Report of a Study on IMRT Planning Strategies for Ethmoid Sinus Cancer

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Aim: This communication reviews the planning strategies and dose statistics of nine IMRT plans generated for a complex head and neck case.
Patient and Method: An ethmoid sinus cancer case was sent as an IMRT planning task to all participants of the ESTRO course on "IMRT and Other Conformal Techniques in Practice", held in Amsterdam in June 2001.
Results: Nine IMRT plans were generated for the case, the majority of the plans generated with commercial planning systems. The number of beam incidences ranged between four and eleven, while five of the nine beam setups were coplanar. The planning target volume dose homogeneity was inversely correlated with the degree of sparing of the surrounding organs at risk.
Conclusion: IMRT strategies for complex head and neck cases, such as ethmoid sinus cancer, can be strikingly different in various aspects, such as beam setup, total number of segments, PTV dose coverage and dose statistics for organs at risks.

Key Words: Radiotherapy planning · IMRT · Ethmoid sinus cancer

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Bericht über eine Studie über IMRT-Planungsstrategien für einen Nasennebenhöhlentumor

Ziel: Diese Kurzmitteilung beschreibt und vergleicht die Planungsstrategien und Dosisstatistiken von neun IMRT-Plänen für einen Nasennebenhöhlentumor.
Patient und Methode: Die Planung einer intensitätsmodulierten Strahlenbehandlung (IMRT) für einen Nasennebenhöhlentumor im Siebbein wurde den Teilnehmern des ESTRO-Kurses „IMRT and Other Conformal Techniques in Practice" in Amsterdam im Juni 2001 als Aufgabe gestellt.
Ergebnisse: Für den vorgegebenen Fall wurden neun intensitätsmodulierte Bestrahlungspläne erstellt, die Mehrzahl unter Verwendung kommerzieller Bestrahlungsplanungssysteme. Die Zahl der Einstrahlrichtungen variierte zwischen vier und elf, fünf der neun Strategien verwendeten ausschließlich koplanare Einstrahlrichtungen. Die Homogenität der Dosisverteilung im Planungszielvolumen korrelierte invers mit dem Schonungsgrad der umliegenden Risikostrukturen.
Schlussfolgerung: IMRT-Planungsstrategien für komplexe HNO-Fälle, wie beispielsweise Nasennebenhöhlentumoren, weisen für eine Vielzahl von Aspekten, wie Zusammenstellung der Felder, Gesamtzahl der Segmente, Homogenität der Dosisdeposition im Planungszielvolumen oder Dosisstatistik der Risikostrukturen, auffallende Unterschiede auf.

Schlüsselwörter: Strahlentherapieplanung · IMRT · Nasennebenhöhlentumor

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Introduction

In June 2001, 165 participants attended the annual ESTRO course on "IMRT and Other Conformal Techniques in Practice" in Amsterdam. An important aspect of the meeting was the discussion of clinical cases. These cases were sent 2 months before the course to all participants and had to be prepared preferably by a team consisting of a radiation oncologist, a physicist and a dosimetrist (radiation technologist). Several aspects, both clinical and physical, were then discussed during the course.

This year, an IMRT planning case for ethmoid sinus cancer was sent to all participants registered for the course, to the members of the teaching staff and to all participating treatment planning companies. The main goal of the planning exercise was to get an impression of the current availability of IMRT planning platforms in different institutions and of the various IMRT strategies used to plan this case. This manuscript reviews the characteristics of nine IMRT plans generated for this case.

Patients and Methods

Case Description

A 60-year-old carpenter was diagnosed in November 2000 with a cT2cN0M0 adenocarcinoma of the right ethmoid sinus cells. After surgical resection of the lesion, the man was referred for a postoperative irradiation.

The patient underwent a CT scan (Siemens Somatom) in supine position from the vertex to the sternoclavicular junction. Adjacent 2 mm thick slices were generated for a region that widely covered the paranasal sinuses, and adjacent 5 mm thick slices outside this region. The dataset consisted of 89 transverse slices, with a pixel resolution of 512 × 512. The pixel size was 0.98 mm and the pixel values ranged between -1,024 and 3,071 Hounsfield units. The dataset file format was DICOM and for ADAC users, the Pinnacle specific image dataset file format was also available.

The CTV was defined up-front (imprinted in the CT dataset), just as for the optic nerves and the optic chiasm, of which the exact locations were determined by the use of MRI (image co-registration). For the spinal cord, the brainstem and other organs at risk, no contours were imprinted in the CT dataset. Figures 1a to 1c show the location of the CTV, the optic nerves and the optic chiasm.

Treatment Plan Objectives and Strategies

The case had to be planned with external photon beam radiotherapy and only IMRT techniques were allowed. The dose prescription was 70 Gy, delivered in 35 fractions of 2 Gy. The median PTV (planning target volume) dose had to be used for dose prescription. For the brainstem, the optic chiasm and the optic nerves, the maximum point dose was not allowed to exceed 60 Gy, while the maximum permitted dose to the spinal cord was 50 Gy.

In total, 14 radiotherapy centers responded to the planning exercise, of which eight centers, listed below the names of the authors, generated an IMRT plan for the case. One center generated two different plans, yielding a total of nine plans suitable for analysis. Two of the nine IMRT plans were generated by members of the teaching staff of the course, and seven plans by other course participants.

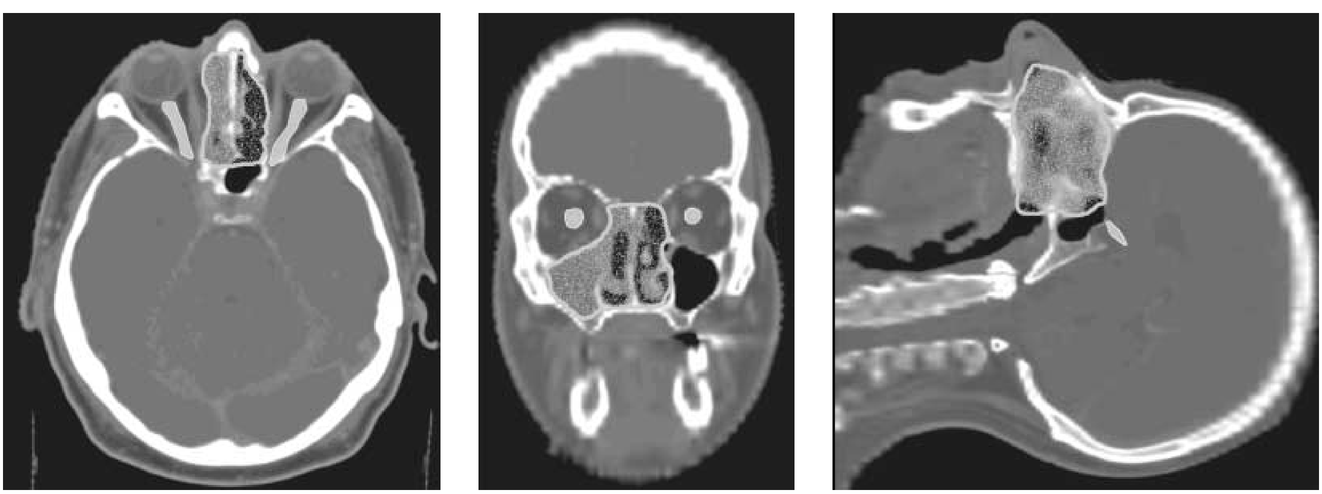

Figure 1a – Abbildung 1a **Figure 1b – Abbildung 1b** **Figure 1c – Abbildung 1c**

Figures 1a to 1c. The clinical target volume (a, b , c: thick gray outline and speckled in white), the optic nerves (a and b: thin white outline and transparent white fill) and the optic chiasm (c: thin white outline and transparent white fill) are outlined in a transverse plane (a), a coronal plane (b) and a sagittal plane (c).

Abbildungen 1a bis 1c. Transversalschnitt (a), Koronalschnitt (b) und Sagitalschnitt (c) durch den Schädel des Patienten mit Darstellung des klinischen Zielvolumens (a, b, c: grau umrandet, weiß gesprenkelt), der beiden Sehnerven (a, b: weiß umrandet, transparente weiße Füllung) und des Chiasmas (c: weiß umrandet, transparente weiße Füllung).

Results

The CTV was expanded to a PTV with a margin of 2 mm (1/9), 2.2 mm (1/9), 3 mm (3/9) and 5 mm (4/9). In only three centers the optic pathway structures were expanded, with margins ranging between 2 and 3 mm. Table 1 summarizes the plan statistics for the nine treatment plans. Plans 1, 4, 5, 7, 8 and 9 were generated with commercially available treatment planning systems. For plan 2 and 3, UM-Plan was used, a planning system developed at the University of Michigan. Plan 6 was generated with GRATIS, a system developed by G. Sherouse, extended with in-house developed IMRT software. The number of beam incidences ranged between four and eleven, while five of the nine beam setups were coplanar. The total number of segments per plan ranged between twelve and 140. Table 2 summarizes the dose statistics of the nine treatment plans. For the PTV, the mean and maximum dose are reported. D_5, defined as the dose level where the cumulative DVH intersects with 5% of the volume, and D_{95}, defined as the dose where the cumulative DVH intersects with 95% of the volume, are also reported. The PTV dose inhomogeneity u, defined as $(D_5–D_{95})/(D_{mean})$, ranged between 10 and 25%. For the optic nerves and the optic chiasm, the mean dose and the maximum dose are reported. The dose limit of 60 Gy for the optic structures was not respected in five of the nine plans. The maximum point dose inside the patient contour ranged from 73 to 85 Gy. For the brainstem and spinal cord no plan did violate the constraints of 60 and 50 Gy, respectively.

Discussion

Ethmoid sinus cancer is usually diagnosed in an advanced disease stage. Cure rates are poor (≤ 50%) and most patients die of direct tumoral invasion of vital organs or rapidly recurring local disease [15]. A PTV encompassing all ethmoidal air cells and the adjacent air cavities (nasal cavity, homolateral maxil-

Table 1. Overview of the plan statistics for the nine IMRT plans specifying the treatment planning systems and the beam and segment characteristics ([a]: tomotherapy with gantry rotation between -150° and 150°; [b]: estimated number of segments; [c]: measured at the isocenter; [d]: mini MLC).

Tabelle 1. Zusammenstellung der Planungsstrategien der neun IMRT-Pläne mit Spezifikation des verwendeten Bestrahlungsplanungssystems sowie Charakterisierung der verwendeten Felder und Segmente.

Plan	Treatment planning system	Beams (number)	Coplanar (yes/no)	Segments (number)	Energy (MV)	Dose computed on	Leaf width (MLC)[c] Beamlet size (BLS)
1	Pinnacle	9	no	79	6 and 18	deliverable beams	10 mm (MLC)
2	UM-Plan	4	no	12	6	deliverable beams	Cerrobend blocks
3	KonRad + UM-Plan	7	yes	43	6	deliverable beams	10 mm (MLC)
4	KonRad	5	yes	60	6	deliverable beams	10 mm (MLC)
5	Helax	5	yes	49	6	deliverable beams	10 mm (MLC)
6	Gratis	6	no	21	6	deliverable beams	10 mm (MLC)
7	Pinnacle	11	yes	140	6	deliverable beams	10 mm (MLC)
8	Corvus MiMic	arc[a]	yes	arc[a]	4	deliverable beams	10 mm (BLS)
9	Radionics Xplan IMRT	6	no	50–60[b]	6	intensity maps	4 mm (MLC)[d]

Table 2. Overview of the dose statistics (Gy) of the PTV and visual pathway structures for the nine IMRT plans ($u = (D_5–D_{95})/(D_{mean})$; D_5: the dose level where the cumulative DVH intersects with 5% of the volume; D_{95}: the dose where the cumulative DVH intersects with 95% of the volume).

Tabelle 2. Zusammenstellung der Dosisstatistiken für das Planungszielvolumen sowie verschiedener optischer Risikostrukturen.

Plan	PTV volume cm³	PTV mean dose Gy	PTV u	PTV D_{95} dose Gy	PTV D_5 dose Gy	PTV max dose Gy	Optic chiasm max dose Gy	Optic chiasm mean dose Gy	Left optic nerve max dose Gy	Left optic nerve mean dose Gy	Right optic nerve max dose Gy	Right optic nerve mean dose Gy	Patient max dose Gy
1	134	70	0.10	67	74	80	50	32	65	40	63	43	80
2	144	72	0.11	67	75	78	45	31	64	39	62	45	79
3	143	70	0.14	64	74	76	37	24	55	49	71	64	76
4	143	70	0.17	64	76	78	65	35	63	54	64	57	79
5	148	69	0.25	59	76	83	55	28	55	28	58	40	83
6	133	69	0.14	62	72	73	51	38	55	36	57	46	73
7	134	70	0.13	66	75	85	64	54	63	57	63	57	85
8	116	73	0.19	66	80	85	23	12	53	44	55	45	85
9	105	69	0.16	64	75	80	29	12	57	37	58	43	80

lary and sphenoidal sinus) may be advisable for these tumors, since locoregional recurrence is the rule. Radiotherapy using high doses and a short overall treatment time are required to increase local control rates [13]. Given the close vicinity of organs at risk, these patients are good candidates to benefit from 3-D conformal or IMRT techniques [3–5, 10, 14].

Expansion margins for the CTV in head and neck irradiation are largely dependent on the accuracy of patient setup, rather than on internal organ motion. The margins of 3 and 5 mm are in agreement with published data for thermoplastic cast immobilization [6, 7]. The smaller margin of 2.2 mm, used in plan 8, may be justified by a more rigid patient immobilization used for tomotherapy [16]. The margin of 2 mm used for plan 9 is explained by the use of a relocatable Gill-Thomas-Cosman frame in that institution for patient immobilization of such cases. This corresponds to previous reported safety margins for similar stereotactic immobilisation devices [1]. Despite the recommendation given in ICRU Report 62 [8] to define a PRV (planning organ at risk volume), in analogy with the PTV concept, in only three of the eight centers margins were added to the organs at risk.

Plan 1 and 2 had a small PTV dose inhomogeneity (10 and 11%), but also a high maximum dose to both optic nerves (≥ 62 Gy), while plan 5 and 8 had the largest dose inhomogeneity (25 and 19%), but also a low maximum dose to both optic nerves (≤ 58 Gy). This can be explained by the close vicinity and partial overlap between the PTV and the optic nerves. The minimum dose to the PTV was not reported, since for most plans, this point was located outside the skin contour. For plans 6, 7 and 8, PRVs were used instead of organs at risk during optimization, which may affect the dose homogeneity over the PTV of these plans.

For doses between 50 and 60 Gy (1.8 or 2 Gy daily fractions), the probability of radiation neuropathy does not exceed 5% [9, 11, 17]. Most NTCP (normal tissue complication probability) data for optic structures were based on conventional radiotherapy techniques, often resulting in a homogeneous irradiation of these structures. Although most of the nervous tissue was considered to have a serial architecture, the volume parameter for optic nerves was significantly higher than for the spinal cord (0.25 vs 0.05), as estimated by Burman et al [4]. This may justify higher doses to small parts of the nerves, while keeping the mean dose much lower. As an example, plans 1 and 2 may result in a significantly lower NTCP for the optic nerves, compared to plans 4 and 7, even if the maximum doses are of the same magnitude. Only three centers contoured the retinae as organs at risk, while the remaining five centers contoured the entire eyeball as organ at risk. The latter method may affect complication probability estimations (based on the mean dose), since a large part of the eyeball consists of the vitreous body. No center reported dose statistics for the lacrimal glands, although relatively low doses (40 Gy) may induce severe eye syndrome [12], often leading to enucleation of the eye. However, by limiting the dose to the entire eyeball or the retina, the dose to the lacrimal gland is also penalized. The sparing of the optic structures, given their small size and distance to the PTV, is dependent on the beamlet size or MLC leaf width and the reported doses may also be significantly influenced by the penumbra widths, i.e. how these were modeled in the treatment planning system.

A non-coplanar beam setup may be beneficial for this case, which is illustrated by plans 2 and 3, both generated at the same institute. For the non-coplanar plan 2, a better dose homogeneity over the PTV was combined with a lower mean dose to the optic nerves, compared to the coplanar plan 3. The dose to the optic chiasm was low for both plans. The treatment delivery time for four non-coplanar beams with a total of twelve segments (plan 2) will be less than 15 minutes, which is comparable to a coplanar delivery time of seven beams with 43 segments (plan 3).

Conclusion

For the same prescribed target dose and dose constraints for organs at risk, IMRT strategies for complex head and neck cases can be strikingly different in various aspects, such as beam setup, total number of segments, PTV dose coverage and dose statistics for organs at risks. For this case, a good correlation was found between the margins used to expand the CTV to a PTV, the PTV dose homogeneity and the degree of sparing of the visual pathway structures. No correlation was observed between the PTV dose homogeneity and the number of beam incidences or segments. The results of this planning exercise demonstrate that the planning of IMRT for head and neck cancer is a complicated issue which needs close cooperation between the various disciplines involved in the preparation and execution of a radiotherapeutical treatment.

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