Journal of Cranio-Maxillo-Facial Surgery xxx (2017) 1–8

Contents lists available at ScienceDirect

Journal of Cranio-Maxillo-Facial Surgery

journal homepage: www.jcmfs.com

Tongue movement during articulation in magnetic resonance imaging: Findings in 20 healthy volunteers and a patient with anterior floor of the mouth squamous cell carcinoma

Katinka Kansy [a, *], Jürgen Hoffmann [a], Martin Bendszus [b], Sabine Heiland [b], Johannes Krisam [c], Matthias Wohlfarth [a], Nicole Mistele [a], Anne Geschwinder [d], Johann Gradl [b]

[a] Department of Oral and Maxillofacial Surgery, Heidelberg University Hospital, Heidelberg, Germany
[b] Department of Neuroradiology, Heidelberg University Hospital, Heidelberg, Germany
[c] Institute of Medical Biometry and Informatics, Department Medical Biometry, University of Heidelberg, Heidelberg, Germany
[d] Department of Otorhinolaryngology and Phoniatrics, Heidelberg University Hospital, Heidelberg, Germany

ARTICLE INFO

Article history:
Paper received 1 May 2017
Accepted 11 September 2017
Available online xxx

Keywords:
MRI
Tongue movement
Speech
Articulation
QOL
OSCC

ABSTRACT

Purpose: Combined ablative and reconstructive oral maxillofacial surgery involves a multitude of anatomical and functional structures for speech and swallowing. Although there are a few methods to objectively examine swallowing function, this is not true for speech. We describe the development of an objective visualization and measurement tool for magnetic resonance imaging (MRI) to evaluate speech and its first application in a patient.

Material and methods: A total of 20 healthy patients and one patient with squamous cell carcinoma localized in the anterior floor of the mouth were included in the study. Examination included an MRI examination of a paced, defined set of fictive words representing all sounds of the German language. The patient underwent MRI preoperatively and 1, 3, 6 and 12 months postoperatively. MRI findings were correlated with speech intelligibility.

Results: In sagittal planes, the correct identification of vowels and consonants was feasible and showed a high accordance between two independent observers and repetitions. Measurements for the patient showed significant deviations 1 month postoperatively but gradually decreased over time. Aberrant values were persistent for sound /s/. Findings correlated with clinical findings of speech intelligibility.

Conclusion: The presented tool seems to be promising for evaluating articulation in (tumor) patients.

1. Introduction

Combined ablative and reconstructive oral maxillofacial surgery involves a multitude of anatomical and functional structures for speech and swallowing. Especially in tumor surgery, radical resection is crucial for successful treatment and reconstruction often fails to completely restore function. Although there are a few methods to objectively examine swallowing function, including transnasal endoscopic evaluation, videofluoroscopy, high-resolution manometry, and barium swallow (Lind 2003), this is not true for speech.

Previous studies focus on clinical speech intelligibility (Urken et al., 1991, Mady et al., 2003, de Carvalho-Teles et al., 2006, de Carvalho-Teles et al., 2008), clinical testing of tongue range of motion (Urken et al., 1991, Lazarus et al., 2014), tongue strength (Lazarus et al., 2013), spectrographic assessment (de Carvalho-Teles et al., 2006, de Carvalho-Teles et al., 2008), three-dimensional (3D) camera tracking of lateral tongue movement (van Dijk et al., 2016) and associated quality of life. Only a few studies have tried to visualize tongue movement following tumor surgery, with inconclusive results via ultrasound (Schliephake et al., 1998, Bressmann et al., 2005, 2007) and MRI (Inoue et al., 2007, Ng et al., 2011, Lee et al., 2014). More effort has been made to visualize physiological

* Corresponding author. Department of Oral and Maxillofacial Surgery, University Hospital Heidelberg, Im Neuenheimer Feld 400, 69120 Heidelberg, Germany.
E-mail address: katinka.kansy@med.uni-heidelberg.de (K. Kansy).

https://doi.org/10.1016/j.jcms.2017.09.003
1010-5182/

tongue movement during articulation via ultrasound (Stone 2005, Parthasarathy et al., 2007, Stone et al., 2007) and magnet resonance imaging (Shinagawa et al., 2005, Parthasarathy et al., 2007, Xing et al., 2013). However, to date, there is no easy, reliable, time- and cost-effective method to objectively and quantitatively evaluate intraoral tongue movement during articulation.

In the current article, we describe the development of an objective visualization and measurement tool for MRI to evaluate speech, its first application in a patient with carcinoma situated in the midline in the anterior floor of mouth preoperatively and 1, 3, 6 and 12 months postoperatively and its comparison with clinical speech intelligibility findings.

2. Material and methods

2.1. Study subjects and procedures

A total of 20 healthy individuals (10 male, 10 female; age range 23–68 years) without speech abnormalities and one 61-year-old female patient with a midline squamous cell carcinoma localized in the anterior floor of mouth volunteered for this study. Prior to MRI examination, all subjects gave written informed consent. The study was conducted according to the Declaration of Helsinki and approved by the local ethics committee (S200/2015). None of the participants had contraindications for MRI.

Volunteers were recruited by oral and written presentation of the study concept to dental students. Students were asked to inform friends and relatives about the study concept. Via this process, 20 healthy volunteers could be enrolled. Study participation was voluntary and could be abandoned at any point. Volunteers had to fulfill the following criteria: normal articulation, German native speaker, no previous operation of the maxilla, mandible, tongue, floor of mouth, palate and velum except minor dentoalveolar surgery, age $\geq$18 years.

MRI scans were obtained via a state-of-the-art 3-Tesla MRI system (Magnetom TIM Trio, Siemens Healthcare, Erlangen, Germany) with a maximum gradient strength of 40 mT/m and a slew rate of 200 T/(m•ms). Data were acquired using a 12-channel head coil and a four-channel neck coil. The acquisitions in mid-sagittal orientation, sagittal paramedian orientation and coronal orientation were using a two-dimensional (2D) linear sequence with in-plane resolution of 1.9 $\times$ 1.8 mm^2, a slice thickness of 6 mm and a field of view of 192 $\times$ 176.64 mm^2. Acquisitions used the following parameters: repetition time (TR) = 26.46 ms, echo time (TE) = 1.92 ms, flip angle = 12°, bandwidth 352 Hz/pixel.

Examination consisted of a defined set of fictive words representing all vowels and consonants of the German alphabet. The set of words was visualized during the examination via a paced Microsoft PowerPoint presentation (Microsoft Office Professional Plus 2010; Microsoft Corporation, Redmond, WA, USA) and a double-mirror system integrated into the head and neck coil. Volunteers trained articulation prior to MRI examination. The set was acquired in six planes (median sagittal, paramedian right and paramedian left sagittal, anterior, middle and posterior coronal) in the supine position. The median sagittal plane was acquired twice to verify reproducibility of the tool. Subjects were placed on the scanner bed and asked to keep still and to breathe quietly. Pads were placed around their head to minimize head motion. We communicated with subjects between recordings of the different planes to ensure that they were awake and able to perform the required task.

Examinations were recorded as DICOM data and later exported into ClearCanvas Personal Edition Workstation (Clearcanvas, Toronto, ON, Canada) to perform measurements. Two independent observers evaluated the images. To measure tongue movement, five points were defined in the sagittal plane: the most anterior caudal point of the tongue (A), the most posterior caudal point (B), the most dorsal point (C), the most cranial point (D) and the tip of tongue (E). Measurements for each vowel and consonant were the distances AB, AC, AD and AE and the angles CAB, DAB and EAB (Fig. 1). To represent tongue movement rather than actual tongue size, for each vowel and consonant we calculated the difference of the corresponding distances and angles between a relaxed tongue position while producing the labials /p/ and /b/ (Fig. 1A and B) with the position of the tongue when producing a certain consonant/vowel. Coronal planes were evaluated for symmetry and successful formation of the midsagittal groove.

Speech intelligibility was evaluated via a scoring system by three independent observers (one language therapist, one surgeon and one untrained listener) as 0 = not intelligible, 1 = hardly intelligible, 2 = intelligible with major deficits, 3 = intelligible with minor deficits and 4 = normal. In addition, vowels and consonants with abnormalities were documented for each point in time. Intelligibility was evaluated in a blinded manner from audiotape recordings of the defined set of fictive words including three repetitions at each point in time (preoperatively and 1, 3, 6, 12 months postoperatively). Listeners did not know whether they were listening to the patient or to a volunteer, or if the recording was pre- or postoperative and when it was made.

The patient was a 61-year old woman with a T2 anterior floor of mouth squamous cell carcinoma. Treatment was performed according to guidelines and consisted of surgical resection with 5-mm safety margins on pathological examination, bilateral conservative neck dissection level I–III and microvascular reconstruction via radial forearm flap. MRI scans were performed preoperatively and 1, 3, 6 and 12 months postoperatively.

2.2. Data analysis

For all vowels and consonants, both absolute and relative mean values were calculated alongside 95% confidence intervals. Means and confidence intervals were also calculated for men and women separately, and p-values were calculated in order to compare the means of men and women. For the determination of confidence intervals and p-values, either generalized (in case of repeated measurements per patient) or general linear models (in case of singular measurements per patient) were fitted. Interrater reliability was calculated for MRI evaluation of the midsagittal plane. Statistical analysis and creation of figures were performed using R 3.2.2 (R Foundation for Statistical Computing, Vienna, Austria) and package lme4.

3. Results

3.1. Control group

3.1.1. Reproducibility of measurements

Results were highly reproducible for the two repetitions of the median sagittal plane and two different observers. Specific values are given in Table 1.

3.1.2. Gender-specific differences

When considering absolute values of tongue position, for all distances (AB, AC, AD and AE), there were gender-specific differences. Although differences for AB were minor, almost all other measurements (74/81 = 91.4%) showed significant differences between men and women ($p < 0.05$). However, this was not true for angles, where only small differences were found.

For evaluation of relative tongue movements, gender-specific differences were not observed either for angles or for distances.

Please cite this article in press as: Kansy K, et al., Tongue movement during articulation in magnetic resonance imaging: Findings in 20 healthy volunteers and a patient with anterior floor of the mouth squamous cell carcinoma, Journal of Cranio-Maxillo-Facial Surgery (2017), https://doi.org/10.1016/j.jcms.2017.09.003