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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A B S T R A C T

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.

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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 Alan-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 Doblare, 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 (Tuine 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,
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 \( \sigma = \frac{dF}{ds} \) with \( ds \) the deformed section, normal to
the acting force \( dF \). The ratio of the deformed length with the original length is the
stretch \( \lambda = \frac{dx}{dX} \), \( dx \) being the undeformed length and \( x \) the deformed length.

The following mechanical properties were analyzed: the maximum stress
\( \sigma_{\text{max}} \), the stretch at maximum stress \( \lambda_{\text{max}} \) and the secant modulus \( E_1 \). The secant
modulus was defined as a ratio of the Cauchy stress to the corresponding 10%
(10% of deformation).

All statistical data were presented as median values and median absolute
development (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 \( p < 0.05 \) (Kirlilova 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, \( \sigma_{\text{max}} \), 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
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 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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