Estimation of range uncertainties in proton therapy associated with sub-CT resolution heterogeneity

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02-12-16

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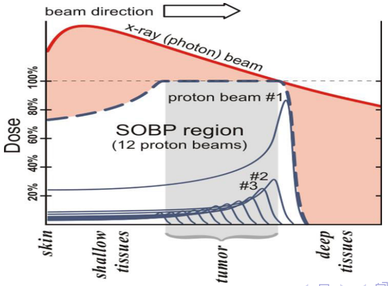
Outlines

- Monte Carlo modelling with FLUKA Monte Carlo code has been used to examine the proton scattering in bone-like tissue substitute.
- Proton therapy
- Bones and their classification
- experimental Model
- Results
- Conclusions

Proton Therapy and associated range uncertainties

- Use of highly energetic protons for cancer treatment
- Steep dose fall-off at the distal edge make proton therapy more susceptible to uncertainties
- Uncertainty in the stopping powers of the tissue,such as bone, is a significant source of range uncertainty.
- Another potential source of range uncertainty is the variation in scattering due to heterogeneity of the tissue at resolutions not achievable with CT imaging.



- Sawakuchi et al (2008) worked out the effect of the multiple Coulomb scatterings (MCS) and nuclear scatterings (NS) on the distal edge of Bragg Peak of the proton therapy beams. MCNPX Monte Carlo code is used for these studies and phantom geometry is varied from a simple to complex module in order to see either the geometric complexity has any effect on the Bragg Peak.

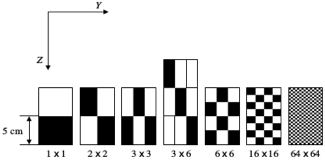
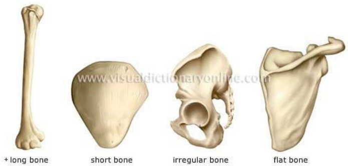


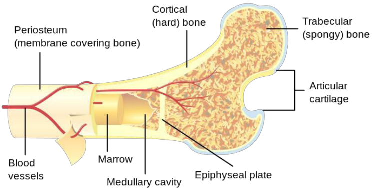
Figure 1. Illustration of density heterogeneities studied in this work. The black areas represent the compact bone through which the proton beam passes upstream of the water phantom, and the white areas represent air. The adopted coordinate system is also illustrated. Geometries are plotted on the plane $x = 0$ cm. The beam axis was in the z direction.

- Titt et al (2015) investigated the effect of sub-millimetre size inhomogeneity on the degradation of proton therapy beams at their distal edges and verified the Monte Carlo methods accuracy for such degradation estimation.
- Nichiporov et al (2011) measured the range shift due to slabs of different materials (Al,Ti,Cu,Sn,Pb), placed in the path of the proton beam at different positions (front and middle) relevant to the water phantom. They purposed an analytical model to notice the range shifts in the presence of high density material in water.

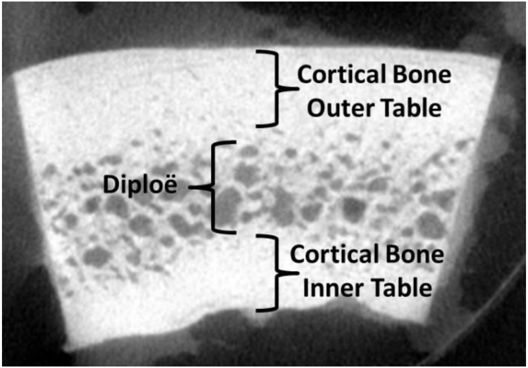
Bones and their classifications

- Bones and joints together form the skeletal system to provide support and shape to the whole body.
- Classified into five main categories
    - i long bones
    - ii Short bones
    - iii Flat bones
    - iv Irregular bones
    - v Sesamoid or round bones





Flat skull bone



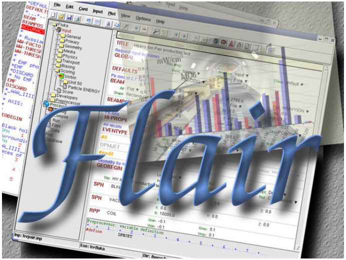
- Female skull (7.1mm) = 2.4mm (cortical bone) +2.3mm (trabecular bone) +2.4mm (cortical bone) Skull flat bone thickness

FLUKA

- Multi particle code
- Simulate interactions and transportation of protons, heavy ions and others
- developments in physics models have comprehended the use of FLUKA to medical applications

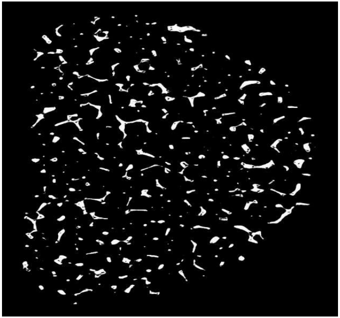
Flair

- User-friendly graphical user interface(GUI)
- Facilitate its user for building, editing and debugging error free input files
- Helpful for execution of the code and visualization of the output files
- Entirely based on python and Tkinter



Methodology

- Bone Model
- The substitute is a plastic material used in surgical practice, possessing similar texture to that of bone and consisting of an open-packed foam, in particular containing trabeculae-like structures.



CT handling

- MATLAB is used to convert raw CT images to DICOM format
- By using linear transformation equation,CT-numbers are converted to the relevant Hounsfield units HU = Gray-Value * slope + intercept

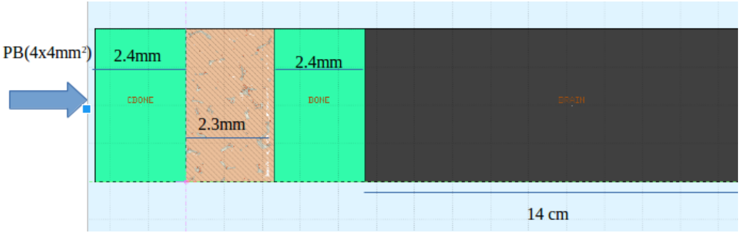
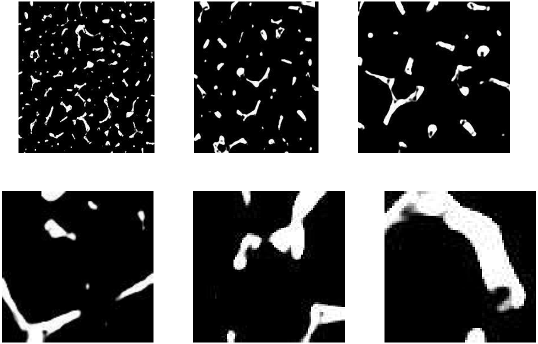
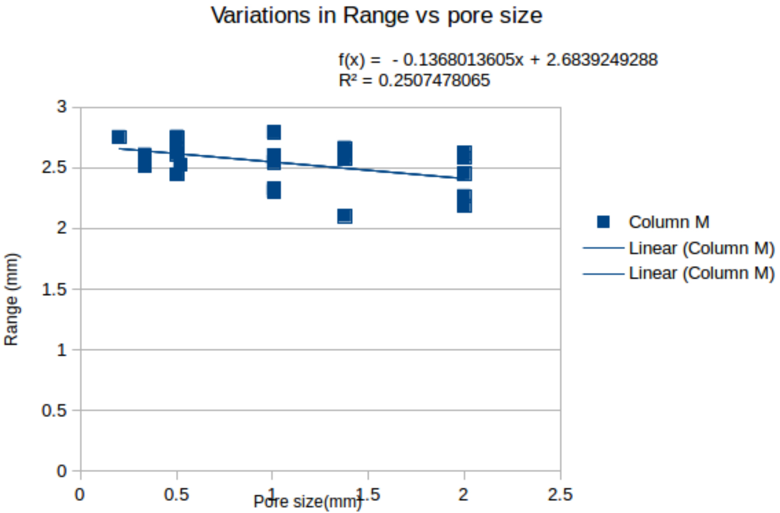


Figure: Modelled phantom having 2.3mm trabecular bone sandwiched in betwwen two(2.4mm each) layers of hard bon.

- The voxel size is changed to see the effect of change in trabeculae on the range of protons passing through the phantom.
- Pore size is varied from 0.2 mm to 2mm



Results


Variations in Range vs pore size
f(x) = - 0.1368013605x + 2.6839249288
R² = 0.2507478065
Range (mm)
Pore size(mm)
0
0.5
1
1.5
2
2.5
3
Column M
Linear (Column M)
Linear (Column M)

Conclusions

- The range of proton beam is examined as a function of pore size.
- The range is found to vary 0.27mm with an $R^2 = 0.25$,suggesting small part of variations to be systematic.
- Result supports the normal practice of irrediating through flat bone and confirm that sub Ct hetergoenity is unlikely to result in significant uncertainties for such a thin part of the bone.
- However, for larger of thickness of trabecular bone, e.g. greater than 10mm, range uncertainties of the order of 1.4mm, may be presesnt.
- Upcoming work is considering the effect of heterogeneity in lung, where the variation in density is much greater than in bone.

Future plan

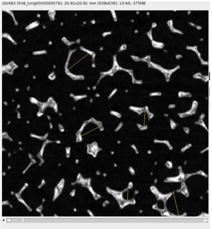


Figure: (a).HU-Scaled images for lung model.

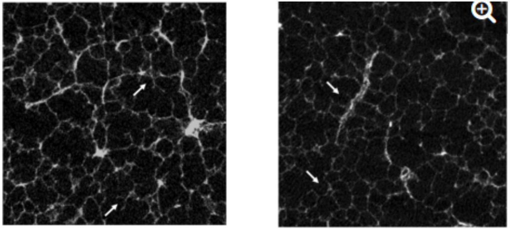


Figure: (b).A microcomputed tomographic image of normal human lung parenchyma.(http://jap.physiology.org/content/118/11/1429)

Thank you for your attention