TECHNICAL REPORT

Dynamic 1.5-T vs 3-T true fast imaging with steady-state precession (trueFISP)-MRI sequences for assessment of velopharyngeal function

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Objectives: To compare the image quality of MRI scans produced with 1.5- and 3.0-T devices during functional test condition.

Methods: 65 MRI scans obtained with 1.5- ($n = 43$) or 3.0-T ($n = 22$) true fast imaging with steady-state precession (trueFISP) sequences from patients with a history of a cleft palate were evaluated. Two experts assessed the MRI scans, independently of each other, and blinded to the MRI technique used. Subjective ratings were entered on a five-point Likert scale. The median planes of three anatomical structures (velum, tongue and pharyngeal wall) were assessed in three functional states (at rest, during phonation of sustained “e” and during articulation of “kkk”). In addition, MRI scans taken during velopharyngeal closure were evaluated.

Results: Under blinded conditions, both observers (radiologist and orthodontist) independently rated the quality of 1.5-T scans higher than that of 3.0 T. Statistical analysis of pooled data showed that the differences were highly significant ($p < 0.009$) in 4 out of 10 test conditions. The greatest differences in favour of 1.5 T were observed for MRI scans of the velum.

Conclusions: 1.5 T used with trueFISP may be preferable over 3.0-T trueFISP for the evaluation of the velopharyngeal structures in the clinical routine.

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Introduction

Among newborns, a cleft lip and palate is a condition with a frequency between 1:500 and 1:1000 in the Caucasian population. While isolated cleft lips are primarily an aesthetic problem, a cleft palate may impair the patient's speech, breathing or eating.¹ To detect anatomical deficits and functional impairments before secondary surgical intervention, imaging of velopharyngeal

distance, closure, motor function and swallowing is mandatory.²

Nasoendoscopy—the gold standard—to diagnose velopharyngeal insufficiency (VPI) explores the oropharynx cavity from the inside only. It reveals little information about the thickness and role of the soft palate and velum for velopharyngeal closure to plan surgery.¹ Videofluoroscopy also permits “imaging while speaking.” However, the radiation exposure limits its use, especially in children.

Real-time MRI depicts the pattern of velopharyngeal closure in close correlation with videofluoroscopy.³ The

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structural resolution is acceptable; the repeatability and relative comfort for the patient are additional advantages. The information gained is similar to that of videofluoroscopy.

When recorded during active speech and swallowing, MRI scans depict normal or impaired velopharyngeal dynamic function.⁴ While for surgeons tongue imaging is less important, images of the velum in motion provide valuable information. Of particular interest are functional MRI scans of velopharyngeal closure, forward movement of posterior pharyngeal wall, velar lift, velar extensibility and medial movement of the lateral pharyngeal walls.⁵

Atik *et al*⁶ regard dynamic MRI as an objective, non-invasive, reliable, effective and adequate modality for the diagnosis of VPI. Three-dimensional MRI scans reveal structural and functional information for the management of cleft palate patients with VPI. Early attempts to visualize the “anatomy of speech” employed fast sequences. Fast sequences are T_1 or T_2 weighted FISP and trueFISP (true fast imaging with steady-state precession),⁷ with a high signal-to-noise ratio, a favourable contrast-to-noise ratio and relatively high temporal resolution.⁸ Typically, 3.0-T MRI provides better resolution, a better signal-to-noise ratio and rapid scanning times, but may suffer from distortion effects.⁹

To optimize the MRI in our patients, we investigated whether trueFISP imaging at 3.0 or 1.5 T during speech yields images of higher quality or not.

Methods and materials

Patients

The study was approved by the institutional review board (approval number 254/2006). 65 image series from patients with a history of a cleft palate and from our Department for Cranio-Maxillofacial and Oral Surgery were analysed. In the group with 1.5 T, we investigated 43 MRI scans from 17 female and 26 male patients with a mean age of 15.8 ± 6.1 years (range from 8 to 35 years). In the group with 3.0 T, we investigated 22 MRI scans from 13 female and 9 male patients with a mean age of 17.7 ± 10.6 years (range from 9 to 31 years).

Because we selected all appropriate image series from the archives of the clinic, the analysed MRI image series pragmatically reflect clinical routine and can exclude any study-specific bias related to the choice of MRI scans. The 3.0-T MRI scanner was installed in 2011, therefore, we analysed more 1.5-T images.

MRI scans of two patients with metal apparatuses revealed extensive artefacts, which hindered assessment; therefore, the images were excluded from evaluation. MRI scans with motion artefacts were included to maintain the pragmatic approach of the study design.

MRI devices

Both the MRI devices used (1.5 T MAGNETOM® Avanto, 3 T MAGNETOM Trio Tim) had been manufactured by the same company (Siemens, Erlangen, Germany).

Because it is not possible to transfer all the parameters between a 1.5-T and a 3.0-T device, every field strength requires specific sequence adaptation. Our sequences were adapted and optimized for routine clinical use. Also the flip angle was adapted to yield optimized image quality. Details of the optimized sequence parameters are given in Table 1.

Static, functional and dynamic imaging

MRI scans of the velum, tongue and pharynx had been obtained during speech and swallowing; more specifically, the following tests were performed:

- (1) the velum, tongue and posterior pharyngeal wall of the pharynx at rest
- (2) because hypernasality becomes evident when a person expresses the vowel “e” in order to assess the function of the velum, tongue and posterior pharyngeal wall, MRI scans were recorded during phonation of “e”
- (3) because “k” is a plosive consonant, and air sealing and sudden inflation occur between the base of the tongue and the soft palate, and because visualization of anatomical structures during repeated articulation of “k” proved very useful to detect functional deficits in the soft palate,¹⁰ we imaged velum, tongue and pharynx during articulation of the consonant “k.” Additionally, velopharyngeal closure was assessed.

Evaluation of MRI scans

In order to consider the views of professional diagnosticians and surgeons, a radiologist and an orthodontist, experienced in the diagnosis and treatment of patients with a cleft palate were independently entrusted with the evaluation (Table 2).

The MRI scans were called up in alphabetical order without knowledge of the imaging technique used (1.5 or 3.0 T). A five-point Likert scale was used to translate image quality into discrete values that could be processed statistically. The ratings from very good,

Table 1 MRI true fast imaging with steady-state precession sequence parameters after optimization for 1.5 T and 3.0 T

Parameter	1.5 T Avanto	3 T Trio Tim
Repetition time (ms)	3.62	3.62
Echo time (ms)	1.31	1.27
Flip angle (degree)	80	46
Acquisition matrix	256 × 256	256 × 256
Field of view (mm)	297 × 297	297 × 297
Slice thickness (mm)	4.5	4.5
Acquisition time (s/images)	0.7	0.36
Acquisition cycle (s/measurements)	58/80	29/80
Slice orientation	Sagittal	Sagittal

MAGNETOM® Avanto and Trio Tim (Siemens, Erlangen, Germany).

Table 2 Inter-rater reliability between the two evaluators, Cohen's kappa with linear weighting indicate moderate (*e.g.* Item 7) to perfect (Item 9) agreement

Item	Condition	Observation of	n	Cohen's Kappa
1	Normal	Velum	65	0.731
2		Tongue	65	0.636
3		Pharynx	65	0.611
4	Phonation of "e"	Velum	65	0.585
5		Tongue	65	0.741
6		Pharynx	65	0.594
7	Articulation of "kkk"	Velum	65	0.555
8		Tongue	65	0.577
9		Pharynx	65	0.829
10		Closure	64	0.655

good, fair, poor and very poor were translated to the ordinate variables A, B, C, D and E, respectively.

Both evaluators had extensive experience in diagnostic investigation of patients with cleft lip and palate. They evaluated the MRI scans independently and in a blinded manner (without knowledge of the imaging devices used; 1.5 or 3.0 T) on a high-resolution monitor. Sagittal images of three regions that were important for the diagnosis (velum, tongue and posterior wall of the pharynx) were evaluated. Three main test conditions (at rest = normal; phonation of "e"; and articulation of "k") were assessed for each region. Additionally, velopharyngeal closure was assessed during articulation of "k." As a result, data obtained from 10 test conditions were available for statistical analysis.

The 65 MRI scans were assessed over a period of about 3 weeks in 3 batches of 20–25 each. The evaluation of the MRI scans of 1 patient (evaluation of 10 test conditions) took about 4–5 min.

After the last evaluation, the handwritten reports were entered twice in two electronic tables (double-entry method). Subtraction of values in the two tables yielded zero, or indicated transmission errors, which were corrected by checking the original recordings. The final data set was released for statistical analysis.

Statistical analysis

The software package IBM SPSS® Statistics v. 20 (IBM Corporation, New York, NY; formerly SPSS Inc., Chicago, IL) was used. After examination of normal distribution and homogeneity of variances, comparisons of means for continuous variables (age of patients) were carried out using the *t*-test for independent samples. Comparisons of subjective ratings on the five-point ordinal scale were conducted non-parametrically using Mann–Whitney *U* test.

To determine interrater reliability between the two evaluators' estimations, Cohen's kappa with linear weighting was used. With this parameter, the magnitude of deviations between the two evaluators on a five-point Likert scale is included in the calculation. To classify interrater reliability, we used the cut-offs suggested by Landis and Koch.¹¹

Results

Figures 1–3 show single images from the functional MRI scans taken with 1.5 and/or 3.0 T. For videos of the MRI at 1.5 T (Supplementary Video A) and at 3.0 T (Supplementary Video B), see the supplementary material shown online.

Analysis of image quality by a radiologist revealed the superiority of sequences obtained with 1.5 T. Only for two parameter mean values related to the tongue, the 1.5-T sequences scored lower. In eight cases, the mean of the 1.5-T image sequence scores was higher; in five cases, the higher scores were statistically significant.

The scores of an orthodontist yielded similar results. Out of the 10 tested conditions, the 1.5-T sequences were superior for 8. Again it was a mean score related to the tongue where the 3.0-T images scored slightly higher (tongue in phonation of "e"; $p = 0.578$).

When tested for interrater reliability (Table 1), four parameters (Items 4, 6, 7 and 8) agreed "moderately," five "substantially" (Items 1, 2, 3, 5 and 10) and one agreed perfectly (Item 9). Given the overall agreement, we pooled (averaged) the scores of the two raters.

In the pooled data set, the scans obtained with the 1.5-T device were superior for 8 of 10 functional tests. As anticipated from the individual assessments with 3.0 T, the scans of the tongue yielded higher—although not significant—scores; (a) at rest and (b) during phonation of "e" ($p = 0.981$ and 0.529 , respectively). For the remaining functional tests, the 1.5-T scans scored higher; the superiority of 1.5-T image series was highly significant for four test conditions ($p \leq 0.009$; Figure 4).

Discussion

Interestingly, this systematic blinded comparison between 1.5-T and 3.0-T trueFISP failed to yield better quality scores for 3.0 T, regardless of the evaluator's medical specialization. Only images of the tongue at rest at 1.5 and 3.0 T were of similar quality. The scores were significantly higher for the images from four test conditions of the velum or pharynx (*i.e.* n-Ve, k-Ve, k-Ph, velopharyngeal closure, Figure 4).

Besides magnetic field strength, the employed sequence is an important determinant of the resulting image quality. trueFISP is a commonly used sequence with very short repetition time and echo time, thus providing short acquisition times and anatomical clarity.¹²

Our reports differ from previously published data with other sequences. Dynamic cardiac imaging¹³ revealed higher signal-to-noise ratio and contrast-to-noise ratio with 3.0-T imaging. However, the image quality did not change or was significantly lower for steady-state free precession sequences.

Because 3.0-T MRI is more susceptible to distortion artefacts, this may adversely affect image quality. Especially artefacts of the balanced steady-state free

Figure 1 (a–d) Real-time two-dimensional true fast imaging with steady-state precession (trueFISP) scans; 1.5 T (a, b) and 3.0 T (c, d); sagittal plane in a 10-year-old patient (1.5 T, or 14-year-old: 3.0 T); in neutral position (a, c) and during “e” phonation (b, d). The velum moves up to the pharyngeal wall (arrows). Note the better imaging with 1.5 T (a, b) compared with the 3.0-T images (c, d) in the same patient.

precession sequences of trueFISP known from 1.5 T may increase at 3.0-T MRI because of B₀ inhomogeneities.⁹ Depending on the sequence, significantly, more

pulsation and susceptibility artefacts were observed with 3.0 T.¹⁴ Kao et al⁴ employed a turbo spin echo sequence and a speech protocol and concluded that 3.0-T MRI

Figure 2 (a–c) Functional true fast imaging with steady-state precession scans (3.0 T) from a 18-year-old patient; sagittal plane, showing the velopharyngeal movement during speech of “kkk”; note the gap at the end of the speech series (arrow).

Figure 3 (a–c) Functional true fast imaging with steady-state precession scans (1.5 T) from a 13-year-old patient, sagittal plane, showing the velopharyngeal movement during speech of “kkk.” Note the long velum (arrows).

with high resolution is superior to the diagnostic investigation of VPI by nasal endoscopy. While a higher field strength is expected to improve image quality, the theoretical doubling of the signal-to-noise ratio was no higher than 25%.¹⁵ In agreement with our results, Debatin and Patak¹⁶ conclude that 3.0-T imaging is subject to significantly more artefacts when using specific sequences such as trueFISP.

MRI sequences have been optimized for 1.5 T over the years. However, the specific settings cannot be directly transferred to higher field strengths. At 3.0 T, for instance, a 40% increase in the longitudinal relaxation time of T1 in tissue signifies a drastic loss of image

quality.¹⁶ After doubling magnetic field strength, a further limiting factor may be the four-fold increase of high-frequency fields and the associated specific absorption rate, which is a measure of tissue heating.¹⁷

Compared with videofluoroscopy, one of the potential limitations of MRI is the fact that the latter does not yield 25 pictures per second. However, we considered it a major advantage to repeat the MRI scans until the radiologist obtains informative image series of good quality. The patient comfort during MRI investigations was described to be good;¹⁸ our experience confirms these reports, none of our patients terminated the examination prematurely.

Figure 4 Pooled data from the evaluators: in 8 of 10 test conditions, the quality scores were generally higher for 1.5-T MRI scans. x-axis: n, normal position; i, imaging under phonation of “e”; k, imaging under articulation of “k”; Ve, velum; To, tongue; Ph, pharynx; clos, velopharyngeal closure under articulation of “k.” Scores for 1.5- and 3.0-T sequences were highly significant ($p < 0.01$) in n-Ve, k-Ve, k-Ph and clos.

MRI is typically performed in recumbent position, which may affect the position of the velum. However, sequences obtained in standing position provide no additional details relevant for planning velopharyngeal surgery. The recumbent position appears to exert no unfavourable impact on the diagnostic investigation by MRI.¹⁹

While the majority of publications on MRI are based on small cohorts and specific inclusion criteria, our approach was pragmatic. We considered all image series produced during the last 5 years under routine clinical conditions. However, to facilitate comparison, we used the same sequence (trueFISP) for 1.5- and 3.0-T imaging. The 3.0-T sequence was optimized *i.e.* the flip angle was reduced to avoid specific absorption rate-related problems at 3.0 T (Table 1).

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As trueFISP is a commonly used sequence for moving body parts, our results are relevant for the routine diagnosis of VPI in patients after cleft repair in clinical routine, they may be relevant for other medical fields.

In conclusion, the trueFISP sequences and 1.5-T imaging—as widely available—may produce better images for the MRI-based diagnosis of structural or neurological VPI. In the specific case of functional tests in VPI patients, 1.5 T may be preferable over 3.0 T.

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