Study of Relationship between Apparent Diffusion Coefficients of the Masticatory Muscles on Magnetic Resonance Imaging and Temporomandibular Joint Disc Displacement

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Article History
Received 13 December 2018
Accepted 8 January 2019

Abstract
To evaluate relationships between apparent diffusion coefficient (ADC) values of masticatory muscles on magnetic resonance imaging (MRI) and temporomandibular joint (TMJ) disc displacement.

Eighty patients with temporomandibular disorders with bilateral symptoms (16 men, 64 women, range 16–83 years, mean 49.2 years) who underwent MRI from November 2015 to January 2017 were included. MRI techniques used included axial diffusion-weighted imaging and short tau inversion recovery imaging through the neck to the skull base. Regions-of-interest were drawn that included the entire right and left lateral pterygoid muscles, medial pterygoid muscles, and masseter muscles on a slice demonstrating the largest area of each muscle on an ADC map. Masticatory muscles involved in TMJ disc displacement on sides with reduction were compared with those on sides without reduction, and the effects of gender and age were analyzed.

ADC values of lateral pterygoid muscles and masseter muscles involved in TMJ disc displacement on sides without reduction were significantly higher than those on sides with reduction (*p<0.05). The respective mean ADC values of lateral pterygoid muscles on sides with and without reduction were 1.22×10⁻³ mm²/s and 1.28×10⁻³ mm²/s, for medial pterygoid muscles they were 1.18×10⁻³ mm²/s and 1.20×10⁻³ mm²/s, and for masseter muscles they were 1.20×10⁻³ mm²/s and 1.24×10⁻³ mm²/s.

In lateral pterygoid muscles and masseter muscles involved in disc displacement, ADC values of those on sides without reduction are higher than those on sides with reduction.

Keywords:
apparent diffusion coefficient, magnetic resonance imaging, masticatory muscle, temporomandibular disorders

Introduction
Temporomandibular disorders (TMDs) is a collective term encompassing a number of clinical conditions that involve the masticatory muscles, temporomandibular joint (TMJ) and associated structures, or both (1). The most common TMJ disorder is disc displacement. Disc displacement can be categorized as anterior displacement with reduction, anterior displacement without reduction, and posterior displacement (1). In disc displacement with reduction the disc is anterior to the condyle in the closed mouth position and returns to its normal position when the jaw is opened (1). In disc displacement without reduction the disc is anterior to the condyle in the closed mouth position but does not return to its normal position when the jaw is opened (1). A diagnosis of disc displacement associated with TMD is reached by a combination of clinical manifestations and diagnostic imaging confirmation.

Magnetic resonance imaging (MRI) is used at many institutions, and diffusion-weighted imaging (DWI) is a recent addition to musculoskeletal diagnostics (2, 3, 4). Apparent diffusion coefficient (ADC) values are quantified by DWI (5), and ADC values have been used to generate quantitative data in head and neck imaging research (6, 7).
However, in terms of DWI there is no report concerned with the question of whether the disc condyle relationship between the ADC values of the masticatory muscles on MR imaging and TMJ disc displacement.

The aim of the current study was to evaluate relationships between the ADC values of masticatory muscles on MRI and TMJ disc displacement.

Materials and Methods

Subjects

This prospective study was approved by the relevant Institutional Review Board (application number EC15–12–009–1), and all patients provided written informed consent prior to MRI examination. Eighty TMD patients with bilateral symptoms (16 men, 64 women, mean age 49.2 years, range 16–83 years) who underwent MRI from November 2015 to January 2017 were included in the study. All patients underwent MRI examination to evaluate brain and maxillofacial diseases as outpatients at the Department of Radiology at Nihon University School of Dentistry at Matsudo. Exclusion criteria were patients with joint effusion, patients aged younger than 15 years, patients with tumors around the TMJ, and imaging records with severe artifacts. None of the patients had documented malignant or benign tumors or osteomyelitis.

MRI

MRI of the TMJ, which included the bilateral medial muscles, lateral pterygoid muscles, and masseter muscles, was performed using a 1.5-Tesla unit (Intera Achieva 1.5T. Philips Medical Systems, Best, The Netherlands) with a 5-channel phased array coil.

The first sequence was DWI, which was obtained using a spin-echo technique. DWI was acquired in the axial plane with the following parameters: TR, 5,800 ms; TE, 69 ms; matrix, 256×256; field of view, 28 cm; section thickness, 6.0 mm; intersection gap, 1.4 mm; imaging time, 3 min 29 s; b-values, 0 and 1000s/mm².

Image analysis

ADC values were calculated using the ADC visualization tool incorporated in a dedicated off-line workstation (Philips Medical Systems). Regions-of-interest (ROIs) were manually generated by tracing the contours of the bilateral lateral pterygoid muscles, medial pterygoid muscles, and masseter muscles on b=0 images that demonstrated the maximal area of each muscle in the postural position (Fig. 1). Fascia, blood vessels, and fat were excluded from the ROIs. ROI placement was performed by two oral radiology specialists independently, then ADC calculation was performed. The temporalis muscles were not clearly depicted in many patients, therefore the ADC values of the temporalis muscles were not measured. Masticatory muscles involved in TMJ disc displacement on sides with reduction were compared with those on sides without reduction, and the effects of gender and age were also analyzed.

Statistical analyses

Relationships between TMJ disc displacement (with reduction and without reduction) and the ADC values of muscles were analyzed with the Mann–Whitney U test. These analyses were performed with the statistical package SPSS, version 21.0 (SPSS Japan, Tokyo, Japan), and *p<0.05 was considered statistically significant.

Results

The ADC values of lateral pterygoid muscles and masseter muscles involved in TMJ disc displacement on sides without reduction were significantly higher than those on sides with reduction (*p<0.05) (Fig. 2). The respective mean ADC values of lateral pterygoid muscles on the sides with and without reduction were 1.22×10⁻³ mm²/s and 1.28×10⁻³ mm²/s. The respective mean ADC values of medial pterygoid muscles on the sides with and without reduction were 1.18×10⁻³ mm²/s and 1.20×10⁻³ mm²/s. The respective mean ADC values of masseter muscles on the sides with and without reduction were 1.20×10⁻³ mm²/s and 1.24×10⁻³ mm²/s.

The ADC values of masticatory muscles involved in disc displacement on sides with and without reduction in men and women patients. (Table 1). There was no significant gender difference in the ADC values of the masticatory muscles.

The ADC values of lateral pterygoid muscles, medial pterygoid muscles, and masseter muscles involved in disc displacement on sides with reduction in different age groups (Table 2). There were no significant age-related differences.

The ADC values of lateral pterygoid muscles, medial pterygoid muscles, and masseter muscles involved in disc displacement on sides without reduction in different age groups (Table 3). There were no significant age-differences.
Discussion

In this study, ADC values of lateral pterygoid muscles and masseter muscles involved in TMJ disc displacement on sides without reduction were significantly higher than those on sides with reduction.

DWI utilizes water diffusion characteristics. These are dependent on multiple factors including cell membrane integrity, cell density, viscosity of extracellular fluid, and vascularity (8). ADC values can be calculated from DWI parametric maps. The structural condition of muscles as determined using ADC values depends on Brownian motion of water molecules. These movements are quantified using a coefficient known as the ADC (5, 6). ADC mapping can yield useful quantitative information pertaining the cellularity of musculoskeletal lesions (7).

In the present study, the ADC values of masticatory muscles on sides without reduction were higher than those on sides with reduction. Repetitive muscle contractions cause a temporal increase in intramuscular microcirculation, elevated capillary pressure and permeability, increased
Fig. 2.
Comparison between ADC values on MRI and disc displacement on sides with and without reduction. The ADC values of the lateral pterygoid muscles and masseter muscles involved in TMJ disc displacement on sides without reduction were significantly higher than those on sides with reduction (*p<0.05).

Table 1
Comparisons of ADC values of masticatory muscles involved in disc displacement on sides with and without reduction in men and women patients. The values shown represent the mean ± standard deviation (×10⁻³ mm²/s).
There were no significant gender differences in ADC values of the masticatory muscles.

|                     | lateral pterygoid muscle | medial pterygoid muscle | masseter muscle |
|---------------------|--------------------------|-------------------------|-----------------|
|                     | with reduction           | without reduction       | with reduction  | without reduction | with reduction | without reduction |
| women (n=16)        | 1.22±0.16                | 1.30±0.16               | 1.18±0.13      | 1.21±0.14          | 1.20±0.15     | 1.26±0.15         |
| men (n=64)          | 1.22±0.09                | 1.23±0.15               | 1.19±0.10      | 1.15±0.16          | 1.17±0.08     | 1.26±0.16         |

Table 2
ADC values of lateral pterygoid muscles, medial pterygoid muscles, and masseter muscles involved in disc displacement on sides with reduction in different age groups. The values shown represent the mean ± standard deviation (×10⁻³ mm²/s).
There were no significant age-related differences.

| age groups | lateral pterygoid muscles | medial pterygoid muscles | masseter muscles |
|------------|----------------------------|--------------------------|-----------------|
| 16-19(n=6) | 1.21±0.25                  | 1.23±0.17                | 1.33±0.23       |
| 20-29(n=11) | 1.20±0.13                  | 1.23±0.11                | 1.15±0.13       |
| 30-39(n=6)  | 1.15±0.20                  | 1.10±0.20                | 1.17±0.23       |
| 40-49(n=19) | 1.18±0.15                  | 1.16±0.13                | 1.17±0.15       |
| 50-59(n=8)  | 1.22±0.08                  | 1.18±0.11                | 1.20±0.12       |
| 60-69(n=18) | 1.25±0.24                  | 1.19±0.17                | 1.20±0.22       |
| 70-79(n=10) | 1.32±0.14                  | 1.19±0.11                | 1.23±0.10       |
| 80-89(n=2)  | 1.20±0.10                  | 1.08±0.10                | 1.12±0.09       |
Table 3

ADC values of lateral pterygoid muscles, medial pterygoid muscles, and masseter muscles involved in disc displacement on sides without reduction in different age groups. The values shown represent the mean ± standard deviation (×10⁻³ mm²/s). There were no significant age-related differences.

| age groups | lateral pterygoid muscles | medial pterygoid muscles | masseter muscles |
|------------|---------------------------|--------------------------|-----------------|
| 16-19(n=6) | 1.23±0.16                 | 1.10±0.14                | 1.28±0.13       |
| 20-29(n=11)| 1.26±0.19                 | 1.23±0.20                | 1.25±0.17       |
| 30-39(n=6) | 1.35±0.13                 | 1.18±0.09                | 1.36±0.13       |
| 40-49(n=19)| 1.32±0.17                 | 1.26±0.14                | 1.22±0.17       |
| 50-59(n=8) | 1.24±0.13                 | 1.22±0.12                | 1.14±0.12       |
| 60-69(n=18)| 1.30±0.15                 | 1.15±0.16                | 1.23±0.15       |
| 70-79(n=10)| 1.24±0.21                 | 1.20±0.14                | 1.31±0.17       |
| 80-89(n=2) | 1.26±0.08                 | 1.16±0.09                | 1.17±0.06       |

osmotic pressure due to metabolite accumulation in the extravascular space, or a combination of these factors, which can increase extravascular water within an exercised muscle (9). In a previous study, Katzberg et al. (10) reported that the severity of disc displacement without reduction was greater than that of disc displacement with reduction.

No significant gender differences were observed between the ADC values of each muscle type. Muscle fiber composition is relatively similar in men and women patients, and it is related to the capillary density within a muscle. There were also no significant differences between the ADC values associated with TMJ disc displacement in different age groups.

In a study reported by Galbán et al. (11) using DWI, water diffusion in skeletal muscles generally decreased with age. Masticatory muscles may become less fatigued than the muscles of the feet, because they only control mandibular movements for mastication and are also involved in speech and facial expressions.

Our study has some limitations. First, we were not able to detect the temporalis muscles because of low resolution images on DWI. Second, we were not able to measure ADC values in patient with severe image distortions from susceptibility artifact.

**Conclusion**

The ADC values of lateral pterygoid muscles and masseter muscles involved in disc displacement on sides without reduction were higher than those on sides with reduction. These results suggest that ADC values are associated with TMJ disc displacement.

**Acknowledgments**

We are grateful for the technological work by Masanori Maehara, Department of Radiology, Nihon University School of Dentistry at Matsudo. The authors declared no conflicts of interest related to this study.

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