SHORT COMMUNICATION

MS Inoue
T Ono
E Honda
T Kurabayashi
K Ohyama

Application of magnetic resonance imaging movie to assess articulatory movement

Authors' affiliations:
M.S. Inoue, T. Ono, K. Ohyama, Maxillofacial Orthognathics Graduate School, Tokyo Medical and Dental University, Bunkyo-ku, Tokyo, Japan
E. Honda, Oral and Maxillofacial Radiology, Graduate School, University of Tokushima, Tokushima, Japan
E. Honda, T. Kurabayashi, Oral and Maxillofacial Radiology, Graduate School, Tokyo Medical and Dental University, Bunkyo-ku, Tokyo, Japan

Correspondence to:
Takashi Ono
Maxillofacial Orthognathics
Graduate School
Tokyo Medical and Dental University
1-5-45 Yushima
Bunkyo-ku
Tokyo
113-8549 Japan
Tel.: +81 3 5803 5533
Fax: +81 3 5803 5533
E-mail: t-ono.mort@tmd.ac.jp

Structured Abstract
Authors – Inoue MS, Ono T, Honda E, Kurabayashi T, Ohyama K
Objective – To introduce the technique of magnetic resonance imaging (MRI) movie and to propose its feasibility for investigating articulatory movement.
Subjects – Five healthy adult females participated in the study.
Methods – Dynamic changes in oropharyngeal structures were assessed with MRI movie during the articulation of a bilabial consonant.
Results – Movements of the velum and tongue at a time resolution of 30 ms were complex at the tip of the tongue and the anterior part of the velum. These movements that were seen with a time resolution of 30 ms could not be interpolated or in any way derived from the results obtained with a time resolution of 120 ms.
Conclusion – The results suggest that MRI movie may be useful in the evaluation of articulation. It is important to reduce the time resolution to 30 ms to obtain images of articulators.

Key words: articulation; magnetic resonance imaging movie; tongue; velum

Introduction

Magnetic resonance imaging (MRI) is a powerful tool for capturing motion of soft-tissue organs such as cardiac movement (1). Fast (e.g. gradient echo imaging) and ultrafast (e.g. echo planar imaging) MRI sequences have been used to image swallowing (2,3) and temporomandibular joint (4,5) movements. However, the minimum time resolution in fast scan sequences was 100 ms. Therefore, motion that occurs within 100 ms

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cannot be observed and results in motion artifacts and/or blurring. In contrast, echo planar imaging provides ultrafast data acquisition at a resolution of typically less than 50 ms. However, the image is distorted at the air-tissue boundary so that the spatial resolution is too crude to observe fast and complex movement in the oropharyngeal region, such as speech.

Oropharyngeal articulators including the lips, tongue, and velum continuously interact at an appropriate timing and configuration during speech. Thus, there is a significant difference in the dynamic image of articulators obtained by MRI movie and the sustained image obtained by the ultrafast MRI sequence (6). This situation encouraged researchers to develop a new imaging method that transcends a time resolution of 100 ms. Masaki et al. (6) modified the synchronized technique described by Foldvik et al. (7) who used the cardiac cine sequence to visualize the dynamic movement of articulators. They applied the synchronized sampling method (i.e. so-called MRI movie) to the subject's utterance and the scan timing using an external trigger (6). Recently, MRI movie has also been shown to be useful for evaluating velopharyngeal insufficiency (VPI) in subjects with cleft lip and palate (8). However, the subjects are required to repeat a given sound 128 times, which may not be suitable for naïve subjects, especially children. Moreover, the signal/noise ratio may deteriorate because of the fluctuation of timing caused by neuromuscular fatigue. The purpose of this preliminary study was to introduce a new method for MRI movie and to propose its feasibility for investigating articulatory movement.

Subjects and methods

Five healthy adult females (age: 25–30 years) participated in this study. None had a cold, allergic rhinitis, or an ongoing respiratory infection at the time of the assessment. They showed no symptoms of neuromuscular or temporomandibular disorder. All of the experimental procedures complied with the Code of Ethics of the World Medical Association (Declaration of Helsinki) and were approved by the institutional ethics committee. Written informed consent was obtained from each subject.

The experimental setting for MRI movie and the procedures for constructing MRI movie are illustrated in Fig. 1. Custom-made circuitry was connected to a 1.5-T MRI apparatus (Magnetom Vision; Siemens AG, Erlangen, Germany), which was equipped with a head and neck coil, to enable an external trigger pulse to control the timing of the scanning sequence and to provide an auditory cue for synchronization of the subject's utterance, which was recorded simultaneously using an optical-fiber microphone (Fig. 1a). Each image had a 219×250-mm field of view with a pixel size of 2.03×1.95 mm (slice thickness: 5 mm), and the matrix size was 108×128. The subject repeated a vowel-consonant-vowel syllable (i.e. /apa/) in whispers, and the run was measured using a gradient echo sequence for a cardiac cine [repetition time (TR): 120, 80, 60, 40 and 30 ms, echo time: 4.8 ms, flip angle: 30°]. During data acquisition, an external trigger pulse was fed to the MRI scanner 12–36 times according to the time resolution (i.e. 120, 80, 60, 40 and 30 ms) in proportion to TR. The time required for data acquisition was approximately from 20 s to 1 min. Articulatory movements in the midsagittal plane were observed as a movie using the same method as in cardiac MRI.

Preliminary results

To compare the differences between various time resolutions, static images of MRI movie from two representative subjects at time resolutions of 30 and 120 ms are shown in Fig. 2. To elucidate the movement of the lips, tongue and velum, traces were made from these images and superimposed (Fig. 3).

Movements of the velum and tongue at a time resolution of 30 ms were complex at the tip of the tongue and the anterior part of the velum (Fig. 3). These movements that were seen with a time resolution of 30 ms could not be interpolated or in any way derived from the results obtained with a time resolution of 120 ms. Thus, it is important to reduce the time resolution to 30 ms to obtain images of articulators.

Discussion

In this study, the simultaneous and complex movement of multiple articulators was visualized in all subjects using MRI movie while they repeated a given sound

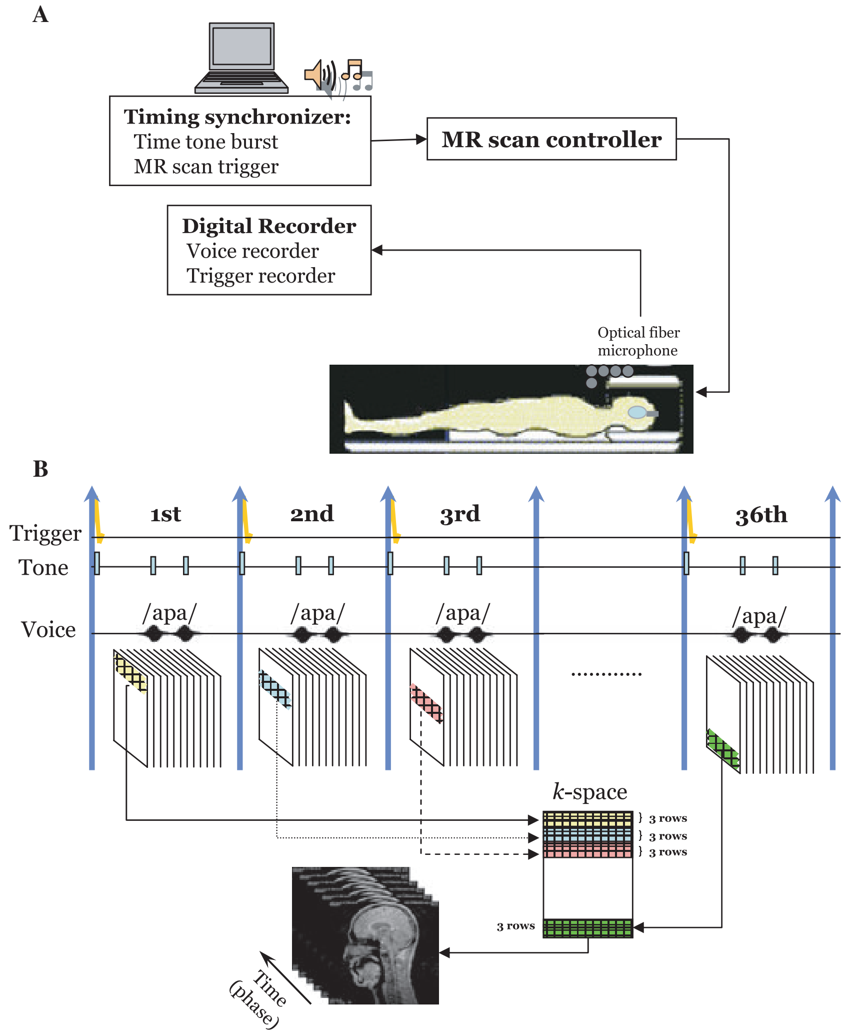

Fig. 1. (A) Experimental setting for MRI movie. (B) Representative procedures for constructing MRI movie with a time resolution of 30 ms.

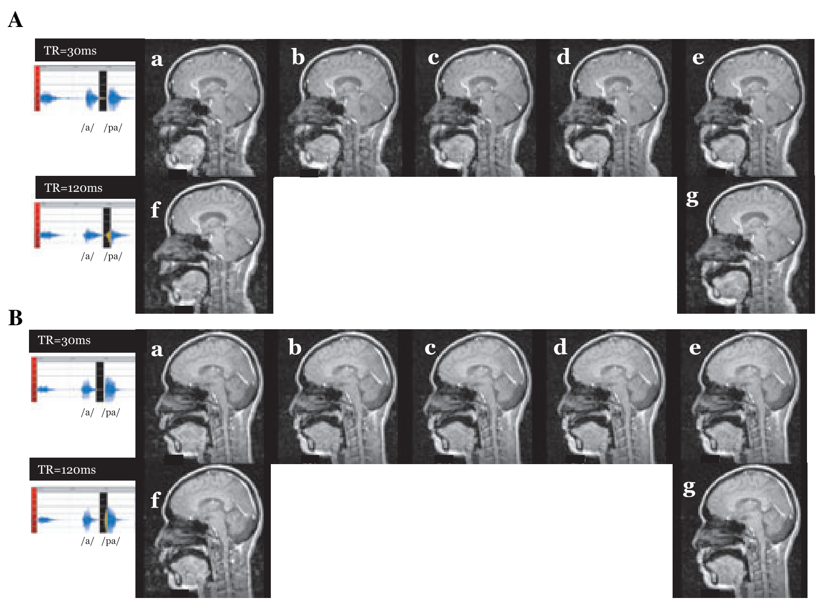

Fig. 2. Images of MRI movie immediately before velopharyngeal closure from two representative subjects (A and B) with different time resolutions, i.e. 30 ms (a–e) and 120 ms (f and g). All images correspond to the timing in the voice records shown on the left; (e) denotes the timing of velopharyngeal closure ($t = 0$) when the time resolution was 30 ms, and (d), (c), (b) and (a) denote −30, −60, −90 and −120 ms, respectively, from $t = 0$. Also, (g) denotes the timing of velopharyngeal closure ($t = 0$) when the time resolution was 120 ms, and (f) denotes −120 ms from $t = 0$.

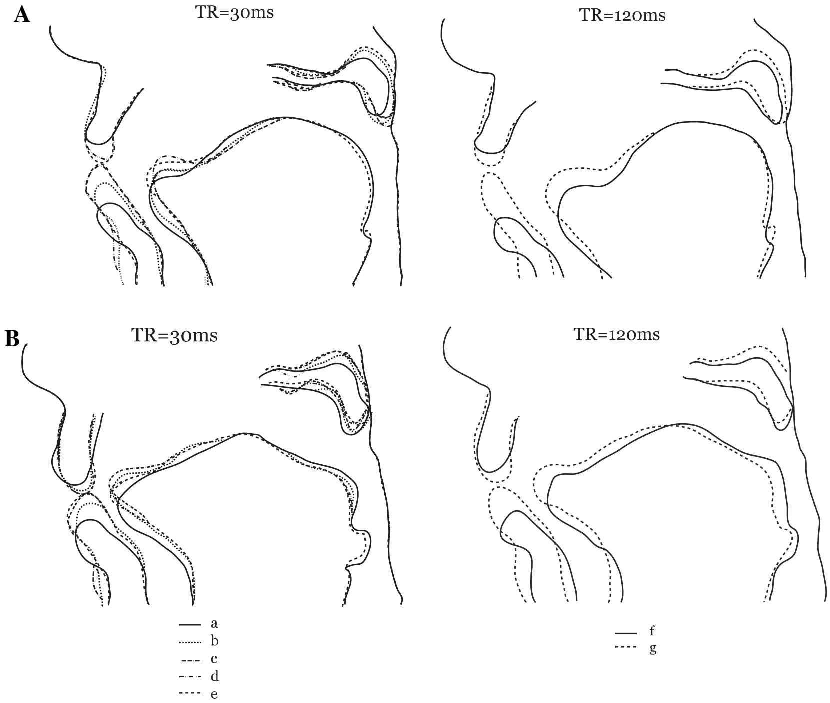

Fig. 3. Superimposition of tracings of articulators including the lips, tongue, and velum from the images in Fig. 2a–g correspond to the timings in Fig. 2. (A) Subject 1, (B) subject 2.

12–36 times. The configurational changes in articulators were more robust with a large time resolution (120 ms) than with a small time resolutions (30 ms) in all subjects. This indicates that the minute changes in the configuration of the velum can only be detected with a smaller time resolution.

Several beneficial changes were made to the technique for MRI movie that was previously described by our laboratory (8). Firstly, each of the two syllables of the subject's utterance was synchronized with a rhythmic auditory cue, which was helpful for reducing noise. Secondly, *k*-space was filled three times faster than before using software. Indeed, we could reduce the time required for image acquisition to approximately 54 s when the time resolution was 30 ms. This is one-fifth of the time used in the previous study (8). Together with the reduction of time required for image acquisition, we also reduced the number of utterances to 12–36, which is one-tenth to one-fourth of that in our previous study (8). The number of repetitions may be critical, as the velum may show neuromuscular fatigue (9). Thirdly, images and voice were simultaneously recorded and displayed in this study using software (Adobe Premiere 6.0; Adobe Systems Incorporated, San Jose, CA, USA). This could not be achieved in the previous study (8) that used irfan View (http://irfanview.tuwien.ac.at/).

Several investigators have used real-time MRI to evaluate speech production (10–12). However, the time resolutions in these studies were relatively large, i.e. 170 ms (11), > 169 ms (10), and 110 ms (12). The spatial resolution of a static image is fixed regardless of the time resolution. However, the spatial resolution of a dynamic image deteriorates in association with a decrease in sharpness with an increase in the time resolution. Thus, although it is a promising tool for the dynamic evaluation of speech, the time resolution in real-time MRI is still insufficient.

It is important to address the methodological differences in image-construction between conventional cine-loop MRI and MRI movie. In conventional cine-loop MRI, each *k*-space is filled one by one, and each *k*-space frame is made by filling one or several rows at a time according to the number of phase encodes using a delay. In this method, at least 100 ms is needed to construct an image even when the ultrafast MRI sequence is used. This duration allows for unexpected motion of the target and results in contamination by noise and/or blurring. MRI movie can be regarded as a type of cine-loop MRI in the sense that several reconstructed static images are displayed sequentially in a loop to mimic actual movement. However, a different method is used to construct static images. In our study, all *k*-space frames are arranged in parallel and the first three rows of the first k-space frame are filled almost simultaneously by the first phase encode (Fig. 1). The first three rows of the second k-space frame are filled 30 ms later when the time resolution is 30 ms. Thus, the first three rows of the nth k-space frame are filled $30\times(n-1)$ ms later. The last three rows of the first k-space frame are filled almost simultaneously by the last phase encode, and the last three rows of the adjacent k-space frame are sequentially filled every 30 ms when the time resolution is 30 ms. Therefore, the interval required for filling the adjacent k-space frame is equivalent to the time resolution. All reconstructed images are completed concomitantly by repeating this procedure according to the number of phase encodes, and these images are viewed in a loop as actual movement. Therefore, contamination by motion artifacts can be minimized as much as possible compared with conventional cine-loop MRI.

The velum plays an important role in articulation as well as in feeding and respiration. However, it has been difficult to visualize its configuration during function with a non-invasive technique. Nasoendoscopy and videofluoroscopy have been popular for evaluating VPI (11,13–15). However, these techniques have potential disadvantages compared with MRI because the former is invasive and nasal anesthesia has an adjunct effect on the function of the velum (16), and the latter is irradiative. A recent study showed that the anatomy of the posterior third of the velum varies among adult subjects with regard to the relative amount and distribution of different tissue types (17). This variation may be associated with the individualized movement pattern of the velum, which was revealed by MRI movie. Another notable issue is that the movement pattern of articulators revealed in the present study might not be identical to that in the upright position, as it has been reported that vocalization is influenced by changes in body position (18).

Conclusion

In this preliminary study, we introduced the technique of MRI movie and suggested its feasibility for investigating articulatory movements. This technique may be useful for studying other fast and complex functions, which conventional MRI sequences have not been able to delineate.

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