MULTI-SCALE FINITE ELEMENT MODELLING TO ASSESS SUTURED TENDON REPAIRS

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ABSTRACT

Over 800,000 tendon injuries are treated in the UK per annum, of which, 7% of repairs re-rupture during healing and 25% of patients achieve an undesirable clinical outcome. Due to low cellular turnover, healing is a slow process, requiring 12 weeks of physiotherapy and restricted loading which is costly, disruptive to the patient, and lack of cooperation (by the patient in following physiotherapy routines) leads to poor results. There remains a lack of consensus on what constitutes the ideal tendon repair. Identifying the suture technique which provides the most favourable environment for healing would benefit clinical outcome, and healing duration.

Suture methods are traditionally assessed by ex vivo tensile testing, animal studies or *in vivo* clinical trials. These methods inform repair strength and gapping resistance, tendon adhesion to surrounding tissue, and resultant clinical outcome, however they are costly and time consuming. Virtual prototyping using the finite element (FE) method promises to speed up research and improve best practice in this area. We have developed a 3D multi-scale FE model to assess tendon suture repairs. The FE model shows detailed stress and strain within the tissue, which is not possible by existing methods of analysis, and is also rapid and cost effective. High stress regions correlate with known acelullar regions (areas of tissue where cells are absent) which arise within the tendon 72 hours postoperatively and remain for at least one year as demonstrated in a murine (mouse) tendon injury model. Acelullarity is detrimental to tendon mechanical properties due to lack of tissue maintenance by the fibroblasts (tendon cells). Comparing high stress regions within various suture repairs will indicate the repair technique which provides the most favourable environment for healing and long term tissue health.

Tendon is highly anisotropic due to its structure; type 1 collagen self assembles into long supermolecular structures called fibrils, which are arranged in aligned fibres along the long axis of the tendon. Tendon microstructure is integral to its material properties; literature has demonstrated tendon tensile modulus to range from 350 to 850 MPa in the longitudinal direction. Tensile testing of porcine flexor digitorum profindus tendon (FDP; a tendon in the pig toe) demonstrated that the transverse tensile modulus ranges from 0.1035 ±0.0454MPa to 0.2551 ±0.0818MPa. To describe tendon mathematically, a repeating unit cell of fibrils embedded within the surrounding tissue was modelled using Abaqus (Version 6.10, Simulia) and assumed to behave analogous to a continuous fibre composite. Homogenisation was performed to deduce the homogeneous material definition which represents the microstructure. This was informed by, and validated against, tensile testing of porcine FDP tendon. Within the microstructure model, the fibrils and matrix were assumed to exhibit linear elastic behaviour, with a Poisson's ratio of 0.3, a fibril modulus of 1700MPa. Matrix modulus was initially set to 1700MPa and was gradually reduced by an order of magnitude, approaching the matrix modulus we concluded from our tensile testing of 0.0416 to 0.1021MPa.

The homogeneous tendon descriptions were input into a macro-scale FE model of two tendon suture repairs; Kessler and Bunnell. Our data demonstrates that as material properties approach those observed in tendon, the resultant high stress region approaches the shape of the acelular region (Figure 1). This was further validated by comparing suture displacement with that observed during *ex vivo* tensile testing of sutured porcine FDP tendons. FE tendon modelling will aid in comparing the healing environment provided by suture repair techniques. Furthermore, the FE model could be used more widely to study common tendon, ligament and joint injury. The material properties and tendon microstructure could be easily adapted for anatomical location, or to model other tendon diseases.

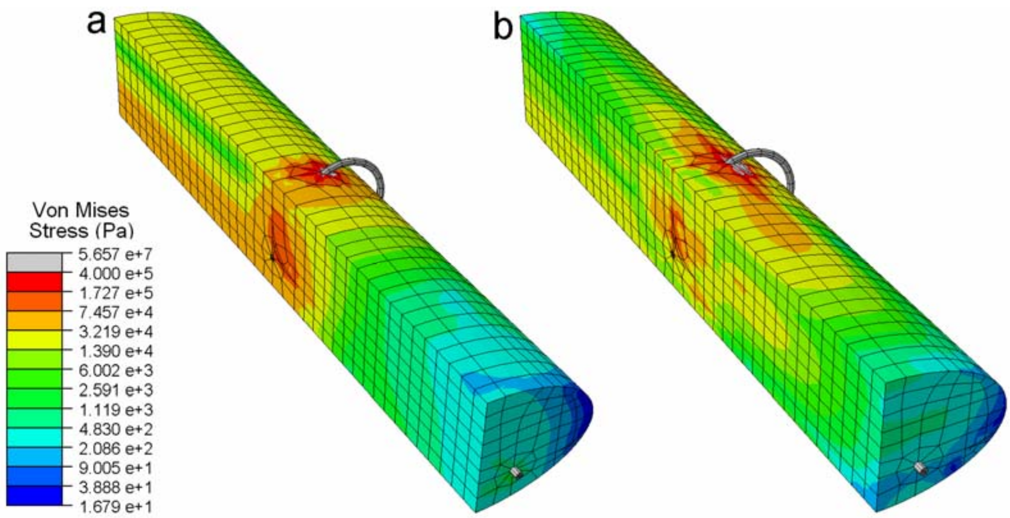

Figure 1 Deformation and stress map of Finite Element Kessler model when a 0.5mm gap between the tendon ends is simulated. (**a**) Tendon described as isotropic linear elastic material with Young's modulus of 200MPa and Poisson's Ratio of 0.3. (**b**) High stress region agrees closer with acelular region. Tendon described as orthotropic linear elastic material derived from microstructure model whereby Matrix modulus is 1MPa, fibril modulus is 1700MPa and Poisson's Ratio is 0.4.

SUGGESTED THEMES

Relevant themes:

Multidisciplinary; Engineering Analysis; Verification and Validation

Keywords:

Multi-scale; Homogenisation; Tendon; Suture