MRI DETECTION OF OLFACTORY BULB AND TRACT

P. HELD (1), J. SEITZ (1), R. FRÜND (1), W.R. NITZ (1), T. HAFFKE (2), H. HEES (2), V. BONKOWSKY (3)

(1) Département of Diagnostic Radiology,
(2) Institute of Anatomy,
(3) ENT Department, University of Regensburg, 93042 Regensburg, Germany.

SUMMARY
Thirty healthy volunteers underwent MRI with 3D MP-RAGE, 3D CISS and 2D turbo spin echo sequences to compare the detectability of olfactory fibers, bulb, tract, and sulcus. The overall detectability was slightly better using MP-RAGE compared with CISS. Both 3D sequences were superior to 2D turbo spin echo.

We therefore recommend including the MP-RAGE sequence in an MR imaging protocol of the olfactory nerve.

Key words : Magnetic resonance imaging, MRI, 2D turbo spin echo, 3D CISS, 3D MP-RAGE, olfactory nerve.

INTRODUCTION
The aim of this study was to evaluate T1 weighted (w.) 3D MP-RAGE, T2 w. 2D Turbo spin echo and T2* w. 3D CISS sequences in the detection of the olfactory nerve anatomy.

MATERIAL AND METHODS
Thirty healthy volunteers, 15 females and 15 males, aged from 18 to 53 years with a mean age of 32.4 years underwent MRI using 3D MP-RAGE, 2D turbo spin echo and 3D CISS sequences. All examinations were carried out using a 1.5 Tesla MR unit (Magnetom Symphony, Siemens, Erlangen) with 20 mT/m gradient strength, a gradient rise time of 20 µs/mT/m, and a circular-polarized head coil. The sequence parameters are listed in table I.

3D MP-RAGE, three dimensional Magnetization Prepared Rapid Acquired Gradient Echoes [9, 16] is a refined version of a 3D FLASH [8] sequence structure, where an inversion pulse is placed prior each partition loop in order to introduce a T1-weighting. The effect of a preparation is usually lost over the length of a 3D acquisition, 3D MP-RAGE acquires all Fourier lines along the depth encoding loops, allows a recovery period, applies the preparation pulse again and continues with the next in-plane phase encoding step [17].

CISS [3, 5], Constructive Interference in Steady State sequence, is based on a 3D gradient echo sequence with gradient refocussing in all three directions (trueFISP) generating a steady state contribution of the transverse magnetization for tissues with long T2 and is therefore called T2-weighted. In order to minimize the destructive interference pattern of the originally published FISP [18], two sequences can be executed and add together, with an alternation of the RF phase. Since the interference pattern are shifted due to the alternation, they almost vanish when combining the images [17].

TSE, Turbo Spin Echo, sequences use multiple spin echoes with different phase encoding steps in order to fill the k-space faster than the single echo approach in conventional spin echo imaging, CSE [4, 11].

When compared with conventional spin echo sequences, turbo spin echo sequences enable the acquisition of multiple spin echos within one repetition time interval. The overall image quality of turbo spin echo sequences is similar to that of conventional sequences [4]. The turbo
spin echo technique thereby allows high resolution examinations; compared with MP-RAGE or CISS sequences, the acquisition time is comparably short.

The detectability of the olfactory bulb, tract, fibers and sulcus was evaluated following the consensus of two radiologists (JS and PH). The evaluation software of the MR scanner console was used for this review. Orthogonal planes of both 2D and 3D sequences were analysed. In the case of 3D sequences, reconstructions of arbitrary orientation adequately matching the anatomical structures were also analysed.

An evaluation scale between 1 and 5 was used:
1 = excellent (i.e. optimal) visible;
2 = well visible and (in the case of olfactory bulb and tract) distinguishable;
3 = visible and distinguishable;
4 = barely visible;
5 = not visible.

Statistical evaluation of the results was achieved by means of the two tailed Wilcoxon’s test (p < 0.05 was considered as statistically significant).

RESULTS

The olfactory bulb, tract and sulcus can be seen using both T1 w. and T2 or T2* w. MR sequences (figures 1-3). The olfactory fibers, on the other hand, could be visualized only using T1 w. high resolution MR image (figures 3c and 3d)

The results of image analysis are shown in table II. The three sequences — T1 w. MP-RAGE, T2*w. CISS and T2w. turbo spin echo sequences — used for the detectability of the olfactory bulb, tract, fibers and sulcus were compared.

Mean values, standard deviation and statistical significance are listed in table II. Olfactory fibers are best visible using MP-RAGE, although MP-RAGE yields only fair results. Olfactory bulb and tract are well detectable on CISS and MP-RAGE images, between these two modalities there is no statistically significant difference. The olfactory sulcus is best shown by CISS; there is a significant difference between CISS and MP-RAGE. Statistically however, 2D TSE is significantly inferior when compared with CISS and with MP-RAGE.

## Table I. — MR examination technique/sequence parameters.

<table>
<thead>
<tr>
<th>sequence</th>
<th>3D MP-RAGE</th>
<th>2D turbo spin echo</th>
<th>3D CISS</th>
</tr>
</thead>
<tbody>
<tr>
<td>contrast</td>
<td>T1</td>
<td>T2</td>
<td>T2*</td>
</tr>
<tr>
<td>band width (Hz/pixel)</td>
<td>130</td>
<td>130</td>
<td>130</td>
</tr>
<tr>
<td>repetition time (ms)</td>
<td>11.08</td>
<td>4 000</td>
<td>17</td>
</tr>
<tr>
<td>echo time (ms)</td>
<td>4.3</td>
<td>102</td>
<td>8.08</td>
</tr>
<tr>
<td>inversion time (ms)</td>
<td>300</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>echo train length</td>
<td>–</td>
<td>11</td>
<td>–</td>
</tr>
<tr>
<td>flip angle (degrees)</td>
<td>15</td>
<td>180</td>
<td>70</td>
</tr>
<tr>
<td>field of view (mm)</td>
<td>230</td>
<td>230</td>
<td>230</td>
</tr>
<tr>
<td>matrix</td>
<td>192×256</td>
<td>286×512</td>
<td>288×512</td>
</tr>
<tr>
<td>pixel size (mm)</td>
<td>1.2×0.9</td>
<td>0.6×0.45</td>
<td>0.6×0.45</td>
</tr>
<tr>
<td>n° of acquisitions</td>
<td>1</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>n° of partitions/</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>orientation</td>
<td>sagittal</td>
<td>paraxial</td>
<td>paraxial</td>
</tr>
<tr>
<td>measurement time</td>
<td>7 min. 22 sec.</td>
<td>7 min.</td>
<td>7 min. 51 sec.</td>
</tr>
<tr>
<td>effective slice thickness (mm)</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

## Table II. — Detectability of structures: mean values, standard deviation and statistical results (two-tailed Wilcoxon’s test*).

<table>
<thead>
<tr>
<th></th>
<th>MP-RAGE</th>
<th>CISS</th>
<th>2DTSE</th>
<th>CISS/MP-RAGE*</th>
<th>CISS/2DTSE*</th>
<th>MP-RAGE/2DTSE*</th>
</tr>
</thead>
<tbody>
<tr>
<td>olfactory bulb</td>
<td>1.35 +/- 0.76</td>
<td>1.32 +/- 0.5</td>
<td>2.78 +/- 0.69</td>
<td>0.712</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>olfactory tract</td>
<td>1.6 +/- 1.09</td>
<td>1.48 +/- 0.77</td>
<td>2.97 +/- 0.76</td>
<td>0.551</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>olfactory fibers</td>
<td>3.23 +/- 1.42</td>
<td>5 +/- 0</td>
<td>5 +/- 0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>olfactory sulcus</td>
<td>1.43 +/- 0.56</td>
<td>1.27 +/- 0.52</td>
<td>2.08 +/- 0.7</td>
<td>0.072</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
DISCUSSION

MRI may be a useful diagnostic method in patients suffering from olfactory dysfunction. Besides lesions of the prefrontal lobe, septal nuclei, amygdala and temporal lobe [25], lesions of the olfactory bulb and tract can also lead to a central sensorineural disorder [15].

— congenital abnormalities, e.g. cephalocele, Kallman’s syndrome (i.e. hypogonadotropic hypogonadism and anosmia) MRI may show absence or hypoplasia of olfactory bulb, tract and sulcus [1, 13, 15, 21-23];

— craniofacial trauma e.g. shearing lesions of olfactory fibers, and/or contusion of olfactory bulb and tract or of the frontal and temporal cortex [12, 24];

— tumors at the rhinobasis or the frontal or temporal lobes or of the sinonasal tract (e.g. esthesioneuroblastoma, meningioma, neurinoma, neurofibroma, metastasis) [6, 7, 14, 19] and;

— inflammatory disease may lead to olfactory dysfunction.

In order to find a suitable examination technique for the evaluation of anatomic details of the first cranial nerve and consequently the diagnosis of lesions of the olfactory fibers, bulb and tract, three MR sequences — one T1 w., two T2 w. — of an acceptably short examination time (the three sequences have a similar acquisition time) were compared. The following questions had to be clarified:

— can olfactory nerve anatomy be better portrayed using a T1 w. or a T2 w. sequence?

— is a combination of both T1 w. and T2 w. sequences needed for this purpose?

T1 w. MP-RAGE was selected for this comparison, because MP-RAGE has some advantages — i.e. a relatively high soft tissue contrast, decreased imaging time and consequently fewer motion artifacts — when compared with T1 w. spoiled 3D gradient echo sequences e.g. FLASH [10]. Concerning T2* contrast, CISS has been widely accepted as a suitable imaging tool of the facial and vestibulocochlear nerves [3]. Therefore CISS was included in this sequence comparison.

Some groups used a head coil [13, 22], other groups a special surface coil [12, 14, 15, 23], for revealing the details of the rhinobase, of the olfactory bulb and tract. We used a circularly polarized (cp) head coil for two reasons:

— cp head coils are widely available and employed; the results of our study can therefore be useful for a greater number of radiologists in clinical routine;

— traumatic, neoplastic and degenerative diseases as well as anomalies (syndromal disease) are rarely limited to the olfactory bulb, tract and nerve
FIG. 2. — 3D CISS T2 w., 1 mm thickness, axial section.
a) axial section showing the olfactorius sulcus (arrows), volunteer BD.
b) axial section showing the olfactory bulb and the olfactory tract (arrows), volunteer BD.
c) coronal section showing the olfactory bulb (arrows), volunteer GC.
d) sagittal section showing the olfactory bulb (arrows), volunteer BD.

FIG. 2. — 3D CISS T2 w., coupe axiale - épaisseur : 1 mm.
a) coupe axiale qui montre le sulcus olfactorius (flèches), volontaire BD.
b) coupe axiale qui montre le bulbe olfactif et le tractus olfactif (flèches), volontaire BD.
c) coupe coronale qui montre le bulbe olfactif (flèches), volontaire GC.
d) coupe sagittale qui montre le bulbe olfactif (flèches), volontaire BD.
FIG. 3. — 3D MP-RAGE T1 w., 1 mm thickness.
a) axial section showing the olfactory bulb and tract (arrows), volunteer BD.
b) sagittal section showing the olfactory tract (arrow) and the olfactory bulb, volunteer GC.
c) coronal section showing the olfactory bulb (inclined arrow) and the fibers (straight arrow), volunteer GC.
d) sagittal section showing the olfactory fibers (arrow), volunteer GC.

FIG. 3. — 3D MP-RAGE T1 w., épaisseur de la coupe 1 mm.
a) section axiale qui montre le bulbe et le tractus olfactifs (flèches), volontaire BD.
b) section sagittale qui montre le tractus olfactif (flèche) et le bulbe olfactif, volontaire GC.
c) section coronale qui montre le bulbe olfactif (flèche inclinée) et les fibres (flèche horizontale), volontaire GC.
d) coupe sagittale qui montre les fibres olfactives (flèche), volontaire GC.
fibers. Other intracranial or cerebral structures can be involved [13, 22] thus necessitating the examination of the whole neurocranium.

Usually MR imaging protocols in patients with olfactory disorders include axial T1 w. and T2 w. TSE sequences of the whole brain, thin (usually 5 mm thick) coronal T1 w. spin echo images [1, 2, 13] or thin T2 w. coronal fast spin echo sequences [23, 24] of the olfactory bulbs and tracts. Caillet prefers 2 or 3 planes to 1 plane imaging [2]. Only Suzuki et al. generally use exclusively axial T1 w. slices [20].

We tested two 3D (T1 w. MP-RAGE, T2*w. CISS) and one 2D (T2 w. TSE) sequences in order to select an appropriate sequence to be introduced in a standard imaging protocol (e. g. axial T1 w. and T2 w. TSE of the whole brain).

Our own results showed the two 3D sequences are superior to the 2D sequence. These results support the recommendation of some groups [2, 12] who preferably perform slices in two or (better) three orientations in order to image the olfactory structures.

One 3D data set with isotropic (or nearly isotropic) voxel is even better than images of the three main planes available using three 2D sequences. This volume mode allows the reconstruction of slices which relate to the anatomy (e. g. course of nerves) of the structures in question. In this way the anatomical details of structures such as nerves can be best analysed. Reconstructability of images not only in the three main planes, but also in arbitrary sections is therefore an important argument in favour of 3D sequences.

The anatomical details of structures can be best analysed using slices adequately relating to the anatomy of the structures in question.

A further argument in favour of 3D sequences is the availability of very thin slices (in the range of 1 mm or even submillimeter slices) and the possibility of gapless imaging. Furthermore, if we consider the need for pluridirectional imaging, the recording of a 3D sequence is less time-consuming than three 2D sequences of comparably high resolution.

As regards MR contrast the T1 contrast of the MP-RAGE sequence yields a rather good differentiation of nerves (olfactory bulb and tract as parts of the cerebrum) and fluids (e. g. liquor). This contrast nerve-liquor is even better using T2 or T2* contrast. In the case of CISS flow compensation nerve-liquor is even better using T2 or T2* contrast. In the case of CISS flow compensation nerve-liquor is even better using T2 or T2* contrast. In the case of CISS flow compensation nerve-liquor is even better using T2 or T2* contrast.

In conclusion, we would therefore recommend the integration of the MP-RAGE sequence in a MR imaging protocol in patients with olfactory dysfunction. This sequence — in addition to standard MR sequences of the brain — will be useful for the detection of olfactory tract, bulb and fibers and for the distinction from abnormalities.

REFERENCES