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Dynamic magnetic resonance imaging of swallowing and laryngeal motion using parallel imaging at 3 T

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Abstract

Object: To evaluate the feasibility of an optimized MRI protocol based on high field imaging at 3 T in combination with accelerated data acquisition by parallel imaging for the analysis of oropharyngeal and laryngeal function.
Materials and Methods: Fast 2D gradient echo (GRE) MRI with different spatial resolutions (1.7×2.7 and 1.1×1.5 mm^2) and image update rates (4 and 10 frames per second) was employed to assess pharyngeal movements and visualize swallowing via tracking of an oral contrast bolus (blueberry juice). In a study with 10 normal volunteers, image quality was semi-quantitatively graded by three independent observers with respect to the delineation of anatomical detail and depiction of oropharynx and larynx function. Additionally, the feasibility of the technique for the visualization of pathological pre- and post-surgical oropharynx and larynx function was evaluated in a patient with inspiratory stridor.
Results: Image grading demonstrated the feasibility of dynamic MRI for the assessment of normal oropharynx and larynx anatomy and function. Superior image quality ($P<.05$) was found for data acquisition with four frames per second and higher spatial resolution. In the patient, dynamic MRI detected pathological hypermobility of the epiglottis resulting in airway obstruction. Additional post-surgical MRI for one clinical case revealed morphological changes of the epiglottis and improved function, i.e., absence of airway obstruction and normal swallowing.
Conclusion: Results of the volunteer study demonstrated the feasibility of dynamic MRI at 3 T for the visualization of the oropharynx and larynx function during breathing, movements of the tongue and swallowing. Future studies are necessary to evaluate its clinical value compared to existing modalities based on endoscopy or radiographic techniques.

Keywords: Swallowing; Laryngeal motion; Parallel imaging; 3 Tesla

1. Introduction

Functional deficits of the pharynx or larynx can cause severe problems such as aspiration pneumonia [1] or stridor [2–4]. Even minor malfunctions may severely affect the patient including recurrent aspiration and cough due to imperfect airway closure during swallowing or voice malfunctions such as improper articulation of speech or hoarseness [5].

Current clinically available methods for the detailed evaluation of oropharyngeal and laryngeal (dys-) function require either invasive techniques or ionizing radiation. Invasive techniques include indirect laryngoscopy or, more recently, fiber-optic nasal endoscopy. A thin and flexible endoscope, inserted through the nostril, is used to visualize the entire pharynx and larynx [6].

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Alternatively, radiographic techniques with contrast media offer the opportunity to examine the oropharynx and cervical esophagus in patients who are at risk for aspiration due to swallowing difficulty [7].

Due to invasiveness or use of ionizing radiation, repeated evaluation based on these modalities, especially in children, can therefore be difficult. Moreover, standard endoscopic methods are limited to superficial images while radiographic examinations rely on indirect measures of function based on the dynamics of contrast medium filling the oropharyngeal space.

In recent years, a growing effort has been made to investigate the oropharynx noninvasively by magnetic resonance imaging (MRI). However, previously reported MRI applications based on single-shot fast spin echo or fast GRE imaging (Turbo-FLASH) did not utilize parallel imaging techniques available on modern MR systems and had relatively low temporal image update rates on the order of one to five images per second and/or low spatial resolution [8,9]. As a result, the depiction of important anatomical details such as the epiglottis or glottis was difficult [10]. More advanced imaging protocols including various high-speed MRI sequences such as echo planar imaging, GRE (FLASH) and fast GRE (Turbo FLASH) techniques were used and evaluated using 1.5-T MR systems comparing different MR protocols for investigating the various phases of deglutition (oral preparatory, oral, pharyngeal and esophageal) [11]. A further study reported the visualization of swallowing using real-time balance steady-state free precession (True FISP) imaging [12]. However, optimized fast data acquisition at high field (3 T) in combination with parallel imaging acceleration techniques to exploit the higher signal-to-noise ratio (SNR) at 3 T for increasing temporal and/or spatial resolution has not been reported to date.

In this study, we evaluated an optimized high-field MRI protocol at 3 T in combination with parallel imaging acceleration which permits temporal update rates of up to 10 images per second while covering the entire oropharynx to the upper thoracic aperture with a large field of view. Swallowing was visualized using natural blueberry juice as a paramagnetic MR contrast agent [13]. Image quality for different trade-offs between spatial and temporal resolutions was analyzed in a volunteer study. In one patient, dynamic MRI was successfully employed for pre- and post-surgical laryngeal function evaluation during breathing and swallowing.

2. Methods

MRI examinations were performed in a study with 10 healthy volunteers (7 male, 3 female, mean age=31.4 years) with no history of laryngeal or oropharyngeal disease. In addition, pathological oropharynx and larynx function was evaluated in one female patient (age=47 years) with laryngomalacia, i.e., abnormal epiglottic motion causing airway obstruction and stridor, after surgery with an anterior approach to the cervical spine at the level of C5. A second follow-up MR examination was performed after the patient underwent laser microsurgery to correct abnormal epiglottal function. All studies were approved by our institutional ethical committee and informed consent was obtained from all subjects.

2.1. Magnetic resonance imaging

All experiments were performed using a 3-T MR system (TIM TRIO, Siemens, Germany, G_{max}=40 mT/m, rise time=200 μs) and standard 12-channel head-and-neck coils. Data acquisition consisted of rf-spoiled 2D GRE imaging. Imaging parameters were adjusted to provide time series of 2D images with different trade-offs between image quality and image update rate. Data were acquired using a sagittal 2D slice (thickness=11 mm) and temporal resolutions of 4 and 10 images per second, respectively.

High frame rates of 10 images per second were achieved by combining parallel imaging (GRAPPA reconstruction [14], acceleration factor R=3) and moderate spatial resolution of 1.7×2.7 mm^2. For reduced image update rates, imaging was performed with an improved spatial resolution of 1.1×1.5 mm^2 and reduced acceleration factor (R=2). A detailed summary of pulse sequence parameters is provided in Table 1.

The sagittal 2D slice was positioned medially covering the whole oropharynx and hypopharynx. Up to 512 consecutive image acquisitions were measured and reconstructed in real time for both temporal resolutions. To evaluate the performance of dynamic MRI at 3 T, different tasks were analyzed in 10 healthy volunteers. Tasks included movement of the tongue, breathing at rest and swallowing with and without oral contrast medium. Due to its paramagnetic properties, i.e., T1 shortening and high signal in GRE imaging, blueberry juice was used as oral contrast agent [13].

For oral contrast agent administration, a plastic cup was taped to the head coil. One end of a flexible straw was fixed inside the plastic cup and the other end was positioned in the subject's mouth. Before the onset of dynamic MR data acquisition, the volunteers or patient was instructed to drink the contrast (blueberry juice) by slowly filling their mouth

Table 1
Pulse sequence parameters for dynamic RF-spoiled GRE imaging with image update rates of 4 and 10 frames per second

	4 frames/second	10 frames/second
TE	1.2 ms	1.3 ms
TR	TR 3.5 ms	2.7 ms
Spatial resolution	1.1×1.5 mm^2	1.7×2.7 mm^2
Matrix	192×144	128×82
FOV	220×220	220×220
Slice thickness	11 mm	11 mm
GRAPPA reduction factor	2	3
Bandwidth	450 Hz/pixel	795 Hz/pixel
Flip angle	10°	10°