Human tooth pulp magnetic resonance microscopy

Abstract

Background and Purpose: A precise image of dental pulp chamber and root channels is of major importance for success of an endodontic treatment. Due to superposition of tooth roots, the information provided by standard X-ray images is often insufficient. Therefore, the number of root channels and their shape cannot be always accurately determined. For that reason a tomographic method is needed that can well image soft dental tissues. In this paper we intended to demonstrate that MR microscopy is a technique that fully meets these criteria.

Material and Methods: Experiments were performed in-vitro on extracted human teeth that were MR imaged by a high resolution 3D spin-echo imaging technique at image resolution of 100 µm. Images were also post processed to calculate advanced volume rendered view to dental pulp.

Results: From 3D MR images it was possible to determine the number of root channels and to track each individual root channel. We also demonstrated that fine details like root channel bifurcations and anastomosis could be visualized.

Conclusion: Current technology allows clinical MR microscopy of teeth at high resolution in 2D and at moderate resolution in 3D. Perhaps MR microscopy will be available for clinical studies of teeth in near future. In that case it may become a replacement for conventional X-ray scanning because it provides accurate information of soft dental tissues and is harmless.

INTRODUCTION

Before endodontic treatment of human tooth due to degenerative changes in pulp tissue, conventional X-ray scanning is inevitable in everyday clinical practice. Endodontic intervention involves extraction of whole infected tooth pulp tissue with special filaments, mechanical and chemical disinfection and medical treatment of pulp chamber and root channels. Therefore precise visualization of dental pulp anatomy is necessary. Unfortunately conventional X-ray scanning, which is a standard clinical procedure before endodontic treatment, is a two dimensional projection technique that can show only hard dental tissues. Dental soft tissues, i.e., tooth pulp, cannot be seen in standard X-ray films. Therefore, it enables visualization of root channels only indirectly (it is presented on the X-ray like an empty space inside the tooth). The problem associated with endodontal treatment of teeth is a large variety of different possible shapes of tooth pulp and variable number of root channels. Root channels may also have very unpredictable shape; they can have anastomosis and may also form pulpo-periodontal communications. Since all that accurate information can usually not be acquired from standard X-ray scans only, the success of endodontic treatment may be questionable. These problems could be overcome by a
technique that would be able to visualize soft dental tissues.

The aim of our study was to demonstrate that magnetic resonance (MR) microscopy is a very powerful tool for visualization of soft dental tissues and can very efficiently help to reveal the complex structure of dental pulp channels. The use of magnetic resonance microscopy in dentistry was so far focused to imaging of pathological changes in a jaw joint (1, 2) as well as to imaging of mouth floor and tongue (3). Not so many attempts were made to image other dental tissues (4–6) in spite of large water content in these tissues. In the present study, a comparison between the MR microscopy and conventional X-ray scanning, which is the most widely used diagnostic method in dentistry, was made.

MATERIALS AND METHODS

For experiments, twelve extracted human teeth were used; five of them were premolars and seven were molars. One premolar had local demineralization process, one molar had occlusal and approximal caries lesion, the other molar had amalgam filling on the occlusal plate. Remaining teeth were intact. The reason for tooth extraction was orthodontic (for premolars) and surgical for molars. The teeth were immersed in physiological solution immediately after extraction and stored at room temperature (21 °C). MRI imaging was started no later than twelve hours after tooth extraction to avoid autolytic changes in the pulp that may affect MR image. MRI scans were done on a TecMag MR spectrometer and a 2.35 T horizontal bore Oxford superconducting magnet equipped with Bruker accessories for MR microscopy with maximum imaging gradients of 300 mT/m. To achieve high spatial resolution, the teeth were scanned by 3D spin-echo imaging technique. This technique enables imaging with very thin slices so that resolution can be set equal for all three spatial directions. In all experiments, the imaging field of view was equal to 25 mm in the tooth axial direction and was equal to 12.5 mm in both perpendicular directions, imaging matrix was 256 by 128 by 128 and yielded imaging resolution of 0.1 mm in all three spatial directions. Other imaging parameters were echo time 2.4 ms and repetition time 600 ms. Images were acquired after eight signal averages to improve signal to noise ratio. This prolonged the imaging time to 22 hours. The imaging time was so long because of high resolution and relatively low magnetic field strength for MR microscopy experiments. To prevent the tooth desiccation during the experiment, all the teeth were protected by either a thin layer of paraffin or tube sealing wax. Tooth coating with sealing wax was very convenient when it was desired to show the outline of the tooth. Actually, with our imaging parameters, the sealing wax had detectable MR signal whereas paraffin had practically no MR signal. All image data processing was done

Figure 1. MR micro-image of a premolar in mesio-distal (a) and in bucco-lingual (b) projection. For comparison, standard X-ray image of identical premolar is shown in Figure (c). The MR images are obtained by co-addition of all 2D MR slices in corresponding orientation and are therefore true projection images as in any X-ray image. MR images may well present only soft dental tissues (dental pulp) that have high water content; hard dental tissues (dentin and enamel) may not be seen because of low water content and short relaxation times of water in these tissues.

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by NTNMR software from TecMag (this was used for controlling spectrometer and Fourier transforming data sets) and by ImageJ, NIH (3D image rotations, segmentation, and volume rendering).

RESULTS

Figure 1a shows a MR image that corresponds to a projection of a premolar in mesio-distal direction. The image was obtained by summation of all 2D slices of 3D data set in corresponding orientation. Dental tissues with large water content, such as dental pulp, have strong MR signal and appear bright on MR images. Therefore, dental pulp chamber with root channels can be well seen on MR images. Contrary to soft dental tissues, hard dental tissues do not have any MR signal detectable by standard MR imaging techniques and cannot be seen on MR images. This is because water content is low and MR relaxation times of water are short in these tissues. Dentin contains 23% of water and enamel 6%, which is very low compared to 95% water content in a dental pulp. Dentin also has higher water content than enamel because of dentin channels which are filled with water. However, dentin channels have a very small diameter (only 3 to 5 mm). So water molecules in the channels cannot freely move and are more likely bound than free. Relaxation times are therefore very short. In addition to that, there is also strong susceptibility effect of dentin channels to water, which also contributes to relaxation time shortening.

In MR images of human tooth, only a dental pulp can be seen and no enamel or dentin. The pulp of the tooth in Figure 1a has in the apical region large opening with a diameter of about 1 mm. The root channel was widened in the apical region since the patient was young (twelve year old child) and the root was not completely formed. The tooth was extracted due to an orthodontic reason. Figure 1b shows an image of the same tooth in different projection – in bucco-lingual orientation. Again, the image was obtained by summation of all 2D slices. The pulp chamber and just one root channel can be seen in this projection. Similar information in the shape and size of a pulp may be obtained also by standard X-ray scanning technique (Figure 1c). The main problem in X-ray scanning is that the information on geometry of the pulp shape can be accessed only indirectly from the outline of hard dental tissues in X-ray images.

Figure 2a shows a MR image of the same premolar as in Figures 1a, 1b. The tooth is shown in a bucco-lingual cross-section in a 0.1 mm thick slice. Hard dental tissues do not have any detectable MR signal and can be visualized only indirectly. To define the outline of hard dental tissues, the tooth was coated by soft wax. The shape or number of root channels cannot be precisely determined from the image in Figure 2a. Actually, it is possible that root channels could overlap in the projection. This dilemma can be cleared by using volume rendered 3D view of the pulp from different view angles (Figure 2b). Volume ren-

Figure 2. MR micro-image of the premolar coated by soft wax in a 0.1 mm thick slice in bucco-lingual section (a), volume rendered 3D reconstruction of the same tooth (b) and of a typical molar (c). Soft wax which is as bright as a dental pulp in the middle forms sharp outline of the tooth. A volume rendered image provides the most complete information on dental pulp anatomy. The number and shape of root channels can be precisely determined from different 3D volume rendered views.

dering provides the most comprehensive view to 3D objects. The method requires heavy computing on large 3D data sets. These were restricted not so long ago to powerful nonstandard computers. However, presently practically any average personal computer has enough computer power to calculate volume rendered view as the one in Figure 2b in just few seconds. From the volume rendered view, it is possible to accurately determine the number and shape of root channels. For example, just one root channel is seen in a single slice view in Figure 2a whereas in Figure 2b, which is a volume rendered view of the same tooth, it can be clearly seen that the tooth has two root channels which join together in the apical region. The pulp anatomy is even more complex in molars. An example of that can be seen in Figure 2c which is shows a volume rendered image of a molar with four root channels.

**DISCUSSION**

The aim of our research was to test the feasibility of MR microscopy as a diagnostic method in dentistry. We were particularly focused on visualization and therefore completing information of dental pulp anatomy by MR microscopy. We compared the method to standard clinical X-ray scanning technique, which is especially deficient in visualization of soft dental tissues. Presently MR imaging is a more powerful technique than X-ray scanning. The main difference is that standard X-ray image corresponds to average X-ray absorption properties along the direction of the X-ray beam. The conventional X-ray image is therefore not a real tomographic image but just a 2D projection of a 3D sample. Contrary to X-ray, MRI is a real tomographic method, i.e., the sample can be imaged undestructively in slices of arbitrary position and orientation, and corresponding images reflect MR properties of the sample in image positions matching sample positions. Results of our study showed that MR images of teeth in in-vitro conditions contained valuable information that enabled precise visualization of dental pulp chamber in 3D and at relatively high resolution. The pulp chamber size and shape as well as the number and the shape of root channels can be precisely determined. Especially important is that it is possible to track every root channel and test it for possible ramifications. Images in side view are very helpful for this purpose. The most comprehensive view may be obtained by volume rendering of the 3D pulp image. This gives a volume view to the pulp which is obtained without actual opening the tooth. It is also possible to calculate a view to the pulp from any point in space. MR microscopy of teeth has the highest potential for use in endodontics due to its more accurate information on the pulp chamber and root channels than possibly obtained by conventional X-ray scanning. Therefore, the MR microscopy could enable better endodontic treatment. We also demonstrated that it is possible to indirectly visualize hard dental tissues by the use of waxes that have sufficient MR signal.

MR microscopy at current stage does not allow in-vivo imaging of human tooth. The main reason for that is the need for a special gradient and RF coils to fit teeth well. Then there still remains a problem associated with very long imaging time which is inevitable to get a high resolution MR image. The experiment time can be shortened by the use of stronger magnets for MR imaging and more efficient imaging sequences. This could also help to reduce the imaging time significantly. However, it is hard to believe that it will be possible to reduce that time to the clinically acceptable limit of the order of ten minutes soon. Current technology allows clinical MR imaging of teeth at high resolution in 2D and at moderate resolution in 3D. Perhaps MR microscopy will be available for clinical studies of teeth in near future. In that case it may become a replacement for conventional X-ray scanning because it provides accurate information of soft dental tissues and is harmless.

**REFERENCES**