Journal of Biomechanics 46 (2013) 845–848

Contents lists available at SciVerse ScienceDirect

Journal of Biomechanics

journal homepage: www.elsevier.com/locate/jbiomech
www.JBiomech.com

Short communication

The region-dependent dynamic properties of porcine temporomandibular joint disc under unconfined compression

Pelayo Fernández [a,*], María Jesús Lamela [a], Alberto Ramos [a], Alfonso Fernández-Canteli [a], Eiji Tanaka [b]

[a] Department of Construction and Manufacturing Engineering, University of Oviedo, Spain
[b] Department of Orthodontics and Dentofacial Orthopedics, Institute of Health Biosciences, the University of Tokushima Graduate School, Tokushima, Japan

ARTICLE INFO

Article history:
Accepted 16 November 2012

Keywords:
TMJ
Soft tissue
Temporal
Viscoelastic

ABSTRACT

In this study, the dynamic compressive properties in five different regions of the porcine temporomandibular joint (TMJ) disc are investigated over a wide range of loading frequencies. The aim was, thus far, to evaluate the regional difference and the frequency-related effect of the applied load on these properties. Eleven porcine TMJ discs were used; each disc was divided into 5 regions, anterior, central, posterior, lateral and medial. Sinusoidal compressive strain was applied with an amplitude of 1.0% and a frequency range between 0.01 and 10 Hz. The dynamic storage and loss moduli increase with frequency, the highest values being attained at the posterior region, followed by the central and anterior regions. Loss tangent, tan δ, ranged from 0.20 to 0.35, which means that the disc is primarily elastic in nature and has a small but not negligible viscosity. The present results suggest that the dynamic viscoelastic compressive modulus is region-specific and depends on the loading frequency, thus having important implications for the transmission of load to the TMJ.

1. Introduction

The disc of the temporomandibular joint (TMJ) is located between the articulating parts of the temporal bone and mandibular condyle and plays an important role as a stress absorber during function (Tanaka and van Eijden, 2003, Tanaka et al., 2008). The TMJ disc provides a large load-bearing capacity over the entire motion range of the human jaw joint (Koolstra and Tanaka, 2009). As both sliding and rotating with slightly lateral excursion occur simultaneously between articulating surfaces, the TMJ disc is subjected to a multitude of different loading regions during mandibular movements. Basically, three modes of loading can be distinguished: compression, tension, and shear. Obviously, during natural loading of the joint, combinations of these basic modes of loading do occur on the articulating surfaces. During every type of loading, the TMJ disc undergoes a deformation commensurate with its material properties, while internal forces are produced within the tissue.

During function, the TMJ disc is subjected to intermittent loading during mastication and to sustained loading during clenching, thus being likely exposed to dynamic loadings rather than static ones. In response to dynamic force conditions, the disc behaves in a viscoelastic fashion, which is different from its behavior during static conditions. Therefore, the viscoelastic properties of the disc should be dynamically determined although the mechanisms responsible for stress distribution, energy dissipation and stress absorption are presumably the same as quasi-static loading. A number of dynamic experiments have been performed (Beek et al., 2001; Tanaka et al., 2003a, 2006), in which the dynamic properties of human and porcine discs such as the maximal stress and the energy dissipation were evaluated at various frequencies and compressive strains. However, relatively little information is available on the dynamic viscoelastic properties of the disc under unconfined compressive load. In this study, the dynamic compressive properties in five different regions of the porcine TMJ disc are investigated over a wide range of loading frequencies. As the disc exhibits an anisotropic and viscoelastic structure, the aim was to evaluate the regional difference and the frequency-related effect of the applied load on these properties.

2. Materials and methods

Eleven healthy-looking TMJ discs from 8 pigs (age: approx. 6–7 months) were obtained at a local slaughterhouse (Gijon, Spain). The protocol of the experiment was approved by the Animal Care and Use Committee at the University of Oviedo, Spain. The discs were carefully dissected immediately after the sacrifice, introduced in hermetic containers immersed in a physiologic saline solution (NaCL 0.09 g/100 ml), and frozen at −25 °C until the experiment was initiated for

* Correspondence to: University of Oviedo, Departamento de Construcción e Ingeniería de Fabricación, Edo. Dep. Oeste. N-7, 7.1.23, CP 33204 Gijón, España, Spain. Tel.: +34 985181932.
E-mail address: fernandezpelayo@uniovi.es (P. Fernández).

0021-9290/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.jbiomech.2012.11.035

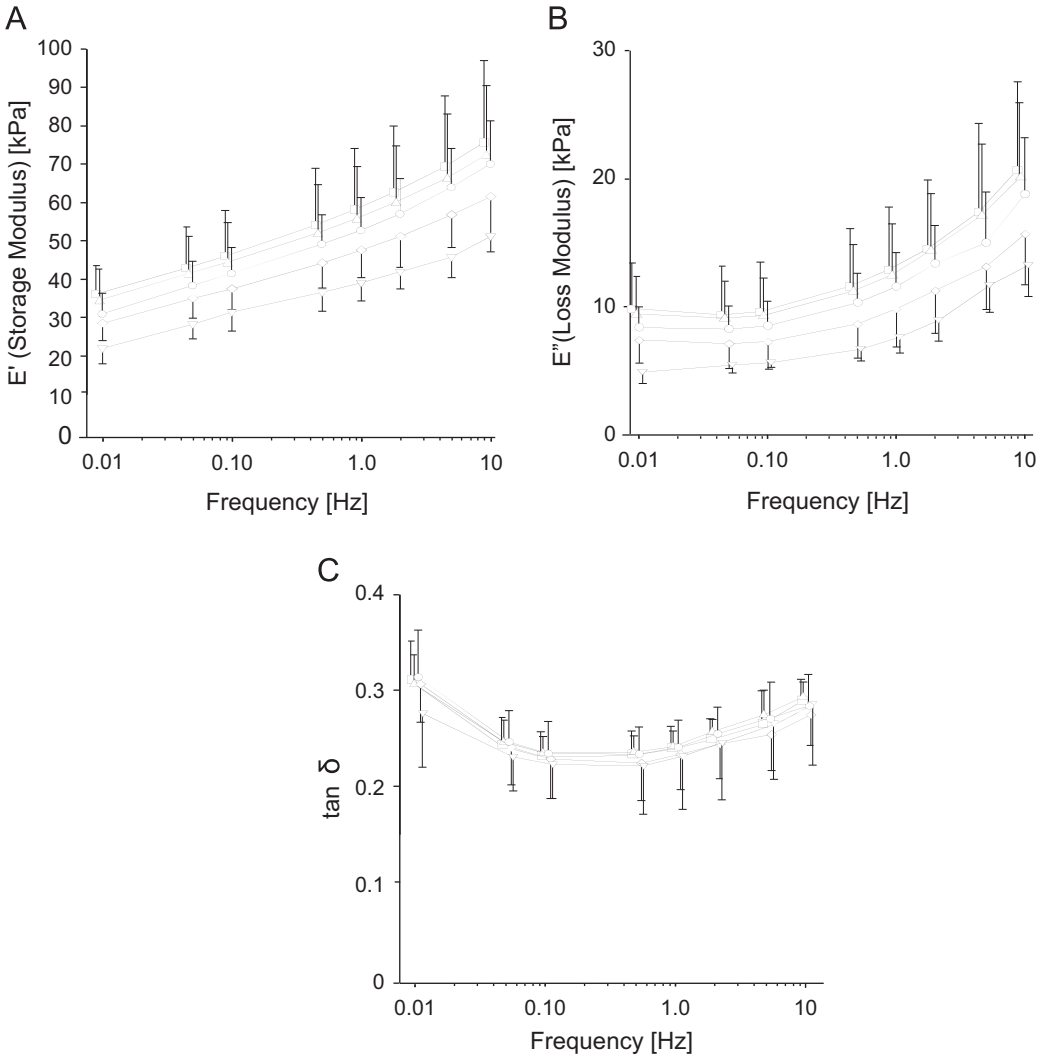

Fig. 1. Mean values of the storage modulus E' (A), loss modulus E'' (B), and the loss tangent tan δ (C) as a function of frequency; the amplitude of compressive strain was fixed at 1.0%. Error bars are standard deviations (for each group, $n=11$). □ Posterior; ◯ central; △ anterior; ▽ lateral; ⋄ medial.

testing. Using a cylindrical 4.0 mm diameter tissue punch, the experimental specimens were dissected from the five characteristic regions of each disc: anterior, central, posterior, lateral and medial region. The average thickness of the specimens was 1.83 ± 0.17 mm without significant differences among the five regions.

All the specimens were tested in a DMA instrument (RSA3, T.A. Instruments, USA) in unconfined compression using parallel plates at room temperature (20 °C). The disc was compressed cyclically by the displacement of the bottom plate, which was larger than the circular specimen. The compressive forces and the distance between the compressive plates were measured instantaneously by means of a load cell and linear variable transducer, respectively. During the experiments, the discs were covered with saline solution that was added to the disc before starting each test.

Due to the nature shape of the disc, it is difficult to obtain perfect uniform thickness specimens. To minimize this inconvenience a steady contact preload of 5 mN was applied before the preconditioning test. After first steady contact, a 3 min preconditioning test was applied with 1% sinusoidal strain before the dynamic test. After confirming no separation of the specimen from the indentation plate and establishing new steady contact, compression was carried out to the specimens by a sinusoidal strain of $\varepsilon=\varepsilon_0 \sin(\omega t)$, where ω is angular velocity at each frequency. The administrative strain was $\varepsilon_0=1.0\%$; the occurring stress was also described by a sinusoidal wave: $\sigma=\sigma_0 \sin(\omega t+\delta)$, δ being the phase between the applied strain and the measured stress. In the present study the oscillation frequency was ranged from 0.01 to 10 Hz: 0.01; 0.05; 0.1; 0.5; 1; 2; 5 and 10 Hz, and the dynamic moduli were estimated and registered.

The above-described relationship between stress and strain can be used to express the viscoelastic behavior of the disc by a number of parameters (Tanaka et al., 2002). As a result of the dynamic behavior of stress and strain, the compressive storage modulus E', the compressive loss modulus E'', and the loss tangent tan δ were determined as dynamic viscoelastic parameters. The storage modulus E' represents the elastic component of the material behavior and the loss modulus E'' the viscous component. The ratio of E'' to E' is given as tan δ.

For each of the five regions of specimens, the mean and standard deviation values of E', E'', and tan δ were calculated for each frequency. A two-way ANOVA was performed to analyze the effect of the region-specificity and the frequency applied on E', E'', and tan δ. More specifically, Student t-tests were performed to test for differences at a frequency of 1.0 Hz. This frequency reflects chewing masticatory conditions (Gallo et al., 2000; Druzinsky, 1993).

3. Results

In all 5 regions, the values of E' and E'' were proportional with the frequency (Fig. 1A, B). The storage modulus E' is increased with the frequency in the specimens from all the regions. The loss modulus E'' exhibited practically no changes between 0.01 and 0.1 Hz, but it increased from 0.1 to 10 Hz. The largest values for E' and E'' were found in the posterior region followed by the central and anterior regions.

In contrast, the loss tangent tan δ presented a higher dependence with frequency whereas a regional difference was not found (Fig. 1C). The values of tan δ ranged from 0.20 to 0.35, which means that the disc is primarily elastic in nature and has slight but not negligible viscosity.

The two-way ANOVA revealed significant effects ($p<0.0001$) of the frequency and region-specificity on the values of E' and E''