3 Tesla Turbo-FLASH Magnetic Resonance Imaging of Deglutition

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Objectives/Hypothesis: In this article we describe a methodology for obtaining high-quality dynamic magnetic resonance imaging (MRI) sequences of the swallow sequence in healthy volunteers. The study includes comparison to previous work done in our lab using a 1.5 Tesla (T) magnet.

Study Design: Case series.

Methods: Three healthy volunteers underwent turbo-fast low angle shot MRI at 3T while swallowing liquid boluses delivered via intravenous tubing to the oral cavity. Imaging was performed in the sagittal and axial planes.

Results: Imaging provided by this sequence provided high temporal resolution, with the ability to depict deglutition in the axial and sagittal planes. Comparison with imaging at 1.5T demonstrated benefits in temporal resolution and signal-to-noise. Anatomic information provided differed from comparative videofluoroscopy.

Conclusions: MRI of swallowing using the described technique is reliable and provides a unique evaluation of the swallowing sequence.

Key Words: Swallowing evaluation, dysphagia, magnetic resonance imaging, dynamic magnetic resonance imaging.

Level of Evidence: 4.


INTRODUCTION

Swallowing disorders are common and have a significant health impact. One recent study found a prevalence rate of 22.6% among an unselected primary care population of patients.1 When specific at-risk populations are analyzed the rates are higher. The incidence among the elderly is estimated to be around 33%.2 Following recent strokes, dysphagia was found in 41% of patients.3 The impact of disordered swallowing is profound. Studies have estimated that in the acute setting, dysphagia results in a significant added cost and length of stay to inpatient treatment of a wide variety of disorders.4 In addition, the presence of dysphagia has been shown to have an independent negative effect on the anxiety, depression, and general health subscales of quality-of-life measures.5

Unfortunately, despite the significance of the disorder, major gaps in our knowledge regarding the normal swallowing mechanism persist. The swallowing apparatus is complicated, involving multiple muscle groups, multiple cranial nerves, and most importantly, coordination. The complexities of the system and the fact that it is largely hidden from view have befuddled efforts to fully evaluate the entire swallow sequence. Current imaging techniques for swallowing, including videofluoroscopic evaluation of swallowing, flexible endoscopic evaluation of swallowing (FEES), and ultrasound of the oral cavity and oropharynx, allow for the assessment of different parts of the tongue base and pharyngeal constrictor region. However, each of these views has drawbacks in that the tongue base and pharyngeal constrictors cannot be totally visualized, specifically with imaging of the entire tongue base in the axial plane. The tongue plays a major role in bolus propulsion during swallowing, providing the pressure on the bolus of food or liquid to propel it through the oral cavity and through the pharynx.6 Reduced tongue motion can contribute to reduced bolus clearance through the oral cavity and pharynx.7–9 The pharyngeal constrictors also contribute to bolus propulsion through the pharynx, with an aborally propagated contraction of the pharyngeal constrictors in the horizontal plane simultaneous with pharyngeal shortening in the vertical plane.10–12 Reduction in pharyngeal constrictor activity can also contribute to reduced bolus clearance through the pharynx, as seen in the elderly, irradiated head and neck cancer patients, and stroke patients.13–15 Symmetry and coordination of posterior tongue base motion and medial pharyngeal wall movement can be evaluated with axial imaging techniques such as high-speed computed tomography (CT). However, this technique is limited due to concerns over radiation exposure.

Magnetic resonance imaging (MRI) is an ideal technique in many ways as it is noninvasive, provides...
significantly better spatial resolution than even CT, avoids radiation, and allows more complete views of the entire tongue base and pharynx in multiple planes. However, MRI of the swallowing process remains a challenge because of the rapidity of the swallowing process (1–2 seconds long), and the presence of the large air column of the aerodigestive tract and regional osseous structures, which contribute to susceptibility artifacts. Additionally, unlike the cardiac cycle, substantial variation is seen across repeated swallows. Prior efforts at MRI of swallowing have made use of single-shot fast spin echo,\textsuperscript{19,20} true fast imaging with steady state precession,\textsuperscript{21} and turbo-fast low angle shot (turbo-FLASH) imaging.\textsuperscript{22,23} In previous comparative work between echoplanar imaging, FLASH, and turbo-FLASH imaging,\textsuperscript{24} turbo-FLASH imaging was determined as having the optimal degree of spatial to temporal resolution at 1.5 Tesla (T). Given improvements in signal-to-noise ratio (SNR) provided by higher-field imaging, our goal was to determine the utility of turbo-FLASH dynamic imaging on a 3T magnet to evaluate the swallowing process, with the ultimate goal of developing improved diagnostic capabilities for patients with swallowing disorders.

**MATERIALS AND METHODS**

**Subjects**

The current study was approved by the institutional review board of the New York University School of Medicine. Three healthy volunteers (two males, one female, ages 31 to 42 years) were subjected to the protocol described below. Exclusion criteria included patients with previous head and neck procedures, recent history of intubation, complaints of severe dysphagia, or history of head and neck radiation therapy.

**MRI PROTOCOL**

MRI was performed on a 3.0T magnet (Trio; Siemens Medical Solutions, Malvern, PA) with a 4-channel multichannel head coil and a dual-channel neck coil. Turbo-FLASH sequence parameters were as follows: TR/TE 110/1.2 msec, slice thickness 10 mm, matrix 80 × 192, FOV 217 × 260 mm, parallel acceleration factor 2 (GRAPPA). Thirty sequential images were acquired over a duration of 3,300 ms. Imaging was performed in the midsagittal plane and in the axial plane at the level of the oropharynx. The axial plane was determined using a scout sagittal image. The tip of the epiglottis was used as the landmark for identifying the proper level for imaging in this plane. Positive oral contrast in the form of a protein drink (Nutrament; Novartis Medical Nutrition, Minneapolis, MN) was delivered via a suspended intravenous bag and roller clamp tubing to allow for patient control of bolus delivery during scanning.

Comparative imaging was performed on a 1.5T magnet (Avanto; Siemens Medical Solutions) with the following parameters: TR/TE 126.9/1.2 msec, slice thickness 10 mm, matrix 80 × 192, FOV 217 × 260 mm, parallel acceleration factor 2 (GRAPPA). Static and cine loop imaging was reviewed on a PACS workstation. One volunteer with mild dysphagia at the oropharyngeal level underwent both dynamic MRI examinations and videofluoroscopy.

**RESULTS**

Temporal resolution of the 3T imaging was 110 msec (Fig. 1). In contrast, temporal resolution on the 1.5T system was 127 msec. Although direct comparison is difficult due to differences in sequence parameters, SNR benefits were achieved in comparison to 1.5T, with an increase of approximately 200% (maximal average SNR: 26.3 ± 13.6 [3T], 8.5 ± 4.5 [1.5T]). We found that continued increases in the parallel acceleration factor to three introduced unacceptable image noise, most likely due to the limited number of coil elements. Axial imaging (Fig. 2) consistently demonstrated early depression of the tongue base, passage of contrast into the oropharynx, followed by apposition of the tonsillar pillars mediated by pharyngeal constrictors. This was followed immediately by posterior movement of the tongue base to result in complete closure of the pharynx following bolus passage. Substantial medial excursion of the carotid sheaths was noted during pharyngeal constriction. Figure 3 demonstrates imaging at the level of the crico-pharyngeus, demonstrating the bolus passing through an open pharyngoesophageal segment along with a fair amount of air. On sagittal imaging (Fig. 4), the aerodigestive tract from the oral cavity to the cervical esophagus was well delineated. Tongue motion, velopharyngeal closure, hyoid and laryngeal elevation, and movement of the epiglottis were well depicted. In comparison to videofluoroscopic imaging, the midline structures were delineated without superimposed signal from the pyriform sinuses. Additionally, regional soft tissue structures could be more discretely identified.

**DISCUSSION**

Efforts to develop alternate evaluative methods to analyze swallowing function are important, as...
videofluoroscopy and FEES, currently the gold standards for clinical evaluation, are both imperfect. FEES offers the ability to visualize the mucosal surface of the upper aerodigestive tract, but is invasive and does not allow direct visualization of the entire act of swallowing (no ability to evaluate the moment of the swallow or esophageal phase). Videofluoroscopy offers the ability to image the act of swallowing in real time and allows for evaluation of the physiology of the soft tissues of the upper aerodigestive tract. However, this method uses ionizing radiation, which limits the number of acquisitions possible and has limited spatial resolution. In addition, fluoroscopy is a nontomographic modality, so axial imaging is not possible with this modality.

In this preliminary investigation, we have been able to demonstrate feasibility to perform relatively high-speed MRI of the swallow sequence. The use of the 3T scanner resulted in a detectable improvement in SNR over the 1.5T scanner, resulting in an improvement in resolution. Although the temporal resolution of 110 ms is not equivalent to the speed of image acquisition of FEES and videofluoroscopy, we were able to gather copious information about the movement of the pharyngeal and laryngeal structures during the swallow without missing significant portions of the swallow sequence. Given that the swallow lasts for about 1 second, we are able to examine approximately nine frames of imaging data per swallow.

In addition, the spatial resolution and particularly the ability to view the entire pharyngeal phase without the overlying shadow of the mandible or the collapse of the pharyngeal structures was a significant upgrade from other methods of swallowing evaluation. When combined with the static images that can be obtained prior to the initiation of the swallow, there is significant information with regard to anatomy and pathology that can be obtained for the dysphagic patient.

Finally, the ability to view the swallow in the axial plane allowed for specific study of the pattern of closure and symmetry of the pharynx during the swallow. This is not a view that can be attained by FEES or videofluoroscopy. This information may allow for improved understanding of swallowing physiology and the ability to evaluate patients who may have unilateral lesions or deficits.

The main limitation of the described dynamic MRI approach is the need for supine positioning. Although there may be concern about increasing the risk of aspiration, it is known that the timing of muscle activation is not substantially changed in the supine position. Additionally, several studies have confirmed that bolus flow through the pharynx is unchanged in the supine versus upright position, and that swallowing physiology as a whole is unaffected by this position change. All of these studies, however, were done on healthy individuals, and the effects of positioning in abnormals have not been adequately examined to date. Unfortunately, at

Fig. 2. Selected images (every other image) from axial 3T MRI sequence displayed from left to right; floor of mouth elevation is demonstrated by visualization of lingual septum on the second image (thick arrow). Depression of the tongue base is noted, followed by bolus passage and subsequent effacement of the airway by the pharyngeal constrictors and tongue base. Horizontal bars at the bottom of the image demonstrate the difference in distance between the internal carotid vessels on the first image (top bar) and last image (bottom bar). The thin arrow points to the bolus as it passes through the oropharynx.

Fig. 3. Selected images from axial 3T magnetic resonance imaging sequence displayed from left to right; upper esophageal sphincter region is demonstrated. The thin arrow points to the bolus as it passes through the oropharynx. Notation is made of the air that is swallowed along with the bolus.
this time, 3T MRI scanners are not available for use in the upright position, so direct comparisons using these sequences may need to await improvements in MRI technology.

Although it is likely that videofluoroscopy and/or FEES will remain the standards for the assessment of aspiration risk for the near future, we envision the use of these sequences as potentially adjunctive in the evaluation of swallowing pathophysiology in the setting of prior infarcts, head and neck surgery, radiation, and evaluating areas which are not fully assessed on standard videofluoroscopic imaging. In these patients, dynamic MRI would be helpful in examining symmetry in the axial plane and isolating segments of the pharynx for more detailed analysis, perhaps in evaluating patients prior to a surgical procedure. In addition, this technique provides a powerful research tool to aid in the study of normal and abnormal swallow physiology.

CONCLUSION

Dynamic MRI of the swallow sequence is feasible, reproducible, and allows for imaging in multiple planes. Use of the turbo-FLASH sequence on a 3T scanner allows for excellent temporal and spatial resolution. Increasing the strength of magnet from 1.5T to 3T allows for improvement in SNR.

BIBLIOGRAPHY