A mathematical framework to quantitatively balance clinical and radiation risk in Computed Tomography

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Purpose

Risk in medical imaging is a combination of radiation risk and clinical risk, which is largely driven by the effective diagnosis. While radiation risk has traditionally been the main focus of Computed Tomography (CT) optimization, such a goal cannot be achieved without considering clinical risk. The purpose of this study was to develop a comprehensive mathematical framework that considers both radiation and clinical risks based on the specific task, the investigated disease, and the interpretive performance (i.e., false positive and false negative rates), tested across a representative clinical CT population.

Materials and Methods

The proposed mathematical framework defined the radiation risk to be a linear function of the radiation dose, the population prevalence of the disease, and the false positive rate. The clinical risk was defined to be a function of the population prevalence, the expected life-expectancy loss for an incorrect diagnosis, and the interpretative performance in terms of the AUC as a function of radiation dose. A Total Risk (TR) was defined as the sum of the radiation risk and the clinical risk. With IRB approval, the mathematical function was applied to a dataset of 80 adult CT studies investigating localized stage liver cancer (LLC) for a specific false positive rate of 5% reconstructed with both Filtered Back Projection (FBP) and Iterative Reconstruction (IR) algorithm. Linear mixed effects models were evaluated to determine the relationship between radiation dose and radiation risk and interpretative performance, respectively. Lastly, the analytical minimum of the TR curve was determined and reported.

Results

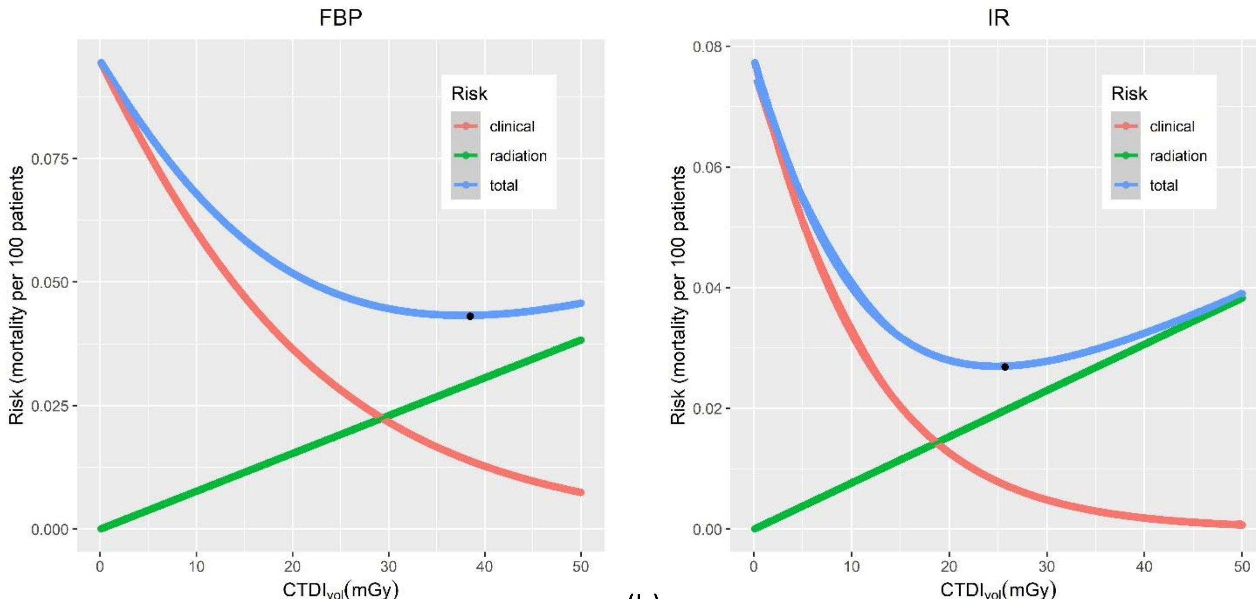
TR is largely affected by clinical risk for low radiation dose whereas radiation risk is dominant at high radiation dose. Concerning the application to the LLC population, the median minimum risk in terms of mortality per 100 patients was 0.04 in FBP and 0.03 in IR images; the corresponding $CTDI_{vol}$ values were 38.5 mGy and 25.7 mGy, respectively.

Conclusion

The proposed mathematical framework offers a complete quantitative description of risk in CT enabling a comprehensive risk-to-benefit assessment essential in the effective justification of radiological procedures and in the design of optimal clinical protocols.

Clinical Relevance statement

The quantification of both radiation and clinical risk using comparable units allows the calculation of the overall risk paving the road towards a comprehensive risk-to-benefit assessment in CT.



(a) (b)

Figure 1. Example of the calculation of radiation risk (green), clinical risk (red), and TR (blue) assuming a 5% of false negative rate for (a) the FBP and (b) the IR reconstructed images. The black dot represents the TR analytical minimum.