Strahlentherapie
und Onkologie

# IMRT with Compensators for Head-and-Neck Cancers

## Treatment Technique, Dosimetric Accuracy, and Practical Experiences

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**Background and Purpose:** With three-dimensional conformal intensity-modulated radiotherapy (3D-c-IMRT) a heterogeneous dose distribution can be achieved in both planning treatment volume and in adjacent normal tissues and organs to be spared. 3D-c-IMRT demands for modified photon fluence profiles which can be accomplished with different techniques. This report deals with the commissioning of metal compensators and the first experiences in clinical use. Dosimetric accuracy, dose coverage and practical experience like treatment delivery time, monitor units and dose outside the treated volume are evaluated.

**Patients and Methods:** From January 2002 to April 2004, 24 patients with head-and-neck cancers were treated with 3D-c-IMRT using tin-wax compensators. The dose prescription included a simultaneously integrated boost (SIB). High-dose volume was irradiated with 60–70 Gy (median 66 Gy), low-dose volume with 48–54 Gy (median 52 Gy) administered by a standardized seven-portal coplanar beam arrangement. Dose at one parotid gland was aimed at 26 Gy. The compensators used consisted of tin granules embedded in wax; recalculation was performed with compensators made of the alloy MCP96 as well.

**Results:** In 21 of 24 patients 3D-c-IMRT with tin-wax compensators reduced the median dose to one parotid gland to < 30 Gy. Recalculation with compensators with higher density which allowed higher attenuation revealed better protection of the parotid gland. The treatment delivery time per fraction was between 6 and 12 min (plus time for patient positioning), approximately 300 MU per 2 Gy were applied. The dose outside the treated volume was increased with regard to open fields and comparable with a physical wedge of 15–30°. Quality assurance and treatment of patient were fast and simple. It was shown, that calculated dose distribution corresponded to measured dose distribution with high accuracy.

**Conclusion:** The described method offers facilities for a good dose coverage of irregular target volumes with different prescribed doses and a considerable dose reduction in adjacent organs at risk. The dose sparing of organs at risk can be further improved, if a compensator material with higher density is used.

**Key Words:** Intensity-modulated radiotherapy · Compensators · Dose coverage · Quality assurance · Treatment delivery time

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**IMRT mit Kompensatoren für Kopf-Hals-Tumoren. Bestrahlungstechnik, dosimetrische Genauigkeit und praktische Erfahrungen**

**Hintergrund und Ziel:** Mit der dreidimensionalen konformalen intensitätsmodulierten Strahlentherapie (3D-c-IMRT) kann eine heterogene Dosisverteilung sowohl im Planungszielvolumen als auch in benachbartem Normalgewebe und zu schonenden Organen erreicht werden. Die 3D-c-IMRT erfordert modifizierte Photonenfluenzprofile, die mit verschiedenen Technologien zustande gebracht werden. Diese Arbeit befasst sich mit der Erprobung der Metallkompensatoren und den ersten Erfahrungen in der klinischen Anwendung. Dosimetrische Genauigkeit, Dosiserfassung und praktische Erfahrungen wie Bestrahlungszeit, Monitoreinheiten und Dosis außerhalb des bestrahlten Volumens werden beurteilt.

**Patienten und Methodik:** Von Januar 2002 bis April 2004 wurden 24 Patienten mit einem HNO-Tumor mit der 3D-c-IMRT-Technik mit Zinn-Wachs-Kompensatoren behandelt. Die Dosisverordnung schloss einen gleichzeitigen integrierten Boost ein. Das Hochdosisvolumen wurde mit 60–70 Gy (median 66 Gy), das Niedrigdosisvolumen mit 48–54 Gy (median 52 Gy) mit einer koplanaren standardisierten Sieben-Felder-Technik behandelt. Die Zieldosis an einer Glandula parotidea betrug 26 Gy. Die verwendeten Kompensatoren bestanden aus Zinngranulat, eingebettet in Wachs; zudem wurden Neuberechnungen mit Kompensatoren aus einer MCP96-Legierung durchgeführt.

**Ergebnisse:** Für 21 von 24 Patienten reduzierte die 3D-c-IMRT mit Zinn-Wachs-Kompensatoren die Mediandosis für eine Glandula parotidea auf < 30 Gy. Eine Neuberechnung mit Kompensatoren höherer Dichte, die eine höhere Schwächung ermöglichen, ergab eine bessere Schonung der Glandula parotidea. Die Behandlungszeit pro Fraktion betrug 6–12 min (zuzüglich Patientenlagerung); etwa 300 MU wurden für 2 Gy appliziert. Die Dosis des Patienten außerhalb des bestrahlten Volumens war gegenüber offenen

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Feldern erhöht und vergleichbar mit einem physikalischen Keil von 15–30°. Qualitätssicherung und Patientenbestrahlung waren einfach und schnell. Es wurde gezeigt, dass berechnete und gemessene Dosisverteilung mit sehr hoher Genauigkeit übereinstimmten.

**Schlussfolgerung:** Die beschriebene Methode ermöglicht eine gute Dosiserfassung irregulärer Zielvolumina mit unterschiedlicher verordneter Dosis und eine beträchtliche Dosisreduktion in angrenzenden Risikoorganen. Die Dosisschonung der Risikoorgane kann weiter verbessert werden, wenn ein Kompensatormaterial mit höherer Dichte verwendet wird.

**Schlüsselwörter:** Intensitätsmodulierte Strahlentherapie · Kompensatoren · Dosiserfassung · Qualitätssicherung · Bestrahlungszeit

## Introduction

Since their introduction, modulators have been mostly used to generate a uniform dose distribution on a specified plane inside of the patient. For calculation of the compensator design missing tissue or internal tissue inhomogeneities have been taken into account [7, 12, 21]. By contrast, for three-dimensional conformal intensity-modulated radiotherapy (3D-c-IMRT) a compensator is used as a beam intensity modifier to achieve the photon fluence distribution generated by the inverse planning procedure [6, 15, 20].

The use of modulators allows for safe and easy-to-handle high-quality IMRT. It was shown, that calculation of dose distribution can be realized very exactly [23, 29]. Furthermore, the spatial resolution can be chosen very high and a sufficient quality assurance management can be realized fast and simple. A detailed overview is given in [5].

From January 2002 to April 2004, 24 patients with head-and-neck cancers were irradiated with the use of compensators. 23 of them had been irradiated with a “simultaneously integrated boost” (SIB).

This article describes the used compensator technologies including the dosimetric accuracy, the results of the quality assurance measurements, and the practical experiences gained. In addition, the dose distributions achieved will be analyzed.

## Patients and Methods

### Treatment Planning

For the treatment planning procedure and dose calculation the three-dimensional treatment planning system Helax®-TMS (Nucletron B.V., Veenendaal, The Netherlands), a modulation-matrix software tool Modifix® (Bebig Isotopen- und Medizintechnik, Berlin, Germany) and, since 2004, the IMRT application KonRad® (Siemens OCS, Heidelberg, Germany) were used.

First, planning treatment volumes as well as organs to be spared are defined in contiguous axial computed tomography slices of the volume of interest in Helax®-TMS. The following total dose prescriptions were made: high-dose planning target volume (PTV): 60–70 Gy (median 66 Gy), low-dose PTV: 48–54 Gy (median 52 Gy), median dose at one parotid gland: 26 Gy.

Second, the isocenter as well as the field arrangement and geometry are defined. Planning was performed using the inverse treatment planning module of Helax®-TMS. Helax generates dose profiles which steer the milling machine [1, 2, 9]. According to other publications [3], a detailed validation of the algorithm had been performed, which has been reported previously [23]. This included the use of well-defined compensators like wedges, stripes, and special steps.

For the treatment planning of 3D-c-IMRT the inverse treatment planning module of Helax®-TMS was felt suboptimal. Both speed and results of the automated optimization process did not completely meet clinical demands. Additional manual optimization steps carried out by an experienced physicist resulted in improved dose distribution.

From April 2004 on, the inverse planning tool of Helax®-TMS was replaced by the commercially available stand-alone IMRT application program KonRad®. Using the calculated fluence profiles, depth profiles of the compensator and dose distribution were furthermore calculated with Helax®-TMS. A typical treatment plan is shown in Figure 1.

### Compensator Set-up and Manufacturing

The use of compensators in clinical routine has to allow for accurate dose delivery and sufficient quality assurance management. Extra time needed for treatment planning and manufacturing should be acceptable.

The compensators consist of tin granules embedded in wax. Tin granulate is recommended for compensators, because it is easy to handle, recycable and homogeneous.

After completing the treatment planning, the thickness value matrix is entered into the programmable milling machine AUTIMO 3D® (Bebig Isotopen- und Medizintechnik). This system cuts the shape of the compensation filter into a styrofoam block. The matrix pixel size (3 mm in source-compensator distance) and divergence of the beam have been taken into account. A typical compensator profile is shown in Figure 2. The maximum thickness of a compensator amounts to 40 mm.

### Pretreatment Quality Assurance

The pretreatment quality assurance encompassed the planning system, the accuracy of the compensator manufacturing including the characteristics of the compensator material, and the accuracy of the quality assurance methods used.

The checks of the milling process were carried out manually and included accuracy of the depth, position of the central axis, and the divergence. Additional checks of some important characteristics of the absorbent material like homogeneity had been done with a number of plane compensators. For these measurements phosphorizing screens (AGFA digital storing system) and films (Kodak X-omat® and EDR2®) had been used.

For dosimetric quality assurance, line doses in water (ionization chambers, PTW Freiburg, Germany) and two-dimensional dose distributions (film Kodak X-omat® and EDR2®, Kodak and Array seven29®, PTW Freiburg) are measured [28]. The analysis of two-dimensional distributions was realized with an in-house developed software [31].

The checks of the planning system were performed with even and extremely shaped compensators. In addition, some final checks with "typical clinical" compensators had been performed. Finally, for an anthropomorphic phantom a complete treatment plan was calculated and dose distribution achieved was compared with that measured with ionization chambers and thermoluminescent rods calibrated specifically for compensators.

### Quality Assurance in Routine

For compensators used for clinical treatments, the dosimetric quality assurance program had been simplified depending on the available technical equipment and increased experiences. At the beginning, we checked line dose distributions of each compensator field. These measurements had been replaced by at least two point dose measurements per field with ionization chambers in a flat phantom. The implementation of the software Verisoft@ (PTW Freiburg) allowed for analysis of film measurements and dosimetric quality assurance with high spatial resolution.

After getting confidence in the accuracy and reproducibility of different steps described above, for routine use of compensators the quality assurance program comprises:

(1) manual check of depth and position during manufacturing a compensator;
(2) an X-ray picture (6 MV) with film, later with a phosphorizing plate to assure that a compensator is not erroneously used with a wrong field;
(3) one point dose measurement in the high-dose region on a three-dimensional phantom after recalculation. This phantom is rebuilt similar to a phantom reported by Rhein et al. [22].

### Treatment Delivery

The treatments were performed with an accelerator Mevatron KD2 (Siemens Medical Systems) without multileaf collimator. The compensators are positioned on a tray with a code to identify the compensator. This tray code is verified by the therapy verification system LANTIS® (Siemens Medical Systems).

Additionally, the treatment delivery time per fraction (without patient positioning) was analyzed retrospectively.

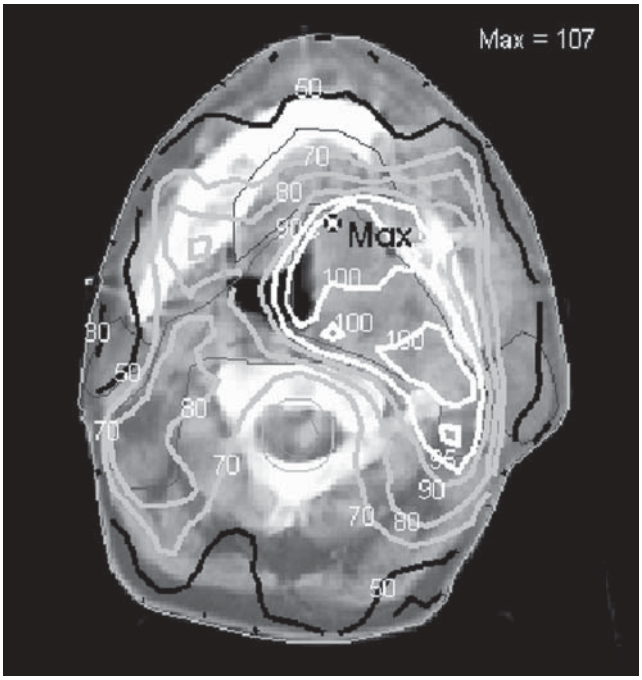

**Figure 1.** Dose distribution of a cancer of tonsils. The prescribed doses are 66 Gy (= 100%, high-dose planning target volume) and 52.8 Gy (low-dose planning target volume). The 95% isodose line circumscribes the planning target volume; the maximum dose of the spinal cord is approximately 40 Gy.

**Abbildung 1.** Dosisverteilung eines Tonsillenkarzinoms. Die verschriebene Dosis beträgt 66 Gy (= 100%, Hochdosis-Planungszielvolumen) und 52,8 Gy (Niedrigdosis-Planungszielvolumen) Die 95%-Isodosislinie umschreibt das Planungszielvolumen; die Maximaldosis des Rückenmarks beträgt ca. 40 Gy.

**Figure 2.** Milled compensator profile. The added holes mark the laser position.

**Abbildung 2.** Gefrästes Kompensatorprofil. Die zusätzlichen Bohrungen markieren die Position des Lasers.

The treatment delivery time is the time elapsed from the beginning of the first field irradiation to the end of the last field irradiation. We analyzed the mean value of fraction 6, 12, and 18 of every patient irradiated in the Lantis® treatment record & verify system (Siemens Medical Systems).

### Patient Accrual

In a pilot phase selected patients with advanced squamous cell cancer of the head and neck (bilateral PTV, curative intention, PTV extension to the base of scull) were irradiated using the 3D-c-IMRT performed with compensators. Quantitative analysis of PTVs was made using dose-volume histograms (DVHs).

**Table 1.** Details and results of the treatment planning of 24 patients with head-and-neck cancer irradiated with tin compensators. PTV: planning target volume.

**Tabelle 1.** Details und Ergebnisse der Bestrahlungsplanung von 24 Patienten mit Kopf-Hals-Tumor, behandelt mit Zinnkompensatoren. PTV: Planungszielvolumen.

| | |
|---|---|
| **Dose prescription** | |
| Patients (n) | 24 |
| Patients with "integrated boost" (n) | 24 |
| Prescribed dose in high-dose PTV | 60–70 Gy, median 66 Gy |
| Dose per fraction in high-dose PTV | 1.8–2.5, mostly (n = 21) 2.0 |
| Prescribed dose in low-dose PTV | 48–54 Gy, median 52 Gy |
| **Treatment technique** | |
| Number of fields (without field for lower neck) | Mostly 7 |
| Separate field for lower neck | 12 |
| **Dose distribution** | |
| Coverage high-dose PTV ($D_{95}$, $D_{90}$) | Median 88%/96% |
| Coverage low-dose PTV ($D_{95}$, $D_{90}$) | Median 90%/96% |
| Dose parotid gland (contralateral) | Median 26.2 Gy<br>1 patient 46.8 Gy (high-dose volumes next to both glands)<br>2 patients > 30 Gy and < 32 Gy<br>21 patients < 30 Gy |
| Dose maximum spinal cord (including margin 5 mm) | 35.5–43.5 Gy, median 39.8 Gy |
| Monitor units per 2 Gy (separate fields for lower neck not included) | 263–326 MU |

**Table 2.** First results of the treatment planning with KonRad® and MCP96 compensators compared with tin compensators. Seven patients were recalculated.

**Tabelle 2.** Erste Ergebnisse der Bestrahlungsplanung mit KonRad® und MCP96-Kompensatoren, verglichen mit Zinnkompensatoren. Sieben Patienten wurden nochmalig berechnet.

| | Compensator (tin granules + wax) | Compensator (MCP96) |
|---|---|---|
| IM range (photons 6 MV) | 45–100% | 16–100% |
| Inverse planning | Helax®-TMS | KonRad® |
| Manual changes of fluence profile after inverse planning | Yes | No |
| Coverage high-dose PTV ($D_{95}$, $D_{90}$) | Median 87%/96% | Median 93%/99% |
| Coverage low-dose PTV ($D_{95}$, $D_{90}$) | Median 88%/96% | Median 89%/96% |
| Dose contralateral parotid gland | Median 26.3 Gy | Median 23.8 Gy |
| Monitor units per 2 Gy (separate fields for lower neck not included) | 263–314 | 343–436 |
| Additional block shielding | Yes (recommended) | No |

## Results

### Treatment Planning

Table 1 shows details and the results of the treatment planning procedure for 24 patients treated with tin-wax compensators.

In April 2004 compensators made of the low melting alloy MCP96 which allow higher attenuation (up to 84%) were introduced in the department. Retrospectively, the treatment plans of seven randomly selected patients treated with tin-wax compensators were recalculated using MCP96. As shown in Table 2, coverage of PTVs and dose sparing of organs at risk can be improved with this material.

Figure 3 shows the DVHs obtained by either tin-wax or MCP96 compensators for a patient with cancer of the nasopharynx. The doses prescribed are: PTV1: 66 Gy, PTV2: 52.8 Gy. Curves of PTV2 end at 66 Gy. This is due to the policy of designing the PTVs: PTV1 is encompassed by PTV2; tail of the curve of PTV2 represents voxels lying next to PTV1. Tail of the curve of PTV2 does not exceed 66 Gy, which means hot spots are lying all within the boundaries of high-dose volume.

Due to manual changes of the calculated fluence maps mandatory to achieve acceptable dose distribution with Helax®-TMS alone, treatment planning took 4–8 h. After implementation of KonRad®, time for treatment planning process was shortened to 1–2 h.

### Quality Assurance

As shown, compensators consisting of tin granules embedded in wax have a sufficient homogeneity and allow for reproducible results (see [24]). So, for example, all compensators of a set of 16 compensators with a homogeneous fluence distribution revealed a deviation of central axis dose of ≤ 1.5%. Similar measurements had been carried out with the low melting alloy MCP96 as well. The measurements of line doses in water as well as two-dimensional measurements with film and phosphorizing plates show a high homogeneity for compensators with different depths. There are no dose deviations due to inhomogeneities exceeding 2% of the target dose.

The checks of the milling process reveal that the shape of the compensators profile can be manufactured with an accuracy of depth of 0.5 mm. In any case, the accuracy of the position relative to the central axis is 1 mm or better at the isocenter.

Before clinical use of compensators, the dose calculation algorithm with a validation instruction and additional fluence profiles was checked. We compared monitor units and dose distribution for flat and for extremely formed compensators. Figure 4 shows a comparison of an "extreme" compensator with high dose gradients. The dose deviation is < 4% (related to local dose) even in this case. The further compensator measurements (wedge-like, "clinical") confirm this result.

Finally, we carried out a final check with an anthropomorphic phantom. This included treatment planning, compensator manufacturing, quality assurance, and irradiation of the phantom. Inside of the phantom thermoluminescent rods had been placed and analyzed. The results of the measurements with 21 thermoluminescent rods and MCP96 compensators are shown in Figure 5. Because of the results of the pretreatment quality assurance we decided to use compensator for clinical irradiation.

The dosimetric quality assurance in clinical routine was carried out with line dose measurements, later with radiographic films in a flat phantom. It can be summarized, that deviations amount to ≤ 3% in the high-dose region, except for dose gradients. The deviations are found to be larger (up to 6%) for small areas (< 2 cm × 2 cm) with a much higher or lower fluence.

### Treatment Delivery

Treatment delivery with compensators is comparable to irradiations with blocks or physical wedges. For small target volumes it is possible that one compensator contains the fluence profiles of two asymmetric fields, so the treatment room must be entered after two consecutive portals have been irradiated. Such "two-field compensators" were used in eleven patients. Irradiations with compensators take between 6 and 12 min per fraction (median 9 min; time for patient positioning not included).

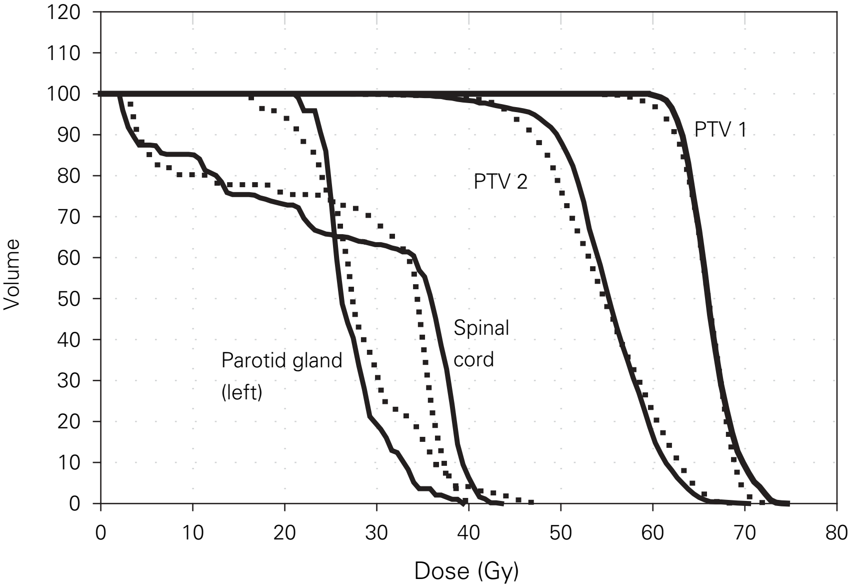

**Figure 3.** Dose-volume histogram of a patient with nasopharyngeal carcinoma, planned with tin granulate compensators (dotted line) and MCP compensators (solid line). Both materials allow a sufficient dose distribution, but with MCP96 the coverage of the planning target volume and the dose sparing of the left parotid gland can be improved.

**Abbildung 3.** Dosis-Volumen-Histogramm eines Patienten mit Nasopharynxkarzinom, geplant mit Zinngranulatkompensatoren (gepunktete Linie) und MCP96-Kompensatoren (durchgezogene Linie). Beide Materialien ermöglichen eine hinreichende Dosisverteilung, aber mit MCP96 können die Erfassung des Planungszielvolumens und die Dosisschonung der linken Glandula parotidea verbessert werden.

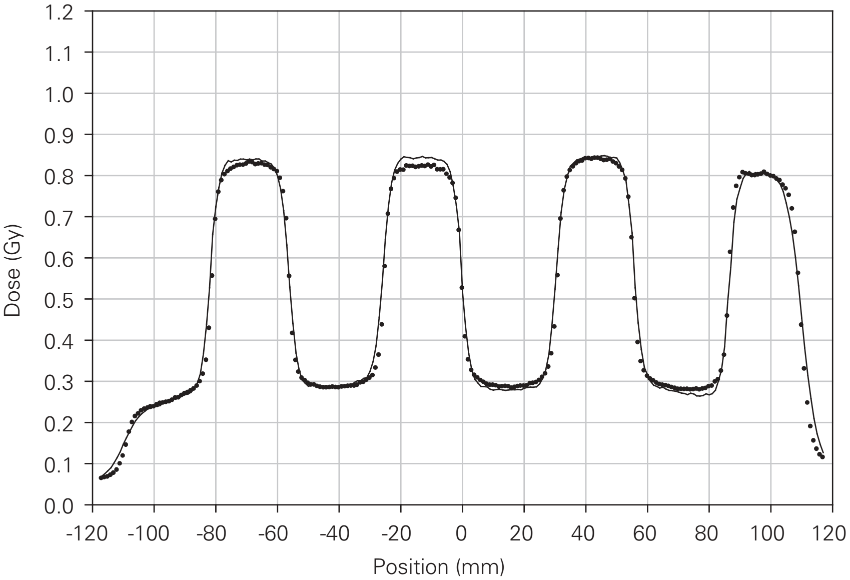

**Figure 4.** Comparison of measured (line) and calculated (small circles) line doses with MCP96 compensators in water. The following parameters were used: field size 22 cm × 22 cm, energy 6 MeV, source-surface distance 90 cm.

**Abbildung 4.** Vergleich zwischen gemessener (Linie) und berechneter (kleine Kreise) Liniendosis mit MCP96-Kompensatoren in Wasser. Folgende Parameter wurden verwendet: Feldgröße 22 cm × 22 cm, Energie 6 MeV, Quelle-Oberflächen-Abstand 90 cm.

A point which should not be ignored is the dose outside the target volume. That is why we measured the line dose in water and in air beginning from the isocenter toward far outside the fields. The results in Figure 6 show, that compensators increase the dose outside the field. This amounts to a factor between 2 and 3, depending on the depth and the material of the compensator.

The additional dosage corresponds to the monitor units: with tin-wax compensators we calculated between 263 and 326 MU per 2 Gy; with compensators consisting of MCP96 between 343 and 436 MU are needed (see Table 2).

### Discussion

According to other methods of 3D-c-IMRT (overview [28], clinical and biological examples [8, 11, 26]), with compensators a prescribed dose distribution can be achieved in both irregular PTVs and in adjacent normal tissues and organs to be spared. A more detailed comparison between 3D-c-IMRT with compensators and with segmental multileaf collimator IMRT technologies is presented in [4] and [5].

### Treatment Planning

As shown in Table 1 for 24 patients treated with tin-wax compensators, 90% of the PTVs was encompassed by the 95% isodose. In 21 of 24 patients 3D-c-IMRT with tin-wax compensators reduced the median dose to one parotid gland to < 30 Gy.

Our aim is, that the PTV is irradiated with a dose of 95–107% of the prescribed dose. A detailed analysis showed that underdosage of high-dose volumes mainly occurs in the built-up region underneath the skin and to a lesser extent at their borders to the surrounding low-dose volume. With increased experiences and the use of the MCP96 for compensators, the dose coverage of the PTV is improved. However, cold or hot spots are not accepted, if they are of a larger value.

Using the inverse treatment tool of Helax®-TMS including manual improvements of the fluence profiles, the procedure was very time-consuming, but the obtained dose distribution resulted both in a better dose coverage of the target volumes and better dose sparing of one parotid gland in comparison with non-IMRT treatment plans. Since the implementation of a tool especially for inverse treatment planning in 2004 (KonRad®), high-quality dose distributions have been achieved without manual changes of the fluence profiles. The time for treatment planning was diminished and is approximately between 1 and 2 h.

### Compensator Set-up and Manufacturing

For compensators, different materials have been suggested and used. Most important are lead [14, 32], a mixture of lead and polyethylene [16], cerrobend [10, 17], steel granulate [27], tin granulate [4, 5], tin granulate and wax [24, 25], and light polymers [13]. A detailed overview about different materials and methods is reported in [5].

Tin granulate was used, because it is easy to handle, recyclable and homogeneous. The alloy MCP96 has a higher density (rho = 9.8 g/ml) and finished the "tin-wax era". Both materials can be recommended for compensator fabrication, the spatial resolutions of 7 mm (tin-wax, source-compensator-distance = 41.3 cm) and 5 mm (MCP96, source-compensator-distance = 56.5 cm) are sufficient for IMRT. Because of the wider IM range (16–100%), the use of MCP96 allows for a better dose conformation and dose sparing of organs at risk.

For the manufacturing and quality assurance of the compensators, approximately 4 h per patient are required. Additional time is needed for automatic milling process and the cooling of the filled mold.

In the study by Meyer et al. [19], some limitations are reported because of a maximum slope of the machining process and the use of spherical cutter. These effects depend on the machine used. They can be neglected, if beam divergence is taken into account and

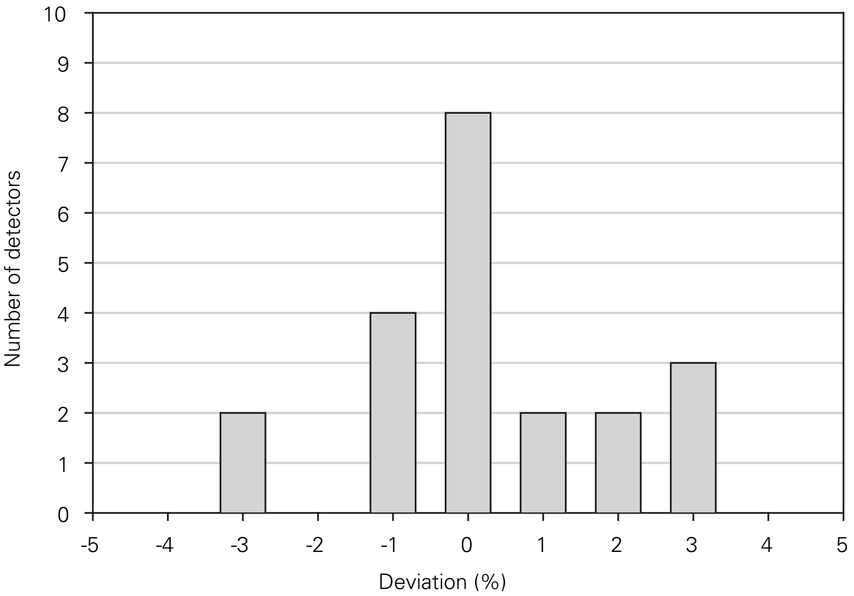

**Figure 5.** Deviations between measured and calculated point doses on 21 points in the high-dose region of a head-and-neck treatment plan, irradiated on a phantom. The dose measurements had been carried out with thermoluminescent detectors (95% confidence interval: 1.0%).

**Abbildung 5.** Abweichungen zwischen gemessenen und berechneten Punktdosiswerten an 21 Punkten in der Hochdosisregion eines Kopf-Hals-Bestrahlungsplans, bestrahlt an einem Phantom. Die Dosismessungen wurden mit Thermolumineszenzdetektoren (95%-Vertrauensintervall: 1,0%) durchgeführt.

interpolations between two adjacent pixel positions are avoided.

### Quality Assurance in Routine

Because of the static nature of compensators, the quality assurance program with compensators is easy to realize, for instance with X-ray pictures with only few monitor units, measurements of line dose in water and the analysis of the depth profile during compensator manufacturing.

It has been shown that the quality assurance program could be simplified with increasing experience without compromising the results. So, the dosimetric quality assurance takes between 30 and 60 min per patient.

For dose measurements, the energy dependence of the sensitivity of the detector material, especially for MCP96 compensators, can change. So for extreme cases is was measured, that the deviation of film X-omat® and EDR2® is approximately 5% between small (3–4 mm) and large (30–35 mm) compensator thicknesses of MCP96. Furthermore, the use of thermoluminescent rods should implement a calibration with compensators as well. According to that it can be concluded, that low-energy photons are preferentially absorbed by the compensator. Because of a fast but safe quality assurance management system, it is recommended to prefer methods based on more energy-independent detectors (ionization chambers, special two-dimensional arrays, film Gafchromic EBT® [ISP]) or to take nonlinear fluence dependence of detectors into account [18, 30].

### Treatment Delivery

With compensators, the treatment procedure is similar to the use of physical wedges or blocks, so that this method is well accepted in clinical routine. The use of "two-field compensators" simplifies the procedure. "Multiportal compensator systems" [21, 33] can reduce the fractional treatment delivery time as well. Hence it can be concluded, that the treatment delivery does not take more time in comparison with non-IMRT procedure.

The irradiated monitor units amount to approximately 300 MU (263–326 MU, see Table 1) for tin-wax compensators and about 400 MU (343–436 MU, see Table 2) for MCP96 compensators. Compared with open fields the dose outside the target volume is increased and comparable with a physical wedge of 15–30° (see Figure 6), which seems acceptable for patient treatments.

### Conclusion

After growing experience we state compensators allow for 3D-c-IMRT of high quality without multileaf collimator. The irradiation is safe and easy to perform. Total treatment delivery time needed for one fraction is comparable with conformal field treatments without compensators. The verification measurements show, that dose calculation and compensator manufacturing work safe and accurate.

The quality assurance program is easy to realize because of static fluence distribution with compensators and the possibility of checking the depth profiles during manufacturing. For the dose measurements at present between 30 and 60 min are needed. We expect this time will diminish with further experience.

For 24 patients with head-and-neck cancer treated with compensators consisting of tin granulate embedded in wax, 90% of the PTVs were encompassed by the 95% isodose. In 21 of 24 patients 3D-c-IMRT with tin-wax compensators reduced the median dose to one parotid gland to < 30 Gy.

With low-density material like tin granulate and wax, the dose sparing of organs at risk for extreme cases can be limited. After switching to MCP96, better coverage of target volumes and improved sparing of the parotid gland are accomplished.

At present, the compensator technology is not only used for IMRT in the head-and-neck region, but also for cancers of

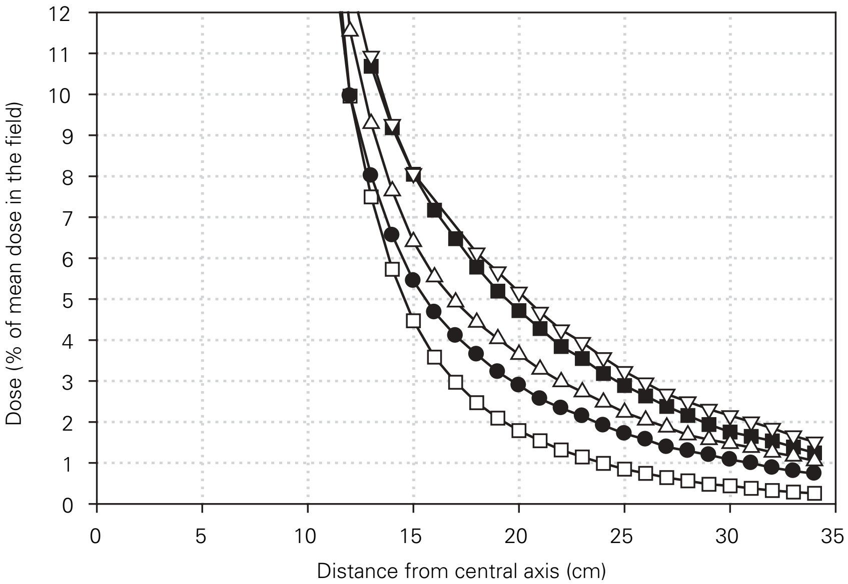

**Figure 6.** Measurements of the dose outside the field in water. The field size is 20 cm × 20 cm. The mean dose inside the fields amounts to 100%. Open field (open squares), physical wedge 30° (open triangles up), physical wedge 45° (open triangles down), clinically used tin compensator (filled circles), and MCP96 compensator with maximum depth of 4 cm (filled squares) are compared.

**Abbildung 6.** Messungen der Dosis außerhalb des Feldes in Wasser. Die Feldgröße beträgt 20 cm × 20 cm. Die mittlere Dosis innerhalb der Felder beträgt 100%. Verglichen werden offenes Feld (offene Quadrate), fester 30°-Keil (offene Dreiecke, Spitze nach oben), fester 45°-Keil (offene Dreiecke, Spitze nach unten), klinisch eingesetzter Zinnkompensator (gefüllte Kreise) und MCP96-Kompensator mit der Maximaltiefe von 4 cm (gefüllte Quadrate).

the anal region (including inguinal lymph nodes) and prostate. The technology is now matured for treatment of a larger number of patients simultaneously.

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