MAYO CLINIC

# 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 ↓

# Use of MRI in Radiotherapy

MRI SNR dependence

$$SNR \propto B_0$$

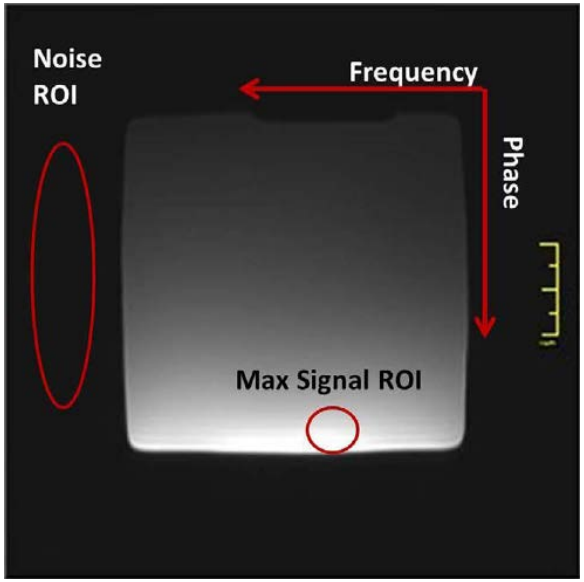
- Main magnetic field ($B_0$) ↑ results in SNR ↑
- $B_0$ ↑ results in geometric distortion ↑

# Use of MRI in Radiotherapy

## 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

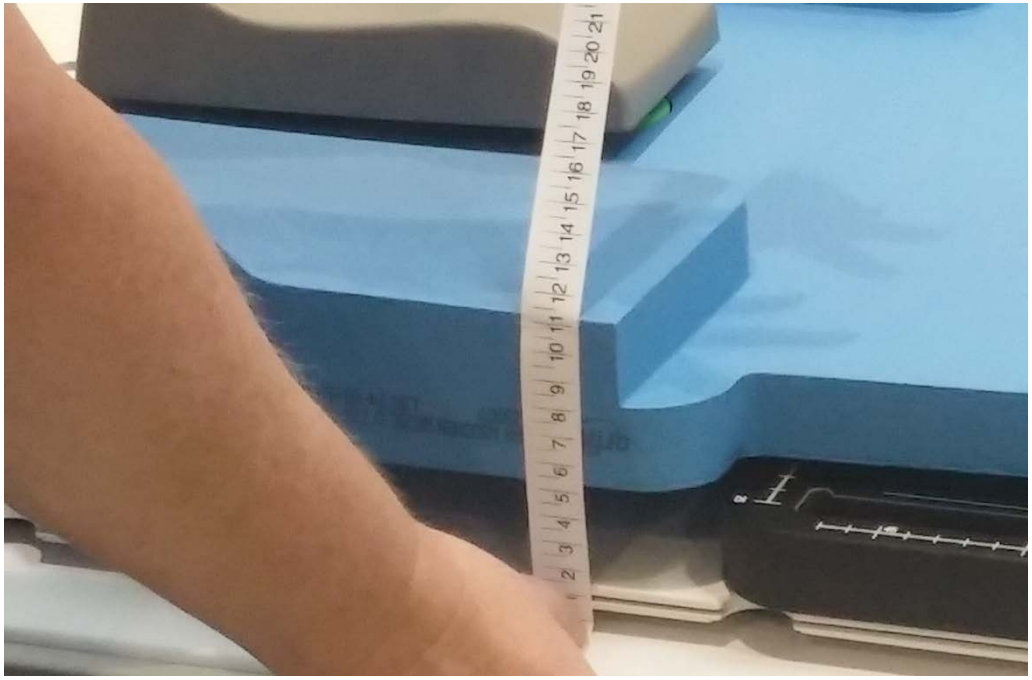


# Effect on MRI Image quality

## 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

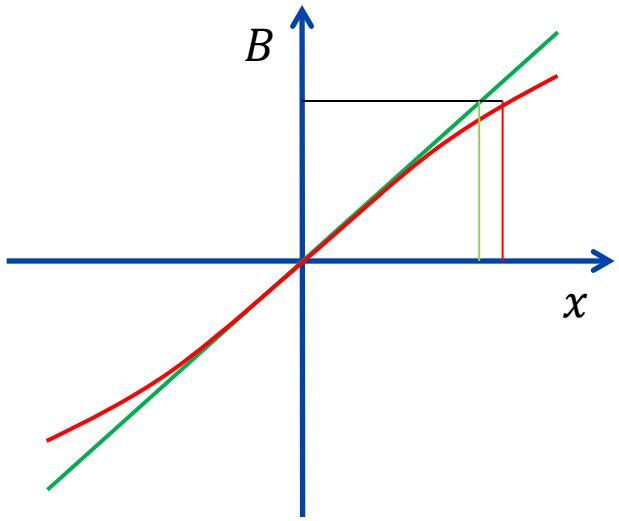
- Hardware imperfection
  - Gradient nonlinearity
  - Magnetic field inhomogeneity

# Effect on MRI Image quality

## Causes of geometric distortion

- Hardware imperfection
  - Gradient nonlinearity



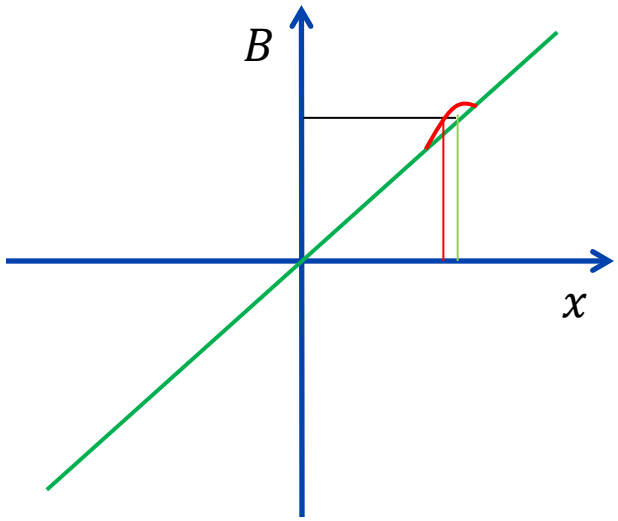

$$B = B_0 + G_x \cdot x$$

# 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

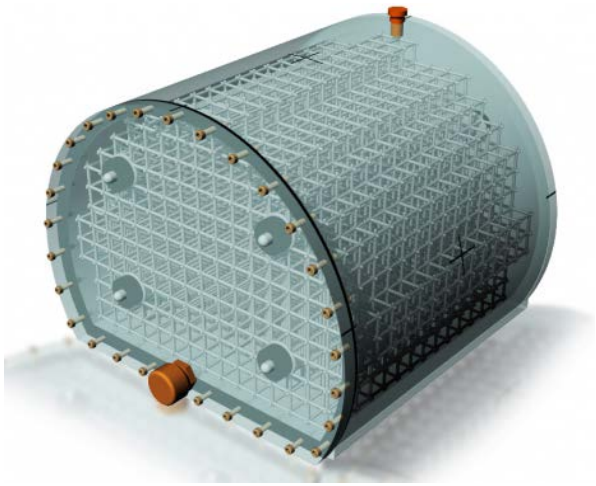
- Hardware performance characterization
  - Calibration during installation
  - Characterization during commissioning
  - Characterization requires use of spatial integrity phantoms and is supposed to be performed using clinical relevant protocols

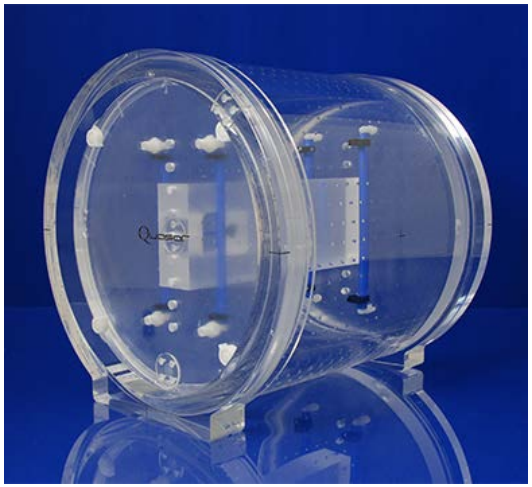

 

# Effect on MRI Image quality

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

# Effect on MRI Image quality

## 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

# Acknowledgements


- Judy A Collins, R.T.(R)(MR)




# Questions & Discussion