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Evaluation of mechanical and geometric accuracy of two different image guidance systems in radiotherapy

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ABSTRACT

Aim: To assess the mechanical and the geometric accuracy of two different clinically used image guidance systems in radiotherapy for a period of 6 months.
Background: With the image guidance procedures being routine in the clinical radiotherapy department, the quality assurance tests for these systems become essential. The mechanical and geometric accuracy of these systems are crucial since it directly affects patient treatment set-up and delivery.
Materials and methods: We have assessed the mechanical and the geometric accuracy of two different image guidance systems (MV and kV based), being used clinically for a period of 6 months. The quality assurance tests such as imager positioning/repositioning, imaging and treatment beam isocentre coincidence, imager mechanical alignment, image scaling, geometric accuracy of cone beam computed tomography system, automatic image registration and offset calculation accuracy were assessed in this period.
Results: It was found that both systems were mechanically and geometrically accurate within ±2 mm in this period.
Conclusion: The quality assurance tests for MV based image guidance system were simple compared to kV based systems. We recommend performing periodic quality assurance tests to verify the integrity of both image guidance systems.

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1. Background and aim

Image guidance in radiotherapy has become essential with sophisticated three dimensional treatment techniques, such as intensity modulated radiotherapy, stereo-tactic radiotherapy, volumetric modulated arc therapy, etc. It is being used routinely in radiotherapy centres to evaluate and correct inter-fractional patient setup errors and internal organ motion.[1–5] In the past, orthogonal mega voltage (MV) portal images were acquired to verify patient positioning with respect to the treatment beam. Using portal images limits the visualisation only to bony structures. In recent times, the cone beam computed tomography (CBCT) has been used to provide a volumetric image of the patient that is acquired just prior to treatment delivery on the treatment table.[6–8] Several CBCT systems are available commercially and are being used clinically in radiotherapy centres: MV CBCT, such as MVision®, kilo voltage (kV) CBCT, such as OBI®, XVI®. A good imaging system needs to be safe, mechanically and geometrically accurate providing good image quality with reasonable imaging dose. With the image guidance system capable of performing CBCT, it can be used for adaptive radiotherapy[9,10] to make decisions to change the treatment plan in the course of treatment to account for changes in patient anatomy due to tumour shrinkage or weight loss. With suitable CT to material density conversion curve, the CBCT can also be used for dose calculation in treatment planning.[11,12] Even though an image guidance system has several clinical applications, its primary use is to verify the patient position with respect to the treatment beam, which makes the mechanical and geometric accuracy of the system more important. Several studies have compared and reported MV and kV based imaging systems' image quality and imaging dose.[13–16] These imaging systems differ in their geometry, acquisition and reconstruction methods. These systems need to be assessed for their alignment with respect to treatment beam and imaging accuracy in order to be used in clinics. We present a study on the mechanical and geometric accuracy assessment of two different clinically used image guidance systems in radiotherapy for a period of 6 months.

2. Materials and methods

2.1. System 1

The Siemens Oncor Expression™ (Siemens Medical solutions Inc., Concord, CA) linear accelerator is capable of delivering high energy photons and electrons. It is equipped with the MV imaging guidance system (OPTIVUE 1000ST™) able to acquire MV planar and CBCT imaging and is attached to the gantry at the counter-part of the head of the linear accelerator, as shown in Fig. 1(a). The image guidance system consists of flat panel detectors which have the sensors of amorphous silicon (a-Si) photo diodes that are deposited on a glass substrate with a scintillator coating. The pixels have a pitch of 400 μm and there are 1024×1024 pixels covering a $40 \times 40\,\text{cm}^2$ area. The X-ray reticule (named 'X-RETIC') consists of two orthogonal radio-opaque tungsten wires, shown in Fig. 1(b), that intersect at the collimator rotation axis and can be inserted in the accessory slot in the gantry head and are used to represent the treatment co-ordinate axis in the acquired MV image. The image quality phantom (Siemens Medical Solutions, Concord, CA), as shown in Fig, 1(c), is a cylindrical acrylic shell of diameter 20 cm with four sections for image quality checks, positioned axially within the shell. It also has tungsten beads at three axial planes such that four tungsten beads are arranged at 12, 3, 6 and 9 o' clock at each axial plane to determine the geometric positional accuracy of CBCT image.

2.2. System 2

The NovalisSTx™ linear accelerator (Varian, Palo Alto, CA and BrainLAB, Heimstetten, Germany), as shown in Fig. 2(a), is capable of delivering high energy photons for conventional and stereotactic treatment delivery and high energy electrons. The MV and kV imaging systems are integrated with the linear accelerator. The MV electronic portal imager consists of a-Si based detector with 1024×768 pixel matrix covering an area of $40 \times 30\,\text{cm}^2$, mounted in the gantry at the counter-part of the head of the linear accelerator. The kV on-board imager (OBI) system, mounted orthogonal to the MV beam axis consists of a kV source and a kV a-Si detector-based imager covering an area of $40 \times 30\,\text{cm}^2$. The detailed description of the system can be found elsewhere.[17] The MV imager can acquire planar images and the kV OBI can acquire both planar and CBCT volumetric images. The isocentre cube phantom and the OBI geometric phantom (Varian, Palo Alto, CA), as shown in Fig. 2(b) and (c), respectively, are used to perform geometric accuracy tests of the imaging system. The isocentre cube phantom consists of a 2 mm spherical radio-opaque ball bearing (bb) in the centre of the cube and several other bbs at the surface. The OBI geometric phantom also known as the Marker seed phantom has five radio-opaque markers inbuilt within the block and can be fixed on the couch using a lock bar.

2.3. Mechanical and geometric accuracy tests

Periodic quality assurance tests were previously developed to assess and evaluate the performance of the imaging system.[18] In this study, the mechanical and geometric accuracy for two different imaging systems were assessed for a period of 6 months. Table 1 lists the QA tests, their frequencies and tolerances. The tolerance values for the tests were set based on recommendations from the American Association of Physicists in Medicine (AAPM) task group (TG) reports[19,20] and manufactures' specifications.

2.4. Imager positioning/repositioning

The imaging device attached to the machine can be extended during imaging and retracted when not in use for easy access for radiographers to set up the patient. This mechanical movement of the imager requires performing imager positioning accuracy and reproducibility tests. The test involves acquiring planar image of a phantom with inbuilt radio opaque markers and verifying its position with respect to image centre with every imager positioning and repositioning. System 1: a slab phantom with 5 radio opaque markers at known distances was used for testing the MV flat panel imager. System 2: the test