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Intra-cavitary dosimetry for IMRT head and neck treatment using thermoluminescent dosimeters in a naso-oesophageal tube

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Abstract
Complex intensity-modulated radiation therapy (IMRT) treatment plans require rigorous quality assurance tests. The aim of this study was to independently verify the delivered dose inside the patient in the region of the treatment site. A flexible naso-gastric tube containing thermoluminescent dosimeters (TLDs) was inserted into the oesophagus via the sinus cavity before the patient’s first treatment. Lead markers were also inserted into the tube in order that the TLD positions could be accurately determined from the lateral and anterior–posterior electronic portal images taken prior to treatment. The measured dose was corrected for both daily linac output variations and the estimated dose received from the portal images. The predicted dose for each TLD was determined from the treatment planning system and compared to the measured TLD doses. The results comprise 431 TLD measurements on 43 patients. The mean measured-to-predicted dose ratio was 0.988 ± 0.011 (95% confidence interval) for measured doses above 0.2 Gy. There was a variation in this ratio when the measurements were separated into low dose (0.2–1.0 Gy), medium dose (1.0–1.8 Gy) and high dose (> 1.8 Gy) measurements. The TLD-loaded, naso-oesophageal tube for in vivo dose verification is straightforward to implement, and well tolerated by patients. It provides independent reassurance of the delivered dose for head and neck IMRT.

(Some figures in this article are in colour only in the electronic version)

1. Introduction

Intensity-modulated radiation therapy (IMRT) for head and neck cancers is becoming more common in clinical practice, and is no longer confined to large, academic centres
The types of tumours treated with head and neck IMRT include oropharynx, nasopharynx, base of tongue and thyroid tumours. Such complex treatment plans demand rigorous quality assurance programmes, especially when a head and neck IMRT programme is first established. There are many articles and textbooks devoted to IMRT quality assurance which have been published in recent years (LoSasso et al 2001, Low 2002, Ezzell et al 2003, Palta and Mackie 2003).

The type of patient-specific quality assurance programme performed by medical physicists and radiation therapy staff varies, but typically comprises ionization chamber point dose measurements as well as verification of the dose distribution in a two-dimensional plane using film or array technology (Ting and Davis 2001, van Esch et al 2002, James et al 2003, Mijnheer and Georg 2008). The use of portal dosimetry using electronic portal imaging devices (EPID) is also increasing in popularity and was recently reviewed by van Elmpt et al (2008). These quality assurance tests are often performed in tissue-equivalent phantom material before the patient starts treatment. In vivo dosimetry using thermoluminescent dosimeters (TLDs) (Bedford et al 2006), semiconductor diodes (Higgins et al 2003) and metal oxide semiconductor field effect transistors (MOSFETS) (Varadhan et al 2006) placed on IMRT patients’ skin has also been reported.

Intra-cavitary dosimetry in which a small dosimeter is placed into the patient’s nose and throat is a step beyond surface dose and pre-treatment phantom measurements. Intra-cavity dosimetry provides independent assessment of the delivered dose under the most realistic of scenarios (inside the patient) and in the presence of an air cavity, thus testing the limitations of the treatment planning system (TPS) (Engström et al 2005, Marcie et al 2005).

The head and neck IMRT programme at the William Buckland Radiotherapy Centre in Melbourne, Australia, was set up in 2004. One of our aims was to use a true in vivo technique to independently measure the delivered dose to our patients. This was done using TLDs inserted into a naso-oesophageal tube for the first fraction of a patient’s treatment. The doses delivered were compared to the planned doses on the TPS. Having accumulated data from 43 patients, we are now re-evaluating the need for in vivo dosimetry for patients undergoing this type of treatment.

2. Materials and methods

2.1. Treatment planning and delivery

Fifteen patients were inverse planned on the Plato treatment planning system (Nucletron, Veenendaal, The Netherlands) and 28 patients were inverse planned using the Eclipse treatment planning system (Varian Medical Systems, Las Vegas, NV, USA). The photon beam algorithms in both the Plato (RTS version 2.5.2) and Eclipse (versions 7.2.24–8.0.05) systems are based on pencil kernel convolution techniques (Storchi and Woudstra 1995, 1996, Bortfeld et al 1993) as described in the review by Ahnesjo and Aspradakis (1999). All patients were planned using a seven-field co-planar technique with 6 MV x-ray photons. The simultaneous integrated boost technique of IMRT (Lauve et al 2004) was used to deliver a total dose of 70, 60 or 50 Gy to target volumes outlined according to the DAnish Head And Neck CAncer Group (DAHANCA 2008) protocol over 35 daily fractions.

We performed quality assurance tests using ionization chamber and film measurements on every IMRT patient plan prior to the first fraction. Treatment delivery was performed on Varian 2100 C and 21EX linear accelerators with 80-leaf and 120-leaf multileaf collimators, respectively. Regular portal images were taken throughout the course of treatment to ensure the positional accuracy of the daily set-up.
2.2. Naso-oesophageal tube preparation and insertion

We loaded 12 lithium fluoride BICRON® (Saint-Gobain, Paris, France) TLD-100 rods (1 mm × 6 mm) into a naso-oesophageal tube interspersed with lead markers, as shown in figure 1. Each TLD was placed inside a small plastic cylinder 2 mm × 15 mm before the cylinders were inserted into a Unomedical (Unomedical Pty Ltd, Engmosen 1, 3540 Lynge, Denmark) 12-gauge flexible naso-oesophageal tube approximately 50 cm in length (figure 1).

We inserted the lead markers (2 mm × 4 mm) between the cylinders in order that the TLD position could be accurately determined from the lateral and anterior–posterior portal images taken prior to treatment. A lead marker was placed on the patient cast which was aligned to the isocentre of the treatment fields before the portal images were taken and then removed before treatment.

A nurse sprayed local anaesthetic into the nose and throat region of the patient, and the tube had a small amount of lubricant applied to the tip before insertion. The nurse then gently guided the tube down the patient’s oesophagus, where it remained for the duration of the treatment fraction (figure 2).

The patient was also given water to sip whilst the tube was being inserted. Most patients tolerated the tube well; however, six patients could not tolerate the tube insertion due to disease or surgical complications in the nasal region and were excluded from this study.

One anterior–posterior and one lateral, open-field, megavoltage electronic portal images were acquired to verify the patient set-up. Figure 3 is an example of such a lateral portal image with the associated digitally reconstructed radiograph from the treatment planning system.

2.3. TLD processing

The TLDs were left for a minimum of 1 h after irradiation to stabilize before read-out. We used the Harshaw QS 5500 read-out system with the BICRON® WinREMS software (Thermo Electron, Oakwood, OH, USA). The measured charge (nC) from the Harshaw read-out system was converted to dose (Gy) using individual calibration factors (nC Gy$^{-1}$) for each TLD. We annealed the TLDs after each use with an annealing cycle of 400 °C for 1 h followed by 100 °C for 4 h. We routinely calibrated the TLDs to 2 Gy at 6 MV to monitor dose response stability, and there were no observed supralinearity effects in TLD response for absorbed doses up to 3 Gy (data not shown).

The predicted dose at the TLD position was determined from the treatment plan, using the EPI images to infer the TLD position as shown in figure 3(c).
Figure 2. Patient set-up on the treatment couch with the naso-oesophageal tube in place.

Figure 3. Lateral digitally reconstructed radiograph (a) and megavoltage EPI (b) showing lead markers, which are used to infer TLD position on the patient CT data set (c) on the treatment plan.

recorded for all TLDs, based on a cylindrical volume surrounding the inferred TLD position, rather than a single point dose. We corrected the measured dose for linac output variations using a dose correction factor, and the estimated dose received from the portal images used in the patient set-up.

There is an element of uncertainty in attempting to infer the precise location of a dosimeter based on portal images and pre-treatment CT scans. The TLD positional uncertainty could be as large as 10 mm, which corresponds to an average variation in the expected dose range of approximately 10% from our data. There is also uncertainty associated with the use of
Table 1. Measured-to-predicted dose ratios (95% CI) of TLDs loaded in a naso-oesophageal tube of head and neck IMRT patients.

<table>
<thead>
<tr>
<th>Dose (Gy)</th>
<th>Ratio (measured/calculation)</th>
<th>Number of TLDs (n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2–1.0</td>
<td>0.860–0.940</td>
<td>65</td>
</tr>
<tr>
<td>1.0–1.8</td>
<td>0.975–1.003</td>
<td>166</td>
</tr>
<tr>
<td>&gt;1.8</td>
<td>1.017–1.039</td>
<td>141</td>
</tr>
</tbody>
</table>

TLDs as a dosimeter. Whereas small ion chambers or pinpoint detectors may measure dose to within ±2%, the uncertainty in TLDs is more likely to be of the order of ±4% (Harris et al 1997). The proposed equation for tolerance represents the absolute sum of the estimated dosimetric and positional uncertainties. We used a conservative estimate of 5% uncertainty in the measured TLD dose plus half the expected dose range for each individual TLD from the treatment planning system:

\[
\text{Tolerance} = \sqrt{(5\% \text{ TLD dose})^2 + (\text{Expected dose range}/2)^2}.
\]  

(1)

3. Results

Data from 431 measurements conducted on 43 patients resulted in 372 measured doses above 0.2 Gy. Measured doses below 0.2 Gy were excluded due to the absolute uncertainty in the measured dose causing excessive variations in the ratio. The mean measured-to-predicted dose ratio was 0.988 ± 0.011 (95% confidence interval) for measured doses above 0.2 Gy. Three hundred and seven measured doses were above 1.0 Gy and 141 measured doses were above 1.8 Gy. There were no measured doses above 3 Gy. There were significant variations in the measured-to-predicted ratio when the measurements were separated into doses between 0.2 Gy and 1.0 Gy, 1.0 Gy and 1.8 Gy and doses greater than 1.8 Gy. Table 1 lists the measured-to-predicted dose ratio (95% CI) across the three dose ranges.

Our measured dose was generally less than our predicted dose for doses between 0.2 Gy and 1.0 Gy. For doses between 1.0 Gy and 1.8 Gy, the ratio was closer to unity. The ratios for doses above 1.8 Gy indicate that the measured dose was greater than the predicted dose.

Figure 4 is a histogram displaying the ratio of the measured dose to the predicted dose for TLDs with measured doses between 0.2 Gy and 1.0 Gy, 1.0 Gy and 1.8 Gy and doses greater than 1.8 Gy. The variation of the measured-to-predicted ratio is evident for the three different dose regions.

We separated the data from the respective planning systems and observed differences between Plato and Eclipse. Table 2 lists the ratio (95% CI) of the measured to planned dose across the three dose ranges, the number of samples (n) and the p value from a two-sided Student’s t-test. We found no significant differences in the ratio of the measured to planned dose between Eclipse- and Plato-planned patients for measured doses between 0.2 Gy and 1.0 Gy (p = 0.20) or for doses between 1.0 Gy and 1.8 Gy (p = 0.49). However, there was a significant difference for doses above 1.8 Gy (p = 0.02).

The ratio for Plato-planned patients was consistently higher than that for Eclipse-planned patients across all dose ranges. Both Plato and Eclipse overestimated the dose between 0.2 Gy and 1.0 Gy; however, the ratio was close to unity for Plato-planned patients for this range. Plato underestimated the dose in the high-dose regions compared with Eclipse. This could be due to differences in the inhomogeneity corrections used in Plato (ETAR) and Eclipse.
Figure 4. Data from 43 head and neck IMRT patients showing the ratio of the TLD measured dose inside a naso-oesophageal tube to the predicted dose from the TPS.

Table 2. Measured-to-predicted dose ratios (95% CI) of TLDs loaded in a naso-oesophageal tube of head and neck IMRT patients planned with Plato and Eclipse software.

<table>
<thead>
<tr>
<th>Dose (Gy)</th>
<th>Plato Ratio (measured/calculation)</th>
<th>n</th>
<th>Eclipse Ratio (measured/calculation)</th>
<th>n</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2–1.0</td>
<td>0.877–0.967</td>
<td>40</td>
<td>0.792–0.938</td>
<td>25</td>
<td>0.196</td>
</tr>
<tr>
<td>1.0–1.8</td>
<td>0.969–1.025</td>
<td>52</td>
<td>0.969–1.001</td>
<td>114</td>
<td>0.490</td>
</tr>
<tr>
<td>&gt;1.8</td>
<td>1.030–1.086</td>
<td>29</td>
<td>1.010–1.032</td>
<td>112</td>
<td>0.020</td>
</tr>
</tbody>
</table>

(Modified Batho) algorithms and differences in the modelling of both the physical geometry and dynamic properties of the MLC leaves by the respective algorithms.

Figure 5 shows the TLD results for one patient. The TLD readings lie within the expected tolerances for this patient. The in vivo measurements were repeated in the case of four patients due to one or more dosimeters in the medium- or high-dose region (>1.0 Gy) being outside our tolerance levels. The cause of the dose discrepancies for three of the four patients was unknown; however, repeat measurements gave satisfactory agreement. Significant weight loss in the other patient between treatment planning and delivery may have caused the observed dose discrepancy. This patient was then replanned and the subsequent in vivo dosimetry was satisfactory.

4. Discussion

With the naso-oesophageal tube system, we can independently assess the dose in biologically and anatomically relevant tissue, instead of a homogeneous, tissue-equivalent phantom. The
method is practical and well tolerated by our IMRT patients. Importantly, it is truly *in vivo* in the literal sense of the word, since we measure the dose inside the patient, and compare the data with the clinical treatment plan. Other IMRT quality assurance regimes (LoSasso *et al* 2001, Low 2002, Ezzell *et al* 2003) rely solely on phantom irradiations, but there are sources of error that will change the dose within the patient but will give the correct dose within the phantom, such as incorrect inhomogeneity corrections.

Our mean ratios and histograms (figure 4) demonstrate overall good agreement between the dose measured *in vivo* and that predicted by the TPS. There were differences however when the data were separated into low-, medium- and high-dose measurements.

To investigate these differences, we examined possible perturbation effects from the lead markers but found no significant contribution to the measured dose from lateral scatter off the lead markers (data not shown).

The differences in the ratio between Plato- and Eclipse-planned patients were not statistically significant at the 0.05 level for doses in the 0.2–1.0 Gy or the 1.0–1.8 Gy ranges. However, the ratio differences were significant for doses above 1.8 Gy. This may be due to differences in the way Plato and Eclipse model inhomogeneity corrections and MLC properties. We did not observe any difference in the calculated-to-measured ratio for the 80-leaf and 120-leaf MLC treatments.

The findings we present here extend the work of Engström *et al* (2005) who presented TLD data on ten patients. We have a larger patient sample size of 43 IMRT patients to better inform our decisions on future directions. There appear to be only limited reports of intra-cavitary dose measurements for IMRT patients in the literature (Engström *et al* 2005, Marcié *et al* 2005). Parsai *et al* (2001) reported an agreement of 2–3% between calculated and measured dose profiles using *in vivo* TLD dosimetry in live and dead dogs.

The pencil beam convolution algorithm used in the TPS to predict dose distribution does not fully model secondary electron transport around objects other than water (AAPM Report No. 85, 2004). An extreme case is an air–water interface. Engström *et al* (2005) investigated this by using Monte Carlo simulation, and demonstrated the failure of their TPS (CadPlan) to predict the dose in an air cavity, where there existed a lack of electronic equilibrium and steep density shifts. However, the authors noted that the influence of this effect was likely to be
minimal since several fields contributed to the total dose delivered to the dosimeter (Engström et al 2005). Marcie et al (2005) attributed their uncertainties to patient position shifts rather than deficiencies in their TPS calculation algorithm, whereas Engström et al (2005) assumed negligible internal organ movement but recognized that swallowing and breathing may affect the position of the oesophagus.

We are sufficiently satisfied with our intra-cavitary in vivo dosimetry data to forgo this time and resource demanding technique for routine head and neck IMRT cases, but maintain it for specialized or unusual cases. This decision was taken in consultation with our radiation oncology clinical colleagues. Pre-treatment quality assurance consisting of point dose phantom measurements and EPID/film dosimetry is still performed for each patient.

Independent reassurance of delivered dose is important when a new technology and practice are implemented at the same time. The two can conspire together to produce the most enigmatic misadministrations. A case in point is the radiation incident in New York State reported by Varian Medical Systems to all its customers in 2005 (Varian Medical Systems 2005). It was reported that ‘a patient may have been treated with 13 Gy of radiation dose per treatment in the head and neck region. The treatments were given once per day for three consecutive days’. A TLD-loaded naso-oesophageal tube would have detected the discrepancy immediately after the first treatment fraction.

In conclusion, the naso-oesophageal tube method of in vivo dose verification is straightforward to implement, well tolerated by patients and independently verifies the delivered dose inside the patient.

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References


Bortfeld T, Schlegel W and Rhein B 1993 Decomposition of pencil beam kernels for fast dose calculations in three-dimensional treatment planning Med. Phys. 20 311–8

Danish Head and Neck Cancer Group 2008 www.dahanca.dk/guidelines


LoSasso T, Chui C S and Ling C C 2001 Comprehensive quality assurance for the delivery of intensity modulated radiotherapy with a multileaf collimator used in dynamic mode Med. Phys. 28 2209–19
Intra-cavitary dosimetry for IMRT head and neck treatment using TLDs in a naso-oesophageal tube

Ting J Y and Davis L W 2001 Dose verification for patients undergoing IMRT Med. Dosim. 26 205–13
Varian Medical Systems 2005 An open letter to our customers. Varian Medical Systems, 4 April 2005