The specific absorption rate (SAR) is a measure of the energy deposited per unit time in a specified tissue by the radiofrequency (RF) pulses applied in MR. When the human body is exposed to an external magnetic field, there exist two different energy levels that a proton (the hydrogen nucleus) can occupy. In quantum mechanical terms, the spin of the proton can either be parallel or antiparallel to the direction of the magnetic field. To receive a signal in MR, an RF excitation pulse is first applied that provides exactly the energy difference between the parallel and antiparallel levels. After excitation, the spins return to their original state, emitting the energy as an MR signal. The RF pulse will also interact with water molecules, accelerating their rotational motion. An increase in motion is equivalent to an increase in kinetic energy and represents an increase in temperature. The likelihood of this interaction scales with the fifth power of the patient’s circumference. Thus SAR is of even greater importance for the obese patient. It is also critical to note that doubling the main magnetic field from 1.5 to 3 T leads to a quadrupling of SAR if RF excitation is performed in the identical manner. Considerations related to SAR, therefore, inherently limit scanner performance by limiting the rate of RF energy deposition and cumulative deposition, in particular at higher field strengths (such as 3 T). This can lead to a reduction in slices per repetition time (TR), longer scan times, and “cooling” delays between acquisitions, if not otherwise compensated, an early challenge to clinical imaging at 3 T.

Heat deposition in MR is regulated by an international standard, specifically IEC 60601-2-33 (September 2001). As general background information, the order of magnitude of heat/power deposition during MR imaging is close to the human basal metabolic rate. Two SAR thresholds were established relevant to clinical imaging: normal mode and first level. Exposure below the normal-mode SAR level is assumed to cause no physiologic stress to the patient. For SAR values within the range of the first level, medical supervision of the patient is required. Specifically, the MR operating software must indicate that it has to switch into first level to execute the requested scan protocol, and the operator must acknowledge the note in order for the system to continue.

**Normal Mode**
- Up to 2 W/kg whole-body exposure
- Up to 2 to 10 W/kg partial-body exposure, depending on the ratio between exposed and unexposed patient mass
- Up to 3.2 W/kg for head exposure
- Up to 10 W/kg for local SAR within the head/trunk region
- Up to 20 W/kg for local SAR values within the extremities
- Body core temperature is not to increase beyond 0.5°C

**First-Level Mode**
- Up to 4 W/kg whole-body exposure
- Up to 4 to 10 W/kg partial-body exposure, depending on the ratio between exposed and unexposed patient mass
• Up to 3.2 W/kg for head exposure
• Up to 10 W/kg for local SAR within the head/trunk region
• Up to 20 W/kg for local SAR values within the extremities
• Body core temperature is not to increase beyond 1°C

Values are averaged over a 6-min time frame. For a period of 10 sec, the average SAR may exceed up to 3 times the level of the current mode. These levels are valid for a bore temperature of up to 77°F and decrease linearly to 0 for the normal mode and 2 W/kg for the first level for a bore temperature of 91.4°F.

The software on any commercial MR system will calculate and compare all possible limits for the selected mode and will in general indicate the most critical value. If the critical value exceeds the level of the selected mode, suggestions are made to the operator regarding which scan parameters to change (and to what value) to stay within the guidelines. No MR system will allow the execution of a protocol that exceeds the guidelines of the country where the scanner is located.

Some strategies that are used to limit SAR, for example reducing the flip angle of the refocusing pulse in fast spin echo (FSE) imaging, can affect both image contrast and SNR. Despite this limitation, reduction of the flip angle for the refocusing pulse is commonly used. It should be noted that SAR is proportional to the square of the value of the flip angle. Another common approach in fast spin echo imaging is to employ a TR that is longer than the minimum necessary, thus in effect building in cooling time at the expense of only a slightly longer scan time.

Parallel imaging can be an important method of reducing RF deposition by decreasing the number of phase-encoding steps that are performed (per unit time) in a given scan. The trade-off in SNR (a parallel imaging factor of 2 reduces SNR by 40%) can be balanced by the higher SNR of 3 T and by the further improvement in SNR provided by multielement coils (see Case 109) now available.

Another technique for managing RF deposition is to interleave SAR-intensive sequences with low-RF deposition scans, for example, to follow a long-echo train, fat-suppressed FSE scan with a 2D gradient echo acquisition before starting the next FSE scan. This technique has limited utility for most current applications but is of some value, particularly for body imaging on early-generation 3 T systems.

Innovative methods of reducing SAR without compromising imaging have recently become available clinically. New short-bore magnet designs can be, when correctly designed, more SAR efficient than were earlier-generation long-bore systems, as less of the body is exposed to the shorter body coil transmitter. Innovations in RF chain technology (and in particular in the design of the RF transmitter) have also improved the efficiency of energy deposition with a resultant formidable net reduction in SAR.

Advances in pulse-sequence design, such as reshaping RF and gradient waveforms (variable rate selective excitation [VERSE]), can reduce peak RF power up to 60% compared with that of conventional techniques. Innovative imaging techniques such as SPACE (see Case 37) have also been developed that lead to substantially lower SAR deposition (due to extensive use of low flip angle refocusing pulses, employed in a sophisticated manner), without the penalty of SNR loss.