Bull Tokyo Dent Coll (2008) 49(3): 113–119

Original Article

Static MR Images for Diagnosis of Swallowing

Mai Ohkubo, Tsukasa Sano*, Ryo Ishida, Takuo Higaki, Keiichi Nishikawa*, Yoshihiko Hayakawa***, Takamichi Otonari*, Mika Yamamoto-Otonari*, Takuya Harada* and Mamoru Wakoh***

Department of Dysphagia Rehabilitation and Community Dental Care, Tokyo Dental College, 1-2-2 Masago, Mihama-ku, Chiba 261-8502, Japan
* *Department of Oral and Maxillofacial Radiology, Tokyo Dental College, 1-2-2 Masago, Mihama-ku, Chiba 261-8502, Japan*
** *Department of Radiology, Chiba Hospital, Tokyo Dental College, 1-2-2 Masago, Mihama-ku, Chiba 261-8502, Japan*
*** *Department of Computer Sciences, Faculty of Engineering, Kitami Institute of Technology, 165 Koen-cho, Kitami, Hokkaido 090-8507, Japan*

Received 2 May, 2008/Accepted for publication 4 August, 2008

Abstract

Evaluation of swallowing has been made possible by cine-Magnetic resonance (MR) imaging with high time resolution. However, the spatial resolution in cine-MR imaging remains inadequate for the detection of anatomical structures. Therefore, it is necessary to refer to static MR images in conjunction with cine-MR imaging. The aim of this study was to determine which MR parameters were appropriate for static imaging of the anatomical structures involved in swallowing. MR imaging was carried out, and T1-weighted, T2-weighted and proton-density-weighted MR images were obtained in the sagittal plane in 5 healthy volunteers. Each image was evaluated for anatomic landmark clarity by 3 oral radiologists. The anatomic landmarks selected were the lip, tip of tongue, center of tongue, tongue base, soft palate and epiglottis. Differences in clarity among 3 imaging modalities were evaluated. A 3-point score rating system was used. The results showed that lower TE sequences, *i.e.*, either T1-weighted or proton-density-weighted images, were the most suitable for use in conjunction with cine-MR imaging in diagnosing swallowing disorders.

Key words: Swallowing—Magnetic resonance imaging—Static imaging—Anatomic

Introduction

Videofluorography (VF), considered the “gold standard” among imaging modalities, has been used to evaluate swallowing[6,8,20]. It has, however, several disadvantages, including radiation exposure and limitations in detection of soft tissues. On the other hand, magnetic resonance (MR) imaging offers excellent contrast resolution in head and neck soft tissues without radiation exposure. Advanced MR technology allows imaging of soft-tissue motion with almost real-time resolution, and has been used to evaluate swallowing disorders. Foucart *et al.*[9] reported that kinetic MRI could be applied to the study of the oropharyngeal apparatus. Anagnostara *et al.*[2] reported that high-speed kinetic MRI allowed direct soft-tissue imaging at close to the real-time resolution offered by videofluorography. Hartl *et al.*[13,14] demonstrated that dynamic MRI with single-shot fast spin echo provided clear images of oral and pharyngeal surfaces, as well as deep tissue structures.

Although, cine-MR imaging for swallowing disorders has been reported[1,5,14,18], it remains to be clinically validated. We have already obtained fine cine-MR imaging with high time resolution using both generalized auto-calibrating partially parallel acquisition (GRAPPA) and fast imaging with steady state precession (True-FISP) data acquisition (Fig. 1). However, spatial resolution in cine-MR imaging remains inadequate for the detection of anatomical structures. A number of studies have found this approach inadequate for imaging of fine structures in swallowing due to the rapid movement of the anatomical structures involved[2,3,9,14,17,18]. Therefore, it is necessary to use static MR images with high spatial resolution in conjunction with cine-MR imaging as a reference. To our knowledge, static MR images for the detection of anatomical structures during swallowing have never been reported. This new technique offers a new method for evaluation of swallowing disorders. The aim of this study was to investigate which MR parameters were appropriate for static imaging in depicting the anatomical structures involved in swallowing.

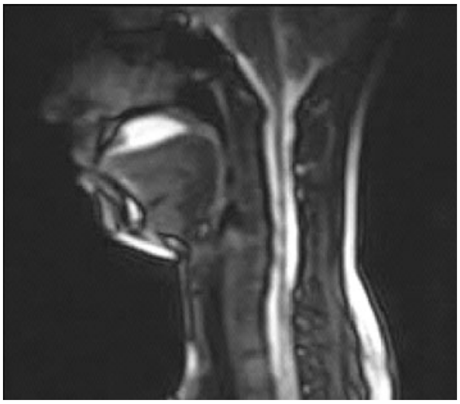

Fig. 1 Cine-MR imaging remains inadequate for detection of anatomical structures

Materials and Methods

Five healthy volunteers (3 men and 2 women) with no history of swallowing disorders or other chronic illness were enrolled in the study. Their ages ranged from 24 to 47 years, with an average age of 31.6 years. Prior informed consent was obtained from all volunteers.

A 1.5 T MR imager (Magnetom Symphony Maestro Class; Siemens, Erlangen, Germany) was used with a head-and-neck coil as a receiver. Imaging was carried out in the median sagittal plane with static sequences while participants were in the supine position.

T1-weighted (T1WI), fat suppression T2-weighted (T2WI) and proton-density-weighted MR images (PDWI) were obtained. The T1WI scan parameters were as follows: relaxation time (TR) 500 ms, excitation time (TE) 11 ms. The T2WI scan parameters were as follows:

Table 1 Scanning parameters for MR imaging

		T1WI	T2WI	PDWI
TR	repetition time	500 ms	5,430 ms	3,300 ms
TE	echo time	11 ms	82 ms	13 ms
FOV 230×230 mm		Matrix 512×512		Thickness 4 mm

TR 5,430 ms, TE 82 ms. The PDWI scan parameters were: TR 3,300 ms, TE 13 ms. Acquisition parameters employed in all cases were as follows: a 230×230 mm field of view (FOV) which was digitally represented by a 512×512 matrix, and a 4 mm slice thickness. The technical parameters specific to each acquisition are listed in Table 1. These parameters were used in routine clinical examinations at our hospital for the diagnosis of malignant/benign tumors in the head and neck regions.

Each MR image was evaluated by 3 oral and maxillofacial radiologists. Anatomic landmarks were selected according to the following criteria: they had to be both visible and important to the act of swallowing. Images were evaluated during the oral preparatory, oral, pharyngeal and esophageal stages of deglutition. The following landmarks were selected: lip, tip of tongue, center of tongue, tongue base, soft palate and epiglottis (Fig. 2). These anatomic landmarks are considered important in the diagnosis of swallowing, particularly in terms of the importation, maintenance and transportation of the bolus.

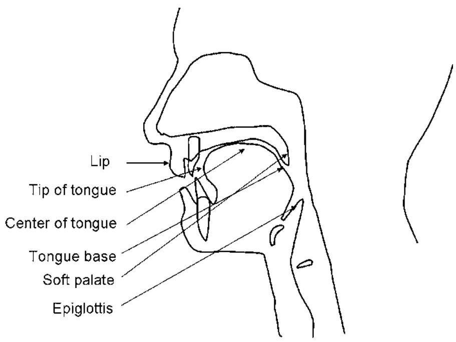

Fig. 2 Lateral view of anatomy of landmarks

The depiction of these landmarks between the 3 different parameters was evaluated. A 3-point-score rating system was used, with 3 points indicating the highest level of excellence and 1 point the lowest, giving a possible highest score of 45 (3 points×5 images×3 observers). Collected data were statistically analyzed by the Steel-Dwass multiple comparison test. Level of significance was set at 0.01.

Results

Figure 3 shows examples of T1WI, T2WI and PDWI. The T1WI and PDWI yielded good depiction of soft-tissue anatomy. T2WI showed a very high signal from water, for example, in saliva or spinal fluid. T2WI were very sensitive in pathological detection.

Table 2 shows the scores for the anatomic landmarks evaluated. Scores at the outline of the lip were 33 for T1WI, 16 for T2WI and 41 for PDWI. The results showed a statistically significant difference between T1WI and T2WI, PDWI and T2WI. For example, the outline of the lip was clearly visible in the PDWI in Fig. 4A. The arrow indicates the lateral view of lip. The tip of tongue was evalu-

Fig. 3 Water produces low signal on T1WI (A), high signal on T2WI (B) and relatively low signal on PDWI (C) Signal intensity from fat is higher in T1WI and PDWI than in T2WI.

ated as follows: 34 for T1WI, 22 for T2WI and 34 for PDWI. The results showed no statistically significant difference. Tongue tips reaching the incisors were clearly visible in Fig. 4B. The arrows indicate the lateral views of tip of tongue with T1WI and PDWI. The center of tongue was evaluated as follows: 39 for T1WI, 23 for T2WI and 28 for PDWI. The results showed a statistically significant difference between T1WI and T2WI. The center of tongue resting against the hard palate was clearly visible in Fig. 4C. The arrow indicates the lateral views of center of tongue with T1WI. The tongue base was evaluated as follows: 38 for T1WI, 24 for T2WI and 28 for PDWI. The results showed a statistically significant difference between T1WI and T2WI. Tongue base and air were clearly distinct in Fig. 4D. The arrow indicates the lateral view of tongue base with T1WI. The soft palate was evaluated as follows: 40 for T1WI, 19 for T2WI and 31 for PDWI. The results showed a statistically significant difference between T1WI and T2WI. The hanging soft-palate was in close contact with tongue base, but they are clearly distinguishable in Fig. 4E. The arrow indicates the lateral views of soft palate with T1WI. The epiglottis was evaluated as follows: 36 for T1WI, 21 for T2WI and 33 for PDWI. The results showed a statistically significant difference between T1WI and T2WI. The erected epiglottis in the airway is outlined clearly in Fig. 4F. The arrows indicate the lateral views of erected epiglottis with T1WI and PDWI.

The T1WI yielded significantly higher scores for center of tongue and tongue base. T1WI also tended to yield higher scores for soft palate and epiglottis. PDWI yielded higher scores for lips. None of the T2WI yielded a higher score for any anatomical landmark.

Discussion

MR imaging has been used to identify soft-tissue abnormalities in the head and neck regions without radiation. It allows safe examination of dysphagia patients, as it uses a water-soluble contrast material rather than barium media. Recently-developed MR imaging techniques allow dynamic imaging cine-MR imaging, in other words, kinetic MR imaging. Echo-planner technology has been used for the diagnosis of the tongue and pharyngeal cavity, but with decreased image resolution[11,12]. Turbo-flash technology offers high temporal resolution and sufficient spatial resolution, but the toxicity of the gadolinium-DTPA contrast-medium if aspirated remains to be determined[2,9]. These techniques are insufficient for the evaluation of soft-tissue morphology related to swallowing physiology and dysphagia. SSFSE technology, however, provides a better diagnostic evaluation of deep structures and mobility in dry swallowing[13,14]. B-turbo technology has made it possible to obtain an intense signal from water

Table 2 Score and lateral view of each landmark

Landmark	T1WI	T2WI	PDWI
Lip	33	16	41
	└ * ┘ (T1WI vs T2WI)	└ * ┘ (T2WI vs PDWI)	
Tip of tongue	34	22	34
Center of tongue	39	23	28
	└ * ┘ (T1WI vs T2WI)		
Tongue base	38	24	28
	└ * ┘ (T1WI vs T2WI)		
Soft palate	40	19	31
	└ * ┘ (T1WI vs T2WI)		
Epiglottis	36	21	33
	└ * ┘ (T1WI vs T2WI)		

*: $p<0.01$

which can be identified from high-contrast liquid bolus material[16].

In spite of certain drawbacks, cine-MR imaging is complementary to VF. Cine-MR imaging is limited by imaging speed. The highest temporal resolution obtainable with

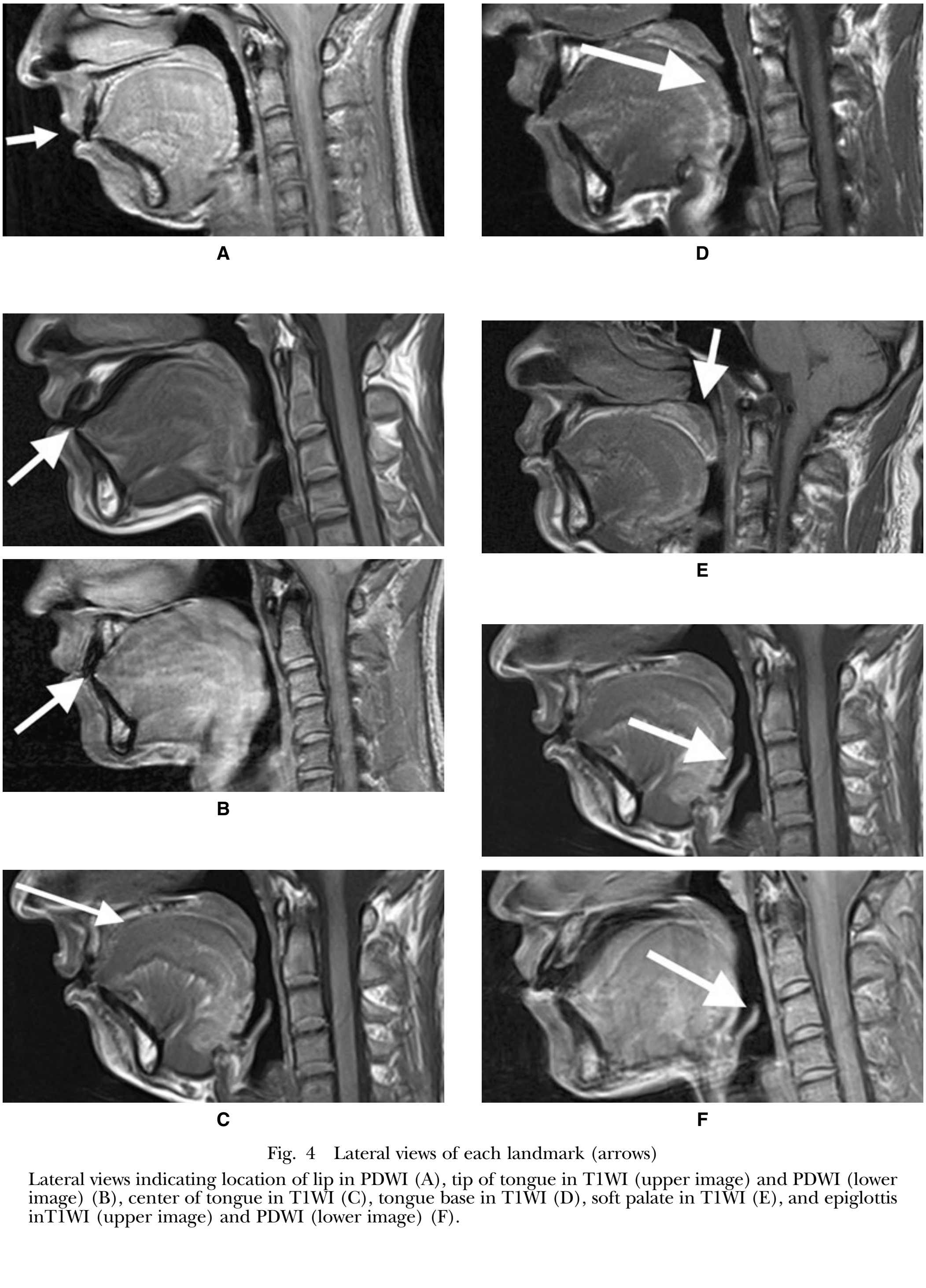

Fig. 4 Lateral views of each landmark (arrows)

Lateral views indicating location of lip in PDWI (A), tip of tongue in T1WI (upper image) and PDWI (lower image) (B), center of tongue in T1WI (C), tongue base in T1WI (D), soft palate in T1WI (E), and epiglottis inT1WI (upper image) and PDWI (lower image) (F).

cine-MR imaging technologies is 0.2–0.3 sec per slice. In contrast, VF is capable of obtaining images at 0.033 sec intervals (30 frame/sec). This produces a much smoother sequence of images than with cine-MR imaging.

Therefore, static MR images, with their high spatial resolution, are necessary in obtaining detailed information concerning the various hard and soft-tissue structures involved in swallowing. In particular, MRI is noted for the depiction of anatomical structures of the oral cavity, oropharynx, hypopharynx and larynx. The sagittal plane of the images allows for better evaluation of base-of-tongue volume, as opposed to recognition of surface area using endoscopy. Static MR images depicts differences in the internal muscles of tongue far better than cine-MR imaging. Vorperian *et al.*[21] reported that most anatomic landmarks were clearly visible in the midsagittal plane in a study using median sagittal images of vocal cord structures. Other researchers[13,14] reported the same with respect to the oral and pharyngeal phases of swallowing, observing the statuses of the lip, tongue and soft palate. Static MR images for vocal cord examination were also useful for detection of anatomical structures[3,4]. Essentially, static MR images are clinically applied to the diagnosis of head and neck cancers, as they offer clear depiction of anatomical sites[15].

The results of this study showed that lower TE sequences, *i.e.*, T1WI or PDWI were the most suitable for static MR images in diagnosing swallowing disorders. T1WI depict soft-tissue anatomy well (Fig. 3A). It is said that normal fat content in the subcutaneous tissue or orbits shows high signal intensity on T1WI[10]. The signals obtained with PDWI are reportedly useful in the diagnosis of the TMJ region due to the clear depiction of anatomical structures[19]. However, water yields very high signal intensity on T2WI (Fig. 3B), as do the majority of tumors[10]. The results of this experiment showed that T2WI are inadequate for the evaluation of the anatomical structures involved in swallowing.

From the viewpoint of tissue appearance, the lower TE sequences for static MR images appear to offer a suitable reference for use in conjunction with cine-MR imaging. Therefore, static reference images need to be used in conjunction with cine-MR imaging in evaluating swallowing. Cine-MR imaging of swallowing necessitates the use of such reference images due to the low image quality of the former. Therefore, static MR images could play an important role in the diagnosis of swallowing disorders. Donnelly[7] reported cine-MR imaging in sleep studies evaluating children with obstructive sleep apnea. In their study, the midline sagittal plane was determined from both 3-dimensional localization images and sagittal T1WI. The transverse cine-MR imaging at the level of the middle portion of the tongue was determined from the sagittal T1WI.

In a study on speech production, Masaki *et al.*[18] compared conventional still images and movie frames obtained by synchronized sampling. They found that tongue shape appeared to be wider where it made contact with the palate in static images compared to in dynamic images. This implies that synchronized sampling allows observation of natural consonant gestures in dynamic articulation. Such pilot experiments indicate an improvement in image quality due to subjects' experience. We intend to improve the image quality of static MR images by optimizing lower TE sequences. Dynamic and static MR images of swallowing are helpful in the diagnosis of the mechanisms of dysphagia, and are also helpful for guidance in swallowing therapy. Quantitative evaluation of tongue-base volume and range of motion on static MR images would be very useful in the guidance of surgical reconstruction and in the examination of patients with palsy. This new technique, namely the conjunctional use of cine-MR imaging and high-quality static MR images, offers a new method for clinically evaluating swallowing disorders.

In conclusion, the results indicate that lower TE sequences, *i.e.*, either T1WI or PDWI, are the most suitable as static high-quality MR images for use in conjunction with cine-MR imaging in diagnosing swallowing disorders.

References

1) Akin E, Sayin MO, Karacay S, Bulakbasi N (2006) Real-time balanced turbo field echo cine-magnetic resonance imaging evaluation of tongue movements during deglutition in subjects with anterior open bite. Am J Orthod Dentofacial Orthop 129:24–28.
2) Anagnostara A, Stoeckli S, Weber OM, Kollias SS (2001) Evaluation of the anatomical and functional properties of deglutition with various kinetic high-speed MRI sequences. J Magn Reson Imaging 14:194–199.
3) Baer T, Gore JC, Boyce S, Nye PW (1987) Application of MRI to the analysis of speech production. Magn Reson Imaging 5:1–7.
4) Baer T, Gore JC, Gracco LC, Nye PW (1991) Analysis of vocal tract shape and dimensions using magnetic resonance imaging: vowels. J Acoust Soc Am 90:799–828.
5) Barkhausen J, Goyen M, von Winterfeld F, Lauenstein T, Arweiler-Harbeck D, Debatin JF (2002) Visualization of swallowing using real-time TrueFISP MR fluoroscopy. Eur Radiol 12:129–133.
6) Dodds WJ, Stewart ET, Logemann JA (1990) Physiology and radiology of the normal oral and pharyngeal phases of swallowing. AJR Am J Roentgenol 154:953–963.
7) Donnelly LF (2005) Obstructive sleep apnea in pediatric patients: evaluation with cine MR sleep studies. Radiology 236:768–778.
8) Ekberg O (1997) Radiologic evaluation of swallowing, Dysphagia-diagnosis, Groher M, 3rd ed., pp. 191–222, Butterworth-Heinemann, Boston.
9) Foucart JM, Carpentier P, Pajoni D, Rabischong P, Pharaboz C (1998) Kinetic magnetic resonance imaging analysis of swallowing: a new approach to pharyngeal function. Surg Radiol Anat 20:53–55.
10) Gholkar A, Gillespie JE (1994) Imaging principles, Magnetic Resonance Imaging and Computed Tomography of the Head and Neck, 1st ed., pp. 1–10, Chapman Hall Medical, London.
11) Gilbert RJ, Daftary S, Campbell TA, Weisskoff RM (1998) Patterns of lingual tissue deformation associated with bolus containment and propulsion during deglutition as determined by echo-planar MRI. J Magn Reson Imaging 8:554–560.
12) Gilbert RJ, Napadow VJ (2005) Three-dimensional muscular architecture of the human tongue determined *in vivo* with diffusion tensor magnetic resonance imaging. Dysphagia 20:1–7.
13) Hartl DM, Albiter M, Kolb F, Luboinski B, Sigal R (2003) Morphologic parameters of normal swallowing events using single-shot fast spin echo dynamic MRI. Dysphagia 18: 255–262.
14) Hartl DM, Kolb F, Bretagne E, Marandas P, Sigal R (2006) Cine magnetic resonance imaging with single-shot fast spin echo for evaluation of dysphagia and aspiration. Dysphagia 21:156–162.
15) Hide IG, Chippindale AJ (2000) Imaging in patients with cancer of the extracranial head and neck. Imaging 12:97–105.
16) Karacay S, Akin E, Sayin MO, Bulakbasi N (2006) Real time balanced turbo field echo cine-MRI in the analysis of deglutition events and transit times. J Oral Rehabil 33:646–653.
17) Kitano H, Asada Y, Hayashi K, Inoue H, Kitajima K (2002) The evaluation of dysphagia following radical surgery for oral and pharyngeal carcinomas by cine-magnetic resonance imaging (Cine-MRI). Dysphagia 17:187–191.
18) Masaki S, Tiede MK, Honda K, Shimada Y, Fujimoto I, Nakamura Y, Ninomiya N (1999) MRI-based speech production study using a synchronized sampling method. J Acoust Soc Jpn 20:375–379.
19) Sano T, Widmalm SE, Yamamoto M, Sakuma K, Araki K, Matsuda Y, Okano T (2003) Usefulness of proton density and T2-weighted vs. T1-weighted MRI in diagnoses of TMJ disk status. Cranio 21:253–258.
20) Seta H, Hashimoto K, Inada H, Sugimoto A, Abo M (2006) Laterality of swallowing in healthy subjects by AP projection using videofluoroscopy. Dysphagia 21:191–197.
21) Vorperian HK, Kent RD, Lindstrom MJ, Kalina CM, Gentry LR, Yandell BS (2005) Development of vocal tract length during early childhood: a magnetic resonance imaging study. J Acoust Soc Am 117:338–350.

Reprint requests to:
Dr. Mai Ohkubo
Department of Dysphagia Rehabilitation and Community Dental Care,
Tokyo Dental College,
1-2-2 Masago, Mihama-ku,
Chiba 261-8502, Japan