Influence of Age and Tooth Loss on Masticatory Muscles Characteristics: A Population Based MR Imaging Study

DABOUL, A, et al.

Abstract
Aging is associated with a decline in masticatory muscles mass and performance. The present study aims to examine the differences in the cross-sectional areas of the masseter, medial and lateral pterygoid muscles in relation to age and the present dental status in a population-based magnetic resonance imaging study.

Reference

DOI : 10.1007/s12603-018-1029-1
PMID : 30080228
INFLUENCE OF AGE AND TOOTH LOSS ON MASTICATORY MUSCLES CHARACTERISTICS: A POPULATION BASED MR IMAGING STUDY

A. DABOUL1, C. SCHWAHN1, R. BÜLOW2, S. KILIARIDIS3, T. KOCHER4, T. KLINKE1, T. MUNDT1, S. MOURAD1, H. VÖLZKE5, M. HABES6, R. BIFFAR1

1. Department of Prosthodontics, Gerodontology and Biomaterials, University Medicine Greifswald, Greifswald, Germany; 2. Institute for Radiology and Neuroradiology, University Medicine Greifswald, Greifswald, Germany; 3. Department of Orthodontics, University of Geneva, Geneva, Switzerland; 4. Department of Restorative Dentistry, Periodontology and Endodontology, University Medicine Greifswald, Greifswald, Germany; 5. Institute for Community Medicine, University Medicine Greifswald, Greifswald, Germany; 6. Department of Radiology, Center for Biomedical Image Computing and Analytics, University of Pennsylvania, Philadelphia, USA. Corresponding author: Dr. Amro Daboul, Department of Prosthodontics, Gerodontology and Biomaterials, University Medicine Greifswald, Walther-Rathenau Str. 42, 17489 Greifswald, Germany, daboula@uni-greifswald.de

Abstract: Background: Aging is associated with a decline in masticatory muscles mass and performance. The present study aims to examine the differences in the cross-sectional areas of the masseter, medial and lateral pterygoid muscles in relation to age and the present dental status in a population-based magnetic resonance imaging study. Methods: This cross sectional study involved 747 subjects aged between 30-89 years (344 male, 403 female) who underwent both a whole body MRI and a full oral examination. The cross-sectional areas of the masseter, medial and lateral pterygoid muscles were measured from MRI images using the software Osirix. Dental and prosthetic status data from the oral examination were classified according to Eichner index. The method of generalized least squares, also called growth curve model, was used to examine the associations between the cross-sectional areas, age and tooth status. Results: The cross-sectional area of the lateral pterygoid muscle decreased substantially with age in women but did not depend on age in men. The medial pterygoid muscle depended on age but an effect modification by gender was uncertain. Masseter muscle was weakly associated with age but strongly associated with the number of teeth in both genders. Conclusions: Our findings suggest that age has a heterogeneous effect on masticatory muscles. This indicates that age related changes to the masticatory muscles are muscle specific and are not consistent between the different muscles.

Key words: CSA, MRI, mastication, oral rehabilitation, prosthodontics, tooth loss.

Background

The primary aims for dental treatment in the elderly are to restore oral function and maintain masticatory performance (1, 2). The impaired oral function as a result of the aging process is usually manifested by reduced chewing ability, which is accompanied by loss of teeth, muscle atrophy and the development of local and systemic changes (3) that will further impact the dietary selection and quality of life in the elderly.

The performance of masticatory muscles has been previously investigated through the study of different muscle parameters and indicators. One of the most important indicators on muscle performance is the maximum bite force that a muscle can produce (4). A crucial determinant of the maximum force that can be produced by a muscle is it’s cross-sectional area (CSA) (5). Previous studies have shown that the cross-sectional area of a muscle is strongly related to maximum muscle strength and that the bite force is proportional to the muscle’s cross-section (6, 7).

With the evolvement of modern imaging techniques, it has become possible to measure the size of the masticatory muscles in vivo. The heterogeneity of each masticatory muscle in terms of cross-sectional area, volume and relationship with craniofacial structures has been investigated in the literature (8-10), where various approaches have been put forward to investigate factors believed to affect the masticatory muscles.

Earlier investigations focused on the influence of age on the size of masticatory muscles and found significant reductions in the masseter and medial pterygoid muscles associated with age (11). Such findings were further corroborated by later studies that reported differences in muscle thickness between different age groups (12). Palinkas et al (13) investigated the influence of gender and age on the size of masticatory muscles and reported that the decrease in the masseter thickness was found to occur after 60 years of age in men and women. However, more recent evidence suggests that the decrease in the size of masticatory muscles is not directly the result of the aging process itself, but rather age related local and systemic diseases. In a recent study, Hatch et al (14) reported that age did not exert a strong effect on the masseter’s cross-sectional area and that the number of functional tooth units was a key determinant of the masticatory performance. They suggested that masticatory performance does not need to decline with age if teeth and occlusion are retained to maintain masticatory function. Further studies were carried out to determine the effects of restoring occlusion on masticatory performance in edentulous patients. While some studies reported an increase in masticatory function that reached the records of dentate subjects (15), other studies (16, 17), on the contrary, reported substantial reduction in muscle thickness and masticatory performance in subjects who have artificial dentition in comparison with dentate subjects. It has been suggested that this continued reduction in muscle thickness and performance is related to tooth loss and the altered functional demands that artificial dentition could not
fulfill (18, 19).

With the increasing numbers of elderly people in societies, there is a need for a more profound understanding of the changes to the masticatory muscles associated with aging and dental status. While previous approaches implemented bite force measurement, granulometry and chewing tests to evaluate masticatory performance, direct changes to masticatory muscles were often overlooked. There has been previously no investigation on the effects of age and tooth loss on the masticatory muscles in a large population. The present study aims to examine the changes in the cross-sectional areas of the masseter, medial and lateral pterygoid muscles in relation to age and dental status in a population-based MRI study.

Methods

Study population and MRI data acquisition

We included in this study subjects from the Study of Health in Pomerania (SHIP), a population based longitudinal cohort study assessing the prevalence and incidence of common population relevant diseases and their risk factors. At SHIP baseline, a two-stage stratified cluster sampling method using population registries was used to select German citizens residing in the study area. Out of 6265 eligible candidates, 4308 subjects participated in the baseline examinations (SHIP-0), which included a medical examination, an oral health examination, a health-related interview, and a self-administered health- and risk-factor-related questionnaire. Two thousand three hundred and thirty-three subjects participated in the 10-year follow-up (SHIP-2), of which 1115 subjects agreed to undergo a whole-body MRI examination.

MRI scans were performed on a 1.5-T system (Magnetom Avanto; Siemens Medical Solutions, Erlangen, Germany) as a part of a whole-body MRI protocol. The complete whole body MRI protocol was described elsewhere (20). The analyzed MRI sequences in this study were: a. T1-weighted head scans (ultra-fast gradient echo sequence: repetition time 1900 ms; echo time (TE) 3.37 ms; flip angle 15o; matrix 256 x 176; 1.0 x 1.0 x 1.0, bandwidth, 130Hz/Pixel). b. T1-weighted head-neck scans (repetition time (TR) 587 ms; echo time (TE) 11 ms; 150° flip angle; matrix, 256 x 192; 1.0 x 0.8 x 4.0, bandwidth, 150 Hz/Pixel). c. T2-weighted full body scans (repetition time (TR) 4891 ms; echo time (TE) 65 ms; 180° flip angle; matrix, 320 x 240; 2.1 x 1.6 x 5.0, bandwidth, 150 Hz/Pixel).

MRI images with the following criteria were excluded from analysis: 1. presence of artifacts, 2. scan not covering area of interest, 3. the presence of any pathology in the head MRI scans affecting muscle measurement.

In summary, the present study included 747 SHIP-2 participants who underwent both the oral and the MRI examinations in SHIP-2. The medical ethics committee of University of Greifswald approved the study protocol, and written informed consents were obtained from each of the study participants.

Oral examination data and MRI muscle measurements

Oral examinations at the follow-up included the assessment of the dental and prosthetic status. Two trained professionals conducted the interview. Eight licensed dentists performed the dental examination. The number of teeth was determined by a full-mouth examination with a maximum of 28 teeth.

Obtained data was classified according to the Eichner index: The Eichner classification (Classes A, B and C) is based on occlusal contact areas in antagonist jaws for the natural dentition, including fixed prostodontic restorations. Class A contains 4 support zones; which means there is a minimum of one tooth in contact between the maxilla and the mandible in both the pre-molar and molar regions in each side. Class B contains 3 (B1), 2 (B2) or 1 (B3) support zones, or support in the anterior area only (B4). In class C, there are no antagonist contacts in the dentition.

Figure 1

Masseter muscle’s long axis determination from coronary T2-weighted inversion recovery sequence and corresponding cross-sectional area perpendicular to the muscle’s long axis on transversal T1-weighted sequence

MR image analysis

An open source DICOM viewer (OsiriX v5.8.1, Pixmeo, Geneva, Switzerland) was used on two workstations with 27-inch monitors (iMac Quad core i7; Apple Corp. Cupertino, CA, USA) to analyze the MRI head images. Four observers went through a training phase on the use of OsiriX and anatomical mapping and profiling. Over the period of 8 months, the observers performed an average of 6 measurements on each subject’s MRI images. To minimize measurement errors and prevent an overestimation of cross-sectional areas, CSA of each muscle was measured at an angle perpendicular to the actual muscle’s long axis.

To determine the long axis in the masseter muscle, the orientation and medio-lateral inclination of the muscle was revealed and fixed in each subject separately (T2-weighted inversion recovery sequence). Later, CSA’s of the masseter muscles were measured on the transversal T1-weighted head-neck buildup images. (Figure 1)

For the medial and lateral pterygoid muscles, reconstructed
Multi-planar T1-weighted head axial images were used to first determine the long axis of each muscle separately and then measure the cross-sectional areas perpendicular to the corresponding muscle’s long axis. (Figures 2 & 3)

Segmentation and edge detection was used to identify the perimeter of the muscles. CSA of each individual muscle was then measured by outlining the borders of the muscles with the polygon selection tool after adjusting the image to level 50 and window width between 300 and 400 to obtain visual discrimination between surrounding connective tissue and muscle. CSA’s were measured as the areas inside the polygon in values of cm². Both right and left sides of each muscle were analyzed separately.

Inter- and intra observer reliability tests were performed before the first measurement session on 10 image sets, and after each measurement session on 15 image sets to insure reproducibility of the cross-sectional area measurements in this study (Intraclass correlation coefficient for the masseter ranged between 0.98 – 0.99, medial pterygoid; 0.79 – 0.81, lateral pterygoid; 0.81 – 0.85)

Statistical analysis
Distributions of the cross-sectional areas of the muscles were described by mean and standard deviation. To compare

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Baseline characteristics: mean over left and right sides of cross sectional areas</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lateral pterygoid muscle</td>
</tr>
<tr>
<td></td>
<td>men</td>
</tr>
<tr>
<td>Overall</td>
<td>344</td>
</tr>
<tr>
<td>Age</td>
<td>344</td>
</tr>
<tr>
<td>30 – 39 years</td>
<td>35</td>
</tr>
<tr>
<td>40 – 49 years</td>
<td>71</td>
</tr>
<tr>
<td>50 – 59 years</td>
<td>82</td>
</tr>
<tr>
<td>60 – 69 years</td>
<td>93</td>
</tr>
<tr>
<td>70 – 79 years</td>
<td>51</td>
</tr>
<tr>
<td>80 – 89 years</td>
<td>12</td>
</tr>
<tr>
<td>Number of teeth</td>
<td>340</td>
</tr>
<tr>
<td>Overall</td>
<td>336</td>
</tr>
<tr>
<td>0 – 9 years</td>
<td>24</td>
</tr>
<tr>
<td>10 – 18 years</td>
<td>40</td>
</tr>
<tr>
<td>19 – 24 years</td>
<td>84</td>
</tr>
<tr>
<td>25 – 27 years</td>
<td>80</td>
</tr>
<tr>
<td>28 – 32 years</td>
<td>90</td>
</tr>
<tr>
<td>Eichner (teeth only)</td>
<td>340</td>
</tr>
<tr>
<td>Overall</td>
<td>336</td>
</tr>
<tr>
<td>A</td>
<td>173</td>
</tr>
<tr>
<td>B1</td>
<td>54</td>
</tr>
<tr>
<td>B2</td>
<td>32</td>
</tr>
<tr>
<td>B3</td>
<td>21</td>
</tr>
<tr>
<td>B4</td>
<td>16</td>
</tr>
<tr>
<td>C</td>
<td>44</td>
</tr>
<tr>
<td>Eichner including fixed restoration</td>
<td>340</td>
</tr>
<tr>
<td>Overall</td>
<td>336</td>
</tr>
<tr>
<td>A</td>
<td>199</td>
</tr>
<tr>
<td>B1</td>
<td>42</td>
</tr>
<tr>
<td>B2</td>
<td>23</td>
</tr>
<tr>
<td>B3</td>
<td>19</td>
</tr>
<tr>
<td>B4</td>
<td>14</td>
</tr>
<tr>
<td>C</td>
<td>43</td>
</tr>
<tr>
<td>School education</td>
<td>345</td>
</tr>
<tr>
<td>Overall</td>
<td>340</td>
</tr>
<tr>
<td>&lt;10 years</td>
<td>80</td>
</tr>
<tr>
<td>10 years</td>
<td>170</td>
</tr>
<tr>
<td>&gt;10 years</td>
<td>95</td>
</tr>
</tbody>
</table>
variability (dispersion) of muscle distributions, we presented the coefficient of variation. Outliers of the two-dimensional normal distribution of the left and right sides were checked by Stata’s hadimvo procedure and excluded from further analysis.

The cross-sectional area of the left and right side as an outcome was analyzed by generalized least squares taking into account the dependent observations on subject level (21). Because age and the number of teeth were exposures of interest, we adjusted only for gender and education. The preferred chewing side was considered to be a mediator between the number of teeth and the cross-sectional area and therefore was not included in the model (22). The side on subject’s level, however, was included as a fixed factor and to model correlation within subjects.

For age and the number of teeth, we used restricted cubic splines with three knots to allow for non-linearity and presented interquartile range effects (third versus first quartile, or median of the upper half versus median of the lower half) (21) Gender interactions with age and teeth were modeled simultaneously. Moreover, gender-stratified estimates were calculated.

Because of the American Statistical Association statement against over-reliance on P values (23) and given our large sample size, we primarily estimated, figured, and interpreted the size of an effect (24); P values were interpreted cautiously but were needed, i.e. for chunk or multiple degree of freedom (d.f.) tests, especially for interaction tests. Graphics and statistical analyses were performed using R (25), specifically the package rms, and Stata, release 14 (Stata Corporation, College Station, TX, USA).

Results

Descriptive baseline characteristics of study participants are described in Table 1. Gender differences in cross-sectional areas are described in Table 2.
areas were large in terms of the mean albeit some overlapping occurred (Table 2). Differences in variability (coefficient of variation) between men and women were small and the distributions were substantially the same.

The correlation coefficient between the left and right sides of the lateral pterygoid muscle was larger in men than in women (0.86 versus 0.77, respectively; P=0.0003). This was also observed to a smaller degree in the medial pterygoid muscle (0.84 versus 0.79, respectively; P=0.0382).

Variability was the lowest in lateral pterygoid muscle, followed by the medial pterygoid and the masseter muscles.

In the lateral pterygoid CSA values, one two-dimensional outlier was observed (Figure 4); in the medial pterygoid muscle, there was a single outlier (Figure 5) and three outliers in the masseter muscle values, (Figure 6).

For muscles (Table 2), we assumed normal distribution or an additive effect of many random variables. Although one-dimensional QQ plots of the muscles indicated lognormal distribution or a multiplicative effect of many random variables, we chose, after having excluded two-dimensional outliers, the two-dimensional normal distribution to allow for easier interpretation of the two muscle sides. Note that a) a subject with highly asymmetric muscle sizes is identified to be an outlier; b) two-dimensional outliers are not necessarily one-dimensional outliers; and c) the variance between muscle sides increases with increasing mean muscle size only slightly.

For muscle models (Table 3), residuals of original muscle sizes showed small deviations from normality, which were of minor concern in this large sample. Moreover, log-transformed muscle sizes were not favorable to reach normality of residuals.

The cross-sectional area of the lateral pterygoid muscle decreased substantially with age in women but did not depend on age in men. The number of teeth was weakly associated with age in both genders. The cross-sectional area of the medial pterygoid muscle depended on age but an effect modification by gender was uncertain (P = 0.0906 for this 2 d.f. test). Whereas the cross-sectional area was almost linearly related to age in women, some deviation from linearity appeared in men (P = 0.0315 for this 1 d.f. test of nonlinear interaction). The number of teeth was weakly associated with age in both genders.

The cross-sectional area of the masseter muscle was weakly associated with age but strongly associated with the number of teeth in both genders. Differences between the left and right sides were close to zero in both men and women (Table 3) (Figures 7a -7f)

**Discussion**

Capitalizing on a large sample from the general population (n=747), a wide age range (30-89 years), and in-vivo head imaging techniques, our study reports that age has a heterogeneous effect on masticatory muscles with sex modification in some. While the lateral pterygoid muscle CSA decreased substantially with age in women, this effect was not present in men. The medial pterygoid muscle CSA depended on age but an effect modification by gender was not present. On the other hand, masseter muscle was strongly associated with the number of functional teeth. These observations suggest
that changes in masticatory muscles during aging are muscle specific, which is in accordance with the results of Monemi et al. (26) who reported that the pattern of age-related changes differed between masticatory muscles, and although those muscles can be simultaneously active, they fulfill different tasks in natural jaw function. The masseter has a multipennate arrangement of relatively short muscle fibers, which enables powerful activity during mandibular elevation, while the lateral pterygoid has a near parallel relationship between its relatively long fibers and it is especially tasked with the positioning and stabilizing of the condyle-disc assembly on the articular eminence during mandibular movements (27). In their study, Menomi et al. (26) found a significant amount of the fast contracting, fatigue-resistant, type IIA fibers in the lateral pterygoid of the elderly that are not found in young adults. Although that type I fibers were still the dominant type, the presence of type IIA fibres in the elderly reflects changes to the muscle’s fibre composition that might be related to alterations in the oral function, due to local factors like the reduced number of teeth or the presence of temporomandibular disorder (28). Furthermore, gender differences in the fiber composition of masticatory muscles, neuromuscular activity and in craniofacial form suggest that the aging process can yield varying rates of muscle loss between men and women, as can be seen in our results in the medial and lateral pterygoid muscles. This is of particular interest in the case of the lateral pterygoid muscle, considering it’s implied rule in the development of temporomandibular disorders (TMD) (29-30) and the higher prevalence of tenderness and pain in this specific muscle among women with TMD (31). Further experimental investigations even suggested that the female superior head of the lateral pterygoid muscle could generate stronger forces than males, which might be associated with the higher prevalence of TMD in females (32). However, there is still considerable uncertainty with regard to gender influence on the development of TMD.

In this study, the number of functioning teeth units had a major effect on the CSA of the masseter, which is relatively independent of age as evidenced by the broad variability in the number of natural teeth in the elderly (28). The greatest decrease in the masseter CSA was present in the edentulous group with no teeth (decrease of 29% in men, 26% in women) when compared to the fully dentate, which was also evident in the Eichner class C (no occlusal contact). Our results also suggest that the greatest loss of CSA in the masseter takes place when the number of teeth falls below 10 teeth units. Newton et al (11) reported significant decrease in the CSA of the masseter (17-30%) and medial pterygoid muscles (10-22% CSA reduction) between dentate and edentulous groups. Although that our results report similar reduction range in the masseter CSA as the number and distribution of teeth decreases, we did not find a significant association between the medial or lateral pterygoid CSA and the number of teeth. Additionally, with respect to age and gender, the measurements of the medial pterygoid muscle reported by Newton et al appear to be overestimated in comparison with the reported values in our study, goto et al (33) and others (34, 35). In our view, a possible explanation for the higher medial pterygoid CSA values reported by Newton et al would be their use of thick 6mm CT slices to perform measurements on this relatively small muscle, which consequently resulted in an overestimation of its dimensions and size. Moreover, in some of the previous studies, measurements were simultaneously made for both sides of the masticatory muscles, and their orientations were according to the estimation within one subject, which was further used on all examined subjects (34, 35). While Goto et al. (33) measured the CSAs of each muscle perpendicular to it’s long axes, previous studies measured the CSAs either directly or parallel to anatomical planes, which might have led to an overestimation, especially for the medial and lateral pterygoid muscles, which have a rather distant medio-lateral orientation. In this context, we ensured that the muscle’s CSA in each side was measured perpendicular to the corresponding muscle’s long axis, after it’s orientation was revealed and fixed in each muscle individually.

Later studies on the effect of tooth loss on masticatory muscles were mostly conducted on either edentulous groups or subjects with prosthodontic replacements, focusing mostly on the effect of restoring teeth on masticatory function (36-38). Although this approach contributes invaluable evidence on the varying effects of different prosthodontic appliances on masticatory function, it falls short in examining changes in the different masticatory muscles in relation to partial edentulism or the present dental status.

Moreover, recent concerns call into question the effect of denture wearing on masticatory function, claiming that the adaptation ability of denture wearers was over stretched (28). Additionally, the reported effects of restoring oral function

Figure 4
Distribution of lateral pterygoid muscle cross sectional area

red: Female, blue: Male
with removable dentures in edentulous subjects cannot be
generalized to include the partially edentulous or subjects with
fixed prosthodontic restorations. Denture wearers are subjected
to additional factors that might influence their masticatory
performance, like the quality of the prosthesis, discomfort in
denture-bearing tissue, compression and denture shifting (39).
While previous approaches tended to evaluate masticatory
performance by comparing granulometry and bite force tests
between dentate and edentulous groups or between groups with
different prosthodontic appliances, the number and distribution
of the remaining functional teeth units and their effect on
masticatory muscles have been majorly overlooked.

**Figure 5**
Distribution of medial pterygoid muscle cross sectional area

![Figure 5](image)

red: Female, blue:Male

**Figure 6**
Distribution of masseter muscle cross sectional area

![Figure 6](image)

red: Female, blue:Male

Because of the population-based design of this study, we
focused mainly on the effects of age and tooth loss to limit the
complexity of the analysis. In future studies, changes to the
masticatory muscles in edentulous subjects and subjects with
oral para-functional activities and temporomandibular disorders
have to be explored. It is also necessary to conduct longitudinal
studies to confirm the findings of this cross sectional study.

**Figure 7**

a. Age effect on lateral pterygoid cross sectional area;
b. Number of teeth effect on lateral pterygoid cross sectional
area; c. Age effect on medial pterygoid cross sectional area;
d. Number of teeth effect on medial pterygoid cross sectional
area; e. Age effect on masseter cross sectional area; f. Number
of teeth effect on masseter cross sectional area

**Conclusions**

Our results showed that age had a heterogeneous effect
on the masticatory muscles. The medial and lateral pterygoid
muscles showed significant reductions associated with aging,
while the masseter muscle was associated with the number and
distribution of teeth independent of age. Taken together, these
findings underline the value of tooth preservation and early
restoration of missing teeth on the masticatory muscles health
and masticatory function in the elderly.

*Ethics approval and consent to participate:* The medical ethics committee of
University of Greifswald approved the study protocol, and written informed consents were
obtained from each of the study participants.
INFLUENCE OF AGE ON MASTICATORY MUSCLES

Consent for publication: Not applicable

Availability of data and material: The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests: The authors declare that they have no competing interests.

Funding: This study was supported by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) (Grant no. DA 1810/1-1)

Authors’ contributions: Conceived and designed the experiments: AD CS RB HV. Performed the experiments: AD TK TM SM HV. Analyzed the data: AD CS RB SK MH. Contributed reagents/materials/analysis tools: HV RBü TKo. Wrote the paper: AD CS.

Critical revision of the manuscript: all

Acknowledgments: SHIP is part of the Community Medicine Research Network at the University Medicine Greifswald, Germany, which is supported by the German Federal State of Mecklenburg-West Pomerania.

References