Inverse Planning – a Comparative Intersystem and Interpatient Constraint Study

Dietmar Georg, Bernhard Kroupa, Petra Georg, Peter Winkler, Joachim Bogner, Karin Dieckmann, Richard Pötter[1]

Purpose: To compare commercial treatment-planning systems (TPS) for inverse planning (IP) and to assess constraint variations for specific IMRT indications.
Material and Methods: For IP, OTP, XiO and BrainSCAN were used and step-and-shoot intensity-modulated radiotherapy (IMRT) delivery was assumed. Based on identical constraints, IP was performed for a prostate, head and neck, brain, and gynecologic case. IMRT plans were compared in terms of conformity/homogeneity, dose-volume histograms (DVHs), and delivery efficiency. For ten patients each of a class of indications, constraint variations were evaluated.
Results: IMRT plans were comparable concerning minimum target dose, homogeneity, conformity, and maximum doses to organs at risk. Larger differences were seen in dose gradients outside the target, monitor units, and segment number. Using help structures proved efficient to shape isodoses and to reduce segmentation workload. For IMRT class solutions, IP constraint variations depended on anatomic site.
Conclusion: IP systems requiring doses as input and having objective functions based on physical parameters had a very similar performance. Constraint templates can be established for a class of IMRT indications.

Key Words: IMRT · Inverse planning · Dose constraints · Dose-volume constraints

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Ein Vergleich von Planungssystemen und Zielgrößen für die inverse Planung

Ziel: Die Funktionalität der inversen Planung (IP) von kommerziellen Bestrahlungsplanungssystemen (TPS) sowie die Unterschiede von Dosiszielgrößen bei typischen IMRT-Indikationen (intensitätsmodulierte Strahlentherapie) wurden untersucht.
Material und Methodik: Für die IP fanden OTP, XiO und BrainSCAN Verwendung, und eine „Step-and-shoot"-IMRT wurde angenommen. Basierend auf gleichen Zielgrößenvorgaben wurde für je einen Fall mit Prostatakarzinom, Hirntumor, HNO-Tumor sowie gynäkologischem Tumor eine IP durchgeführt. Die IMRT-Pläne wurden anhand von Dosis-Volumen-Histogrammen (DVHs), Konformität, Homogenität und Bestrahlungseffizienz bewertet. Für je zehn Patienten mit bestimmten Indikationen wurde die Schwankung der IP-Zielgrößen untersucht.
Ergebnisse: Mit allen drei TPS konnten ähnliche IMRT-Pläne mit vergleichbarer Zielgebietsauslastung, Dosishomogenität, Konformität und maximaler Dosisbelastung der Risikoorgane erstellt werden. Größere Unterschiede wurden hinsichtlich des Dosisgradienten außerhalb des Zielgebiets, der Monitoreinheiten sowie der Segmentzahlen beobachtet. Die Verwendung von Hilfsstrukturen erwies sich als zeitsparend. Für eine IMRT-Indikation schwanken die Zielgrößenvorgaben in Abhängigkeit von der Patientenanatomie.
Schlussfolgerung: Mit TPS, deren Zielgrößen und Zielfunktionen auf physikalischen Dosen beruhen, konnten ähnliche IMRT-Pläne erzielt werden. Für IMRT-Konzepte lassen sich Standardzielvorgaben festlegen.

Schlüsselwörter: IMRT · Inverse Planung · Dosiszielgrößen · Dosis-Volumen-Zielgrößen

[1] Department of Radiotherapy and Radiobiology, AKH Vienna, Medical University of Vienna, Austria.

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Introduction

Intensity-modulated radiotherapy (IMRT) has significantly changed the planning, delivery and quality assurance in radiotherapy [1, 2, 4, 21]. Its potential is relatively easy to demonstrate in planning exercises and the enthusiasm leads to a continuously increasing number of centers implementing IMRT [6, 9, 12, 13, 17, 18, 24]. It is generally accepted that the trial-and-error process typical of conformal planning has shifted inverse planning (IP) to an iterative adjustment of prescription, weights and penalties to obtain the desired dose distribution. Various IP systems are now commercially available, applying quadratic dose-based objective functions, anatomy-based segmentation and segment weighting [8, 14, 19], or the dynamic penalized likelihood method [16].

The determination of prescription parameters of an objective function is a key issue in IP. If a constraint set has been determined for an individual patient, it is not obvious to which extent it holds for an IMRT class solution and whether it is specific to a treatment-planning system (TPS). The aim of our study was to compare the performance of IP systems for typical IMRT indications. Additionally, constraint variations within a class of indications (prostate, gynecology, head-and-neck) were determined.

Material and Methods

Inverse Planning Systems

The following TPS were compared: OTP (V1.3, Nucletron), XiO (V4.2, CMS), and BrainSCAN (V5.2, Brainlab). OTP and XiO were configured for an ELEKTA linac for 6, 10, and 15 MV. For dose calculation during optimization a pencil-beam model is applied. The calculation grid size was set to 3 mm. The objective function of both systems is based on quadratic differences between desired and actual doses, and importance factors/weights can be assigned to structures. Segmental MLC (multileaf collimator) was assumed, with ten intensity levels and a minimum leaf opening of 1 cm for sequencing.

IMRT with BrainSCAN was restricted to 6 MV but was based on a micro-MLC with restricted field size [7]. Dose calculation is based on a pencil-beam model. The calculation grid was 2 mm. The BrainSCAN IMRT solution calculates automatically four IMRT plans giving zero, low, medium and high priority to organs at risk (OARs) [10]. IMRT delivery was based on segmental MLC delivery as well, with a fixed average segment number of 15 because BrainSCAN does not allow to specify the maximum number.

All TPS allow to specify dose-volume histogram (DVH) constraints for OARs and various prescription/goal doses for targets. All IMRT plans were normalized to the prescription dose.

Patients

Contouring was done on a Virtual-Simulation workstation. In the following, OARs are listed with decreasing importance in organ ranking for IP.

Prostate cancer. The clinical target volume (CTV; 40 cm^3) encompassed prostate and base of seminal vesicles. A 10-mm isotropic margin was used to construct planning target volume 1 (PTV-1; 162 cm^3). PTV-2 (148 cm^3) was similar to PTV-1, but with a 5-mm margin toward the rectal wall. The prescription was 70 Gy to PTV-1 and 78 Gy to PTV-2. Rectal wall, bladder, femoral heads, and penile bulb were considered OARs. Seven beams with equidistant angles (first beam at 180°) were used.

Postoperative tonsil carcinoma. The CTV (285 cm^3) was defined following consensus guidelines [3, 11]. The boost CTV (96 cm^3) was defined as the tumor bed plus 2-mm margin. A 5-mm margin was used to define PTV_1 (528 cm^3) and PTV_{boost} (115 cm^3). The goal dose was 50 Gy to PTV_1 and 60 Gy to PTV_{boost}. The following OARs were considered: spinal cord, right parotid gland, and larynx. Two help structures were delineated which followed the PTV concavity in anterior and posterior direction. The isocenter was placed in the PTV_{boost} and seven beams were used (gantry: 13°-64°-116°-167°-219°-270°-321°).

Glomus tumor. The CTV (219 cm^3) was isotropically extended (3 mm) to construct the PTV (339 cm^3) with 50 Gy prescribed dose. Chiasm, brainstem, eye bulbs, and optic nerves were considered OARs. A help structure was defined which followed the PTV's concavity. Seven beams (gantry: 0°-40°-160°-200°-280°-320°-340°) were selected for IP.

Cervix carcinoma. A 10-mm isotropic margin was applied to the CTV (646 cm^3) to construct a PTV (1,671 cm^3). The following OARs were defined: small bowel, colon, rectal wall, sigma, bladder, and femoral heads. The prescribed dose was 45 Gy. A seven-beam arrangement with equidistant angles (first beam at 0°) was used.

The interpatient variation of IP constraints was assessed for ten prostate, gynecologic (five cervix, five endometrium) and head-and-neck cancer patients each (postoperative oropharynx). Contouring and IP were similar as described above. However, gynecologic cases received 50.4 Gy, and a structure denoted as intestine was defined instead of small bowels and colon.

Inverse Planning

For each patient all IMRT plans were based on the same geometry. Using the same energy (mainly 15 MV) as in OTP and XiO was not possible with BrainSCAN. Due to the field size limitation a comparison of all TPS was restricted.

In a first step, constraints were defined and IP was performed with OTP using a weight ratio of 4 : 1 for PTV : OARs. After the first IP procedure, constraints and weights were modified until the planning goal was achieved, i.e., to encompass 95% of the (boost) PTV with the 95% isodose. The number of IP iterations was recorded. Then, IP was performed on the other TPS using settings of the best OTP plan. Next, constraints and weighting were modified, if necessary.

Structure weighting was not applied with BrainSCAN; instead, all weights were set to maximum. IMRT plans with medium or low priority for OARs fulfilled the planning goals best. Upper or lower dose limits for the PTV could not be specified, which represented a limitation.

For the assessment of interpatient constraint variations, prostate cases and head-and-neck cases were planned on OTP, gynecologic patients on XiO.

Evaluation Criteria

Target coverage was defined as the PTV fraction covered by the 95% isodose. *Target conformity* was defined as the ratio of the volume encompassed by the 95% isodose and the PTV fraction covered by the 95% isodose. For PTVs $D_{1\%}$ and $D_{99\%}$ were recorded (dose in 1% and 99% of the PTV), which are surrogates for minimum and maximum doses but less prone to calculation artifacts. Target dose homogeneity was defined as $(D_{5\%}–D_{95\%})/D_{prescribed}$. The ratio of the volume encompassed by the 50% isodose (V50/TV) and the PTV was derived as an indicator of the "overall" dose gradient. For OARs, DVHs were analyzed and $D_{1\%}$ was recorded. To quantify treatment efficiency, the number of monitor units (MUs) per fraction and the segment number were evaluated.

Comparison of Fluence Matrices

For each plan and gantry angle, fluence matrices were converted to a 1 × 1 mm^2 beamlet size and analyzed using the software package I'mRT (Wellhöfer, Schwarzenbruck, Germany). Since exported fluence files were of different format, we normalized them to their central-axis values.

Results

Prostate Case

Almost identical OAR constraints could be used on all systems. Compared to OTP, the rectal wall weight needed to be increased on XiO to achieve similar sparing. On BrainSCAN it was necessary to draw a help structure to improve conformity near the seminal vesicles. For bladder, D_{max} needed to be decreased from 80 Gy to 65 Gy. PTV D_{max} limits (86 Gy) were not applicable in BrainSCAN to limit dose inhomogeneity.

Table 1a summarizes the IMRT plan evaluation. Figure 1 shows a DVH comparison for the rectal wall. With XiO the best plan was obtained in terms of conformity and 50% isodose volume, DVH for bladder between 20 and 70 Gy, and $D_{1\%}$ for penile bulb and femoral heads. MUs per fraction were lowest for XiO, but because the segment number was nearly three times higher compared to OTP, a longer treatment time is expected.

Head-and-Neck Case

Differences in constraints for the best OTP and XiO plan were as follows: for target structures different D_{min} (47.5 vs. 45 Gy) and D_{max} (57 vs. 60 Gy) were needed, while for larynx and help structures identical constraints could be used. For spinal cord D_{min} needed to be decreased (from 35 to 30 Gy) in XiO and the parotid gland weighting was doubled to achieve D_{mean} < 26 Gy.

Table 1b summarizes the IMRT plan evaluation. Figure 2a shows the axial dose distributions, Figure 2b the parotid gland DVH. The XiO plan shows best conformity and smallest 50% isodose. Delivery efficiency was better for OTP. At a dose rate of 500 MU/min, the MU and segment number difference will result in about 10-min treatment time differences.

Table 1a. Summary of treatment plan evaluation for intensity-modulated radiotherapy (IMRT) case "prostate". Target coverage with the 95% isodose volume was > 97% for all IMRT plans. IP: inverse planning; PTV: planning target volume.

Tabelle 1a. Zusammenfassende Auswertung der Bestrahlungspläne bei intensitätsmodulierter Strahlentherapie (IMRT) der Prostata. Bei allen IMRT-Plänen umschloss die 95%-Isodose > 97% des Zielvolumens. IP: inverse Planung; PTV: Planungszielvolumen.

Structure	Parameter	OTP	BrainSCAN	XiO
PTV-1	Homogeneity (%)	14	6	13
	Conformity	2.11	1.55	1.35
PTV-2	Homogeneity (%)	10	5	9
	Conformity	1.46	1.34	1.02
	$D_{1\%}$ (Gy)	83.7	81.9	83.1
	$D_{99\%}$ (Gy)	72.9	73.3	71.60
Non-target tissue	V50/TV	8.13	4.31	3.38
Femoral heads	$D_{1\%}$ (Gy)	43	30	33
Penile bulb	$D_{1\%}$ (Gy)	66.8	58.5	34.5
Monitor units per fraction		481	731	440
Number of segments		55	358	155
Number of IP iterations		7	2[a]	7[a]

[a]number of iterations starting with constraints from best OTP plan

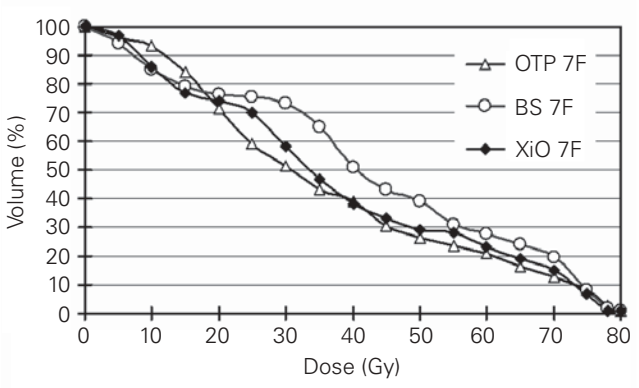


Figure 1. DVH comparison for the rectal wall in IMRT case "prostate" for three different TPS. OTP and XiO IMRT plans are very similar for doses beyond 35 Gy.

Abbildung 1. DVH-Vergleich der Rektumwand bei IMRT der Prostata für drei verschiedene Planungssysteme. OTP- und XiO-IMRT-Pläne sind oberhalb von 35 Gy sehr ähnlich.

Table 1b. Summary of treatment plan evaluation for IMRT case "head-and-neck". Target coverage with the 95% isodose volume was > 95% for all IMRT plans. For abbreviations see Table 1a.

Tabelle 1b. Zusammenfassende Auswertung der Bestrahlungspläne bei HNO-IMRT. Bei allen IMRT-Plänen umschloss die 95%-Isodose > 95% des Zielvolumens. Abkürzungen s. Tabelle 1a.

Structure	Parameter	OTP	XiO
PTV_1	Homogeneity (%)	33	35
	Conformity	1.57	1.41
PTV_{boost}	Homogeneity (%)	13	14
	Conformity	1.48	1.17
	$D_{1\%}$ (Gy)	67.6	66.7
	$D_{99\%}$ (Gy)	57.7	56.0
Non-target tissue	V50/TV	4.99	3.99
Myelon	$D_{1\%}$ (Gy)	45.2	45.4
Larynx	$D_{1\%}$ (Gy)	50.2	51.4
Monitor units per fraction		371	532
Number of segments		67	187
Number of IP iterations		3	3[a]

[a]number of iterations starting with constraints from best OTP plan

Table 1c. Summary of treatment plan evaluation for IMRT case "brain". Target coverage with the 95% isodose volume was > 96% for all IMRT plans. For abbreviations see Table 1a.

Tabelle 1c. Zusammenfassende Auswertung der Bestrahlungspläne bei IMRT eines Gehirntumors. Bei allen IMRT-Plänen umschloss die 95%-Isodose > 96% des Zielvolumens. Abkürzungen s. Tabelle 1a.

Structure	Parameter	OTP	BrainSCAN	XiO
PTV	Homogeneity (%)	6	3	7
	Conformity	1.26	1.16	1.31
	$D_{1\%}$ (Gy)	53.3	51.0	54.7
	$D_{99\%}$ (Gy)	45.9	45.0	43.2
Non-target tissue	V50/TV	3.17	2.62	3.55
Chiasm	$D_{1\%}$ (Gy)	40.3	43.7	43.8
Eye bulb right	$D_{1\%}$ (Gy)	28.6	27.5	30.5
Eye bulb left	$D_{1\%}$ (Gy)	11.5	7.5	2.2
Optic nerve right	$D_{1\%}$ (Gy)	25.4	31.5	15.9
Optic nerve left	$D_{1\%}$ (Gy)	9.2	9.0	5.3
Monitor units per fraction		301	590	457
Number of segments		76	377	128
Number of IP iterations		4	3[a]	2[a]

[a]number of iterations starting with constraints from best OTP plan

Brain Tumor Case

To achieve similar coverage, the main difference between OAR constraints was a reduced D_{max} for the brainstem in BrainSCAN (45 vs. ~50 Gy) and lower structure weights in OTP compared to XiO.

Table 1c summarizes the IMRT plan evaluation. The XiO IMRT plan resulted in the best optic structure sparing between 5 and 20 Gy. DVH values between 20 and 40 Gy for the chiasm were also lowest for XiO. For the brain-

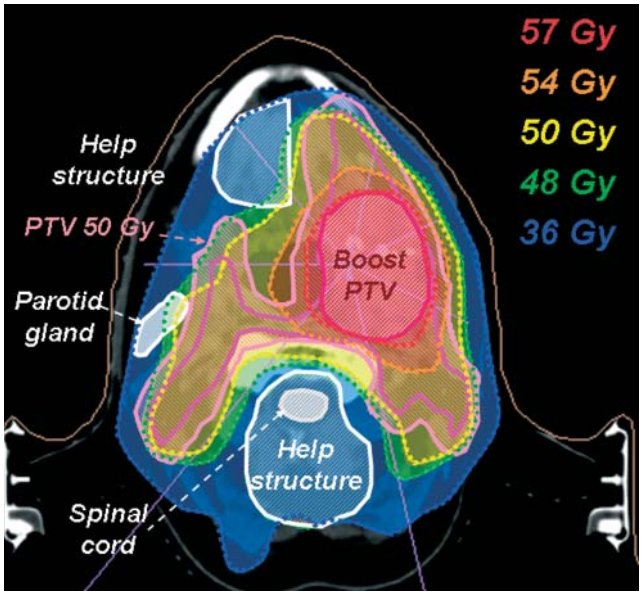


Figure 2a

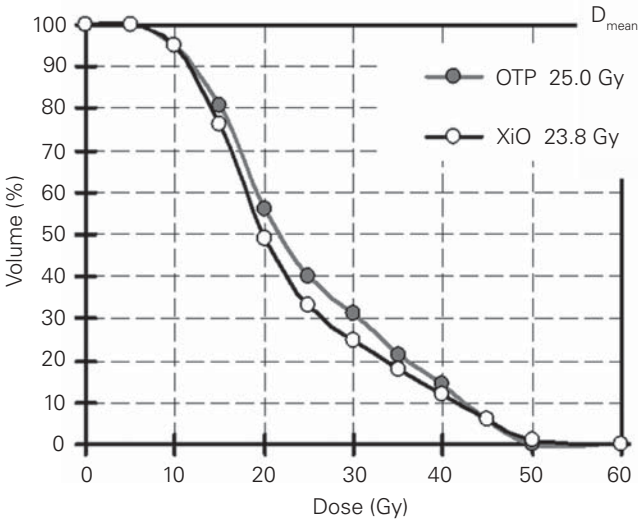


Figure 2b

Figures 2a and 2b. a) Axial slice of the head-and-neck IMRT plan (XiO) with delineated structures and isodose levels. At the anterior part and the posterior part so-called help structures were defined to improve dose conformity. b) DVH comparison for the right parotid gland in IMRT "head-and-neck" for two different TPS.

Abbildungen 2a und 2b. a) Axiale Schicht des HNO-IMRT-Plans (XiO) mit eingezeichneten Strukturen und Isodosen. Anterior und posterior sind jene Hilfsstrukturen zu sehen, die zur Verbesserung der Konformität verwendet wurden. b) DVH-Vergleich der rechten Parotis bei HNO-IMRT für zwei verschiedene Planungssysteme.

Table 1d. Summary of treatment plan evaluation for IMRT case "cervix". Target coverage with the 95% isodose volume was > 96% for all IMRT plans. For abbreviations see Table 1a.

Tabelle 1d. Zusammenfassende Auswertung der Bestrahlungspläne bei IMRT der Zervix. Bei allen IMRT-Plänen umschloss die 95%-Isodose > 96% des Zielvolumens. Abkürzungen s. Tabelle 1a.

Structure	Parameter	OTP	XiO
PTV	Homogeneity (%)	13	8
	Conformity	1.43	1.16
	$D_{1\%}$ (Gy)	51.3	48.6
	$D_{99\%}$ (Gy)	41.0	41.3
Non-target tissue	V50/TV	4.03	3.41
Bowel/colon	$D_{1\%}$ (Gy)	48.5/45.5	47.1/43.8
Rectal wall	$D_{1\%}$ (Gy)	47.8	48.3
Femoral heads	$D_{1\%}$ (Gy)	47.5	47.0
Monitor units per fraction		624	843
Number of segments		87	233
Number of IP iterations		8	4[a]

[a]number of iterations starting with constraints from best OTP plan

stem almost identical DVH and $D_{1\%}$ < 50 Gy were obtained. The XiO plan was, however, slightly less conformal. MUs and segment number differences between OTP and XiO were estimated to result in a 5-min delivery difference at 500 MU/min.

Cervix Case

Compared to OTP, on XiO minimum dose constraints (43.5 vs. 42.8 Gy) and maximum dose limits (47 vs. 51.8 Gy) for PTV had to be modified and OAR weights needed to be increased by a factor of 5 to achieve the planning goal. However, using different OAR weights, almost the same IP constraints could be used. The main differences regarded D_{max} for colon and bowel and DVH parameters for bladder.

Table 1d summarizes the IMRT plan evaluation. Similar DVHs were obtained for femoral heads, kidneys, and bladder. Bowel and colon sparing was best with XiO, with differences mainly between 20 and 40 Gy. For sigma and rectal wall DVH differences occurred only at doses > 35 Gy (again better sparing with XiO). While conformity was best for XiO treatment delivery, efficiency was best for OTP.

Fluence Profiles

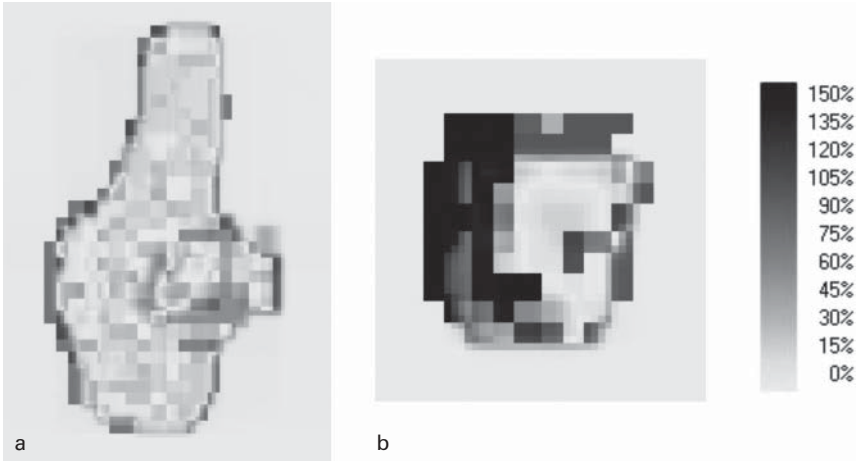
The relative fluence distributions were separated into intervals with local differences > 50%, > 100%, and > 150%. Figure 3a shows a comparison of an IMRT beam from OTP and XiO for the gynecologic case. Besides differences at the periphery (local deviations ≥ 100%), differences inside the PTV are small (Δ_{mean} ~15%). Figure 3b shows a similar comparison for the prostate case. Deviations are larger, with 28% of beamlets having differences > 100% and 46% having differences between 50% and 100%.

The overall fluence deviations were considered by adding intensity variations for each IMRT plan. For case "cervix" the smallest average deviations (Δ_{mean}) of 24% were obtained with only 1% of beamlets exceeding 150% local difference. For case "prostate" Δ_{mean} were between 30% and 40% with about 3% of beamlets having differences > 150%. The best agreement between the three IMRT plans was observed for case "brain" (Δ_{mean} ~25%, but < 1% of beamlets showed local differences > 150%). The largest differences were observed for IMRT plans from OTP and XiO for case "head-and-neck" (Δ_{mean} ~55% and > 7% of beamlets having relative differences > 150%).

Variation of Constraints for a Class of Indications

Tables 2 to 4 summarize IP constraints and their variation for prostate, gynecologic and head-and-neck cancer patients. Resulting IMRT plans were similar to the ones described above.

For prostate cases standardized IP constraints could be used for PTVs and for bladder. For rectal wall, femoral heads and penile bulb individual constraints were needed. The interpatient constraint variation was significantly larger for gynecologic and head-and-neck cancer patients, where anatomic variations were significantly larger.



Figures 3a and 3b. Comparison of relative fluence distributions of intensity-modulated (IM) beams resulting from IP on OTP and XiO. a) IM beam at 256° gantry angle for the gynecologic case. b) IM beam at 26° gantry angle for the prostate case.

Abbildungen 3a und 3b. Unterschiede von Fluenzverteilungen intensitätsmodulierter (IM) Felder, erzeugt mit OTP und XiO. a) IM-Feld bei 256° Gantrystellung des gynäkologischen Falls. b) IM-Feld bei 26° Gantrystellung des Prostatafalls.

Table 2. Constraint variation for IMRT planning within a group of ten prostate cancer patients. IP was performed using OTP. PTV structure weights were 1000 for both PTVs and 250 for organs at risk. SD: standard deviation; for other abbreviations see Table 1a.

Tabelle 2. Schwankungen der Optimierungszielgrößen für zehn Patienten mit Prostatakarzinom. Die IP wurde mit dem OTP-System durchgeführt, wobei die Gewichtung für alle PTV-Strukturen auf 1000 und für Risikoorganstrukturen auf 250 gesetzt wurde. SD: Standardabweichung; übrige Abkürzungen s. Tabelle 1a.

Structure			SD	Range
PTV 10 mm	Minimum dose (Gy)	67	0	–
	Prescribed dose (Gy)	67	0	–
	Underdose volume (%)	0	0	–
	Maximum dose (Gy)	85	0	–
PTV 5 mm	Minimum dose (Gy)	74	0	–
	Prescribed dose (Gy)	74	0	–
	Underdose volume (%)	0	0	–
	Maximum dose (Gy)	85	0	–
Rectal wall	Constraint 1 – volume (%)	100	0	–
	Constraint 1 – dose (Gy)	10	0	–
	Constraint 2 – volume (%)	41.5	9	30–55
	Constraint 2 – dose (Gy)	50.5	1.5	50–55
	Maximum dose (Gy)	80	0	–
Bladder	Constraint 1 – volume (%)	100	0	–
	Constraint 1 – dose (Gy)	10	0	–
	Constraint 2 – volume (%)	40	0	–
	Constraint 2 – dose (Gy)	50	0	–
	Maximum dose (Gy)	80	0	–
Penile bulb	Constraint 1 – volume (%)	100	11.5	17.5–48
	Constraint 1 – dose (Gy)	36.5	0	–
	Constraint 2 – volume (%)	50	0	–
	Constraint 2 – dose (Gy)	50.8	8.1	37–60
	Maximum dose (Gy)	63.2	3.2	58–72
Femoral heads	Constraint 1 – volume (%)	100	1.5	25–30
	Constraint 1 – dose (Gy)	25.5	0	–
	Constraint 2 – volume (%)	65	0	–
	Constraint 2 – dose (Gy)	35.5	3.9	30–40
	Maximum dose (Gy)	45	5	40–50

Discussion

IP modules of TPS have improved during the last years. While at the early stage of IMRT mean doses were mainly used as input, dose and DVH constraints have become today's standard. IP modules of commercial TPS perform very similar and "best" IMRT plans tend to converge, at least for the three systems tested. Assessing more IP systems was not possible because of limited access. Main differences of IMRT plans concerned dose gradients outside the target and delivery efficiency. The sequencer has thus an important impact but is often overlooked. Beam energy has an important impact on the dose to non-target tissue and the 50% isodose volume. For radiation protection at the patient level the dose to non-target tissue and the overall treatment time should be considered when evaluating IMRT. Based on our IMRT experience, the difference between OTP and XiO in delivery efficiency amounts up to 10 min in favor of OTP, while concerning dose outside the target and conformity, XiO plans were superior.

Table 3. Constraint variation for IMRT planning within a group of ten gynecologic cancer patients. IP was performed using XiO. For abbreviations see Tables 1a and 2.

Tabelle 3. Schwankungen der Optimierungszielgrößen für zehn Patientinnen mit gynäkologischen Tumoren. Die IP wurde mit dem XiO-System durchgeführt. Abkürzungen s. Tabellen 1a und 2.

Structure			SD	Range
PTV	Minimum dose (Gy)	49.4	0.5	48.5–50
	Goal dose (Gy)	50.4	0	–
	Maximum dose (Gy)	55.9	0.3	55–56
	Weight	1000	0	–
Rectal wall	Constraint 1 – volume (%)	74	4.9	70–80
	Constraint 1 – dose (Gy)	40	0	–
	Constraint 2 – volume (%)	64	4.9	60–70
	Constraint 2 – dose (Gy)	45	0	–
	Maximum dose (Gy)	53	0	–
	Weight	300	100	250–500
Sigma	Constraint 1 – volume (%)	73	6.4	70–90
	Constraint 1 – dose (Gy)	40	0	–
	Constraint 2 – volume (%)	36.5	4.5	35–50
	Constraint 2 – dose (Gy)	44.5	1.5	42–45
	Maximum dose (Gy)	50.2	0.6	50–52
	Weight	325	115	250–500
Bladder	Constraint 1 – volume (%)	100	0	–
	Constraint 1 – dose (Gy)	30	0	–
	Constraint 2 – volume (%)	50	0	–
	Constraint 2 – dose (Gy)	40.5	1.5	40–45
	Maximum dose (Gy)	50	0	–
	Weight	275	75	250–500
Intestine	Constraint 1 – volume (%)	72	6	70–90
	Constraint 1 – dose (Gy)	20	0	–
	Constraint 2 – volume (%)	53	6.4	50–70
	Constraint 2 – dose (Gy)	30	0	–
	Constraint 3 – volume (%)	32	4	30–40
	Constraint 3 – dose (Gy)	40	0	–
	Maximum dose (Gy)	50	0	–
	Weight	275	75	250–500
Femoral heads	Constraint 1 – volume (%)	100	0	–
	Constraint 2 – dose (Gy)	30	0	–
	Constraint 2 – volume (%)	69	3	60–70
	Constraint 2 – dose (Gy)	37.3	0.9	37–40
	Maximum dose (Gy)	50	0	–
	Weight	290	75	250–500

IP remains, basically, an iterative process but experience in conformal planning facilitates IMRT. However, IP can be time-consuming. On both XiO and OTP time for one IP iteration takes roughly 1 h, depending on case and computer hardware. For IP on BrainSCAN about half of the time was needed.

Using IP constraints from the literature might be misleading, as relative DVH parameters for parallel OARs depend on delineation. Applying absolute doses and volumes instead of relative ones, as used in brachytherapy, might help to overcome this difficulty [15].

Tables 2 to 4 indicate that site-specific definition of IP templates for dose- and DVH-based objective functions is feasible. For the same structure set and organ ranking the appli-

Table 4. Constraint variation for IMRT planning within a group of ten oropharynx cancer patients. IP was performed using OTP. PTV structure weights were 1000 and 250 for organs at risk. For abbreviations see Tables 1a and 2.

Tabelle 4. Schwankungen der Optimierungszielgrößen für zehn Patienten mit Oropharynxkarzinom. Die IP wurde mit dem OTP-System durchgeführt, wobei die Gewichtung für alle PTV-Strukturen auf 1000 und für Risikoorganstrukturen auf 250 gesetzt wurde. Abkürzungen s. Tabellen 1a und 2.

Structure			SD	Range
PTV 60 Gy	Minimum dose (Gy)	57	1.9	54–60
	Prescribed dose (Gy)	60.1	0.2	0–10
	Underdose volume (%)	5.0	3.2	0–10
	Maximum dose (Gy)	68.4	1.2	66–69
PTV 50 Gy	Minimum dose (Gy)	47.3	1.3	47.5–49
	Prescribed dose (Gy)	50.1	0.2	50–50.5
	Underdose volume (%)	5.0	3.2	2–10
	Maximum dose (Gy)	55.4	0.5	54–55
Spinal cord	Constraint 1 – volume (%)	100	0	–
	Constraint 1 – dose (Gy)	36	3.7	30–40
	Constraint 2 – volume (%)	28	18.3	10–50
	Constraint 2 – dose (Gy)	41.6	1.4	40–43
	Maximum dose (Gy)	45.4	0.5	45–46
Parotid gland	Constraint 1 – volume (%)	100	0	–
	Constraint 1 – dose (Gy)	12	2.4	10–15
	Constraint 2 – volume (%)	34.4	7.4	26–46
	Constraint 2 – dose (Gy)	27	2.7	25–30
	Maximum dose (Gy)	52	2.5	48–54
Larynx	Constraint 1 – volume (%)	100	0	–
	Constraint 1 – dose (Gy)	40	0	–
	Constraint 2 – volume (%)	32	9.8	20–50
	Constraint 2 – dose (Gy)	49	2	45–50
	Maximum dose (Gy)	58	4	50–60
Help structures[a]	Constraint 1 – volume (%)	100	0	–
	Constraint 1 – dose (Gy)	38.6	2.3	35–40
	Constraint 2 – volume (%)	20.7	18.6	5–50
	Constraint 2 – dose (Gy)	44.3	0.9	43–46
	Maximum dose (Gy)	47.4	0.6	46–48

[a]similar constraints were used for help structures in the region of the mouth and at the side of the spinal cord

cation of a parameter set to different IP modules leads to comparable IMRT plans. This is important for the implementation of IMRT class solutions, for multicenter trials and related external quality assurance audits.

Efficient structure segmentation is essential for IP. In that aspect artificial "help structures" are a noteworthy alternative to pure anatomic contouring. Delineation of help structures requires experience or the assessment of isodose distributions, assuming that target conformity or OAR sparing could be improved. In the present study a distance of 1 cm was respected between PTV and help structures.

If the objective function is determined from quadratic differences between desired and actual doses, the optimization will stop, if the desired goal is met. This disadvantage can be overcome by using biological objective functions where the optimization tries to go even beyond the specified limit [5, 22]. Next-generation IP systems might use objective functions based on biological factors and/or clinical decisions [14, 20, 23]. Nevertheless, it must be emphasized that current clinical experience is based on physical doses and DVHs from conformal treatments. Even in the future "traditional" parameters will deserve attention and their translation for next generation IP systems requires further research.

References

1. Bogner L, Scherer J, Treutwein M, et al. Verification of IMRT: techniques and problems. Strahlenther Onkol 2004;180:340–50.
2. Cavey ML, Bayouth JE, Colman M, et al. IMRT to escalate the dose to the prostate while treating the pelvic nodes. Strahlenther Onkol 2005; 181:431–41.
3. Chao C. Intensity modulated radiation therapy for head & neck cancer. Philadelphia: Lippincott Williams & Wilkins, 2002.
4. Chao KS, Ozyigit G, Tran BN, et al. Patterns of failure in patients receiving definitive and postoperative IMRT for head-and-neck cancer. Int J Radiat Oncol Biol Phys 2003;55:312–21.
5. Choi B, Deasy JO. The generalized equivalent uniform dose function as a basis for intensity-modulated treatment planning. Phys Med Biol 2002; 47:3579–89.
6. Claus F, Mijnheer B, Rasch C, et al. Report of a study on IMRT planning strategies for ethmoid sinus cancer. Strahlenther Onkol 2002;178:572–6.
7. Cosgrove VP, Jahn U, Pfaender M, et al. Commissioning of a micro multi-leaf collimator and planning system for stereotactic radiosurgery. Radiother Oncol 1999;50:325–36.
8. De Meerleer G, Vakaet L, De Gersem W, et al. Direct segment aperture and weight optimization for intensity-modulated radiotherapy of prostate cancer. Strahlenther Onkol 2004;180:136–43.
9. Eisbruch A, Ship JA, Dawson LA, et al. Salivary gland sparing and improved target irradiation by conformal and intensity modulated irradiation of head and neck cancer. World J Surg 2003;27:832–7.
10. Georg D, Dieckmann K, Bogner J, et al. Impact of a micromultileaf collimator on stereotactic radiotherapy of uveal melanoma. Int J Radiat Oncol Biol Phys 2003;55:881–91.
11. Gregoire V, Levendag P, Ang KK, 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.
12. Hermesse J, Devillers M, Deneufbourg JM, et al. Can intensity-modulated radiation therapy of the paraaortic region overcome the problems of critical organ tolerance? Strahlenther Onkol 2005;181:185–90.
13. Huang E, Teh BS, Strother DR, et al. Intensity-modulated radiation therapy for pediatric medulloblastoma: early report on the reduction of ototoxicity. Int J Radiat Oncol Biol Phys 2002;52:599–605.
14. Intensity Modulated Radiation Therapy Collaborative Working Group. Intensity-modulated radiotherapy: current status and issues of interest. Int J Radiat Oncol Biol Phys 2001;51:880–914.
15. Kirisits C, Pötter R, Lang S, et al. Dose and volume parameters for MRI-based treatment planning in intracavitary brachytherapy of cervix cancer. Int J Radiat Oncol Biol Phys 2005;62:901–11.
16. Llacer J, Solberg TD, Promberger C. Comparative behavior of the dynamically penalized likelihood algorithm in inverse radiation therapy planning. Phys Med Biol 2001;46:2637–63.
17. Mundt AJ, Mell LK, Roeske JC. Preliminary analysis of chronic gastrointestinal toxicity in gynecology patients treated with intensity-modulated whole pelvic radiation therapy. Int J Radiat Oncol Biol Phys 2003; 56:1354–60.
18. Pirzkall A, Debus J, Haering P, et al. Intensity modulated radiotherapy (IMRT) for recurrent, residual, or untreated skull-base meningiomas: preliminary clinical experience. Int J Radiat Oncol Biol Phys 2003; 55:362–72.

19. Sterzing F, Munter MW, Schafer M, et al. Radiobiological investigation of dose-rate effects in intensity-modulated radiation therapy. Strahlenther Onkol 2005;181:42–8.
20. Tsien C, Eisbruch A, McShan D, et al. Intensity-modulated radiation therapy (IMRT) for locally advanced paranasal sinus tumors: incorporating clinical decisions in the optimization process. Int J Radiat Oncol Biol Phys 2003; 55:776–84.
21. Wiezorek T, Banz N, Schwedas M, et al. Dosimetric quality assurance for intensity-modulated radiotherapy feasibility study for a filmless approach. Strahlenther Onkol 2005;181:468–74.
22. Wu Q, Mohan R, Niemierko A, et al. Optimization of intensity-modulated radiotherapy plans based on the equivalent uniform dose. Int J Radiat Oncol Biol Phys 2002;52:224–35.
23. Yang Y, Xing L. Clinical knowledge-based inverse treatment planning. Phys Med Biol 2004;49:5101–17.
24. Zelefsky MJ, Fuks Z, Happersett L, et al. Clinical experience with intensity modulated radiation therapy (IMRT) in prostate cancer. Radiother Oncol 2000;55:241–9.

Address for Correspondence
Dietmar Georg, PhD
Associate Professor
Division of Medical Radiation Physics
Department of Radiotherapy and Radiobiology
Medical University of Vienna
Währinger Gürtel 18–20
1090 Wien
Austria
Phone (+43/1) 40400-2695, Fax -2696
e-mail: Dietmar.Georg@akhwien.at