

ULTRASOUND AND ANALYSIS OF THE DEFORMATION PATTERNS OF THE MASSETER MUSCLE: COMPARING SURGICAL ANATOMY, ULTRASOUND AND FUNCTIONAL ANATOMY

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SUMMARY

Purpose. We have tried to demonstrate whether the analysis of the muscle strain allows us to identify the three distinct functional areas of the architecture of the masseter, as one would see them by performing or viewing an anatomical dis-section of said muscle, and whether these sections have behave differently in terms of origin and coping of the strain they face (quantitative analysis).

Materials and methods. This work has been elaborated by use of an ultrasound machine (MicrUs EXT-1H Teleded UAB, Vilnius, Lithuania) and a linear probe (L12-5L40S-3 5-12 MHz 40 mm) which allowed us to record a 45 frame per second video (DCM). Videos has been elaborated by use of an ultrasound machine (MicrUs EXT-1H Teleded UAB, Vilnius, Lithuania) and a linear probe (L12-5L40S-3 5-12 MHz 40 mm) which allowed us to record a 45 frame per second video (DCM). The number of videos of masseter muscles in contraction at maximum exertion due to dental clenching made during this research is around 12,000. Out of these we chose 1,200 videos which examine 200 patients (100 female, 100 male).

Results. The deformation pattern analysis of the skeletal muscle on ultrasound basis seems to be an adequate instrument to use during the investigation of the functional structure of the masseter muscle given its ability to highlight the distinct activity of each separate part of the muscle.

Conclusions. Moreover the strain does not apply to the muscle uniformly; instead it varies according to the observed area.

Key words: masseter muscle, ultrasound, deformation pattern, strain, masticatory organ, biomechanics.

Introduction

The Masseter is a pennate structured muscle, consisting of three distinct sections: the superficial section at the anterior end of the muscle (Figure 1, point 1), the middle section (Figure 1 point 2), and the internal section at the deep end of the muscle (Figure 1 point 3). These can be detected by both a surgical dissection of the area and an ultrasound examination (Figure 2).

With this last option one has the advantage of observing the structure of the muscle either contracting due to the clenching of the teeth, with or without biting aids in between the dental arches (such as cotton rolls, occlusal test films, custom made dental devices, etc.), or contracting repeatedly as occurs when one is chewing food or swallows over and over. The superficial masseter consists of two layers of aponeurotic muscle oriented at 60° to the occlusal plane (Figure 2 layer 1 and 2). The two layers are separated by a thin membrane of connective tissue, which is particularly dis-



Figure 1
Masseter: (1) Superficial section; (2) Middle section; (3) Internal section.

cernible if observed throughout an isometric contraction of the muscle, during which this membrane can clearly be seen separating the two layers (Figure 3 point 1). The middle masseter (Figure 2 layer 3) is typically described in the books as single stripe of aponeurotic muscle perpendicular to the occlusal plane that inserts itself coronally to the inferior margin of the zygomatic arch, thanks to two tendinous strips that connect them, and caudally on the lateral surface of the blade tendon of the outward layer of the deep masseter (Figure 3 point 3). Once again observation by means of an ultrasound examination allows us to appreciate the volume of the muscle during an isometric contraction (Figure 3 point 2). The weaving of this portion of the muscle is decidedly different than the other two which are defined by the presence of

several connective septi (Figure 3 point 4) with the exception for the middle layer of the deep masseter. The deep masseter (Figure 2 layers 4, 5, 6) is organized in three layers as well: outward, middle and inward. The outward layer is extremely complex (Figure 3 point 4) and is composed of numerous thin structures that insert themselves on the inferior margin of the zygomatic arch and on the blade tendon of the middle layer, which in turn is fixed to the zygomatic arch and on the anterior edge of the capsule and of the articular disc of the temporo-mandibular joint. The inward layer enters from the mandibular notch to the zygomatic arch ahead of the articular tubercle of the temporal bone. The isometric contraction highlights the three layers and the gap, more or less deep, that separates the superficial masseter from the internal masseter and the dynamics that establish themselves between these two layers during masticatory activities. The functions that the masseter, in its entirety, is responsible for reported by the literature are the lifting and protrusion of the mandible (Figure 4).

During a voluntary clenching of the jaw the load applied onto the first molar by the contraction of the masseter muscle and the other elevating agents of the mandible can reach 500-900 newton per square centimeter (first molar in male). This type of performance requires the masseter muscle's maximum exertion, which can be documented through a surface electromyography. This exam, though, cannot define neither the separate activity of the three sections of the masseter muscle or the different layers within each, nor can it quantitatively describe the relationship between the architecture of the muscle and its functional activity. An electromyography, in other words, is unable to determine how muscle deformation occurs or how said muscle copes, both as a whole and within the separate parts, with the exhaustion intrinsically associated with muscle deformation.

The objective which the following work has set to achieve is to verify if the analysis of the deformation patterns in ultrasound videos obtained through a dedicated software is a valid instrument for the description of the masseter's structure from a functional (qualitative data) point of view, and if the results can be compared to the visual observations recorded in the literature.

That is to say, we have tried to demonstrate whether

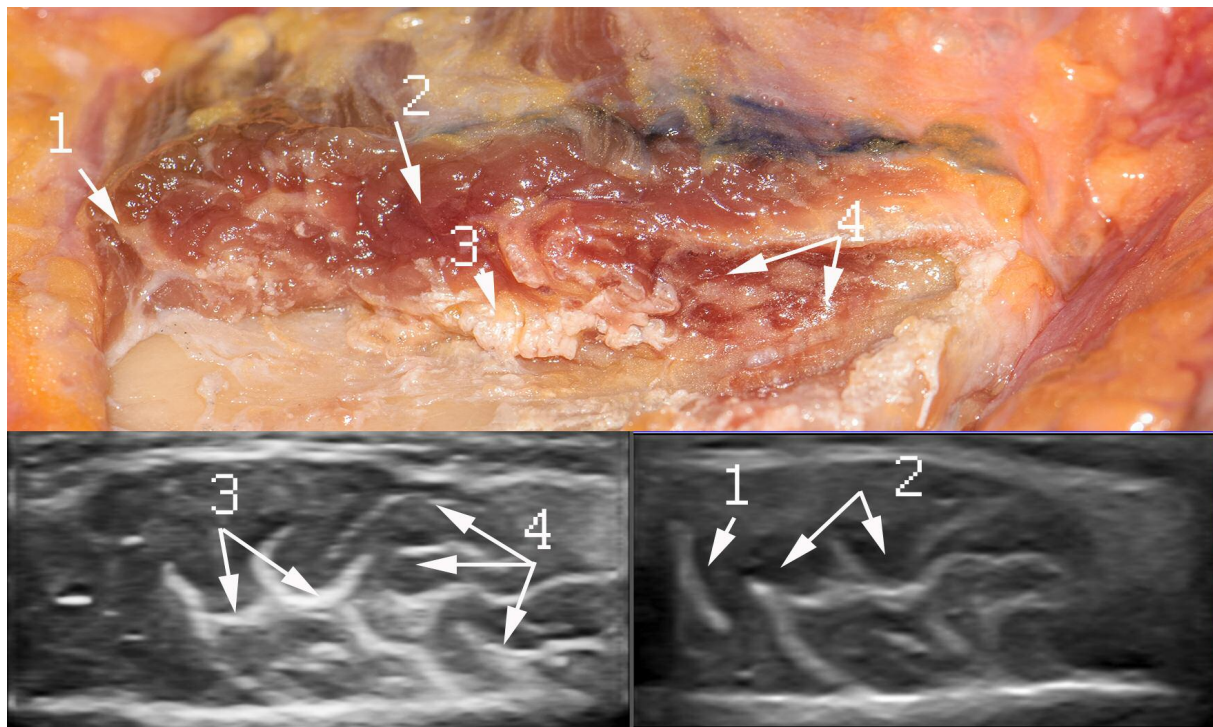


Figure 2
Masseter dissection vs. ultrasound image: (1) Parting of the two layers of the external masseter; (2) Intermediate section; (3) Blade tendon of the internal masseter; (4) Layers of the internal masseter.

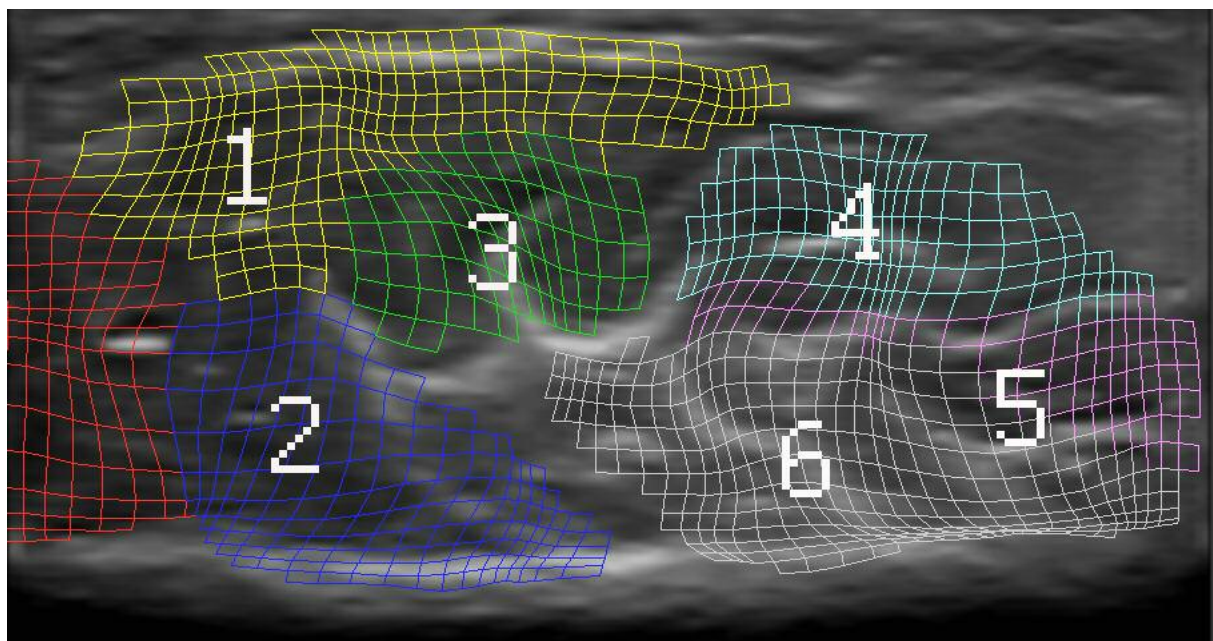


Figure 3
Ultrasound of the master during maximum exertion. External section: (1) external layer; (2) internal layer. (3) Intermediate section. Internal section: (4) outward layer; (5) central layer; (6) inward layer.

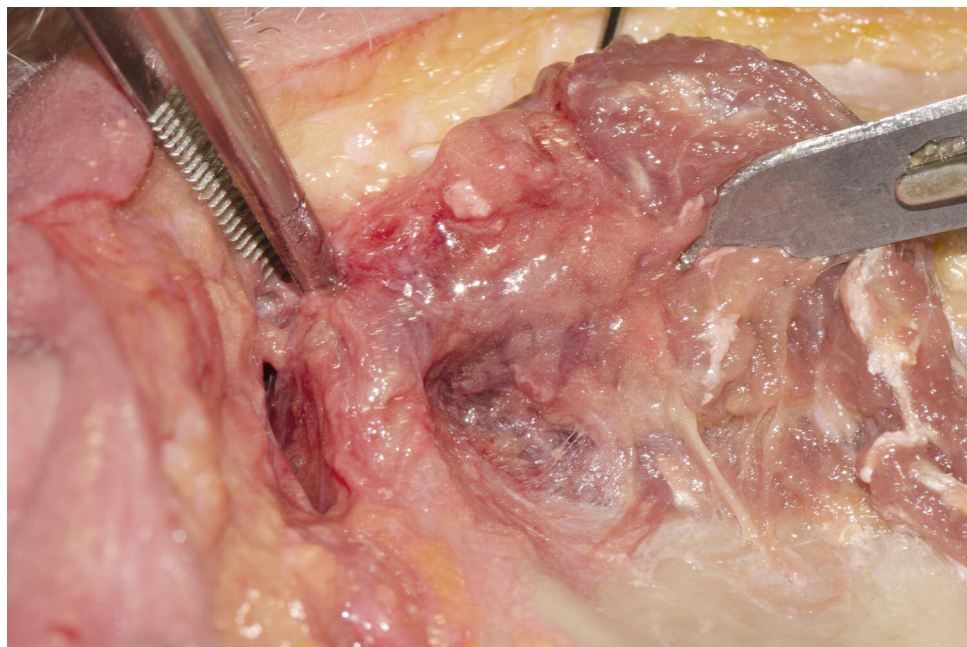


Figure 4
Deep masseter and temporo-mandibular joint:
(1) Deep Masseter; (2) Mandibular Condyle.

the analysis of the muscle strain allows us to identify the three distinct functional areas of the architecture of the masseter, as one would see them by performing or viewing an anatomical dissection of said muscle, and whether these sections have behaved differently in terms of origin and coping of the strain they face (quantitative analysis). During the contraction, the masseter suffers a notable deformation and is subject to potentially wearing activities which can lead to repeated deformations that do not follow the natural physiological process. The possibility of precociously discovering a pattern of damaging deformations is certainly an auspicious goal (1).

Materials and methods

This work has been elaborated by use of an ultrasound machine (MicrUs EXT-1H Teleded UAB, Vilnius, Lithuania) and a linear probe (L12-5L40S-3 5-12 MHz 40 mm) which allowed us to record a 45 frame per second video (DCM). The probe was fixed to a brace and the patient was asked to clench their teeth as hard as possible, obtain the muscle's maximum exertion, for 5 seconds three times, with 30 seconds intervals in

between. Both right and left masseter muscles were analyzed.

During this procedure the patients were seated down on a dentists' chair with their head leaning on the headrest. The section of the muscle chosen is that in which the greatest possible expansion and the best view of the muscle layers during the contraction were visible. Said section was then marked on the patient's skin using an L shaped ruler that allows us to mark the bottom edge of the mandible.

Then we applied to the resulting video a software (Mudy 1.7.7.2 AMID Sulmona Italy) for the analysis of muscle deformation patterns (contraction, dilatation, cross-plane, vertical strain, horizontal strain, vertical shear, horizontal shear, horizontal displacement, vertical displacement) (2). During the contraction some sections of the muscle dilate and others clench. The strain, shear and displacement patterns, describe the recorded phenomena analyzing the movement of the points that form the two-dimensional ultrasound image with respect to two axes, horizontal and vertical. The cross-plane pattern adds the third dimension indicating the movement of those same points in cross-section. The compression and dilatation patterns show the global movement of all of points on the two axes (3-18).

In this work the pattern used for the analysis is the cross-plane pattern. The aim of the study of the ultrasound videos has been to determine whether the software for the analysis of deformation patterns has the ability to show and highlight three distinct areas and if said areas matched the sections that form the masseter muscle.

Another quantitative analysis of the muscle's contraction was done, dividing the muscle in three sections (superficial, middle and deep) in order to measure the deformation pattern inside each separate section and compare it to that of the adjacent sections (Figure 5). Each video includes the recording of three contractions at maximum exertion in order to confirm both the repeatability of the data and to obtain average data of the muscle's behavior (Figure 6).

The number of videos of masseter muscles in contraction at maximum exertion due to dental clenching made during this research is around 12,000. Out of these we chose 1,200 videos which examine 200 patients (100 female, 100 male). The criteria for the choice of which videos to include in this case studies are:

- a) The patients do not have any conditions or pathologies that affect the masticatory muscles or the temporo-mandibular joints. No evident symptoms of DCM.
- b) At palpation the contractions were ranked 0-5 based on the following criteria, which take in consideration the stiffness of the muscle at the moment maximum exertion, the speed of the contraction, the ability to keep the muscle contract for 5 seconds and to repeat it for three times. The ranking was done by a single operator. (0) contraction absent; (1) weak contraction; (2) satisfactory contraction; (3) good contraction; (4) excellent contraction; (5) outstanding contraction.
- c) Both masseters (left and right) show the same amount of force during contraction.
- d) Alternate bilateral chewing.

The aim of this selection is to have a group based entirely on clinical criteria such as those that are normally considered satisfactory in order to consider the masticatory muscles in good health and in full functional efficiency. Only videos that ranked at 4 were taken into consideration.

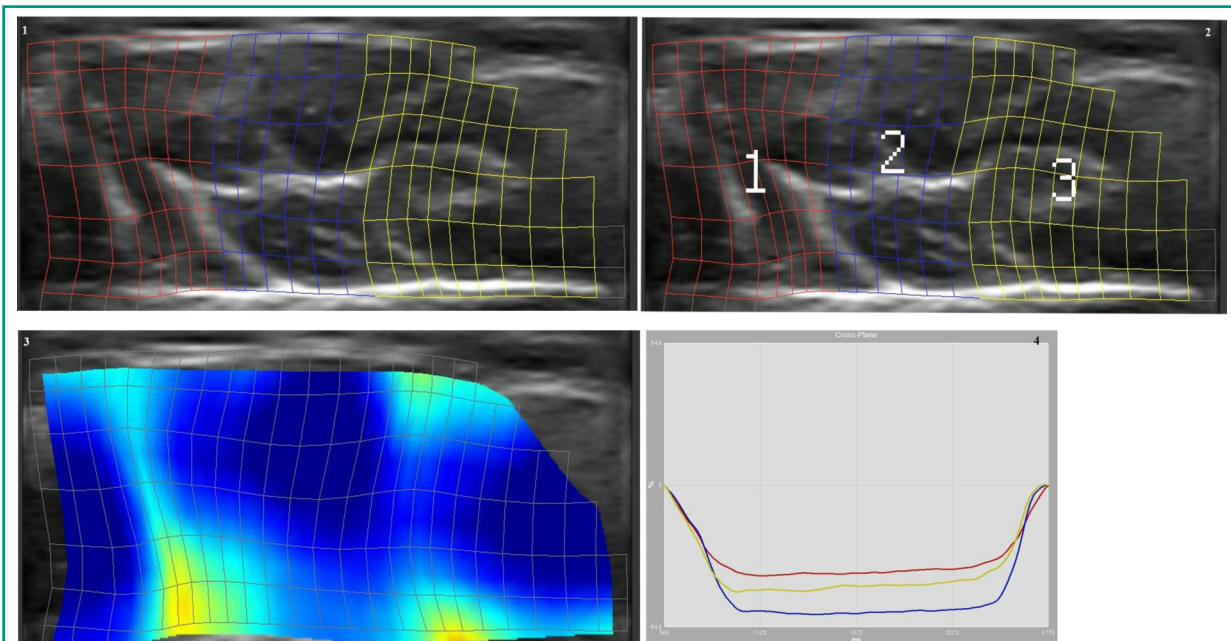
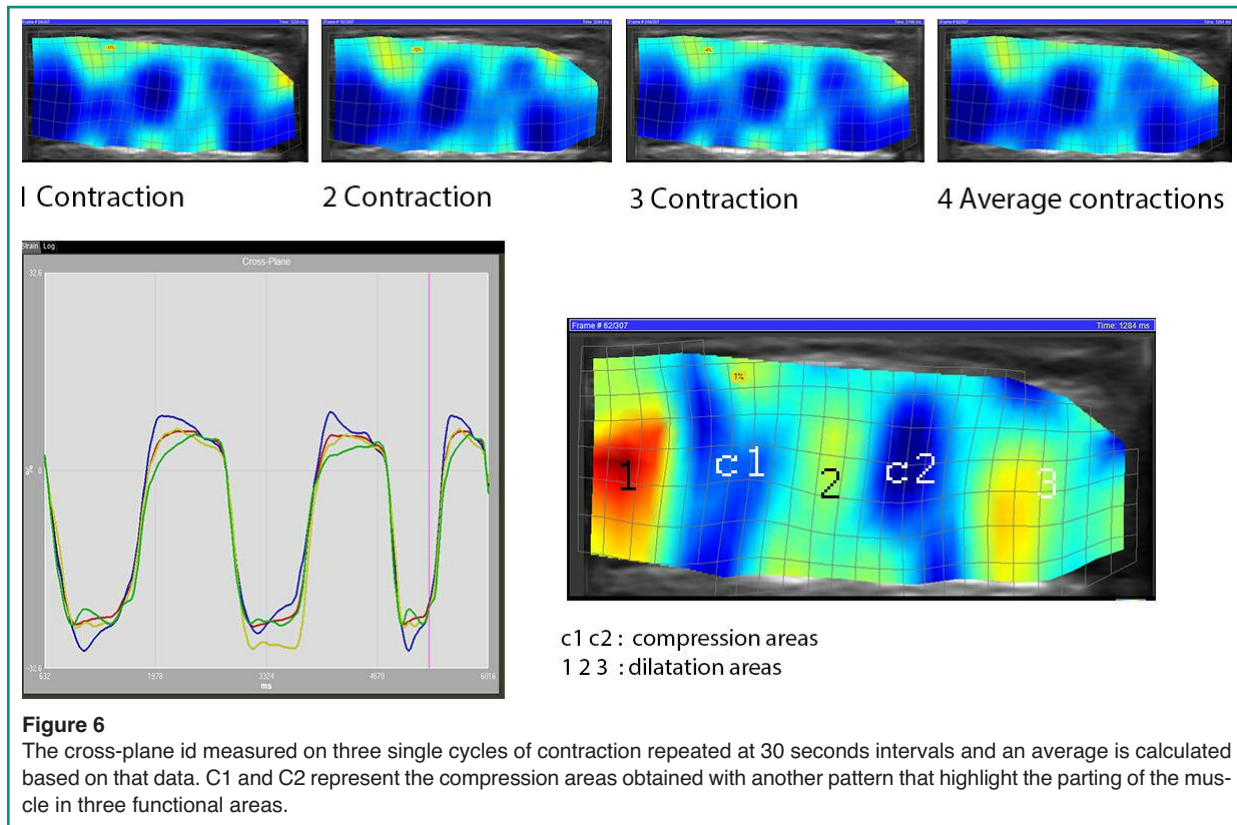


Figure 5
(1) masseter in maximum exertion contraction with grid for the study of patterns; (2) masseter in maximum exertion contraction with grid for the study of patterns divided in three areas; (3) masseter in maximum exertion contraction and cross-plane; (4) curves time/strain of the three parts of the muscle.



Results

During a maximum exertion contraction of patients belonging to group 4, we can observe on the cross-plane pattern the highlighting of three sections (superficial, middle and deep) with variable degrees of extension that present a higher value in the central area. The superficial section can comprehend one area (40%) or two areas (60%). In 30% of cases the middle section is divided in two areas, whereas in the other 70% it appears as one single area. The deep section presents itself as an area with a single spot (60%), two spots (30%) or three spots (10%). The qualitative analysis of the videos allows us to observe the constant presence of three distinct functional areas (100% of cases) seemingly corresponding to the three sections of the masseter muscle (superficial, middle and deep). The images suggest that there is a match between the surgical anatomy of the masseter as described in the literature and the functional anatomy on ultrasound base as described by the analysis of the de-

formation patterns. The strain does not apply to the muscle uniformly, instead it applies to separate areas. Said strain differs greatly in the three sections with predominance in the middle section in 75% of cases followed by the superficial section (15%) and the deep section (10%). In the investigated sample, the clenching of the masseter (right and/or left) had been able to produce a cross-plane pattern of the muscle movement equal to or greater than 30% of its potential and negative in 98% of cases.

Discussion

The deformation pattern analysis of the skeletal muscle on ultrasound basis seems to be an adequate instrument to use during the investigation of the functional structure of the masseter muscle given its ability to highlight the distinct activity of each separate part of the muscle. Unlike the surface electromyography the deformation pattern analysis on ultrasound

basis allows to compare the study of the structure of the muscle (form, size, weaving, etc.) with its clenching capabilities, both as a whole and as separate parts. This is of paramount importance also in orthodontics and implantology (19-79). Moreover the strain does not apply to the muscle uniformly; instead it varies according to the observed area. The deformation pattern analysis of the skeletal muscle on ultrasound basis apparently offers new, fertile soil for the development of applications useful for the diagnosis and treatment of various dysfunctions of the masticatory organ because we believe that it can be used not only for the study of its functional structure but also to identify and distinguish with clarity patterns of physiological deformations from pathological ones and/or dysfunctions both during the clenching test and during real activities such as food chewing, swallowing and phonation.

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