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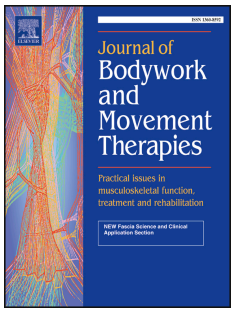

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Novel Method to Measure Active Myofascial Trigger Point Stiffness Using Ultrasound Imaging

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Abstract

Introduction: Myofascial trigger points (MTrPs) are one of the most common and important causes of musculoskeletal pain. An ultrasound is a useful modality in examining musculoskeletal disorders. By applying compressive stress and observing changes in ultrasound images, the elastic modulus (Young's modulus) can be calculated. Our objective was to develop a novel method to distinguish MTrPs from normal tissues. **Methods:** A total of 29 subjects with MTrP in the sternocleidomastoid muscle were assessed. A force gauge was attached to a transducer to obtain stress levels. To obtain strain, images were recorded in both with stress and without stress states. By dividing the stress level by the measured strain, the elastic modulus was determined. **Results:** Elastic modulus in MTrPs and the normal part of the muscle were measured to be 13379.57±1069.75Pa and 7078.24±482.92Pa, respectively (P=0.001). This indicated that MTrPs were stiffer than normal parts of the muscle. **Conclusion:** This study presented a new method for the quantitative measurement of the elastic modulus of MTrP, thereby distinguishing MTrPs from normal adjacent muscular tissue with more simplicity and lower cost, compared to other ultrasound methods.

Keywords: Myofascial pain syndrome, trigger points, ultrasonography, sonography, stiffness, Young's modulus

Introduction

Myofascial pain syndrome (MPS) is a non-articular musculoskeletal disorder (Turo et al 2015) that causes motor and sensory abnormalities. MPS is considered to be a challenging issue for health care providers due to its high prevalence (85-95%) as well as its physical and financial burden on society (Gerwin 2001). Myofascial trigger points (MTrPs) have been identified as an important neurophysiologic phenomenon in the pathophysiology of MPS. MTrPs are considered as the most common and important cause of acute and chronic musculoskeletal pain (Simons et al 1999, Bron and Dommerholt 2012) such as headache (Simons et al 1999).

MTrPs are stiff, localized spots of extreme tenderness in a palpable taut band of skeletal muscle(Simons et al 1999). Palpation of referred pain away from the MTrP site (Simons et al 1999). An active MTrP produces spontaneous referred pain, and always evokes clinical symptoms. A latent MTrP is usually asymptomatic and may cause referred pain in response to compression, stretch or overload of the affected tissues (Simons et al 1999). Various elastography techniques have been proposed and developed to image the relative mechanical properties of tissues (Muro-Culebras and Cuesta-Vargas 2013).

Ultrasound is an available, portable, and non-invasive method for examining, evaluating and guiding therapeutic interventions (Verbeek et al 2014). It also helps to obtain information such as the biomechanical properties of tissues (Ballyns et al 2011, Shamdasani et al 2008). Diagnostic ultrasound has been widely used in real-time and the non-invasive imaging of muscles, tendons, fascia, vessels, and other soft tissues (Sikdar et al 2009). Ultrasound is also an alternative method for MRI in the diagnostic imaging of soft tissues (Leineweber and Gao 2015).

The current assessment of MTrPs is commonly based on palpation techniques, which alone may not be reliable (Hsieh et al 2000, Kumbhare et al 2017), as they require immense clinical experience. An ultrasound can provide an objective assessment of MTrPs which may be helpful to determine superiority of therapeutic methods (Sikdar et al 2009). A growing body of evidence states that MTrPs can be visualized under ultrasound-guided examination,

especially when the results are matched with the findings of a physical examination such as palpable tender nodule (Ballyns et al 2011, Sikdar et al 2009, Kumbhare et al 2016). A recent study found that ultrasound has excellent intra-rater reliability for detecting MTrPs (Adigozali et al 2017).

By applying compressive stress and observing changes in ultrasound images, the biomechanical properties of tissues such as stiffness can be examined (Thomas and Shankar 2013). Compressive stress, when applied to tissues cause axial displacement. According to Hooke's law of elasticity, Young's modulus or elastic modulus (*E*) as a physical quantity for measuring stiffness can be determined according to the equation *E = Stress/Strain*. *Strain* is the change in size or shape produced by a system of forces. It is expressed as a ratio (e.g. the change in length per unit length). The force acting on an area is known as *stress* (Drakonaki et al 2012). This method of ultrasound is extensively used in the diagnosis of malignancies of breast, prostate, liver, pancreas, thyroid, cervix, and lymph nodes based on tissue stiffness (Drakonaki et al 2012). Given the biomechanical changes in neuromuscular and musculoskeletal disorders, this method has clinical application in musculoskeletal disorders (Drakonaki et al 2012, Brandsma et al 2012).

So far, the assessment of MTrP stiffness and its difference from normal adjacent tissues have been studied by vibration elastographic methods. However, familiarity and cost limitations may cause elastography to be unavailable in certain places (Thomas and Shankar 2013). So, our objective was to develop a low-cost and simple method to distinguish MTrPs from normal adjacent tissues through quantitative measurement of elastic modulus based on ultrasound imaging, which may reveal the biomechanical properties of MTrPs more easily.

Materials and Methods

Study Population

This study was carried out at the Department of Physiotherapy, Faculty of Medical Sciences, Tarbiat Modares University, Tehran, Iran. Subjects with MTrP in SCM muscle were eligible. The subjects underwent physical examination according to Simons and Travell

criteria (Simons et al 1999) to find active MTrP in SCM muscle and to rule out other causes of pain. The subjects were excluded if they had more than one active MTrP in the SCM muscle, exhibited rheumatologic diseases, suffered from physical/psychiatric limitation, and had experienced neck or shoulder surgery. Based on their history and physical findings in the SCM muscle, 29 female subjects were enrolled in the study. Written informed consent was taken from all subjects before enrollment in the study. All stages of this study have been approved by the Committee of Ethics in Biomedical Research at the Faculty of Medical Sciences, Tarbiat Modares University.

Clinical Examination

The subjects underwent an examination to diagnose active MTrP. This was conducted by experienced physiotherapist according, to Simon and Travell criteria (Simons et al 1999). This included the: presence of a palpable taut band in a skeletal muscle, presence of a hypersensitive spot within the taut band, palpable or visible local twitch on snapping palpation, and reproduction of referred pain elicited by palpation in the sensitive spot.

Imaging Procedure

The subjects underwent an ultrasound examination using a clinical ultrasound system (SonixTouch, Ultrasonix Medical Corporation) with linear 5-14 MHz array L14-5/38 transducer targeted at sites palpated in physical examination. An expert sonographer performed all the ultrasound examinations. The MTrPs in the SCM muscle were visualized longitudinally with the subject sitting upright in a comfortable position. MTrPs in ultrasound images were usually considered as hypoechoic focal points (Kumbhare et al 2016) with heterogeneous echotexture (Sikdar et al 2009, Ballyns et al 2011, Turo et al 2013, Sikdar et al 2008, Kumbhare et al 2016) (see Fig 1).

PLACE FIGURE1 HERE

To gain MTrP elastic modulus, the images were recorded in two states: with stress and without stress. In images of with stress state, the compressive stress imposed on the tissue by

the transducer and the applied force level were measured using a force gauge (Lutron Electronic Enterprise Co) attached to the transducer by a polylactic acid ring holder (see Fig 2). The force gauge was connected to a computer and the Lutron 801 software (Lutron Electronic Enterprise Co.) allowed us to check and control the stress applied during the imaging process.

To gain elastic modulus in the normal part of the muscle, images of with and without stress states in the visualized healthy part of the muscle were recorded.

PLACE FIGURE2 HERE

Image Analysis and Measuring of Elastic Modulus

After recording and transferring the images to a computer, ImageJ software version 1.50h (US National Institute of Health) was used to compare the images of with and without stress states. First, the coordinates of MTrPs in the image without stress were recorded. Then, the length of the maximum vertical line in the MTrP region was measured. In regard to recorded coordinates, the length of maximum vertical line in the MTrP was measured in the image of with stress state (see Fig 3). Each measurement was performed at least three times, and the average was recorded if the coefficient of variation was less than 5%. Finally, using the measured length of maximum vertical lines in images of with stress and without stress states, strain was measured. By dividing applied force (1.02±0.08 N) by transducer contact area (6.24 cm^2), the amount of stress was measured. After measuring strain and stress, the elastic modulus was determined using the relation between stress and strain. Elastic modulus measurement was performed on the assumption that the stress was at the level that stiffness followed linear behavior.

The same procedure of elastic modulus measurement was done in the normal part of the muscle. Strain measurement in the part was done by calculating changes in the diameter of the muscle in with stress and without stress images (see Fig 3).

PLACE FIGURE3 HERE

Statistical Analysis

The Kolmogorov-Smirnov test showed that MTrP elastic modulus did not follow normal distribution ($P<0.05$). Elastic modulus in MTrPs and that in normal parts of the muscle were compared by the Mann-Whitney test using IBM SPSS Statistics 22. P-value less than 0.05 was considered significant.

Results

A total of 29 subjects with a mean age of 36.37±10.56 years underwent ultrasonography. All the subjects were female. Ultrasound images recorded in the location of MTrP corresponded with findings of a physical examination. On ultrasound imaging, MTrPs were found in the oval area of hypoechogenicity. The mean applied stress was 1635.72±137.98 N/m^2, and measured strain values in the MTrP region and the normal part of the muscle were 18.84%±2.33% and 26.36%±1.99%, respectively (see Table 1). Elastic modulus in MTrPs and that in the normal part of the muscle were found to be 13379.57±1069.75 Pa and 7078.24±482.92 Pa, respectively (see Table 1 and Fig 4). The Mann-Whitney test revealed that elastic modulus in the MTrP region was significantly higher than in the normal part of the muscle ($P=0.001$). This finding indicated that MTrPs were stiffer than in the normal parts of the muscle.

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Discussion

This study presented a new method for the quantitative measurement of MTrPs elastic modulus and through that, distinguished MTrPs from normal adjacent muscular tissue. This method can be helpful as it is an objective examination to precisely locate MTrPs.

Furthermore, this non-invasive method can provide informative data after treating MTrPs, which may be helpful in determining the superiority of therapeutic modalities in clinical settings.

Several ultrasound elastography methods were used in literature. In vibration elastography, where a handheld vibrator is used, a shear wave of specific frequency is generated. When the wave propagates in the tissue, the peak vibration amplitude decreases in the stiffer area compared to the surrounding tissue. Then, by Doppler imaging techniques, vibration amplitude is estimated and areas associated with MTrP are identified. This method is sensitive to the alignment of an ultrasound transducer and the position of a handheld vibrator (Ballyns et al 2012). Furthermore, vibration elastography usually requires ultrasound machines with expensive software and hardware equipment. But the advantage of our method over other methods, is availability, simplicity, and reasonable costs. In addition, this method provides quantification of the elastic modulus in MTrPs. So, we believe this sonographic technique may have an important role to play in the objective assessment of active and latent MTrPs and to better describe the complex environment of MTrPs.

In our study, the mean values of the elastic modulus in MTrPs and the normal part of muscle were 13.37±2.06 KPa and 7.07±0.48 KPa, respectively. The measured elastic modulus could successfully classify MTrPs vs. normal tissue successfully. A significant difference between the two measured moduli suggests that our method makes the study of biomechanical properties of MTrPs feasible.

To date, the only other study investigating the quantitative stiffness of MTrPs that we know of, was done by Maher et al (2013). In that study, the mean of MTrP shear modulus was found to be 13.56 KPa in the sitting positions. In our study the elastic modulus was measured, and the results were consistent with their findings.

The results confirmed that MTrPs have biomechanical abnormalities that cause a small degrees of strain in the area. Thus, MTrPs appear stiffer, as be confirmed by palpation. Hypoechogenicity and stiffness of MTrPs suggest muscle fiber contraction. The pathogenesis and pathophysiology of MTrPs are still vague. According to the most commonly accepted

hypothesis known as the Integrated Hypothesis, the decrease in blood flow and ATP leads to an energy crisis in the muscle (Simons et al 1999). Decreased energy levels lead to contracture of sarcomere units, due to the reduction of calcium returned to the sarcoplasmic reticulum (Kuan et al 2007). The movement of calcium from the sarcoplasm to the sarcoplasmic reticulum is performed by pump which requires ATP consumption.

The presented method indicates a preliminary gate that should be investigated further in future studies. So far, several therapeutic modalities such as muscle energy techniques, manual therapy, and dry needling have been suggested in the literature to reduce the symptoms of MTrPs. Through this new method, it is possible to study the effect of the proposed therapeutic modalities on MTrP stiffness and to investigate the relation between the biomechanical properties of MTrP and its signs and symptoms. However, the experience of the sonographer is important to ensure the accuracy of musculoskeletal ultrasound.

Limitations

We believe that the method of ultrasonography used in the study, based on calculation of stress and strain, may enable the quantification of the elastic modulus of MTrPs and muscles. However, this study has several limitations, which should be taken into consideration. The findings of the study were obtained from a small number of subjects. In addition, in this study, only the SCM muscle and associated MTrPs were assessed. Since there was no possibility of measuring the MTrP cross-sectional area, the transducer contact area was used to calculate the stress level. Furthermore, although we tried to locate and measure MTrPs carefully, the risk of error and unintentional bias in taking measurements were unavoidable.

Conclusions

In this study, the transducer was attached to a force gauge. The measurement of MTrPs and normal parts of the muscle elastic modulus was performed using this method. Our findings

support the application of this novel method to distinguish quantitatively MTrP stiffness from the normal part of the tissue. Future studies would benefit from the method in assessment of MTrPs.

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Table

Table 1. Calculated stress, strain, and elastic modulus in MTrPs and normal part of the muscle

n=29	MTrPs	Normal part of muscle
Stress (N/m^2)	1635.72±137.98	
Strain (%)	18.84±2.33	26.36±1.99
elastic modulus (Pa)	13379.57±1069.75	7078.24±482.92

MTrPs, myofascial trigger points*; Pa*, pascals

Captions to Illustrations

Fig 1. Hypoechoic trigger point (arrow). An isolated MTrP appears as a focal hypoechoic nodule.

Fig 2. Attached Transducer to force gauge by ring holder. Through this attachment applied force to tissue was available.

Fig 3. The images of with stress and without stress states. A, MTrP in image of without stress state is shown. B, the MTrP in image of with stress state is shown. C, maximum vertical lines in MTrP (yellow line) and diameter of normal part of the muscle (red line) are measured in image of without stress state. D, maximum vertical lines in MTrP (yellow line) and diameter of normal part of the muscle (red line) are measured in image of with stress state.

Fig 4. Measured elastic modulus in MTrPs and normal part of the muscle. The difference was statistically significant.

Figures

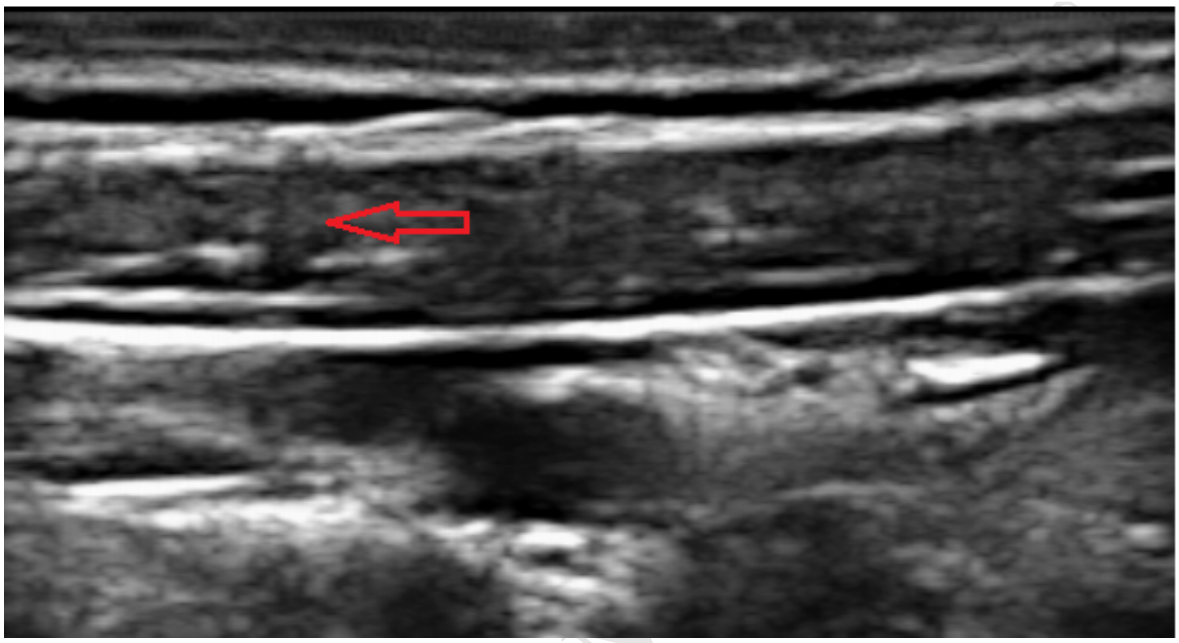

Figure 1

Figure 2

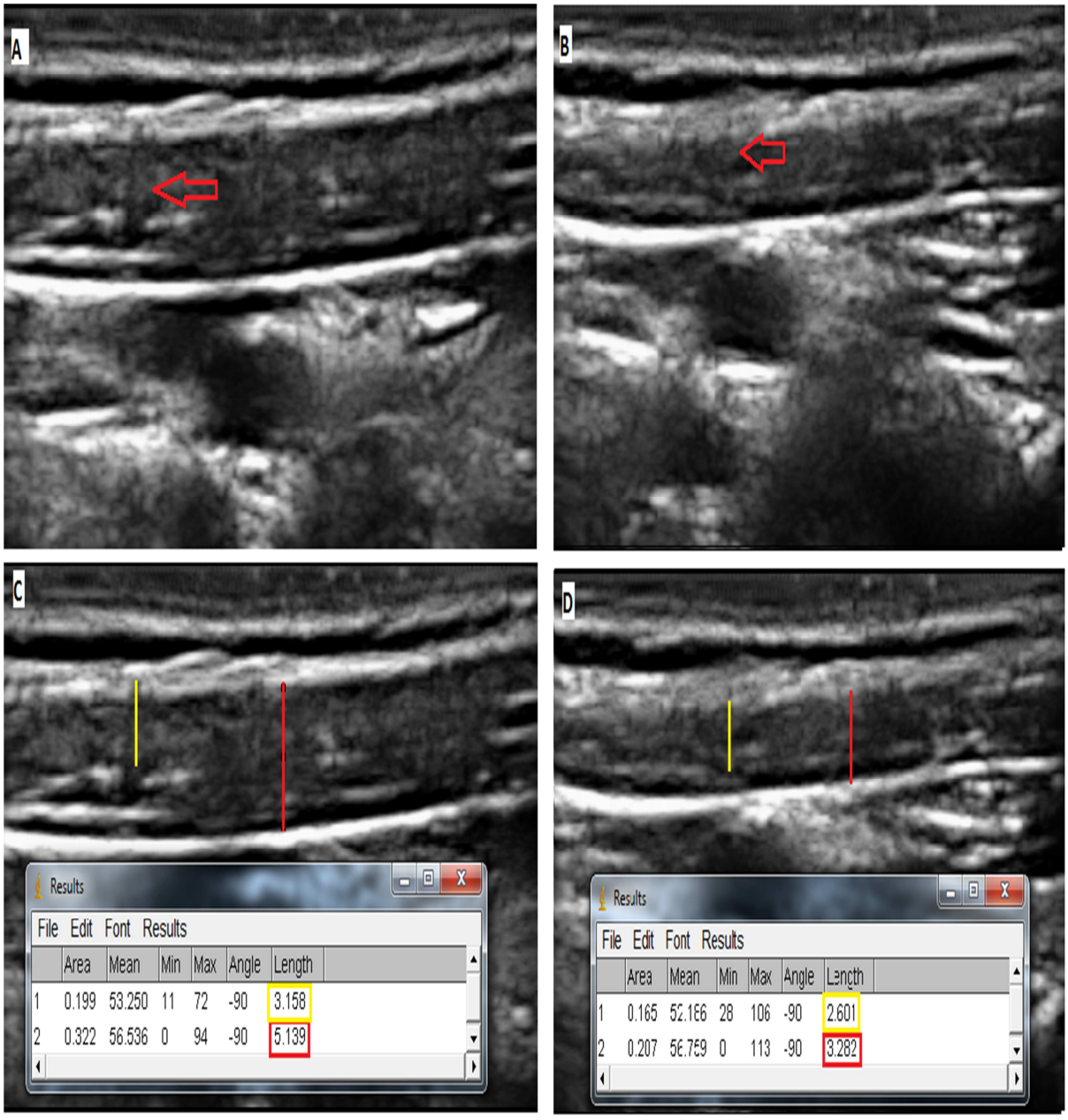
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Figure 3

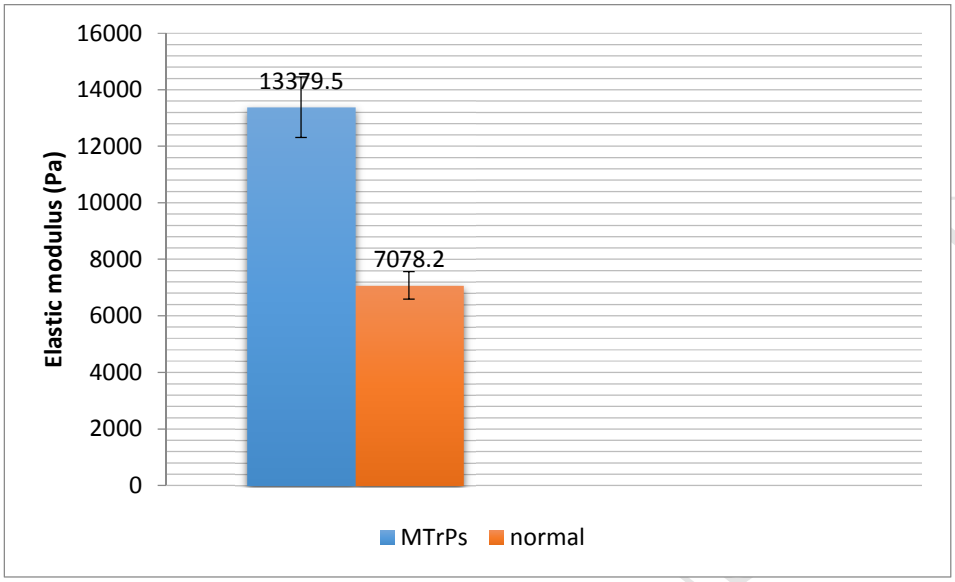

Figure 4