lso warrants mention that higher B_0 values are associated with higher system invest-
ment and life cycle costs.

n what follows, we offer a summary of the relevant physical constraints (in the order
of their importance).

F losses heating the patient (*SAR*) and required peak RF power

ccording to Maxwell's equations, an electric field E is always connected to a time-
arying magnetic field:

$$\oint \vec{E}\,\mathrm{d}r = -\int_F \frac{\partial \vec{B}}{\partial t}\,\mathrm{d}\vec{F} \qquad (15.8a)$$

his yields the following for a homogeneous magnetic field B_1 varying harmonically
n time:

$$2\pi r_\perp E = -\pi r_\perp^2 \omega \hat{B}_1 \qquad (15.8b)$$

he electric field $\vec{E}$ causes eddy currents of density $\vec{j}$ inside conductive objects (con-
ductivity σ), such as the human body, that increase linearly along with the distance $r_\perp$
rom the object's center:

$$\vec{j} = \sigma\vec{E} \qquad (15.9)$$

he electric power losses thus amount to

$$P = \int_V \vec{j}\,\vec{E}\,\mathrm{d}V = \int_V \sigma E \mathrm{d}V = \frac{\sigma}{4} B_1^2 \omega^2 \int r_\perp^2 \mathrm{d}V. \qquad (15.10)$$

he RF transmitter will be required to compensate for these losses. RF losses in the pa-
ient are proportional to MR frequency squared and can create heat.

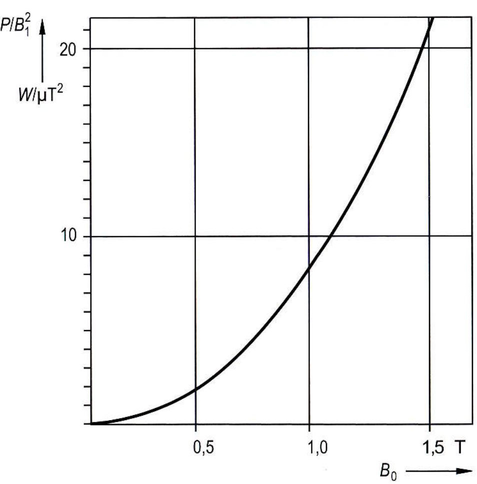

Figure 15.3
Absorbed RF power per B_1^2 by an average person weighing 70 kg as function of the main magnetic field B_0 when imaged with proton MR applying a circular polarized RF field B_1.

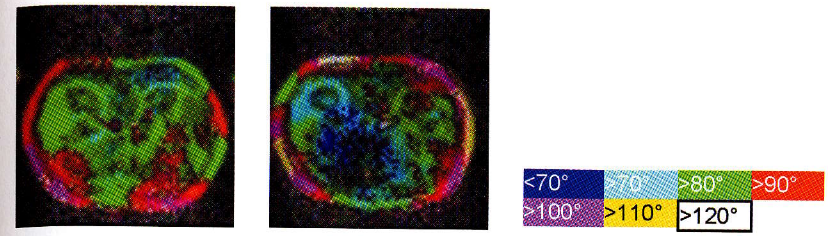

Figure 15.4
Flip angle distribution due to an inhomogeneous B_1 field in a human object at 63 MHz **(left)** and 126 MHz **(right).**

National and international standards have been introduced to restrict the exposure o
humans to RF heating (see fig. 15.3). For instance, the IEC standard 60601-2-33 which
has been adopted by most national regulatory authorities requires that the whole
body specific absorption rate (*SAR*) may not exceed 2 W/kg (or 4W/kg under special su
pervision of the patient). The lower limit can cause limitations in the repetition rate o
short high peak power 180° pulses at 1.5 T or 63 MHz. Here, it warrants bearing in
mind that the required RF transmitter's peak power capacity also increases. While
15 kW might be considered sufficient to support 180° pulses of 0.5 ms at 1.5 T, one
would need approximately 60 kW to perform the same sequence at 3 T. This high pow
er would introduce considerable challenges, not only for RF transmitter design, bu
also for transmitter resonator design (seeing as how the latter would be required to
withstand the high RF voltage of several kV).

RF object penetration, dielectric resonance effects

Conductive material such as human body tissue also prevents the penetration of the
electromagnetic RF field. This is referred to as the skin effect. Penetration depth de-
creases along with increasing frequency. The explanation for this phenomenon is the
same as that for the power losses discussed above: eddy currents weaken the effect of
the RF field by shielding the inner portions of the body. The effect referred to as di-
electric resonance plays a similar role. The human body consists mostly of water with
a relative dielectric constant of $\varepsilon_r \approx 81$. The wavelength inside the body is therefore
shortened by a factor of 9 compared to that in free space. While the wavelength in free
space is around 2.4 m at 126 MHz (B_0 = 3 T), it is only 26 cm inside a watery object,
thereby clearing the way for the occurrence of standing waves that undermine the ho-
mogeneity of the RF field. This is shown in fig. 15.4, which offers a comparison of the
flip angle distribution at 63 MHz (1.5 T) and at 126 MHz (3 T).

Size, weight, fringe field and cost

A magnet's size, weight, fringe field (i.e. if a high field magnet is scaled from a medi-
um field magnet) and cost (for the system as well as for its infrastructure require-
ments) are likely to increase along with its field strength. While a degree of juggling
is permitted when combining these variables, it is impossible to gain anything with-