Finite Element Analysis Of SDFT Microdamage

Sushmitha Durgam, The Ohio State University –Two Year Grant

This proposal will study the multi-scale finite element models (FEM) that predict equine superficial digital flexor tendon (SDFT) mechanical behavior that are essential to delineate microdamage mechanisms preceding clinical injury.

Superficial digital flexor tendon (SDFT) injuries are common career-ending injuries in racehorses; are due to tendon overstrain from cumulative damage to tendon microstructure (microdamage). The elastic strength of equine SDFT is mainly due to the sliding motion between type I collagen-rich fascicles that are separated and connected by elastin-rich interfascicular matrix (IFM). This complex hierarchical structure as well as the non-uniform matrix distribution in the fascicles and IFM impart SDFT its elastic strength. Even though cumulative microdamage has been linked to SDFT injuries, the precise changes at the tendon fascicle-IFM and collagen-elastin levels are largely unknown. Our prior GJCRF-funded research has demonstrated that fascicle size decreased and IFM thickness increased in 3-year-old Thoroughbred racehorses compared to 2-year-olds in response to athletic training; tendon tensile strength increased even though IFM elastin decreased.

These findings provide a strong premise to develop non-invasive tools to study tendon microdamage and for gaining insight on tendon injury mechanisms, since, at present, destructive methods like ex-vivo tensile mechanical testing remain the gold standard means to understand tendon loading. For finite element analysis (FEA), any given structure is segregated into smaller, simple, interconnected structures, each with assigned mechanical properties.

We will leverage our expertise in fascicle, IFM and whole tendon histomorphology and experimental tendon mechanics to develop computational finite element models (FEM) that can predict equine SDFT mechanical behavior. Equine bone FEM have proven to be useful to understand distal third metacarpal bone and P1 fracture predilection sites as well as determine load-induced risk factors for fracture. To date, finite element analyses (FEA) of equine tendon have not been conducted; specifically, multi-scale FEM that take into account the complex SDFT hierarchical structure and its non-uniform ECM composition will facilitate evaluation of SDFT internal loading as it is difficult to measure in-vivo.

Fresh cadaveric metacarpal SDFT will be used for the proposed foundational equine SDFT FEA. Intact and elastase-digested specimens will be used to parse out the contributions of collagen and elastin to tendon function. In AIM 1, the dimensions, and tensile properties of fascicles and IFM measured via confocal histology and tensile testing, respectively, will be used to construct fascicle and IFM FEM such that stress-strain properties can be calculated.

These results will be used to develop non-uniform constitutive models that consider both the fascicles and the IFM. Such a model would account for the tendon""s tensile and recoil (elastic) properties, providing a more comprehensive representation of SDFT load bearing function. In AIM 2, the entire SDFT (quantified via MRI and 3D scan) will be used to estimate fascicle and IFM directionality and construct a multi-scale FEM through optimization methods while also measuring fascicle-IFM frictional properties.

A few published human Achilles tendon FEM describe simple models that only account for the collagen fibers or rely on macro models that predict muscle to tendon force transfer. Therefore, this research proposes FE² (Finite Element squared) method where this multi-disciplinary team will use advanced multiscale models to determine how interactions between fascicles and the IFM influence SDFT mechanics. This foundational FEA are vital not only for further research investigating how SDFT micro- and macro-damage can impact tendon tensile strength, but also for evaluating the efficacy of tendon therapeutics and improve tendon rehabilitation strategies.

Importance to the Equine Industry: This research is important because, SDFT injuries continue to be a common cause of wastage in Thoroughbred racehorses. Although cumulative microdamage (chronic damage to the tendon microstructure) pathogenesis leads to clinical SDFT injury, mechanisms responsible tendon injury are largely unknown. At present, ex-vivo destructive tendon mechanical testing remains the gold standard method to understand tendon tensile properties and tendon injury development. Therefore, constructing a noninvasive computational technique that considers SDFT's complex hierarchical structure and non-uniform matrix composition, will be invaluable to gain insights on tendon microdamage and injury development mechanisms.

This research will address this unmet clinical, and research need by constructing multi-scale finite element models (FEM) representing the complex hierarchical structure ECM composition and study equine SDFT mechanical behavior, for which currently there is no information. Further, this computational methodology (that has been beneficial to understand bone fracture risk and predilection sites) holds the potential for combining with magnetic resonance-based fiber tractography and enable functional tendon imaging efforts.

This research builds on our (1) prior GJCRF-funded research and (2) laboratory's overarching goal of understanding tendon microdamage mechanisms causing Thoroughbred racehorse SDFT injuries. The ability to predict SDFT mechanical behavior through FEM (1) will pave the way for equine distal limb dynamic modeling and subsequently be beneficial for reducing injury incidence and associated economic losses, (2) can evaluate the efficacy of novel and existing tendon therapeutics, and (3) improve tendon rehabilitation strategies.

Funded by Grayson-Jockey Club Research Foundation