QUALITY ASSURANCE OF PATIENT SETUP USING MEGAVOLTAGE PORTAL IMAGING AND DIGITALLY RECONSTRUCTED RADIOGRAPH IN RADIOTHERAPY FACILITY WITHOUT KILOVOLTAGE IMAGING

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Abstract

The purpose of this study is to assess the quality assurance (QA) of patient treatment setup using megavoltage (MV) images and digitally reconstructed radiographs (DRRs). Thirty anonymized image pairs (30) of DRR and MV images of patients treated on Varian Medical System Clinac IX were used. Identical landmarks were selected by experts on both images using an in-house MATLAB program called the Assisted Expert Manual Point Selection Application (ASEMPA). The differential translations were calculated using the combinatorial rigid registration optimization (CORRO) for both Anterior Posterior (AP) and Lateral (Lat) images to get the 3D shifts from two orthogonal 2D-images. The anatomical sites used were prostate and head/neck. The systematic error for Prostate cases ranged from 0.46cm – 18.62cm, while that for Head and Neck cases ranged from 1.57cm – 11.56cm. The study revealed significant variances and aided in evaluating the facility's setup accuracy. The results proved that our institution needs to do periodic quality assurance on the patient setup process given we currently do not have three-dimensional imaging capabilities for cone beam. Periodic quality assurance will be a guiding tool in correcting any discrepancies that may show up in the clinical workflow as well as periodic education and training on how to properly set up patients.

Keywords
Patient Setup, CORRO, Image Registration, Quality Assurance

I. INTRODUCTION

The main goal of radiotherapy is to deliver an optimal dose to the target volume while minimizing the dose to adjacent normal tissues. External Beam Radiation Therapy (EBRT) typically accomplishes this goal by employing multiple beams to ensure an even distribution of doses within the target volume. External beam radiotherapy techniques require positioning and the use of immobilization devices to ensure accurate tumour localization and treatment setup reproducibility. Accurate and reproducible patient setup using Image Guided Radiation Therapy (IGRT) requires registering the daily images to the reference image set mostly from the planning computed tomography (CT) [4]. A digitally reconstructed radiograph (DRR), which is used to verify treatment in CT simulation, is one of the critical images that can be transmitted via radiotherapy communication [5]. To confirm patient positioning, digitally reconstructed radiographs (DRR) from the planning CT, or the planning CT itself are from compared to 2D electronic portal images obtained on the treatment, or 3D cone beam computed tomography (CBCT) images respectively.

The digital formats are communicated and managed using Digital Imaging and Communications in Medicine (DICOM). DICOM is the de facto standard in the industry for an image file format for radiological hardware [2]. For proper utilization, consistent portal image quality and a stable radiation response are required, which necessitates routine quality assurance (QA).

There are four widely used techniques for evaluating the integrity of image registration: visual inspection, fiducials, landmark point sets, and mutual information [5]. The patient position deviation can be calculated using the landmark point method to assess the images. Before beam delivery, the correction is used to align the patient nearly perfectly with the reference image position. Over the years, physicians visually verified registered images by comparing portal and diagnostic quality images to a digitally reconstructed radiograph (DRR). The accuracy with which this method of evaluating the quality of image registration is applied has been reported to be between 5 to 10 mm [4]. However, this method of registration is subjective and therefore unsuitable for large amounts of data.

The motivation for this study in our institution was to perform a quality assurance and management procedure on our newly installed Clinac IX to make sure patients set-up was being performed properly and find any gaps in the process that needed to be addressed.

Currently, our institution uses visual inspection for patient set up prior to beam delivery, fiducial, and landmark point methods to verify the patient's alignment, and these methods are subjective. The facility does not have the means to quantify the deviation occurring in the setup. Therefore, there is a need to input a system that will quantify the deviations for optimal patient alignment and reduce the unevaluated incidences of exposure organs at risk. Figure 1 shows an image retrieved from the treatment offline review of the setup done for a patient during treatment.

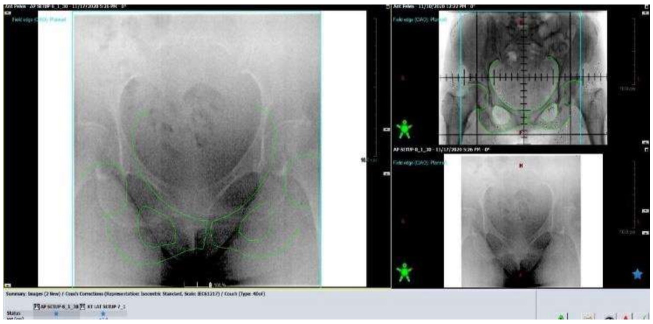

Figure 1: A Treatment Offline Review of Patient Setup from the Linear Accelerator (LINAC) Machine

Using an in-house developed tool, that employs the mathematics of combination without replacement, combinatorial rigid registration optimization (CORRO) we demonstrate the optimal alignment of clinical image pairs in our institution as a way to perform a rigorous post patient set-up quality assurance to inform future workflow.

II. MATERIALS AND METHODS

This study was a retrospective study using a quantitative research approach carried out at the Radiotherapy department at the Oncology Directorate of Komfo Anokye Teaching Hospital (KATH), Kumasi, Ghana after seeking ethical clearance from the Institutional Review Board (IRB) of the hospital. The sampling was done using the simple random method from the data provided by the hospital with a sample size of thirty (30); twenty (20) head and neck and ten (10) prostate cases. These images were from patients who had completed their full treatment.

This study was a quality control (QC) measure to improve radiotherapy patient setup in the radiation beam and to achieve set up reproducibility. In our facility we currently do not have a kilovoltage (kV) imager. We currently use MV portal imaging with a 2D digitally reconstructed radiograph for patient's set-up. Since transitioning from our Co-60 to a conventional linear accelerator (Clinac IX) we haven't performed any quality assurance measures to check the performance of the patient setup process. For an institution like ours it was very important to go through this retrospective study to inform and improve our current practice and workflow.

The centre treats majority of all cancers, with over 1,200 patients treated yearly. Using an independent MATLAB-based user interface assisted expert manual point selection algorithm (ASEMPA) corresponding landmark points were selected on the MV portal images and the DRRs for both image sets (Anterior-Posterior view and Lateral view) for a single case by medical physics experts and the image registration between the corresponding image pairs are calculated using in-house MATLAB based algorithm combinatorial rigid registration optimization (CORRO) landmark point algorithm. Given the image quality of the MV images, corners and angles and pointed anatomy were the regions of focus. The output translation was applied to the MV image to match the DRR. The output translation Tx, Ty, Tz, were used to adjust the patient in three dimensions.

III. RESULTS AND DISCUSSION

The results were obtained after loading the image pairs to run an analysis on each image pair by picking corner points on the image pairs for Anterior-Posterior and Lateral views simultaneously. This analysis was done to compare the outcome with that which was done clinically. The tx and ty values gotten after running the registration in the in-house MATLAB algorithm were pixel values. The values were then multiplied by the ratio of the MV and kV image spacing since they did not have the same values. The ratio between MV and kV Image Spacing was achieved by equation (1):

The ratio between MV and kV image spacing

$$= \frac{MV_{Image\ Spacing}}{kV_{Image\ Spacing}} \quad (1)$$

The values were changed to centimetres (cm) because the standard (clinical shifts) are in centimetres.

To convert the pixel values to shifts in centimetres using equations (2) and (3):

$$\text{Tx (cm)} = \frac{\boldsymbol{tx\ (pixel)} \times \text{Ratio}}{\mathbf{10}} \quad (2)$$

$$\text{Ty (cm)} = \frac{\boldsymbol{tx\ (pixel)} \times \text{Ratio}}{\mathbf{10}} \quad (3)$$

Based on Fig. 2 in the information provided, the 2D plane images for the anterior-posterior plane and the 2D lateral plane were translated to provide us with the x, y and z values. For the Anterior-Posterior view, as stated before, the x and z values were gotten, and for the lateral view, x and y values were gotten. The two x values were added and divided by 2 to find the average.

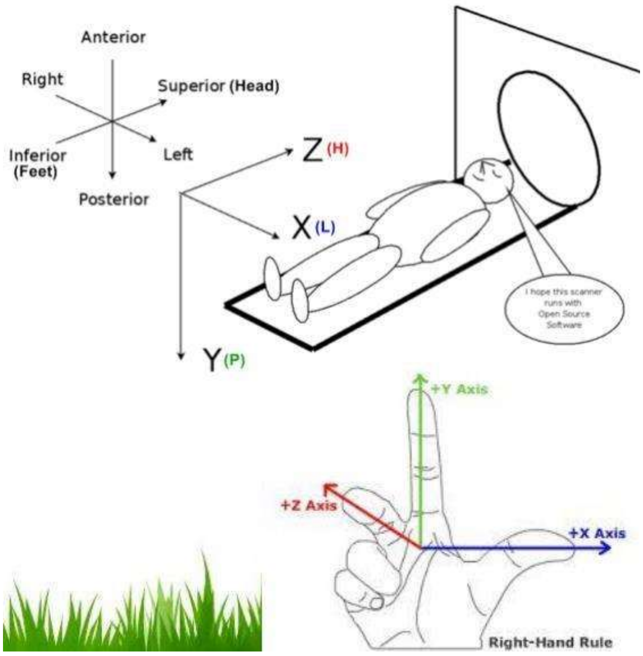

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Figure 2: DICOM Geometry Information

$$x = \frac{x_{AP} + x_{LAT}}{2} \qquad (4)$$

The minimum root mean square distance between the Image pairs (i.e. MV_{AP} and kV_{AP}, MV_{LAT} and kV_{LAT}) was found using CORRO computation using equation 5. The results were compared to what was reported clinically by the therapists.

$$\sqrt{(\mathbf{Lat}_{\mathbf{Corro}} - \mathbf{Lat}_{\mathbf{Clinical}})^2 + (\mathbf{Lng}_{\mathbf{Corro}} - \mathbf{Lng}_{\mathbf{Clinical}})^2 + (\mathbf{Vrt}_{\mathbf{Corro}} - \mathbf{Vrt}_{\mathbf{Clinical}})^2} \qquad (5)$$

Calculating the shifts

Sample results are shown in Table 1 for Prostate and head and neck cases. The ratio between MV and kV Image Spacing was calculated to be 0.401 mm.

Table 1 represents the differences between the CORRO and Clinical Lateral, Longitudinal and Vertical shifts as well as the root mean deviation. The table shows large variations between the two registrations. This is as a result of a lack of accuracy when it comes to patient setup reproducibility and these were because of the poor patient positioning, as could be seen in the offline review images. These were of much concern because they indicated the lack of precision and accuracy in the setup, and hence this led to the toxicity of healthy tissues, which goes against the aim of radiotherapy.

Table 1: A table showing the shifts calculated from the CORRO algorithm, shifts from the Eclipse Treatment Planning System (TPS) and the Calculated Root Mean Square Deviation for ten (10) Prostate cases and Head and Neck cases respectively.

PROSTATE							
Study ID	**Lat_{Corro} (cm)**	**Lng_{Corro} (cm)**	**Vrt_{Corro} (cm)**	**$Lat_{Clinical}$ (cm)**	**$Lng_{Clinical}$ (cm)**	**$Vrt_{Clinical}$ (cm)**	**Root Mean Square**
MS001	0.6	18.6	-0.1	0.0	0.0	-0.6	18.616
MS002	-0.6	15.9	-0.4	-0.8	0.4	-1.3	15.527
MS003	2.5	7.1	8.4	1.6	-3.0	0.8	12.672
MS004	1.8	-2.9	-3.5	0.1	1.6	1.7	7.084
MS005	0.8	-4.6	1.2	1.1	0.2	-0.2	5.009
MS006	-1.0	-0.4	-0.9	-0.4	0.1	-0.9	0.781
MS007	-0.6	0.5	0.4	0.6	-4.1	-17	18.038
MS008	-2.2	-2.9	4.9	0.0	-0.3	-3.3	8.879
MS009	-0.7	2.0	-0.3	0.0	-0.4	0.2	2.550
MS012	0.0	1.0	1.3	-1.3	-2.3	0.0	3.778
HEAD AND NECK							
Study ID	**Lat_{Corro} (cm)**	***Lng_{Corro}* (cm)**	***Vrt_{Corro}* (cm)**	**$Lat_{Clinical}$ (cm)**	**$Lng_{Clinical}$ (cm)**	**$Vrt_{Clinical}$ (cm)**	**Root Mean Square**
HMS010	-4.7	-8.4	0.2	-0.2	0.3	0.4	9.7969
HMS011	0.7	-2.7	1.0	-0.2	0.4	-0.2	3.4438
HMS017	-0.6	-0.4	1.4	0.0	0.0	0.0	1.5748
HMS022	-1.6	3.3	7.3	0.0	0.0	2.3	6.2008
HMS023	-0.1	-1.5	0.9	0.0	0.0	0.0	1.7521
HMS025	0.6	1.8	11.2	-0.4	0.2	-0.2	11.5551
HMS047	0.2	0.3	5.3	0.0	0.6	-0.1	5.4120
HMS048	-0.5	-0.2	0.8	1.0	-0.2	0.1	1.6553
HMS049	-0.6	-2.9	1.9	0.0	-0.4	0.6	2.8810
HMS050	-1.1	0.6	2.2	-2.9	-3.6	-1.8	6.0729

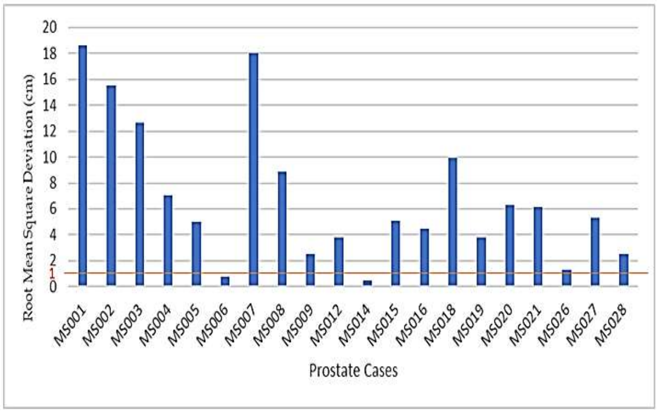

Figure 3: Graphical View of the Deviations Occurring in the Setup for Prostate cases.

Figure 3 is a graphical representation of the root mean square deviation that was calculated to find the deviation occurring between the two registrations. It was found that the root mean square deviations occurring in the shifts between that of the CORRO algorithm and that of the Clinical standard for the Prostate cases was found to be in the range of 0.46 cm – 18.62 cm. The range buttresses the lack of patient setup accuracy in the facility. The cases whose bar are below the red line in the graph are the cases that passed the facility's accuracy protocol of at most 1cm deviation.

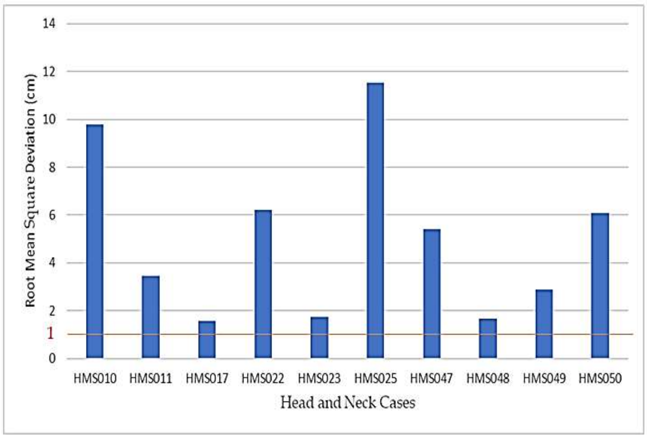

Figure 4: A Graphical View of the Deviations Occurring in the Setup for Head and Neck cases.

Figure 4 represents the graphical view of the root mean square deviation calculated for the CORRO and Clinical shifts for each head and neck case. The root mean square deviations occurring in the shifts between that of the CORRO algorithm and that of the Clinical standard of the Head and Neck was found to be between 1.57 cm – 11.56 cm. This represents the systematic error for both cases. The deviations occurring shows that there are large shift differences between that gotten from CORRO, which is being used for the quality assurance of the setup and that of which is done clinically. This proves that there is a gap that needs to be filled when it comes to the patient setup at the study location. The bars below the red line in Figure 4 represent the cases that passed the accuracy standard of at most 1cm deviation, of the facility, all others failed.

IV. CONCLUSION

It is well documented that patient setup plays a very vital role in delivering the prescribed dose to the target. Any misalignment will be detrimental to the patient. For a radiotherapy centre in the process of transitioning from Co-60 to modern linear accelerators without kV imaging capabilities as a guidance in the patient set up process, it is important to go through periodic quality assurance of this process to come up with mitigation strategies or update the workflow based on the findings. From our study, the results showed large discrepancies from the expected results and as such the large deviations observed between the set-up shifts recorded versus the results obtained from our CORRO algorithm in three dimensions. The poor accuracy in the setup can be attributed to the patients getting their simulation CT from outside the institution which does not necessarily match the treatment coordinates. Also, it is recommended that the radiation therapists perform the CT simulation and record the treatment positions and any anatomical position the patient might be in at the time of simulation so that this could be reproducible at the time of treatment. However, given the current workflow at our institution this aspect is missing and puts a dent in the current workflow. As a result, the therapist must rely on information given to them by the medical physicists or the diagnostic radiographers the outside institution who took the images. Hence their exclusion from this crucial step makes it very difficult to reproduce the patient’s set-up positioning and this might have contributed to the large discrepancies. We recommend that clinics with this current type of workflow must include radiation therapists or train them to perform patient CT simulation because such large deviations could be detrimental to the patient.

VI. ABBREVIATIONS

2D: two dimensional; 3D: three dimensional; AP: anterior – posterior; ASEMPA: assisted expert manual point selection application; cm: centimetre; CT: computed tomography; CORRO: combinatorial rigid registration optimization; DICOM: digital imaging and communications in medicine; DRR: digitally reconstructed radiographs; EBRT: external beam radiation therapy; EPI: electronic portal images; IGRT: image-guided radiation therapy; IRB: institutional review board; KATH: Komfo Anokye Teaching Hospital; kV: kilovoltage; Lat: lateral; LINAC: linear accelerator; mm: millimetre; MV: megavoltage; TPS: treatment planning system; QA: quality assurance.

CONFLICT OF INTEREST

The authors have declared that no competing interest exists with publication of the study.

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