Uniformity in the analysis of head and neck image guided radiotherapy across multiple departments

Abstract ***Purpose:*** Head and Neck Image Guided Radiation Therapy (IGRT) is of vital importance particularly with the advent of Intensity Modulated Radiation Therapy (IMRT). The responsibility of IGRT rests with the treating radiation therapy team, therefore it is essential that they undertake IGRT in a uniform manner. This study represents an assessment of head and neck IGRT analysis across multiple radiation oncology departments, inclusive of radiation therapist seniority, image modality and anatomical variation within the treatment volume. ***Methods:*** Site visits were undertaken at three radiation oncology departments. At each site kV and MV image datasets were analysed by one senior radiation therapist and one junior radiation therapist. The influence of differing sites, radiation therapist seniority, image modality and cervical vertebra position on head and neck IGRT was then assessed. ***Results:*** Statistical analysis of the diagnosed field placement errors indicated that head and neck IGRT was undertaken consistently regardless of site, radiation therapist seniority, image modality and the position of the cervical vertebra. ***Conclusion:*** In the era of sophisticated treatment planning it is vital that the treatment delivery mechanism (IGRT) is performed consistently. Head and neck IGRT is the responsibility of the treating radiation therapist regardless of site, seniority, image modality and positioning challenges.

Keywords: electronic portal imaging, head and neck stabilisation, image guided radiotherapy, kilovoltage imaging, megavoltage imaging.

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Introduction

Image Guided Radiation Therapy (IGRT) is an accepted and integral part of head and neck radiotherapy particularly if delivering Intensity Modulated Radiation Therapy (IMRT).[1,2] IGRT has been accepted as a core duty of the radiation therapist.[3] Uniformity of IGRT analysis has been investigated for prostate radiotherapy across multiple sites.[4] However head and neck IGRT could be seen as a greater challenge due to difficulties in match anatomy visualisation, proximity of critical healthy structures to high dose regions, and decision making frameworks. In the real time environment of online corrections the treating radiation therapist is required to diagnose, analyse and potentially intervene on field placement errors under the pressure of time constraints. It is therefore essential that radiation therapists, regardless of seniority, are able to undertake head and neck IGRT in a uniform fashion.[5,6]

Previous work by the authors illustrated that the introduction of kilovoltage (kV) imaging with its increased clarity and enhanced field of view improved consistency between observers in field placement analysis.[7] However, this enhanced field of view also identified other anatomical variation within the treatment volume, notably the discrepancy between the position of first and seventh cervical vertebrae. This discrepancy can cause indecision for the radiation therapist to make a real time decision. It has been noted that the first cervical vertebra (C 1) and the clivus are the most reliable structures to utilise for head and neck IGRT.[1] However, if the lower cervical vertebra present a different position than planned then this can pose a dilemma as to which match anatomy takes precedence over the upper cervical vertebra and clivus.

An initial study was undertaken at Radiation Oncology Queensland (ROQ), Australia to benchmark the uniformity of response in IGRT analysis across the radiation therapy team.[7] Two patient datasets were analysed; one being kV and the other megavoltage (MV). It was decided the study be broadened to incorporate two other radiation oncology departments, these being The Harley St Clinic in London, United Kingdom and the Andrew Love Cancer Centre in Geelong, Australia.

The aim of this study was to assess if radiation therapists across three different departments would analyse head and neck IGRT uniformly. This IGRT uniformity would also be compared against seniority of the radiation therapist, modality of the image data set and any potential anatomical variation between C 1 and cervical vertebra 7 (C 7).

Comparison of radiation therapist seniority and image modality has been undertaken before in the context of IGRT.[4] However, this was in the arguably much more straightforward scenario of intraprostatic fiducials. The inclusion of potential anatomical variation in the datasets was provided to mimic the conditions that radiation therapists face in the standard treatment day.

The radiation therapy group is now recognised as

Figure 1: Med-Tec standard immobilisation equipment.

the only group with the feasible capacity to take responsibility of daily IGRT.[3] With this increased responsibility it is essential that radiation therapists across all sites and seniority can undertake IGRT in a uniform manner regardless of image modality. Additionally, in the complex area of head and neck IGRT where anatomical variation can occur, it is important that the IGRT response to unexpected scenarios also be uniform.

As radiation therapists progress further into the field of IGRT and other research initiatives, it is important to note collaboration between multiple sites. The collaboration between the three sites in this study can only benefit each organisation and strengthen their head and neck IGRT programmes.

Methods

Ethics approval

This study received low risk ethics approval from the Toowoomba and Darling Downs Health Services District (TDDHSD) Human Research Ethics Committee (HREC) on the 13th August 2010.

Site visits

Three radiation oncology departments participated in this study. In January 2009 a site visit was undertaken at each of these sites inclusive of a research laptop with a complete suite of Varian's™ (Palo Alto, CA, USA) Offline Review verification image analysis software. Within Offline Review were two complete datasets (two patients) of pre-intervention verification data, one kV and one MV, inclusive of anterior-posterior and lateral orthogonal digitally reconstructed radiographs (DRRs) and 28 corresponding verification images. These two datasets consisted of images taken while stabilised with Med-Tec standard immobilisation equipment (Figure 1). Silverman (MT-SILVER) (Civco Medical Solutions, IA, USA) standard head and neck supports were used. These supports come in six standard sizes and are chosen depending on the patient's natural posture and disease location. For reporting purposes the participating site's results are anonymous.

Seniority

At each site a senior radiation therapist and a junior radiation therapist were asked to analyse each of the datasets. The senior radiation therapist was designated as being at charge level or above and the junior radiation therapist could not be or had not acted in a senior role.

Data analysis

Each of the radiation therapists were asked to retrospectively analyse 28 pre-treatment orthogonal verification images comparing it to the DRR generated from the planning computed tomography (CT). The analysing radiation therapist was asked to analyse both datasets using the first cervical vertebra as the primary matching mechanism. The translational error diagnosed by this analysis was then exported to PASW Statistics Release 18 for statistical analysis. Match data was then erased and the radiation therapists were asked to analyse the datasets again using the seventh cervical vertebra. This process was repeated at each site giving rise to senior and junior radiation therapist analysis for the first and seventh cervical vertebrae for both imaging modalities. This process is graphically represented in Figure 2.

The mean squared deviation from zero was determined for each of the 72 sets of 28 errors, one set for each combination of the three orthogonal directions, three locations, two imaging modalities, two levels of seniority and two vertebrae matchings. That is, for a set of *n* errors $y_1, y_2, \ldots, y_n$, the mean squared deviation from zero was calculated as:

$$\text{MSE} = \frac{1}{n} \sum_{i=1}^{n} y_i^2$$

Note that MSE is zero if and only if all errors in the set are zero. If one or more of the errors is non zero, regardless of direction, MSE will be positive. In particular, MSE increases both with increasing mean deviation from zero, whether positive or negative, and with increasing variance amongst the errors. Consequently, MSE captures both systematic error (or bias) and random error in field placement and is therefore a useful statistic in assessing the overall performance of the radiation therapists.

For the purposes of analysis and reporting of results, the square root of MSE (RMSE) was used rather than MSE as the statistic of interest. Clearly, the properties described above for MSE also apply to RMSE. RMSE however is better behaved than MSE with regard to normality and homogeneity of variance, properties, which are required to validate the analyses described below. Also RMSE, unlike MSE, is measured in mm, the same as displacement error, and is therefore a more convenient metric than MSE in comparing performances.

The RMSEs associated with each of the three directions were cross classified according to location and seniority (between-subjects factors) and modality and vertebrae (within-subjects factors). There were insufficient data to pursue an inferential analysis involving the between-subject factors. However, since each of the six therapists generated two repeated measures on each of the within-subjects factors, matched *t*-procedures were carried out to assess the effects of modality and vertebra matching alone. These analyses provide 90% confidence intervals for effect sizes.

Results

Site

Across the three sites there was uniformity of analysis of head and neck IGRT. For the MV modality there was a mean difference in RMSE of 0.3 mm for the anterior-posterior plane (AP), 0.25 mm for the right to left plane (RL) and 0.4 mm for the cranio-caudal (CC). The kV modality showed a difference in RMSE of 0.04 mm (AP), 0.07 mm (RL) and 0.20

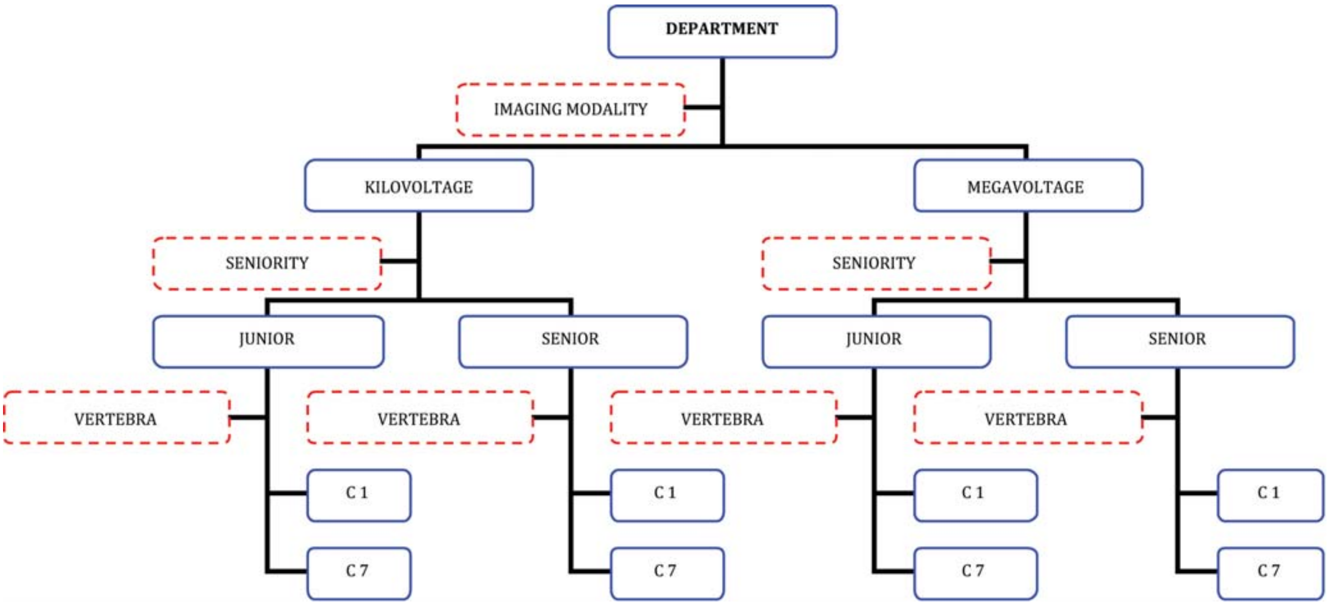

Figure 2: Department analysis flowchart.

Table 1: RMSE (mm) for the anterior-posterior plane for MV imaging inclusive of site, seniority and cervical vertebra indicating uniformity of IGRT analysis.

AP RMSE (mm) MV Image Modality

Site	Vertebrae	Modality	Junior (mm)	Senior (mm)
1	Cervical vertebra 1	MV	1.72	0.93
	Cervical vertebra 7	MV	2.09	1.21
2	Cervical vertebra 1	MV	1.79	2.07
	Cervical vertebra 7	MV	2.24	1.4
3	Cervical vertebra 1	MV	1.97	2.82
	Cervical vertebra 7	MV	1.93	1.36

AP – anterior-posterior; MV – megavoltage; RMSE – root mean square error

Table 2: RMSE (mm) for the anterior-posterior plane for kV imaging inclusive of site, seniority and cervical vertebra indicating uniformity of IGRT analysis.

AP RMSE (mm) kV Image Modality

Site	Vertebrae	Modality	Junior (mm)	Senior (mm)
1	Cervical vertebra 1	kV	1.33	1.85
	Cervical vertebra 7	kV	1.45	1.35
2	Cervical vertebra 1	kV	1.33	2.2
	Cervical vertebra 7	kV	1.6	1.27
3	Cervical vertebra 1	kV	1.62	1.93
	Cervical vertebra 7	kV	2.94	1.43

AP – anterior-posterior; kV – kilovoltage; RMSE – root mean square error

mm (CC). Tables 1–6 illustrate the consistency of the IGRT analysis across the three sites taking into account seniority, modality and cervical vertebra for the RL, CC and AP planes.

Seniority

The distributions of errors in the RL, CC and AP planes are displayed in Tables 1–6 for senior and junior radiation therapists. This takes into account each site and both image modalities. The differences in RMSE between senior and junior radiation therapists across all three orthogonal planes are substantively small in a clinical sense.

Modality

Table 7 represents the RMSE 90% confidence intervals for differences between the kV and MV image datasets, taking into account all sites, all radiation therapists and cervical vertebra. Differences in the RMSE between the two modalities were small and non-significant in the RL, CC and AP planes.

Cervical vertebra

There was no significant difference between the use of cervical vertebra 1 and 7 across the three orthogonal planes. Table 7 represents the RMSE confidence intervals for vertebra matching differences taking into account all sites, all radiation therapists and cervical vertebra.

Discussion

It is clear from the results presented by this study that there is uniformity of head and neck IGRT analysis across all participating sites, regardless of radiation therapist seniority, image modality or the cervical vertebra used. The era of IGRT demands that all radiation therapists are able to assess, diagnose and intervene in a uniform fashion. This uniformity in response has been illustrated in the area of prostate fiducial IGRT,[4] and in this smaller study head and neck IGRT is shown to be conducted uniformly between the participating departments. The consistency of inter-observer response at each site was consistent with previous work.[5,8]

Table 3: RMSE (mm) for the right to left plane for MV imaging inclusive of site, seniority and cervical vertebra indicating uniformity of IGRT analysis.

RL RMSE (mm) MV Image Modality

Site	Vertebrae	Modality	Junior (mm)	Senior (mm)
1	Cervical vertebra 1	MV	2.54	1.19
	Cervical vertebra 7	MV	1.91	1.21
2	Cervical vertebra 1	MV	2.38	2.47
	Cervical vertebra 7	MV	2.12	3.03
3	Cervical vertebra 1	MV	1.82	3.21
	Cervical vertebra 7	MV	3.09	4.39

RL – right-left; MV – megavoltage; RMSE – root mean square error

Table 4: RMSE (mm) for the right-left plane for kV imaging inclusive of site, seniority and cervical vertebra indicating uniformity of IGRT analysis.

RL RMSE (mm) kV Image Modality

Site	Vertebrae	Modality	Junior (mm)	Senior (mm)
1	Cervical vertebra 1	kV	2.42	1.18
	Cervical vertebra 7	kV	1.91	1.21
2	Cervical vertebra 1	kV	2.38	2.47
	Cervical vertebra 7	kV	2.12	3.03
3	Cervical vertebra 1	kV	1.54	2.24
	Cervical vertebra 7	kV	2.52	3.2

RL – right-left; kV – kilovoltage; RMSE – root mean square error

Table 5: RMSE (mm) for the cranio-caudal plane for MV imaging inclusive of site, seniority and cervical vertebra indicating uniformity of IGRT analysis.

CC RMSE (mm) MV Image Modality

Site	Vertebrae	Modality	Junior (mm)	Senior (mm)
1	Cervical vertebra 1	MV	1.83	1.33
	Cervical vertebra 7	MV	1.61	3.31
2	Cervical vertebra 1	MV	1.53	1.49
	Cervical vertebra 7	MV	1.72	2.21
3	Cervical vertebra 1	MV	1.34	1.6
	Cervical vertebra 7	MV	2.06	2.58

CC – cranio-caudal; MV – megavoltage; RMSE – root mean square error

There were no significant differences ($P < 0.05$) in the way each location analysed both image datasets regardless of modality or primary matching vertebra (Table 7). Additionally, uniformity was observed in the way senior and junior radiation therapists conducted the analysis. IGRT is considered to be a core duty of the radiation therapist, regardless of seniority and these results support this proposition.

Within this study there are four independent variables: location, experience, modality and vertebra. On face value it would appear that every location and every radiation therapist diagnosed a consistent field placement error on both kV and MV image datasets. This suggests that radiation therapist led field placement intervention can be carried out with confidence.[5,9]

With four explanatory factors we can look deeper into the results and answer specific questions. If each location was analysed individually, was there uniformity between senior and junior radiation therapists? The answer is yes. There were still no significant differences between the two levels of experience. Tables 1–6 illustrate that across all sites regardless of the factor or combination of factors, no significant differences were present in the analysis of the two head and neck image datasets.

In a practical sense this implies that a patient undergoing head and neck radiotherapy at each of these three sites receives a consistent IGRT outcome. If the mechanism that ensures accurate treatment delivery (IGRT) is uniform across multiple sites a range of possibilities are available, possibilities recently highlighted particularly in the context of clinical trials.[4]

It has been noted previously that kV imaging enhances clarity and the field of view thus enabling more defined images of the vertebral column compared to MV imaging.[7] Additionally, it has been found that observers are able to see smaller and lower contrast objects in kV images than MV images.[10,11] However, the results across all three sites indicate that there was consistent analysis between C 1 and C 7 regardless of image modality. It was reassuring that there is a uniform approach given that the vertebra positionings are on the same patient on the same dataset. In an ideal scenario, the difference between C 1 and C 7 image analysis would be zero. However, the results presented in this study demonstrated substantively small difference in a clinical sense.

Interestingly the mean error difference in the right to left plane approached near significance across image modalities indicating possible differences in assessment of each modality (Table 7). This outcome is not surprising given the greater field of view and clarity offered by kV imaging relative to MV imaging. The more anatomical variation that can be seen and analysed,[9] the more complex the analysis decision making becomes. This level of information is expected to increase as IGRT progresses towards a reliance on volumetric data and this is a challenge all radiation therapists will encounter.[2] It must also be highlighted that none of the anatomical planes caused problems for each participating site. However the analysis of C 1 and C 7 in the anterior-posterior plane returned a P value of 0.07, which while not significant indicated a potential source of variance (Table 7). One possible explanation of this discrepancy within the cervical vertebra is the generic nature of the stabilisation. Stabilisation where one of several head rests can be chosen in a one size fits all approach may no longer be appropriate in the age of complex IMRT treatments with steep dose gradients and IGRT. Very slight differences in patient position on a daily basis on this head rest could result in an anatomical variation of the cervical spine and lead to difficulty in assessing and intervening in an IGRT setting.

A successful IGRT program relies heavily on the preparation of the patient *before* arriving for treatment. Part of this process is to ensure that there is a stabilisation solution that manages the majority of set-up errors, leaving the residual error to be captured and managed by IGRT. In order to carry out real time IGRT the treating radiation therapist needs to make judgements under time constraints and pressure. It therefore makes sense to use stabilisation that will manage as much of this set-up error as feasible and reduce the pressure on the treating radiation therapist in the online environment.

Table 6: RMSE (mm) for the cranio-caudal plane for kV imaging inclusive of site, seniority and cervical vertebra indicating uniformity of IGRT analysis.

CC RMSE (mm) kV Image Modality

Site	Vertebrae	Modality	Junior (mm)	Senior (mm)
1	Cervical vertebra 1	kV	1.71	1.44
	Cervical vertebra 7	kV	1.33	1.14
2	Cervical vertebra 1	kV	1.47	2.51
	Cervical vertebra 7	kV	2.08	2.33
3	Cervical vertebra 1	kV	1.12	1.27
	Cervical vertebra 7	kV	2.16	2.28

CC – cranio-caudal; kV – kilovoltage; RMSE – root mean square error

Table 7: RMSE 90% confidence intervals for vertebra matching differences and modality differences.

Effect	RMSE 90% CI (mm)	*P*-value
RL CV7 – CV1	–0.60, 1.33	0.5
CC CV7 – CV1	–0.20, 0.84	0.3
AP CV7 – CV1	0.03, 0.56	0.07
RL kV – MV	0.09, 0.94	0.06
CC kV – MV	–0.56, 0.20	0.4
AP kV – MV	–0.46, 0.25	0.6

RL – right-left; CC – cranio-caudal; AP – anterior-posterior; CV – cervical vertebra; kV – kilovoltage; MV – megavoltage; RMSE – root mean square error; CI – confidence interval; *P*-value < 0.05 significant

The potential presence of anatomical variation makes this online process problematic and open to error. The uniformity of IGRT analysis highlighted in this study are a reflection of a group of treating radiation therapists being able to successfully analyse, diagnose and intervene on image datasets that contain more than translational error. Radiation therapists do and should take the leading role in IGRT. This study supports the radiation therapists' ability to do so. As a profession progressing further into the IGRT sphere, challenges will arise, most prominently in the form of increased volumetric data.

Conclusion

Head and neck IGRT is a complex undertaking and this study has illustrated the uniformity of analysis regardless of site, seniority, modality and cervical vertebra. Radiation therapists have embraced head and neck IGRT and can undertake this process accurately and effectively even in the presence of variables such as vertebra anatomical variation. Stabilisation, IGRT and sophisticated treatment delivery such as IMRT are intricately linked and this study has highlighted the robust and consistent approaches to IGRT at all three sites. If the mechanism for treatment delivery (IGRT) can be verified then head and neck IMRT can be safely delivered and IGRT can be a core duty of all radiation therapists, regardless of seniority.

Acknowledgement

Paul Fenton's contribution was derived from work undertaken while at Andrew Love Cancer Centre, Geelong, Australia.

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