Nuclear Magnetic Resonance Imaging in Endodontics: A Review

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Abstract

Introduction: This review analyzes the increasing role of magnetic resonance imaging (MRI) in dentistry and its relevance in endodontics. Limits and new strategies to develop MRI protocols for endodontic purposes are reported and discussed. **Methods:** Eligible studies were identified by searching the PubMed databases. Only original articles on dental structures, anatomy, and endodontics investigated by *in vitro* and *in vivo* MRI were included in this review. Original articles on MRI in dentistry not concerning anatomy and endodontics were excluded. **Results:** All the consulted studies showed well-defined images of pathological conditions such as caries and microcracks. The enhanced contrast of pulp provided a high-quality reproduction of the tooth shape and root canal *in vitro* and *in vivo*. Assessment of periapical lesions is possible even without the use of contrast medium. **Conclusions:** MRI is a nonionizing technique characterized by high tissue contrast and high image resolution of soft tissues; it could be considered a valid and safe diagnostic investigation in endodontics because of its potential to identify pulp tissues, define root canal shape, and locate periapical lesions. *(J Endod 2018;■:1–7)*

Key Words

Dental anatomy, dental magnetic resonance imaging, endodontics, magnetic resonance imaging

Significance

Potentially, MRI can reproduce not only hard and soft dental and periodontal tissues, but it can also differentiate their peculiar attributes in pathological and nonpathological conditions. Peculiar anatomical aspects, such as the presence of lateral canals or microcracks, can be visualized.

Three-dimensional (3D) images of the human skull are currently acquired by computed tomographic, cone-beam computed tomographic (CBCT), and magnetic resonance imaging (MRI) devices (1). MRI has become fundamental for noninvasive diagnosing of soft tissue diseases without using ionizing radiation. It is almost comparable with CBCT imaging in terms of spatial resolution and offers the possibility to visualize data in cross-sectional and panoramic views more familiar to dentists. MRI is based on nuclear magnetic resonance (NMR) spectroscopy whereby an electromagnetic field in the radiofrequency (RF) range is used to stimulate the spins of hydrogen nuclei that are immersed in a strong magnetic field (B_0). Because of nuclear paramagnetism, these spins align themselves parallel and antiparallel to the B_0 direction. The most numerous spin population with the same orientation to the B_0 generates the macroscopic magnetization (M_0). The RF stimulation moves the magnetization M_0 from the direction parallel to B_0 to the direction perpendicular to B_0. When the spins of the hydrogen nuclei are no longer stimulated, they return to their initial position, creating signals that are received by the RF probe as electromotive force. The acquired signal decays exponentially in time because of spin-spin and spin-lattice relaxation processes, which are quantified by the parameters T2 and T1, respectively. Moreover, the signal is characterized by a unique frequency response that provides physical-chemical information about the investigated tissues.

Superimposing over the main magnetic field time-dependent and controlled magnetic field gradients, images are obtained similarly to computed tomographic scanners (2, 3). By manipulating the length and shape of the RF pulses that excite the nuclear spins or the direction and strength of the field gradients, a specific plane or volume of interest can be selected in different orientations.

In particular, a 3D MRI scan is composed of several 2-dimensional images of a selected thickness. NMR signals are processed by a computer that constructs the MRI images (essentially a map of the spatial distribution of hydrogen nuclei) using algorithms based on the Fourier transform (4, 5).

MRI in dentistry is currently performed most commonly for diagnosing temporomandibular joint disorders and to evaluate the extent of tumors and osteomyelitis (6). Because MRI does not use ionizing radiation, it is particularly relevant for repeated examinations in children (4, 7). It has also been proposed for diagnosis, treatment planning, and evaluation of outcomes in endodontics. The aim of this review was to show potential applications of MRI in endodontics and highlight current advantages and limitations in clinical use.

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Materials and Methods

A search for original articles on dental MRI was performed using PubMed electronic databases. Three hundred twenty-two articles were screened, and only 38 studies were included. Only articles on dental structures, dental anatomy, and endodontics investigated by the use of *in vitro* and *in vivo* MRI were included. Articles on joint disorders, orthodontics, and prosthetics not concerning dental and root anatomy were excluded.

Results

All of the included articles showed that dental MRI is capable of obtaining a well-defined image of dental structures like enamel, dentin, pulp, and periodontal tissues. Dental MRI can also recognize pathological conditions such as decay, microcracks, and necrotic pulp tissues, and it can differentiate solidlike periapical periodontitis from a cystic lesion because of its capacity to discriminate hydrated tissues.

Discussion

Signal-to-noise Ratio and Image Resolution

Signal-to-noise ratio (SNR) and resolution are 2 fundamental parameters for dental MRI. SNR is measured by calculating the ratio between the signal intensity in an area of interest and the standard deviation of the signal from the background (in an area chosen from the object).

The image resolution is quantified by the image voxel size. More specifically, the base area of the voxel provides the in-plane resolution of the image, whereas the height of the voxel is determined by the slice thickness of each bidimensional image. Image resolution depends on magnetic gradients' strength of imaging gradients. In clinical scanners, the maximum gradient strength is around 40 mT/m and 80 mT/m depending on NMR companies and the scanner model.

SNR is proportional to the volume of the voxel and the square root of the number of averages (NA). Because averaging takes time, SNR is related closely to the acquisition time.

In MRI, SNR can be improved by increasing the voxel size, reducing the bandwidth using surface coils, using an echo time (TE) of spin-echo sequence as short as possible, and increasing the number of signal acquisitions (NA). In particular, the voxel size can be increased by increasing the field of view (FOV), decreasing the matrix size, and increasing the slice thickness.

On the other hand, assuming constant magnetic gradient strength, all the aforementioned actions that increase SNR decrease the image resolution. Therefore, new strategies should be used to perform dental MRI with a good compromise between SNR and image resolution.

RF and Imaging Gradient Coils

A good strategy to reduce FOV for increasing the image resolution without lowering the SNR is to use dedicated RF coils. Head or neck coils cannot reach the resolution needed for practical dental applications; extraoral placement of the coil can result in images that will contain more signals from less important tissues such as the fat of the cheek. In other words, head-neck RF coils provide a large FOV that, together with the limited imaging gradient strength of clinical scanners, can provide an image with a maximum in-plane resolution of $300 \times 300\ \mu m^2$.

Intraoral positioning of the RF coil may increase both resolution and SNR, but it can be difficult to implement because of anatomic structures such as tori and frenula that will prevent the most distal elements or root tips of the teeth from appearing in the acquired volume. One of the most comfortable coil positions was proposed by Idiyatullin et al (8), who explained the advantages of using a loop coil in the occlusal position for dental applications. The coil's shape is similar to an impression tray, and it can be kept in the mouth between dental arches (8). The high patient comfort and the increased signal sensitivity of a dedicated coil may be helpful for implementing future imaging sequences needing very high excitation and receiving bandwidths (9).

Artifacts

A study on the affection of dental materials on the NMR signal (10) showed that composites, amalgam, gold, and nickel-titanium alloys can produce relatively strong artifacts; stainless steel brackets or wires can produce voids in the signal. These materials may alter the precession frequencies of hydrogen nucleus spins and distort the linear magnetic field gradients, resulting in signal loss from spin dephasing and mismapping artifacts associated with frequency shifts. Glass ionomer cement, gutta-percha, zirconium dioxide, and some composites appear to be fully compatible with MRI because they can be present even in the tooth of interest without creating significant artifacts (7, 11, 12). Polycarboxylate, zinc phosphate–based cement, and some modified dimethacrylates can also produce small image artifacts (7).

Technical Issues

The NMR signal decays over time because of the spin-spin relaxation, quantified by the parameter T2, indicating how quickly the signal is canceled (goes to 0), and the spin-lattice relaxation, quantified by the time constant T1, indicating how quickly the system returns to the initial equilibrium state (ie, the one it had before absorbing RF).

Conventional MRI performed with clinical scanners is characterized by hardware and software to acquire signals with T2 higher than 2 milliseconds. Because T2 relaxation time of human enamel runs from about 14 to 61 microseconds and in mineralized dentin only $\sim$10% of the NMR signal exceeds 250 microseconds (13, 14), the mineralized tissues such as dentin and enamel will result in a black zone because of the impossibility of capturing their signals by the device (15). Conversely, pulp and periodontal tissues, which are soft tissues and therefore more hydrated, will be acquired properly and appear white or gray in the NMR image (16).

In vitro studies can reach better performance in terms of resolution because of the higher SNR provided by a high magnetic field (higher than 7 T), a higher magnetic field gradient (higher than 300 mT/m), reduced FOV, the possibility of carrying out many of the signal averages (NA) (15), and the possibility of using MRI acquiring sequences with very short echo times (TE) (17). For these reasons, the development of *in vitro* studies is highly desirable in the future.

MRI Diagnosis of Dental Caries

Microscopic MRI seems to be well suited to studying the development of dental caries; it is nondestructive and noninvasive, does not use ionizing radiation, and leaves tissues available for further investigations (18). To visualize mineralized tissues of the teeth, some authors proposed techniques based on short TE time acquisition such as stray field imaging, single and multinuclear solid-state techniques, single-point imaging, sweep imaging with Fourier transformation (SWIFT), zero echo time imaging (ZTE), ultrashort echo time (UTE) imaging, and free induction with steady-state procession, but, actually, none of these techniques can produce satisfying diagnostic images of calcified tissues within reasonable scanning times (19–21).

In contrast to conventional MRI sequences, Hövener et al (22) showed that a ZTE acquisition protocol could clearly represent soft tissues as well as solid-state components. In addition, the contrast provided by the ZTE sequence allows differentiation between the dental