Development of a Linear Accelerator Head for Upright Radiotherapy

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The Problem: Cancer

is the second most common cause of death worldwide. Radiotherapy is recommended for over half of all cancer patients but **access to this treatment is unacceptably low**. This is especially prevalent in low and middle-income countries where 90% of cancer patients lack access to radiotherapy.

The Status Quo: Supine

Conventionally, radiotherapy patients are treated lying on their backs, with a **6-tonne linac gantry** rotating around them, delivering X-ray treatment beams from multiple angles.

The Future: Upright

radiotherapy instead slowly rotates a seated patient through a fixed X-ray treatment beam.

The components needed for upright radiotherapy are cheaper and easier to manufacture and maintain. A fixed treatment beam also means upright radiotherapy requires less concrete radiation shielding and a smaller radiation bunker. These factors mean that upright radiotherapy could **reduce the cost of a treatment room by 50%.**

To date, treatment methods for upright radiotherapy have not been developed to meet the needs of the 21st century. However, a young British company, Leo Cancer Care have developed an upright CT scanner and upright patient positioning system.

My PhD is a collaboration between Leo Cancer Care, the National Physical Laboratory and the University of Surrey. Together we are researching an innovative fixed X-ray beam generation system (a linac) for upright radiotherapy.

Patient Benefits of Upright Radiotherapy include:

- Better treatment experience, especially **comfort.**
- Larger baseline lung volume, so better **sparing of healthy lung tissue**.
- More **stable positioning** for abdominal organs such as the prostate and liver.

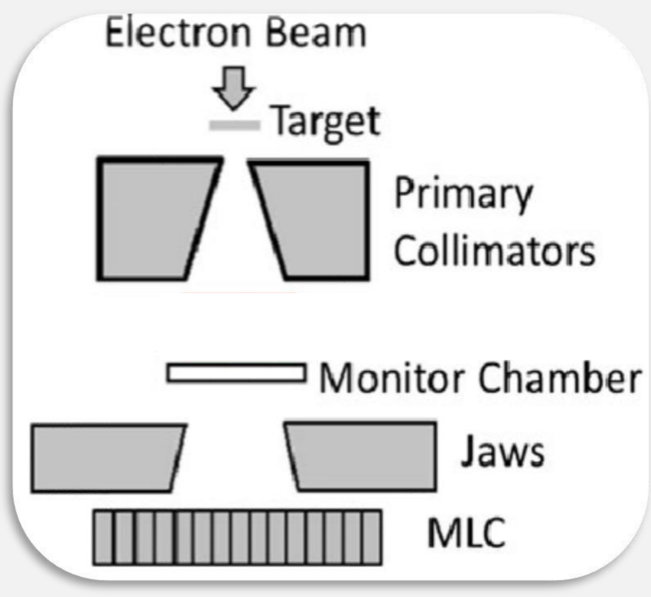
To develop modern treatments the design of the fixed beam X-ray treatment head must first be optimised. The treatment head must be designed to irradiate just the tumour and limit irradiation of the surrounding healthy tissues. **Dose delivered outside the tumour increases the risk of radiation-induced secondary cancers.** For example, historically radiotherapy for prostate cancer has increased patients' risk of secondary cancer by 6%, relative to surgery.

Through physics research and Monte Carlo Modelling, the treatment head design process can be accelerated. Improvements in design can be made without iterative prototyping and measurement, saving time and valuable resources.

So how can we design a linac?

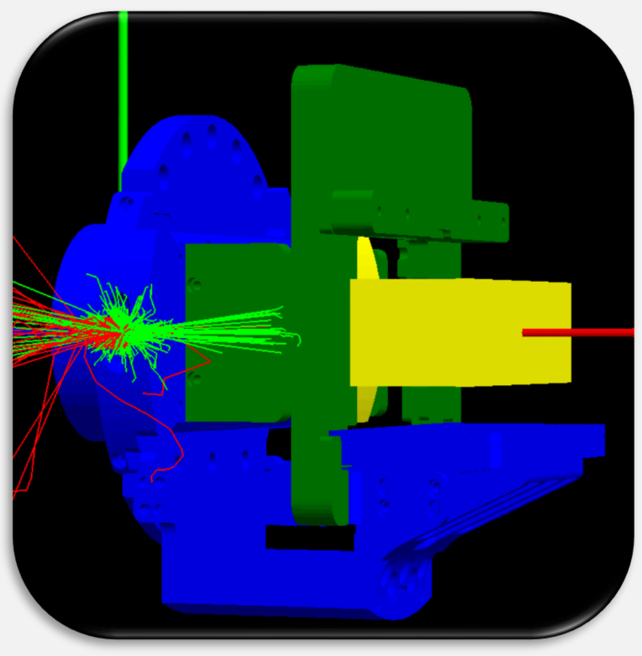
My Research: Monte Carlo Modelling

Simulate



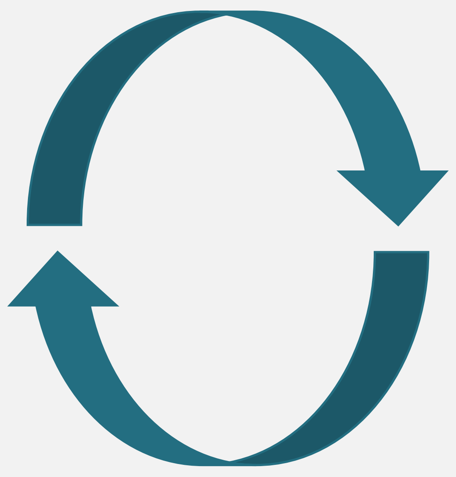
A linac head is made up of heavy material (e.g. tungsten and lead) used to shape the radiation beam. There are fixed shielding parts such as a "primary collimator" and dynamic shielding parts such as "jaws" and a "multi leaf collimator". To simulate the effectiveness of the treatment head's radiation shielding, **3 billion, 6 MeV incident electrons** were simulated using the Monte Carlo method.

Monte Carlo simulations of radiation transport **consider the probability of all particle interactions** from the Bremsstrahlung and characteristic X-rays produced by the initial electron beam, to photon interactions within the protective radiation shielding material (mainly Compton scattering and the photoelectric effect). Scoring planes are used to calculate the amount of energy deposited - the dose - after the radiation is transported through the shielding materials.



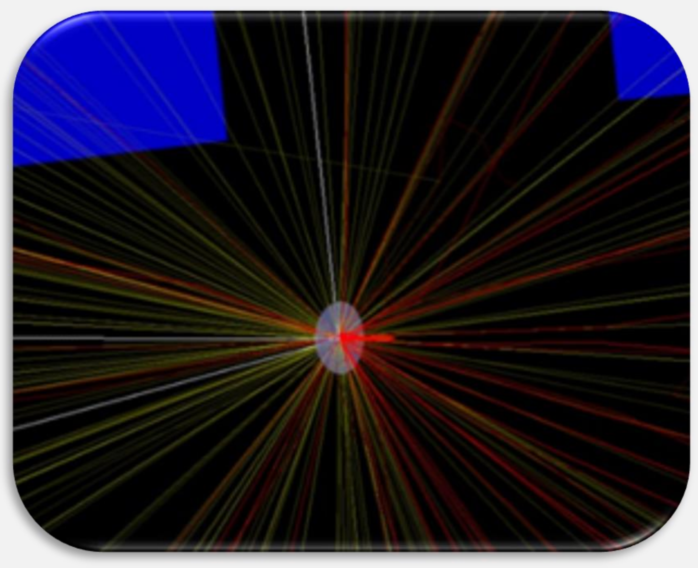
Update

In collaboration with Leo Cancer Care engineers, new design suggestions were explored. 3D envelopes needed to be considered for all components of the linac head, such as electronics to move the dynamic shielding, and water pipes to cool the system. Once the design for a particular component was adjusted, the Monte Carlo simulation process was restarted.



Analyse

To analyse the dose, to each segment of the scoring plane, Python scripts were created to interpret the results. The shielding of the linac in the closed position was compared to an open field value to show the extent of the shielding of the entire system.



Identify

From the Python scripts, any areas of the linac head where excess radiation leaked through (outside the useful treatment beam) were highlighted. Adjustments to the design, shape, size or material of specific components could then be proposed.

Final Note:

As of today, my simulations and iterative design process have reduced treatment head leakage to around 0.1% of the primary beam: better than the industry standard. Relative to iterative prototyping and measurement, my research using Monte Carlo simulations is accelerating the industrial design process. In this case, physics research is playing a key role in improving the quality and accessibility of radiotherapy.

References

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[2] Dracham CB, et al. Radiation induced secondary malignancies: a review article. *Radiat Oncol J*. 2018;36(2):85-94. doi:10.3857/roj.2018.00290