REVIEW ARTICLE

SWIFT MRI: VISUALIZE THE INVISIBLE

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ABSTRACT

The oral cavity is prone to a variety of diseases starting from simple tooth decay to life-threatening carcinomas. Injudicious use of ionizing radiation may increase the exposure of a patient and this has been overcome with the use of magnetic resonance imaging. For the better evaluation of dental pathosis, there is a need for non-invasive and accurate diagnostic methods in clinical dentistry. The magnetic resonance imaging (MRI) technique, called Sweep Imaging with Fourier Transform (SWIFT), is used to visualize soft tissue and hard tissue imaging. The state of art, sweep imaging with Fourier transform is fast, quiet, and identifies issues with ultra-short relaxation times.

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INTRODUCTION

Diagnostic imaging in dentistry depends mostly on x-ray–based techniques that carry some risks and limitations such as exposure to ionizing radiation and its associated increased risk of cancer and the inability to visualize the pulpal tissue.[1] Three dimensional diagnostic imaging like cone beam computed tomography (CBCT) imaging system is more likely to increase in the field of endodontics.[1,2] However, besides exposure to radiation, such systems cannot simultaneously image calcified and noncalcified dental tissues, which is a significant limitation, particularly as regenerative endodontic procedures become more common in clinical practice.[3]

In a recent review of parameters used in diagnostic testing for assessing pulpal and periapical tissues, the following conclusion was highlighted: "diagnosis of dental pulp diseases suffers from the operator's inability to test/or image that tissue directly because of its location within a relatively hard tissue, dentin".[1,2] This review also outlined technical advances underway to address these limitations but did not include magnetic resonance imaging (MRI) techniques. This is justified because of the technical challenges with this diagnostic technique that severely inhibit endodontic application at this time, which is likely the reason behind the paucity of research on the topic.[3,4]

Diagnosing and monitoring disease in soft tissues without using ionizing radiation non invasively, MRI has become an indispensable tool. In biological tissues, the MRI signals measured arise from the spinning magnetic moments of the hydrogen nuclei in water molecules (hereafter called "water signal" or "signal").[4] The water signal is detectable after a radiofrequency (RF) pulse is applied, which causes the nuclear spins to resonate in the strong static magnetic field. Due to the high mineral content; minerals occupy 50% of a tooth's dentin and 90% of its enamel by volume, with water and proteins occupying the rest, conventional MRI cannot easily visualize teeth.

Also, because the water signal has a highly restricted molecular motion within these densely mineralized tissues, the signal decays very quickly after RF excitation.[6,7] The time constant describing the signal's free induction decay (FID) is known as the transverse relaxation time (T2). The FID of mineralized dental tissue has multiple components, with a mean T2 of about 200 microseconds for the dentin and 60 microseconds for the enamel.[7] These time intervals are less than those needed for conventional MRI pulse sequences to accomplish spatial encoding with pulsed magnetic field gradients, which typically requires more than 1 millisecond.[7,8] In other words, the signal from mineralized dental tissues decays before MRI signal digitization occurs, resulting in MRI images with little or no image intensity (black zone).[9] Consequently, conventional MRI techniques in dentistry have been restricted to imaging pulp, attached periodontal membrane, and other surrounding soft tissues or have required indirect imaging of enamel and dentin through contrast produced by MRI-visible medium. Clinical dentistry is in need of non-invasive and accurate diagnostic methods to better evaluate dental pathosis.[10] The purpose of this work is to assess the feasibility of a recently developed magnetic resonance imaging (MRI) technique, called Sweep Imaging with Fourier Transform (SWIFT), to visualize dental tissues.

Principle of SWIFT

The key innovation of SWIFT is the simultaneous signal acquisition and time-shared excitation which is acquired by inserting gaps into an FM pulse. An MRI image is acquired through the spinning magnetic moments of hydrogen molecules that are present in tissues as water molecules.[10]

A radiofrequency is then applied to detect the signals causing the spins to resonate in the strong magnetic field. Transverse relaxation time (T2) is the time constant used to describe the signals' free induction decay (FID). The FID value of enamel and dentin has multiple components with a mean T2 of 200 µs for dentin and 60 µs for enamel which is very short when compared to the time interval needed for the standard MRI to acquire spacial encoding with pulsed magnetic field gradients which is typically more than 1 ms.10 Solid-state MRI techniques such as single-point imaging and stray field imaging techniques are used in imaging mineralized structures.[11] Rapid acquisition with relaxation enhancement and echo-planar imaging are the multi-echo imaging methods used for the rapid acquisition of data. However, these methods depend on tissues with relatively long T2 for multiple data acquisition.

SWIFT is an advanced imaging technique that overcomes most of these difficulties in detecting fast relaxing signals by using low peak amplitude and also is feasible for in vivo studies.[10]

The basic principle involved in SWIFT is the simultaneous excitation and signal acquisition in a time-shared mode which is achieved in a field gradient by inserting gaps into an FM.[11,12] With simultaneous RF excitation and signal acquisition, SWIFT obtains signals from densely calcified tissues that have fast decaying signals, produces less distortion in the presence of materials that have magnetic susceptibility, and is less sensitive to motion artefacts, overcoming three significant barriers inhibiting MRI use for dental applications.

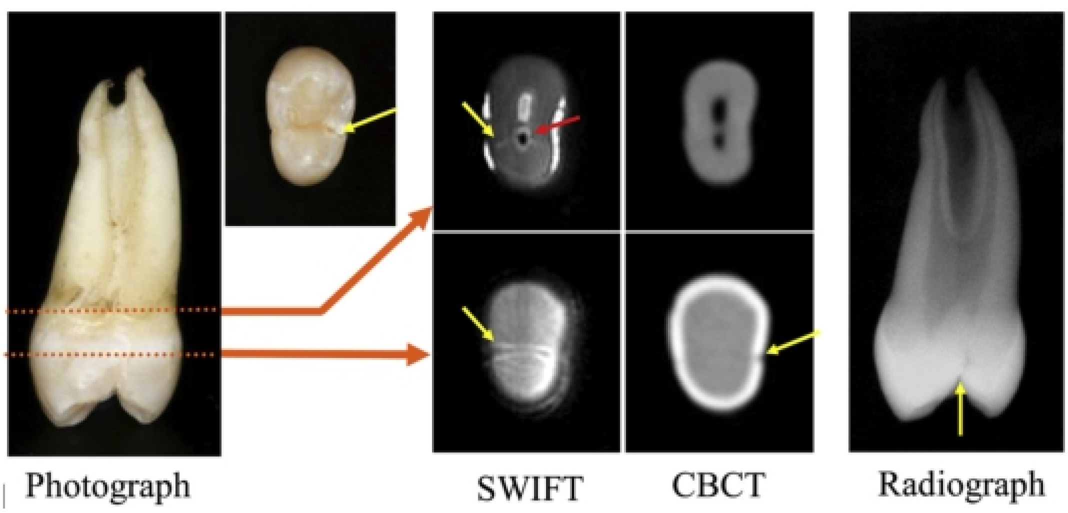
Unlike "adiabetic pulse" in which the carrier frequency during the pulse varies with time, SWIFT uses a frequency where the power is dropped thereby producing a small tip angle for spin excitation.[13] The transmitter and the receiver are alternatively switched on and off with only 1-2 µs of signal acquisition delay in between them. This allows efficient imaging of tissues with a short T2 value.[11,12] The repetition time TR is accordingly comparable with the pulse length resulting in a shorter acquisition time. This gapped FM pulse is applied repeatedly in the magnetic field changing its orientation with each TR in a stepwise manner resulting in almost continuous gradients with low stress and relatively quiet operation.[13]

SWIFT can simultaneously image both hard and soft dental tissues with high resolution in short enough scanning times to be practical for clinical applications.[12] With SWIFT, minute details not observed with currently available clinical imaging techniques can be visualized within three dimensions without the use of ionizing radiation. Also, at present, there does not seem to be an acceptable method for in vivo evaluation of the contribution accessory canals, filled or unfilled, have on the outcome of endodontic treatment, which is a clinical issue that may also be able to be addressed with the development of dental MRI.[12] Moreover, SWIFT-based MRI has the potential to precisely determine the extent of carious lesions and simultaneously assess pulpal tissue, which would be an important step toward being able to distinguish between reversible and irreversible pulpitis.

Applications

Tooth anatomy and dental caries

Applications of MRI in imaging teeth are broadly classified into hard tissue imaging and soft tissue imaging.[13] Hard tissue imaging, in particular, remains challenging because of less water content in enamel and dentin and the T2 relaxation times of water in these tubules are very short. Studies have shown that imaging teeth with SWIFT, which helps in acquiring such ultra-short T2 relaxation times, not only



gives well-resolved tooth anatomy, delineating enamel, dentin and pulp but also detects early carious lesions.[14] It clearly demarcates the extent of demineralization which is not acquired by any of the radiographic methods. The relative variation in the intensities of enamel, dentin and pulp is in the order of 10:35:100 owing to the amount of water (8:20:100) in these structures, respectively.15 The finest details of the tooth-like accessory canals are identified with help of SWIFT images which are not visualized by standard radiographic techniques.

Restorations and calcifications in pulp

Composite restorations are generally demarcated as radiopaque or radiolucent as they contain varying amounts of minerals or heavy metals. Hence, conventional radiographic methods have difficulty in detecting recurrent caries when present adjacent to the radiolucent restoration or when present in the gingival margins of the restoration.[15] Fortunately, the composite resin materials exhibit short T2 relaxation times and hence easily be detected on swift images.[16] It also helps in demarcating reparative dentin which is formed as a result of past lesions thereby reducing the misconception of existing recurrent caries and multiple restorations. Moreover, in contrast to CBCT images, the presence of restorative materials does not seem to cause image distortion in SWIFT.

Detect microcracks in teeth

Detection of microcracks in teeth is mainly done by visual findings in conjunction with other methods such as transillumination, magnification, or using dyes.[17] These methods lack the ability to determine the exact extent and detect the cracks that are within the roots or are apical to restorations. SWIFT MR image helps in visualizing cracks which are as small as 20 µm as the water content in the cracks results in a positive enhancement of the contrast and also have the advantage of minimum artefacts due to any adjoining restorations.[18]

Detection of oral cancer

SWIFT MRI aids in the three-dimensional assessment of medullary and cortical bones in the finest detail and also has the potential to detect mandibular invasion, and the results were found to be in excellent qualitative agreement with histopathological findings.

Implantology

Taking the advantage of SWIFT MR imaging which helps in imaging ultra-short relaxation times of hard tissues such as bone not only aids in accurately visualizing the density of the bone during the initial planning of implant placement but also helps in assessing the success of implant placements.[19]

Advantages of swift over standard MRI

SWIFT has the advantage of not only acquiring the images of tissues with ultra-short T2 relaxation times but also is fast, avoiding associated delays of refocusing pulses and time required for an excitation pulse.[20] It demonstrates little or no motion artefacts because it does not have echo time and less distortion due to dental restorations. It is quiet, uses TR in a stepwise manner, and hence can be used in patients with ligyrophobia. This technique is unique in imaging both hard and soft tissues simultaneously with high resolution detecting even minute pathological and anatomical abnormalities.[21]

CONCLUSION

SWIFT imaging is a fast and newer imaging modality that offers simultaneous three-dimensional imaging of soft and hard tissues of the teeth without the use of ionizing radiation. This modality has many important applications in the field of dentistry with some powerful features such as its ability to visualize hard tissues such as enamel, dentin, and bone and offer a nearly silent operation reducing anxiety in claustrophobic patients.

Furthermore, it has the potential to image minute dental structures within clinically relevant scanning times. This technology has implications for endodontists because it offers a potential method to longitudinally evaluate teeth where pulp and root structures have been regenerated. But more in vivo trials are to be done to demonstrate its application in regular diagnostic imaging.

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