Use of MRI in Radiotherapy: Technical Consideration

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Conflict of Interest: None
Objectives

• Identify the difference between use of MRI for diagnostic and therapeutic purposes

• Discuss additional requirements in incorporating MRI in radiotherapy and their effects on image quality

• Provide thoughts regarding how to balance, from a technical perspective, among various requirements to serve the needs for therapeutic applications
MRI: Diagnosis vs Treatment

High priorities in diagnostic MRI

- Image quality
- Spatial resolution
- Relatively focused on the disease area (e.g. tumor)

Low priorities in diagnostic MRI

- Spatial integrity
- Reproducible setup
- Normal tissues
MRI: Diagnosis vs Treatment

High priorities in therapeutic MRI

- Image quality
- Spatial integrity
- Reproducible setup in treatment position
- Visualization of the target and organs-at-risk (OARs)

Low priorities in therapeutic MRI

- Spatial resolution
Use of MRI in Radiotherapy

Requirements specific to therapeutic MRI

- Reproducible setup in treatment position – use of immobilization devices
- Spatial integrity – distortion mitigation and characterization
- Visualization of the target and OARs – use of large field of view (FOV)
Use of MRI in Radiotherapy

All these RT specific requirements negatively impact MRI SNR or image quality

- A balance needs to be maintained between image quality, reproducible patient setup, spatial integrity and target and OAR visualization
Use of MRI in Radiotherapy

MRI SNR dependence

\[ SNR \propto \Delta x \Delta y \Delta z \sqrt{N_{ave} N_x N_y N_z \Delta t} \]

- Voxel size \((\Delta x \Delta y \Delta z)\) ↑ results in SNR ↑
- Number of Ave \((N_{ave})\) ↑ results in SNR ↑
- Number of sampling points ↑ results in SNR ↑
- Bandwidth ↑ results in \(\Delta t\) ↓ results in SNR ↓
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MRI SNR dependence

\[ SNR \propto B_0 \]

- Main magnetic field \((B_0)\) ↑ results in SNR ↑
- \(B_0\) ↑ results in geometric distortion ↑
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MRI SNR dependence

- For surface coils and phase-array coils, SNR decreases rapidly as the separation between the coil and anatomy of interest increases

2015 MRI QC manual
Effect on MRI Image quality

Immobilization devices

- An essential component to maintain reproducible patient setup in treatment position
- Increase separation between the RF receiving coil and human anatomy
- Decrease SNR substantially
Effect on MRI Image quality

Immobilization devices

- An example of immobilization devices
Effect on MRI Image quality

Immobilization devices

- An example of immobilization devices
Effect on MRI Image quality

Immobilization devices

➢ An example of immobilization devices
Effect on MRI Image quality

Immobilization devices – mitigation

- Easy to implement but less effective method
  - Increase number of averages – Improve SNR at a cost of scan time

- Easy to implement and relatively effective method
  - Reduce receiver bandwidth – Improve SNR but may introduce more distortion
  - Increase voxel size – Improve SNR at a cost of spatial resolution
Effect on MRI Image quality

Immobilization devices – mitigation

- Effective but not so easy to implement method
  - Reduce separation between receiving coil and anatomy of interest – Improve SNR but not exactly in treatment position, so additional effort is needed for image registration
Effect on MRI Image quality

Spatial integrity

- Geometric distortion is inherent in MRI images
- Distortion is minor in the center of the bore, but gets larger towards peripheral region
- It depends on hardware performance and imaging protocols
- Acceptable distortion may be specific to individual applications (MR+CT, or MR only)
Effect on MRI Image quality

Causes of geometric distortion

➢ Hardware imperfection
  • Gradient nonlinearity
  • Magnetic field inhomogeneity
Effect on MRI Image quality

Causes of geometric distortion

➢ Hardware imperfection
  • Gradient nonlinearity

\[ B = B_0 + G_x \cdot x \]
Effect on MRI Image quality

Causes of geometric distortion

- Hardware imperfection
  - Magnetic field inhomogeneity

\[ B = B_0 + G_x \cdot x \]
Effect on MRI Image quality

Severity of geometric distortion

➢ Hardware imperfection
  • Gradient nonlinearity
  • Magnetic field inhomogeneity

➢ Sensitivity to hardware imperfection
  • MRI sequence
  • Imaging parameters (receiver bandwidth)
Effect on MRI Image quality

Mitigation of geometric distortion

➢ Hardware performance characterization
  • Calibration during installation
  • Characterization during commissioning
  • Characterization requires use of spatial integrity phantoms and is supposed to be performed using clinical relevant protocols
Effect on MRI Image quality

Mitigation of geometric distortion

➢ Examples of spatial integrity phantoms
Effect on MRI Image quality

Mitigation of geometric distortion

- Hardware imperfection
  - If possible, place anatomy of interest in the central area of the bore
  - Consider the step and shoot method
Effect on MRI Image quality

Mitigation of geometric distortion

- Sensitivity to hardware imperfection
  - MRI sequences (clinical driven, not much flexibility)
  - If available, enable the geometric distortion correction in the protocol
  - Imaging parameters: increasing receiver bandwidth to reduce geometric distortion
Effect on MRI Image quality

Mitigation of geometric distortion

- Sensitivity to hardware imperfection
  - Imaging parameters: Increasing receiver bandwidth to reduce geometric distortion
  - Consequence: SNR decrease
  - Remedy: Increasing the number of average (increased scan time), increasing voxel size (reduced spatial resolution)
Effect on MRI Image quality

Target and OAR visualization

- Large field of view (FOV) is required
  - For MRI-only simulation, it is required to include the entire external body
  - For CT+MRI simulation, large FOV is preferred to facilitate image registration and OAR delineation
Effect on MRI Image quality

Target and OAR visualization

- Trade-offs for using large FOV
  - Spatial resolution decreases if the acquisition matrix remains the same
  - Potentially larger geometric distortion in the peripheral region
Effect on MRI Image quality

Target and OAR visualization

➤ Mitigation of spatial resolution degradation

• Good spatial resolution is usually preferred for the delineation purpose
• Increasing spatial resolution decreases SNR
• Increasing spatial resolution is often accompanied with increase scan time to either compensate SNR or avoid exceeding gradient system hardware limits
Effect on MRI Image quality

Target and OAR visualization

- Mitigation of geometric distortion
  - Geometric distortion can be reduced by using a higher receiver bandwidth
  - Increasing bandwidth decreases SNR
Effect on MRI Image quality

Target and OAR visualization

➢ Available options to recover SNR

  • Increase the number of average (or acquisition) – increased scan time and have more chances for voluntary motion

  • Use of 3D acquisition methods instead of 2D acquisition methods – more susceptible to motion artifacts

  • Reduce spatial resolution

  • Reduce receiver acquisition bandwidth
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Use of MRI in radiotherapy

- An ideal solution may not always exist

- An acceptable solution is usually achievable through a careful balance among image quality, reproducible patient setup, spatial integrity and target and OAR visualization
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Questions & Discussion