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Improving image reconstruction for Compton camera based imaging for proton radiotherapy verification

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Purpose or Objective: To improve analysis and reconstruction techniques for data measured with a Compton Camera (CC) imaging system for prompt gamma imaging for proton radiotherapy.

Material and Methods: The CC consists of four detector stages containing CdZnTe (CZT) crystals. Two stages contain crystals with dimensions of 20 mm x 20 mm x 15 mm, while the other two stages have crystals with dimensions of 20 mm x 20 mm x 10 mm. Rather than looking at γ interactions that occur in multiple detector stages, double- or triple-scatter events from γ-rays emitted from a 60Co point source (2 mm full width at half maximum) that occurred in only one detector plane were studied. Using triple-scatter events in a single stage, 2D images of the γ emission were reconstructed.

The energy deposited in the first interaction (\(E_{dep1}\)) as a function of the scatter angle (\(\theta\)) of the γ was analyzed (see Fig. 1A). Next, the measured triple-scatter data was filtered so that it included only events satisfying the “Compton line” equation,

\[ E_{dep1} = E_\gamma \frac{\alpha(1 - \cos \theta)}{1 + \alpha(1 - \cos \theta)} \]

where \(\alpha=E_0/(m_e c^2)\), \(m_e\) is the rest mass of the electron, and \(E_0\) is the initial energy of the γ. Finally, the Compton line filtered triple-scatter data was used to reconstruct 2D images of the γ emission and was compared to the image reconstructed using all triple-scatter events.

Results: There was a dramatic difference in the position reconstruction of the point source, as seen in images reconstructed with all measured triple-scatter interactions in one CC stage (see Fig. 1B) and images reconstructed using only measured triple-scatter interactions in one stage that were within ±10% of the Compton lines (see Fig. 1C). The location of the source in both runs was ±0.2 ± 2 mm along the z-axis. Fig. 1D shows that all measured data gives a reconstructed source position of -21 mm (19 mm from the actual source position and within the uncertainty of the source position). Following tests of the Compton line filtering technique with point sources, initial imaging tests are being completed for measured data of prompt gammas emitted during irradiation of a water phantom with clinical proton therapy beams.

Conclusion: We have developed a new method of analyzing and filtering data from a Compton camera that can be used to greatly improve the image quality and position reconstruction of prompt gammas. With this new filtering method, the position localization was improved from within 19 mm of the actual source location to within 1 mm of the actual source location for the filtered data.

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The new ‘R’s in radiation biology

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Over the last decades the precision of radiotherapy delivery has vastly improved. Using the newest image-guided, intensity-modulated radiotherapy techniques radiation oncologists can be fairly sure that two identical patients with seemingly identical tumors will receive the same radiotherapy dose distribution. In these cases, reasons for radiotherapy failure within the field cannot be found in clinical factors or in the delivery of the radiotherapy, but must be sought in the (heterogeneous) biological makeup of the tumor. Knowledge of an individual tumor’s biology could contribute to a better prediction of radiotherapy failure and the design of approaches to radiosensitize resistant tumors. The classical biological factors influencing radiotherapy response conveniently all start with a ‘R’: Reoxygenation, Redistribution, Repair and Repopulation. Intrinsic Radiosensitivity has been added as a fifth factor to describe the difference in radiosensitivity of individual cells. This factor can be broken down into three main mechanisms. Firstly, a difference in radiosensitivity could be explained by a difference in received damage upon irradiation, for example due to different levels of reactive oxygen scavengers. Secondly, a difference in (DNA) repair capability is a well-known cause for variation in intrinsic sensitivity. Thirdly, tumor cells can respond differently to inflicted damage depending on their ability to engage cell cycle or cell death pathways.

In recent years new factors have been added to the list of ‘Rs’. The most important new players are cancer stem cells, the tumor microenvironment, the immune response, the cell’s energy metabolism, angiogenesis and vasculogenesis. Although new techniques like pre-treatment expression profiling enable us to study different biological processes simultaneously, some major challenges remain in the accurate prediction of radioresponse. The most important relates to (spatial and temporal) tumor heterogeneity: different cells within a tumor could have different properties and all biological factors mentioned (and possible more that are yet to be discovered) could interact with each other, making it difficult to assess the overall effect within a tumor. In addition, little is known about the changes in the biological behavior of a tumor during a course of fractionated radiotherapy. This lecture will address these new Rs in radiation biology and their relevance for clinical practice.

Teaching Lecture: The new ‘Rs’ in radiation biology

SP-0568
Texture analysis of medical images in radiotherapy

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