Chapter 3

Segmental IMRT for oropharyngeal cancer in a clinical setting

This chapter is based on
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Abstract

Purpose: To develop a segmental intensity-modulated radiotherapy (IMRT) technique for the treatment of oropharyngeal cancer.

Methods and Materials: Eight patients previously treated for oropharyngeal cancer were replanned with segmental IMRT. The dose distribution was optimized using beam geometries consisting of 3, 5, 7 and 9 equiangular beams. The optimization procedure resulted in a theoretical fluence for each beam. In order to vary the number of segments, the optimized fluence was divided in four different equidistant levels. The final dose distribution was calculated using clinically deliverable segments obtained from optimized fluence.

Results: For our segmental IMRT technique the dose homogeneity within the target volumes improved when the total number of segments increased and reached a saturation level at approximately 150 segments. Seven beams were sufficient to achieve the saturation level for dose homogeneity. The mean dose to the parotid glands depended on the beam geometry and tumor location and did not depend on the number of segments. On average the mean dose to the contralateral parotid gland was 35.7 Gy (27.1 - 39.9 Gy) for all seven beam plans.

Conclusion: Seven beams are sufficient to achieve an acceptable dose homogeneity within the target volumes and significant parotid sparing. These results will be used to introduce IMRT in routine clinical practice.


3.1 Introduction

Due to the complex geometry of the various target volumes and organs at risk, it is useful to apply intensity-modulated radiotherapy (IMRT) for the treatment of oropharyngeal cancers. Most studies concerning the IMRT treatment of oropharyngeal cancers (Vineberg et al., 2002; Chao et al., 2000; Wu et al., 2000; van Asselen et al., 2002), focus on the sparing of the parotid glands, since xerostomia is a severe complication of irradiation of the head-and-neck region (Roesink et al., 2001; Eisbruch et al., 1999). Besides the ability to deliver highly conformal dose distributions, IMRT can be used to deliver different dose levels to different target volumes at the same time, such as the tumor and the electively treated lymph nodes. This ability can also be used to improve the tumor control probability (TCP) by increasing the dose to the target volume, without increasing the dose to the surrounding tissues (Nederveen et al., 2001b; Wu et al., 2000; Mohan et al., 2000).

The number of beams, the beam orientations and the number of segments, when using a segmental MLC delivery technique, are important parameters for the optimization process of an IMRT plan and result in a vast amount of degrees of freedom for the optimization process.

Optimization of beam orientation for IMRT has been studied by several groups (Pugachev et al., 2001; Rowbottom et al., 2001; Söderström and Brahme, 1995; Stein et al., 1997). In most of these studies, beam orientation optimization resulted in improved dose distributions, when a small number of beams (<5) was applied (Rowbottom et al., 2001; Söderström and Brahme, 1995; Stein et al., 1997). The clinical introduction of beam orientation optimization is, however, hampered by the long computation times (Pugachev et al., 2001; Rowbottom et al., 2001). Consequently, IMRT is often clinically introduced using a fixed beam geometry (Nederveen et al., 2001b; Vineberg et al., 2002; Zelefsky et al., 2000; Wu et al., 2000). Generally nine beams are considered to be sufficient (Bortfeld et al., 1990; Mohan et al., 1995). In most recent planning studies concerning IMRT for the treatment of oropharyngeal cancers, nine equiangular coplanar beams were used (Manning et al., 2001; Vineberg et al., 2002; Wu et al., 2000). Wu et al. (2000) reported that the quality of IMRT plans improved with increasing number of beams, up to 9 beams. The differences between various beam geometries were, however, not fully quantified. Both Vineberg et al. (2002) and Manning et al. (2001) did not show data that supported their choice of nine beams.

In our institute segmental IMRT, also known as step-and-shoot IMRT, is used (Nederveen et al., 2001b), in contrast with the use of dynamic MLC in the above mentioned planning studies. For segmental IMRT, the optimal fluence maps obtained by an inverse planning process, are divided in a discrete number of intensity levels. By increasing the number of intensity levels, a better approximation of the optimal fluence map is obtained. The use of segmental IMRT has the advantage
of less complicated quality assurance procedures compared to dynamic MLC. For practical implementation, the total number of MLC segments is an important parameter, since the treatment time is closely related to the number of segments. The use of many segments will not only result in long treatment times but will also result in many small segments with few monitor units. This might lead to unacceptable uncertainties in the treatment delivery (Que, 1999). Potter et al. (2002) reported that the treatment efficiency, represented by the total number of MLC segments, firstly depended on the number of intensity levels used and secondly on the segmentation technique used. The number of intensity levels used to obtain results close to the optimal intensity maps was 5 to 10 (Chui et al., 2001; Keller-Reichenbecher et al., 1999; Potter et al., 2002).

The relation between the quality of a treatment plan and the number of beams in combination with the number of segments is important for the clinical introduction of segmental IMRT. This relation has only been studied for two individual head-and-neck cases (Keller-Reichenbecher et al., 1999). It was the purpose of this work to investigate this relation in detail for the IMRT treatment of oropharyngeal cancers and lymph nodes level II-IV in a clinical setting. Few beams with many segments, i.e. a better approximation of the optimized fluence, might give similar results than many beams with few segments. For this purpose, the planning software (PLATO) and linear accelerator (Elekta) available at our department will be used. The results will be used for developing an efficient and reliable segmental IMRT technique.

Table 3.1: The original tumor site and TNM classification.

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* anterior
Figure 3.1: The contours of various volumes of interest delineated in a transversal plane. For the primary tumor the gross tumor volume (GTV) and the clinical target volume (CTV) are delineated as well as the planning target volume (PTV) of the GTV (PTV\textsubscript{GTV}) and the CTV (PTV\textsubscript{CTV}). Furthermore the CTV and the PTV of ipsilateral and the contralateral lymph node containing regions (ILLN and CLLN) are delineated. Finally the build-up region around the primary target is shown.

3.2 Method

3.2.1 Patients

Eight patients previously treated with conventional radiotherapy for oropharyngeal carcinoma at our institute (Table 3.1), were replanned for this study. All patients underwent a planning computer tomography (CT) scan with 3-5 mm slice intervals, which was transferred to our treatment planning system (PLATO RTS 2.4, Nucletron Ltd., Veenendaal, NL). The clinical target volume (CTV) of the lymph node containing regions, the CTV of the primary target and the organs at risk (OAR; the parotid glands, the brain and the spinal cord) were delineated by a physician (Fig. 3.1). According to the protocol used in our department, the margins necessary to account for microscopic invasion, applied to the GTV to obtain the CTV of the primary tumor differ for each direction: 2 cm cranial; 1 cm caudal,
ventral and medial; 0.5 cm lateral and dorsal. For the delineation of the CTV of the lymph node containing regions the guidelines of Wijers et al. (1999) and Nowak et al. (1999) were used. The cranial border of the lymph node containing region is at the base of skull for both sides. A margin of 5 mm was applied to each CTV to take into account the set-up uncertainties and organ motion, resulting in the planning target volume (PTV) of the CTV of the primary tumor (PTV\textsubscript{CTV}), the PTV of the ipsilateral lymph nodes (PTV\textsubscript{ILLN}) and the PTV of the contralateral lymph nodes (PTV\textsubscript{CLLN}). No margins were applied to the organs at risk. The intention was to deliver a extra dose to the primary tumor, therefore an extra volume was delineated (PTV\textsubscript{GTV}), which is the GTV with an extension of 5 mm. Furthermore an extra volume was delineated around the PTV\textsubscript{CTV} with a margin of 5 mm in order to guide the optimization process. The optimization program can be forced to deliver the build-up of the dose to the prescribed dose to the primary PTV inside this volume (Fig. 3.1). Thus when the primary PTV overlaps with the PTV of the lymph node containing region, the dose gradient from the dose prescribed to the lymph nodes to the dose prescribed to the primary target should be within this volume. All the extensions were limited in the region containing the skin, where the PTV was adjusted by hand when necessary to assure a minimal distance of 5 mm between the PTV and the skin. The minimal margin between the PTVs and the spinal cord and the brain was approximately 10 mm.

3.2.2 Dose prescription

Conventionally, the prescribed dose to the lymph nodes is 50 Gy (2 Gy/fraction; 5 times weekly) and the prescribed dose to the primary tumor 70 Gy (2 Gy/fraction; 5 times weekly) in our institute. In the presented study, the primary disease and the electively treated regions are treated simultaneously with the same number of fractions. Therefore a different fractionation is needed. The data of Mohan et al. (2000) were used to determine the fractionation schedule, using a α/β ratio of 20 Gy and an accelerated tumor clonogen doubling time of 4 days. This resulted in a prescribed dose of 54 Gy (1.8 Gy/fraction; 5 times weekly) for the elective irradiation of the lymph nodes and a prescribed dose of 66 Gy (2.2 Gy/fraction; 5 times weekly) for the CTV of the primary tumor. An extra dose of 3 Gy was planned for the GTV in order to increase the TCP, resulting in a total prescribed dose to the GTV of 69 Gy (2.3 Gy/fraction; 5 times weekly). The dose to all target volumes was delivered in 30 fractions, resulting in a simultaneous integrated boost IMRT strategy (Mohan et al., 2000). The maximum dose allowed to the CNS and the spinal cord was 45 Gy. Since the parotid glands are located adjacent to the lymph node containing regions, part of the volume is overlapping with the PTV of the lymph node containing regions, which should receive the prescribed dose. The homogeneous irradiation of the target volumes was the most important aim. Sparing of the parotid gland will be obtained by reducing the dose to the none
overlapping parts without affecting the dose to the target volumes (van Asselen et al., 2002).

3.2.3 Inverse planning

IMRT plans were generated using the inverse treatment-planning module ITP of PLATO (version 1.0). This is a commercially available version of the KonRad program, developed by the Bortfeld group (Bortfeld et al., 1993). The ITP module optimizes the fluence for a fixed beam geometry to obtain a dose distribution that best fits a series of dose constraints. For the target volumes a maximum and minimum dose is specified. For organs at risk only a maximum dose is specified. The relative weight of these constraints is tuned with so called 'penalties'. All dose constraints are related to a given contour. Therefore the judicious choice of contours is important for dose painting. When the contours are overlapping, the overlapping volume is assigned to one of the volumes during the optimization process. The parotid glands for example overlap with the PTV of the lymph nodes. During the optimization the overlapping volume is considered to be PTV, since the main goal is to deliver the prescribed dose to the lymph nodes and not reducing the dose to the parotid gland.

A standard set of dose constraints (van Asselen et al., 2002) was determined by systematically varying the penalties, minimum en maximum dose values. For this purpose we used a generic patient including all PTVs and OARs. The starting point was to irradiate only the PTVs without considering the organs at risk. When acceptable dose homogeneity was achieved within the PTVs, organs at risk were added to the optimization process. Since the dose constraints are relative to each
3.2. Method

other, the settings of the target volumes did not need to be adjusted and the constraints of the organs at risk could slowly be increased in relative importance. Increasing the penalty was stopped when the volume of the PTVs receiving 95% of the prescribed dose reduced significantly. After obtaining the standard set, it was tested on 3 other patients using three different beam geometries. In each case, clinically acceptable results were obtained and further individual adjustments of the constraints only resulted in mild changes in the dose parameters. In this way a set of dose constraints was obtained which ensures dose homogeneity to the PTVs. This standard set, using moderate sparing for the parotid glands (van Asselen et al., 2002), was then used for all IMRT plans presented in this paper.

During the optimization, a fluence matrix for each beam angle is generated and iteratively adjusted resulting in a dose distribution matching the prescription as closely as possible. For the delivery of the optimized fluence we use step-and-shoot IMRT applying the Elekta MLC (Elekta Oncology Systems, Crawely, UK). The standard ITP sequencer for the Elekta MLC was used for the sequencing procedure. The optimized intensity values of each fluence map were therefore subdivided into a number of equidistant levels. This sequencer is based on the algorithm of Convery and Webb (Convery and Webb, 1998) and tends to minimize the effect of the transmission of the collimators, the leaves and the tongue-and-groove region. In order to minimize the number of segments, a 1-D median filter is applied to the theoretical fluence with a width of 3 bixels. An example of an optimized fluence map and the resulting sequenced fluence map is shown in figure 3.2.

The fluence matrix had a resolution of 1$\times$1 cm$^2$ in the isocenter. The resolution of the dose calculation matrix, for the iterative dose optimization, is 2.9 mm. After sequencing, the dose distribution as actually delivered, is recalculated using a 3D planning system (PLATO RTS version 2.5) using a resolution of 3–4 mm for the dose calculation matrix.

For each patient, the dose distribution was optimized using a different number of equiangular beams (3, 5, 7 and 9), with the gantry angle of the first beam at 0 degrees. The number of segments cannot be varied in a direct way. Theoretical fluence with a continuous intensity distribution was converted into a deliverable fluence with distinct intensity levels using 5, 7, 10 or 15 equidistant intensity levels. It should be noted that the number of resulting segments in a beam could be much larger than the number of intensity levels. The variations in number of beams and intensity levels resulted in 16 dose distributions for a single patient.

3.2.4 Analysis of the dose distribution

The dose received by 95% of the PTV ($D_{95}$) and the dose received by 5% of the PTV ($D_5$) were calculated. The difference between the $D_{95}$ and $D_5$, $D_{95} - D_5$, was used as a parameter indicating the homogeneity of the dose distribution. The
volume receiving less than 95 % of the prescribed dose ($V_{<95\%}$) and more than 105 % of the prescribed dose ($V_{>105\%}$) were used as parameters indicating underdosages and overdosages respectively. For the PTV of the lymph nodes the volume receiving less than 90 % of the prescribed dose was also calculated. Furthermore, the mean dose to the target volumes was calculated. For the $PTV_{CTV}$ the dose distribution for the part which was not overlapping with the $PTV_{GTV}$ was used in the analysis, since the overlapping part should receive the dose to the $PTV_{GTV}$. Consequently the $PTV_{CTV}$ is a shell around the $PTV_{GTV}$. The PTVs of the lymph nodes are overlapping with the $PTV_{CTV}$. In the analysis of the dose distribution only the part which is not overlapping is taken into account because the overlapping part should receive the dose prescribed to the $PTV_{CTV}$.

The mean dose to the parotid glands was calculated, including the overlapping...
3.3 Results

3.3.1 Primary tumor

Highly conformal dose distributions were obtained using IMRT for the treatment of oropharyngeal cancers (Fig. 3.3). The mean dose to the PTV\textsubscript{GTV} was on average 69.4 ± 0.8 Gy (1 standard deviation, SD), which was close to the prescribed dose for this volume. The mean dose to the PTV\textsubscript{CTV} was on average 66.7 ± 0.7 Gy (1 SD). The dose homogeneity, indicated by D\textsubscript{95−5}, of the dose distribution within the PTV\textsubscript{GTV} and the PTV\textsubscript{CTV} varied for the different combinations of numbers of beams and intensity levels (Fig. 3.4). In general, the dose homogeneity increased when the total number of segments increased. The dose homogeneity was independent of the beam geometry. In order words, the dose homogeneity was similar when the IMRT plans for various beam geometries had a similar total number of segments. Only for the PTV\textsubscript{CTV} irradiated with the 3 beams this was not the case, similar number of segments resulted in worse dose homogeneity compared to irradiation with 5 beams. When more than approximately 100 segments are used, however, only limited further improvement in dose homogeneity was observed (Fig. 3.4).

The part of the PTV\textsubscript{GTV} which received a dose less than 95 % of the prescribed dose was small ( < 1 % of the volume) when more than approximately 100 segments were used (Table 3.2). The underdosed part of the PTV\textsubscript{CTV} was larger and increased when fewer beams were used (Table 3.2). The over-dosed area of the PTV\textsubscript{GTV} was relatively small for most cases. On average V\textsubscript{>105\textsubscript{Gy}} was 7.2 ± 13.6 (1 SD) %, 3.3 ± 4.1 (1 SD) %, 0.9 ± 1.7 (1 SD) % and 1.8 ± 5.0 (1 SD) % for 3,
5, 7 and 9 beams respectively. The overdosed volume of the PTV\textsubscript{CTV} was larger than that of the PTV\textsubscript{GTV} due to the dose gradient, from 66 to 69 Gy, which is located in this shell around the PTV\textsubscript{GTV}. On average the $V_{>105\%}$ of the PTV\textsubscript{CTV} was $14.4 \pm 9.6$ (1 SD) $\%$, $13.1 \pm 7.1$ (1 SD) $\%$, $10.4 \pm 4.3$ (1 SD) $\%$ and $12.9 \pm 5.0$ (1 SD) $\%$ for 3, 5, 7 and 9 beams respectively. The $V_{>105\%}$ increased when fewer segments were used.
3.3. Results

Table 3.2: The volume (%) receiving a dose lower than 95% of the prescribed dose of the planning target volume of the gross tumor (PTV\textsubscript{GTV}), clinical target volume (PTV\textsubscript{CTV}), the contra- and ipsilateral lymph node containing region (PTV\textsubscript{CLLN} and PTV\textsubscript{ILLN}) for different combinations of number of beams and intensity levels used for sequencing. Beside the mean (m) $V_{<95\%}$ over 8 patients, the standard deviation (SD) is shown.

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3.3.2 Lymph nodes
The mean dose to the PTV of the ipsilateral lymph nodes (PTV\textsubscript{ILLN}) and the PTV of the contralateral lymph nodes (PTV\textsubscript{CLLN}) was on average 55.5 ± 0.7 Gy and 55.0 ± 0.5 Gy (1 SD) respectively. The dose homogeneity of the PTV\textsubscript{ILLN} (Fig. 3.5) improved, as was observed for the primary targets, when the total number of segments increased and did not depend on the number of beams. This was not the case for the dose homogeneity of the PTV\textsubscript{ILLN} for the 3-beam plans. The dose homogeneity of the PTV\textsubscript{CLLN} however, showed a different trend. For each beam geometry the saturation level was reached at a different value of dose homogeneity. In other words, the dose homogeneity increased with increasing number of beams.
Figure 3.5: The dose homogeneity of the PTV<sub>CLLN</sub> (a) and PTV<sub>ILLN</sub> (b) as a function of the total number of segments for 3, 5, 7 and 9 beams. Each data point is the mean value of 8 patients. The error bar indicates 1 standard deviation.

for a similar total number of segments.

The $V_{<95\%}$ increases when a smaller number of intensity levels was chosen and for a smaller number of beams (Table 3.2), especially for the contralateral part of the lymph nodes. The volume receiving less dose than 90 % of the prescribed dose ($V_{<90\%}$) for the PTV<sub>ILLN</sub> was smaller than 1 % for the plans with more than approximately 90 segments. For a smaller number of segments $V_{<90\%}$ amounted to 1-2 %. For the PTV<sub>CLLN</sub>, $V_{<90\%}$ was on average 4.2, 1.6, 1.3 and 0.8 % for 3, 5, 7 and 9 beams respectively. The overdosage of the lymph nodes was relatively
3.3. Results

Figure 3.6: The volume receiving more than 105% of the prescribed dose ($V_{>105\%}$) to the contralateral (a) and ipsilateral (b) lymph node containing region. Each data point is the mean value of 8 patients. The error bar indicates 1 standard deviation.

large (Fig. 3.6), especially for the ipsilateral part which was close to the high dose areas. It was also observed that the overdosed volume depended on the number of beams and number of segments, especially for the contralateral side.
3.3.3 Spinal cord and brain

On average $D_{\text{max}}$ of the brain was 33.6 Gy (range 11.4 – 46.8 Gy). For one case, with 3 beams and 7 intensity levels, the maximum dose did exceed 45 Gy. The average of the maximum dose to the spinal cord was 32.6 Gy and did not vary much from patient to patient (range 30.2 – 37.5 Gy).

3.3.4 Body

No large difference was observed between the high dose volumes for 5, 7 and 9 beams. On average $V_{>60\text{Gy}}$ and $V_{>70\text{Gy}}$ were 34.2 cm$^3$ (range 13.1 – 59.0 cm$^3$) and 0.4 cm$^3$ (range 0.0 – 2.3 cm$^3$) respectively. These volumes decreased when more segments were used. The high dose volume of the body for 3 beams was larger than for the other beam geometries. On average $V_{>60\text{Gy}}$ and $V_{>70\text{Gy}}$ were 45.2 cm$^3$ (range 11.6 – 81.8 cm$^3$) and 3.0 cm$^3$ (range 0.0 – 9.7 cm$^3$) respectively. High dose volumes in the body appeared not only near the target volume but also in the posterior part of the neck for the 3-beam geometry.

3.3.5 Parotid glands

The mean dose to the parotid glands did not depend on the number of intensity levels. The variation in mean doses for a varying number of intensity levels using the same beam geometry was smaller than 0.5 Gy. The mean dose was, however, influenced by the beam geometry, especially for the contralateral parotid gland (Fig. 3.7). On average the mean dose to the contralateral parotid gland was 32.6 Gy for the 5 beam plans. This was lower than the average mean dose for the 3, 7 and 9 beam plans, which amounted to 38.0, 35.7 and 34.4 Gy, respectively. Although small, the difference in the mean doses for the different beam geometries were statistically significant ($p < 0.001$). There was no statistically significant difference between the mean doses of the ipsilateral parotid gland (on average 42.6 Gy) calculated for the 5, 7 and 9 beam plans. The mean dose for the 3 beam geometry was on average 45.3 Gy, and was significantly higher ($p < 0.001$) than the mean doses of the other beam geometries.

NTCP values were calculated using the mean doses to the parotid glands. This resulted in mean NTCP values for the contralateral parotid gland of 0.48, 0.36, 0.43 and 0.40 for the 3, 5, 7 and 9 beam plans, respectively. For the ipsilateral parotid gland the NTCP values were higher, 0.64 for the 3 beam plan and approximately 0.58 for the other beam geometries.

3.3.6 Segments

The total number of segments after sequencing ranged from 22 to 234 depending on the number of beams and intensity levels. The differences between the seg-
3.4 Discussion

In this planning study on the segmental IMRT treatment of oropharyngeal tumors and lymph nodes level II-IV, various combinations of beam geometries and intensity levels were investigated. The dose homogeneity within the target volumes mainly depended on the total number of segments and was only slightly influenced by the number of beams. For the $\text{PTV}_{\text{GTV}}$, $\text{PTV}_{\text{CTV}}$ and $\text{PTV}_{\text{ILLN}}$ the dose homogeneity, using 5, 7 and 9 beams, was similar when the total number of segments was similar. For the contralateral lymph nodes, however, the dose homogeneity improved for plans with a constant number of segments when more beams were used. The difference in dose homogeneity between the plans with 7 or 9 beams with many segments was small for all target volumes, indicating that more than 7

![Figure 3.7](image-url)  

**Figure 3.7:** The mean dose for the contralateral and ipsilateral parotid gland for 3, 5, 7 and 9 beams. The mean dose is averaged over 8 patients and 4 numbers of intensity levels. The error bar indicates 1 standard deviation.
beams are not needed. In a study of Wu et al. (2000), IMRT using various beam geometries was analyzed. Although not quantified in detail, they reported that the quality of the IMRT plan improved when the number of beams increased, up to 9 beams. Vineberg et al. (2002) used 9 beams for the IMRT treatment of oropharyngeal cancer, in order to have sufficient degrees of freedom to achieve high-quality dose distributions. Although beam optimization becomes less important when 7 or more beams are used (Stein et al., 1997; Söderström and Brahme, 1995; Rowbottom et al., 2001), Pugachev et al. (2001) showed improvements in the dose distribution for a nasopharyngeal case using 9 noncoplanar beams when beam angle optimization was applied.

The underdosage of the PTV\textsubscript{GTV} was small (Table 3.2). V\textsubscript{<95\%} amounted to 0.1 – 0.3 \%, for the 7- and 9-beam plans with many segments. For the PTV\textsubscript{CTV} the V\textsubscript{<95\%} was larger and amounted to 3 – 4 \% for the IMRT plans with the best dose homogeneity. The volumes within the target volume receiving a dose lower than 95 \% of the prescribed dose were always located near the border of the volume. In most cases they were observed at the posterior side of the PTV, relatively close to the spinal cord and the brain. The V\textsubscript{<95\%} of the PTV of the lymph nodes were comparable with the V\textsubscript{<95\%} of the PTV\textsubscript{CTV}. Since most of the PTV of the lymph nodes received a dose larger than 90 \% of the prescribed dose (on average 99 \% of the PTV) this will still result in low risk of metastasis (Withers et al., 1995a).

Although the dose homogeneity to the target volumes was considered the most important, it was possible to achieve mean doses to the contralateral parotid gland of approximately 35 Gy, the dose to the ipsilateral gland was approximately 10 Gy higher. Using conventional conformal techniques mean doses of approximately
50 – 70 Gy are obtained. For the IMRT plans this results in a NTCP value of approximately 0.40 for the contralateral parotid gland. Several groups studied the IMRT treatment of oropharyngeal cancers and elective irradiation of the lymph nodes. Vineberg et al. (2002) reported mean doses ranges of approximately 17 – 34 Gy and 28 – 53 Gy for the contralateral and ipsilateral parotid glands respectively, using a contralateral parotid-sparing protocol (Eisbruch et al., 1998). The homogeneity of the dose in the target volumes was within 5 % of the prescribed dose. Using a simple three-dimensional conformal radiotherapy technique with beam intensity modulation van Dieren et al. (2000) reported a mean dose to the parotid glands of 41.5 Gy, while the PTV was fully covered by the 95 % isodose surface for most plans. Chao et al. (2000) reported a mean dose of 22.4 ± 5.22 Gy (1 SD) for irradiations involving the primary tumor and neck nodes. The mean volume of the targets receiving less than 95 % of the prescribed dose was 3 % ± 1.4 % (1 SD). A tomotherapy-based IMRT system was used. Using a planning organ-at-risk volume and a dynamic multileaf collimation technique, Manning et al. (2001) reported that 0.1 ± 0.0 % (1 SD) of the contralateral parotid received a dose more than 30 Gy for three cases. The coverage of the elective treated volume (ETV) was however, diminished, i.e. 92.5 ± 4.4 % (1 SD) of the ETV received a dose higher than or equal to the prescribed dose (54 Gy). Variation in the mean dose to the parotid gland and target dose homogeneity reported by the various groups may be the result of different treatment planning strategies and different IMRT delivery techniques. Also the volumes will not always be delineated in the same way. For example, the cranial border of the lymph node containing region is at the base of skull for both sides in our study, while others might lower the cranial border in order to spare the contralateral parotid gland. The influence of lowering this cranial border and the associated risks are currently investigated.

The mean dose to the parotid glands did not decrease using additional beams. In this paper, the mean dose to the contralateral parotid gland was statistical significantly lower for 5 beams than for the other beam geometries. This might be due to the fact that in the five-beam geometry, a favorable beam angle is present. Another reason might be the use of a fixed set of dose constraints and penalties independent of the beam geometry. The reason for this effect will be further investigated. There was also no effect of the number of intensity levels on the mean dose to the parotid gland. Using more intensity levels might result in a sharper dose gradient between the parotid glands and the lymph nodes. The mean dose, which is the best known prognostic factor for xerostomia (Roesink et al., 2001; Eisbruch et al., 1999), is, however, not very sensitive to a sharper dose gradient and is dominated by the overlapping volume receiving the prescribed dose (54 Gy). Keller-Reichenbecher et al. (1999) reported for two head-and-neck cases that using additional beams and intensity levels, it was possible to improve the dose homogeneity in the target volume. This, however, did not automatically result in a better sparing of OARs. For a nasopharyngeal case, Chui et al. (2001), reported
that increasing the number of levels resulted in improved target coverage, but the critical organ protection was little affected.

The total number of segments after sequencing ranged from 22 to 234 depending on the number of beams and intensity levels. The absolute number of resulting segments depends on the sequencing technique (Chui et al., 2001; Potter et al., 2002; Que, 1999). The number of segments needed per field per intensity level was 1.4, which is similar to the value of 1.3 (±0.2) determined by Potter et al. (2002) for three head and neck cases. The number of segments is also influenced by the resolution of the fluence matrix. Although a finer resolution might result in an improved dose distribution, it could also result in more segments and thus in longer treatment times. We therefore choose for a resolution of 1 cm × 1 cm in this work and will further investigate the influence of a higher resolution.

When the total number of segments increased from approximately 100 to approximately 150, relatively little improvement in dose homogeneity was observed. When many segments are used, the individual segments will become smaller. The use of many small segments has dosimetric disadvantages such as a larger contribution from leaf transmission and uncertainties caused by small field dosimetry. Furthermore, many segments result in longer treatment times and consequently an increased risk for intrafraction motion of the patient (van Asselen et al., 2003).

The optimization in radiotherapy is a multi-parameter problem. Parameters such as treatment modality, beam energy, number and orientation of beams and the fluence profiles all require optimization to obtain the best possible treatment plan for an individual patient (Rowbottom et al., 1999). The optimization of all parameters requires too much time even on a research basis. We therefore choose a reasonable sub-set of these parameters and investigated for this sub-set the best clinically achievable treatment plan. The patients were all planned using the same parameters, what makes the introduction of IMRT more easy since this would be less time consuming than individually optimize the parameters for each patient. Individual optimization might, however, result in a slightly better treatment plan. Although the optimal plan for each individual patient might not be achieved using the class solution, the presented IMRT plans resulted, however, in highly conformal and clinically acceptable plans. The findings of this paper are now used for the clinical introduction of IMRT for the treatment of oropharyngeal tumors at our department and can be used as a starting point for further improvements.

3.5 Conclusion

A subset of treatment parameters has been investigated for the segmental IMRT treatment of oropharyngeal cancers and the elective treatment of the lymph nodes level II-IV. Significant parotid sparing was obtained for 5, 7 and 9 beams, with acceptable dose homogeneity within the target volumes and dose escalation in the
GTV. The dose homogeneity in the PTVs depended mainly on the total number of segments and was only slightly influenced by the number of beams. The number of segments did not influence the mean dose to the parotid glands. When only the dose distribution to the target volumes is considered, 7 beams and a total of approximately 100 segments were sufficient to achieve a highly conformal and homogeneous dose distribution. Between 100 and 150 segments little improvement in the dose distribution was observed.