Aim

In order to accurately deliver modulated radiotherapy treatments to spinal metastases, while strictly limiting the doses to the spinal cord, a high degree of patient positioning accuracy and precision is required. The Canadian guidelines on stereotactic body radiotherapy suggest that bony anatomy is sufficient for target localisation when performing image guided radiotherapy (IGRT) for spinal lesions, while also noting that the most commonly reported form of image guidance for spinal cases is kilovoltage cone-beam computed tomography (kV CBCT) [1]. Because CBCT imaging is not widely used in Australia [2, 3], this study evaluated the ability of three more-common planar IGRT systems to detect and reproducibly measure small shifts in vertebral bony anatomy, in order to establish the adequacy of setting up spinal radiotherapy treatments without using CBCT.

Methods and materials

The three IGRT systems investigated in this study were:

1. Orthogonal 2D megavoltage (MV) electronic portal imaging device (EPID) imaging (Varian, Palo Alto, USA),

2. Orthogonal 2D kV on board (OBI) imaging (Varian, Palo Alto, USA), and

3. Non-orthogonal 2D kV x-ray imaging (Brainlab, Feldkirchen, Germany).

These systems were each used to acquire images of a pelvis phantom containing sacrum and lumbar vertebra, with the phantom shifted, in 1 mm steps (applied simultaneously in longitudinal, lateral and vertical directions), up to 5 mm from its planned "treatment" position. Digitally reconstructed radiographs (DRRs) of the phantom, suitable for use with the Varian and Brainlab imaging systems, had been previously produced by importing a CT scan of the phantom into the Varian Eclipse treatment planning system. The IGRT images of the phantom were auto-matched with these planning DRRs, and the required shifts identified by the imaging systems were compared with the physical shifts applied to the phantom.

All images were acquired using fields at least 13x13 cm$^2$ in area and registration of all EPID and OBI images was performed using a 10x10 cm$^2$ region of interest (ROI). The auto-registration of the MV EPID images was repeated using a ROI limited to approximately 4x6 cm$^2$, to simulate the use of a treatment portal for pre-treatment imaging.
Results

The orthogonal MV and kV images (exemplified in Fig. 1 on page 3(a) and (b)) showed precipitous gradients in pixel values at the superior and inferior edges of individual vertebrae, causing the orthogonal imaging systems to be very sensitive to longitudinal shifts in the phantom position. The non-orthogonal imaging directions used by the other kV x-ray imaging system led to regions of overlap between adjacent vertebrae, which appeared as small, high-contrast regions, in the resulting images as well as the corresponding DRR.

These differences in image quality and image composition, in combination with differences in auto-registration algorithms and features led to several important differences in the accuracy and reproducibility of phantom shift detection achieved by the three imaging systems investigated.

The orthogonal MV EPID and kV OBI images provide more accurate and reproducible identification of longitudinal shifts than lateral shifts (as shown in Fig. 2 on page 4(a), (b) and (c)). The standard deviations in the kV OBI system's measurement of 1mm lateral and longitudinal shifts were, respectively, 0.5 mm and 0.3 mm. The MV EPID imaging system was similarly able to accurately detect longitudinal shifts in the phantom's position, but generally failed to accurately identify lateral shifts of up to 2 mm when combined with longitudinal and vertical shifts. In particular, the use of a treatment-portal sized ROI caused the MV EPID imaging system to detect lateral shifts with the largest overall inaccuracy identified in this study, across all shift distances.

The kV OBI system and the non-orthogonal kV x-ray system were generally able to identify small shifts more accurately than the MV imaging system. However, comparison of Fig. 2 on page 4(c) and Fig. 2 on page 4(d) indicates how the results for a 0.5 mm applied shift differ between the two systems, due to the precision with which their user interfaces report shift distances: the kV OBI system reports shifts with millimetre precision and therefore cannot provide an accurate measurement of the 0.5 mm shift (Fig. 2 on page 4(c)) whereas the non-orthogonal kV x-ray system reports shifts with sub-millimetre precision and is therefore able to accurately measure and report the 0.5 mm shift, to within 0.1 mm (Fig. 2 on page 4(d)).

Images for this section:
Fig. 1: L5 and L6 vertebrae in pelvis phantom, as they appear in the (a) MV EPID and (b) kV OBI images.
Fig. 2: Phantom position shifts identified using (a) the MV EPID images, with a treatment-portal sized ROI, (b) the MV EPID images, with a 10x10 cm² ROI, (c) the kV OBI images, with a 10x10 cm² ROI, and (d) the non-orthogonal kV x-ray images. Detected shifts are plotted against physical shifts, with one-to-one correspondence indicated by dotted line.
Conclusion

All IGRT systems were able to use bony anatomy matching to identify shifts in the position of a pelvis phantom of 1 to 5 mm, with uncertainties of up to 2 mm for the MV EPID system and uncertainties up to 0.5 mm for the kV OBI and non-orthogonal x-ray imaging systems. This study suggests that high-precision modulated spinal treatments may be accurately deliverable without the use of CBCT, if a kV planar imaging system, preferably a non-orthogonal system designed to provide sub-millimetre precision, is utilised. In future, this work should be extended to evaluate the precision with which automated couch movements can account for the anatomical shifts detected by radiological imaging.

Personal information

Tanya Kairn, B.A., B.Sc. (Hons.), Ph.D., CMPS, MACPSEM, Radiation Oncology Medical Physicist¹, Associate Professor in Medical Physics².


1. Genesis Cancer Care Queensland, Wesley Medical Centre, Auchenflower 4066, Australia

2. Science and Engineering Faculty, Queensland University of Technology, Brisbane 4000, Australia

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