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Original article

Changes in frictional coefficient with increased tendon surface tear—An experimental animal model

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ABSTRACT

Aim: Surface tribological properties of a tendon in terms of coefficient of friction and lubrication mechanism are expected to change with the progression of surface tears which can affect the optimal function of the tendon. This study investigated whether coefficient of friction proportionally increases with the progression of a surface tear in a bovine tendon model.
Methods: The study was performed using a pin-on-glass tribometer and bovine tendon samples ($n = 16$) divided into 4 groups. One group of tendons had no surface tears and thus served as a control, whilst the other 3 groups comprised tendons with increasing severity of artificially-induced surface tears. The coefficient of friction and the lubrication mechanism of the four groups of samples were investigated, calculated and compared.
Results: Statistical analysis showed significant change in coefficient of friction between the control group and the group with minimal tear ($p < 0.05$) while no difference noted between the groups of moderate to severe tear suggesting that the coefficient of friction increases initially with appearance of surface tears, though further progression to a significant tear do not cause a further increase in the frictional coefficient. There was no change in the lubrication mechanism between the groups.
Conclusion: This finding appears to contradict the speculation that the frictional coefficient continues to increase with an increase in surface tear severity. The finding has not been reported before and requires validation in future with testing in human tissue.

1. Background

Tendons primarily serve to transmit the forces generated by muscles to cause motion about a joint. Functional efficiency of the tendon primarily depends on its ability to glide with minimal friction.[1] Research continues to be performed to seek a better understanding of tendon excursion and their gliding properties, with multiple methods trialled to measure the coefficient of friction and to understand the lubrication mechanism at the tendon surface. Studies have also explored how the paratenon influences these frictional properties, with in vitro studies indicating that this tissue reduces tendon gliding resistance.[2]

An enhanced understanding of tendon tribology, and in particular the interaction of the tendon surface with neighbouring tissues, provides potential to alleviate tendon pathology, in identifying less disruptive surgical techniques and to aid in developing novel therapeutic interventions. Indeed, it is widely reported that repair increases a tendon's frictional coefficient,[3] with others now aiming to identify tendon grafts with inherently lower coefficient of friction, including intrasynovial grafts[4] and the use of novel materials and methods.[4–8] Other innovations are focussing on improving lubrication and preventing re-rupture of the tendon, preventing adhesion and failure of tendon repairs, tendon transfers and tendon grafting.

Maintaining the specialised tendon sliding surface ensures optimal frictional characteristics. Surface tears are common in supraspinatus tendon of the shoulder, possibly due to degeneration or as a consequence of bony or soft tissue impingement extrinsically. Tendon surface tears do continue to occur however, with little scientific data available to understand their progression and tribological properties of a tendon with surface tears. Whilst disruption of the outer tendon surface by a tear would likely increase tendon friction, it is as yet unknown whether the frictional coefficient continues to increase with progression of the surface tear.

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This study explores the progression of surface tears, by investigating the variation in frictional coefficient with increasing surface tear seeking to determine whether the coefficient of friction proportionally increases with increasing severity of a surface tear.

2. Materials and methods

Surface tears were created in a series of bovine tendon samples, to investigate the influence of tears on the frictional coefficient and the efficiency of lubrication. Extrasynovial flexor tendons were carefully dissected from mature bovine legs (Fig. 1a), which were obtained from a local abattoir following slaughter for the food industry. Ethical committee approval was not required as the animals had not been slaughtered for the study purpose but for the food industry. The tendons were visually examined for any obvious pathology, before the midsubstance was divided into 10 mm long samples (Fig. 1b). In total 16 samples were collected and divided into four groups of 4 samples. Four samples were retained with an intact surface for use as a control group (Group 1), with surface tears of 3 different severities created on the other samples, by rubbing the tendon surface with sand paper [emery tape P120 25 mm]. In Group 2, an early/mild surface tear was induced by abrading the tendon 50 times with sand paper. Group 3 samples were abraded 150 times to create a moderate surface tear, whilst the final 4 samples had a severe surface tear by being abraded 300 times (Group 4). For uniformity, the ventral side was always the surface of interest.

The frictional coefficient and lubrication regime of each sample was ascertained using a pin on plate tribometer (Fig. 2), a validated experimental model for analysing the frictional properties and lubrication of the tendon surface, as published by Theobald et al.[9,10] The pin on plate tribometer has been routinely used to study the tribological properties of articular cartilage[11,12] with our setup described as a schematic presentation in Fig. 3. The principle relies upon the surface of interest being slid against a rotating glass surface, with the amount of friction measured by the subsequent rotation of a pivoted metal beam. Here, the glass surface was first lubricated with a phosphate buffered saline (PBS) layer approximately 1 mm thickness (i.e. 50 ml), as described by Theobald et al.[9] Cyanoacrylate was then used to adhere the dorsal tendon surface to the free end of the metal beam (M1 in Fig. 3), with the tendon sample (Fig. 4) orientated such that when the glass plate rotates, the fibre direction is parallel to the frictional force and thus simulates a tendon gliding movement. Each sample was then preloaded once before conducting a set of experiments of increasing sliding speed (5, 10, 20, 26, 31 mm/s), with varying compressive loads (1N, 2N, 4N, 8N, 10N) applied perpendicular to the tendon surface. As the glass plate rotated, friction between the tendon and glass surfaces caused rotation of the metal beam, to which the former was attached. The extent of beam rotation was then measured and, in combination with the known stiffness of the

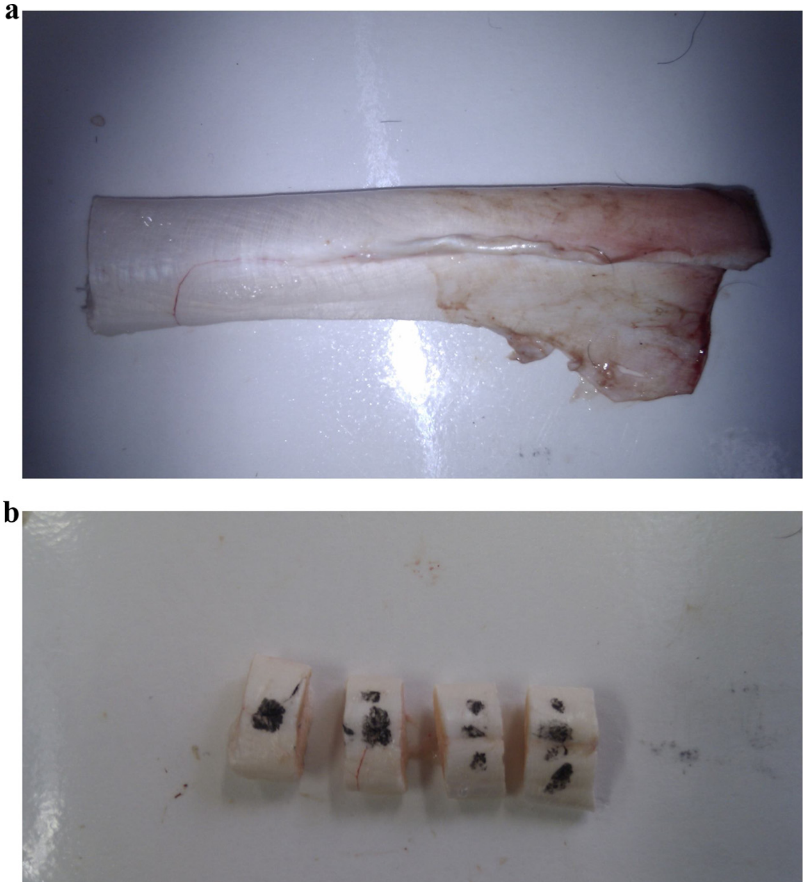
a
b


Fig. 1. a) A deep flexor tendon harvested from a bovine calf leg. b) Four 1 cm samples of 1 cm prepared from a deep flexor tendon, viewed from the dorsal surface. Each dot represents the identical sample allotted to group 1–4.

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