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MRI Linear Based Treatment in Radiation Therapy

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MRI Linear Accelerator Based Treatment in Radiation Therapy

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Introduction

Radiation therapy is crucial component in the treatment of cancer patients. This treatment typically involves the use of a linear accelerator, a specialized machine that generates radiation and electrons. In recent years, advancements have led to the development of a new type of linear accelerator that incorporates magnetic resonance imaging (MRI). This innovative combination allows for enhanced radiation treatment alongside high-resolution cross-sectional images of soft tissues.

What is Radiation Therapy?

- A medical treatment that uses high-energy radiation to target cancerous tissues while minimizing damage to surrounding healthy tissues
- The radiation can be delivered externally through machines such as linear accelerators or internally via radioactive substances placed near cancer cells, a method known as brachytherapy
- Utilized as a standalone treatment or in conjunction with other treatments such as surgery or chemotherapy
- Often tailored to the individual's specific type of cancer, location, and overall health condition (Michaels, 2023)

What is a Linear Accelerator (LINAC)?

- A sophisticated treatment machine used in radiation therapy to deliver high-energy X-rays or electrons to a patient's tumor
- Works by accelerating electrons through a waveguide, which are then directed towards a high-density target, resulting in the production of high-energy photons, or X-rays
- Is an open machine, meaning the patient is not enclosed within the machine while it rotates around them
- X-rays are shaped and controlled to conform precisely to the shape of the tumor, using various techniques such as multi-leaf collimators and imaging systems for precise targeting
- Can be used to perform several advanced radiation therapy techniques, including Intensity-Modulated Radiation Therapy (IMRT), Image-Guided Radiation Therapy (IGRT), and Volumetric Modulated Arc Therapy (VMAT)

(Michaels, 2023)

External beam radiation therapy (EBRT).
(Provincial Health Services Authority, n.d.)

What is MRI?

- A non-invasive diagnostic imaging technique used to create detailed images of the organs and tissues within the body
- Utilizes powerful magnets and radio waves to generate images, which are then processed by a computer to produce cross-sectional or three-dimensional views of the body's internal structures
- Valuable because it provides excellent contrast between different soft tissue structures
- Does not require ionizing radiation, which eliminates the risk associated with exposure to x-rays

(Pierce & Nelson, 2023)

What is an MRI Linear Accelerator?

- Manages organ motion and dose delivery in real time
- Linear accelerator with built in low-field or high-field MRI
- Some machines can:
  - Reduce risk of skin toxicities
  - Allow oncologists to visualize the tumors edge and surrounding organ position in real time using non-ionizing stream video perspective
  - Provide real time on table adaptive radiotherapy
- Split magnet MR design to provide an unobstructed radiation beam path
- Double focused multi-leaf collimators (MLC) for minimum penumbra
- SRS and SBRT tailored penumbra
- Generate daily on table MR setup scans
- Improve soft tissue visualization
- Rapidly reshape dose delivery to accommodate subtle anatomical changes that occur daily throughout treatment

(GenesisCare UK, 2021)

- Types of cancer treated with an MRI Linear Accelerator

Prostate	Liver	Breast
Lung	Pancreas	Ogliometastases

(Ladbury, 2023)

MRI linear accelerator.
(Henry Ford Health,2022)

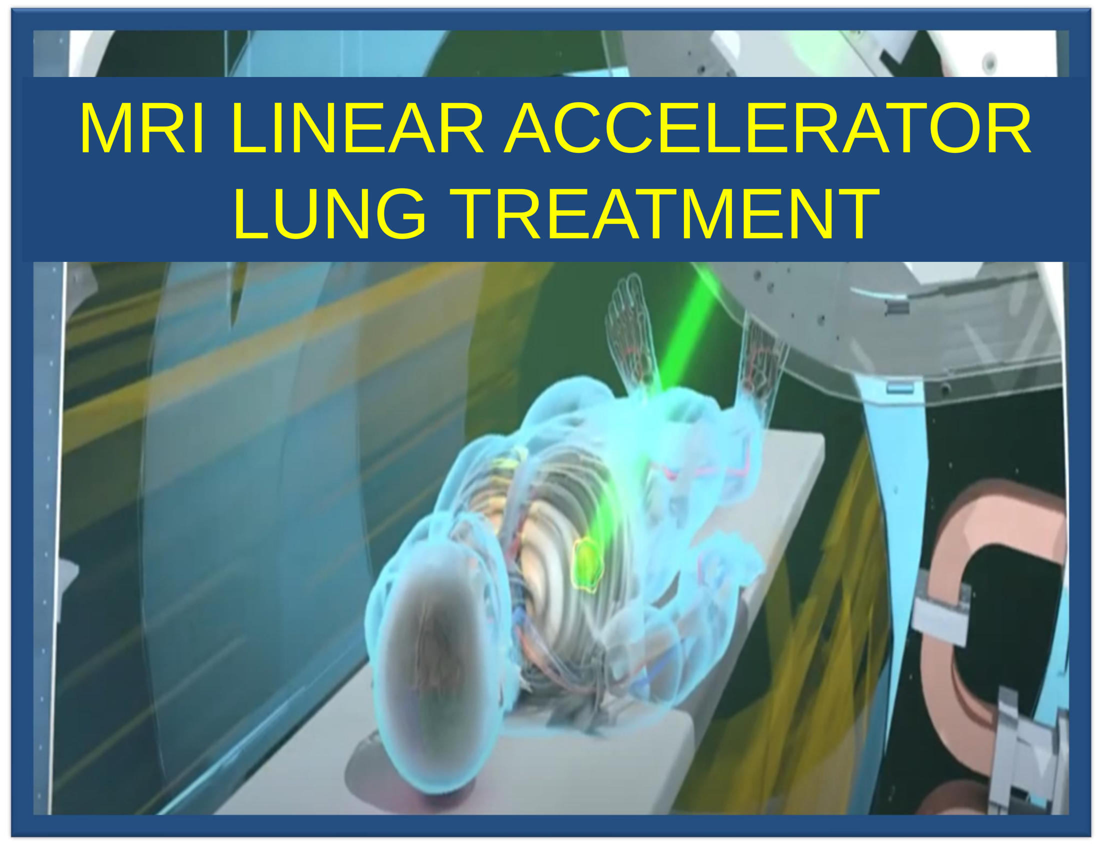
PROS and CONS of MRI Linear Accelerator treatment

PROS:

- Integrates various MRI pulse sequences, enhancing MR imaging with diverse functional information to better characterize the tumor microenvironment
- Fully integrates treatment planning software with the radiation delivery unit, utilizing advanced rapid dose calculation algorithms
- Enables updated MRI scans while the patient remains on the treatment table, allowing plan adjustments for anatomic changes, which can tighten treatment margins and permit dose escalation with less toxicity
- Provides real-time imaging of soft tissues through hybrid MRI-Linac systems for accurate visualization of targets during treatment, improving intra-fraction reproducibility by monitoring physiological organ movements
- Allows setting of threshold boundaries for maximum safe displacement of the treatment target
- Opens possibilities for reducing treatment margins, increasing target doses, and minimizing exposure to organs at risk through real-time intra-fractional imaging and active gating (Ng et al., 2023)

CONS:

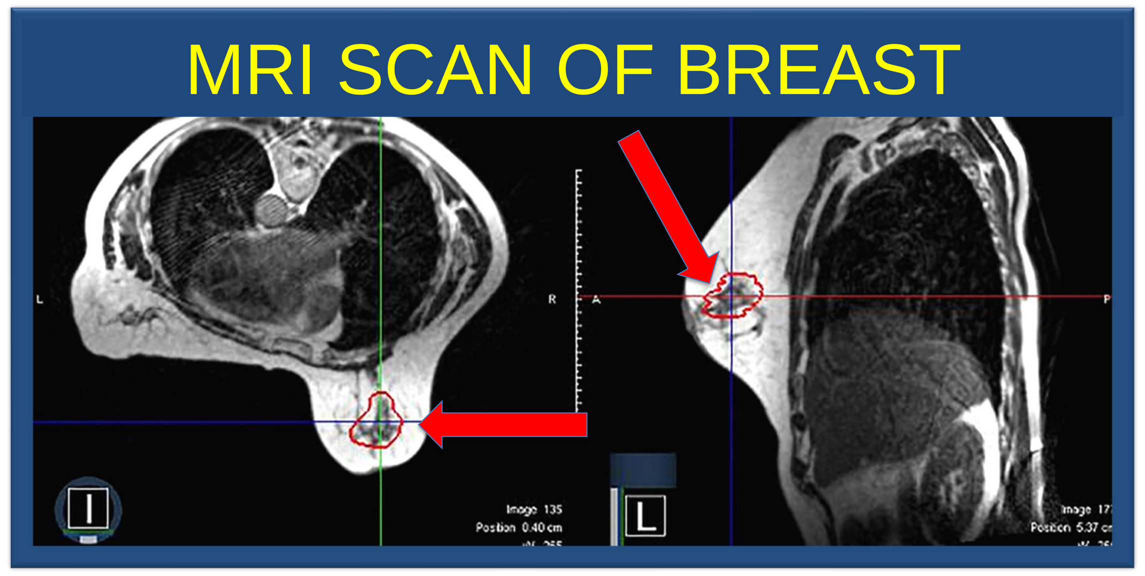
- Significant capital costs are required for acquiring and maintaining the system
- Implementing real-time treatment management takes 30-60 minutes per session
- MR-guided radiotherapy with adaptive radiation therapy requires 90-120 minutes per session, needing the full clinical team's presence
- MRI-Linac systems cannot deliver arc therapy, non-coplanar beam therapy, or electron beam therapy
- There are limited capabilities for table adjustment and couch rotation
- The size of the MRI bore restricts use to patients with a suitable body habitus
- Claustrophobia in MRI scanners affects 10-15% of patients, often requiring sedation (Ng et al., 2023)



MRI linear accelerator targeting tumor volume in specific breathing range for lung treatment.
(GeneisCare UK, 2021)

Accelerated Partial Breast Irradiation (APBI) Treatment

- Magnetic resonance-guided radiotherapy (MRgRT) is playing an emerging role in breast cancer management, favoring partial breast irradiation (PBI) over whole breast irradiation
- Gaining traction due to lower toxicity and patient convenience but requires accurate delineation of the postoperative breast cavity
- Differentiating soft tissue densities on computed tomography (CT) scans can be challenging, often needing 1 cm margins which can compromise cosmetic outcomes; MRgRT improves visualization of the lumpectomy cavity, allowing for smaller margins
- MRgRT also aids in managing motion related to breathing and daily setup for breast positioning



Patient receiving prone breast irradiation with an MRI image in the axial plane and sagittal plane. (Ng et al., 2023)

Case Study

- Kennedy et al. evaluated MRgRT for APBI in a phase I/II trial involving 50 women with low-risk, hormone-positive breast cancer, differing from typical APBI regimens that require at least 5 fractions
- Most patients received MRgRT, with treatment volumes focused on the surgical bed (no expansion within 5 mm of the skin) and an additional volume including a 1 cm margin
- The surgical bed was treated to a total dose of 20 Gy, with the additional margin receiving a minimum dose of 5 Gy
- At a median follow-up of 25 months, there was one noninvasive tumor recurrence, no acute grade ≥ 3 toxicity observed, and only one case of grade 2 chest wall pain
- There were no negative impacts on quality of life or cosmetic outcomes (Ladbury et al., 2023)

Conclusion

The integration of MRI Linear Accelerator (MRgRT) technology in cancer treatment marks a significant advancement in precisely targeting advanced cancers. This approach enhances imaging capabilities, allowing for more accurate radiation therapy and resulting in improved treatment outcomes, such as higher tumor control rates and reduced damage to healthy tissues. While MRgRT has limitations—including availability, specialized training requirements, and workflow challenges—future advancements are expected to address these issues. Ongoing research is likely to enhance the efficacy and accessibility of this treatment, enabling clinicians to further personalize care and maximize therapeutic benefits. Ultimately, these improvements aim to provide patients with more effective and less invasive treatment options, greatly enhancing their chances of successful recovery and long-term health.

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