Clinical challenges in the implementation of a tomotherapy service for head and neck cancer patients in a regional UK radiotherapy centre

¹S CHATTERJEE, MBBS, MRCP, FRCR, ²J H MOTT, MIPEM, PhD, ²G SMYTH, MIPEM, MSc, ¹S DICKSON, DCR(T), ¹W DOBROWSKY, FRCR and ¹C G KELLY, MB, ChB, FRCP, FRCR

¹Northern Centre for Cancer Care and ²Regional Medical Physics Department, Freeman Hospital, Freeman Road, Newcastle upon Tyne NE7 7DN, UK

Objective: Intensity-modulated radiotherapy (IMRT) is increasingly being used to treat head and neck cancer cases.

Methods: We discuss the clinical challenges associated with the setting up of an image guided intensity modulated radiotherapy service for a subset of head and neck cancer patients, using a recently commissioned helical tomotherapy (HT) Hi Art (Tomotherapy Inc, WI) machine in this article. We also discuss the clinical aspects of the tomotherapy planning process, treatment and image guidance experiences for the first 10 head and neck cancer cases. The concepts of geographical miss along with tomotherapy-specific effects, including that of field width and megavoltage CT (MVCT) imaging strategy, have been highlighted using the first 10 head and neck cases treated.

Results: There is a need for effective streamlining of all aspects of the service to ensure compliance with cancer waiting time targets. We discuss how patient toxicity audits are crucial to guide refinement of the newly set-up planning dose constraints.

Conclusion: This article highlights the important clinical issues one must consider when setting up a head and neck IMRT, image-guided radiotherapy service. It shares some of the clinical challenges we have faced during the setting up of a tomotherapy service. Implementation of a clinical tomotherapy service requires a multidisciplinary team approach and relies heavily on good team working and effective communication between different staff groups.

Received: 5 January 2010

Revised 16 February 2010

Accepted 16 February 2010

DOI: 10.1259/bjr/19586137

© 2011 The British Institute of Radiology

The advantages of intensity-modulated radiotherapy (IMRT) in head and neck cancer, in terms of target conformation, organ at risk sparing and associated improvement in quality of life, and the potential for dose escalation, have been well documented [1–3]. The development and commercial release of the helical tomotherapy (HT) Hi Art (Tomotherapy, Madison WI) system by Mackie et al [4] has introduced advanced helical IMRT delivery techniques and combined these with integrated onboard image guidance capabilities [5]. Recent adoption of this technology within the NHS by two centres (Cambridge and Newcastle), alongside existing provision within a private sector treatment centre (BUPA Cromwell Hospital, London), enables delivery of highly conformal image-guided IMRT in the UK.

The physical characteristics of the HT system are described in detail elsewhere [4,5]; however, in basic terms, the system is a short waveguide 6 MV linac mounted on a spiral CT gantry system. Beam collimation is by a pneumatically controlled binary multileaf collimator (MLC), with each leaf projecting to 6.25 mm at isocentre, for three selectable field widths [6]. Owing to its

continuous rotational delivery technique and rapid beam modulation throughout its full arc of travel, the HT system gives greater flexibility than conventional linear accelerator (linac)-based IMRT that provides intensity modulation at multiple fixed gantry angles. Planning comparisons between tomotherapy and rotational techniques using conventional linacs, volumetric arc therapy (VMAT) or intensity-modulated arc therapy (IMAT), have also been published [7,8]; however, there is ongoing debate as to the relative merits of each technique [9–12].

The complexity of head and neck radiotherapy is due to the proximity of multiple organs at risk (OAR), including critical structures such as the brain stem and spinal cord and important functional organs such as the parotid glands, optic nerve, optic chiasm, larynx and mandible. The dose prescription to the head and neck area also differs from other sites as there is usually one or more high-dose planning target volume (PTV) and a prophylactic nodal PTV receiving a differing radiation dose. Owing to its wider availability, most UK centres providing a head and neck IMRT service deliver linac-based IMRT; however, HT IMRT can achieve improved dose sparing to OAR compared with linac-based IMRT in the treatment of certain head and neck cancer sites [13].

This paper summarises the clinical challenges encountered in establishing a clinical helical tomotherapy IMRT

Address correspondence to: Dr Sanjoy Chatterjee, Northern Centre for Cancer Care, Freeman Hospital, Freeman Road, Newcastle upon Tyne NE7 7DN, UK. E-mail: Sanjoy.Chatterjee@nuth.nhs.uk

service for head and neck cancer. Experiences, practical problems and unexpected issues encountered in the first 10 head and neck patients treated will be described.

Methods and materials

Pre-clinical set-up

Prior to the start of clinical service, an extensive period of system commissioning, applications training, clinical workflow development and routine quality assurance was undertaken, with an action plan agreed for clinicians, physicists and radiographers. During this period, a class solution for head and neck HT IMRT was developed by physics staff based on delineation exercises carried out by clinicians. A specific image-guidance protocol and an IMRT treatment protocol for head and neck cancer management were also developed.

Patient selection

Head and neck cancer patients needing radical radiotherapy treatment were referred to a multidisciplinary tomotherapy selection group comprising clinicians, physicists, radiographers and dosimetrists. Cases were prioritised on the basis of the potential clinical benefit with HT, specific benefit likely from IMRT/IGRT (image-guided radiotherapy) and the availability of treatment slots without breaching the UK cancer waiting time targets. Local treatment planning and image guidance experience was also taken into account. Table 1 lists the first 10 head and neck cancers treated in our institution using HT.

Localisation imaging

All patients were immobilised using a custom-made beam directional shell (BDS) made from polyethylene terephthalate glycol (PTEG). Contrast-enhanced CT localisation scans, covering the vertex to the upper thorax, were acquired 40 s after a 70 ml Omnipaque (iohexol) injection using a Somatom Sensation Open wide-bore CT scanner (Siemens, Concord, CA). Images were reconstructed with a 3 mm slice thickness and exported to Oncentra MasterPlan (Nucletron, the Netherlands) for target volume definition. Positron emission tomography (PET)-CT fusion was also available for selected patients recruited to an in-house National Cancer Research Institute (NCRI) study [14].

Target volume definition

All volume delineation and volume growing was performed in Oncentra MasterPlan before export to the tomotherapy planning station because of perceived limitations of volume definition tools and three-dimensional (3D) margin-growing algorithm in its existing clinical software release (versions 3.1.3 and 3.1.4). This also allowed consistency with the existing local non-tomotherapy clinical workflow, reducing the need for additional staff training.

Clinical target volume (CTV) and organs at risk (OAR) delineation was performed by consultant clinical oncologists, based on an agreed in-house protocol. This protocol was based on local expertise as well as published guidelines for target definition for node-negative [15] and node-positive neck [16] for head and neck squamous cell carcinomas. PTVs were created by applying a 3 mm margin to CTV outlines but manually edited back from the patient's skin surface by 2–3 mm, but extra consideration must be taken not to compromise the clinician-defined CTV. This trimming of the PTV was to avoid driving the optimisation algorithm in the build-up region. Planning risk volumes (PRVs), as recommended in ICRU 60 [17], were also defined for the spinal cord and brain stem, with a 1 mm and 3 mm margin, respectively.

A number of non-anatomical “dummy volumes” (Table 2) were also defined for each patient, with the aim to assist in the optimisation process and prevent “dose dumping” in what would have been conventionally undefined areas. These will be discussed in the treatment planning section below.

As with conventional IMRT, given the need to accurately outline additional target or boost structures and multiple OAR (for the clinician) and significant “dummy volumes” to guide optimisation (for the planning physicist or dosimetrist), the volume definition process can be significantly more time-consuming than conventional radiotherapy treatment techniques for these sites. It is recommended that centres moving to implement HT IMRT factor these additional time demands into the appropriate staffing complements.

Treatment planning

Plan optimisation for HT is similar to existing IMRT planning systems, in that a number of dose–volume criteria

Table 1. First 10 head and neck cases selected during first 2 months of starting helical tomotherapy

Patient	Diagnosis	Stage (M0)	Age	Retreatment
1	SCC (level III LN) unknown primary	TxN2	38	No
2	SCC soft palate	T1N0	58	No
3	SCC oropharynx	T3N2b	68	No
4	Recurrent SCC right internal ear	T4N0	70	Yes
5	Small cell carcinoma of paranasal sinus	T4N0	59	Yes
6	SCC supraglottis	T2N2b	60	No
7	SCC oropharynx	T3N1	61	No
8	Choroidal melanoma	T4N0	50	No
9	SCC oropharynx	T2N2a	57	No
10	Extensive BCC scalp	T4N0	95	No

Patients 3, 5 and 6 had planning target volume 4 outlined (54 Gy); mean doses achieved were 58.13, 55.12 and 57.39 Gy, respectively. BCC, basal cell carcinoma; LN, lymph node; SCC, squamous cell carcinoma.

Table 2. Structures delineated for a typical squamous cell carcinoma of head and neck origin needing bilateral neck irradiation. This could change according to the specific planning requirements

Outlined by clinician
CTVs: high dose and prophylactic (as per protocol based on consensus guidelines)
Left and right parotid glands
Spinal cord
Brain stem (and brain if needed)
Mandible
Larynx
Optic nerves, chiasm and retina
Created by planner (to assist in planning and optimisation)
Skin
PTVs (grow CTVs by 3 mm, avoiding skin by 4 mm, edit to include all of CTV): reviewed by clinician
Spinal cord PRV (grow spinal cord by 3 mm)
Brain stem PRV (grow spinal cord by 1 mm)
Left parotid PTV (copy parotid and manually edit)
Right parotid PTV (as above)
Cord block (non-anatomical volume behind cord to eliminate dose dumping)
Floor of mouth (non-anatomical volume reducing dose between PTV and mandible)
PTV $n+5$ (grow PTVs by 5 mm)
Ring (draw structure that encompasses all outlined volumes except skin)
Ring + 10 (grow ring by 10 mm)
Ring + 20 (grow ring by 20 mm)

CTV, clinical target volume; PRV, planning risk volume; PTV, planning target volume.

are defined to guide optimisation, with the planning system performing an iterative optimisation to best achieve those demands. The current version of the clinical Tomotherapy Planning Station limits the number of optimisation criteria for each structure, so a more iterative approach is necessary with refinement of the optimisation.

The “dummy volumes” outlined previously were used to guide the optimisation. The parotid glands often lay partially within the defined PTVs, and therefore the low mean dose requirement for the parotids heavily conflicted with the high dose required for the targets. Where targets and OAR overlap, the target always takes priority in the optimisation, so changes in the dose constraints for the mean parotid dose only actually apply to those voxels of parotid outside the PTV. Separate “dummy volumes” were created for each parotid excluding any PTV so that dose–volume data could be reported for this non-overlap region in addition to data for the whole organ.

“Dose dumping” behind the spinal cord is a known potential problem in head and neck IMRT [18], as the optimisation attempts to boost dose to PTVs while sparing the spinal cord itself. This can lead to a doughnut-style ring of high dose around the spared spinal cord and is particularly undesirable because of the risk that weight loss or set-up errors could cause the cord position to relax into the high-dose area. To ensure this did not develop, a non-anatomical volume was defined in the area directly behind the cord. During class solution development, dose–volume optimisation criteria were used for test cases and compared with a directional block technique (where beams are forbidden from entering through the defined area but can exit through it). The directional block technique was found to be preferable and, owing to its relatively small size, did not restrict beam delivery angles so much as to significantly compromise the optimisation’s ability to ensure PTV coverage.

Further “dose dumping” during class solution development was also seen in the oral cavity because of the lack of optimisation criteria in the area between the mandible and the primary PTV. A non-anatomical

“dummy volume”, referred to as “floor of mouth”, was created to enable sculpting of high doses around the PTV counteracting any potential dose overspill from the PTV owing to irregular shaping in-slice or the interplay between field width and pronounced superior–inferior changes in PTV shape. A number of additional “dummy volumes” were created, including rings around PTVs to improve conformity in high dose regions and large “tuning structures” intended to reduce low-dose dumping in otherwise undefined areas of normal tissue.

As well as the dose–volume criteria, HT uses three distinct parameters for the planning process: field width, pitch and modulation factor. Field width is the width of the fan beam defined by the two jaws of the primary collimator [19]; the machine is commissioned for three field widths: 1 cm, 2.5 cm and 5 cm. Pitch is the couch travel distance relative to the axial beam width during a complete gantry rotation [20], and modulation factor is defined as the maximum divided by the average leaf-opening time for all non-zero leaf openings [19]. With experience, an appropriate combination of these parameters can be selected for a particular patient in order to achieve a highly conformal plan that can be delivered with a reasonable treatment time. The plan is then evaluated according to set IMRT constraints. Table 2 describes the plan acceptance criteria used for approval and the tuning structures that were initially drawn for planning purposes.

The treatment plan prescription dose for each patient was defined as the intended median dose to the primary PTV. Most patients were planned using a 2.5 cm field width and a requested modulation factor of 2.4. Dose calculations were performed using a fine dose resolution matrix (1.95 mm grid) apart from the first patient when a matrix of 3.9 was used.

Image guidance strategy

HT has the advantage of an inbuilt Megavoltage CT (MVCT) scanner that can be used for daily image acquisition to confirm patient positioning prior to

treatment. MVCT scan images for our patients were acquired daily prior to treatment, covering the entire length of the treatment volume. Three imaging modes are available with HT: coarse (6 mm), normal (4 mm) and fine (2 mm). For head and neck patients images are obtained in normal mode and matched to the planning CT scan by trained radiographers. The images are initially registered automatically, with manual adjustments performed if necessary. Positioning corrections are performed in the vertical and longitudinal directions by applying automatic couch shifts, rotational corrections (roll correction) using automatic adjustment of treatment angles [21], lateral couch shifts are performed manually. The value of daily image guidance has been addressed in the literature [21] and we continue to perform daily CT scans for all our HT patients, given the steep dose gradient with such treatment (Figure 1).

Results

Dose–volume histogram (DVH) data for the first 10 treated cases and the beam on time for each fraction is shown in Table 3.

Examples of clinically challenging cases encountered during the planning, evaluation and verification processes are discussed below.

Geographical miss

This patient (Case 2, Table 1) was referred for HT treatment with a diagnosis of T1N0 soft palate (uvula) tumour; HT treatment was justified to spare the parotid glands to reduce long-term xerostomia.

In many centres, conventional parallel opposed beams would have been used to treat the tumour, thereby including the level IIa nodal areas within the radical

isodose. Figure 2 shows the axial dose distribution of the lower part of the HT treatment field, where the level II nodes were prescribed a lower prophylactic radiation dose in order to reduce dose to the parotid glands, since there was no reported nodal involvement on the diagnostic CT scan. On peer review of the CT scan a pathological lymph node was identified at level II on the right side (Figure 2). This case highlights the importance of peer review and accurate target delineation for planning HT treatments. As seen clearly in Figure 2, the HT plan could have easily missed tumour that otherwise would have been treated using conventional radiotherapy techniques.

Case 10 (Table 1) refers to a patient with locally advanced basal cell carcinoma of the scalp. In order to achieve adequate dose to the skin surface bolus was applied to the scalp and the CTV was extended up to the skin. An automatic editing process of 2–3 mm from the skin, as discussed above, would have resulted in under-dosage of the skin tumour. Detailed discussion of the HT planning process for such complex scalp tumours has been addressed by our group in a separate publication [22].

Helical delivery: examples of new areas of dose dumping?

HT generally achieved most of the prescribed clinical dose constraints; however, during treatment, Patients 1 to 3 complained of specks of blood while blowing their noses. Their plans were reviewed and an area near the posterior nasal turbinate was found to be getting in excess of 55 Gy (Figure 3a). This was because in the absence of a defined avoidance structure in this region, the inverse planning algorithm was free to deliver relatively more dose from the anterior approach to achieve the dose required at the retropharyngeal area in conjunction with the other dose constraints that had been set.

After discussion with other tomotherapy and IMRT users nationally, further improvements in planning were introduced:

- The area around the posterior turbinate was defined as another OAR, with the dose being limited to 30 Gy maximum to this area. Even if this constraint cannot be adhered to completely, there is still a substantial reduction in “dose dumping” at the specified site (Figure 3b).
- In patients where the tumour target might give high dose at the posterior turbinate area, patients were set up with a greater degree of neck extension when the thermoplastic shell was made.

Following these minor changes, no further patients reported epistaxis during treatment.

More generally, the issue of dose dumping in HT requires careful consideration as, with the increased number of possible beam directions compared with conventional IMRT, the number of possible areas susceptible to dose dumping may increase for a specific patient set. The relatively large field width of the spiral delivery can also result in a lack of conformity in the superior–inferior direction owing to rapid changes in

Figure 1. Megavoltage CT (MVCT) taken on the day of treatment (blue squares) fused to planning CT image (grey square). Note the shrinkage of the paranasal sinus tumour during treatment (Case 5, Table 1).

Table 3. Dose prescribed (Gy) and achieved in each of the cases

Patient	PTV1 Isodose (%) covering 95% and 2% of volume (prescribed dose)	PTV2 Isodose (%) covering 95% and 2% of volume (prescribed dose)	PTV3 Isodose (%) covering 95% and 2% of volume (prescribed dose)	Right parotid (mean)	Left parotid (mean)	Cord (max)	Brain stem (max)	Beam-on time (s)
1	98 and 102.5 (65)	98.7 and 101.9 (54)	99.1 and 101.1 (54)	34.45	25.45	24.23	33.74	421.5
2	97.4 and 102 (65)	99.1 and 103.9 (54)	N/A	25.6	25.05	26.32	28.74	272.1
3	97.5 and 101.2 (65)	99.6 and 93.1 (54)	99.1 and 100.9 (54)	28.05	26.33	19.04	24.15	347.7
4	98.3 and 102.2 (63)	(N/A)	(N/A)	(N/A)	(N/A)	16.67	27.74	288.2
5	96.9 and 102.5 (65)	92.7 and 102.2 (60)	96.9 and 99.5 (54)	(N/A)	(N/A)	19.98	29.61	814.3
6	97.4 and 100.6 (65)	98.5 and 100.7 (54)	98.5 and 100.6 (54)	25.5	28.55	27.17	29.66	457.1
7	97.4 and 101.8 (65)	100.9 and 102.4 (54)	98.5 and 100.9 (54)	27.46	28.35	25.9	30.16	440.6
8	98.9 and 104 (65)	(N/A)	(N/A)	(N/A)	(N/A)	1.13	20.62	430.1
9	97.8 and 102.5 (65)	98.5 and 100.7 (54)	98.9 (and 100.7 (54)	22.77	23.17	29.01	36.51	469
10	96.2 and 104.1 (63)	94.3 and 100 (63)	(N/A)	(N/A)	(N/A)	(N/A)	(N/A)	721.3

PTV, planning target volume; N/A, not applicable.

PTV shape in this direction or at the ends of the PTV volume. This effect can be minimised by choosing the smallest (1 cm) field width available; however, this was not deemed practical for these clinical head and neck patients because of the significantly increased "beam on time" that would result. Sterzing et al [23] detailed a developmental version of the HT delivery and planning software that takes advantage of a running start/stop, variable jaw size and dynamic couch movement to counteract these issues.

Re-irradiation

Locoregional disease recurrence is one of the commonest patterns of failure following radical or adjuvant radiotherapy for head and neck cancers [24]. Salvage

surgery is often not possible, given the proximity of the recurrence to vital structures. IMRT can be used for locoregional recurrence to achieve long-term local control with a view to cure [25, 26].

As an example, one patient was referred with recurrent disease at the base of skull region. Although a 3D conformal plan resulted in an unacceptably high dose to the brain stem, with the HT plan this was significantly reduced (Figure 4) from 40.8 Gy to 27.7 Gy. The conformity indices [27] of the conformal and tomotherapy plans were 0.59 and 0.83, respectively. Close margins around the PTV and OAR were possible with the assurance of daily image guidance.

Weight loss

Weight loss secondary to acute radiation toxicity is a well-recognised side effect of patients having radical treatment for head and neck tumours. Figure 5a,b is an example of changes in patient shape identified on verification imaging. The patient in Figure 5a was admitted and hydrated. Figure 5b shows the improved match achieved.

This example highlights the importance of daily image guidance with IMRT. Although we record patient weight and provide supportive services to all our patients, a mismatch in the daily image matching can be used to alert the treatment team to the need for more supportive measures or admission. If there is significant change in the daily match, a simulated dose calculation is done (Figure 6) to confirm that the original plan can still be used to continue treating the patient safely and effectively. With the advent of the "planned adaptive" software (Figure 6) from tomotherapy, such instances of

Figure 2. The axial CT scans with helical tomotherapy plan (Case 2, Table 1). A pathological lymph node was later identified on peer review.

Figure 3. Helical tomotherapy plans of patients with oropharyngeal cancers. The patient on the left has been planned without a nasal-tuning structure whereas the one on the right has a nasal-tuning structure to assist in reducing the high dose in the posterior turbinate. (a) Splaying of the isodose with doses in excess of 55 Gy to areas of posterior turbinate. (b) Better conformity of isodoses to planning target volume and less dose to the posterior turbinate.

difference in dose with changes in patients contour can be monitored more confidently and areas of higher or lower doses can be identified easily. Figure 6 refers to the planned adaptive calculations performed for Case 7 (Table 1).

Discussion

Head and neck radiotherapy can be challenging. Multiple PTVs need differing doses depending on the risk of tumour involvement, whereas OAR dose should be kept to a minimum to reduce morbidity. Additional “dummy volumes” are used by planners to assist in achieving a homogeneous dose to the PTV while meeting the specified dose constraints to OAR. Conventional techniques may barely achieve a good conformity to the PTV, and often OAR such as the parotid glands receive an ablative dose of radiation leading to xerostomia. IMRT has been shown to achieve sparing of the parotid

glands and reduce radiation-induced xerostomia in head and neck cancer [28–31]. In addition, conformity to the PTV is also improved with IMRT when compared with 3D conformal radiotherapy.

In comparison with linac based step and shoot IMRT, tomotherapy improves the conformity index to the PTVs and significantly reduces dose to the OAR [13, 32], thereby improving the therapeutic index.

When setting up an IMRT service in a regional UK centre, the pressure to achieve cancer waiting time targets has to be taken into account. The extra time required for outlining, planning and treating patients with IMRT can be compensated by streamlining the different aspects of the multidisciplinary process with effective communication and organisation. Setting up a close interdisciplinary co-operation between physicists, radiographers and clinicians will help to overcome many of the initial barriers. Class solution development and staff training can facilitate an easier transition from pre-clinical to clinical use. Despite this, there is a significant

Figure 4. The patient was planned to have retreatment of recurrent squamous cell carcinoma of the internal ear (Case 4, Table 1). The plan in the left (a) is forward planned three-dimensional conformal and the one on the right (b) is a helical tomotherapy (HT) plan. Note the increased conformity of the isodoses to the planning target volume with the HT plan. The arrows show that the brain stem planning risk volume (PRV) receives a lower dose with HT making it safe to retreat. The brain stem received doses of 40.8 Gy and 27.7 Gy.

Figure 5. Case 3, Table 1. (a) The patient had significant mismatch of skin contour when the verification megavoltage CT scan (blue) was fused to planning CT scan (grey) mismatch secondary to dehydration and weight loss. Yellow and red dots on the skin contours highlight the mismatch between the fused images. (b) The same patient was rehydrated and received intensive supportive treatment. The fused images now show a better match of skin contour. MVCT, megavoltage CT.

effect on use of consultant time and this should ideally be resourced and included in consultant job plans.

With HT it was important to develop an understanding of the planning process and appreciate the subtle but important differences between HT and linac-based IMRT delivery, as discussed above.

Accurate target volume definition is of utmost importance with IMRT and care must be taken to avoid giving precedence to OAR sparing at the expense of possible disease recurrence. The presence of positive nodal involvement needs to be ruled out prior to assigning a prophylactic dose to regional lymph node levels and focused review at the clinical multidisciplinary meetings can help accurate radiological reporting of staging scans. Recurrences post IMRT usually occurs within the high-dose PTV region and less commonly in the prophylactic nodal region [22]. The case discussed above where the nodal recurrence could have occurred in the low-dose area highlights the fact that a focused peer review process could change treatment plans. The M D Anderson Cancer Centre group described that in up to 11% of cases this modification could lead to changes in therapeutic outcomes [33]. A similar experience has been reported by Sanguineti et al [34]. During reporting of diagnostic scans and discussions at multidisciplinary meetings prior to planning radiotherapy, any suspicious nodal involvement should be confirmed or excluded by further investigations including ultrasound-guided fine needle aspiration (FNA) or PET-CT scans [9].

Implementation of an effective image guidance strategy is possible only with skilled radiographers. The radiographers at the Northern Centre for Cancer Care (NCCC) had considerable previous experience with cross-sectional imaging and image-matching techniques. Our initial experience confirms the good image quality of

the in-built MVCT scanner in the HT machine and reinforces the value of carrying out daily verification scans.

With changes in technology, vigilance is required to detect any new morbidity that patients might develop. The fact that we did not have any more patients complaining of bleeding from the nose confirms the effectiveness of the posterior nose tuning volume when treating the upper retropharyngeal nodal areas to a high dose.

Conclusion

HT treatment has enabled us to treat head and neck cancer patients with improved conformity to the PTVs and improved dose sparing of OAR. The clinical challenges encountered while setting up tomotherapy for head and neck cases can be overcome with the help of multidisciplinary team working. As IMRT and tomotherapy offer potential improvements in the therapeutic index, the next generation of trials will look at dose escalation [35] with a view to improving local control and overall survival. At NCCC we are currently exploring a dose escalation strategy in oropharyngeal cancers within a controlled study [14]. Appropriate quality assurance and peer review must be implemented during the setting up period to ensure adequate coverage of the target volumes with little morbidity. This could be made possible by taking part in nationally peer-reviewed controlled trials where IMRT is being used as a modality of treatment. Auditing ones outcome stringently, especially after the initial set up, is vital in picking up any unusual side effects that implementation of this new technology may produce.

Figure 6. Planned adaptive software showing changes in the dose distribution with changes in patients contour (Case 7, Table 1). (a) Sagittal sections of the planning CT scans with the target volumes (beaded) and isodose distribution (complete lines). (b) The patient lost weight and therefore there is a change in contour. The broken isodoses represent the recalculated isodoses following the change in patient shape. (c) The percentage change in dose per fraction following weight loss is shown in this sagittal image. Areas in green represent no change in dose. Pink and red represent 3% and 5% overdosage respectively. The isobar represents the changed dose (Gy) per fraction.

Acknowledgments

The clinical introduction of tomotherapy at NCCC has been made possible by the active team working between clinicians, physicists and radiographers, in particular Dr A Branson, Ms Michele Wilkinson, Ms Tracy Wintle, Ms E Stockley and Mr P Addison. We would also like to acknowledge the support and encouragement from our colleagues at Addenbrooke's Hospital, Cambridge.

References

1. Bhide S, Clark C, Harrington K, Nutting C. Intensity modulated radiotherapy improves target coverage and parotid gland sparing when delivering total mucosal irradiation in patients with squamous cell carcinoma of head and neck of unknown primary site. *Med Dosim* 2007;32:188–95.
2. Ahmed M, Hansen VN, Harrington KJ, Nutting CM. Reducing the risk of xerostomia and mandibular osteoradionecrosis: the potential benefits of intensity modulated radiotherapy in advanced oral cavity carcinoma. *Med Dosim* 2009;34:217–24.
3. Lee N, Puri DR, Blanco AI, Chao KS. Intensity-modulated radiation therapy in head and neck cancers: an update. *Head Neck* 2007;29:387–400.
4. Mackie TR. History of tomotherapy. *Phys Med Biol* 2006;51:R427–53.
5. Beavis AW. Is tomotherapy the future of IMRT? *Br J Radiol* 2004;77:285–95.
6. Chen AM, Jennelle RL, Sreeraman R, Yang CC, Liu T, Vijayakumar S, et al. Initial clinical experience with helical tomotherapy for head and neck cancer. *Head Neck* 2009;31:1571–8.
7. Ulrich S, Sterzing F, Nill S, Schubert K, Herfarth KK, Debus J, et al. Comparison of arc-modulated cone beam therapy and helical tomotherapy for three different types of cancer. *Med Phys* 2009;36:4702–10.
8. Rao M, Yang W, Chen F, Sheng K, Ye J, Mehta V, et al. Comparison of Elekta VMAT with helical tomotherapy and fixed field IMRT: plan quality, delivery efficiency and accuracy. *Med Phys* 2010;37:1350–59.

9. Ling C, Zhang P, Archambault Y, Bocanek J, Tang G, Losasso T. Commissioning and quality assurance of rapidarc radiotherapy delivery system. *Int J Radiat Oncol Biol Phys* 2008;72:575–81.
10. Mehta M, Hoban P, Mackie TR. Commissioning and quality assurance of RapidArc radiotherapy delivery system: in regard to Ling et al. (*Int J Radiat Oncol Biol Phys* 2008;72:575–81): absence of data does not constitute proof; the proof is in tasting the pudding. *Int J Radiat Oncol Biol Phys* 2009;75:4–6.
11. Mohan R. Dueling technologies: in regard to Ling et al. (*Int J Radiat Oncol Biol Phys* 2008;72:575–81). *Int J Radiat Oncol Biol Phys* 2009;75:6–7.
12. Ling CC, Archambault Y, Bocanek J, Ling CC, Zhang P, LoSasso T, et al. Scylla and charybdis: longer beam-on time or lesser conformality—the dilemma of tomotherapy. *Int J Radiat Oncol Biol Phys* 2009;75:8–9.
13. Lee TF, Fang FM, Chao PJ, Su TJ, Wang LK, Leung SW. Dosimetric comparisons of helical tomotherapy and step-and-shoot intensity-modulated radiotherapy in nasopharyngeal carcinoma. *Radiother Oncol* 2008;89:89–96.
14. UK Clinical Research Network: Portfolio Database MREC No: 08/H0907/127, UKCRN ID 7341. Chatterjee S (Chief investigator). VortigERN: variation of radiotherapy target volume definition, dose to organs at risk (OAR) and clinical target volumes using anatomic (CT) vs. combined anatomic and molecular imaging (PET-CT): intensity modulated radiotherapy delivered using a tomotherapy Hi Art machine. (Cited 4 Jan 2010). Available from: <http://public.ukcrn.org.uk/search/StudyDetail.aspx?StudyID=7341>
15. Grégoire V, Levendag P, Ang Kian K, Bernier J, Braaksma M, Budach V, et al. CT-based delineation of lymph node levels and related CTVs in the node-negative neck: DAHANCA, EORTC, GORTEC, NCIC, RTOG consensus guidelines. *Radiother Oncol* 2003;69:227–36.
16. Grégoire V, Eisbruch A, Hamoir M, Levendag P. Proposal for the delineation of the nodal CTV in the node-positive and the post-operative neck. *Radiother Oncol* 2006;79:15–20.
17. Prescribing, recording and reporting photon beam therapy. (Supplement to ICRU Report 50). ICRU Report 62. Bethesda, MD: ICRU, 1999.
18. Reddy NM, Mazur AK, Sampath S, Osian A, Sood BM, Ravi A, et al. The potential for dose dumping in normal tissues with IMRT for pelvic and H&N cancers. *Med Dosim* 2008;33:55–61.
19. Soisson ET, Tomé WA, Richards GM, Mehta MP. Comparison of linac based fractionated stereotactic radiotherapy and tomotherapy treatment plans for skull-base tumors. *Radiother Oncol* 2006;78:313–21.
20. Kissick MW, Fenwick J, James JA, Jeraj R, Kapatoes JM, et al. The helical tomotherapy thread effect. *Med Phys* 2005;32:1414–23.
21. Schubert LK, Westerly DC, Tomé WA, Mehta MP, Soisson ET, Mackie TR, et al. A comprehensive assessment by tumor site of patient setup using daily MVCT imaging from more than 3,800 helical tomotherapy treatments. *Int J Radiat Oncol Biol Phys* 2009;73:1260–9.
22. Chatterjee S, Mott J, Dickson S, Kelly CG. Extensive basal cell carcinoma of the forehead and anterior scalp: use of helical tomotherapy as a radiotherapy treatment modality (Letter to Editor). *Br J Radio*. 2010;83:538–40.
23. Sterzing F, Uhl M, Hauswald H, Schubert K, Sroka-Perez G, Chen Y, et al. Dynamic jaws and dynamic couch in helical tomotherapy. *Int J Radiat Oncol Biol Phys* (in press).
24. Bernier J, Dörmge C, Ozsahin M, Matuszewska K, Lefebvre JL, Greiner RH, et al. Postoperative irradiation with or without concomitant chemotherapy for locally advanced head and neck cancer. *N Engl J Med* 2004;350:1945–52.
25. Sulman EP, Schwartz DL, Le TT, Ang KK, Morrison WH, Rosenthal DI, et al. IMRT reirradiation of head and neck cancer-disease control and morbidity outcomes. *Int J Radiat Oncol Biol Phys* 2009;73:399–409.
26. Popovtzer A, Gluck I, Chepeha DB, Teknos TN, Moyer JS, Prince ME, et al. The pattern of failure after reirradiation of recurrent squamous cell head and neck cancer: implications for defining the targets. *Int J Radiat Oncol Biol Phys* 2009;74:1342–7.
27. Feuvret L, Noël G, Mazeron JJ, Bey P. Conformity index: a review. *Int J Radiat Oncol Biol Phys* 2006;64:333–42.
28. Fenkell L, Kaminsky I, Breen S, Huang S, Van Prooijen M, Ringash J. Dosimetric comparison of IMRT vs. 3D conformal radiotherapy in the treatment of cancer of the cervical esophagus. *Radiother Oncol* 2008;89:287–91.
29. van Rijn CM, Oughlane-Heemsbergen WD, Ackerstaff AH, Lamers EA, Balm AJ, Rasch CR. Parotid gland sparing IMRT for head and neck cancer improves xerostomia related quality of life. *Radiat Oncol* 2008;3:41.
30. Parliament MB, Scrimger RA, Anderson SG, Kurien EC, Thompson HK, Field GC, et al. Preservation of oral health-related quality of life and salivary flow rates after inverse-planned intensity-modulated radiotherapy (IMRT) for head-and-neck cancer. *Int J Radiat Oncol Biol Phys* 2004;58:663–73.
31. Lin A, Kim HM, Terrell JE, Dawson LA, Ship JA, Eisbruch A. Quality of life after parotid-sparing IMRT for head-and-neck cancer: a prospective longitudinal study. *Int J Radiat Oncol Biol Phys* 2003;57:61–70.
32. Whitelaw GL, Blasiak-Wal I, Cooke K, Usher C, Macdougall ND, Plowman PN. A dosimetric comparison between two intensity-modulated radiotherapy techniques: tomotherapy vs dynamic linear accelerator. *Br J Radiol* 2008;81:333–40.
33. Rosenthal DI, Asper JA, Barker JL, Jr, Garden AS, Chao KS, Morrison WH, et al. Importance of patient examination to clinical quality assurance in head and neck radiation oncology. *Head Neck* 2006;28:967–73.
34. Sanguineti G, Gunn GB, Endres EJ, Chaljub G, Cheruvu P, Parker B. Patterns of locoregional failure after exclusive IMRT for oropharyngeal carcinoma. *Int J Radiat Oncol Biol Phys* 2008;72:737–46.
35. Guerrero Urbano T, Clark CH, Hansen VN, Adams EJ, A'Hern R, et al. A phase I study of dose-escalated chemoradiation with accelerated intensity modulated radiotherapy in locally advanced head and neck cancer. *Radiother Oncol* 2007;85:36–41.