PhD Thesis title: 'A uniform framework for the objective assessment and optimisation of radiotherapy image quality'

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ABSTRACT:

Image guidance has rapidly become central to current radiotherapy practice. A uniform framework is developed for evaluating image quality across all imaging modalities by modelling the 'universal phantom': breaking any phantom down into its constituent fundamental test objects and applying appropriate analysis techniques to these through the construction of an automated analysis tree. This is implemented practically through the new software package 'IQWorks' and is applicable to both radiotherapy and diagnostic imaging.

For electronic portal imaging (EPI), excellent agreement was observed with two commercial solutions: the QC-3V phantom and PIPS Pro software (Standard Imaging) and EPID QC phantom and epidSoft software (PTW). However, PIPS Pro's noise correction strategy appears unnecessary for all but the highest frequency modulation transfer function (MTF) point and its contrast to noise ratio (CNR) calculation is not as described. Serious flaws identified in epidSoft included erroneous file handling leading to incorrect MTF and signal to noise ratio (SNR) results, and a sensitivity to phantom alignment resulting in overestimation of MTF points by up to 150% for alignment errors of only ±1 pixel.

The 'QEPI1' is introduced as a new EPI performance phantom. Being a simple lead square with a central square hole it is inexpensive and straightforward to manufacture yet enables calculation of a wide range of performance metrics at multiple locations across the field of view. Measured MTF curves agree with those of traditional bar pattern phantoms to within the limits of experimental uncertainty. An intercomparison of the Varian aS1000 and aS500-II detectors demonstrated an improvement in MTF for the aS1000 of 50–100% over the clinically relevant range 0.4–1 cycles/mm, yet with a corresponding reduction in CNR by a factor of $\sqrt{2}$. Both detectors therefore offer advantages for different clinical applications.

Characterisation of cone-beam CT (CBCT) facilities on two Varian On-Board Imaging (OBI) units revealed that only two out of six clinical modes had been calibrated by default, leading to errors of the order of 400 HU for some modes and materials – well outside the ±40 HU tolerance. Following calibration, all curves agreed sufficiently for dose calculation accuracy within 2%. CNR and MTF experiments

demonstrated that a boost in MTF f_{50} of 20–30% is achievable by using a 512^2 rather than a 384^2 matrix, but with a reduction in CNR of the order of 30%.

The MTF f_{50} of the single-pulse half-resolution radiographic mode of the Varian PaxScan 4030CB detector was measured in the plane of the detector as 1.0±0.1 cycles/mm using both a traditional tungsten edge and the new QEPI1 phantom. For digitally reconstructed radiographs (DRRs), a reduction in CT slice thickness resulted in an expected improvement in MTF in the patient scanning direction but a deterioration in the orthogonal direction, with the optimum slice thickness being 1–2 mm. Two general purpose display devices were calibrated against the DICOM Greyscale Standard Display Function (GSDF) to within the ±20% limit for Class 2 review devices.

By providing an approach to image quality evaluation that is uniform across all radiotherapy imaging modalities this work enables consistent end-to-end optimisation of this fundamental part of the radiotherapy process, thereby supporting enhanced use of image-guidance at all relevant stages of radiotherapy and better supporting the clinical decisions based on it.

References to author publications that relate specifically to the dissertation:

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