to clinical improvement after joint distraction in the treatment of ankle osteoarthritis. Osteoarthritis Cartilage.
12. Koelling S, Kruegel J, Irmer M, Path JR, Sadowski B, Miro X, Miosge N. 2009. Migratory chondrogenic progenitor cells from repair tissue during the later stages of human osteoarthritis. Cell Stem Cell 4:324–335.
13. Martin JA, Brown T, Heiner A, Buckwalter JA. 2004. Post-traumatic osteoarthritis: the role of accelerated chondrocyte senescence. Biorheology 41:479–491.
14. Martin JA, McCabe D, Walter M, Buckwalter JA, McKinley TO. 2009. N-acetylcysteine inhibits post-impact chondrocyte death in osteochondral explants. J Bone Joint Surg Am 91:1890–1897.
15. Maxian TA, Brown TD, Weinstein SL. 1995. Chronic stress tolerance levels for human articular cartilage: two nonuniform contact models applied to long-term follow-up of CDH. J Biomech 28:159–166.
16. McKinley TO, Rudert MJ, Koos DC, Brown TD. 2004. Incongruity versus instability in the etiology of posttraumatic arthritis. Clin Orthop Relat Res:44–51.
17. McKinley TO, Tochigi Y, Rudert MJ, Brown TD. 2008. The effect of incongruity and instability on contact stress directional gradients in human cadaveric ankles. Osteoarthritis Cartilage 16:1363–1369.
18. McKinley TO, Tochigi Y, Rudert MJ, Brown TD. 2008. Instability-associated changes in contact stress and contact stress rates near a step-off incongruity. J Bone Joint Surg Am 90:375–383.
19. Ramakrishnan P, Hecht BA, Pedersen DR, Lavery MR, Maynard J, Buckwalter JA, Martin JA. 2010. Oxidant conditioning protects cartilage from mechanically induced damage. J Orthop Res 28:914–920.
20. Segal NA, Anderson DD, Iyer KS, Baker J, Torner JC, Lynch JA, Felson DT, Lewis CE, Brown TD. 2009. Baseline articular contact stress levels predict incident symptomatic knee osteoarthritis development in the MOST cohort. J Orthop Res 27:1562–1568.
21. Tochigi Y, Buckwalter JA, Martin JA, Hillis SL, Zhang P, Vaseenon T, Lehman AD, Brown TD. 2011. Distribution and progression of chondrocyte damage in a whole-organ model of human ankle intra-articular fracture. J Bone Joint Surg Am 93:533–539.
22. Tochigi Y, Vaseenon T, Heiner AD, Fredericks DC, Martin JA, Rudert MJ, Hillis SL, Brown TD, McKinley TO. 2011. Instability dependency of osteoarthritis development in a rabbit model of graded anterior cruciate ligament transection. J Bone Joint Surg Am 93:640–647.