Detection and assessment of caries lesions by MR microscopy

Poster No.: C-0503
Congress: ECR 2011
Type: Scientific Paper
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Keywords: Head and neck, Research, Anatomy, MR, Experimental, Imaging sequences, Physics, Inflammation, Tissue characterisation, Demineralisation-Bone
DOI: 10.1594/ecr2011/C-0503

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Purpose

A reliable and reproducible detection of dental caries by diagnostic aids is still a challenging diagnostic problem. Various different approaches have been made to recognize and stage caries lesions as their assessment is of a major importance for a successful treatment. Therefore, a method with high-resolution visualization of impaired dental tissues is a necessity for an efficient caries detection. Magnetic resonance imaging (MRI) has all attributes to meet these requirements. To the best of our knowledge, no study so far has associated MRI of caries with dentine-pulp complex response encoded in ICDA (International Caries Detection and Assessment System) scores [1, 2].

The purpose of present study was to evaluate the successive use of three MRI techniques (3D $T_1$-w SE, 3D DWI, 3D SPI) in the assessment of caries severity and to compare the MRI results of dentine-pulp complex response with commonly used ICDAS coding.

Methods and Materials

**Human teeth ex vivo:**

For the experiments, 14 extracted human teeth were used; 6 of them were molars and 5 were premolars. Four premolars had local demineralization process, five molars had occlusal and proximal caries lesion, and the other molar had amalgam filling on the occlusal plate. The remaining teeth were intact and were considered as a reference. The reasons for tooth extraction were orthodontic or surgical. The teeth were immersed in physiological solution immediately after their extraction and stored into cold incubation box at 8°C. MR imaging was started no later than twelve hours after tooth extraction to avoid autolytic process in the dental pulp that may affect MRI results.

In order to prevent dental pulp desiccation during the experiment as well as to visualize a tooth outline along with prompt MR microscopy, all the teeth were coated by the two composite dental impression material. Subsequently, the teeth were inserted into Teflon tubes with diameter of 12 mm and a height of 30 mm and were further placed centrally into the RF probe with diameter of 15 mm (Fig. 1).

**Magnetic resonance microscopy:**

MR imaging was performed on a MRI scanner consisting of a 2.35 T (100 MHz proton frequency) horizontal bore superconducting magnet (Oxford Instruments, Oxon, UK) equipped with a Bruker micro-imaging system (Bruker, Ettlingen, Germany) for MR microscopy with a maximum imaging gradients of 300 mT/m and a TecMag spectrometer (Houston TX, USA).
All teeth were imaged by three different imaging techniques:

**3D T<sub>1</sub>-w SE:** High spatial resolution of the dental pulp anatomy was achieved by a high-resolution 3D T<sub>1</sub>-weighted MRI using the 3D spin-echo imaging sequence. Imaging parameters were the following: TE/TR = 2.3 ms / 400 ms, imaging matrix 256 × 128 × 128, field of view 30 × 15 × 15 mm and imaging time 30 min. (Fig. 2). In order to improve the signal-to-noise ratio eight signal averages was done before image acquisition, therefore, the total scan time of one 3D T<sub>1</sub>-weighted spin-echo imaging sequence was 16 hours. To minimize the scan time, the frequency encoding direction was set along the largest matrix direction (256), which coincided with the longitudinal direction of the dental pulp.

**3D DWI:** Each tooth was also imaged by the 3D DWI method (Fig. 3) in an identical slice with the field of view 30 × 15 × 10 mm and imaging matrix 256 × 128 × 8. Diffusion weighting was achieved by the pulsed-field gradients spin-echo (PGSE) technique having two 11 ms gradient pulses positioned symmetrically with respect to the refocusing RF pulse (# = 11 ms, # = 18 ms). The repetition time and the echo time in the 3D DWI method were 1300 and 34 ms, respectively. Four DW images were acquired with different diffusion weightings; at b values of 0, 132, 317, and 635 s/mm<sup>2</sup>. The images were also used to calculate the corresponding ADC maps.

**3D SPI:** SPI images were obtained using a data matrix of 64 × 32 × 32 with the field of view of 30 × 15 × 15 mm. The signal was detected 125 µs (detection time, t<sub>p</sub>) after the 6.4 µs excitation pulse (# in Fig. 4). The repetition time was equal to 105 ms so that the total experiment time was 1 h : 20 min.

**Images for this section:**
Fig. 1: Freshly extracted teeth were first dried and then coated with an impression material to prevent drying during MR imaging. Teeth were then inserted into a 15 mm RF coil for MR microscopy
Fig. 2: 3D spin-echo
Fig. 3: 3D diffusion-weighted imaging
Fig. 4: Single-point imaging (SPI) 3D sequence
Results

Soft dental tissues are bright in T₁-w MR images, while hard dental tissues cannot be seen due to too short T₂ relaxation times (Fig. 1). 3D MRI allowed frontal (bucco-lingual) as well as side (mesio-distal) views, which cannot be seen by standard radiography. In addition, 3D high-resolution MR microscopy enabled view of a dental pulp in a sequence of thin consecutive slices.

Fine anatomical details (e.g. dental-pulp complex response) as well as distances between caries lesions and the intact dental pulp in incisal-cervical, mesio-distal and bucco-lingual direction were obtained (Fig. 2).

Use of 3D SPI enabled visualization of decayed hard dental tissues (enamel, dentin and cementum) in detection and assessment of distinct caries lesions with low ICDAS (Fig. 3).

ADC mapping enabled additional quantitative analysis of the pulp tissue integrity and discrimination between intact and decayed regions of the pulp (Fig. 4). Relation between various compartments of the decayed tooth and ADC values (Fig. 5) showed that ADC might have the potential in assessment of the pulp tissue integrity comparable to standard ICDAS coding (Fig. 6).

Images for this section:
Fig. 1: MR image of first upper premolar obtained after co-addition of all 3D slices. Bucco-lingual (left) as well as mesio-distal (right) high-resolution MR images were obtained in a series of very thin slices.
**Fig. 2:** Multi-sliced axially oriented high-resolution T1-w MR image of a representative dental-pulp complex response from a severely decayed lower molar. All three spatial directions were obtained by 3D volume rendering (imaging parameters: FOV = 15 x 7.5 x 7.5 mm³, matrix = 256 x 128 x 128, TE/TR = 2.4/400 ms, imaging time = 16 hours).

**Fig. 3:** Comparison between 3D volume rendering of T1-w MRI of dental-pulp complex response (left) and 3D SPI technique (right) for the same decayed tooth. SPI enabled visualization of the superficially decayed hard dental tissues and allowed the assessment of distinct caries lesions.
Fig. 4: Apparent-diffusion (ADC) mapping of the same decayed molar with ICDAS score 6. Six slices, each acquired at different b values of 0, 132, 317 and 635 s/mm², were used to calculate the corresponding ADC values.

<table>
<thead>
<tr>
<th>Compartement</th>
<th>ADC (x 10⁻⁹ m²/s)</th>
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<tbody>
<tr>
<td>Caries cavity</td>
<td>1,8 ± 0,2</td>
</tr>
<tr>
<td>Intact pulp tissue</td>
<td>1,0 ± 0,2</td>
</tr>
<tr>
<td>Impaired pulp tissue</td>
<td>0,2 ± 0,1</td>
</tr>
</tbody>
</table>

Fig. 5
**Fig. 6:** Correlation between ADC values of variously impaired teeth and standard clinical ICDAS coding (0 = intact, 6 = severe impairment).
Conclusion

1. MR microscopy enables non-invasive visualization of caries lesions, especially approximal lesions and occult caries in dentin due to the MRI signal rise in the demineralised dental hard tissues.

2. Specifically, a complex 3D view of pulp chamber anatomy in an arbitrary orientation with the detection of affected root canals could be obtained. Tracking of individual root canal and the assessment of the distance between caries lesions and the pulp is also possible.

3. Advanced MR microscopy techniques (e.g. SPI) enable direct visualization of hard dental tissues and can be used for detection of surface caries lesions.

4. ADC mapping in decayed teeth is helpful for quantitative analysis of the pulp tissue integrity. ADC could be an efficient prognostic and diagnostic marker for the assessment of the pulp tissue integrity depending on the caries severity.

5. ADC mapping and measurements of the distance between caries lesion and the dental pulp by 3D SE/SPI may represent a complementary method in diagnostics and treatment of dental diseases. However, prospective studies are needed.

References


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