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Original article

Quantitative evaluation of masseter muscle stiffness in patients with temporomandibular disorders using shear wave elastography

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ABSTRACT

Purpose: The aim of this study was to quantify masseter muscle stiffness in patients with masticatory myofascial pain.

Methods: Stiffness was measured using shear wave elastography, which expresses stiffness as shear wave velocity (Vs). A phantom study was conducted to confirm the reliability of the measuring device. The study participants were 26 females with bilateral masseter muscle pain who were classified into either Research Diagnostic Criteria for Temporomandibular Disorders (RDC/TMD) group Ia (myofascial pain; n = 13) or RDC/TMD group Ib (myofascial pain with limited opening; n = 13). Healthy controls consisted of 24 female volunteers with normal teeth and jaws, who were not classified into groups I/II/III by RDC/TMD.

Results: Muscle stiffness was 1.96 m/s (12.5 kPa) in 13 patients in group Ia, 2.00 m/s (13.0 kPa) in 13 patients in group Ib and 1.27 m/s (5.25 kPa) in 24 control subjects. Vs was significantly greater in groups Ia and Ib than in the control group ($p < 0.05$). Characteristic pain intensity (CPI) became clear as an independent factor impacting *Vs* (partial regression coefficient = 0.714; multiple regression analysis , $p < 0.05$). Masseter muscle stiffness was positively correlated with CPI ($p < 0.05$) and negatively correlated with maximum assisted mouth opening ($p < 0.05$) and painless mouth opening ($p < 0.05$).

Conclusion: Shear wave elastography is useful to quantify masticatory muscle stiffness. Masseter muscle stiffness of females measured using shear wave elastography was about two-fold greater in group Ia and Ib than in the healthy control group.

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1. Introduction

Temporomandibular disorders (TMD) are characterized by pain and dysfunction involving the temporomandibular joint and masticatory muscle [1,2]. Myofascial pain, one of the most common finding in TMD, is diagnosed on the basis of the presence of pain and tenderness by palpation [3,4]. The diagnosis depends on a subjective assessment by patients and clinicians; therefore, it is difficult to assess the disease objectively. Myofascial pain is often associated with regional pain in tender areas, known as trigger points, which are expressed in taut bands of skeletal muscle and tendon. Clinically, the masticatory muscle associated with myofascial pain is hard and stiff to the touch [5]. However, this is a subjective finding by practised clinicians well-experienced in palpation. A clear objective assessment of masticatory muscle stiffness in patients with myofascial pain has yet to be made. Therefore, it is necessary to establish an effective method to objectively evaluate the severity of masticatory muscle stiffness and the effect of treatment on myofascial pain.

Shear wave elastography is a recently developed type of ultrasound elastography that uses shear wave propagation velocity, measured in m/s, to quantify tissue stiffness. This technology has only recently begun to be used worldwide to predict the severity of fibrosis in chronic hepatitis C patients [6–8]. Therefore, the aim of this study was to investigate the utility of shear wave elastography to quantify masseter muscle stiffness in myofascial patients using shear wave elastography.

2. Materials and methods

2.1. *Shear wave velocity (Vs) measurement*

Vs was measured using the ACUSON S2000® diagnostic ultrasound system (Siemens AG, Munich, Germany). Stiffness was measured using shear wave elastography, which is based on a physical phenomenon that occurs when an object is irradiated with ultrasonic waves and part of the energy is converted into force as the waves penetrate the object. Consequently, the object is moved away from the ultrasound source. It is generally known that Young's modulus, representing the stiffness of an object, is positively correlated with the propagation velocity of shear waves, which are generated when shock is applied to an object. A higher Vs value indicates greater stiffness. In this study, shear wave elastography was used to measure the propagation velocity of shear waves to a region of interest (ROI) with a fixed dimension of 5 × 5 mm. Vs was automatically measured 10 times per second, and the average value was displayed on the monitor of the system. Examinations were performed using an Acuson 9L4 linear vascular probe (Siemens AG, Munich, Germany) at 4–9 MHz, with water soluble transmission gel as a contact surface.

2.2. *Phantom study*

A phantom study was conducted to confirm the reliability of the device. This phantom (Elasticity QA Phantom Model 039; CIRS, Norfolk, VA, USA) was developed for quality assurance of elastography systems and is the only commercially available model. The tissue equivalent material used in this phantom is made from a water-based polymer (Zerdine®) patented in the US. According to the user guide, model 039 includes four separate phantoms of varying stiffness (Young's modulus): 3.3, 10.9, 24.7 and 46.7 kPa (density: 1.276–1.284 g). The following settings were used for the phantom: Ø, 4.5 in.; height, 5.5 in. Shear wave elastography allows for confirmation of the accuracy and reproducibility of measurements and the relationship between known hardness and Vs.

The phantoms were measured to confirm the reliability of Vs measurements. Three examiners (YA, MT and AK) made 10 Vs measurements to confirm interoperator reliability. One examiner (YA) performed three sessions: one on Day 1 and two one day later to confirm intraoperator reliability. Each of these three examiners have more than 4 years of experience in the diagnosis and treatment of temporomandibular disorders.

The phantoms of the four different hardness were measured to confirm the validity. Vs values for the four separate phantoms were measured in the ROI for total 27 times (9 sites, 3 times) for each lesion type by one examiner (MT).

According to the WFUMB guidelines and recommendations for the clinical use of ultrasound elastography [9], differences in the elasticity of soft tissues are expressed in kPa by elastic moduli, such as Young's modulus (E) and shear modulus (G), and Vs values were expressed as $G = \rho Vs^2$ (ρ = density), which is approximately 1–10 m/s in soft tissue. Thus, E will be equal to approximately three times G, as $E \approx 3G$ [9]. The four different hardness of the phantom and the shear modulus (G) calculated from the Vs measurement were analysed with linear regression analyses.

2.3. *Clinical evaluation of TMD patients*

The Research Diagnostic Criteria (RDC) [1,4,10,11] was used for TMD diagnosis and classification. Patients with a chief compliant of TMD who sought treatment at Niigata University Graduate School of Medical and Dental Sciences (Niigata, Japan) from April 2012 to April 2016 were eligible for participation in this study. The study participants were 26 females (age, 15–46 years) with bilateral masseter muscle pain who were classified into either RDC/TMD group Ia (myofascial pain; n = 13) or RDC/TMD group Ib (myofascial pain with limited opening; n = 13). The study participants were limited to women, who experienced pain at least once weekly for ≥3 months and classified as either group Ia or group Ib according to the RDC/TMD. Exclusion criteria for the patient groups were those belonging to group II or group III in RDC/TMD and undergoing dental treatment for something other than TMD. Healthy controls comprised 24 female volunteers (age, 23–45 years) with normal teeth and jaws, who were not classified into groups I/II/III by RDC/TMD, had no history of jaw movement dysfunction, pain in the temporomandibular joint, abnormalities in mouth opening function or trauma surgery involving mastication function over the previous 3 months and who agreed to participate in this study. Exclusion criteria for the control group included those with neurological disease, bone disease, systemic disease, cancer, acute pain, a history of drug ingestion within the past week (e.g. pain relievers, muscle