Title # Ultra High Field MRI

Speaker

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Session Clinical Interpretation & Advanced Imaging

Target Audience

Clinicians, scientists and students interested in MRI research in general, and in the development of ultra high field MRI with medical applications in particular.

Outcome/Objectives

The students will be able to understand the challenges of ultra high field MRI.

Purpose

To review the recent developments in ultra high field (UHF) MRI, with its advantages and disadvantages, and its potential unique medical applications. To give an overview of the challenges to overcome—from the hardware, software and medical point-of-view—in order to make UHF MRI clinically relevant.

Highlights

- **Why UHF MRI?** Increase the SNR for increasing image resolution and time of acquisition.
- **Advantages:** High SNR, high spatial resolution, fast imaging, increased spectral resolution, multinuclear MRI, new contrast (SWI, CEST).
- **Disadvantages:** B_0 inhomogeneity, B_1^+ inhomogeneity, high SAR, longer T1, shorter T2 and $T2^*$, susceptibility, system complexity and cost.
- **Applications:** Brain (MS, Alzheimer, TBI, tumors, epilepsy, stroke), MSK (cartilage and osteoarthritis), breast, cardiac.

Introduction to Ultra High Field (UHF) MRI

- **Definition:**
  - Ultra low field (ULF): $B_0 < 1$ T (Ex: 0.2 T, 0.5 T)
  - Low field (LF): $1 \text{ T} \leq B_0 < 3$ T (Ex: 1 T, 1.5 T, 2 T)
  - High field (HF): $3 \text{ T} \leq B_0 < 7$ T (Ex: 3 T, 4.7 T)
  - Ultra high field (UHF): $B_0 \geq 7$ T (Ex: 7 T, 8 T, 9.4 T, 11.7 T)
- **Why UHF?**
  - Increase signal-to-noise ratio (SNR) of MRI, in order to improve spatial, temporal and spectral resolution of the images.
  - New contrasts: SWI, multinuclear MRI (^{23}Na, ^{31}P, ^{25}Cl, ^{17}O), CEST.
- **Hardware:**
  - Magnet: Superconducting NbTi magnet, shielding, shimming, long bore with small diameter, liquid helium and refrigeration, mechanical forces.
  - RF coils: Multichannel transmit/receive RF coils for parallel transmit/receive MRI, double-tuned RF coils (^{1}H/^{23}Na, ^{1}H/^{31}P, ...).
- **Software:**
  - Pulse sequences: Ultrashort TE (UTE), non-Cartesian acquisitions
  - RF pulses: Customized RF pulses for better homogeneity (adiabatic, 2D tailored pulses).
- **Potential medical applications:**
  - Brain: MS, Alzheimer, TBI, tumors, epilepsy, stroke.
  - MSK: Cartilage (knee, hip, ankle) and osteoarthritis, muscle (diabetes, muscular dystrophy).
  - Breast.
  - Cardiac.

Advantages

- **Signal-to-noise ratio (SNR):** SNR increase with B_0 (approximately)
  - Increase spatial resolution
  - Increase temporal resolution: (ultra)fast imaging
- **Spectral resolution:** Better separation of different metabolites (chemical shift)
  - Chemical exchange saturation transfer (CEST) MRI
  - ^{1}H MR Spectroscopy (^{1}H MRS)
  - ^{31}P MRI/MRS
- **Susceptibility:** Increase of magnetic susceptibility between tissues
  - Susceptibility weighted imaging (SWI): higher contrast with higher resolution
  - Blood oxygen level dependant (BOLD) contrast: higher BOLD contrast allows higher spatial resolution and higher contrast-to-noise ratio in fMRI applications.
- **Diffusion weighted/tensor imaging (DWI/DTI):**
  - Higher SNR: More diffusion sensitive gradient directions for DTI, higher resolution.

- Dynamic DTI/DWI: Temporal variation of the diffusion coefficient.

- **Arterial spin labeling (ASL):**
    - Longer T1 of blood: longer acquisition times after tagging pulses can be utilized, increase of ASL SNR.
- **Multinuclear MRI**
    - Sodium (^{23}Na) MRI.
    - Phosphorus (^{31}P) MRS/MRI.
    - Chlorine (^{35}Cl) MRI.
    - Oxygen (^{17}O) MRI.
    - Potassium (^{39}K) MRI.

Disadvantages

- **B_1^+ (transmit) inhomogeneity:**
    - Wavelength: The RF wavelength at 7 T is of the order of 0.1 m in biological tissues (for ^1H nuclei), which is the order of the size of the body. This will create standing waves which, associated with constructive interference, will result in the generation of a bright spot in the center of brain for example (dielectric artifact).
    - Parallel imaging.
    - RF shimming: Increase $B1^+$ homogeneity during RF pulses.
    - Parallel transmit.
- **Specific absorption rate (SAR):**
    - RF heating: A higher RF power is required to produce a 90° pulse compared to low field MRI.
- **Effects on relaxation:**
    - T1: Longer T1 and convergence for most tissues inducing the need of longer TRs for full recovery of the longitudinal magnetization, and lower T1 contrast between tissues.
    - T2: T2 should not be affected by B_0 in theory, but the apparent T2 is shorten for spin-echo sequences due to diffusion effects through microgradients surrounding capillaries. This effect depends on tissue type.
    - T2*: Decrease of T2* due to magnetic susceptibility effect which will affect contrast in GE sequences and need of shorter TEs.
- **Susceptibility**:
    - Magnetic susceptibility effect: effect of $T2^*$ and GE contrast.
    - Metal implants: higher distortion of the images next to metal implants due to increase magnetic susceptibility difference.
    - Image blurring and geometric distortion artifacts in rapid imaging.
- **System complexity:**
    - B_0 inhomogeneity.
    - B_1 inhomogeneity.
    - Shimming: passive and active.

- Shielding.
- Mechanical forces.
- Liquid helium.
- Gradient coils.
- Cost.

Applications

- **Brain**
    - High resolution structural imaging.
    - High resolution functional MRI (fMRI).
    - MRS: High spectral resolution.
    - DTI.
    - Multinuclear MRI: ^{23}Na MRI (intracellular sodium), ^{31}P MRI/MRS.
    - SWI.
    - Vascular imaging.
    - Medical applications:
        - Epilepsy.
        - Tumors.
        - Multiple sclerosis (MS).
        - Alzheimer's disease (AD).
        - Traumatic brain injury (TBI).
        - Stroke.
- **Musculoskeletal (MSK)**
    - Cartilage and osteoarthritis (OA):
        - High resolution cartilage morphometry.
        - Delayed gadolinium-enhanced MRI of cartilage (dGEMRIC).
        - T2 mapping.
        - T1ρ mapping.
        - DTI/DWI in cartilage.
        - gagCEST.
        - ^{23}Na MRI with fluid suppression.
    - Muscle:
        - Diabetes: ^{31}P MRS and MRS.
        - Muscular dystrophy: ^{23}Na MRI.
- **Breast**
    - High resolution structural MRI.
    - ^{23}Na MRI.
- **Cardiac**
    - High spatial and temporal resolution.

Discussion/Conclusion

- **Research interest?**
  - Methodological developments: RF coil design, RF shimming, parallel transmit.
  - New metabolic information in vivo with multinuclear MRI.
  - High resolution structural and functional MRI.
- **Clinical usefulness?**
  - Killer applications compared to 1.5 and 3 T for clinical practice? Still work in progress...
  - Metabolic imaging (in vivo, quantitative, non-invasive)?

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