Effective performance of contrast enhanced T2-weighted imaging with SPACE and CISS in evaluating cavernous sinus invasion by pituitary macroadenomas on 3T MR

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Purpose

Pituitary adenoma (PA) can grow to cause compression and invasion of surrounding anatomic structures[1]. When treating invasive PAs the tumor resection is usually partial, and surgical morbidity as well as complications such as significant hemorrhage might increase in invasive PA. Accurate pre-operative evaluation of the existence and degree of cavernous sinus invasion (CSI) by PA is of great importance in guiding surgical planning and adjunct therapy.

However, because of the complex anatomical structures of sellar turica and the limitation of spatial resolution, conventional 2D spin echo sequence for depicting morphological details in the sella is often suboptimal [2]. Moreover, the small tissue contrast difference between PA and cavernous sinus makes the accurate evaluation of CSI difficult.

As 3D imaging yields 3D volume data with isotropic information, thinner section images can be acquired in any plane; this minimizes the partial volume effect between small lesions and surrounding tissue[3]. Based on previous experience, 3D sampling perfection with application-optimized contrasts by using different flip angle evolutions (SPACE) sequence and 3D constructive interference in steady state (CISS) sequence can increase the signal intensity of space filled with slow flowing fluid, such as the cavernous sinus. In the preliminary study, we compared the images of two sequences before and after administration of Gd-DTPA on 14 patients. The signal intensity of cavernous sinus is higher on contrast enhanced (CE) images than on non-enhanced ones (Figure 1).

Therefore, this study aimed to use CE SPACE and CE CISS sequences to obtain better evaluation of the relationship between PA and cavernous internal carotid artery against the background of the bright cavernous sinus. Good contrast of PA with surrounding structures will be helpful in the evaluation of CSI by PA.
Fig. 1: Coronal images of sellar region obtained using SPACE before (a) and after (b) injection of Gd-DTPA. The signal intensity of CS is higher on CE image than on non-enhanced one with slight decline of pituitary signal intensity

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Methods and Materials

Patients

The study population included 28 patients (16 females, 12 males; age range, 19~68 years, 56 sides of cavernous sinus) who had newly diagnosed pituitary macroadenoma (diameter of tumor >= 10mm). None of the patients had previously undergone surgery.

This study was approved by the local institutional review board and prospectively performed after obtaining informed consent from all patients.

MR Imaging

All studies were performed with a 3.0T MR imaging system (MAGNETOM Verio 3.0 T, Siemens, Germany) by using an 8-channel head coil. CE 3D imaging was performed after injecting the standard dose (0.1 mmol/kg) of gadopentetate dimeglumines (Gadopenetetate Dimeglumine Injection; Beilu, Beijing, China) by using the following parameters: repetition time (TR)/echo time (TE) 2000 /129 ms, flip angle(FA) 120°, matrix 320×320, two excitations, field of view (FOV) 180×180 cm, bandwidth 289 Hz/pixel, slice thickness 1mm, voxel size 0.6 ×0.6×1.0mm for SPACE; repetition time(TR)/ echo time (TE) 5.84/2.52ms, flip angle 47°,matrix 320×307, one excitation, FOV 170×170 cm, bandwidth 422 Hz/pixel, slice thickness 1mm, voxel size 0.6 ×0.6×1.0mm for CISS. SPACE and CISS images were obtained through the sellar turcica in the coronal plane. Before obtaining these CE 3D images, 2D T1-weighted (SE, axial), 2D T2-weighted (fast SE, axial), and CE 2D T1-weighted (SE, axial and coronal) images were obtained. Postcontrast MR studies were started about 60-120 seconds after contrast material injection. A 2D T1-weighted sequence was obtained as the first sequence after contrast injection. After acquiring CE 2D T1-weighted images, the two 3D MR images were performed. To avoid timing bias after contrast injection, we alternated the order of the two 3D sequences in 28 patients by rotation.

CSI grade evaluation

CSI were classified into four grades based on the readily detectable cavernous internal carotid artery and the venous compartment serving as the radiological landmark. Following features were evaluated: (1) if there is whole rim enhancement around the intracavernous internal carotid artery, (2) the percentage of encasement of cavernous internal carotid artery, (3) the depiction of venous compartment of cavernous sinus. Our grading standard of CSI is shown in Table 1.

Table 1. The grading standard of CSI by PA
Grade 0: one or more of following signs is visible
(1) With good enhancement of cavernous sinus, the medial venous compartment is visible or there is whole rim enhancement around internal carotid artery
(2) PA encases cavernous internal carotid artery but the percentage of encasement is less than 25% (3/12) (balloon-like contact)

Grade 1: both of following signs are visible
(1) With good enhancement of cavernous sinus, the medial venous compartment is invisible or there is no whole rim enhancement around internal carotid artery
(2) PA encased cavernous internal carotid artery and the percentage of encasement is 25% (3/12) to 42% (5/12)

Grade 2: both of following signs are visible
(1) With good enhancement of cavernous sinus, the medial venous compartment is invisible or there is no whole rim enhancement around internal carotid artery
(2) PA encased cavernous internal carotid artery and the percentage of encasement is 42% (5/12) to 67% (8/12)

Grade 3: one or more of following signs is visible
(1) Inferior venous compartment is invisible
(2) With good enhancement of cavernous sinus, there is no whole rim enhancement around internal carotid artery and PA encased cavernous internal carotid artery and the percentage of encasement is more than 67% (8/12)

Two experienced radiologists reviewed the CE images obtained with SPACE and CISS. They were blinded to the sequence type and patient identification, and independently evaluated the invasion grade of 56 sides of cavernous sinus according our grading system of CSI (Table 1). CE SPACE images and CE CISS images of these patients were classified into two groups.

Moreover, CSI classification according to the widely-used intercarotid lines described by Knosp [4] on the conventional CE T1-weighted images was also performed and compared with our assessment results. On inconsistent CE SPACE or CE CISS cases, two reviewers reached consensus after discussion.

Qualitative evaluation

Two radiologists reviewed CE SPACE and CE CISS images and independently evaluated the image quality in terms of the following 5 points: 1. overall image quality in CSI evaluation; 2. signal contrast of the lesion with cavernous sinus; 3. relationship between the tumor and the cavernous internal carotid artery; 4. susceptibility artifacts, 5. vessel flow artifacts. We evaluated point 1 through point 3 according to a five-point scale under
the following criteria: excellent, 4; good, 3; fair, 2; poor, 1; non-diagnostic, 0. Point 4 and 5 were evaluated according to the following criteria; 0, imperceptible; 1, discernible. The observers were blinded to sequence information.

Statistical analysis

Statistical analyses were performed using SPSS version 16.0 (SPSS, Chicago, IL, USA). The agreement of CSI assessment results from two observers on the same sequence (CE SPACE & CE CISS) was analyzed with $K$-statistics respectively. Inter-sequence variability (our CSI grade evaluation on CE SPACE/CISS compared with Kosp's classification on CE T1-weighted images) was also analyzed with $K$-statistics. Kappa value $> 0.7$ was considered to be indication of good consistency. The image quality assessment data were expressed as mean± standard deviation. Qualitative analyses were compared using the Wilcoxon signed-rank for statistical analysis. A $P$-value of $<0.05$ was considered to be of statistic significance.
Results

CSI evaluation

The CSI assessment results on SPACE and CISS by two observers are summarized in Table 2. The results were in substantial agreement between two reviewers both on CE SPACE \((k=0.87)\) and CE CISS \((k=0.83)\).

Table 2. Results of CSI evaluation from two observers on CE SPACE and CE CISS

<table>
<thead>
<tr>
<th>The degree of CSI</th>
<th>The sides of the cavernous sinus</th>
<th>Observer 1</th>
<th>Observer 2</th>
<th>(k) value between two observers</th>
</tr>
</thead>
<tbody>
<tr>
<td>CE SPACE</td>
<td>Grade 0 28 26</td>
<td>0.87</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grade 1 9 13</td>
<td></td>
<td></td>
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<td></td>
<td>Grade 2 1 1 8</td>
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<tr>
<td></td>
<td>Grade 3 8 9</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>CE CISS</td>
<td>Grade 0 32 28</td>
<td>0.83</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Grade 1 8 12</td>
<td></td>
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<td></td>
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<td></td>
<td>Grade 2 9 11</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Grade 3 7 5</td>
<td></td>
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</tr>
</tbody>
</table>

Inter-sequence variability (CE SPACE/CISS compared with conventional T1-weighted sequence) of CSI evaluation results were summarized in Table 3 and Table 4. The consistency \(k\) value between our CSI classification on CE SPACE and Knosp’s classification on CE T1-weighted images was 0.76. The consistency \(K\) value was 0.73 between our classification on CE CISS and Knosp’s classification.

Table 3. CSI evaluation according to Kosp's classification on T1-weighed images and our classification on SPACE

<table>
<thead>
<tr>
<th>Our classification on CE SPACE</th>
<th>Kosp's classification on CE T1-weighted images</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade 0</td>
<td>Grade 0 25</td>
<td>Grade 1 3</td>
</tr>
</tbody>
</table>
Table 4. CSI evaluation according to Kosp’s classification on T1-weighed images and our classification on CISS

<table>
<thead>
<tr>
<th>Grade 1</th>
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<th>7</th>
<th>3</th>
<th>0</th>
<th>10</th>
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<td>0</td>
<td>8</td>
<td>2</td>
<td>10</td>
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<tr>
<td>Grade 3</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>Total</td>
<td>25</td>
<td>10</td>
<td>12</td>
<td>9</td>
<td>56</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Our classification on CE CISS</th>
<th>Kosp's classification on CE T1-weighted images</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Grade 0</td>
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</tr>
<tr>
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<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>25</td>
<td>10</td>
</tr>
</tbody>
</table>

Qualitative Evaluation

The mean scores of each visual assessment are shown in Figure 2.

Identification of CSI by PA worked well with either CE SPACE or CISS but SPACE performed better (mean, 3.48±0.61 versus 3.28±0.80, P<0.05) on 3T MR. CE SPACE had significantly higher image scores than CE CISS in description of the relationship between PA and internal carotid artery (mean, 3.26±0.93 versus 2.96±1.01, P<0.05). Moreover, CE CISS demonstrated more susceptibility artifacts (10.7% versus 0%, P<0.05) and vessel flow artifacts (53.6% versus 0%, P<0.05). However, there was no significant difference between CE SPACE and CE CISS regarding contrast enhancement of PA and cavernous sinus (mean, 3.07±1.12 versus 3.04±0.96, P>0.05).

Representative case was shown in Figure 3-5.
**Fig. 1:** Coronal images of sellar region obtained using SPACE before (a) and after (b) injection of Gd-DTPA. The signal intensity of CS is higher on CE image than on non-enhanced one with slight decline of pituitary signal intensity

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**Fig. 2:** Qualitative evaluation of contrast-enhanced images obtained with SPACE and CISS. total image: overall image quality in CS invasion evaluation, lesion/CS: the signal contrast of the lesion and CS, lesion/ICA: demonstration of the relationship between the lesion and intracavernous ICA. ND: no significant difference, *P < 0.05

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**Fig. 3:** Coronal CE images of a pituitary macroadenoma obtained by CISS (a) and SPACE (b) at 3.0 T. The border of the lesion under the background of bright cavernous sinus is seen clearly on both sequences. Slight vessel flow artifact is observed on CISS. Entire rim enhancement is seen around the right ICA (Grade 0), and there is no entire rim enhancement around the left side (Grade 1).

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**Fig. 4:** Coronal CE images of a PA obtained with CISS (a) and SPACE (b) at 3.0T. The vessel flow artifact (both side of ICA) and susceptibility artifact (left side of ICA) are
observed on CISS image which blurs the PA and ICA boundary. Good vascular flow void and clearer lesion border are observed on SPACE image.

Fig. 5: Coronal CE images of a pituitary adenoma obtained with conventional T1-weighted sequence (a), CISS (b) and SPACE (c). The left side of tumor edge was hazy on T1W image, and it was considered to have passed the medial intercarotid line and approximately achieve the median intercarotid line (Grade 2) according Knosp's classification). On CISS and SPACE, clearer tumor edge was depicted#Grade 1#
Conclusion

Our study revealed that CE SPACE and CE CISS both yielded better differentiation of PA with cavernous sinus. Besides of high resolution of PA edge and dual delineation, enhanced signal intensity of cavernous sinus was important to CSI evaluation.

**CSI evaluation**

According to our classification, we obtained excellent inter reader agreement on CSI of PA and better result with CE SPACE compared to CE CISS. Thus, CSI evaluation on both CE SPACE and CE CISS were stable and practical. We also compared our assessment results to the widely-used Kosp’s classification on CE T1-weighted images. Consistencies between them were high both on SPACE and CISS, though SPACE still performed better.

Both CE SPACE and CISS tended to give a higher CSI grade assessment in some cases (7 cases in 56 cases on CE SPACE and 9 cases in 56 cases on CE CISS) compared to Konsp’s classification on conventional CE T1-weighted images. We concluded it was because on conventional CE T1-weighted images, 1) in some cases, enhancement of the PA could blur the boundary with the cavernous sinus; 2) the internal carotid artery is not always round on images and sometimes it can be a curved line owing to its compression by the adenoma which made it difficult to draw accurate lines between petrous and cavernous sinus internal carotid artery. In the first scenario, the superior contrast between the adenoma and cavernous sinus seen on CE SPACE and CE CISS images are helpful to overcome and better delineate the boundary. In the second scenario, the 3D imaging techniques allow different planes to better visualize the carotid artery. Therefore, CE SPACE and CE CISS can provide additional information for these difficult cases on CE T1-weighted images for the evaluation of CSI by PA. CE SPACE and CE CISS may be best used to supplement CE T1-weighted imaging when T1-weighted is insufficient to accurately depict the PA/cavernous sinus border.

**Image quality**

It was reported that variable flip angle and a high turbo factor allow good vascular flow void on SPACE [4]. In our study, the superior signal differentiation among low intensity flow of internal carotid artery, high signal of venous blood in the cavernous sinus and PA was confirmed by both observers. The clear visualization of interfaces of these structures makes the assessment of CSI easier and more accurate.

Although CISS can provide images with good signal contrast between the lesion and cavernous sinus, we found it was prone to artifacts in our study. The focal hyper or iso-signal intensity achieved with CISS in the internal carotid artery is considered to result from the vessel flow artifact. In addition, because CISS is true FISP-based, it is also prone to residual banding artifacts in regions of rapid spatial variation of susceptibility. These
artifacts sometimes overlap features of interest, making the image difficult to delineate the structures accurately. The generally accepted rationale for better contrast of CE CISS is considered to be the well-enhanced venous plexus of the cavernous sinus playing a role similar to CSF. In our study, the contrast enhancement of the cavernous sinus was similar on both the CE CISS and CE SPACE. The better performance of SPACE in our study was mainly due to the superior visualization of the ICA flow void and the lack of susceptibility artifact.

Our results demonstrate that both CE SPACE and CE CISS permit good evaluation of CSI by PA. CE SPACE performed better than CE CISS in terms of overall imaging evaluation, description of the relationship between PA and internal carotid artery with less vessel flow artifact or susceptibility artifact.
References


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