影像假影與磁振安全
A Course of MRI

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本週課程內容

- 影像假影(Image Artifacts)
- 磁振安全

影像假影

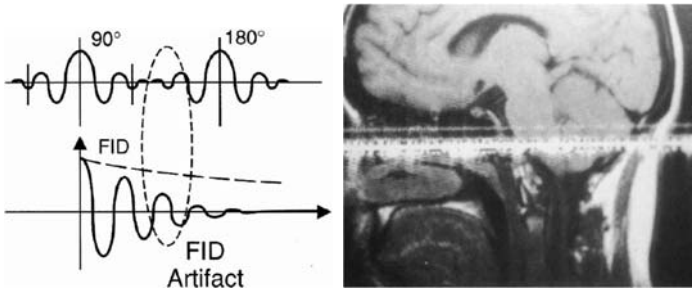
Image Artifacts

Hardware-related Artifacts

- Radio frequency (RF)-related artifact
  - Zipper artifacts
  - RF feedthrough
  - RF noise
  - Cross-talk
- External magnetic field artifacts
  - Magnetic inhomogeneity
- Gradient-related artifacts
  - Eddy currents
  - Nonlinearity
  - Geometric distortion

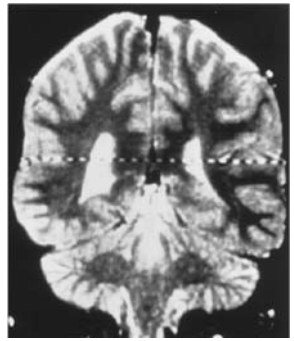
RF-related artifacts: Zipper artifacts

- along the frequency-encoding axis without phase encoded
- FID artifact: the overlapping of 180° RF pulse with the FID
- Stimulated echo: imperfect RF pulses of adjacent slices, imperfect 90°-180°-180° pulses



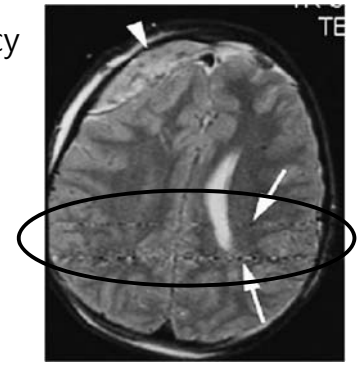
RF-related artifacts: RF feedthrough

- The excitation RF pulse is not completely gated off during data acquisition and feed through the receiver coil.
- Along the phase encoding axis at zero frequency
- Remedy: alternate the phase of RF pulsed by 180° on successive acquisitions.



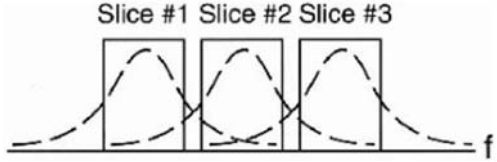
RF-related artifacts: RF noise

- Unwanted external RF noise (TV, radio station, electronic monitoring equipment)
- Occurs at the specific frequency
- Remedy: improve RF building, shut the door of MR room



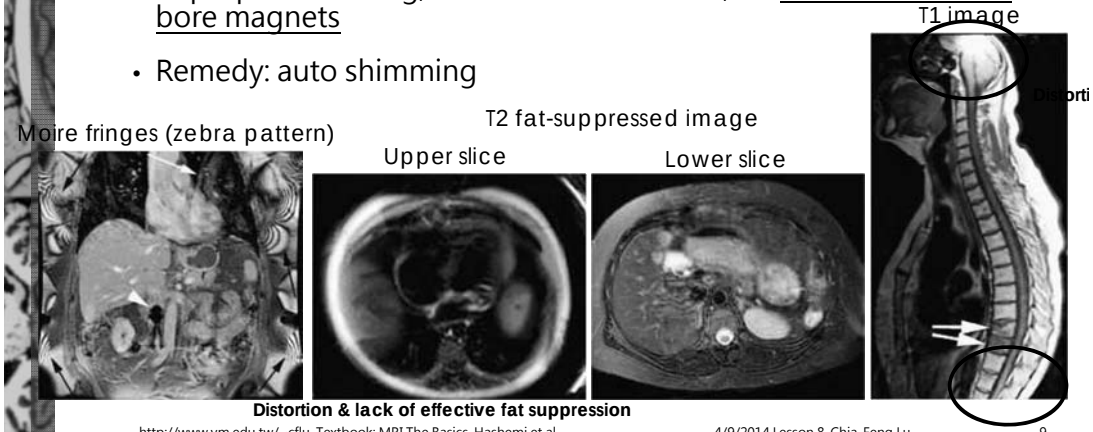
RF-related artifacts: Cross talk

- an imperfect rectangle of the FT of the RF pulse
- Decrease TR due to saturation of protons by the RF for adjacent slices.
- T1 weighting ↑ and SNR ↓
- Remedy: interleaving, increase gap, rectangular wave



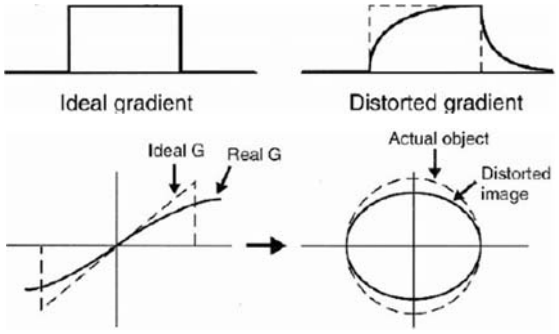
External magnetic field artifacts

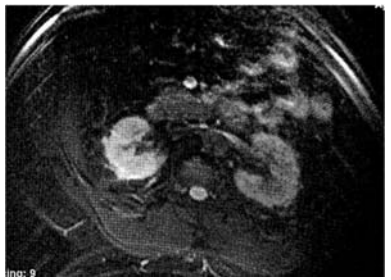
- Improper shimming, environmental factors, far extremes of short bore magnets
- Remedy: auto shimming



Gradient-related artifacts

- Eddy currents are generated when the gradients are rapidly switched on and off, resulting in a distortion in the gradient profile.



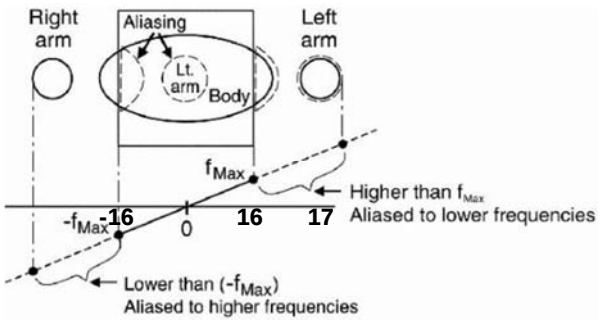


Software-related Artifacts

- Image processing artifact
  - Aliasing
  - Chemical shift
  - Truncation
  - Partial volume
- Errors in the data

Image processing Artifacts: aliasing

- Any frequency higher than the maximum frequency allowed by the gradient cannot be detected correctly.
- f(perceived)= f(true)-2f(Nyquist)



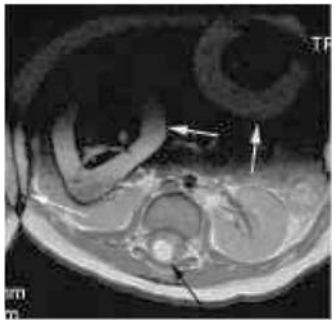


Image processing Artifacts: aliasing

- 2D imaging: along frequency-encoding or phase-encoding directions
- 3D imaging: in all three directions

3D axial imaging 3D coronal imaging

Kidneys in lungs!

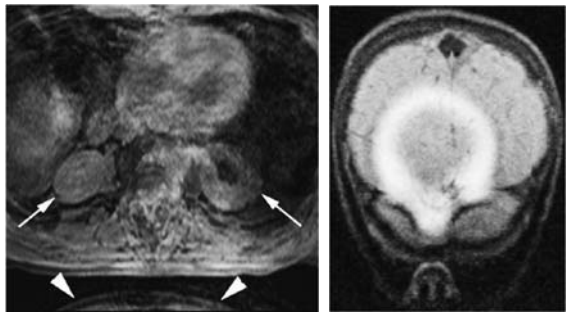


Image processing Artifacts: aliasing

- Remedy:
  - **Surface coil**: only get signal from FOV within the maximum frequency range
  - **Increase FOV** (not practical)
  - **Oversampling**: frequency oversampling (NFW), phase oversampling (NPW)
  - **Saturation pulses**: saturate the signals coming from outside the FOV

Image processing Artifacts: chemical shift

- The protons from different molecules precess at slightly different frequencies.
- The protons in H_2O precess slightly faster than those in fat (about 3.5 ppm).

- $\omega_0=\gamma B_0=(42.6\ MHz/T)(1.5T)=64\ MHz$
- $64\ MHz \times 3.5\ ppm = (64 \times 10^6\ Hz)(3.5 \times 10^{-6}) = 220\ Hz$
- $B_0 \uparrow$,chemical shift ↑

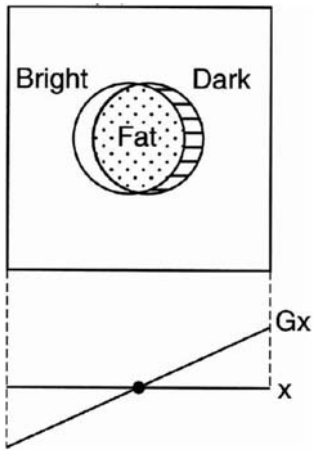
Image processing Artifacts: chemical shift

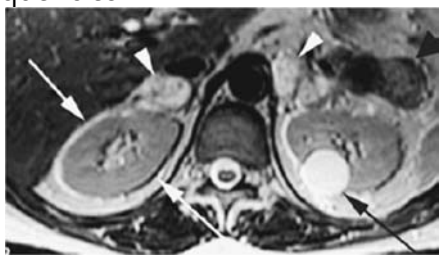
- BW = Nx/Ts = 256/8 msec = 32 kHz
- BW/pixel = 1/Ts = 125 Hz
- Pixel difference (H_2O/fat) = 220 Hz/ 125Hz = 1.76 pixels

- Fat protons are going to be misregistered from H_2O by about 2 pixels (in a 1.5 T magnet using a standard 32kHz bandwidth).
- $chemical\ shift(in\ mm) = \frac{3.5\times10^{-6}\gamma B_0 \times FOV}{BW}$

Image processing Artifacts: chemical shift

- Chemical shift artifact only occurs in the frequency-encoding direction.
  - A bright band toward the lower frequencies
  - A dark band toward the higher frequencies

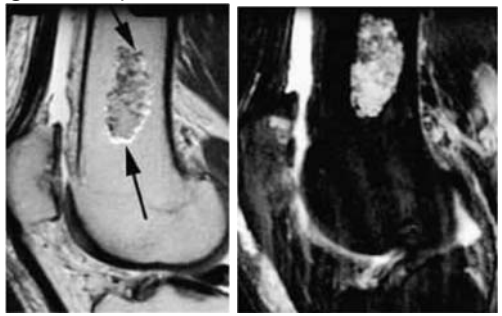




T2 FSE

Image processing Artifacts: chemical shift

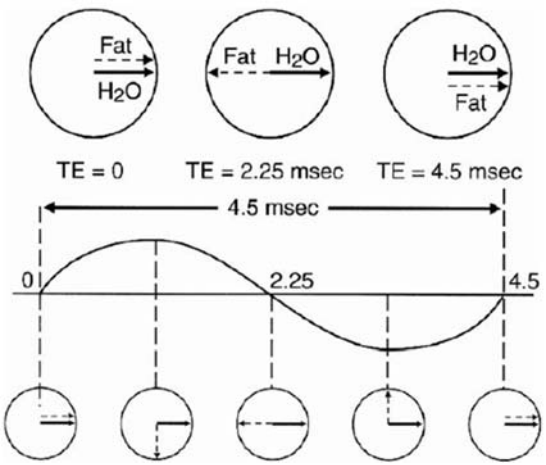
- Remedy:
  - Fat suppression
  - Increase pixel size by keeping FOV the same and decreasing Nx (spatial resolution ↓)
  - Lower the magnet's field strength (not practical)
  - Increase bandwidth (SNR ↓)
  - Use a long TE



T2 with/without fat saturation

Chemical shift of the second kind

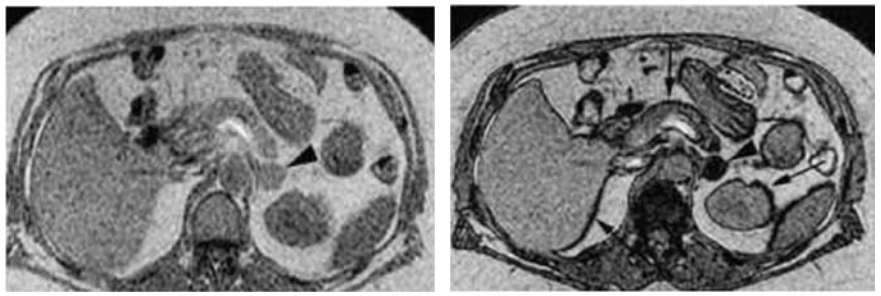
- 220 Hz at 1.5T:
- Fat and water are in phase every 4.5 msec.
- Only exist in GRE (without 180° rephasing pulse).
- Not only in the frequency-encoding direction



Chemical shift of the second kind

- Boundary effect (when out of phase)

In phase | Out of phase



Spoiled gradient T1 images

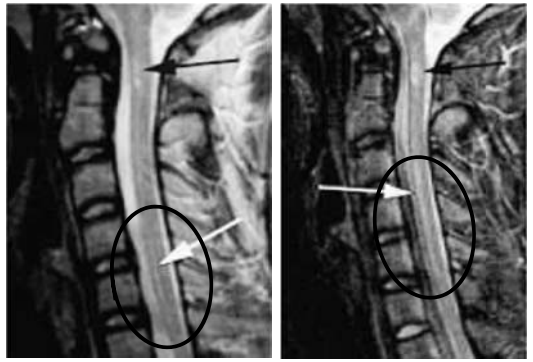
Image processing Artifacts: Truncation

- Truncation artifacts (Gibbs Phenomenon)
- Occurs at high contrast interfaces
  - Skull/brain, spinal cord/CSF, meniscus/fluid in the knee
- Causes alternating bright and dark bands
  - Pseudo syrinx of the spinal cord
  - Pseudo tear of the knee meniscus
- Due to insufficient samples for the large signal changes
  - Mostly seen in the phase direction

Image processing Artifacts: Truncation

- Remedy:
  - Increase sampling time (BW ↓)
  - Decrease pixel size (increase phase encoding steps, reduce FOV)

Fat-saturated T2



224 Ny 192 Ny

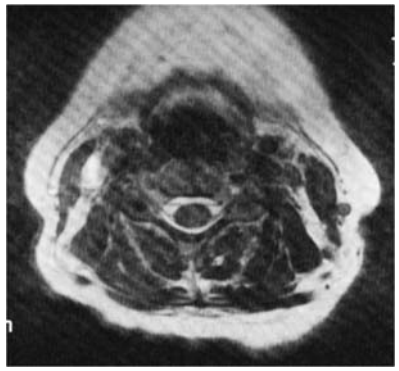
Image processing Artifacts: Partial volume

- Remedy: decrease the slice thickness

Axial FLAIR image

Image processing Artifacts: Errors in the Data

- A single calculation error in processing the data related to the k-space of a single slice.
- A crisscross striation artifact
- Remedy:
  - Delete the discrete error and average out the neighboring data.
  - Simply repeating the sequence.



Subject-related Artifacts

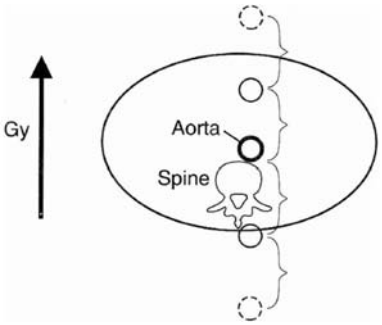
- Motion artifacts
- Magnetic susceptibility artifacts
  - Diamagnetic, paramagnetic, ferromagnetic
  - Metal

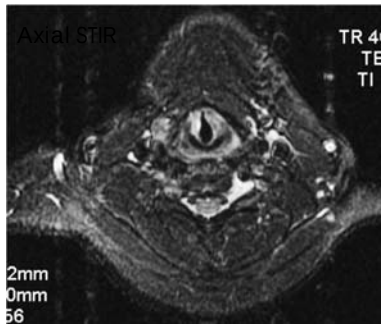
Subject-related Artifacts: Motion

- Random movements, periodic motion (pulsating flow in vessels)
- We only get motion artifacts in the phase-encoding direction (the sampling time for frequency-encoding is short).

Periodic Motion

- Ghost artifacts of the vessels are equally separated along phase-encoding direction.
- $\boldsymbol{separation\ (SEP\ in\ pixels)} = \frac{\boldsymbol{TR \times Ny \times NEX}}{\boldsymbol{T(motion)}} = \frac{\boldsymbol{acquisition\ time}}{\boldsymbol{T(motion)}}$

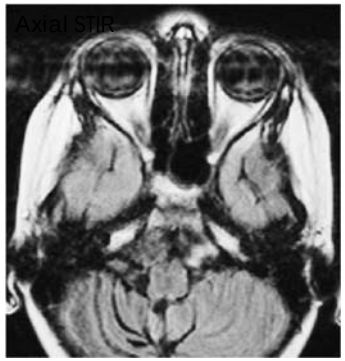




Motion artifacts

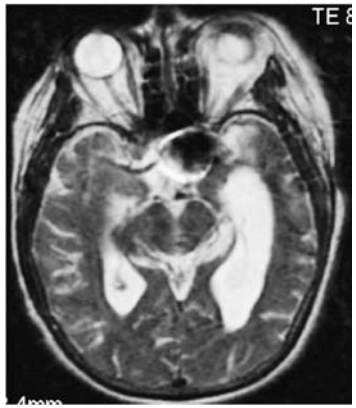
- Remedy for Periodic motion
  - Spatial presaturation pulses to saturate inflowing protons
  - Increase separation between ghosts
  - Swap phase and frequency (only change the direction of artifacts)
  - Use cardiac gating
  - Use flow compensation
- Remedy for random motion
  - Patient instruction: **don't move!**
  - Use of glucagon in the abdomen to reduce bowl peristalsis
  - Sedation
  - Fast scanning techniques

Random eye movements



Magnetic susceptibility artifacts

aneurysm clip

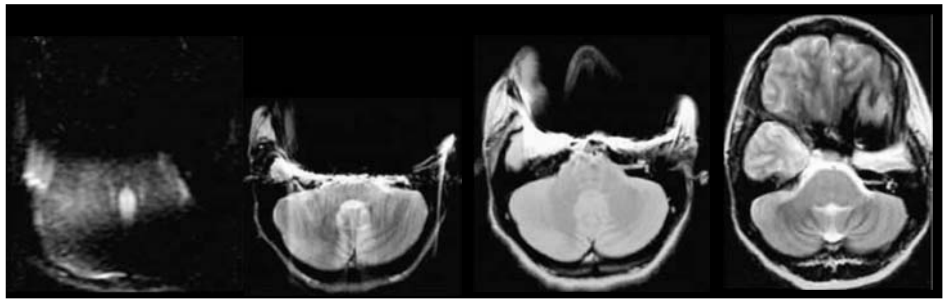


Metallic foreign body

Magnetic susceptibility artifacts

- A patient with dental braces

EPI B0 CSE T2 CSE PD FSE T2



磁振安全

Magnetic Resonance Tomography, Reiser et al, 2008 by Springer

Safety Issues

- A high static magnetic field (B_0)
  - Generating a macroscopic nuclear magnetization
- Rapidly alternating magnetic gradient fields (Gx,Gy,Gz)
  - Spatial encoding of the MR signal
- RF electromagnetic fields
  - Excitation and preparation of the spin system

Safety Regulations

- International Commission on Non-Ionizing Radiation Protection (ICNIRP)
  - http://www.icnirp.de/index.html
- International Electrotechnical Commision (IEC)
  - http://www.iec.ch/index.htm

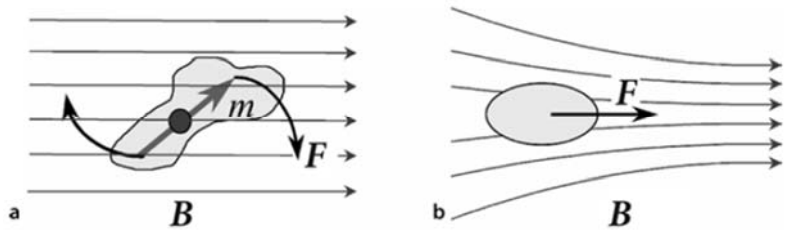
Operating Modes

Operating mode		
Normal	Controlled	Experimental
$B_0 \leq 2$ T	2 T < $B_0 \leq 4$ T	$B_0 > 4$ T

- Normal operating mode
  - Routine MR examinations
- Controlled operating mode
  - Specific MR examinations
  - Discomfort or physiological stress to some patients may occur
  - Medical supervision for patients
- Experimental operating mode
  - Potential risks for patients and volunteers
  - Ethical approval and medical supervision

Static Magnetic Fields

- Magneto-mechanical interactions
  - A unniform magnetic field: a magnetic moment experience **a mechanical torque** that align their magnetic moment parallel (or antiparallel) to the B.
  - A non-uniform magnetic field: paramagnetic and ferromagnetic materials become **dangerous projectiles**.



Static Magnetic Fields

http://www.impactednurse.com/?p=2927

How dangerous are magnetic items near an MRI magnet: http://youtu.be/6BBx8BwLhqg

Static Magnetic Fields

- Magneto-hydromechanical interactions
  - Static magnetic fields also exert **Lorentz forces** on moving ionic charge carriers giving rise to induced electric fields and currents.
  - At very high B, it can reduce the flow velocity and the flow profile of blood in large vessels.
  - Reduce the volume flow rate of blood in the human aorta by a maximum of 1.3, 4.9, and 10.4% at 5, 10, 15T, respectively.
- Magnetic effects on chemical reactions

Static Magnetic Fields

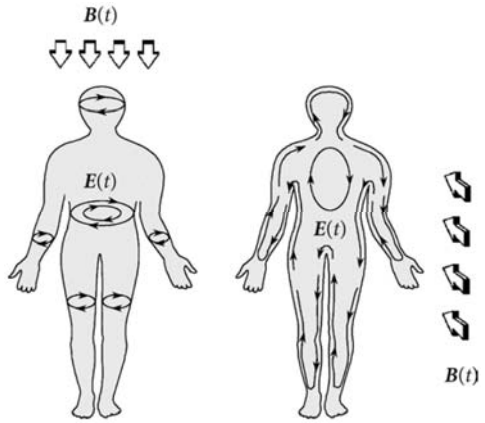
- No magnetic effects on implantation, prenatal, and postnatal development were reported between 1 and 9.4T.
- Humans exposed to a maximum flux density of 8T did not yield clinically relevant changes.
  - Heart rate
  - Respiratory rate
  - Diastolic blood pressures
  - Finger pulse oxygenation levels
  - Core body temperature
  - Systolic blood pressure ↓

Static Magnetic Fields

- Epidemiological studies is at present not sufficient to draw any conclusions about potential health effects.
- From evaluation of 1421 pregnancies of women working at clinical 1T MR facilities, no significant increased risks for…
  - spontaneous abortions
  - Delivery before 39 weeks
  - Reduced birth weight
  - Male gender of the offspring
- No serious health effects from the exposure of healthy human up to a flux density of 8T.

Time-Varying Magnetic Gradient Fields

- Faraday's law: a time-varying magnetic field B(t) induces an electric field E(t).
- $\boldsymbol{E(r) = -\frac{r}{2} \cdot \frac{dB_z(t)}{dt}}$
- r: the radius of loop
- $\boldsymbol{j(r) = \sigma E(t)}$
- Eddy current
- σ: the electric conductivity



Time-Varying Magnetic Gradient Fields

- The induced currents can influence cellular properties involve interactions at the level of the cell membrane.
- The primary concern is cardiac fibrillation (life threaten)
- The practical concern is the peripheral nerve stimulation (uncomfortable or intolerable stimulation)
- Limited dB/dt level to be 80% to 100% of the mean perception threshold for peripheral nerve stimulation.

Radiofrequency Electromagnetic Fields

- In RF range, the conductivity of cell membranes is comparable to that of the extra- and intracellular fluid.
- Thermal effects due to tissue heating are of importance.
- Specific absorption rate (SAR, in W/kg)
- $SAR \propto B_0^2 \cdot \alpha^2 \cdot \frac{tp}{TR} \cdot Ns$
- The duty cycle tp/TR. The ratio of the pulse duration tp and the TR of the sequence
- NS the number of slices in a TR.

Radiofrequency Electromagnetic Fields

- In case of a continuous RF exposure, the temperature rise even in poorly perfused tissues is less than 0.5°C for each W/kg of power dissipated.
- Thermoregulatory adjustments:
  - Reduced metabolic heat production
  - Vasodilatation
  - Increased heart rate
- Heat loss mechanisms
  - Sweat
  - Dynamic range of blood flow rates

Radiofrequency Electromagnetic Fields

- Exposure of resting humans for 20-30 min to RF fields producing a whole-body SAR of up to 4 W/kg results in a body temperature increase between 0.1 and 0.6°C.

Operating mode	Rise of body core temperature (°C)	Spatially localized temperature limits		
		Head (°C)	Trunk (°C)	Extremities (°C)
Normal	0.5	38	39	40
Controlled	1	38	39	40
Experimental	> 1	> 38	> 39	> 40

Radiofrequency Electromagnetic Fields

- Prevent the focal skin-to-skin contacts

Current-induced third-degree burns

THE END

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