A SINGLE INSTITUTIONAL AUDIT OF SETUP ERRORS FOR 3DCRT RECTAL CANCERS

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Abstract

Background: Set-up errors are errors which are inevitable in radiotherapy. However, they should be kept to a minimum to achieve the maximum radiation dose to a tumour as to maximise treatment efficacy. This study aims to quantify those errors and assess if they remain within the tolerance limit of 5 mm in all directions. This study will also determine the adequacy of the margins for set up error for 3DCRT of rectal cancers at University of Malaya Medical Centre (UMMC).

Methods: A total of 20 rectal cancer patients (July 2018 to May 2019) who were treated with radiotherapy amounting to a total of 119 CBCT images were included in the study. Population systematic errors and random setup errors were calculated.

Results: Population systematic errors and random setup errors in the vertical, longitudinal and lateral direction were tabulated in Table 1. There is a large deviation (>5 mm) noted in some patients' setup between the first 3 days and the next successive day of imaging. Clinical target volume (CTV) to planning target volume (PTV) margin were calculated using Van Herk's margin recipe (M=2.5Σ+0.7σ). The margins were 5.0 mm, 6.2 mm, and 4.0 mm for vertical, longitudinal and lateral directions, respectively. The systematic error for the population was 1.1 mm, 0.9 mm, 0.9 mm in the vertical, longitudinal and lateral directions respectively, while the random error is 3.2 mm, 5.7 mm and 2.5 mm in the vertical, longitudinal and lateral directions respectively.

Conclusion: All of the patients involved in the study were within tolerance limits at some point in their treatment. The results demonstrated that a larger margin is needed in the longitudinal direction. Weekly CBCT is also necessary after the initial 3-day imaging to ensure that patients are kept within the tolerance limits.

Keywords: *Audit, Set-up errors, Radiotherapy, 3DCRT*

Introduction

The primary aim of radiotherapy is to deliver sufficient dose to the target volume whilst sparing the organs at risk (OAR) (1). Advances in radiotherapy imaging and treatment methods such as three-dimensional conformal radio therapy (3DCRT) have helped to achieve this aim by improving the conformality of the dose to the target tissues. However, with increasing conformal techniques, there is a risk of missing the target volume during treatment if no steps are taken to ensure the accurate positioning of the patient for the treatment.

Typically, a planning target volume (PTV) margin is employed to account for set-up uncertainties in the position of the target volume during day-to-day treatment. Set-up errors are the errors which occur as a patient is being prepared for radiotherapy. These errors are inevitable during radiotherapy. To resolve this issue, extra treatment margins are irradiated to ensure that the treatment area receives sufficient radiation for treatment. The set-up errors can be divided into two groups; systematic and random errors. Systematic errors require correction because they will affect all radiation delivery sessions and can damage healthy tissues while causing the tumour to be undertreated. Systematic errors are always consistent and hence can be easily evaluated and corrected. Random errors occur in a patient and do not occur throughout the entire population.

The use of image-guided radiotherapy (IGRT) prior to treatment has been shown to improve the accuracy of treatment delivery. There are multiple types of technology used for IGRT, including cone-beam CT (CBCT) and kilovoltage orthogonal imaging. The type of system used and the frequency of imaging usually depends on the resources and staff skill of the department as well as the level of accuracy that needs to be achieved (2, 3). IGRT has been shown to reduce variations from systematic and random errors. A robust IGRT protocol would provide confidence that the tumour is accurately targeted and inform the medical team if further reductions in the PTV margin could be safely undertaken.

This study aims to quantify those set up errors and assess if they remain within the tolerance limit of 5 mm in all directions. This will assess the adequacy of the margins for set up error for 3DCRT of rectal cancers at University of Malaya Medical Centre (UMMC).

Materials and methods

Participants

Twenty rectal cancer patients (July 2018 to May 2019) treated with 3DCRT in the radiotherapy department in UMMC were identified and included in this study. Patients were selected via convenience sampling. After analysis, a more suitable treatment margin would be proposed if the current margins are inadequate.

CT simulation and planning

Prior to the start of radiotherapy, planning CT scans were acquired in the supine position with knee and foot support provided for patient comfort. Patients were instructed to ingest 500 ml of plain water 30 minutes before the simulation for bladder filling. This helps to reduce the amount of small bowel within the treatment field. Skin tattoos were applied to aid in set-up. The median radiotherapy dose was 45 Gy (range: 25-60 Gy) and the median number of fractions is 25 (range: 5-30). Treatments were planned using either anterior-posterior opposed beams, 3-fields or 4-fields techniques.

Imaging

The IGRT protocol for 3DCRT of rectal cancer in UMMC involves the acquisition of kilovoltage cone-beam computer tomography (kv-CBCT) images, for the first 3 days or fractions and then subsequently once a week. The region of interest for matching covers the treatment field of view. The tolerance margins are 5 mm in all directions.

The CBCT image will be matched online with the planning CT image using automatic matching to the patient's bone. Shifts will be employed if the images taken are outside 5 mm. The radiotherapist will assess the fullness of the rectum and bladder on the CBCT image and provide feedback to the patient where relevant. The oncologists are required to conduct an offline review of treated patients within 48 hours of their first fraction to ensure that the set-up of each patient is acceptable.

Following the first 3 fractions, the systematic error will be calculated using pre-defined protocols and a manual shift correction will be applied for all future fractions if the error is larger than 5 mm. A deviation in set up during treatment will require an additional imaging day. Large errors which are more than 5 mm would require reset-up of the patients and repeat imaging taken.

A systematic error is an error that occurs in the same direction and is always of the same value for each fraction during the treatment. A random error is an error that occurs in any direction and magnitude and might not be present in every fraction.

The equipment details are as follows: all imaging and radiotherapy treatment are done on a linear accelerator (LINAC) Variance Novalis Tx linear accelerator (Varian Medical System, Palo Alto, California). The treatment planning System is Varian Eclipse Version 13.6 (Varian Medical System, Palo Alto, CA). In this technique, neither target nor organ at risks were contoured. CT images are taken on a Philips Brilliance Big Bore CT Scanner, The Netherlands with a slice thickness of 5 mm. The patient will lie in a supine position and the scan will be from the first lumbar vertebrae to 5 cm beyond the base of the pubic symphysis.

Audit process

A total of 119 CBCT images were included in the study. The errors in setup in the three translational directions namely the vertical (mm), longitudinal (mm) and lateral (mm) - are recorded and the mean, maximum, minimum, standard deviation, systematic and random errors were calculated using pre-defined formulas as displayed below (E1: population systematic error, E2: individual random error) (4). For the purpose of analysis; anterior, superior and right-sided shifts were coded as positive shifts and posterior, inferior, and left-sided shifts as negative shifts.

$$\sum\nolimits^{2}_{set\text{-}up} = \frac{(m_1 - M_{pop})^2 + (m_2 - M_{pop})^2 + (m_3 - M_{pop})^2 + ... + (m_n - M_{pop})^2}{(P-1)} \quad \text{E1}$$

$$\sigma^{2}_{individual} = \frac{(\Delta_1 - m)^2 + (\Delta_2 - m)^2 + (\Delta_3 - m)^2 + ... + (\Delta_n - m)^2}{(n-1)} \quad \text{E2}$$

Results

Table 1 displays individual patient data in the categories labelled as such below. Population systematic and random setup errors in vertical, longitudinal and lateral direction were tabulated in Table 2. The ± symbol means that the direction could have occurred in either of the two directions in any field. The clinical target volume (CTV) to planning target volume (PTV) margin were calculated using Van Herk's margin recipe (M=2.5Σ+0.7σ). The margins were 5.0 mm, 6.2 mm, and 4.0 mm for vertical, longitudinal, and lateral directions, respectively.

Discussion

Our audit results show that the population systematic and random errors are within tolerance limits in all directions

Table 1: Individual patient data for the mean random error, minimum and maximum setup error and the range of their readings

Patient	Individual random error			Minimum setup error			Maximum setup error			Range		
	vert (mm)	long (mm)	lat (mm)	vert (mm)	long (mm)	lat (mm)	vert (mm)	long (mm)	lat (mm)	vert (mm)	long (mm)	lat (mm)
1	1.4	1.4	2.1	3.0	2.0	-1.0	5.0	4.0	2.0	2.0	2.0	3.0
2	3.0	2.1	1.5	±1.0	0.0	±1.0	-7.0	-4.0	-4.0	8.0	4.0	3.0
3	2.1	0.6	1.5	0.0	1.0	1.0	4.0	2.0	-2.0	4.0	1.0	3.0
4	11.8	72.0	6.9	0.0	0.0	0.0	-33.0	289.0	-17.0	38.0	289.0	17.0
5	0.7	3.1	1.4	0.0	±2.0	0.0	-2.0	-6.0	±2.0	2.0	9.0	4.0
6	4.0	1.1	4.3	0.0	-1.0	1.0	-7.0	-4.0	-11.0	7.0	3.0	12.0
7	1.5	1.5	2.6	0.0	0.0	0.0	-3.0	3.0	-5.0	3.0	3.0	5.0
8	11.2	2.7	1.1	0.0	0.0	0.0	21.0	-7.0	3.0	28.0	7.0	3.0
9	0.9	0.0	0.0	0.0	0.0	0.0	-1.0	0.0	0.0	1.0	0.0	0.0
10	2.4	2.5	2.2	-1.0	0.0	1.0	-4.0	3.0	4.0	3.0	5.0	3.0
11	5.0	1.3	1.7	2.0	0.0	0.0	-9.0	-2.0	-4.0	11.0	3.0	4.0
12	3.7	4.7	7.3	0.0	0.0	-1.0	-8.0	11.0	-17.0	8.0	11.0	16.0
13	3.3	1.4	1.0	±2.0	2.0	1.0	-5.0	5.0	3.0	7.0	3.0	2.0
14	3.4	4.3	2.2	0.0	0.0	0.0	±7.0	11.0	-10.0	14.0	16.0	10.0
15	0.8	0.9	4.9	1.0	0.0	2.0	2.0	1.0	6.0	1.0	1.0	4.0
16	1.5	4.2	1.5	±1.0	2.0	0.0	1.0	±4.0	2.0	3.0	8.0	3.0
17	1.7	2.6	0.6	-1.0	±2.0	0.0	-4.0	3.0	1.0	3.0	5.0	1.0
18	2.4	3.4	3.3	1.0	1.0	1.0	-3.0	-7.0	±4.0	5.0	8.0	8.0
19	1.5	2.3	2.0	0.0	-1.0	1.0	2.0	3.0	5.0	3.0	4.0	4.0
20	0.6	2.6	2.5	-1.0	0.0	-3.0	-1.0	5.0	-10.0	1.0	5.0	7.0

vert: vertical; long: longitudinal; lat: lateral

Table 2: Population mean systematic and random setup errors

Setup error	Field of study	Error margin (mm)
Systematic error	Vertical	1.1
	Longitudinal	0.9
	Lateral	0.9
Random error	Vertical	3.2
	Longitudinal	5.7
	Lateral	2.5

except for the longitudinal direction. Our results are within the range reported by other studies (5-8) (Table 3). Three patients (patient 4, 12 and 14) in our study experienced large amounts of set-up errors in the longitudinal direction. Potential sources of set-up errors include mechanical shortcomings (e.g. laser misalignment), patient-related (e.g. skin mark movement), or fixation related (e.g. patient mobility) factors. One study (9) reported large cranial-caudal errors for large pelvic fields due to the positioning technique, where only a vertical pin was used to determine the cranial-caudal field placement. Subsequent study (10) has shown that the use of markings over the lateral aspect of both hips in addition to the centre marking improved the set-up accuracy. The use of isocentre-couch distance as an additional fixed set-up parameter was shown to reduce anterior-posterior set-up errors (11). Patients with larger body habitus were also more likely to experience larger set-up errors.

The tolerances used in practice will take into account several factors including the immobilisation method, anatomical site and internal organ motion, treatment

Table 3: Comparison of current study and 4 previous studies (5-8)

	Systematic error of population			Random error of population			CTV-PTV margin		
	Vert (mm)	Long (mm)	Lat (mm)	Vert (mm)	Long (mm)	Lat (mm)	Vert (mm)	Long (mm)	Lat (mm)
Yao et al. (2015) (5)	1.6	2.5	2.4	2.5	3.1	2.3	5.6	8.3	7.6
Santanam et al. (kV) (2008) (6)	2.4	3.6	3.7	3.1	3.8	3.3	6.0	8.1	9.5
Santanam et al. (MV) (2008) (6)	1.5	4.6	2.0	3.7	4.8	3.4	7.2	9.4	6.7
Laursen et al. (2012) (7)	3.6	2.6	2.9	3.6	2.4	3.2	11.6	8.2	9.6
Patni et al. (2017) (8)	2.0	3.5	1.9	1.2	2.3	1.3	5.8	10.3	5.6
Present study (2019)	1.1	0.9	0.9	3.2	5.7	2.5	5.0	6.2	4.0

Vert: vertical; Long: longitudinal; Lat: lateral

technique and patient compliance. The mean displacement using bony anatomy in the pelvis can be expected to be in the range of 2-5 mm (12). Stable bony structures such as the sacrum, pubic symphysis or acetabulum should be chosen and standardised for the planning CT and CBCT match. The planning techniques used in our study, although more conformal than older two-dimensional planning techniques, still ~~ends~~ up providing a generous cover to the target volumes. The role of internal organ motion such as rectal movement has less influence on the outcomes compared to highly conformal techniques such as intensity-modulated radiotherapy (IMRT) where there is rapid dose fall-off outside of the target volume. There is a significant risk of under dosing the target if insufficient margins are used without taking into account internal organ motion.

There are no written standard guidelines on the type and frequency of imaging for IGRT in this institution. The guideline changes will depend on the departmental workload, staff training and expertise in addition to the treatment technique and margins used. CBCT gives additional soft tissue information such as rectal and bladder filling as well as visualisation of the gross tumour. However, it takes a much longer time to perform a CBCT and it may not be feasible to do a daily CBCT in a busy department with a huge patient load. Using daily orthogonal kV imaging would be a feasible option instead of a CBCT if we are only matching to bony anatomy as it is much faster to acquire the images than a CBCT. CBCT can be reserved for IMRT cases where the soft tissue information is important to ensure target coverage due to the tight margins used.

Conclusion

In summary, our study demonstrates that the set-up errors are within the 5 mm tolerance limits set for rectal 3DCRT in our department, except for the longitudinal direction, where a 7 mm margin is recommended when matching is done using bony anatomy. However, in cases where more conformational imaging techniques are used, either larger margins or more frequent imaging is needed to reduce the risk of missing the target because of inadequate set up.

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Competing interests

The authors declare that they have no conflict of interests.

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