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Short Communication

Experimental study of the influence of senescence in the biomechanical properties of the temporal tendon and deep temporal fascia based on uniaxial tension tests

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ABSTRACT

The present study focuses on the determination of human temporal tendons and deep temporal fascia biomechanical behavior. The tensile and shear loads generated by the temporal muscle are transmitted to the masticatory system by the temporal tendons and muscle fascia. Establishing these connective tissues' biomechanical properties will help to develop proper finite element-based simulations of the human masticatory system, which will allow better understanding of diseases affecting the temporomandibular joint.

The tissues were harvested from 8 male fresh cadavers, who were subjected to uniaxial tension tests. Available literature states that different connective tissues undergo identical biochemical, cellular and mechanical changes during senescence. Several mechanical phenomena occur during maturation, resulting in stiffer, stronger and more stable connective tissues, although less flexible. Based on this evidence, the present study suggests that older temporal tendon and fascia samples are stiffer than younger ones. We also found significant higher secant moduli with increasing age.

1. Introduction

Bruxism is a parafunction characterized by a rhythmic activity of the masticatory system, triggering forced contact between dental surfaces (Ohayon et al., 2001) and also leading to temporomandibular disorders (TMD). Chronic headaches, myofascial face pain and ear-related problems are known symptoms (Gremillion, 2001), consistent with the International Criteria of Sleep Disorders Diagnostic for recurrent TMD-related symptoms.

Knowledge of basic anatomy is crucial to understand the role of temporal muscle and associated ligaments on masticatory system activity. The temporal muscle enables elevation and retraction of the mandible, thus its overstimulation leads to recurrent temporal headaches. The connective tissue of the temporal fascia (Wormald and Alun-Jones, 1991) allows some amount of shear deformation to occur between the muscle and the fascia in such a way they can "glide" past one another. The temporal tendon is a roughly uniaxial composite made of mainly type I collagen fibers that connects the temporal muscle to the coronoid process (Gray and Lewis, 2000).

To better understand how the temporal tendons and fascia are related to TMD, the present paper enhances the characterization the soft tissues' biomechanical behavior, in order to develop realistic finite element models of the masticatory system (Pérez del Palomar and Doblaré, 2006; Beek et al., 2000). On these referred works, the constitutive laws used for human temporal muscles were based on sets of material constants obtained by animal testing. The present work emphasizes the need to identify the specific material mechanical characteristics for human temporal tendons and fascia, to calculate the appropriate constitutive equation parameters that enable mathematical modeling (Kirilova et al., 2011).

During senescence, the increase in the total amount of collagen fibers in elderly tendons, leads to a cascade of biological, biochemical and mechanical transformations that contribute to a decrease in maximum stretch and an increase in mechanical stiffness (Tuite et al., 1997). Age-dependent mechanical changes and mechanical behavior are expected to be identical for both connective tissues (Vogel, 1978). The present work studies younger and older samples to determine the differences in the biomechanical behavior of these collagen rich tissues related to senescence.

2. Materials and methods

The temporal muscles, together with tendons and deep temporalis fascia, were resected from eight fresh cadavers at the North branch of the National Institute of Legal Medicine (INML), with the approval of the ethics committee. After autopsy,

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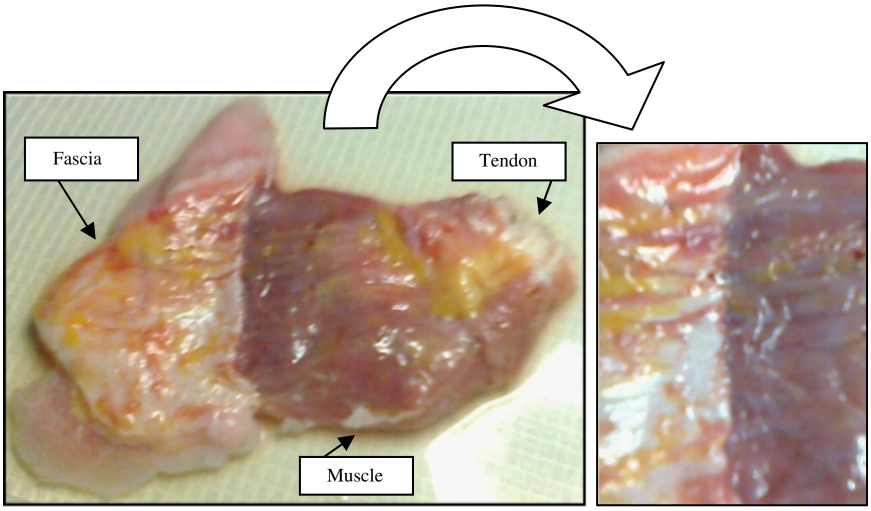

Fig. 1. The deep temporal fascia has clear anatomical boundaries as it lies directly over the temporalis muscle confined by the anatomical limits of the muscle. An effort was made to isolate the deep temporal fascia from the attached muscle fibers, carefully with the back of the scalpel. A closer look into the incision area is provided, showing the fascia is undamaged.

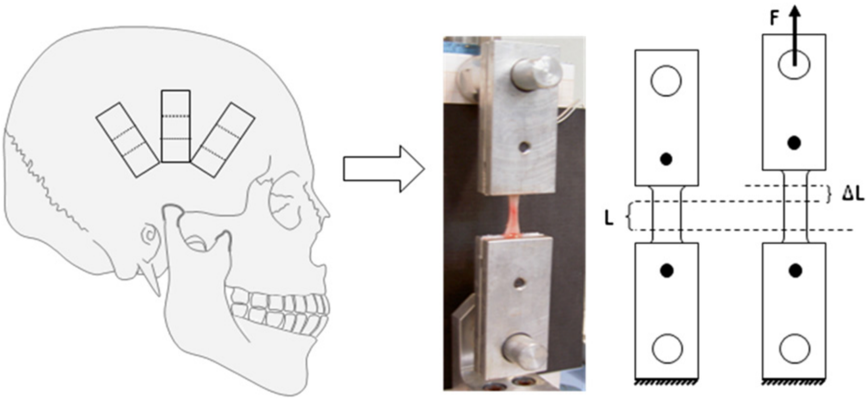

Fig. 2. Temporal tendon, aponeurosis and how it is incorporated in the measuring apparatus.

the fresh tissues were carefully dissected into muscle, tendon and fascia. The deep temporal fascia closely covers the temporalis muscle and its aponeurosis follows the muscle's anatomical boundaries (Wormald and Alun-Jones, 1991). The muscle fibers were thoughtfully removed from the deep temporal fascia and temporal tendon using the back of the scalpel, avoiding damage to the underlying fascia, Fig. 1.

The samples were stored in a saline bath at 6 °C until the mechanical tests were performed, for no more than 6 h post-mortem. The cross-sectional area of each sample was calculated using frontal and lateral images, and the measurements were performed using the grip dimensions as reference and the image analysis software package ImageJ, Fig. 2. The video records of each mechanical test enabled a detailed verification of inadequate alignments or slippage (Martins et al., 2010).

Longitudinal strips of 8 ± 1 mm length and 2 ± 1 mm wide were dissected, with longitudinal oriented fibers, following the same procedure used by Lynch et al. (2003). The samples were divided according to age-related criteria, as the younger group considered from 20 to 50 years and the older group from 51 to 70 years old, as shown on Table 1. A total of 36 tests were successfully performed using a constant deformation rate technique of 5 mm/min traction ratio. The choice of a quasi-static deformation rate (5 mm/min) was influenced by the interest in future applications in finite element models of the masticatory system, based on hyperelastic models.

Using the experimental force/displacement curves, the stress/stretch ratio curves were obtained. The Cauchy stress $\sigma_i = dF_i/ds$ with ds the deformed section, normal to the acting force dF_i. The ratio of the deformed length with the original length is the stretch $\lambda_{11} = |dx|/|dX|$, dX being the undeformed length and dx the deformed length.

The following mechanical properties were analyzed: the maximum stress $\sigma^{\max}$, the stretch at maximum stress $\lambda^{\sigma^{\max}}$ and the secant modulus $E(i)$. The secant modulus was defined as a ratio of the Cauchy stress to the corresponding $10 = 1.10$ (10% of deformation).

All statistical data were presented as median values and median absolute deviation (MAD), creating a measure for the variability of the samples. The data followed a normal distribution. Comparison between the parameters according to age was accomplished by means of two-tailed, paired t-tests, Table 1. Statistical significance was considered for $p < 0.05$ (Kirilova et al., 2011).

3. Results

Tendons' secant moduli values were higher for the older subjects sample (51 to 70 years old) when compared to the younger ones (20 to 50 years old) for E_5 and E_{10}. Older tendon samples are stiffer than younger samples, respectively, 97% and 85% (the results are statically significant, $p < 0.05$), as shown in Table 1. Similar findings were obtained for the secant moduli values in the fascia samples: E_5 and E_{10} are 86% and 92% higher (results near statistical significance, as $p = 0.054$).

The maximum stress, $\sigma^{\max}$, was 2.5 and 6.5 times higher for older samples, respectively, for tendon and fascia samples. Fig. 3 indicates an increase in stiffness on the older subjects group, which appears to be compensated by an increase in stretch at maximum stress, on the younger subjects group. Younger tendon samples have 14% higher stretch at maximum stress, than older tendon samples and younger fascia samples have 15% higher stretch at maximum stress than older fascia samples.

4. Discussion

Mechanical factors such as stiffness, maximum stress and stretch at maximum stress, were measured, revealing that a

Table 1
Tendon samples divided into the young group (age 20 to 50 years old) and into the old (age 51 to 70 years old), fascia samples divided into young and old groups. The fascia samples are referred to the deep temporal fascia, immediately adjacent to the temporal muscle. The number of samples, median values, median absolute deviation (MAD) and p values (significance $p < 0.05$) for paired t-tests are presented for each group.

	Number samples	E_5 (MPa)			E_{10} (MPa)			$\sigma^{\max}$ (MPa)			$\lambda^{\sigma^{\max}}$		
		Mean	**MAD**	***p***	**Mean**	**MAD**	***p***	**Mean**	**MAD**	***p***	**Mean**	**MAD**	***p***
Tendon young	10	0.064	0.029	0.027	0.144	0.060	0.025	0.594	0.257	0.050	1.418	0.151	0.027
Tendon old	10	0.311	0.277		0.999	0.935		1.458	1.144		1.241	0.163	
Fascia young	8	0.060	0.020	0.076	0.139	0.061	0.054	1.143	0.414	0.038	1.555	0.149	0.021
Fascia old	8	0.411	0.427		1.778	1.792		7.576	6.273		1.3427	0.182	

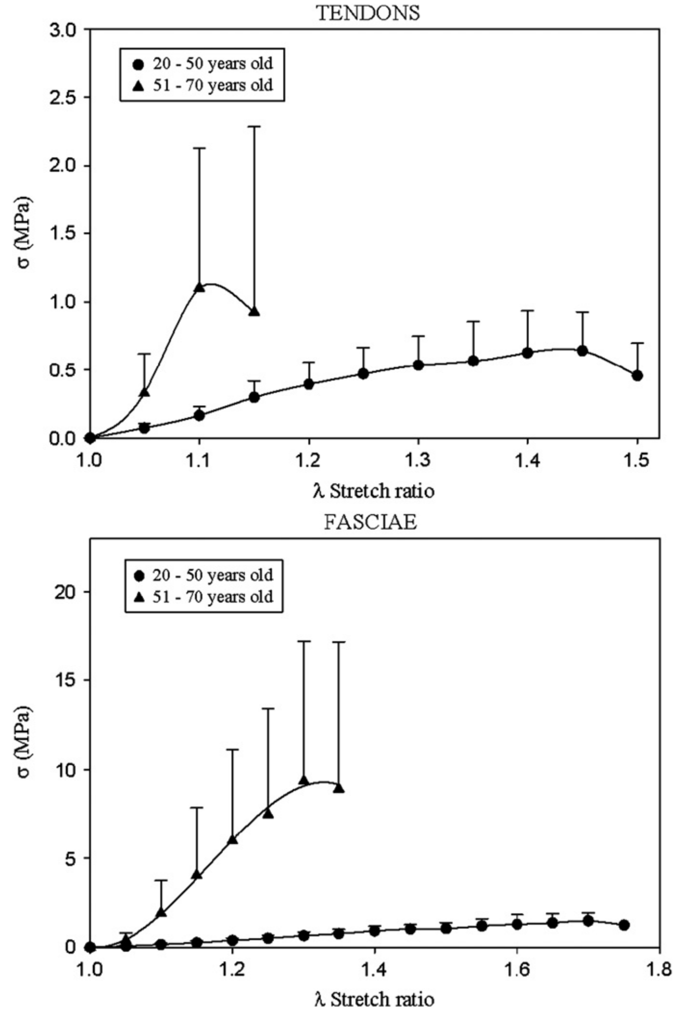

Fig. 3. Each curve was elaborated based on the median stress–stretch ratio and absolute deviation values (MAD). Only positive MAD is plotted. The median stress values at each of the considered stretch points, {1, 1, 1, 1, 2, 1, 3, 1, 4, 1, 5, 1, 6}, are represented by the dots on each plot. The represented plots are: the tendons (young and old group) and the fasciae (young and old group).

particular combination of factors takes place during senescence of connective tissues. After maturation, tendons undergo many biochemical, cellular and mechanical changes that bring about a general decline in both structure and function of the tendon, resulting in stiffer and stronger connective tissues, with a decrease in maximum stretch and an increase in mechanical stiffness (Tuite et al., 1997). This phenomenon reflects macroscopically the microscopical changes on the ration and number of elastin and collagen fibers (Tuite et al., 1997). Results in Table 1 corroborate the literature regarding biomechanical behavior changes that occur with senescence, as it indicates tendons exhibit a decrease in maximum strain and higher secant modulus as well as an increase in maximum stress with age.

Table 1 also shows that fascia results exhibit similar mechanical behavior to tendons as it reveals a decrease in maximum strain and higher secant modulus with increasing age. The present results can be validated through literature: a study conducted by Vogel (1978) states that age-dependent mechanical changes and mechanical behavior, is identical in various connective tissues supporting our similar results for fascia and tendons. Much work has been done regarding senescence in tendons but not for the fascia, so this work is complementing the lack of information in literature.

Conflict of interest statement

None of the authors has any relation with a commercial or industrial company that may constitute a potential conflict of interest.

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