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FULL PAPER

Fat suppression in magnetic resonance imaging of the head and neck region: is the two-point DIXON technique superior to spectral fat suppression?

¹CHRISTINA M WENDL, ²JOHANNES EIGLSPERGER, ¹LENA-MARIE DENDL, ^{1,3}HARALD BRODOEFEL, ⁴KARL-MICHAEL SCHEBESCH, ¹CHRISTIAN STROSZCZYNSKI and ¹CLAUDIA FELLNER

¹Department of Radiology, University Hospital Regensburg, Regensburg, Germany

²numares AG, Regensburg, Germany

³Department of Radiology, Ortenau Klinikum Lahr-Ettenheim, Lahr, Germany

⁴Department of Neurosurgery, University Hospital Regensburg, Regensburg, Germany

Address correspondence to: Dr Christina M Wendl

E-mail: christina.wendl@ukr.de

Objective: The aim of our study was to systematically compare two-point Dixon fat suppression (FS) and spectral FS techniques in contrast enhanced imaging of the head and neck region.

Methods: Three independent readers analysed coronal T_1 weighted images recorded after contrast medium injection with Dixon and spectral FS techniques with regard to FS homogeneity, motion artefacts, lesion contrast, image sharpness and overall image quality.

Results: 85 patients were prospectively enrolled in the study. Images generated with Dixon-FS technique were of higher overall image quality and had a more

homogenous FS over the whole field of view compared with the standard spectral fat-suppressed images ($p < 0.001$). Concerning motion artefacts, flow artefacts, lesion contrast and image sharpness no statistically significant difference was observed.

Conclusion: The Dixon-FS technique is superior to the spectral technique due to improved homogeneity of FS and overall image quality while maintaining lesion contrast.

Advances in knowledge: T_1 with Dixon FS technique offers, compared to spectral FS, significantly improved FS homogeneity and over all image quality in imaging of the head and neck region.

INTRODUCTION

MRI has been increasingly used for the non-invasive detection and clarification of pathologies of the head and neck region.¹ The neck is known to be a challenging anatomic region for MRI, which is mainly due to its shape, its high density of moving structures (vessel pulsation, pharyngeal and laryngeal movement during swallowing) and in particular its large portion of fat tissue. Thus, besides a reduction of flow and motion artefacts, a homogenous fat suppression (FS) is indispensable to detect pathologies within this region and to reliably determine their extent. Commonly, frequency-selective chemical shift FS is used for post-contrast T_1 weighted images. The method suffers from several limitations which are widely known. A reliable FS can only be achieved if the frequency of the selective suppression pulse equals the resonance frequency of lipids. Inhomogeneities of the static magnetic field can shift the resonance frequencies of both water and lipid, resulting in poor FS. These inhomogeneities can be reduced by decreasing the field of view, thereby centring the region of

interest of autoshimming.^{2,3} Moreover, substantial inhomogeneities can be caused by local susceptibility differences as, e.g. found around metal implants or at tissue—bone interfaces. Besides, they often occur in areas of sharp variations in anatomic structures as for example the neck.^{2,4}

Recently, Dixon FS techniques have been introduced as an alternative for spectral FS to circumvent B_0 inhomogeneities and for fat quantification.^{5–7} The Dixon FS technique is based on the acquisition of (at least) two echoes (in-phase and opposed-phase) after the exciting radiofrequency (RF) pulse. Using these data, in-phase and opposed-phase images, water-only and fat-only images can be calculated.⁸ Thus, instead of being a true FS technique, the Dixon method is a water-fat separation method. With its improved homogeneity of FS and improved image quality, this technique has already shown promising results concerning imaging, e.g. of the spine and breast.^{9–11} However, although the Dixon technique is already routinely used in many examination protocols,

data about the usefulness of the Dixon FS technique in the head and neck area are still limited.^{12–14} Therefore, the aim of our study was to systematically compare two-point Dixon FS and spectral FS techniques in contrast enhanced imaging of the head and neck region.

METHODS AND MATERIALS

Patients

Consecutive patients scheduled for a MRI of the neck in our department between November 2013 and May 2014 were prospectively enrolled in this study. All patients gave written informed consent for the examination. The study was approved by the institutional review board (14-101-0081).

85 patients (50 males, 35 females, 18–83 years old, mean age 51 years) were included in the study.

MRI examinations

MRI examinations were performed on a 1.5 T Scanner (Magnetom Symphony TIM; Siemens Healthcare, Erlangen, Germany) using a combination of head, neck and spine array coil elements. Our routine protocol was applied to all patients, consisting of coronal short tau inversion recovery, coronal T_1 turbo spin echo (TSE), axial T_2 TSE, axial T_1 TSE, post-contrast coronal T_1 TSE FS, post-contrast axial T_1 TSE FS and post-contrast sagittal T_1 TSE FS. In addition, a coronal two-point Dixon-FS sequence was applied to all patients for study purpose after intravenous application of 0.1 mmol kg⁻¹ body weight gadoterate meglumine (Dotarem, Guerbet, Villepinte, France). The acquisition order of spectrally FS and Dixon-FS sequences was performed in a randomized manner. Both sequences were based on TSE sequences with an echo train length of 3 and very similar settings of repetition time (FS: 542 ms, Dixon-FS: 582 ms) and echo time (FS: 15 ms, Dixon-FS: 16 ms). The geometrical parameters were identical for both techniques, flow compensation in readout direction was used in both sequences. The acquisition time for T_1 TSE FS was 3 min 43 s and for the T_1 Dixon-FS 5 min 52 s. Detailed information about the scan parameters of spectral FS and Dixon-FS is given in Table 1.

Image analysis

Blinded to acquisition parameters as well as to patient data, medical history or additional MR images three independent readers (LMD, CMW, HB) with different years of experience in head and neck imaging (3, 5 and 10 years, respectively) assessed the study criteria. Images were evaluated on a workstation used for clinical interpretation.

Every reader independently scored the spectrally fat-suppressed and Dixon fat-suppressed sequences separately on a patient-per-patient base using an ordinal scale ranging from 1 to 4, on which a score of 1 indicates excellent quality; a score of 2, good quality with no relevant quality losses; a score of 3, moderate quality, but still of diagnostic value; and a score of 4, unacceptable quality. Thereby, the following criteria were evaluated: overall homogeneity of FS, lesion contrast, image sharpness and overall image quality. Lesion contrast was only evaluated in patients with a clearly definable pathological lesion (tumour, enlarged lymph node). Finally, patient motion and flow artefacts were assessed in a similar fashion with a score of 1 indicating no artefacts; a score of 2, minor artefacts; a score of 3, moderate artefacts; and a score of 4, not acceptable image quality due to severe artefacts. All readers were allowed to choose optimal window and centre settings by their own judgement.

Images were subsequently read again by two readers (CMW, CF) in consensus in a second session to look for water–fat swaps in Dixon-FS. Artefacts were classified as diagnostic relevant or irrelevant due to size (smaller than 1 cm) and location.

Statistical analysis

The results of the visual 4r-point evaluations for spectral FS and Dixon-FS were compared with the sign test. For each quality parameter a one-sided sign test, where ties were counted in favour of spectral FS, was performed in order to test the null hypothesis that the FS sequence is at least as good as the Dixon-FS sequence. One-sided $p < 0.025$ was considered to indicate statistical significance.

Statistical analyses were performed using the statistic computing environment R (v. 2.15, R Foundation for Statistical Computing).

Table 1. Sequence parameters of coronal T_1 sequences with spectral FS (T_1 FS) and Dixon-FS technique after CE

	T_1 FS CE	Dixon-FS CE
TR	542 ms	582 ms
TE	15 ms	16 ms
Number of slices	28	28
Slice thickness	5 mm	5 mm
Acquisition time	3 min 43 s	5 min 52 s
FOV	300 mm	300 mm
Matrix size (phase × read)	358 × 448	358 × 448
Readout bandwidth	130 Hz / pixel	203 Hz / pixel

CE, contrast administration; FS, fat suppression; TE, echo time; TR, repetition time; FOV field of view.

Table 2. Sequence graded as superior for the different criteria by the three readers and *p*-values (sign-test)

Parameter	Rater	Dixon-FS superior	FS superior	Tie	<i>p</i> -value ^a
Homogeneity of fat saturation	1	82	0	3	<0.001
	2	80	0	5	<0.001
	3	82	0	3	<0.001
Motion artefacts	1	7	9	69	1
	2	9	12	64	1
	3	7	15	63	1
Flow artefacts	1	9	0	76	1
	2	18	7	60	1
	3	19	4	62	1
Lesion contrast	1	10	0	32	1
	2	10	6	26	1
	3	12	1	29	0.999
Image sharpness	1	4	3	78	1
	2	12	3	70	1
	3	15	6	64	1
Overall image quality	1	65	1	19	<0.001
	2	78	0	7	<0.001
	3	70	1	14	<0.001

FS, fat suppression.

^a*p*-value is given for one-sided sign test where ties are counted in favour of FS.

RESULTS

Qualitative image analysis

p-values of image-based grading of the different criteria evaluated by the three readers are summarised in Table 2.

Only 42 patients had a definable lesion (25 lymph nodes, 7 tumours of the parotid or submandibular gland, 5 lesions of the thyroid gland, 5 oropharyngeal tumours) to compare the contrast behaviour of both techniques. The other 43 patients had no lesion and, therefore, this criterion was not evaluated in those patients.

According to the sign test performed on basis of the 4-point quality assessment, images with Dixon-FS technique showed a significantly ($p < 0.001$) higher overall image quality than spectrally fat-suppressed images. In addition, the overall homogeneity of the FS was found to be of significantly ($p < 0.001$) higher quality for the images with Dixon-FS (Figure 1).

For the quality measures concerning motion artefacts, flow artefacts, image sharpness and lesion contrast the null hypothesis cannot be rejected (Figure 2). The large numbers of ties for these quality measures indicates that both sequences are comparable for motion and flow artefacts, image sharpness and lesion contrast (Table 2).

Local failure of FS (local water–fat swaps) was seen with Dixon-FS in 14 patients, the size of artefact measuring below 1 cm in 12

cases and exceeding a diameter of 1 cm in 2 cases. According to the readers, diagnostic image quality was not influenced by these artefacts.

With spectral FS, inhomogeneous fat suppression was seen in eight patients, where as in three of these cases the diagnostic image quality was influenced by the artefacts.

DISCUSSION

In the last few years, the Dixon-FS technique has aroused much interest in the field of fat-suppressed MRI. Recently, several studies have suggested improved FS with the Dixon-FS technique in MRI of the breast, the pelvis and the musculo-skeletal system.^{10,11,15–18} Improved FS in detail means better homogeneity of FS over the whole field of view due to reduced field inhomogeneity effects after phase correction during image reconstruction. To date, however, there have been only two technical reports about the use of the Dixon-technique in the head and neck region. One technical note presented initial experiences with a modified three-point Dixon technique using fast spin echo (FSE) T_1 and T_2 weighted images without systematic comparison of the results.¹² The second technical note used two modified FSE techniques (a two-point and a single-scan triple echo Dixon) as well as conventional FSE with FS for T_2 weighted imaging of the neck in seven patients. Both reports showed significantly improved homogeneity of FS for the sequences with Dixon-FS technique compared with the spectrally fat-suppressed sequences.¹³ In concordance

Figure 1. Distribution of grades for overall image quality and for FS homogeneity for images recorded with (a, c) spectral FS and (b, d) Dixon fat suppression technique (Dixon-FS). The results are displayed for each reader separately. FS, fat suppression

with these results, our study also demonstrates a much higher uniformity of FS in sequences with Dixon-FS compared to our standard spectrally fat-suppressed coronal T_1 after contrast medium administration (Figure 3).

In our study, small areas of local failure of FS (fat-water swaps) were seen in some cases but did not influence the diagnostic quality of the images because of their small size (Figure 4).¹⁹ In contrast, FS inhomogeneities in spectral fat-suppressed images

Figure 2. Distribution of grades for motion artefacts, image sharpness and lesion contrast for images recorded with (a, c, e) spectral FS and (b, d, f) Dixon FS technique (Dixon-FS). The results are displayed for each reader separately. FS, fat suppression.

Figure 3. Coronal T_1 weighted image with Dixon-FS (a) and spectral FS (b) technique of the same patient. The images with Dixon-FS provide uniform FS throughout the whole field of view. The spectrally fat-suppressed images show considerable fat suppression inhomogeneity in the shoulder region on both sides. FS, fat suppression.

Figure 4. Coronal T_1 weighted image after contrast medium administration with Dixon-FS technique (a) and spectral fat suppression (b). On the image with Dixon-FS, a 1.8 cm measuring polygonal artefact caused by phase error (water-fat swap) is visible (white arrow). The corresponding slice of the spectrally fat-suppressed image shows no artefact in the same area. Nevertheless, the diagnostic sensitivity is not influenced by the structure identified clearly as artefact. FS, fat suppression.

were typically extensive and, therefore, frequently influenced the diagnostic quality. In case of local or global fat-water swaps in the Dixon technique, the fat image can be reconstructed and used additionally to the water image for diagnostic purpose. In contrast, inhomogeneous FS in images with spectral FS means that the fat-suppressed image information is not available at all.

Overall, the homogeneity of FS is the only statistically significant difference contributing to overall image quality in our study (Figure 1).

The current study also includes assessment of predefined pathological lesions. Dixon-FS images showed a superior lesion contrast compared to spectrally fat-suppressed images, although the difference was not statistically significant. The superiority in lesion definition is likely due to the excellent homogeneity of FS in Dixon-FS images, which leads to better

delineation of enhancing lesions from surrounding fat and parenchyma. Although not examined in this study, former studies already showed that the improved suppression of background fat signal with Dixon-FS additionally results in better detection rates concerning pathologic lesions. For example, Beddy et al reported significantly improved contrast between fat-suppressed and non-fat-suppressed tissue and between pathological lesions and suppressed fat with the Dixon technique compared to spectral FS in the MRI of the female pelvis.

The Dixon-FS technique is also known to have some limitations. In case of spectral FS, which uses the spectrally based RF pulse, the sensitivity to inhomogeneity in both B_0 and B_1 fields is a well-known problem. The Dixon-technique, not using the spectrally based RF pulse, overcomes this limitation and has reduced field inhomogeneity effects through phase correction during post-processing. Nevertheless, Dixon techniques are sensitive to constant magnetic

induction field inhomogeneities, which result in phase errors on the images.¹⁵

Another potential clinical limitation of the current Dixon-FS sequence is the length of acquisition, approximately 6 mins, which could lead to a higher frequency of motion artefacts.²⁰ However, only mild motion artefacts were observed with Dixon-FS as well as spectral FS, meaning that both types of FS are of equal quality concerning motion and flow artefacts.

The results of our study strongly indicate that the image quality of Dixon-based fat-suppressed T_1 weighted sequences

is superior to routinely used spectrally fat-suppressed T_1 . Applying Dixon-FS in contrast-enhanced coronal sequences of the neck achieves uniform and excellent FS, which results in superior overall image quality compared to spectrally fat-suppressed images as rated by three independent readers. In addition, the Dixon-FS technique displays the same good properties as the spectral FS technique concerning motion artefacts, flow artefacts, lesion contrast and image sharpness. Therefore, we propose to replace the standard spectrally fat-suppressed T_1 weighted coronal sequence with the Dixon fat-suppressed coronal sequence in the standard MRI protocol for head and neck imaging.

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