The feasibility of Phosphorus-31 SWIFT and ZTE dental MRI

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Target audience: dentists, calcified tissue imaging, short T_2 acquisition.

Purpose: X-ray based imaging techniques, which use ionizing radiation, remain the gold standard for clinical dental imaging. Recently an association between dental x-ray and the occurrence of intracranial meningioma was reported,[1] which is in lined with the well know harmful effects of exposing humans to ionizing radiation. Several studies have demonstrated the potential of MRI in dental imaging instead of x-ray.[2, 3] Due to very short T2 values of water in teeth, it requires the use of ultra-short echo time (UTE)[4] or zero echo time (ZTE)[5] sequences. With a recently developed acquisition technique without echo time, Sweep Imaging With Fourier Transformation (SWIFT), it was possible to perform the first human studies showing high-resolution 3D images of teeth within clinically relevant scanning times.[6] However, as the main content of human tooth is hydroxylapatite, a crystalline calcium phosphate, we reasoned that phosphorus MRI might provide relevant information. ***In this study, the feasibility of ^{31}P SWIFT and ZTE dental imaging was explored as a model system of imaging densely calcified human tissues.*** Obtaining a direct non-invasive measure of phosphorous content in tissues is important for several human diseases chiefly characterized by a change in calcified mineral content, such as dental caries and osteoporosis.

Methods: The extracted human mandibular second molar was imaged in a 9.4T MR system (Agilent-Varian) with a home-built double channel surface coil. Proton SWIFT images were acquired with an excitation bandwidth of 125kHz, flip angle (FA) 15°, TR of 2.5ms, FOV of 3*3*3cm, and a matrix of 256*256*256, the total acquisition (TA) time is 100sec. Phosphorus SWIFT imaging was acquired with an excitation bandwidth of 45kHz, FA of 3.6°, oversampling factor of 8, TR of 200ms, FOV of 3*3*3cm, and a matrix of 64*64*64,TA around 4mins. The relaxation times of ^{31}P spins were also obtained, for T_1 by inversion recovery and for T_2* by measuring line widths. Another extracted human tooth, maxillary first molar, was imaged in a 11.7T MR system (Bruker, Biospin) with a home-built phosphorus surface coil. Phosphorus ZTE imaging was performed with an excitation bandwidth of 80kHz, FA of 2.9°, TR of 8ms, FOV of 3*3*3cm, with 16 averages and a matrix of 64*64*64, and TA around 30mins.

Results: For ^{31}P, the measured T_2* value was 100μs and T_1 was 130sec, which necessitates rapid data acquisition and a small flip angle. On ^{1}H SWIFT images, a clear delineation of enamel, dentin and pulp is visible. (*Fig.1,B*). The ^{31}P images clearly reflect the shape and size of the tooth *(Fig.1,C),* further delineation of molar structures is also possible: the enamel shows higher signal intensity due to high content of mineral hydroxylapatite. In contrast pulpal tissue did not appear on the ^{31}P images because of the low phosphate concentration. The tooth used for ZTE image (*Fig.2*) with large cavitated carious defect on the buccal surface, which was reproduced in the ^{31}P ZTE image. The latter image also showed variability in the phosphate content of the tooth, enamel and dentin shown less signal intensity due to the pathological defect in the tooth crown.

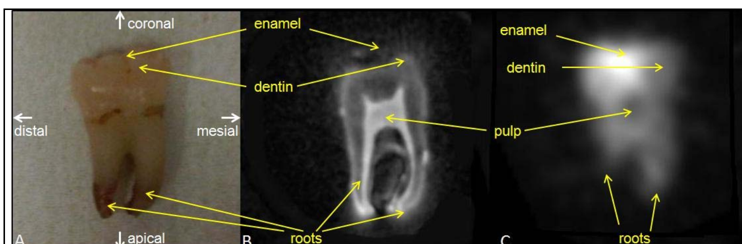

Figure 1. Macroscopic view(A), ^{1}H(B) and ^{31}P(C) SWIFT images of human molar. Dental anatomy is well resolved in the ^{1}H images, including enamel, dentin and pulpal structures are visible. In ^{31}P SWIFT imaging, the pulp cannot be detected.

Discussion: Human applications have been demonstrated now for both ^{1}H SWIFT and ZTE techniques. In this study, the feasibility of ^{31}P SWIFT and ZTE dental imaging was demonstrated for the first time. The functional information on phosphate density may be of additional quantitative value in dental diagnostics. For instance, the resultant defect from caries within the clinical crown of the tooth is clearly visualized in the ^{31}P ZTE image and coincide with the absence of ^{31}P signal and thus represents less mineralized structure, which may be an important parameter to characterize the quality of teeth, as well as being applied to other health-related problems involving changes in calcified mineral content. SWIFT imaging of ^{31}P requires extremely fast transmit/receive switching, which could be further optimized to enhance imaging quality and spatial resolution. Likewise further optimization of the ZTE imaging is possible.

Conclusion: ^{31}P SWIFT and ZTE have potential value in tooth imaging because it is a direct measurement of the phosphorous content of teeth. The extension of ^{31}P imaging to human applications may be relevant to detect early demineralization not clearly defined by ^{1}H MRI. Apart from dental imaging, ^{31}P imaging might also be attractive for evaluating disorders chiefly characterized by changes in mineral content, such as osteoporosis.

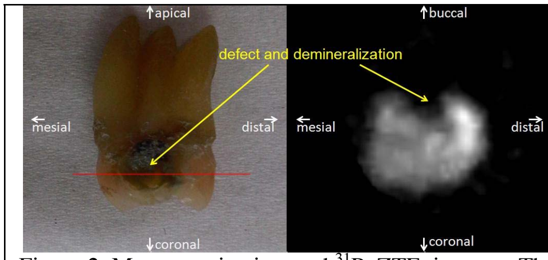

Figure 2. Macroscopic view and ^{31}P ZTE images. The ZTE image represents the cross-section (red line) through the clinical crown of the tooth.

References. ***1***. *Claus E.B. et al. 2012* ***2***. *Baumann M.A. et al 1993* ***3***. *Wu Y. et al. 1993* ***4***. *Bracher A.K. et al. 2011* ***5***. *Weiger M. et al. 2012* ***6***. *Idiyatullin D. et al. 2011*

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