Application of digital image correlation method to assess temporalis muscle activity during unilateral cyclic loading of the human masticatory system

Dominik Pachnicz[1,a*], Przemysław Stróżyk[2,b]

[1]Faculty of Mechanical Engineering, Łukasiewicza 5 str., 50-371 Wrocław, Wrocław University of Science and Technology, Poland

[2]Department of Mechanics, Materials and Biomedical Engineering, Smoluchowskiego 25 str., 50-370 Wrocław, Wrocław University of Science and Technology, Poland

[a]dominik.pachnicz@pwr.edu.pl, [b]przemyslaw.strozyk@pwr.edu.pl

Keywords: In Vivo Measurements, Optical Method, Masticatory Muscle Activity

Abstract. This paper presents an in vivo experimental study in which an optical digital image correlation system was used to assess the activity of the temporalis muscle. The muscle activity was analysed and assessed based on its displacements resulting from unilateral cyclic loading and unloading of a specimen placed on one side of the mandible between pairs of corresponding premolars and molars. Two sets of synchronised cameras (two per side) positioned on the working and non-working sides were used for the measurements. The results of the measurements were analysed individually for each part of the muscle, i.e. the anterior temporalis, the middle temporalis and the posterior temporalis and each side. The results indicate that the presented measurement method made it possible to determine temporalis muscle activity in vivo from displacement measurements. It also confirms the information on temporalis muscle function given by other researchers. In addition, the advantage of the presented method is that it offers significantly greater measurement capabilities (larger area of analysis) than other measurement methods, such as electromyography.

Introduction

Muscle activity or muscle force values are usually determined by electromyography (*EMG*) or numerical simulations. In the first method, the electrical potential of the muscle is measured, which is the determinant of its bioactivity. Force values are then calculated based on empirical equations relating a given potential value [1, 2] and the muscle's physiological active cross-section (*PCS*) [3, 4]. In numerical simulations, muscle forces can be determined by inverse kinematics and dynamics analysis [5, 6, 7, 8, 9].

During *EMG* measurements of the masticatory muscles, the temporalis and masseter muscles are most commonly studied because they are located externally from the buccal side, allowing easy access for electrode placement. In the case of the lateral pterygoid and medial pterygoid muscles, the application of *EMG* is very difficult because their location (hidden behind bony elements and soft tissues) requires the application of electrodes intraorally [10, 11].

Based on an analysis of the biomechanics and mechanics literature [12], a method based on 3D digital image correlation can also be used to measure surface muscle activity. The main advantage of the method is that it is possible to measure the activity of the entire muscle and not just a limited area lying around the electrode, as in *EMG* measurements. Disadvantages include the need to cover the surface of the test area with a suitable mask and illuminate it with monochromatic light.

The temporalis muscle was chosen for the study described in this article because: (1) it is easily accessible from the outside, (2) it is located in a zone with little adipose tissue, (3) anatomically, it is the largest muscle in the head and also the largest muscle involved during mastication and (4) it is divided in a plane rather than by depth.

In anatomical terms, the muscle is divided into two areas according to the actions performed by its muscle fibres: the anterior part, characterised by a near-vertical fibre arrangement, is responsible for retracting the mandible, while the posterior part, characterised by a near-horizontal fibre arrangement, retracts the protruding mandible forwards. In the biomechanics of the masticatory system, the temporalis muscle is divided into two or three areas [13, 14, 15, 16]. Each area is most often modelled by a single vector (a component of the principal vector of the temporalis muscle).

This study aimed to identify areas of peak temporalis muscle activity in vivo during unilateral cyclic loading and unloading of the masticatory system. The analysis was performed for rhythmic changes in muscle displacement on the working and non-working sides using a 3D digital image correlation system.

Material and Methods

Determination of temporalis muscle displacement required the preparation of an experimental rig based on a non-contact optical digital image correlation system (*DIC* - Dantec Q400, Dantec Dynamics A/S, Skovlunde, Denmark), consisting of 2 synchronised camera sets to set up on the working (*W*) and balancing sides (*N*) - fig. 1. Initial testing was performed on an adult male subject after informed consent. The subject had full dentition with no known masticatory dysfunction. During the measurement, he sat comfortably in an upright position with his head resting against the headrest.

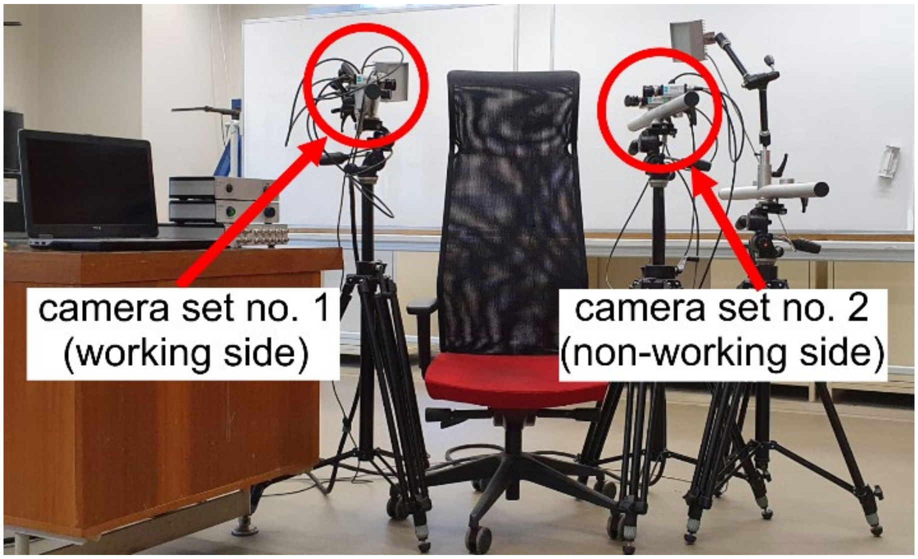

*Fig. 1. The experimental setup used a digital image correlation system (*DIC*) to measure the temporalis muscle displacement during the masticatory system's unilateral cyclic loading and unloading.*

Temporalis muscle activity was assessed based on its displacement during unilateral cyclic loading and unloading of a specimen (made of rubber-derived material) placed on one side of the mandible, between pairs of corresponding premolars (45-15) and molars (46-16) - fig. 2.

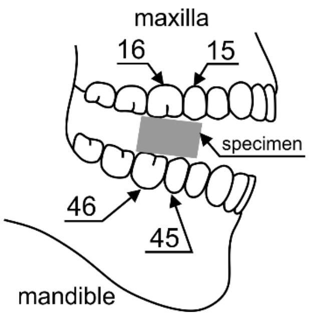

Fig. 2. Schematic showing the specimen placement between pairs of corresponding premolars (45-15) and molars (46-16).

Taking measurements with the *DIC* system required the temporalis muscle (i.e. the skin covering the temporalis muscle) to be covered with a unique pattern of black and white spots, which are used by the correlation algorithm as a source of information (Fig. 3). Prior to the final measurement, a reference photo (the so-called zero state) of the temporalis muscle was taken, the tension of which corresponded to the placement of the sample between the teeth.

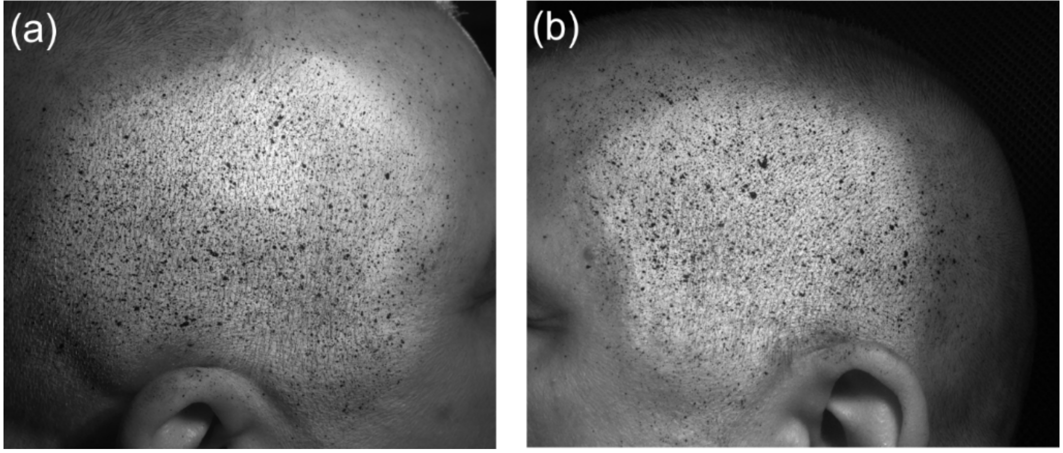

Fig. 3. Unique pattern of black and white spots; (a) working side and (b) non-working side.

During the test, the subject was asked to bite at a constant natural rate and a subjectively accepted force close to the maximum bite force. Measurements were taken three times for five cycles of loading and unloading. Images were taken at 4 Hz.

Results

The parameter analysed to determine the activity of the temporalis muscle was displacement perpendicular to the plane of the image, i.e. in the *Z*-axis direction (fig. 4). The results of the measurements were analysed from circular areas, defined on the surfaces of each of the three parts of the temporalis muscle, i.e. the anterior temporalis (*AT*), the middle temporalis (*MT*) and the posterior temporalis (*PT*) - fig. 4. The division of the muscle was carried out based on information reported in the literature related to the biomechanics of the temporalis muscle [17, 18]. The displacement values are the average of the results from a 10.0 [mm] diameter circle - fig. 4. The sites were selected based on the images obtained for the maximum displacement values for each side and part of the muscle, respectively, for the working side (p_{AWz}, p_{MWz}, p_{PWz}) and non-working side (p_{ANz}, p_{MNz}, p_{PNz}) - fig. 5. In addition, for each maximum displacement value, the standard deviations (±*SD*) were determined - Table 1.

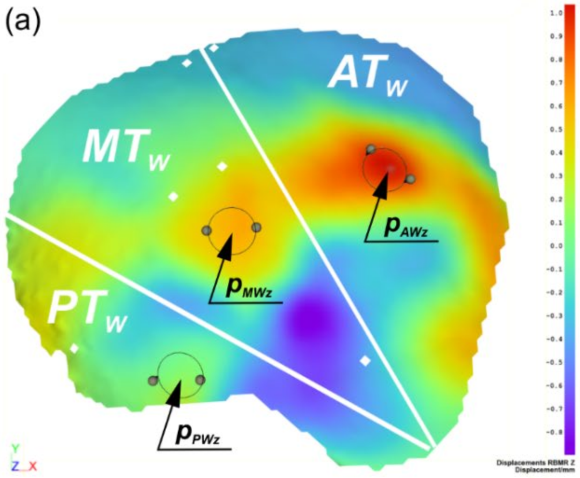

Fig. 4. Division of the temporalis muscle into three parts; (a) working side and (b) non-working side, and the areas (delimited by a circle) from which the mean values of temporalis muscle displacement were analysed.

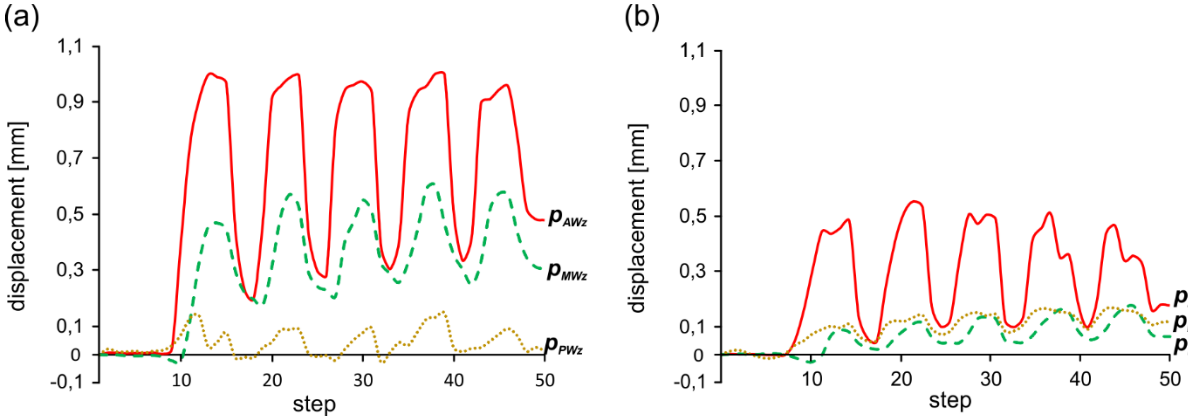

Fig. 5. Mean displacement values determined for the different parts of the temporalis muscle; (a) working side and (b) non-working side.

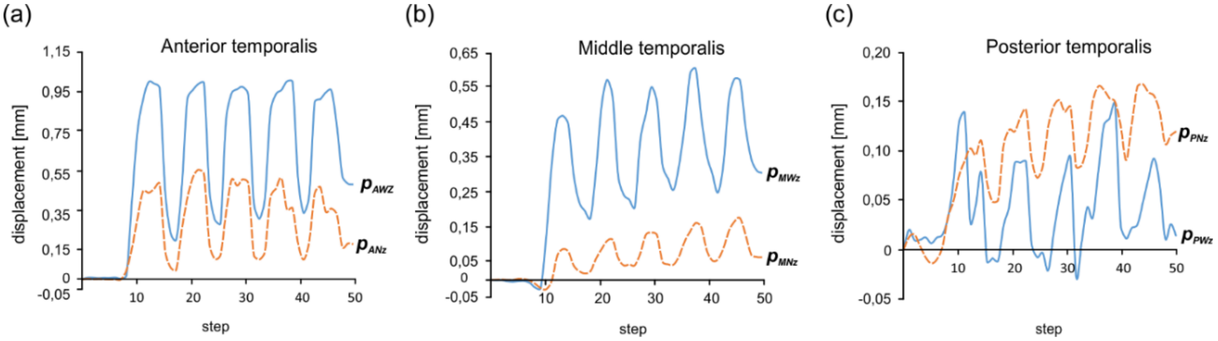

Fig. 6. Comparison of mean displacement values between the working side (p_{AWz}, p_{MWz}, p_{PWz}) and the non-working side (p_{ANz}, p_{MNz}, p_{PNz}) for the three parts of the temporalis muscle; (a) anterior temporalis, (b) middle temporalis and (c) posterior temporalis.

Table 1 Maximum, mean displacement values [mm] and standard deviation (±SD) for each part of the temporalis muscle, corresponding to the working side (p_{AWz}±SD, p_{MWz}±SD, p_{PWz}±SD) and non-working side (p_{ANz}±SD, p_{MNz}±SD, p_{PNz}±SD).

Step	Part of muscle		
	AT	*MT*	*PT*
Working side			
	(p_{AWz}±SD)	(p_{MWz}±SD)	(p_{PWz}±SD)
1	0.99±0.010	0.47±0.001	0.08±0.010
2	0.99±0.010	0.57±0.002	0.08±0.003
3	0.97±0.010	0.55±0.002	0.09±0.001
4	0.95±0.006	0.59±0.004	0.12±0.013
5	0.94±0.004	0.57±0.008	0.07±0.013
Non-working side			
	(p_{ANz}±SD)	(p_{MNz}±SD)	(p_{PNz}±SD)
1	0.46±0.030	0.09±0.009	0.11±0.030
2	0.55±0.060	0.11±0.006	0.13±0.030
3	0.50±0.003	0.13±0.007	0.14±0.020
4	0.50±0.002	0.14±0.004	0.16±0.030
5	0.47±0.003	0.17±0.007	0.16±0.020

Conclusions

This paper presents an experimental study in which the *DIC* system was used to assess the activity of the temporalis muscle during unilateral cyclic loading and unloading-of the masticatory system.

The most important result of the experimental studies carried out is the demonstration that the use of the *DIC* makes it possible to determine the activity of the entire temporalis muscle, and the results clearly show that the involvement of the muscle on the working side is different from that on the non-working side. This confirms the results presented in other work [14, 15, 19], in which similar results were obtained based on muscle forces. This means that there is a correlation between the results obtained from the *DIC* system and, for example, methods based on vector calculus.

The analysis of the mean displacement values shows that the anterior part on the working side is more involved than the other parts - similar correlations occur on the non-working side. Based on the maximum displacement values (Table 1), it was noted that on the working side, the temporalis muscle activity is significantly higher than on the non-working side for the *AT* and *MT* parts by 49% and 77%, respectively. For the *PT* part, the non-working side shows more activity than the working side by 59%. This means that the muscle is primarily responsible for lifting the mandible and pressing the teeth against the specimen on the working side. In contrast, on the non-working side, muscle activity is related to lifting (stabilising) and retracting the mandible. The cycles of muscle activity overlap in phase on both sides. This indicates that they work evenly and are involved in the masticatory function.

It can also be seen from the displacement analysis (Table 1 fig. 5) that on the working side *MT* and *PT* activity are lower than *AT* by 43% and 91%, respectively. On the non-working side, on the other hand, *MT* and *PT* are also smaller than *AT*, by 72% and 75%, respectively, with the difference that *PT* displacements are slightly larger than *MT*.

The study results indicate that the presented measurement method made it possible to determine temporalis muscle activity from displacement measurements. Furthermore, the method is an interesting complement to existing measurement methods, e.g. *EMG* [20, 21, 22] but offers a greater range of analysis than *EMG*. In addition, the software used by the *DIC* system offers the possibility to export the results to *FEM* (Finite Element Method) software and to compare the results between the real and virtual object, i.e. to perform validation.

The presented research needs to be further developed to expand the possibilities of using the *DIC* method to analyse masticatory system function. The number of subjects needs to be increased, allowing statistical processing of the results and more extensive inference. In addition, different load cases can be considered. Furthermore, finding correlations between the results obtained by both methods, i.e. vision and *EMG*, seems to be an important issue. The results of such considerations can be used, among other things, to determine the forces in the muscles and, after a more in-depth study of the subject, can also be useful in diagnosing the masticatory system.

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