MRSO Exam Prep Course

Module 8

Slowly Changing Gradient Magnetic Fields

Gradients in magnetic resonance (MR) imaging play a crucial role in spatial encoding and signal generation. They are sets of electromagnets strategically positioned behind the walls of MR scanners. Gradients work by predictably distorting the main magnetic field, causing protons' resonance frequency to vary based on their position.

It's important to note that the strength of the magnetic fields produced by the gradients is less than 3% of the main magnetic field B_0, meaning their static effects on the imaging process are negligible. However, the time rate of change of these gradient fields, denoted as dB/dt, can give rise to potential safety concerns in MR imaging due to rapid fluctuations.

In a typical cylindrical MR scanner, three sets of gradient coils are utilized – one for each of the x-, y-, and z-directions. These gradients are usually constructed from thin wires or foil sheets arranged in a "fingerprint"-like pattern. They are held together using epoxy resin and encapsulated into an assembly that also integrates cooling channels for efficient operation.

The x- and y-gradient coils are paired and positioned on opposing sides of the isocenter. This arrangement results in the highest values of dB/dt being located eccentrically near the ceiling and walls, typically around ±30 cm from the isocenter. Notably, the peak values of dB/dt adjacent to the wall can be about three times greater than those observed in the center of the scanner at the same z-axis position.

High voltage and high current amplifiers are used to power these gradient coils. Typically located in an adjacent equipment room, these amplifiers can deliver voltages of up to 1500V and currents of several hundred amperes. During normal operation, the gradients are rapidly switched on and off, with slew rates reaching as high as 200 T/m/s. The swift changes in current flowing through the coils lead to two significant physical effects: mechanical vibration of the gradient system, and induced currents in nearby conductive materials, both proportional to dB/dt in line with Faraday's Law.

Section 8.1 Acoustic/Auditory Considerations

The vibration of gradient coils due to rapidly switched electrical currents produces sound waves during routine MR imaging. Some sequences (especially echo-planar imaging) generate sound pressures as high as 110-130 dB. In general, 3T scanners are noisier than those operating at 1.5T.

In addition to being painful, acoustic noise at the higher end of this range may cause temporary or permanent hearing loss. Even noise of lower intensity may cause anxiety or distress in patients, especially infants, young children, and the elderly. This may manifest as patient motion artifacts and degraded image quality.

Short-term exposure to intense (100+ dB) noise may result in **temporary threshold shifts (TTS)** and impaired hearing that typically lasts 15 minutes or less. However, some MR patients have experienced TTS with tinnitus lasting days or weeks.

There are no precisely agreed-upon limits for sound exposure related to MRI. In the US, the Occupational Safety and Health Administration (OSHA) has defined permissible noise exposures for workers based on length of exposure. Applying these limits to typical MRI timeframes, noise exposures should not exceed 115 dB for 15 minutes of exposure down to 105 dB for 60 minutes. At no time should peak noise exposure exceed 140 dB. Because of this risk, ear protection should be offered to all patients (and accompanying family members) undergoing MRI examinations. The International Electrotechnical Commission (IEC) requires that ear protection should reduce exposure levels in MRI to below 99 dB. (Typical foam earplugs provide approximately 25 dB of noise reduction).

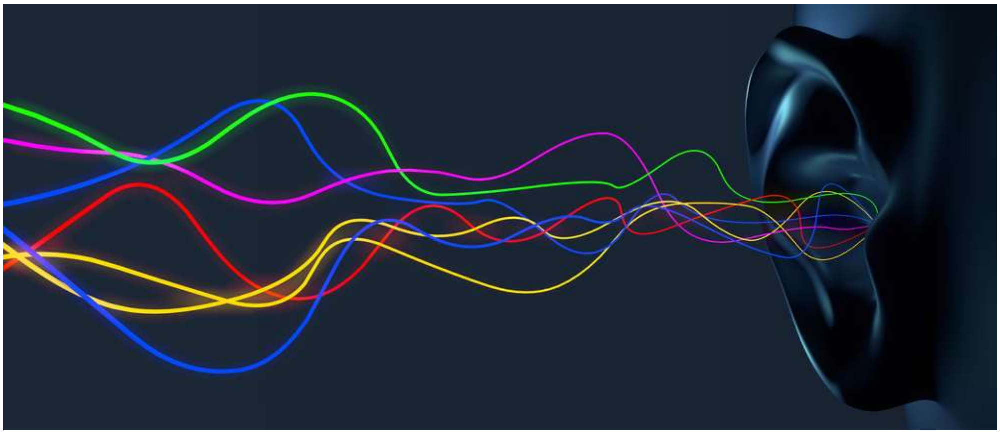

Image 8.1

Section 8.2 Acoustic Noise Control Techniques

8.2.1 Passive Noise Control

Encourage the routine use of earplugs or headphones during MR procedures as the most convenient and least expensive way of reducing difficulties caused by acoustic noise. When properly applied, earplugs can reduce noise by 10 to 30 decibels (dB), which is usually enough sound attenuation for the MR environment. The following items can be used as passive noise control:

- Earmuffs
- Headphones
- Disposable earplugs

Noise reduction ratings are assigned to earplugs. The noise reduction rating is between 25 and 33. Subtracting seven and dividing by two yields the number of decibels lowered for each noise reduction rating. As a result, a noise reduction rating of 25 equals 9 dB.

The type and design of ear protection utilized will affect the amount and frequency range of noise reduction. The protector should be tested if data is lacking for noise abatement. Because hearing protectors come in a variety of styles, caution should be exercised while recommending them to patients. Instructions for proper fitting must be provided.

Patients who are confused, young, or have trouble adequately fitting hearing protection may require further assistance to avoid poor fitting and noise attenuation. If you use earmuffs or headphones, check for wear on the seals on a regular basis and replace them if necessary.

8.2.2 Active Noise Control (ANC)

The adoption of active noise cancellation (ANC) or "anti-noise" technology has resulted in a significant reduction in the level of acoustic noise created by MR techniques. Unlike many other noise reduction techniques, which have a negative influence on the MR method or hardware, this technique has a negligible impact on the MR system's performance.

Using a feedback control technique, the adaptive ANC controller seeks to minimize the erroneous signal power. A zone of calm will form around the faulty microphone if this minimizing is successful.

8.2.3 Minimizing the Gradient Effects

Reducing the level of gradient pulsing in a pulse sequence can also help to reduce acoustic noise levels. **STEAM-Burst** is a single-shot approach based on stimulated echoes that do not require the quick gradient switching that other single-shot techniques, such as echo-planar, require. The STEAM-Burst sequence combines the Burst approach, which involves firing repeated RF pulses at a constant gradient and then focusing on the echoes that occur, with the STEAM-stimulated echo collection mode. When compared to a similar EPI sequence, the peak noise attenuation is 15 dB, according to limited data on acoustic noise measurements.

Image 8.2

Section 8.3 Peripheral Nerve Stimulation

Faraday's Law states that the rate of change of the magnetic gradient field (dB/dt) is inversely correlated with the strength of the electric field (E), causing nerve or muscle depolarization. Peripheral Nerve Stimulation (PNS) is the electrical voltage potential caused by rapidly varying magnetic gradients that stimulate nerves in the extremities. When PNS is minor, it may be felt as a tingling or tapping sensation, which frequently surprises the patient but poses no significant discomfort or risk to their physical safety. Motor neuron depolarization causes increasingly intense and painful muscle fasciculations/contractions as stimulation intensity rises. In animal models, very high exposure levels (much above those that people would experience in the present generation of MR scanners) might cause stimulation of cardiac Purkinje fibers with arrhythmias.

Some of the largest gradient fields may occur outside the field of view in pulse sequences using rapid gradient switching, such as echo planar, turbo-SE, or SSFP techniques. It is essential to consider contributions from all three gradients (x-, y-, and z-) to determine the full effect.

The ramp-up and ramp-down portions of the gradient waveform are when dB/dt (and consequently E) are maximum. The strongest generated E fields are often seen in the patient's more exposed areas, where more peripheral nerves are present. E fields are also concentrated near metallic implants or tissues with various conductivities (bone, fat, and muscle).

To understand this better, we can look back at Faraday's Law of Induction, which states that a changing magnetic field can produce an electrical current in a wire or conductive substance. In the context of MRI, the time-varying gradient field changes the magnetic field on a kilohertz scale, which is not enough to cause warming in our patients but can generate an electrical current.

The slew rate, which describes how quickly the gradient coil turns on and off, is a crucial factor in determining the risk of PNS. The higher the slew rate, the greater the chance of PNS.

Gradient coils are placed in three planes around our patients, with one set placed anterior to posterior, another set at left to right, and a third set at the head and foot. The area of the patient that experiences the most significant change in magnetic field from the gradient coils is located beneath the active gradient coil. This region, known as the isocenter, is where the tissue is most vulnerable to peripheral nerve stimulation.

Therefore, as MRSOs, we must take precautions to minimize the risk of PNS in our patients. We can do this by using appropriate gradient coils, monitoring the slew rate, and adjusting the MRI parameters.

Pulse sequences influence the degree of peripheral nerve stimulation produced in our patients. Depending on the MRI pulse sequence, you may either enhance or reduce the likelihood of stimulation. Surprisingly, when we choose a pulse sequence that minimizes peripheral nerve stimulation, we usually choose one that enhances our patient's warmth and vice versa.

Gradient pulse sequences are viable for MR technicians who want faster imaging than a spin echo sequence. The standard gradient echo uses a single 90° radiofrequency pulse followed by a series of shifting gradient fields. These shifting gradient fields are typically not fast enough to generate significant peripheral nerve stimulation and do not cause pain in patients.

The Echo Planar Imaging (EPI) pulse sequence is a technique that utilizes rapidly changing magnetic fields. This sequence uses fast-shifting magnetic fields to cover the entire k-space in one or more repetitions. The gradients must change quickly to accomplish this, resulting in a significant possibility of peripheral nerve activation. The diffusion-weighted imaging (DWI), perfusion imaging, and fMRI pulse sequences all employ the EPI approach.