Effect Of Partial Meniscectomy On Cartilage Shear Stress: Walking Versus Running.

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Introduction: Partial meniscectomy is a surgical treatment for meniscal lesions which allows athletes to return to sporting activities within six weeks (Osti et al., 1994; Lysholm and Gillquist, 1983). Partial meniscectomy results in increased contact stress at the articular cartilage, leading to premature osteoarthritis (Rangger et al., 1995; Schimmer et al., 1998; Wyland et al., 2002; Cicuttini et al., 2003; Sturnieks et al., 2008). It is therefore important to understand the biomechanical changes within the tibiofemoral joint that are influenced by the loading and kinematic changes that arise after a partial meniscectomy. The aim of this study was to predict the effects of different volumes and locations of partial meniscectomies on shear stress in the cartilage at the end of weight acceptance in walking and running.

Methods: A three-dimensional (3D) finite element (FE) knee model was developed from 3D-SPGR and 3D-CUBE magnetic resonance images of a cadaveric specimen to obtain accurate representations of the bones, cartilage, menisci and ligaments. The menisci were modelled as transversely isotropic and the cartilage was assumed to behave as a linear elastic, isotropic material. The cruciate and collateral ligaments were modelled as isotropic hyperelastic materials. The meniscal horns and peripheral meniscal attachment were simulated, using one-dimensional linear springs elements. Varying degrees of partial meniscectomies (10%, 60% and 100%) were modelled by removing elements from the meniscus to emulate clinical surgeries. The FE knee model was validated (Mootanah et al., 2014). Loading conditions (forces and moments in all degrees of freedom) of a healthy 76-kg male subject were then applied to the models to simulate end of weight acceptance in walking and running. FE analyses were run to predict maximum shear stress at the articular cartilage.

Results: For the healthy knee, maximum shear stress at the articular cartilage was 2.00 MPa medially and 1.71 MPa laterally for walking. Maximum shear stress was 3.48 MPa medially and 4.70 MPa laterally for running. Stress distribution was dependent on meniscectomy size and location (Figure 1). For walking, a 30% medial anterior, central and posterior meniscectomy increased the medial stress by 25.9%, 44.9% and 32.5%, respectively. Lateral meniscectomies of a similar percentage and similar locations produced a corresponding 12.4%, 25.7% and 17.8% increase in stress laterally. A 60% medial meniscectomy increased the medial stress by 47.2%. A 60% lateral meniscectomy increased the lateral stress by 31.8%. For running, a 30% medial anterior, central and posterior meniscectomy increased the medial stress by 9.6%, 8.3% and 7.1%, respectively. Lateral meniscectomies of a similar percentage and similar locations produced a corresponding 31.6%, 37.5% and 43.6% increase in stress laterally. A 60% medial meniscectomy increased the lateral stress by 10.0%. A 60% lateral meniscectomy increased the lateral stress by 51.8%.
Discussion: Our findings are consistent with previous FE and in vitro studies which have demonstrated the importance of the meniscus in reducing knee joint contact pressure (Zielinska and Donahue, 2006; Yang, Nayeb-Hashemi and Canavan, 2009; Dong et al., 2011; Bae et al., 2012; Kazemi et al., 2012; Mononen, Jurvelin and Korhonen, 2013; Lee et al., 2006; Seitz et al., 2011). In particular, this is the first study that has estimated how much of a stress increase can be expected at the end of weight acceptance in walking and running for successively larger amounts of meniscal tissue removed. Maximum shear stresses were 100% higher at the end of weight acceptance in running compared to walking. Stress was higher in the lateral compartment during running stance and higher in the medial compartment during walking. This is because there is a valgus moment acting at the joint at the end of weight acceptance in running while a varus moment acts at the joint in walking. A similar trend was observed for the simulated meniscectomies.

Significance: The model developed from this research has potential for applications in planning meniscal surgeries and developing rehabilitation strategies for athletes. Understanding the local load environment following partial meniscectomy may help delay the onset of OA and the eventual need for total knee replacement.

Figure 1: Predicted maximum shear stress for increasing amounts of meniscal tissue removal following medial and lateral meniscectomies during walking and running.

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