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Schnelle und genaue IMRT

DGMP AK IMRT
Würzburg, 26./27.März 2009

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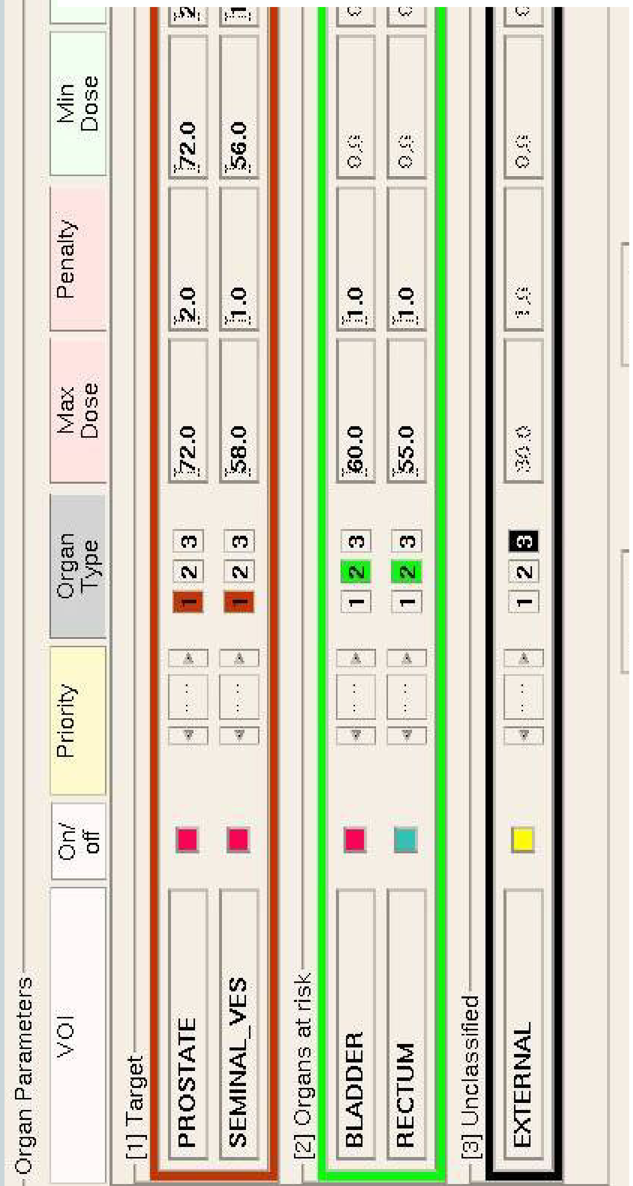
Agenda

1. InversePlanning / KonRad
2. DAO and DMPO
3. IM-Confident
4. IM-RealART
5. 160 MLC
6. Diskussion

Agenda



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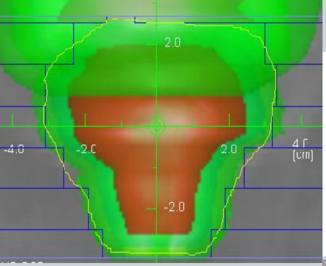
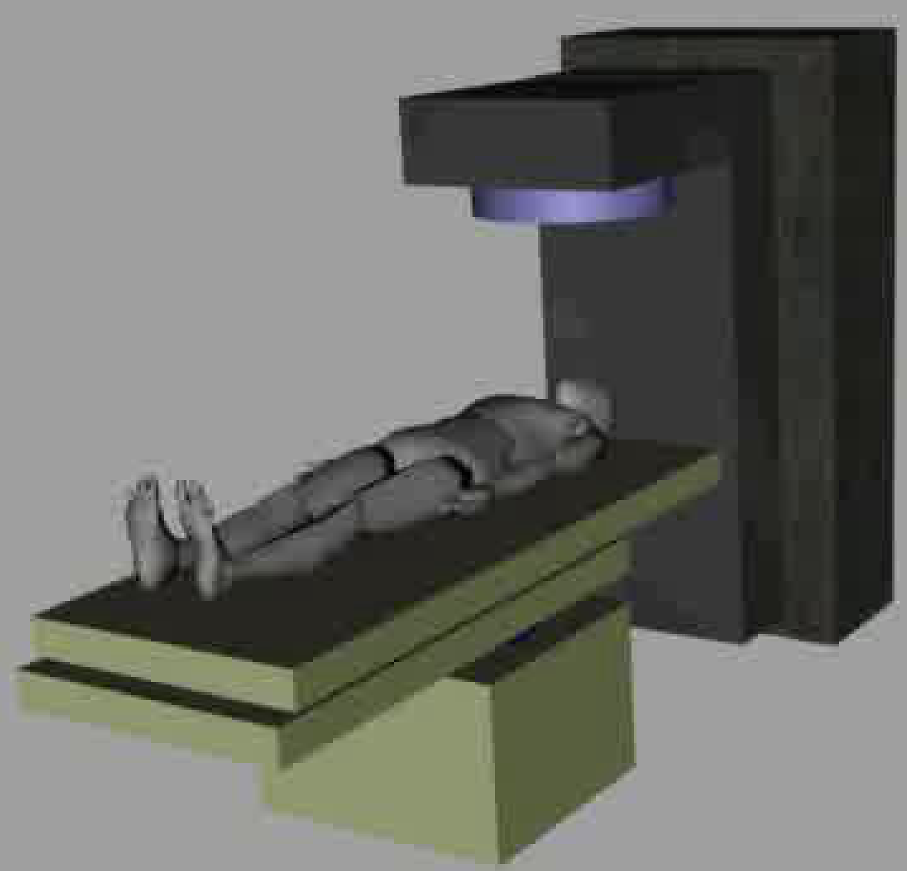
4. **IM-RealART**
5. **160 MLC**
6. **Diskussion**



IMRT



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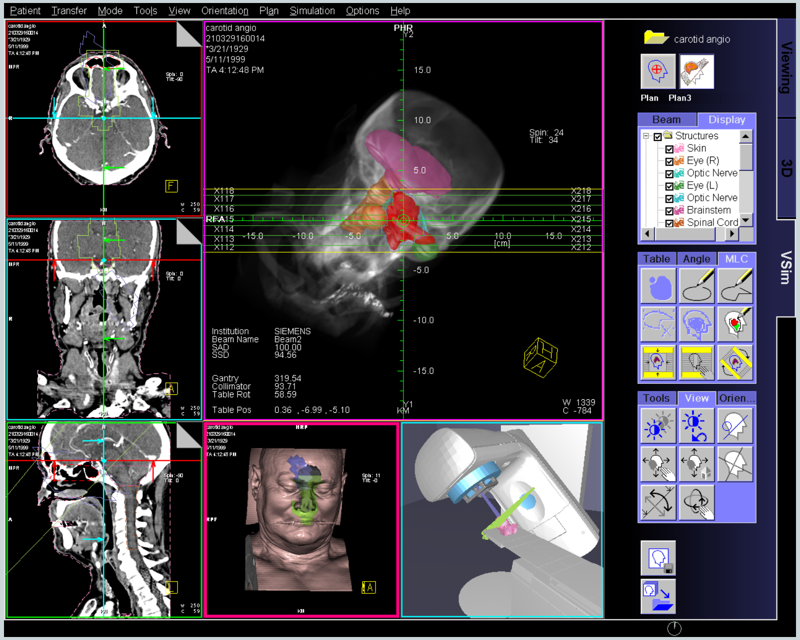
Inverse Planning / KonRad

Bildgebung / Konturierung



Oncologist

3rd Party system

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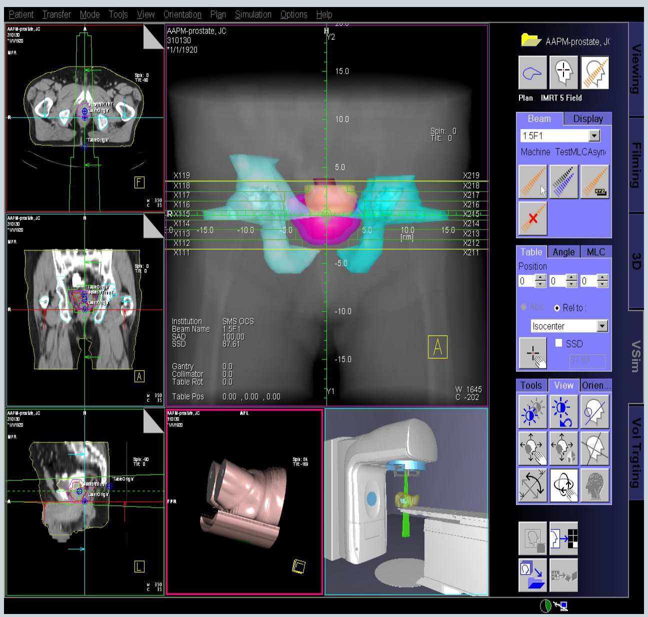
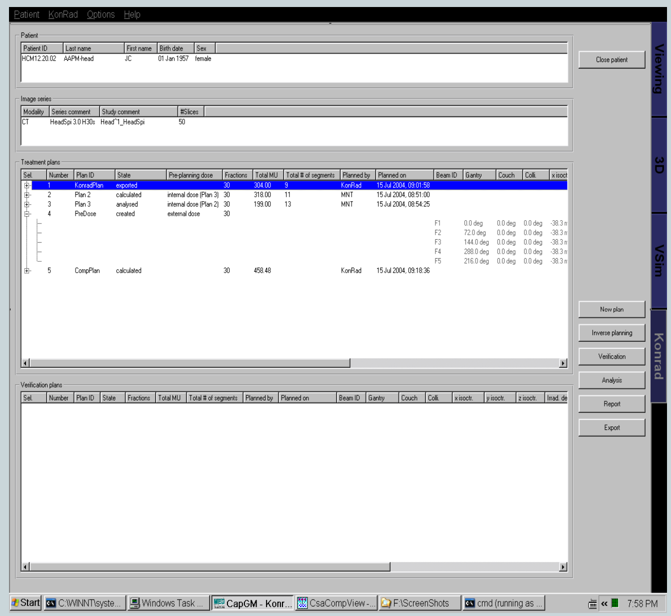
Inverse Planning / KonRad

Geometric Field Setup



Dosimetrist/VSim



Inv.Planning/KonRad

3rd party system

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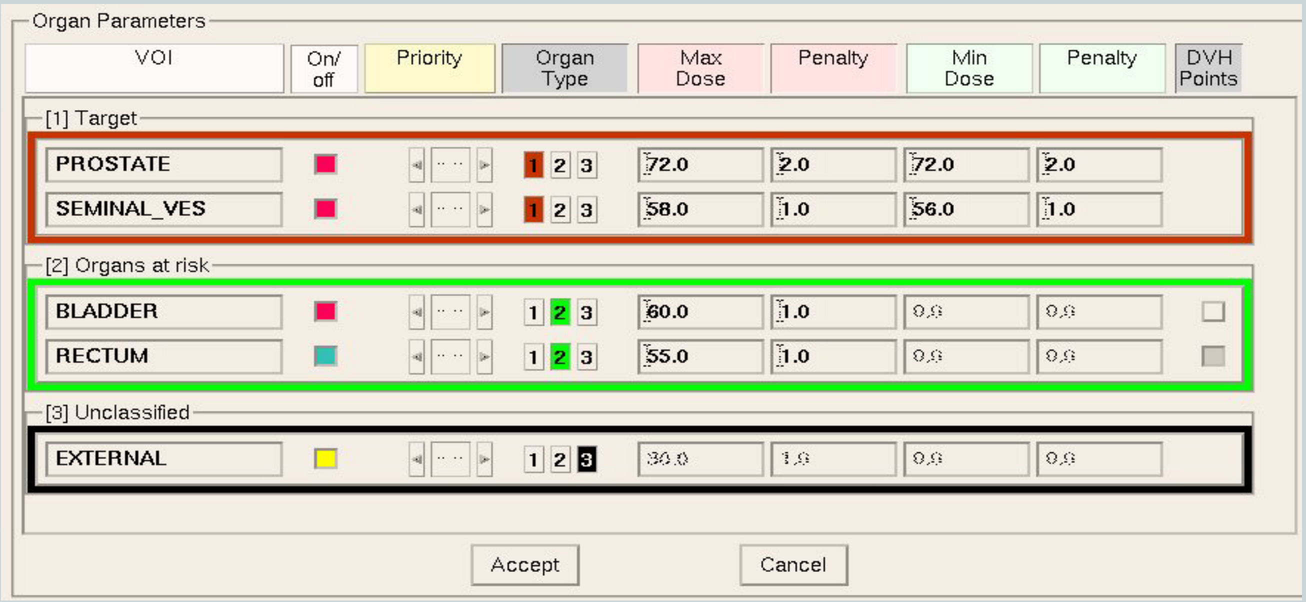
Inverse Planning / KonRad

Define Constraints and Penalties



- Full flexibility on the number of target structures and organs at risk
  Dose and dose-volume constraints
- Interactive setup of dose-volume markers in DVH
- User defined overlap priorities: Bool operators
- Constraint templates

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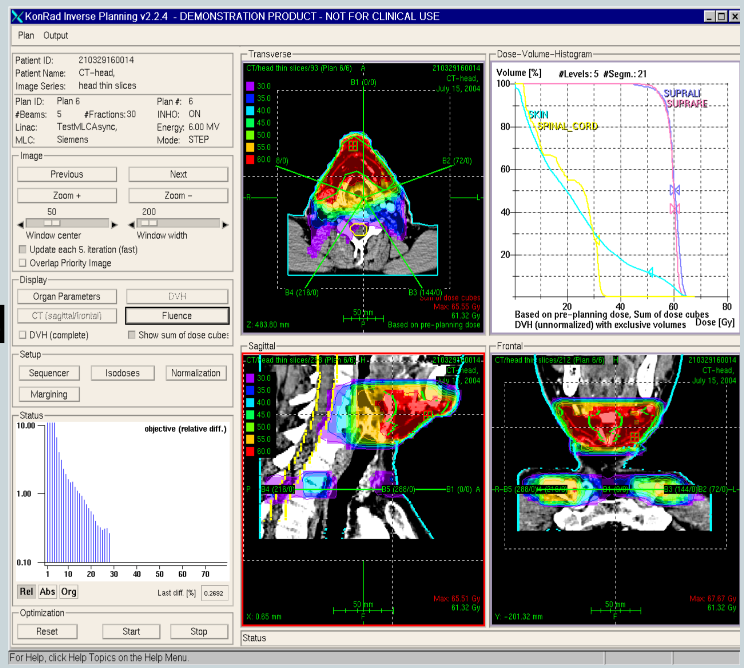
Inverse Planning / KonRad

Optimize Intensity Profiles

3D Dose Calculation

MLC Sequences

Multi Kernel dose calculation (Bortfeld et al; enhanced Pencil Beam Alg.)



Supports:

-static & dynamic delivery

- Linacs & MLC of all major vendors

- considers all MLC constraints

- filter to smooth intensity maps during optimization

DVH, Display of Dose Distribution in 3 planes, continuously updated during optimization

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Inverse Planning / KonRad

Evaluation of Dose Distribution

Clinical Acceptable?

Dose Statistics

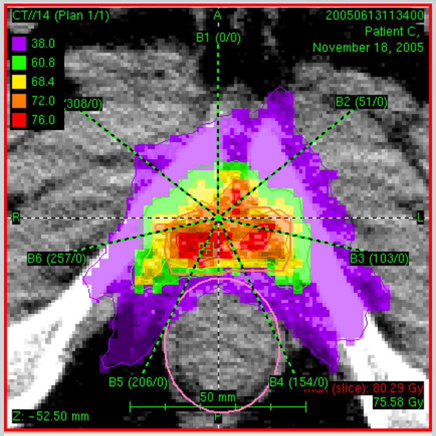
VOI	Type	Min Dose [Gy]	Mean Dose [Gy]	Max Dose [Gy]	Std Dev Dose [Gy]	Vol > Max [%] [Gy]	Vol < Min [%] [Gy]	5% Vol [Gy]	50% Vol [Gy]	95% Vol [Gy]	Volume [ccm]	#Voxel	Overlap [%]
RECTUM	O	3.14	22.38	78.99	16.47	0.64 (68.00)	--	56.43	17.83	4.67	120.25	7696	--
BLADDER	O	2.23	21.54	83.07	19.96	6.90 (60.00)	--	64.74	15.06	3.12	290.52	18593	2.32
CTV	T	54.63	74.99	86.55	4.09	80.23 (72.00)	19.77 (72.00)	80.66	75.64	67.51	96.25	6160	58.73
GTV	T	57.69	76.75	84.41	3.07	64.05 (76.00)	35.95 (76.00)	81.18	77.20	71.49	55.72	3566	1.01
SKIN *	O	0.65	13.73	86.13	14.38	4.84 (42.00)	--	41.72	6.75	1.90	3803.63	243432	11.60

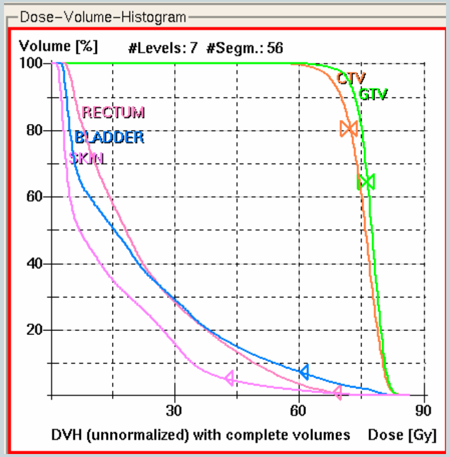
Isocenter dose 74.07 Gy

Max dose 86.55 Gy

Using complete volumes – (*) VOIs are partially hidden

Ok Print

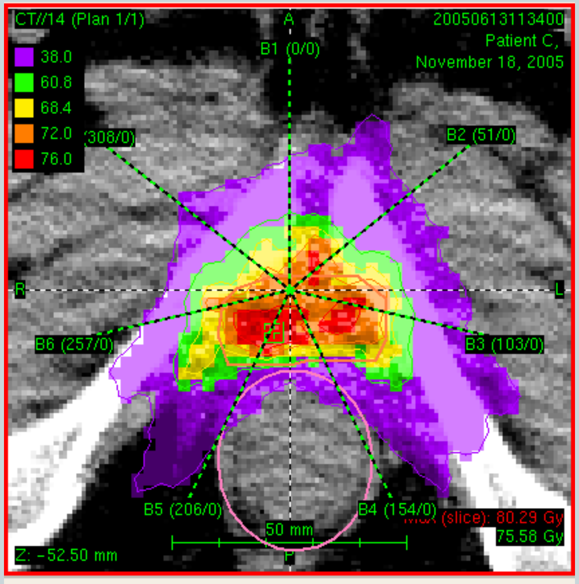


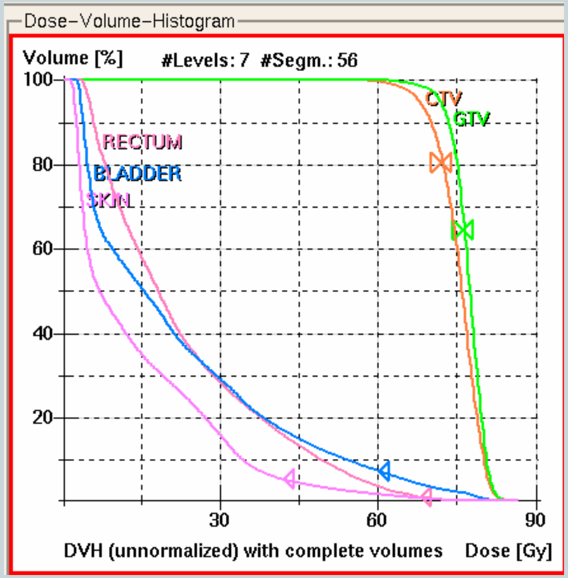


- 3D dose distibution
- Dose statistics
- DVH

Inverse Planning / KonRad

- **bewaehrt und sehr präzise**
- **schnelle Optimierung**
- **flexibel (MLCs, IMRT Techniken)**





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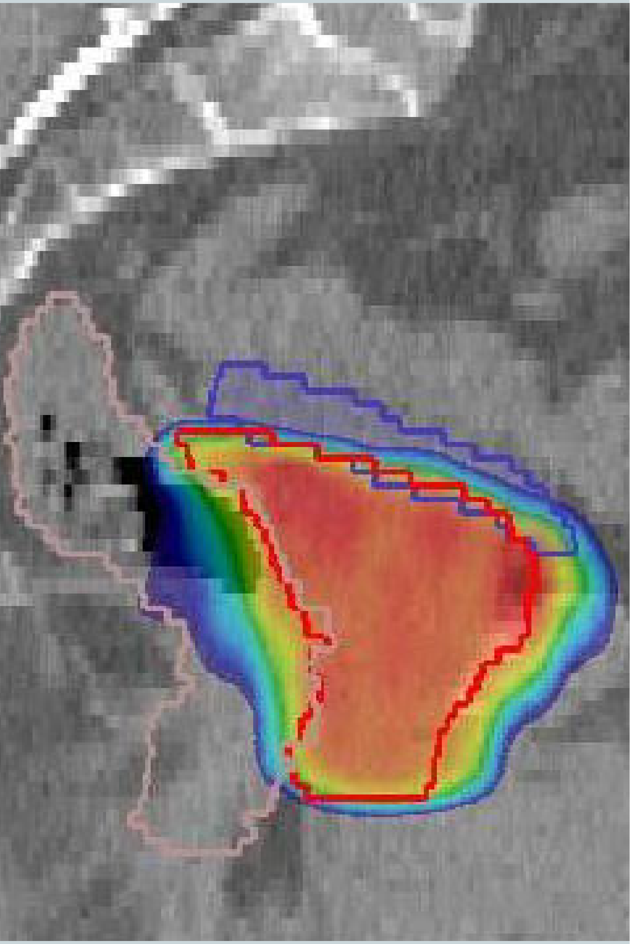
Agenda



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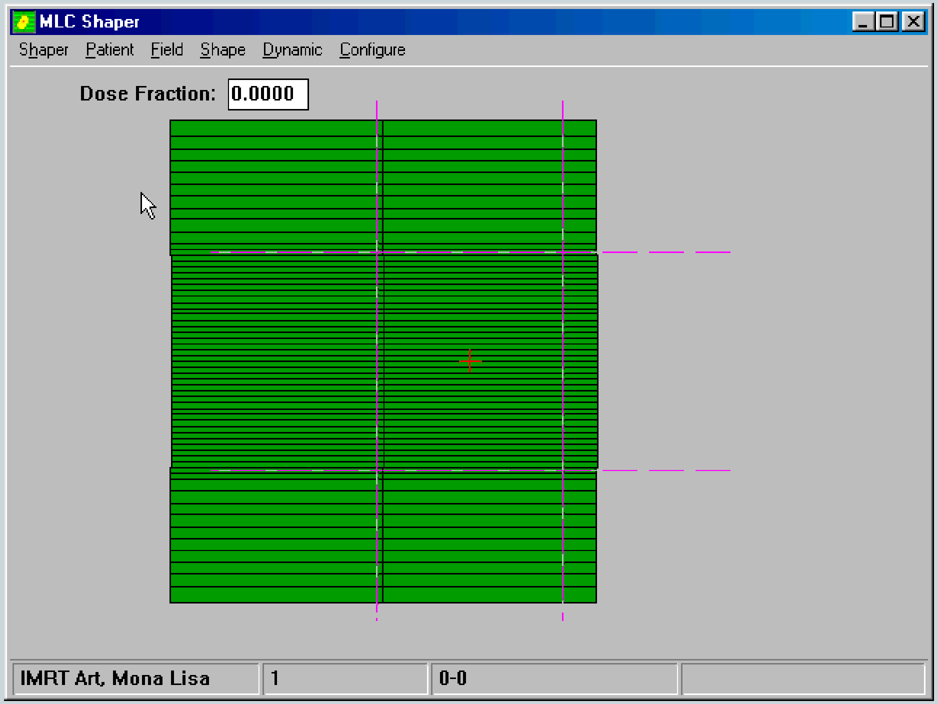
What is the possible difficulty with traditional IMRT

- It requires many segments (apertures)
- Small apertures require high leaf positioning accuracy for dosimetric accuracy.
- High amount of monitor units leads to:
  - Higher leakage
  - Higher total body dose
  - Shielding problems
- **Lesser MUs** are needed for a **static delivery**
- **Higher MU** are needed for any **dynamic delivery**



Think about dynamic as a fast sequence of very many segments…and each segment receiving certain MUs.

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Traditional IMRT

Goal: Ideal Fluence map

Deliverable fluence map with MLC

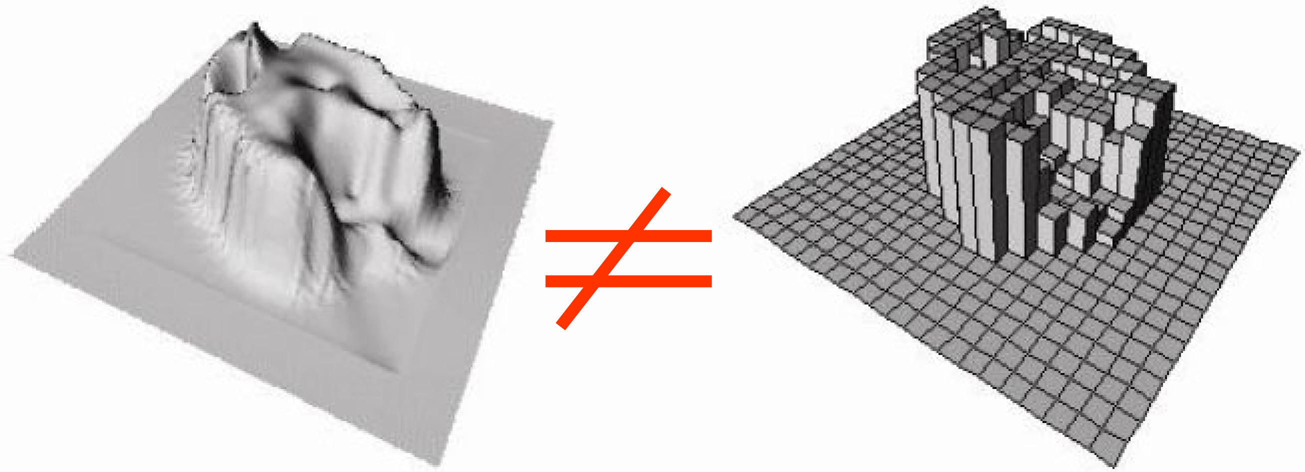

FIG 1. An ideal intensity map (left) produced by index-dose gradient optimization for a head and neck treatment with a multistructure objective. IMRT-compensator is generated from the ideal intensity map. For segmental MLC-IMRT treatment a discrete intensity map (right) is converted from the ideal map for MLC segmentation. The discrete "skyscraper" map displayed has 10 intensity levels.

JOURNAL OF APPLIED CLINICAL MEDICAL PHYSICS, VOL. 5, NO. 3, SUMMER 2004

Example of plan degradation for traditional IMRT Cinematic and Dynamic Treatment Deliveries

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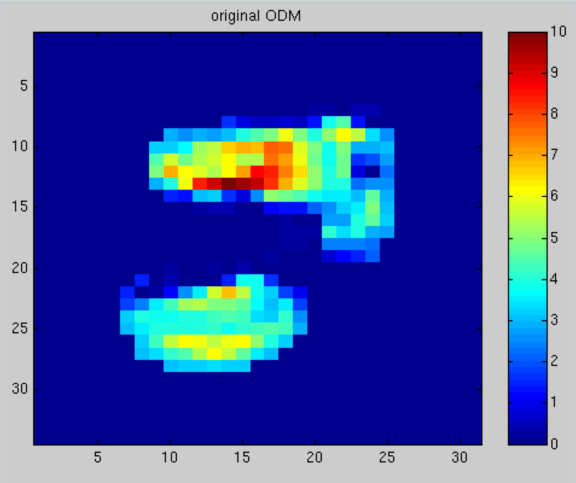
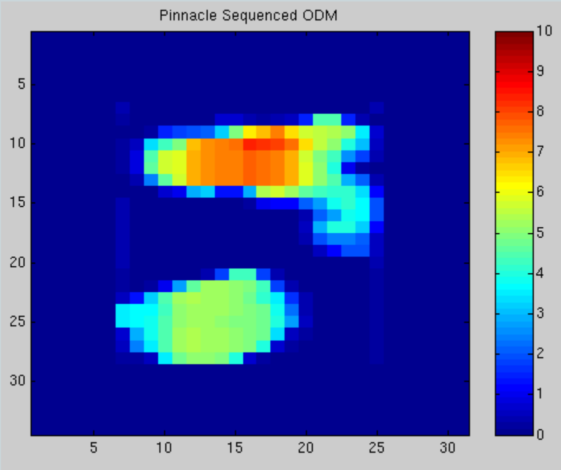


A: Optimized Intensity Map from Pinnacle



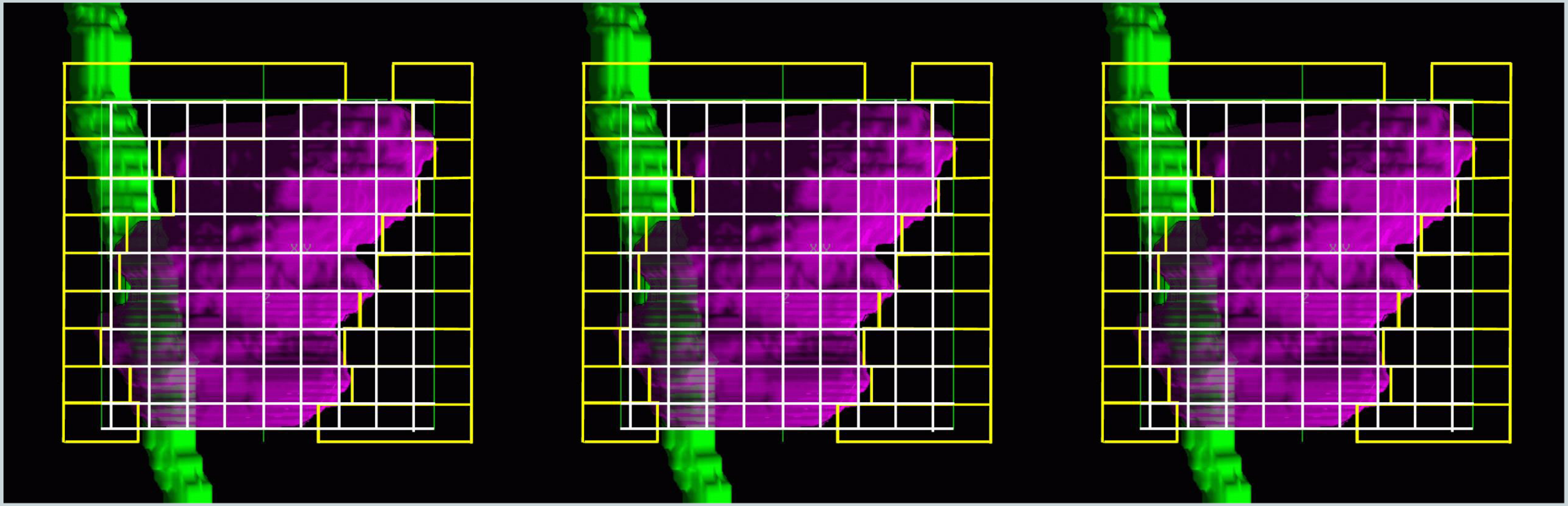
B: The Sequenced Intensity Map using Pinnacle with total of ***28*** segments

Direct Aperture Optimization (DAO)

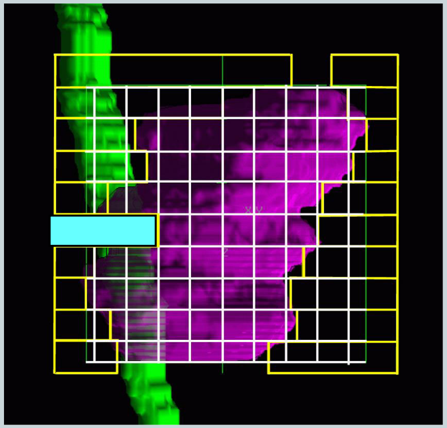
Set your beam angles

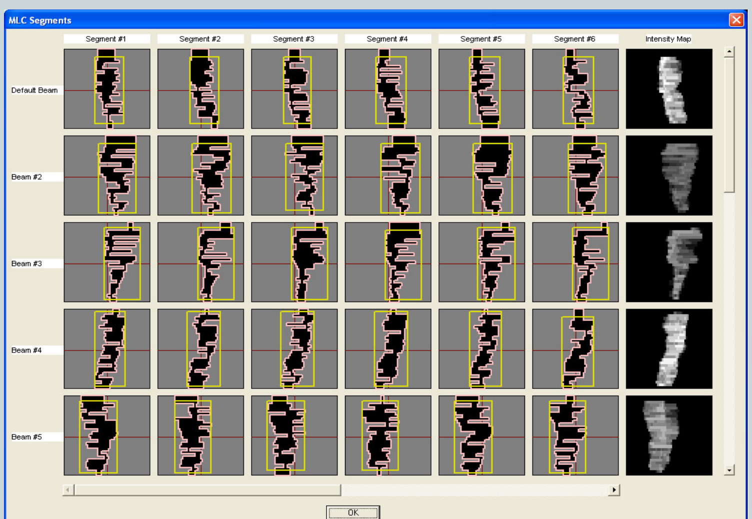
Determine your number of apertures

Begin with n identical copies



Direct Aperture Optimization (DAO)



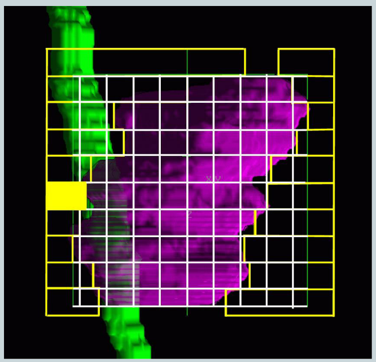


- Pick an Aperture and Make a <u>Change</u>
- consider all possible constraints and DVH requirements.

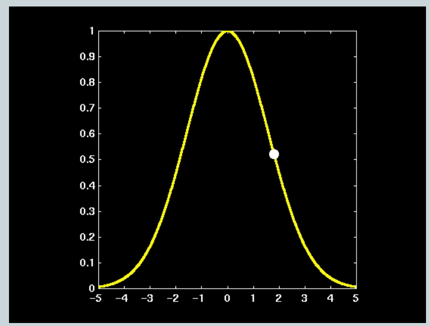
- Do this change many times and keep or reject the aperture and MUs, based on the constraints and DVH.

What is DAO - IMRT about ?

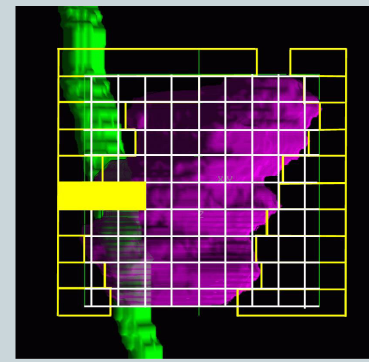
Pick a parameter:
(eg. 5th leaf of 4th angle in 2nd aperture)



Sample size of change from a Gaussian distribution



Make the change



Does change satisfy delivery constraints?

No

Yes

Calculate Objective function value (can be Dose, DVH, or Biological)

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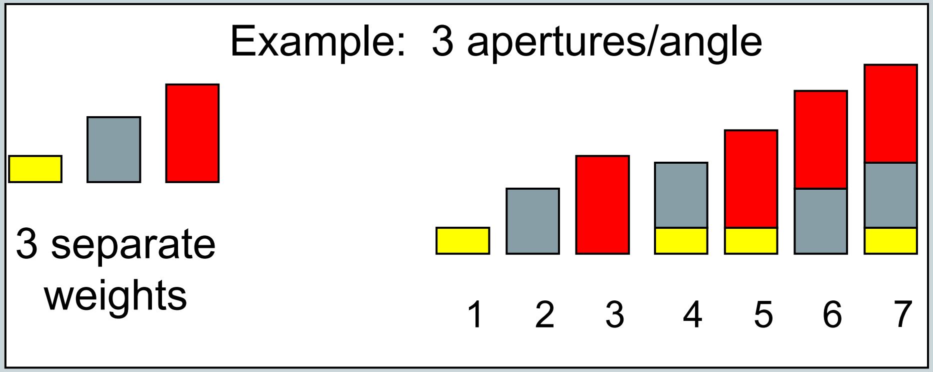
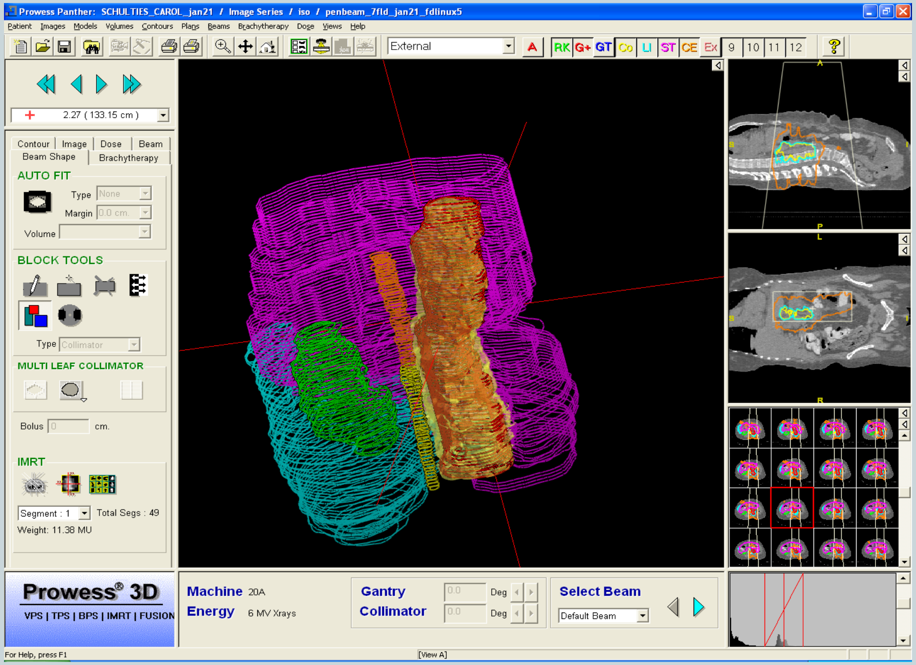
Direct Aperture Optimization (DAO)



- A **low** number of apertures/segments produces a high number of intensity levels

$$N_n = 2^n - 1$$

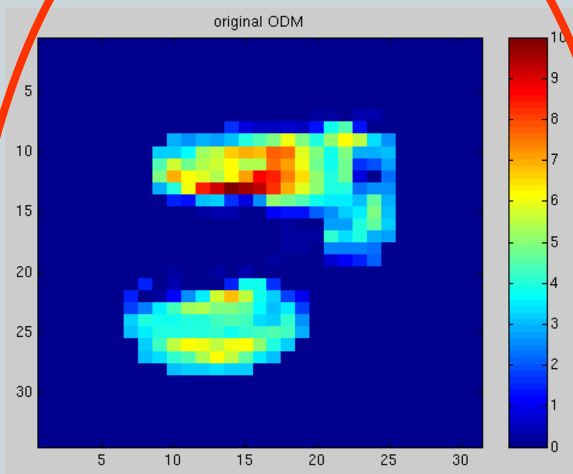
- This means **high plan quality**



- This can produce complex dose distributions

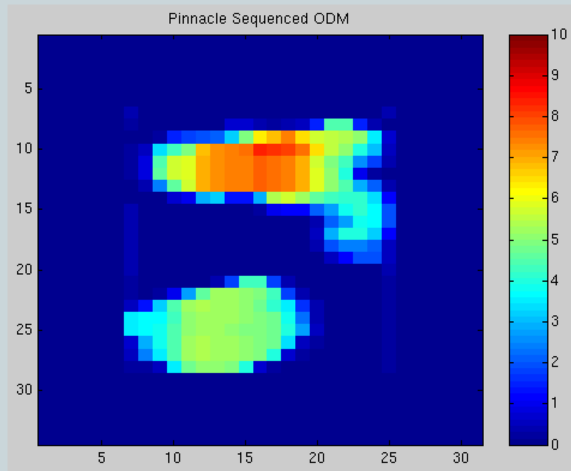
To bring it to the point …

Optimized Map



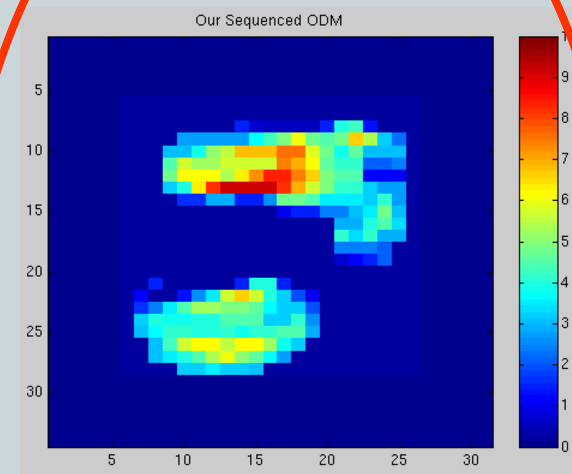
A: The original optimized Intensity Map from traditional IMRT

Traditional IMRT competitor (degraded to make deliverable)



B: The Sequenced Intensity Map using traditional IMRT competitor with total of ***28*** segments

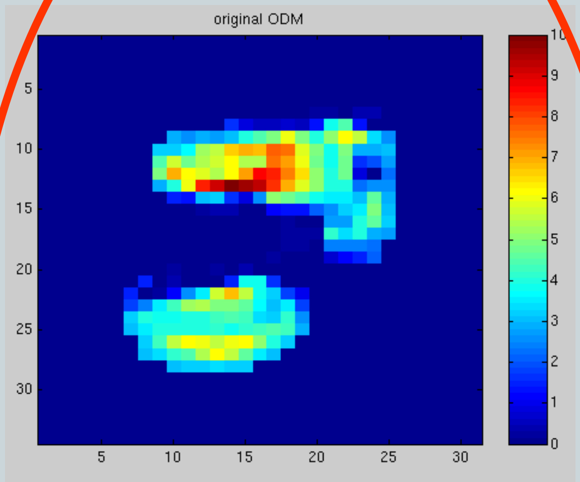
DAO IMRT



C: The Sequenced Intensity Map using DAO IMRT with total of ***12*** segments

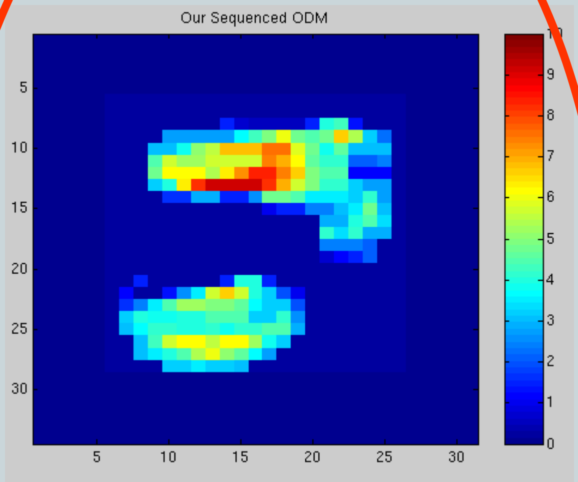
To bring it to the point – DAO is WYSIWYG

Optimized Map



A: The original optimized Intensity Map from traditional IMRT competitor

DAO IMRT



C: The Sequenced Intensity Map using DAO IMRT with total of ***12*** segments

DAO and DMPO
Efficiency - Simplicity – Safety - Confidence

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	Traditional IMRT	**DAO and DMPO**
Initial Optimization set up	1. Beam angles, DVH goals, **Unable to specify segments**	1. Beam angles, DVH goals, **Set segments**
Result of Optimization	2. Fluence Map – Ideal goal **Technique:** optimizes the fluence map to meet the DVH goals.	2. Leaf Shapes, MU with all **deliverable** shapes to get the final fluence map **Technique:** optimizes leaf shapes and MU to meet the DVH goals
Delivery	3. Leaf Sequencing – Create segments and MU from fluence Map	**Not Required – already done in step 2**
MLC constraints	**4. Delete non-deliverable segments**	**Not Required – already done in step 2**
Compare delivery result with Optimization	**Degraded – Deliverable fluence map not as good as ideal planned fluence map**	**3. WYSIWYG**
Conclusion	**Leaf sequencing creates excess segments and MU**	**Low number of segment and MU with no plan degradation**

DAO efficiency

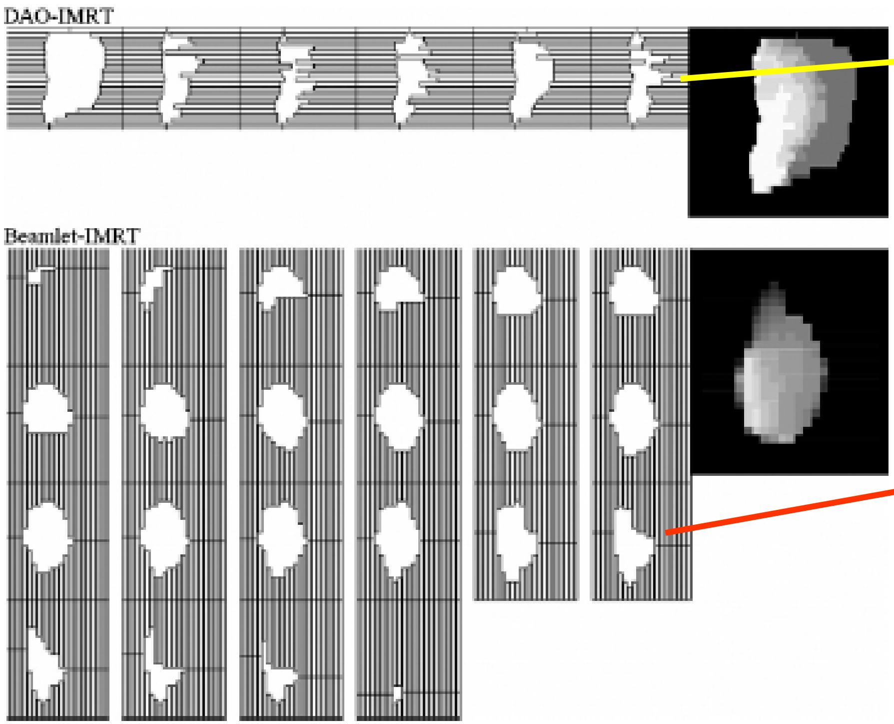

Fig. 3. Shapes of segments and the resulting intensity map for a typical beam direction are shown for both direct aperture optimized intensity-modulated radiotherapy (DAO-IMRT) and beamlet optimized IMRT plans.

Segments created by DAO

Segments created by trad. IMRT

Segment shapes and the resulting intensity map is shown for one of the tangent beams for both DAO-IMRT and beamlet-IMRT plans.

Source: Medical College of Wisconsin, Allan Li

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DAO efficiency - published

DIRECT APERTURE OPTIMIZATION–BASED INTENSITY-MODULATED RADIOTHERAPY FOR WHOLE BREAST IRRADIATION

Ergun E. Ahunbay, Ph.D., Guang-Pei Chen, Ph.D., Steven Thatcher, M.D., Paul A. Jursinic, Ph.D., Julia White, M.D., Katherine Albano, M.S., and X. Allen Li, Ph.D.

Department of Radiation Oncology, Medical College of Wisconsin, Milwaukee, WI

Purpose: To investigate the technical and dosimetric advantages and the efficacy of direct aperture optimized intensity-modulated radiation therapy (DAO-IMRT) over standard (*e.g.*, beamlet optimized) IMRT and conventional three-dimensional conformal radiotherapy (3D-CRT) for whole breast irradiation in supine and prone positions.

Methods and Materials: We retrospectively designed DAO-IMRT plans for 15 breast cancer patients in supine (10 patients) and prone (5 patients) positions with a goal of uniform dose coverage of the whole breast. These DAO-IMRT plans were compared with standard IMRT using beamlet optimization and conventional 3D-CRT plans using wedges. All plans used opposed tangential beam arrangements.

Results: In all cases, the DAO-IMRT plans were equal to or better than those generated with 3D-CRT and standard beamlet-IMRT. For supine cases, DAO-IMRT provided higher uniformity index (UI, defined as the ratio of the dose to 95% of breast volume to the maximum dose) than either 3D-CRT (0.88 vs. 0.82; $p = 0.026$) or beamlet-IMRT (0.89 vs. 0.85; $p = 0.003$). Direct aperture optimized IMRT also gave lower lung doses than either 3D-CRT (V20 = 7.9% vs. 8.6%; $p = 0.024$) or beamlet-IMRT (V20 = 8.4% vs. 9.7%; $p = 0.0008$) for supine patients. For prone patients, DAO-IMRT provided higher UI than either 3D-CRT (0.89 vs. 0.83; $p = 0.027$) or beamlet-IMRT (0.89 vs. 0.85; $p = 0.003$). The planning time for DAO-IMRT was approximately 75% less than that of 3D-CRT. The monitor units for DAO-IMRT were approximately 60% less than those of beamlet-IMRT.

Conclusion: Direct aperture optimized IMRT improved the overall quality of dose distributions as well as the planning and delivery efficiency for treating whole breast in both supine and prone positions.

Breast, Direct aperture optimization, IMRT, Segmentation methods, Step-and-shoot.

IMRT Treatment Planning with Direct Step and Shoot Optimization

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RaySearch Laboratories

Purpose

The classic multi-step IMRT inverse planning process can now be reduced to an effective one-step process using direct step-and-shoot optimization (DSS). This one-step method uses the very MLC settings produced during the DSS optimization and the weight of the segments as optimization variables. All MLC-related constraints and user specifications are taken into account throughout the DSS optimization, leaving the plan deliverable from start to finish with no need for conversion, filtering, weight optimization or other plan degrading post optimization actions. This study will investigate if DSS optimization can be used to somewhat streamline treatment planning and delivery while preserving and perhaps improve treatment quality.

Introduction

The goal of IMRT planning is to find machine settings that produce the best possible treatment plan given certain machine limitations, physical limitations and user preferences. Optimization-based software for solving this type of problem has traditionally followed the strategy of optimizing fluence profiles to produce a desired dose distribution as a first step and to convert these profiles to MLC settings as a second step. The deliverability of the profiles are not taken into account during optimization and a large number of segments will typically be necessary to realize the complicated profiles. Segment weight optimization (SWO) may restore the plan quality lost in the conversion process but will also add substantial time to the planning process.

Direct step and shoot (DSS) optimization is a one-step method that optimizes directly on the MLC settings and segment weights. MLC-related constraints and user specifications are taken into account throughout the DSS optimization leaving the plan deliverable from start to finish with no need for conversion, filtering, weight optimization or other plan degrading post optimization actions.

Theory

The starting point for IMRT planning is the dose, d, that the physician would like the patient to receive. The physician's preferences are requirements can be formulated as linear constraints and include minimum gaps, interdigitation, maximum tip differences, segment areas and more. By including such constraints, it is guaranteed that the optimized plan always is deliverable. A gradient-based method is used to solve the DSS optimization problem and the gradients wrt machine parameters are computed by the chain rule

$$\frac{\partial f}{\partial x} = \frac{\mathrm{d} f}{\mathrm{d} d}\frac{\mathrm{d} d}{\mathrm{d} \tau}\frac{\partial \tau}{\partial x}$$

The computational flow when computing objective values and gradients is illustrated in Figure 1.

Method

Five different Head Neck patients were planned using the beta version v.7.4d of Pinnacle[3] v.7.4. Three different plans were created for each patient and evaluated in terms of planning time, number of MUs, number of MLC segments and plan quality. The plan quality was determined from dose volume histogram (DVH) curves, dose statistics and composite objective values.

Plan 1. An initial *Classic IMRT* plan was created through fluence profile optimization (optimization type *Intensity Modulation* in P^3IMRT), conversion and SWO. The fluence optimization was run for 40 iterations with a CC dose computation at the fifth iteration. An error tolerance of 5% was accepted between the ideal and deliverable fluence map and 10 intensity levels were used during conversion. SWO was run for 20–25 iterations.

Plan 2. Secondly, a *Plan Equivalent DSS* plan was optimized using DSS optimization (optimization type *DMPO* in P^3IMRT). The aim was to create a DSS plan with fewer segments than what was produced for the corresponding Classic IMRT plan, without compromising plan quality. Segment reduction during DSS optimization was obtained by constraining the maximum number of segments allowed for the plan to about half compared to the number of segments obtained for the Classic IMRT plan. The DSS optimization was run for 40–60 iterations, with a CC dose computation at the 8–15th iteration.

Plan 3. Finally a *Segment Equivalent Classic IMRT* plan was created using the process and parameter values described for Plan 1. The only difference was the conversion parameters used. A larger deviation, 6–11% between the ideal and deliverable fluence map and intensity levels up to a maximum of 15 was allowed during conversion to reduce the

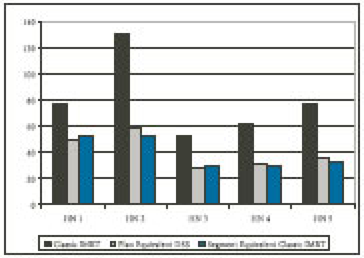

Figure 2: Total number of segments.

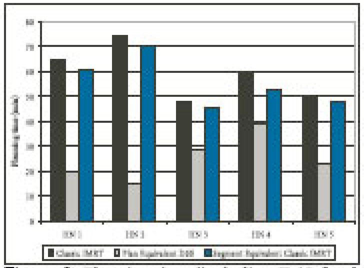

Figure 3: Planning time (including SWO for the Classic IMRT plans).

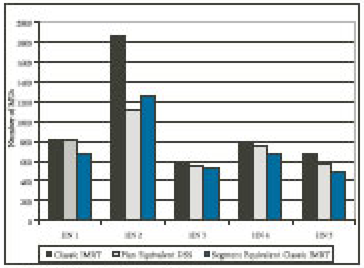

Figure 4: Number of MUs.

Unterschied Raysearch (DMPO/DSS) und PROWESS DAO

DMPO/ DSS

- Gradientenverfahren
- Einfacher und damit etwas schneller in Rechenzeit
- Risc: Je nach Initialisierung findet es nicht das globale,sondern ein lokales Minimum (u.U. nicht die „optimalste“ Lösung)

DAO

- Simulated annealing Optimierungsverfahren
- Algorithmus findet das „globale“ Maximum, somit die Möglichkeit gegeben ist die effektivste Segmentanordnung zu finden
- Verfahren ist jedoch relativ aufwändig, daher normalerweise etwas langsamer in der Optimierungszeit.

Delivery efficiency - Beispiele

Prowess DAO IMRT delivered on Siemens Artiste

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	# of beams	# of segments	MU#	Delivery time
Prostate	7	28	403	4’43”
Prostate	7	35	457	5’34”
Head&Neck	7	42	275	5’45”
Prostate	7	42	387	5’29”
Prostate	7	28	439	5’7”

Source: Medical College of Wisconsin, Allan Li

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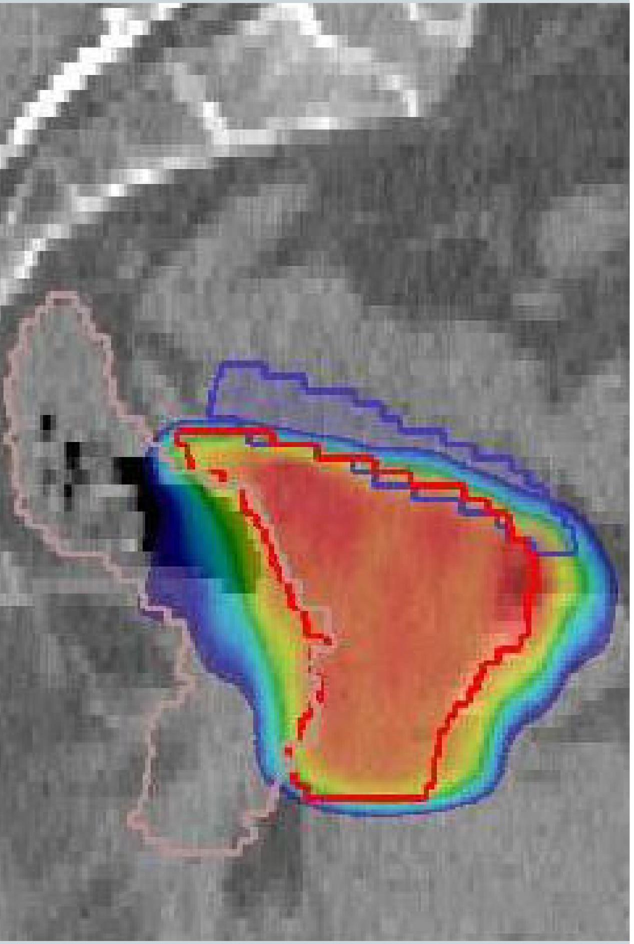
Agenda



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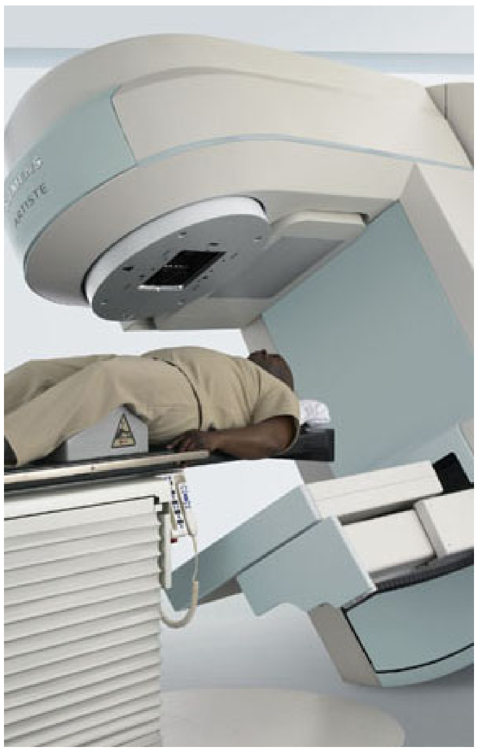
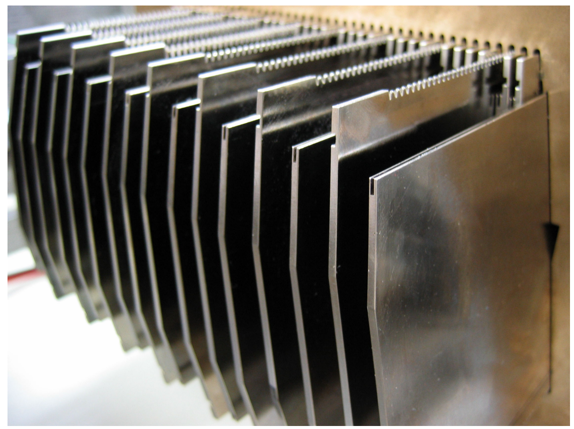
IM–Confident™ . . .

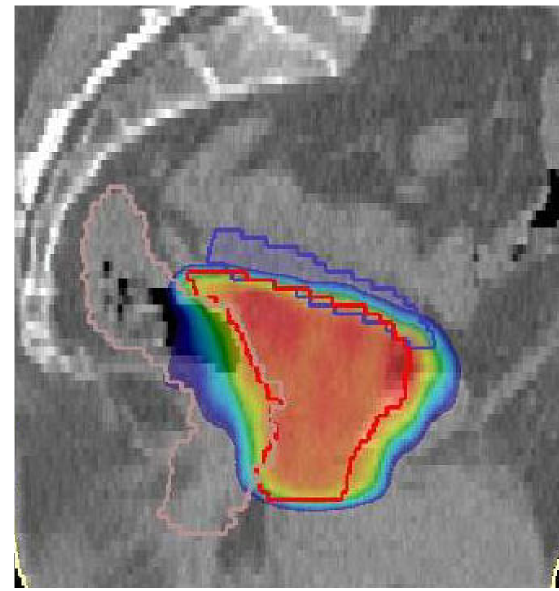
- Methode für die schnelle und präzise IMRT
- Bestehend aus:
  - TPS
  - Beschleuniger
  - MLC
- Für schnelle IMRT Bestrahlungszeiten
- Für drastisch reduzierte Anzahl an MLC Segmenten
- Für drastisch reduzierte Anzahl an MUs
- Für reduzierte Bestrahlungszeiten
  bei gleichzeitiger hoher Bestrahlungs-Qualität!
- **Verfügbarkeit: JETZT**

IM–Confident™ ist . . .

ARTISTE + **160 MLC** + **DAO / DMPO**







DAO: PROWESS

DMPO: Pinnacle (*)

(*) Pinnacle ist ein Produkt von Philips

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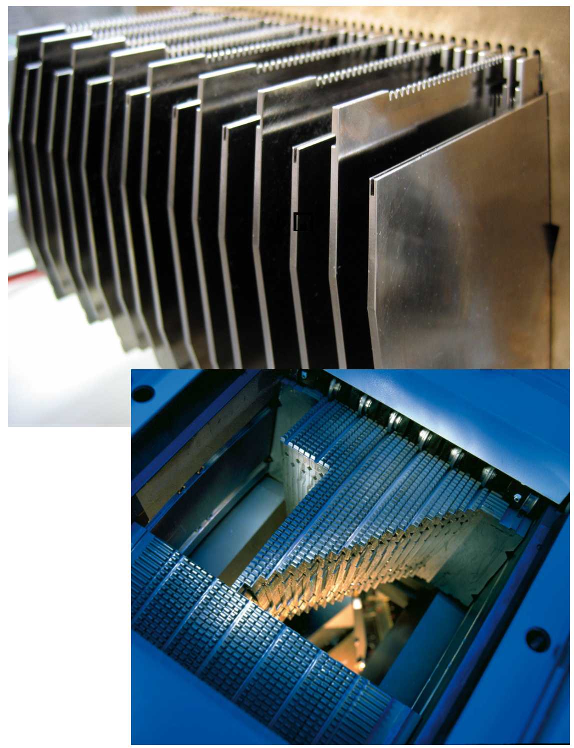
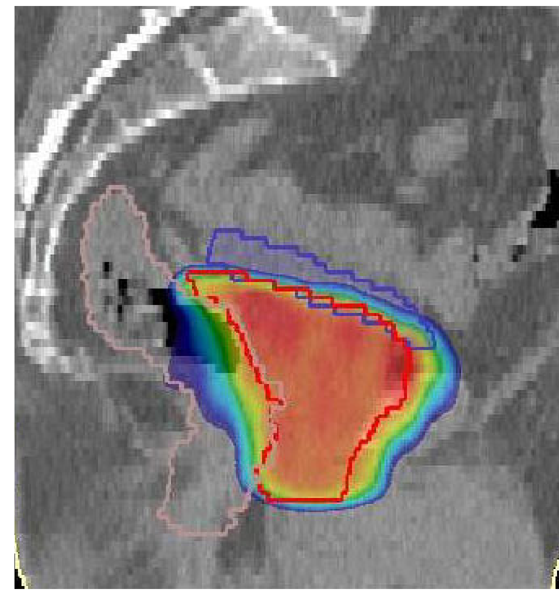
IM–Confident™ ist . . .

ONCOR + **OPTIFOCUS / 160 MLC** + **DAO / DMPO**





DAO: **PROWESS**

DMPO: **Pinnacle (*)**

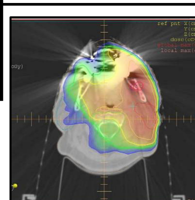
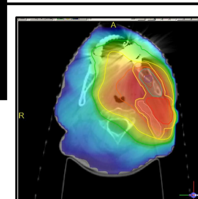
(*) Pinnacle ist ein Produkt von Philips

IM-Confident Plan
Geschwindigkeit und Qualität – schnelle IMRT

- IMRT Bestrahlung mit zum Teil hervorragenden Bestrahlungszeiten (z.T.< 5Minuten) mit exzellenter Dosisreduktion bei den Risikoorganen

- 160 MLC™ in Kombination mit Zeit optimierenden Planungs-Algorithmen PROWESS DAO oder Philips DMPO

Beispiel: H & N (160MLC mit ARTISTE)

	Traditionelle IMRT RTP	IM-Confident	Überzeugende Resultate
# der Strahlen	**7**	**7**	-
# der Segmente	**94**	**42**	**≈ 1/2 # de Segmente**
# der Monitor Units (MU)	**537**	**284**	**≈ 1/2 # der MU**
Behandlungszeit (in min)	 **15**	 **5**	**≈ 1/3 der Gesamtbehandlungszeit**

Source: Medical College of Wisconsin, Allan Li

IM-Confident Plan
Geschwindigkeit und Qualität – schnelle IMRT

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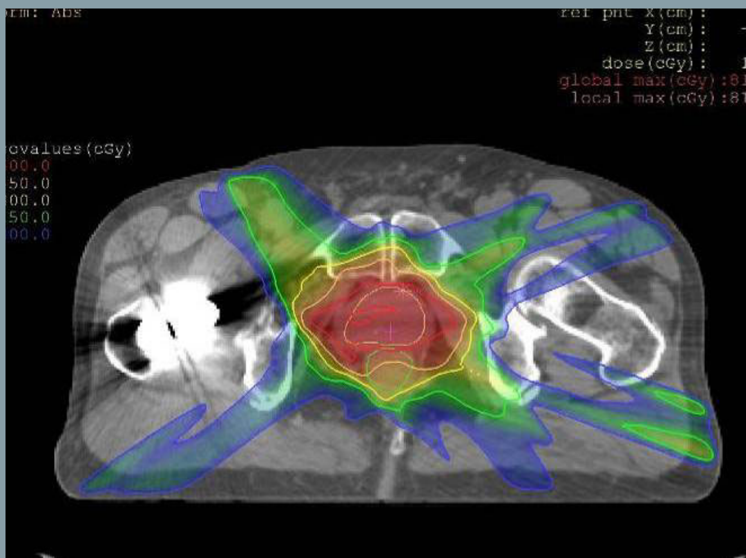
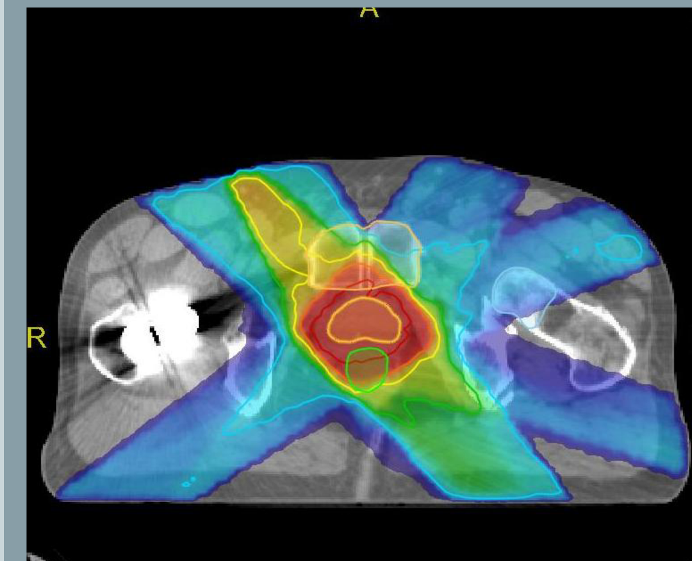
traditionelle IMRT RTP



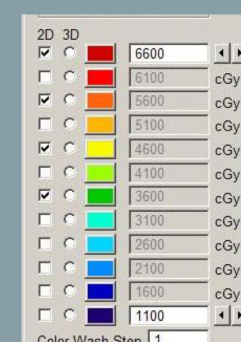
Number of Beams: 7
Segments: 98
MU: 643
Tx time OPTIFOCUS: 15 min

IM-Confident



Number of Beams: 7
Segments: 42
MU: 374

Tx time 160 MLC*: 5 min



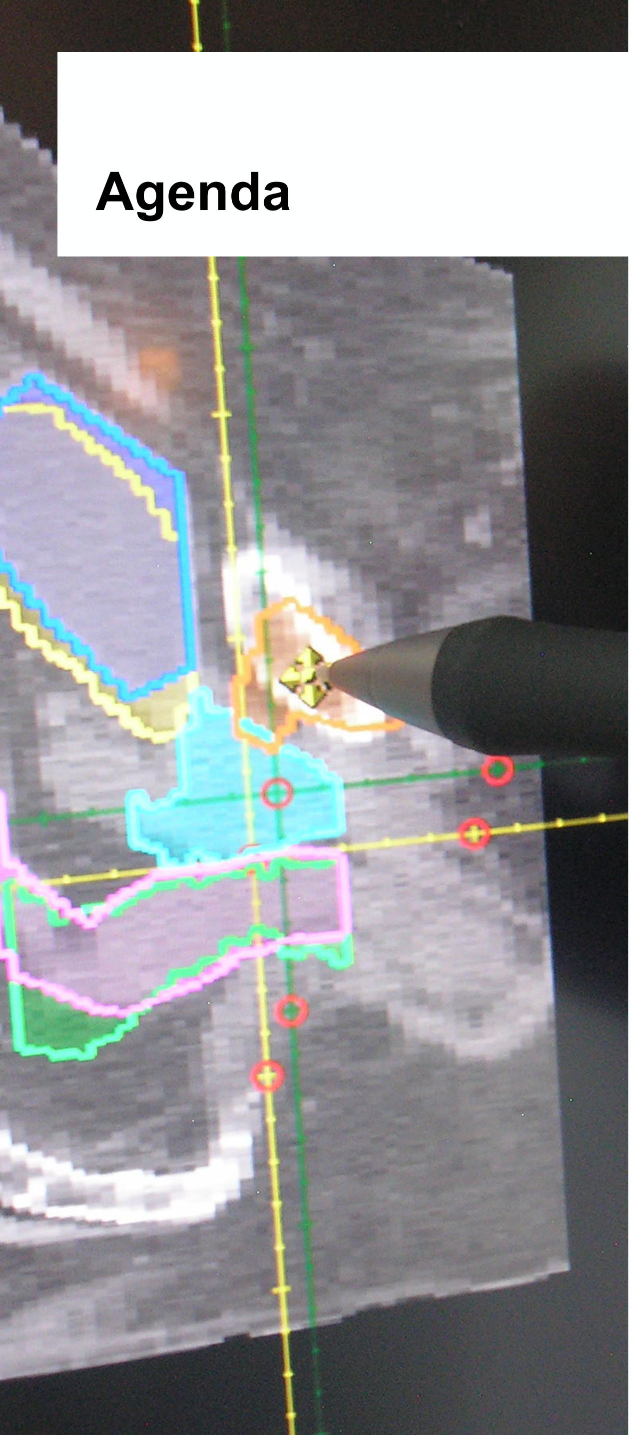
Source: Medical College of Wisconsin, Allan Li

IM-Confident Plan
Speed up Quality – Fast IMRT, possible in less than 5 minutes

- IMRT delivery for high range of disease sites, possible in less than 5 minutes with superior sparing of healthy tissue

Treatment Quality

Treatment Time



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Agenda

1. InversePlanning / KonRad
2. DAO und DMPO
3. IM-Confident
4. IM-RealART
5. 160 MLC
6. Diskussion

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IM-RealArt™ . . . – Works in Progress

- Methode für die Adaptive Strahlentherapie (ART)
- Für die schnelle und präzise Neu-Planung, bei Anpassung von Strukturen und MLC-Segmenten
- Bestehend aus:
    - PROWESS RealArt TherapiePlanungsSoftware
    - CTVision (CT im Bunker, Beschleuniger – PRIMUS, ONCOR oder ARTISTE) oder „stand-alone“ CT
    - MLC (OPTIFOCUS oder 160MLC)
- Liefert über den Adaptionsprozess eine hochpräzise Bestrahlung in einer für den Patienten vertretbaren Zeit

- **Verfügbarkeit: möglich Ende 2009**

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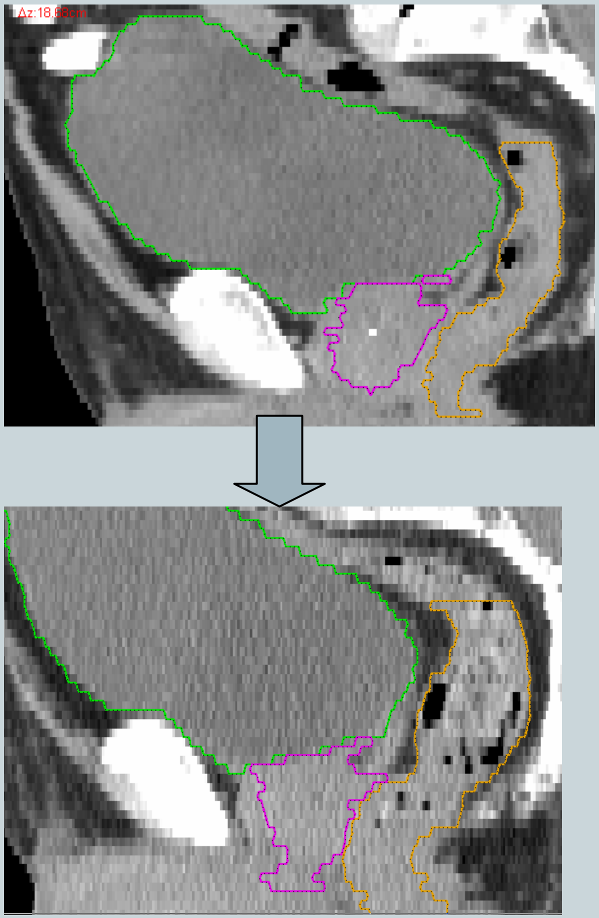
IM-RealART Lösung



Warum Neuplanung?

- Interfraktionielle Veränderungen bzgl.:
  - Positionierung
  - Volumenverschiebung
  - Volumenänderung
  - . . .

  Führen zu zusätzlichen Anforderungen an IGRT !

- Es kann in einer dem Patienten zumutbaren Zeit durchgeführt werden (<10 Minuten)

- Ideal wäre die Neuplanung für nahezu jede Fraktion

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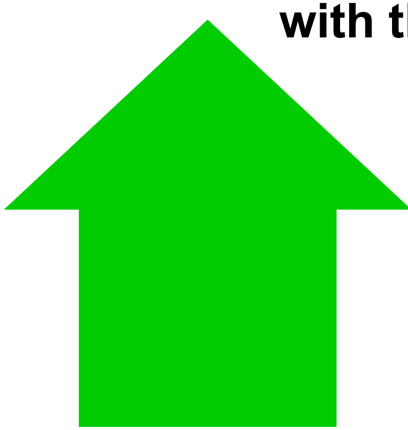
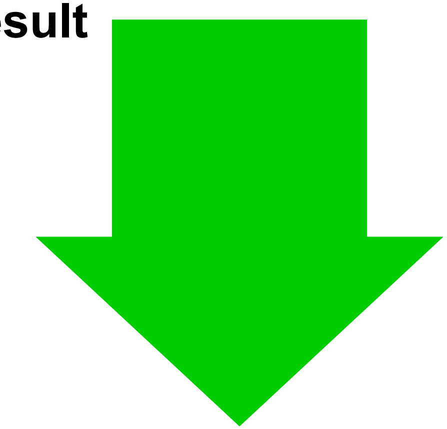
IM-RealART
Replan on the Spot – possible in less than 7 minutes

- Organs move and deformate between fractions
  making the original plan worthless and re-planning necessary

Replan on the Spot
possible in about 7 minutes
with the clinically proven result



Tumor Dose



Dose to Organs at Risk

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160 MLC™ Multileaf Collimator
Mehr Präzision, schnell und komfortabel

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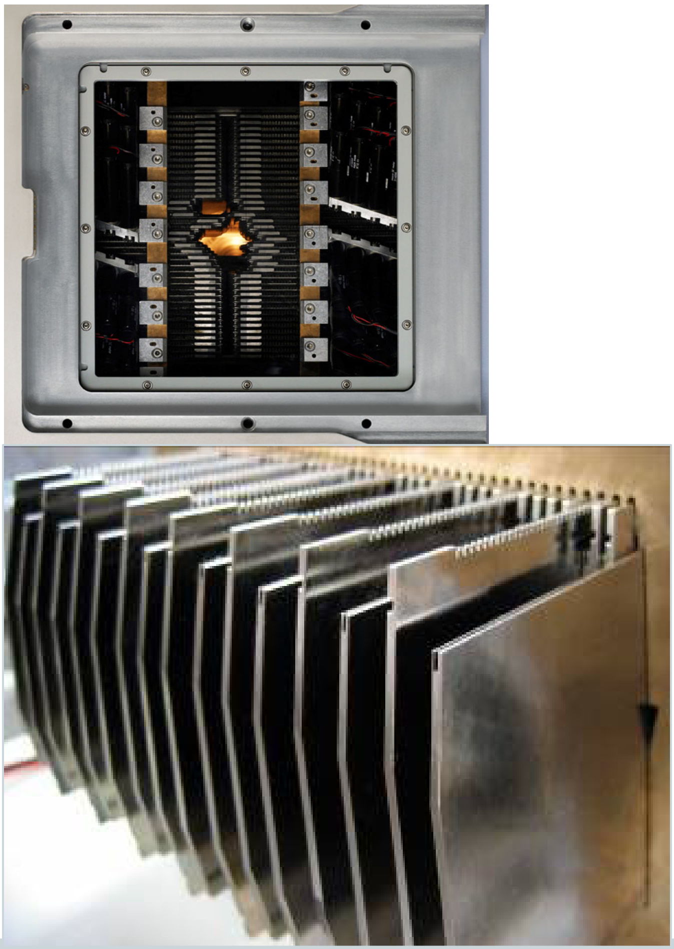
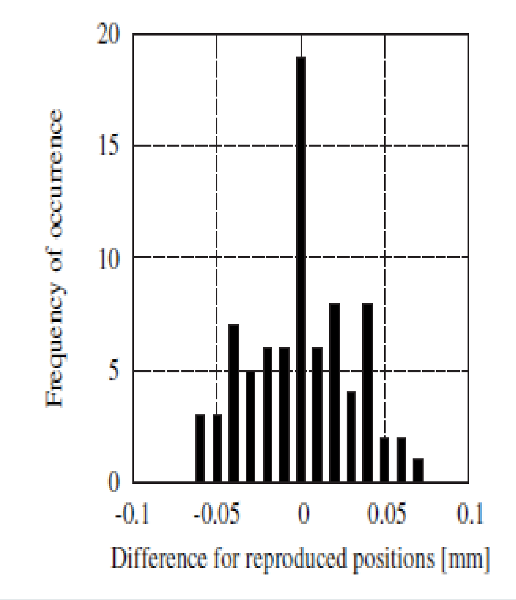


- **Hohe Auflösung und Präzision**
  dank 5 mm Lamellenbreite
  über die gesamte Feldgröße
- **Präzise Tumorkonformalität**
  - homogene Dosisverteilung
- **Hohe Lamellengeschwindigkeit**
  (4cm/s),
  höchste Genauigkeit (± 0,5 mm)
- **Extrem niedrige Leckstrahlung**
  (unter 1 %) durch gestapelte
  Lamellenanordnung, höhere Lamellen
  und einzigartige Lamellenenden

Genauigkeit und Reproduzierbarkeit

Charakteristik	Siemens - 160 MLC	Mitbewerb A	Mitbewerb B
Leaf Positionierungsgenauigkeit	0.5mm Incl. Führungsschlitten Positionierungsgenauigkeit	1.0mm Incl. Führungsschlitten Positionierungsgenauigkeit	1.0mm Incl. Führungsschlitten Positionierungsgenauigkeit
Leaf Positionierung Reproduzierbarkeit	0.3mm Incl. Führungsschlitten Positionierungsgenauigkeit	0.5mm Incl. Führungsschlitten Positionierungsgenauigkeit	?



Quelle: Tacke et al., DKFZ Heidelberg, Med. Phys. 35 (5), May 2008

Medizinische Anwendung: Bestrahlungszeiten

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Bestrahlungszeiten im Vergleich zum OPTIFOCUS, 82 MLC

Indication	Number of cases	160 MLC without interdigitation		160 MLC with interdigitation	
		Beams/segments	Time reduction (%)	Beams/segments	Time reduction (%)
Head and neck	2	9/105	9.5	9/88	18.5
Prostate including lymph channels	2	9/100	5	9/83	12
Prostate without lymph channels	1	9/75	3	9/73	0
Pancreas	1	7/63	4	7/63	2
Mean value of saved time		6%		11%	

Quelle: Tacke et al., DKFZ Heidelberg, Med. Phys. 35 (5), May 2008

Im Durchschnitt 11% Zeitersparnis bei Behandlung mit 160 MLC im Vergleich zu OPTIFOCUS
Ursache: höhere Leafgeschwindigkeit, Interdigitation

160 MLC: Messungen – Vergleich zum Mitbewerb

Characteristic	Result	Comparison to competition
Intraleaf/Interleaf Leakage	<0.40%/<0.63%*	almost a magnitude better
Leaf tip leakage	13.5%*	50% better
Resolution	5mm over the whole field	best resolution over the whole field for non-stereotactic MLCs
Penumbra d10, 10 cm x 10 cm field size, 6 MV	<7mm	Comparable
Positioning accuracy/reproducibility	0.5/0.2mm	50% better
Tongue-and-groove effect	19%*	Slightly better
Clearance without/with accessory holder	47.5/43.8cm	Up to 15%/28% higher
Treatment times	17% better than Optifocus MLC*	Comparable

*** Daten gemessen von Tacke et al., DKFZ Heidelberg, Med. Phys. 35 (5), May 2008**

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Danke für Ihre Aufmerksamkeit !

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