Utility of the luminance standard deviation to quantify magnetic resonance imaging motion artifact induced by tongue movement

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Abstract: Clear magnetic resonance imaging (MRI) is required to diagnose tongue cancer. However, the absence of occlusal support may cause tongue movements which are known to introduce artifacts on the MR image. This pilot study compared the manifest of artifacts from the tongue at rest and during motion using luminance standard deviation (LSD) to quantify the artifacts, in dentulous subjects. Participants were ten dentulous participants (5 males, 5 females; age 31.50 ± 8.38 years) with occlusal support. MRI was conducted with the tongue at rest and during lateral movement. The LSD was measured in the regions of interest (ROI) in the axial and sagittal planes. Tongue movement evoked unclear MR images, compared with the images taken at rest. Statistical analysis revealed that the LSD significantly differed between the tongue at rest and in motion in the axial (P = 0.004) and sagittal planes (ROI-A: P = 0.002, ROI-P: P = 0.006). These findings suggest that tongue movement introduces motion artifact and the LSD responds quantitatively to the magnitude of artifacts. Future studies will evaluate whether a prosthetic device used to provide occlusive support can decrease these artifacts when analyzed using LSD.

Keywords: motion artifacts; tongue movement; magnetic resonance imaging; luminance standard deviation.

Introduction

According to an unprecedented super-aged Japanese society demographic, tongue cancer, salivary gland disease, and temporomandibular joint disease are expected to increase (1). Prevalence of cancer among those aged 50 years and older is expected to increase by 2040 in the Japanese population (1). Magnetic resonance imaging (MRI), computed tomography (CT), and positron emission tomography/CT (PET/CT) are the standard methods used to detect and diagnose lymph node metastasis and distant metastasis in malignant neoplasms (2). Among these methods, MRI is a particularly useful technique that affords examination without exposure to radiation (3-6). However, tongue movements or unstable swallowing may cause image artifacts which lower the accuracy of the MRI examination.

Tongue movement or unstable swallowing is thought to be associated with an age-related decrease in the number of remaining teeth and the loss of occlusal support. Recent reports indicate that the movement of the mandible and tongue during swallowing are more prominent in edentulous subjects than in healthy dentate subjects (7-9). The tongue/mandible motion causes motion artifacts on the MR images. For this reason, it is more difficult to diagnose and provide a stage classification based on the size of lingual squamous cell carcinoma, the external tongue muscle, and invasion of the tongue. Therefore, improved accuracy of MRI examinations of
elderly subjects without occlusal support is crucial to support adequate patient care.

Several studies have reported that denture wearing assures occlusal support and stabilizes tongue movement in edentulous elderly patients (7-10). Wearing dentures during MR examinations will provide occlusal support; it is also expected to reduce tongue/mandible motion and may reduce motion artifacts.

Several reports have assessed the motion artifacts related to respiration during abdominal imaging and blood flow from arteries during head imaging (11-16). However, the evaluation of motion artifacts due to tongue movement has not been thoroughly investigated. Motion artifacts are usually evaluated using multiple calibrated evaluators (11,16,17). This method, however, can be subjective and may introduce bias. Thus, objective and quantitative assessment of motion artifacts is expected to increase the reliability of these types of measurements.

Therefore, the objective of this pilot study was to investigate the concurrent validity of the luminance standard deviation (LSD) for the assessment of motion artifacts associated with tongue motion by comparing the levels of artifacts of dentulous subjects with the tongue at rest and during movement. These results could be used to evaluate whether a prosthetic device used to provide occlusal support can decrease image artifacts.

Materials and Methods

Subjects

Ten patients (five men and five women; average age: 31.50 ± 8.38 years; the average number of remaining teeth: 27.50 ± 1.27) who received treatment at the Kita Kashiwa Rehabilitation General Hospital participated in this investigation. Inclusion criteria for the current study were as follows: (i) dentulous subjects with occlusal support; (ii) no consecutive tooth loss of more than 2 teeth; and (iii) no soft tissue disease in the oral cavity.

Exclusion criteria were as follows: (i) involuntary movement during MR imaging in the oral and maxillofacial regions and any other part of the body; (ii) absolute and/or principle contraindications of MR imaging, such as a pacemaker, a cochlear implant, or claustrophobia; (iii) ferromagnetic metal in the oral cavity; (iv) swallowing disorders caused by a 10-mm increase or decrease in the occlusal vertical dimension when compared to the proper position.

Written informed consent was obtained from all participants after they had received a written form and explanation of the purpose and methods of the study. The study protocol was approved by the Ethical Committee of Nihon University School of Dentistry at Matsudo (EC16-019-1). The protocol was also registered to a clinical trial registry database (clinicaltrials.gov, NCT03018158).

MRI

The MR images were obtained using 1.5-T scanners (Vantage Titan, Toshiba Medical Systems, Otawara, Japan) with a head coil. All images were obtained in both the axial and sagittal planes. Measurements of the MR images were performed on T2-weighted images with fat saturation (T2WI+FS) owing to the high-quality depictions of tumors (3,18).

Axial imaging was performed within the following parameters: repetition time (TR) = 6,500 ms; echo time (TE) = 100 ms; number of excitations (NEX) = 1; slice thickness = 4.0 mm; gap = 0.8 mm. Sagittal imaging was performed within the following parameters: TR = 6,500 ms; TE = 100 ms; NEX = 1; slice thickness = 5.0 mm; gap = 0.1.

MRI conditions

Before the MRI scan, an examiner observed the occlusal status of the patient and identified the stability and reproducibility of their intercuspal position. All subjects practiced tongue movement under the guidance of a clinician, and reproducibility of the movement was confirmed, prior to the MRI. During the MRI, the participants were asked to maintain the intercuspal position with the mouth closed. Imaging was conducted with the tongue in the resting position, followed by movement of the tongue to the right and left within the oral cavity at the pace of one movement per second.

Image analysis

The region of interest (ROI) of each image was a circle: 20 mm in diameter (Figs. 1, 2). The settings of the ROIs were decided by consensus among the three examiners; a radiological technologist, and two dentists. The LSD was measured within the ROIs of the axial and sagittal planes on the T2WI+FS during tongue movement and under resting conditions. Furthermore, to examine the effect of the tongue thickness to the LSD, the thickness of the tongue muscle was measured and analyzed (19) in the sagittal plane under resting conditions (Fig. 3). All images were analyzed using ROI tools software version 2.31 on the console of the MRI device.

Statistical analysis

A two-way repeated measures analysis of variance (ANOVA) was used to analyze the effect of tongue movement and the ROI position on the LSD in the axial plane. Paired t-test was used to analyze the difference...
between the tongue in motion and at rest on the LSD; both at sagittal ROI-A and P respectively. A single linear regression analysis was used to analyze the effect of tongue thickness on LSD. SPSS Statistics for Windows, version 21.0 (IBM Corp., Armonk, NY, USA) was used for analysis, \( P \) value of less than 0.05 was considered significant.
Results

Image findings
The MR images of the tongue at rest and during movement are shown in Fig. 4. No obvious tongue motion artifacts of the MR image were observed in either the axial or the sagittal planes at rest (Fig. 4A). The lack of clarity of the MR images was prominent when the tongue was in motion. The intrinsic muscle of the tongue in the axial plane, and the anatomical forms at the base of the tongue and the oropharynx in the sagittal plane MR images were unclear (Fig. 4B).

LSD
In the axial plane, the LSD was significantly higher with the tongue at rest compared with that when it was moving ($P = 0.004$). No significant differences between the four ROIs positions were observed ($P = 0.16$) (Fig. 5). In the sagittal plane, the LSD was significantly higher with the tongue at rest compared with that when in motion at ROI-A ($P = 0.002$) and ROI-P ($P = 0.006$). There were no significant differences between the two ROIs positions ($P = 0.82$) (Fig. 6). Single regression analysis showed that the thickness of the tongue had no influence on LSD both in the axial ($P = 0.26$) and in the sagittal planes ($P = 0.74$).

Discussion
The results of this study demonstrate that motion artifacts occur in the MR image when the tongue is in motion. In the axial plane, blurring of the image occurred both in the central and marginal parts of the tongue. In the sagittal plane, blurring occurred from anterior to the posterior part of the tongue. The LSD values were significantly lower when the tongue was in motion compared with those when it was at rest, in both axial and sagittal planes, indicating that LSD provides a valid objective assess-
ment of motion artifacts.

Luminance has already been used in the field of orthopedic surgery as an objective index of images to evaluate knee symptoms and a change of the luminance in MR image (20). The luminance standard deviation value is used as an objective index of the MR image, as a definition of contrast and as an estimated value of noise (21-23).

In this study, the fact that as blurring of the image increases, the contrast is reduced and the luminance standard deviation decreases is evident (12,24). In the MR image, the contrast is reduced in images blurred by motion artifact. The results showed that LSD was significantly lower in MR images with motion artifacts. Therefore, it is possible to evaluate the presence of motion artifacts using the LSD objectively.

Fig. 5 Comparison of the LSD between tongue at rest and in motion in the axial plane, with respective ROIs.

In addition, we examined the change in LSD due to the occurrence of motion artifacts in high and low luminance regions of normal images in different regions of the tongue in the axial plane. No significant differences were observed among the regions, indicating that the LSD is an effective evaluation of motion artifacts in any region of the tongue. The LSD also significantly decreased tongue movement in the sagittal plane, even at different regions of the tongue. In the axial and sagittal planes, the LSD of the MR images with motion artifacts converged to the approximate value regardless of the regions with different contrast intensities in the normal image. Furthermore, the possibility of predicting the presence or absence of motion artifacts by using the LSD of the isolated image was implied. Furthermore, a regression analysis revealed that the thickness of the tongue does not have a direct influence on the LSD.

A potential limitation of this investigation is that the subjects were dentulous and aged between 23 and 45 years. Patients with cancer requiring MR imaging are typically elders (1). However, we consider that this evaluation is effective in older adults and cancer-affected subjects as we were able to evaluate images in a dentulous patient, moving the tongue consciously to cause significant motion artifact.

The absence of tongue and head movement is essential during MR imaging to prevent motion artifact. However, evaluating whether the artifacts were caused by tongue movement or by the movement of other parts reflected in the tongue is difficult. Head movement can be managed by fixing the head or through patient self-consciousness. However, tongue movement of edentulous persons or persons without occlusal support presents a challenge as controlling the tongue movement during the dynamic movements required for swallowing is unconscious (25). Therefore, future studies are required to examine the reduction of motion artifacts in people with specific oral conditions (i.e., edentulous persons or persons without occlusal support) which strongly influence instability of the tongue or swallowing. To test the hypothesis that the artifacts can be reduced by wearing dentures during MR imaging, the LSD can be valid and objective measures to assess and clarify the effect.

Collectively, these results suggest that the LSD is a valid objective measuring tool to evaluate the occurrence of artifacts due to tongue movement. Future studies will evaluate whether a prosthetic device used to support occlusion will decrease artifacts according to the LSD.

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Conflict of interest
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