KlinikumDarmstadt GmbH
Akademisches Lehrkrankenhaus

Extrakranielle non-coplanare Radiotherapie

Optimierung in der Praxis durch **MapRT**

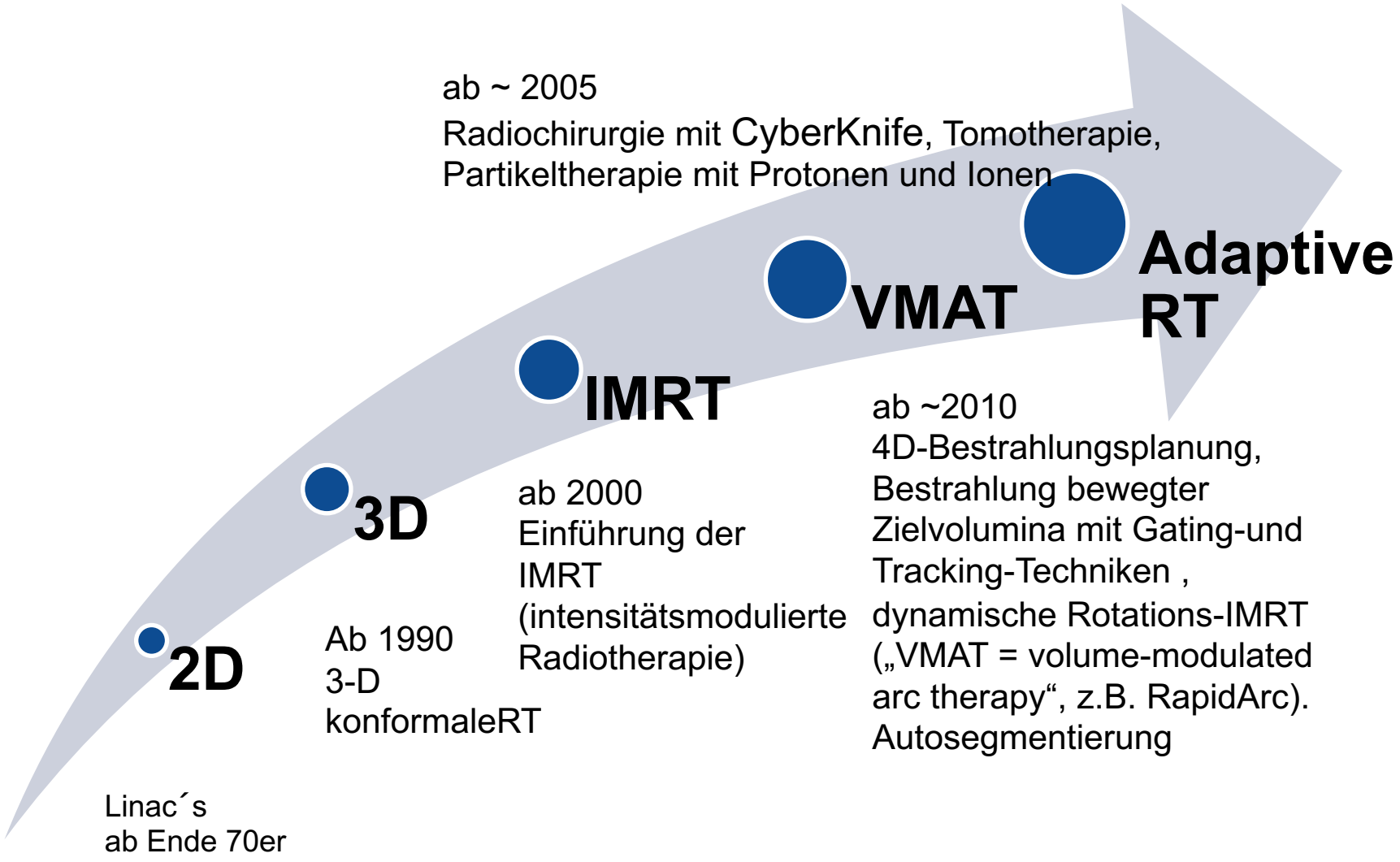
Gemeinsam fürs Leben

Discosure

Die Klinikum Darmstadt GmbH, hat ein “**professional service agreement”** / Referenzkundenverträge mit Varian (Siemens Healthineers International AG) und Vision RT.

Christian Weiß erhält/erhielt Honorare und Unterstützung durch Varian Medical Systems, Vision RT, Merck Serono, Roche, MSD, BMS, Eli Lilly, Sanofi Aventis, Janssen Cilag

Von 2D zu 3D IMRT – VMAT und 4D ……



Non-coplanare Bestrahlung am LINAC

Technique	Clinical sites investigated	Technological approach	Computational methods	Clinical implementation	Challenges
NC-IMRT	Liver[13,19,22] lung[14] brain[15,20,21] head & neck[16] prostate[17,18]	Up to 30 static non-coplanar beams	Beam orientation optimization using existing methods[13–22]	Ready for implementation	Automated trajectory sequencing
SCNC-VMAT	Brain[23–27]	VMAT with multiple fixed patient couch rotations	Manual selection from limited arc set	Ready for implementation	Automated delivery and collision prevention on non-HyperArc platforms
Coronal VMAT	Partial breast[28–31]	Dynamic patient couch rotation with fixed or limited linac gantry rotation	Manual[28,29] or algorithmic[30,31] trajectory definition	Requires substantial further development	Collision prevention Intrafraction motion Patient compliance Investigation of other clinical sites Non-research delivery technology
Trajectory VMAT	Brain[33,35–42,44] head & neck[32,34,43] prostate[38,40,44] lung[40–42,44] liver[42] chest wall[44] oesophagus[44]	Synchronized dynamic patient couch rotation and linac gantry rotation.	Manual[33,34] or mathematical[37] trajectory definition Beam scoring[35,36,38,39] or fluence-based[32,39–42,44] trajectory optimization	Requires substantial further development	Collision prevention Intrafraction motion Patient compliance Non-research delivery technology
CyberArc	Brain and prostate[45,46]	Arc delivery sequencing for robotic arm mounted linac	Dose mimicking and fluence-based trajectory optimization[45,46]	Requires some further development	Integration into proprietary treatment planning and linac control software
Dynamic Wave Arc	Brain[48] metastatic disease[47,49] prostate[47,49] pancreas[47] lung[47,49] breast[49]	Dynamic rotation of O-ring linac	Manual definition[47–50]	Ready for implementation	Application of trajectory optimization techniques to O-ring linac geometry

Smyth G et al. Br J Radiol 2019

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Kranielle non-coplanare Bestrahlung

CEREBRAL RADIATION SURGERY USING MOVING FIELD IRRADIATION AT A LINEAR ACCELERATOR FACILITY

GÜNTHER H. HARTMANN, PH.D.,[1] WOLFGANG SCHLEGEL, PH.D.,[1] VOLKER STURM, M.D.,[2] BERND KOBER, M.D.,[3] OTTO PASTYR, ENG.[1] AND WALTER J. LORENZ, PH.D.[1]

Institut für Nuklearmedizin, Deutsches Krebsforschungszentrum; [2]Neurochirurgische Abteilung der Universität und Tumorzentrum Heidelberg Mannheim; and [3]Universitätsstrahlenklinik Heidelberg, D-6900 Heidelberg 1, PO Box 101949, Federal Republic of Germany

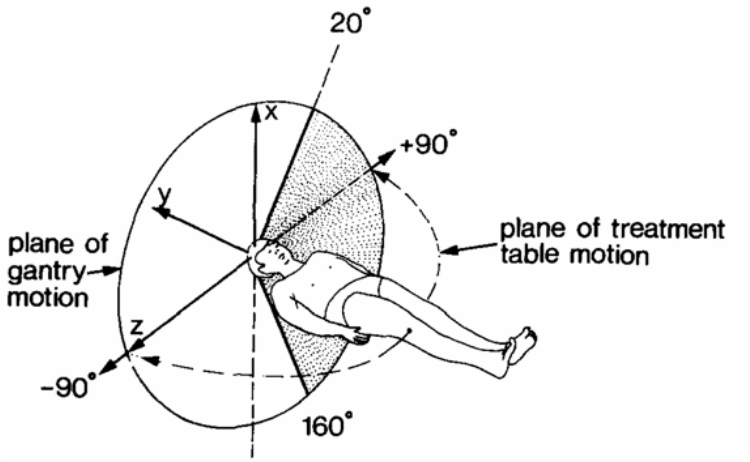
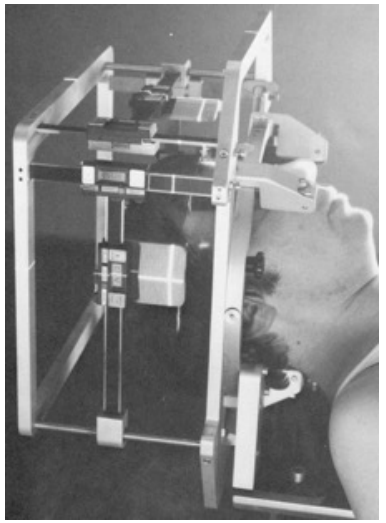


Fig. 1. Schematic illustration of the three dimensional cross fire irradiation. The shadowed area represents the moving field angle (20°–160°). Each of the 11 irradiations is performed at a different angle of the treatment table varying between −90° and +90°.



Hartmann GH et al. IJROBP 1985

Kranielle non-coplanare Bestrahlung

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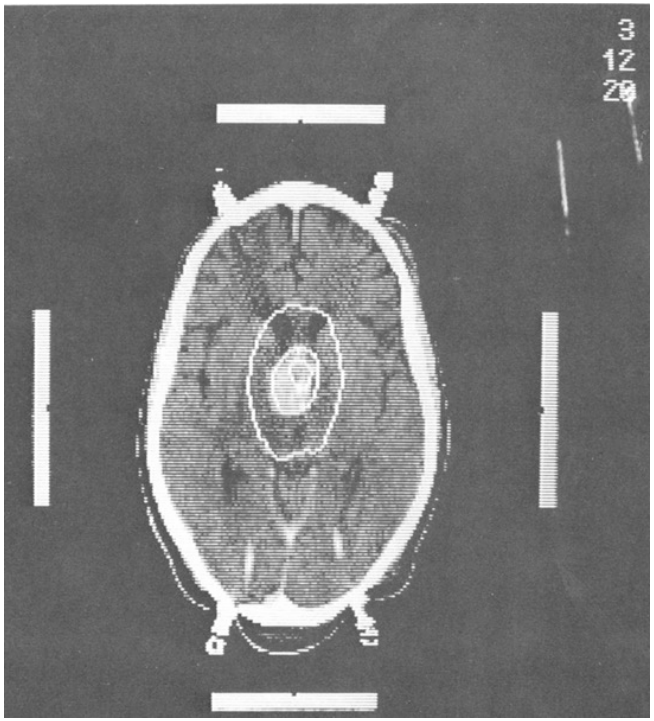
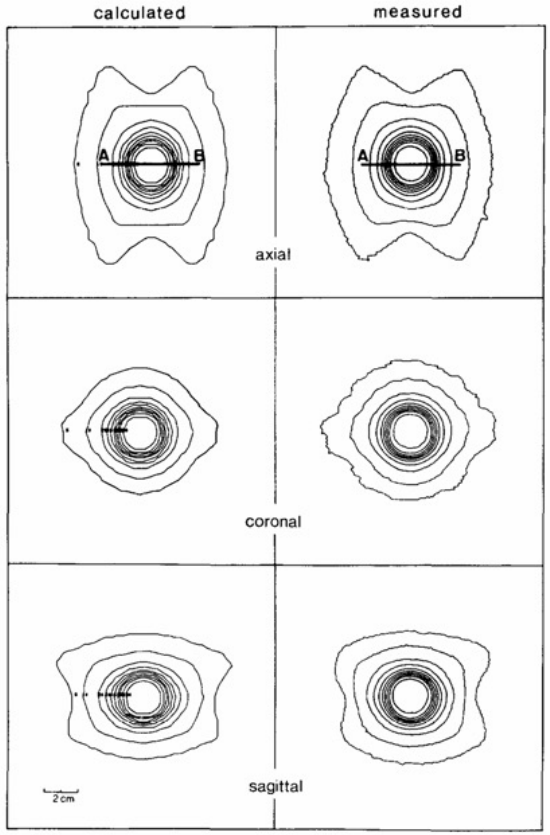
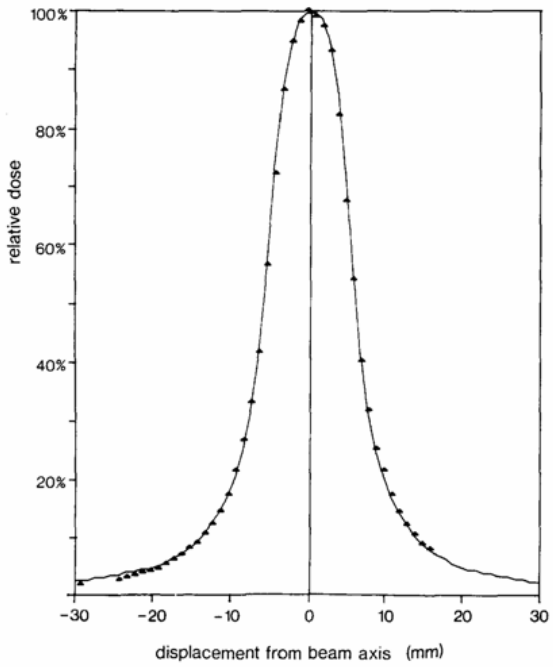






Hartmann GH IJROBP 1985

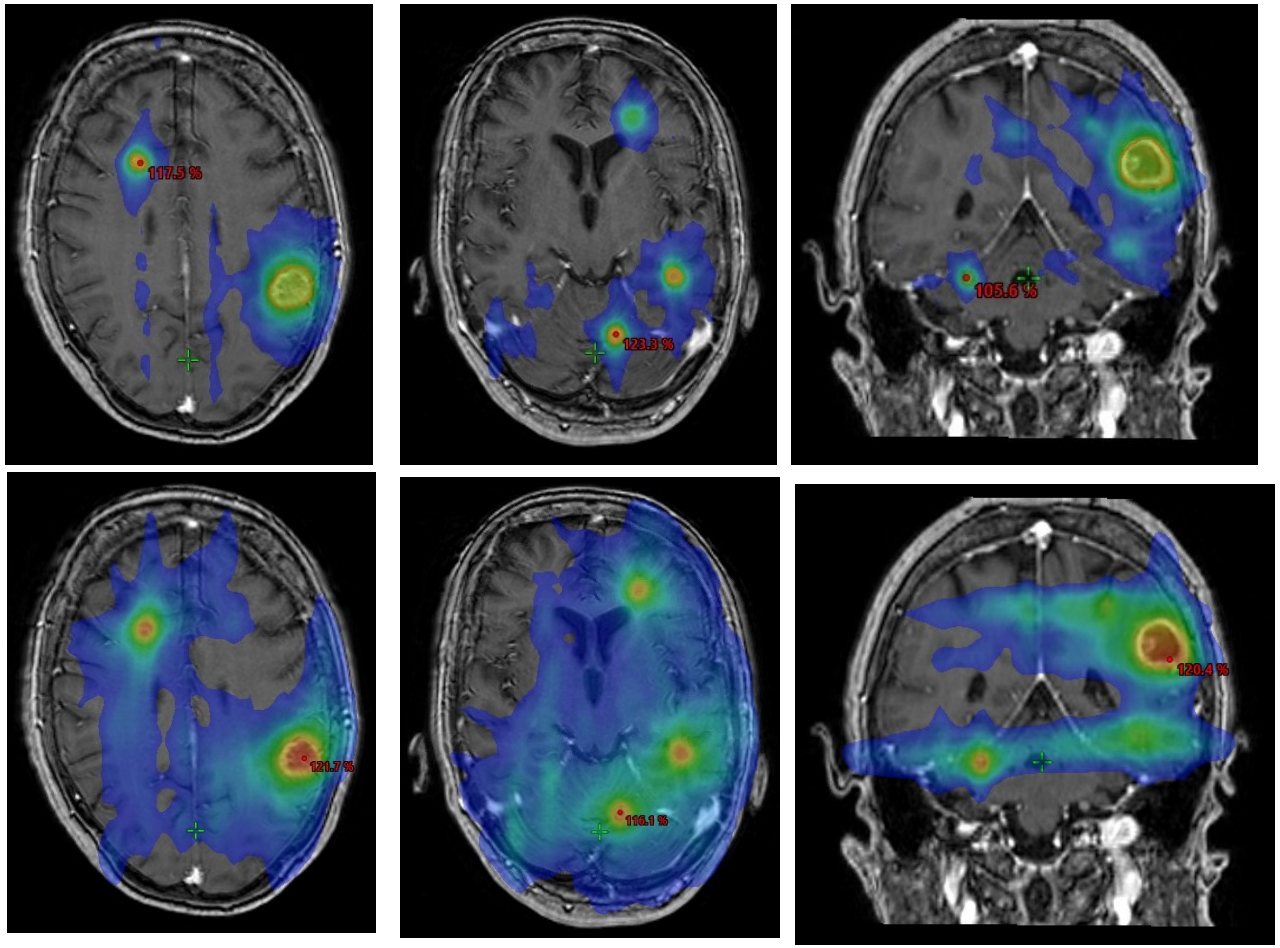
Kranielle non-coplanare Radiotherapie (HyperArc™)

Erster Praktischer Einsatz: Juni 2018

Planungsbeispiel: EDGE, 6FFF

HyperArc SRS NTO

NTO



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Akademisches Lehrkrankenhaus

Extrakranielle non-coplanare Bestrahlung – Muss oder Spielerei –

Extrakranielle non-coplanare Bestrahlung

Nutzung in der Routine

in Ausnahmefällen vorstellbar

eher Spielerei

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Akademisches Lehrkrankenhaus

Extrakranielle non-coplanare Bestrahlung – Muss oder Spielerei –

- **Komplexe Planung**
- **Höheres Risiko für Einstellungsfehler**
- **Erhöhtes Kollisionsrisiko**
- **Behandlungszeit**
- **Nur geringe Planverbesserung**

KlinikumDarmstadt GmbH
Akademisches Lehrkrankenhaus

Extrakranielle non-coplanare Bestrahlung
– Muss oder Spielerei –

Con´s

- **Komplexe Planung**
- **Höheres Risiko für Einstellungsfehler**
- **Erhöhtes Kollisionsrisiko**
- **Längere Behandlungszeit**
- **nur geringe Planverbesserung**

Pro´s

Realität? Praxis?

Vielen Dank für ihre Aufmerksamkeit!

KlinikumDarmstadt GmbH
Akademisches Lehrkrankenhaus

Extrakranielle non-coplanare Bestrahlung – Muss oder Spielerei –

Con´s

- Komplexe Planung
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- Erhöhtes Kollisionsrisiko
- Behandlungszeit
- Nur geringe Planverbesserung

Pro´s

- **steilerer Dosisabfall**
- **bessere Konformität**
- **bessere Schonung OAR´s**
- **weniger Nebenwirkungen**
- **Dosiseskalation**
- **bessere lokale Kontrolle**

Realität? Praxis?

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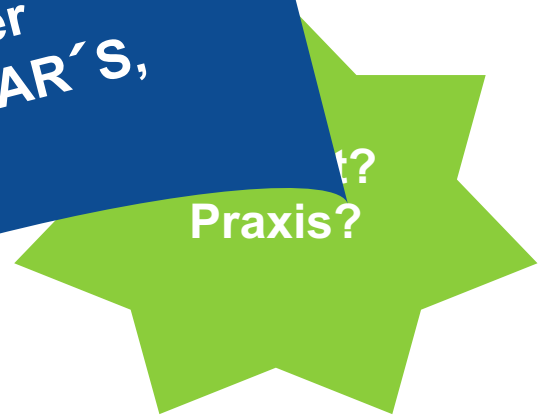
Akademisches Lehrkrankenhaus

Extrakranielle non-coplanare Bestrahlung
– Muss oder Spielerei –



Besondere Bedeutung bei stereotaktischen Hochpräzisionstherapien, extremer Hypofraktionierung, Schonung von OAR´S, Dosiseskalation

- E
- E
  K
- Be
- Nu
  Plan

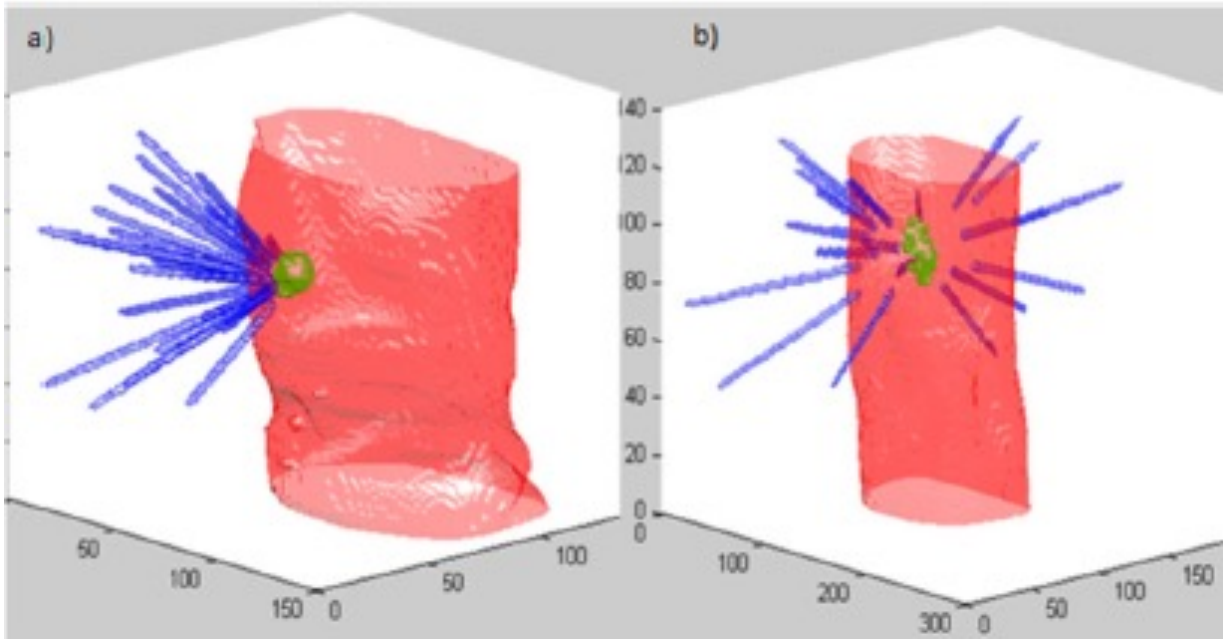
kungen
kalation
ssere lokale
Kontrolle

Klinisches Szenario 1: Leber SBRT

4pi Non-Coplanar Liver SBRT: A Novel Delivery Technique

n=10, Dosis 50-60Gy in 5#, VMAT-SBRT

14-22 non-coplanare Felder vs VMAT-Plan – Behandlungszeit ???



off-centered tumor central tumor

Dong P., Sheng K et al. IJROB 2013

Klinisches Szenario 1: Leber SBRT

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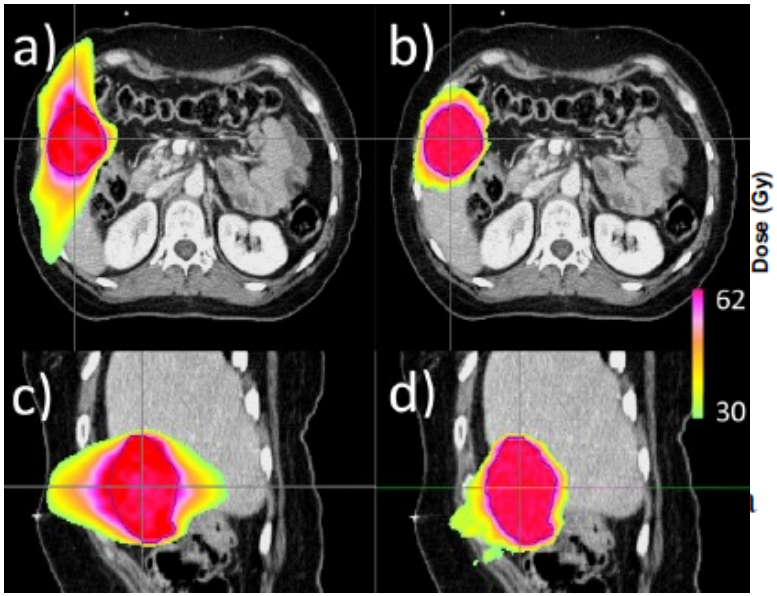
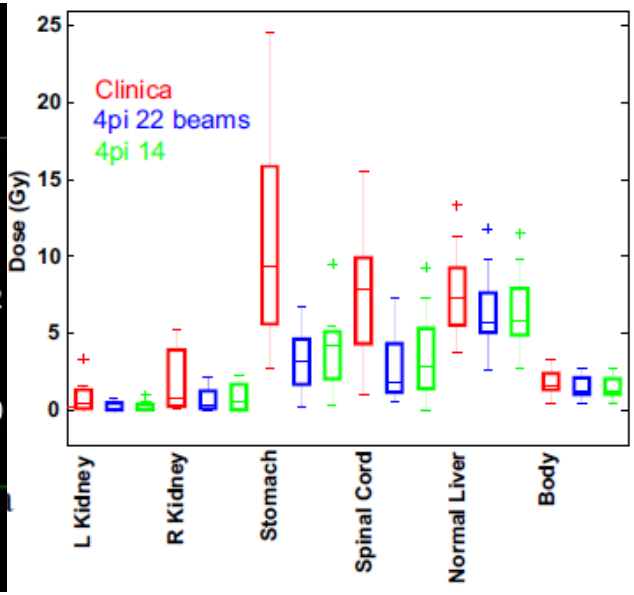
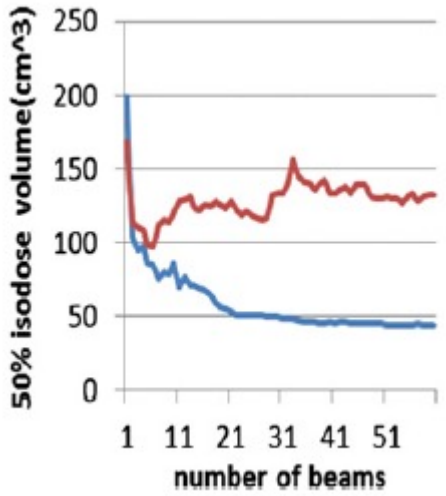


VMAT





4π planning

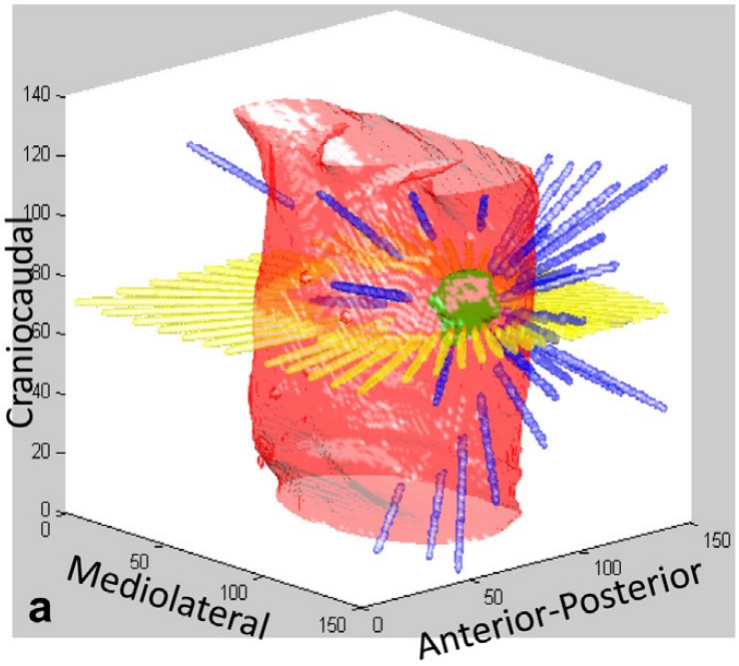
Dong P., Sheng K et al. IJROB 2013

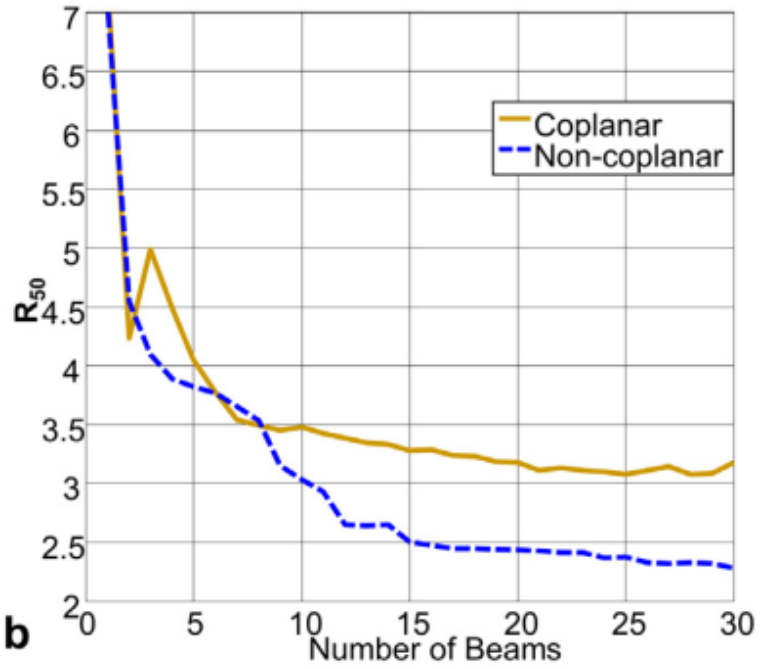
Klinisches Szenario 2a: Lungen SBRT zentral

4p Non-Coplanar Lung SBRT: A Novel Delivery Technique

n=12, Dosis 50-60Gy in 4-(5)#, VMAT-SBRT

20-30 non-coplanare Felder vs VMAT-Plan





VMAT

4π planning

Dong P., Sheng K et al. IJROB 2013

Klinisches Szenario 2a: Lungen SBRT zentral

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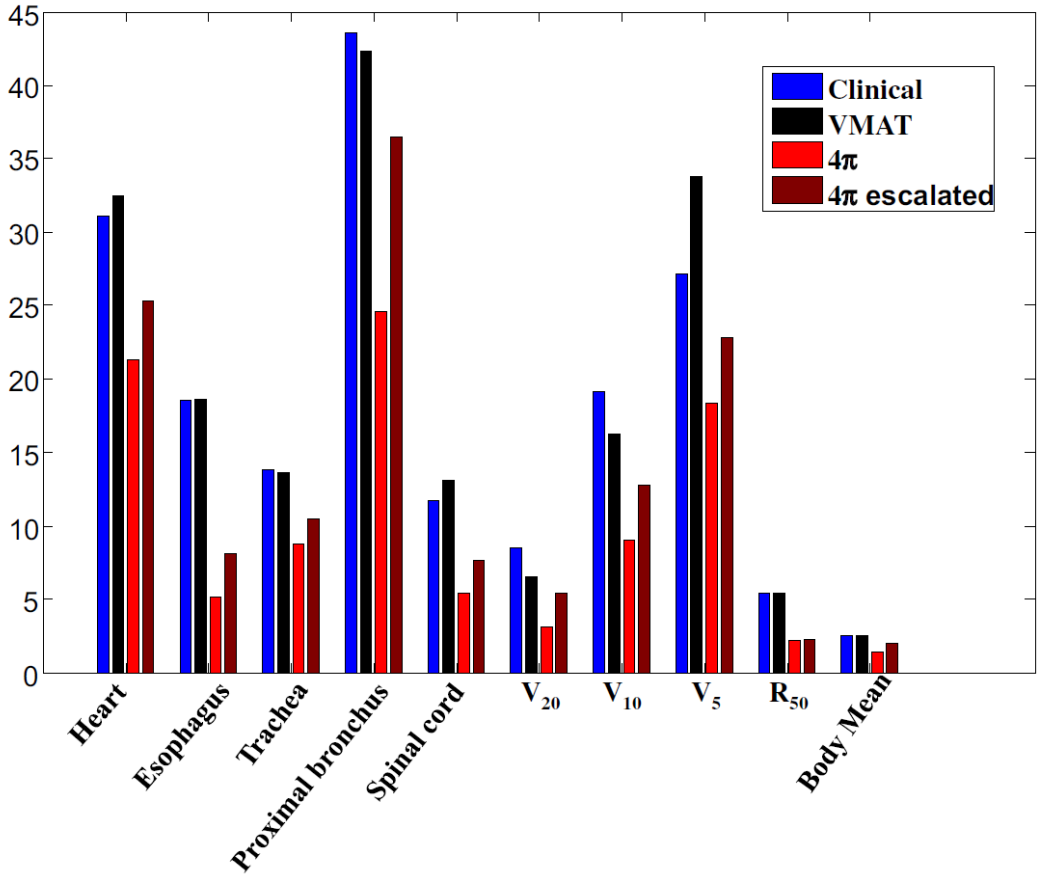

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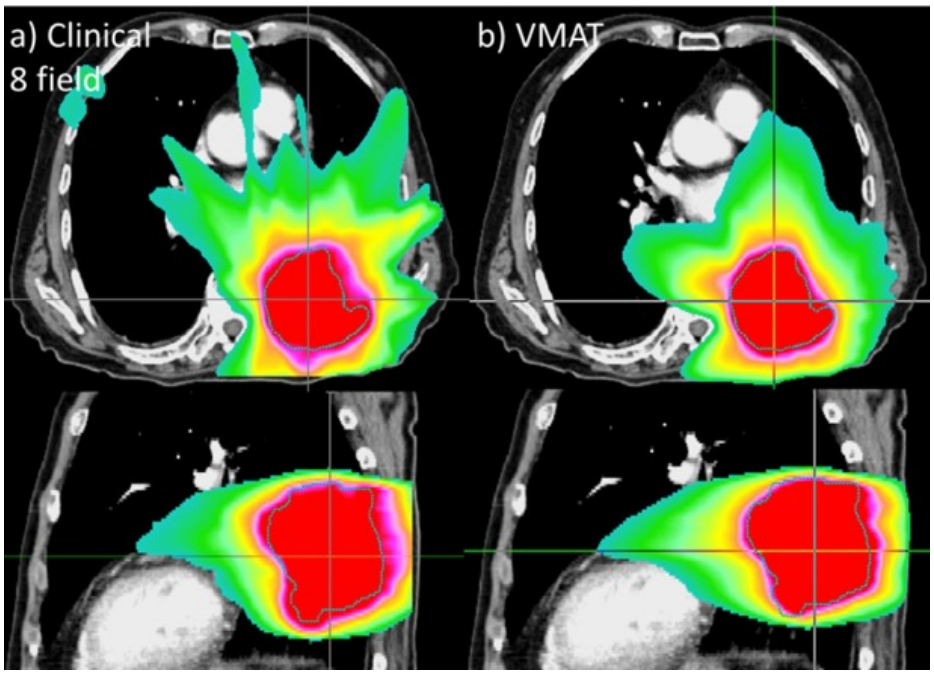

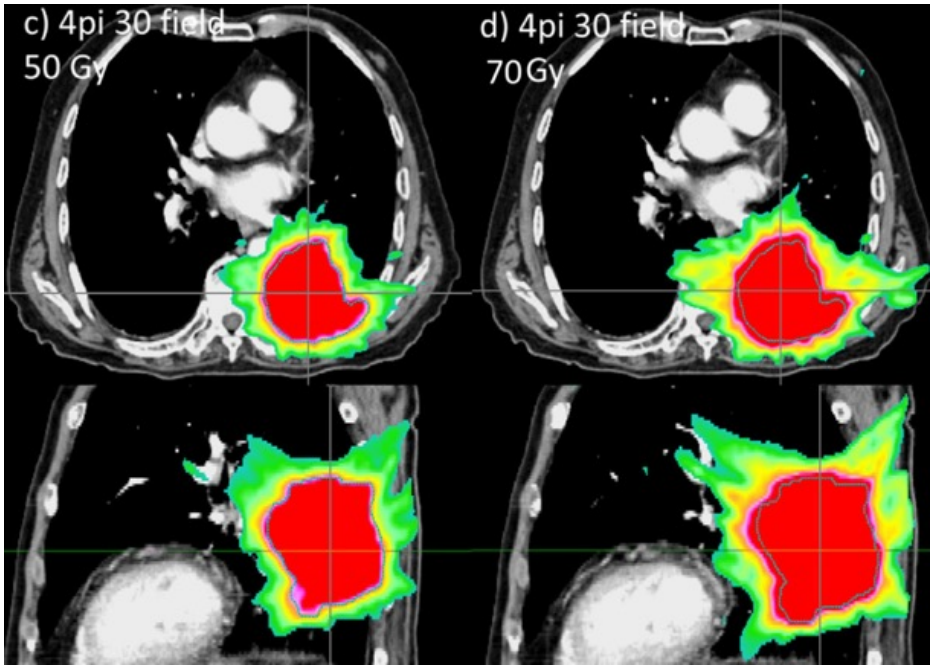

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Klinisches Szenario 2a: Lungen SBRT zentral

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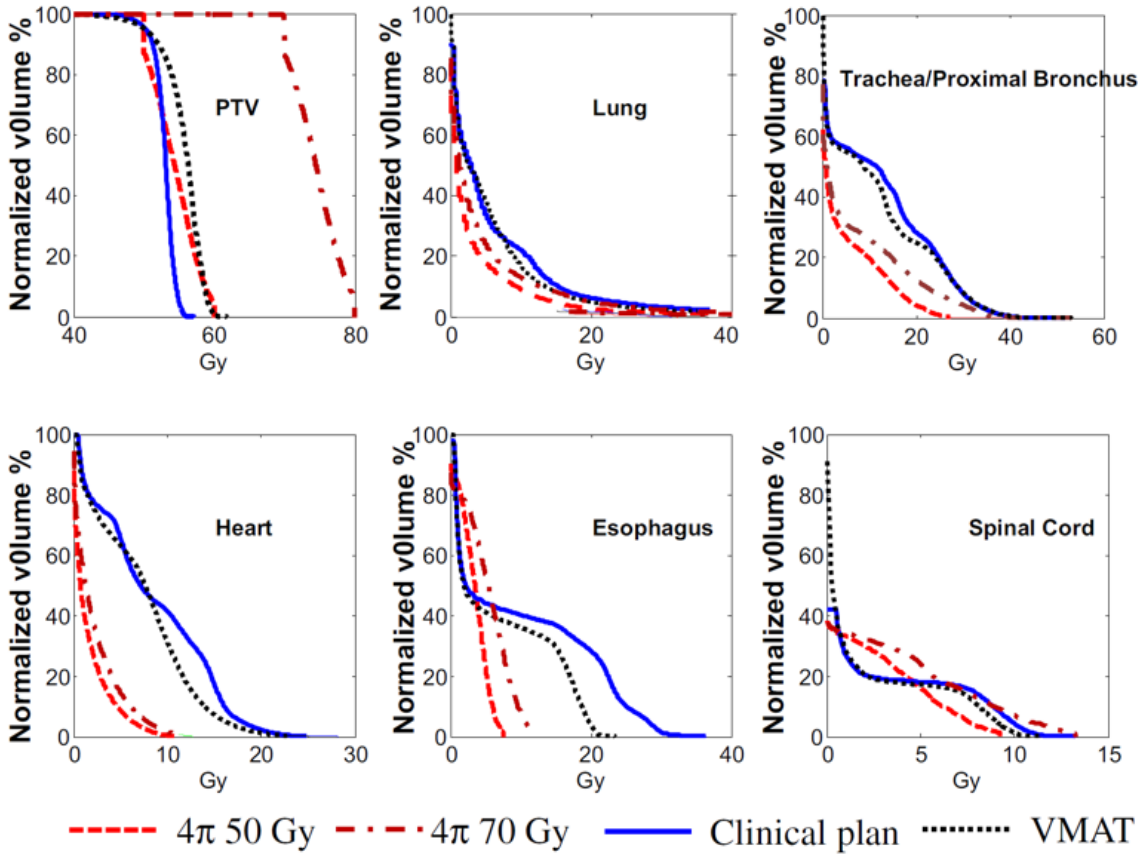
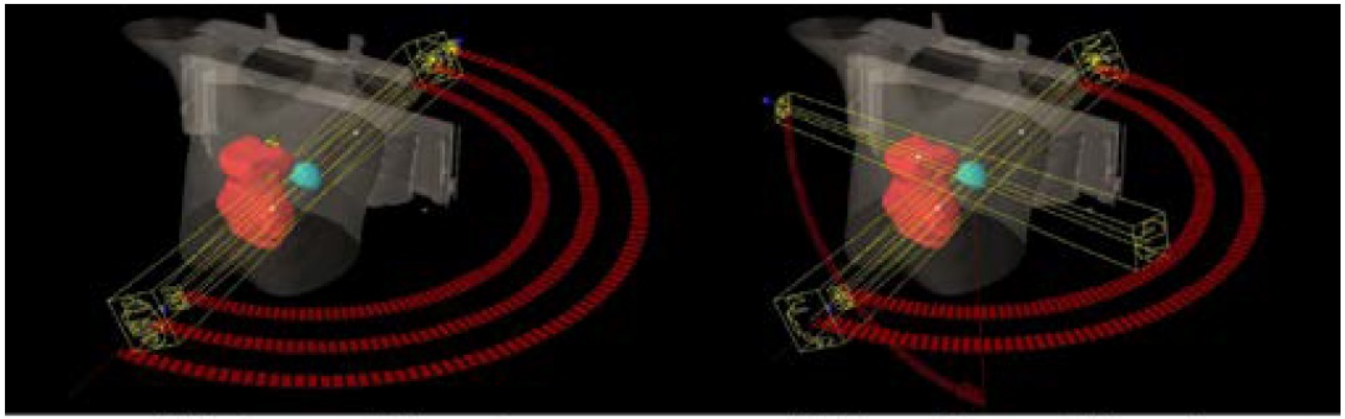


Dong P., Sheng K et al. IJROB 2013

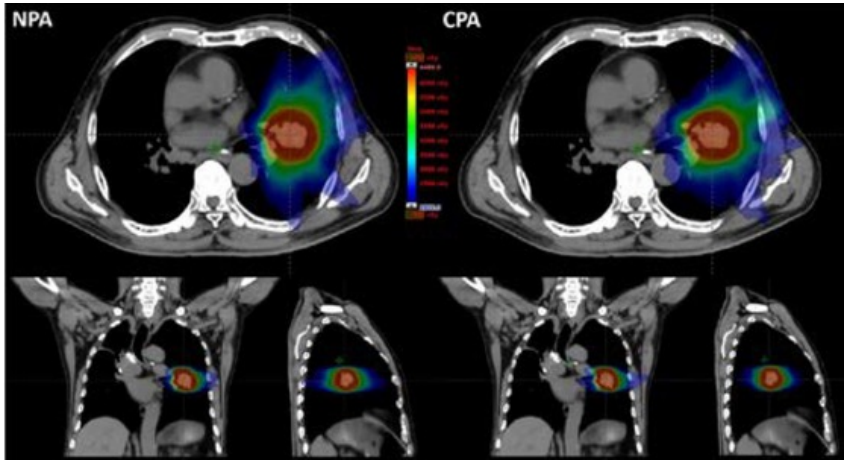
Klinisches Szenario 2b: Lungen SBRT

Non-Coplanar Lung SBRT: Tumore in Herznähe

n=20, Dosis 48-54Gy in 4#, VMAT-SBRT Coplanar 3 Arcs vs Non Coplanar 3 Arcs



(a) Coplanar partial arc plan (b) Non-coplanar partial arc plan



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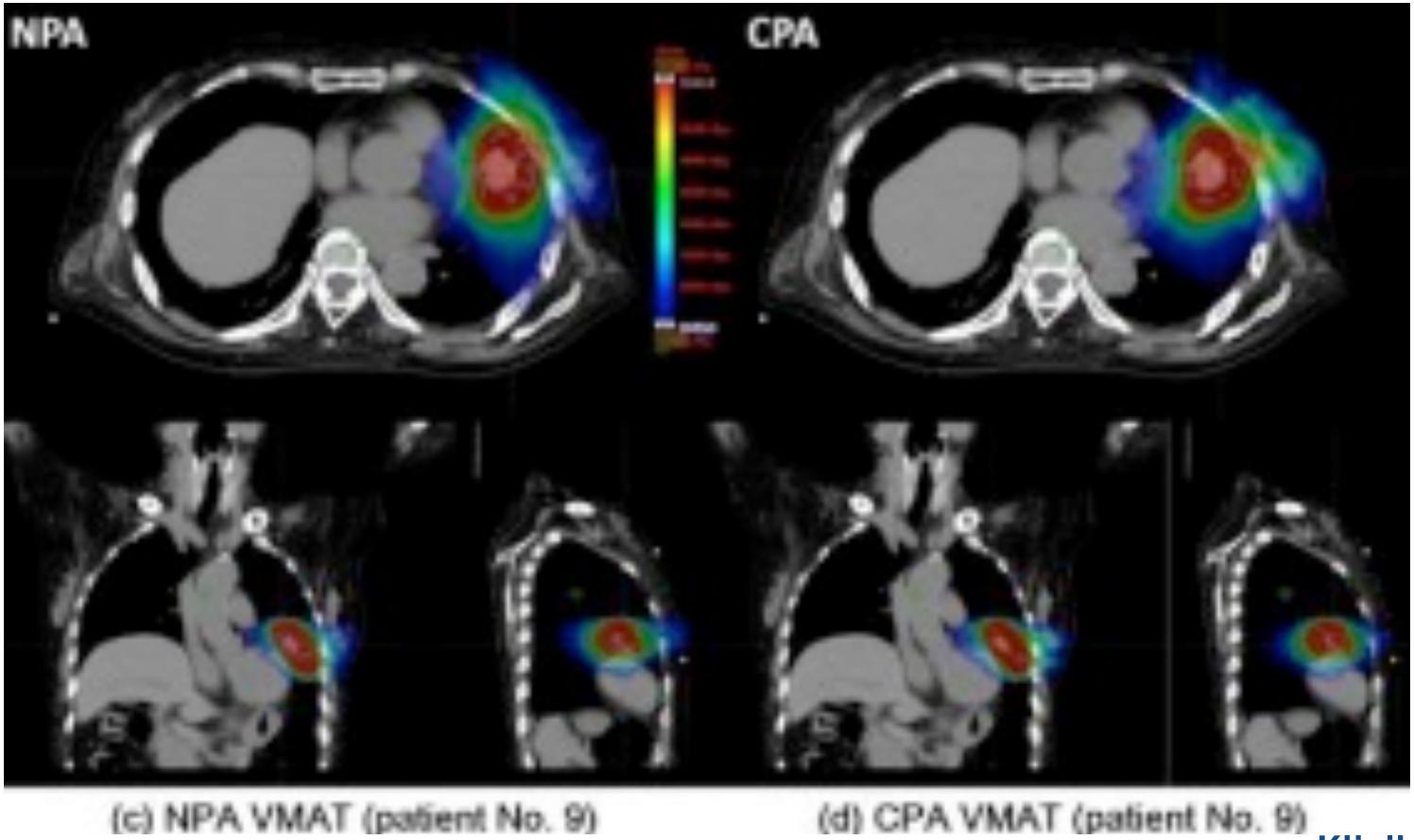
Klinisches Szenario 2b: Lungen SBRT

Non-Coplanar Lung SBRT: Tumore in Herznähe

n=20, Dosis 48-54Gy in 4#, VMAT-SBRT Coplanar 3 Arcs vs Non Coplanar 3 Arcs



Kim S-T et al. Br J Radiol 2020

Klinisches Szenario 2b: Lungen SBRT

Non-Coplanar Lung SBRT: Tumore in Herznähe

n=20, Dosis 48-54Gy in 4#, VMAT-SBRT Coplanar 3 Arcs vs Non Coplanar 3 Arcs

DV parameter	Coplanar VMAT	Non-coplanar VMAT	*p*
Maximum dose (Gy)	62.86 ± 2.66	62.78 ± 3.39	0.739
Mean dose (Gy)	60.28 ± 2.92	60.15 ± 3.42	0.524
Minimum dose (Gy)	51.03 ± 10.76	50.37 ± 11.18	*0.043*
$D_{98\%}$ (Gy)	57.31 ± 5.18	57.34 ± 5.18	0.765
$D_{95\%}$ (Gy)	58.50 ± 3.73	58.50 ± 3.73	-
$D_{5\%}$ (Gy)	61.47 ± 2.75	61.31 ± 3.35	0.480
$D_{2\%}$ (Gy)	61.72 ± 2.75	61.55 ± 3.35	0.486
Homogeneity index	0.075 ± 0.052	0.072 ± 0.046	0.518
Conformity index	1.008 ± 0.032	1.001 ± 0.029	0.226

DV parameter, dose-volumetric parameter; $D_{n\%}$, dose received by at least *n*% volume of the planning target volume.; VMAT, volumetric modulated arc therapy.

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Klinisches Szenario 2b: Lungen SBRT

Non-Coplanar Lung SBRT: Tumore in Herznähe

n=20, Dosis 48-54Gy in 4#, VMAT-SBRT Coplanar 3 Arcs vs Non Coplanar 3 Arcs

DV parameter	Coplanar VMAT	Non-coplanar VMAT	*p*
Heart			
Maximum dose (Gy)	32.40 ± 14.33	25.72 ± 12.26	*<0.001*
Mean dose (Gy)	2.85 ± 1.93	2.34 ± 1.72	*<0.001*
$D_{0.1cc}$ (Gy)	29.42 ± 13.37	21.71 ± 9.20	*<0.001*
$D_{2\%}$ (Gy)	15.10 ± 6.75	12.53 ± 6.49	*<0.001*
V_{34Gy} (cm^3)	1.13 ± 2.23	0.00 ± 0.01	*0.041*
V_{28Gy} (cm^3)	2.51 ± 4.11	1.72 ± 3.30	*0.004*
V_{20Gy} (cm^3)	31.04 ± 10.59	24.32 ± 8.04	*<0.001*
V_{10Gy} (cm^3)	143.01 ± 43.18	110.68 ± 36.19	*<0.001*
Esophagus			
Mean dose (Gy)	1.57 ± 0.81	1.22 ± 0.58	*<0.001*
V_{30Gy} (cm^3)	0.00 ± 0.00	0.00 ± 0.00	-
$V_{18.8\,Gy}$ (cm^3)	0.01 ± 0.02	0.00 ± 0.00	0.330
Trachea and bronchi			
$D_{2\%}$ (Gy)	12.41 ± 8.46	10.76 ± 7.54	*0.006*
$D_{0.1cc}$ (Gy)	15.47 ± 10.64	13.99 ± 10.67	*0.023*
$V_{34.8\,Gy}$ (cm^3)	0.02 ± 0.06	0.02 ± 0.09	0.623
$V_{15.6\,Gy}$ (cm^3)	1.14 ± 2.45	0.75 ± 1.77	0.073

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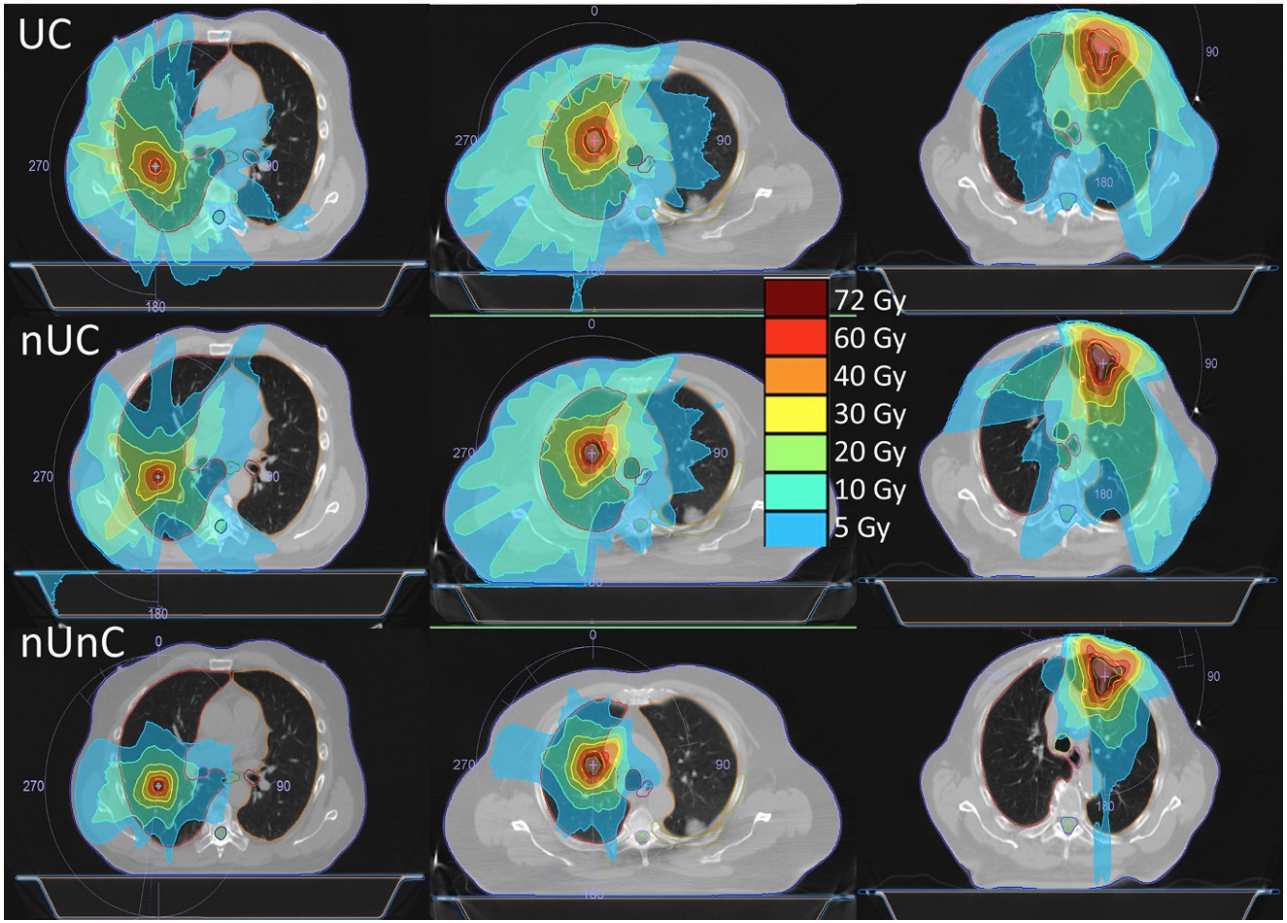
Klinisches Szenario 2c: Lungen SBRT

Non-Coplanar Lung SBRT: Tumore in Herznähe

n=46, Dosis 60Gy in 5#, VMAT Coplanar vs Non Coplanar 5Teilarcs

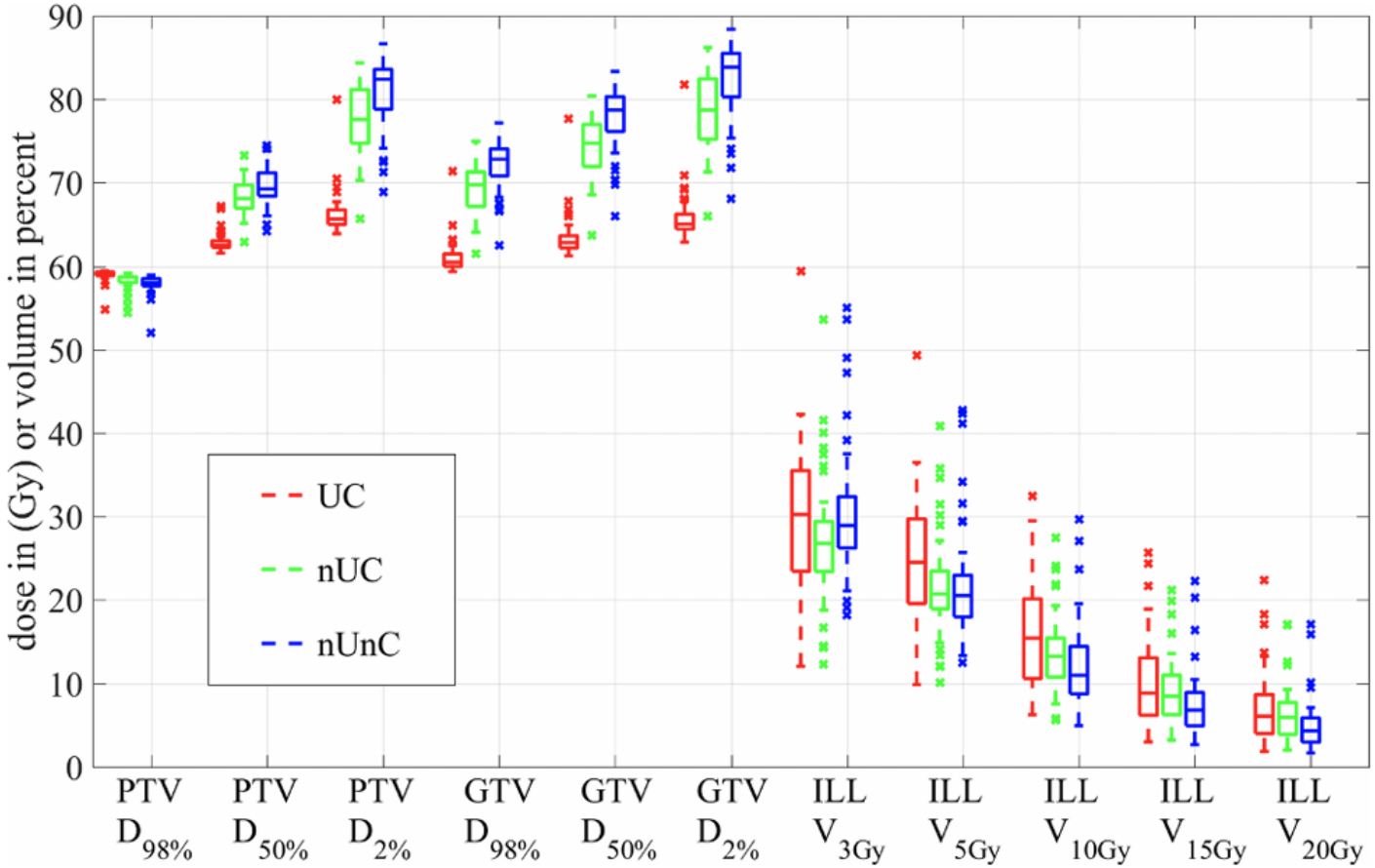


Fleckenstein J et al. STO 2018

Klinisches Szenario 2c: Lungen SBRT

Non-Coplanar Lung SBRT: Tumore in Herznähe

n=46, Dosis 48-54Gy in 4#, VMAT-SBRT Coplanar vs Non Coplanar 5Teilarcs



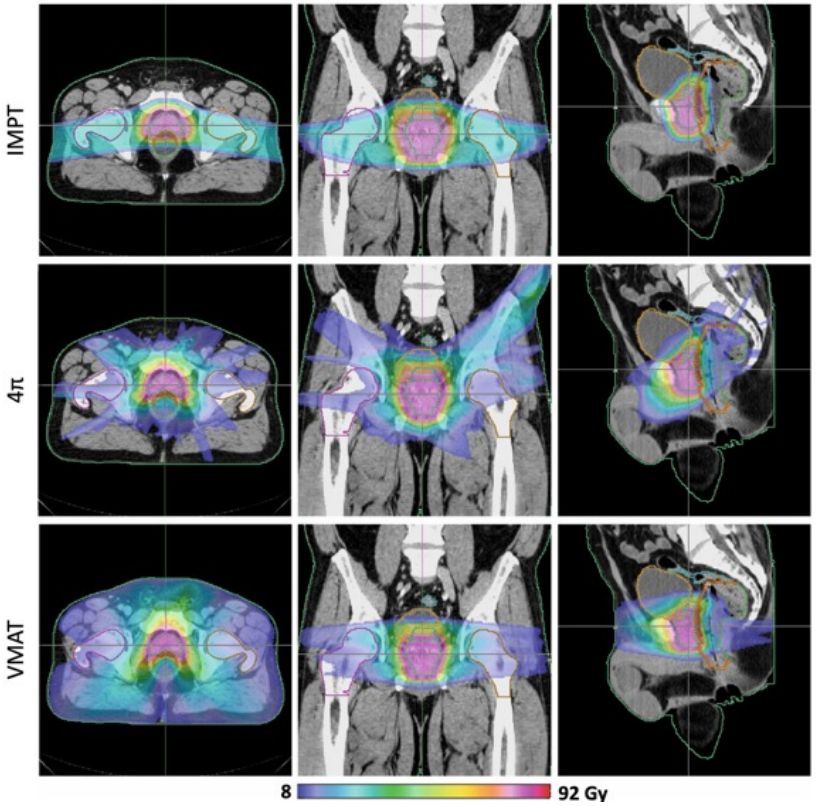
Fleckenstein J et al. STO 2018

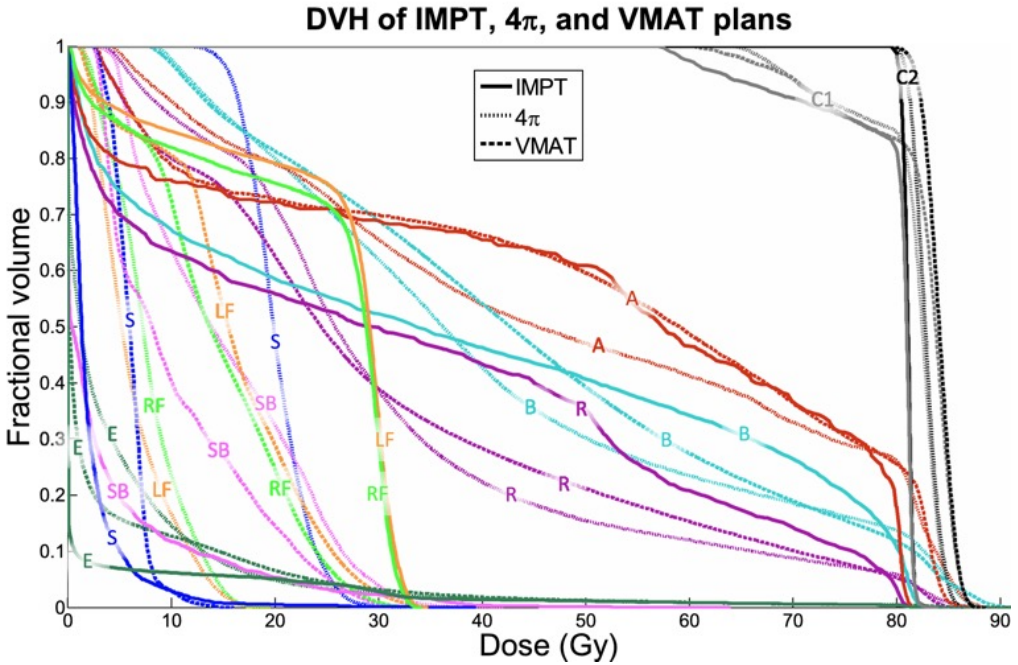
. 2017

Klinisches Szenario 3: Prostatabestrahlung

Planungsstudie: Protonen, VMAT, non-coplanare RT

n=10, Dosis 79,2Gy in 40#, 2 Feder IMPT, VMAT (2arcs) und 30 non-coplanare Felder





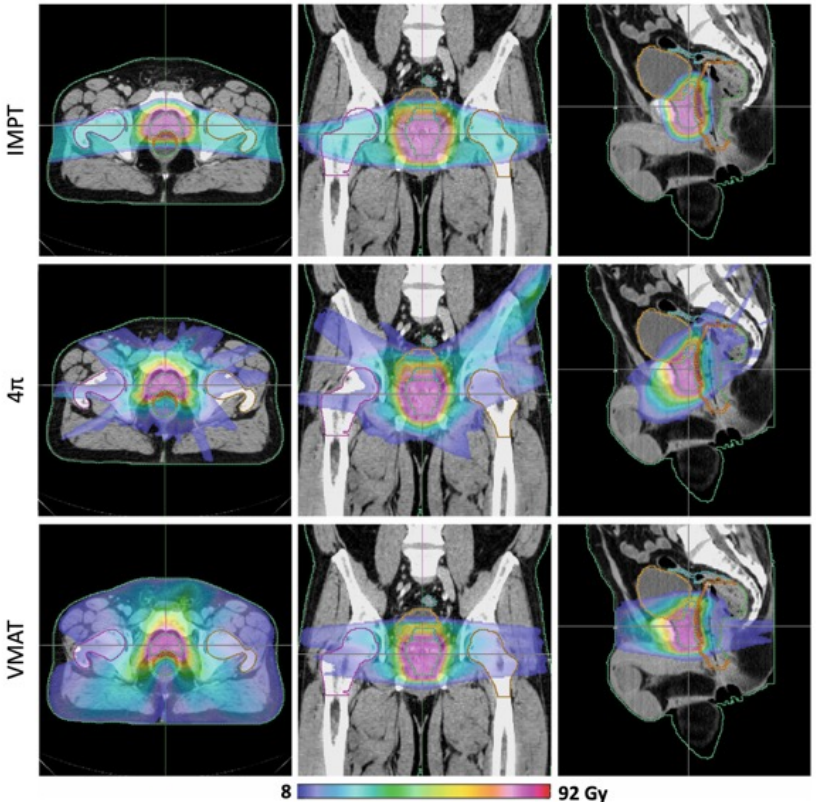
Tran A., Sheng K Radiat Oncol 2017

. 2017

Klinisches Szenario 3: Prostatabestrahlung

Planungsstudie: Protonen, VMAT, non-coplanare RT

n=10, Dosis 79,2Gy in 40#, 2 Feder IMPT, VMAT (2arcs) und 30 non-coplanare Felder

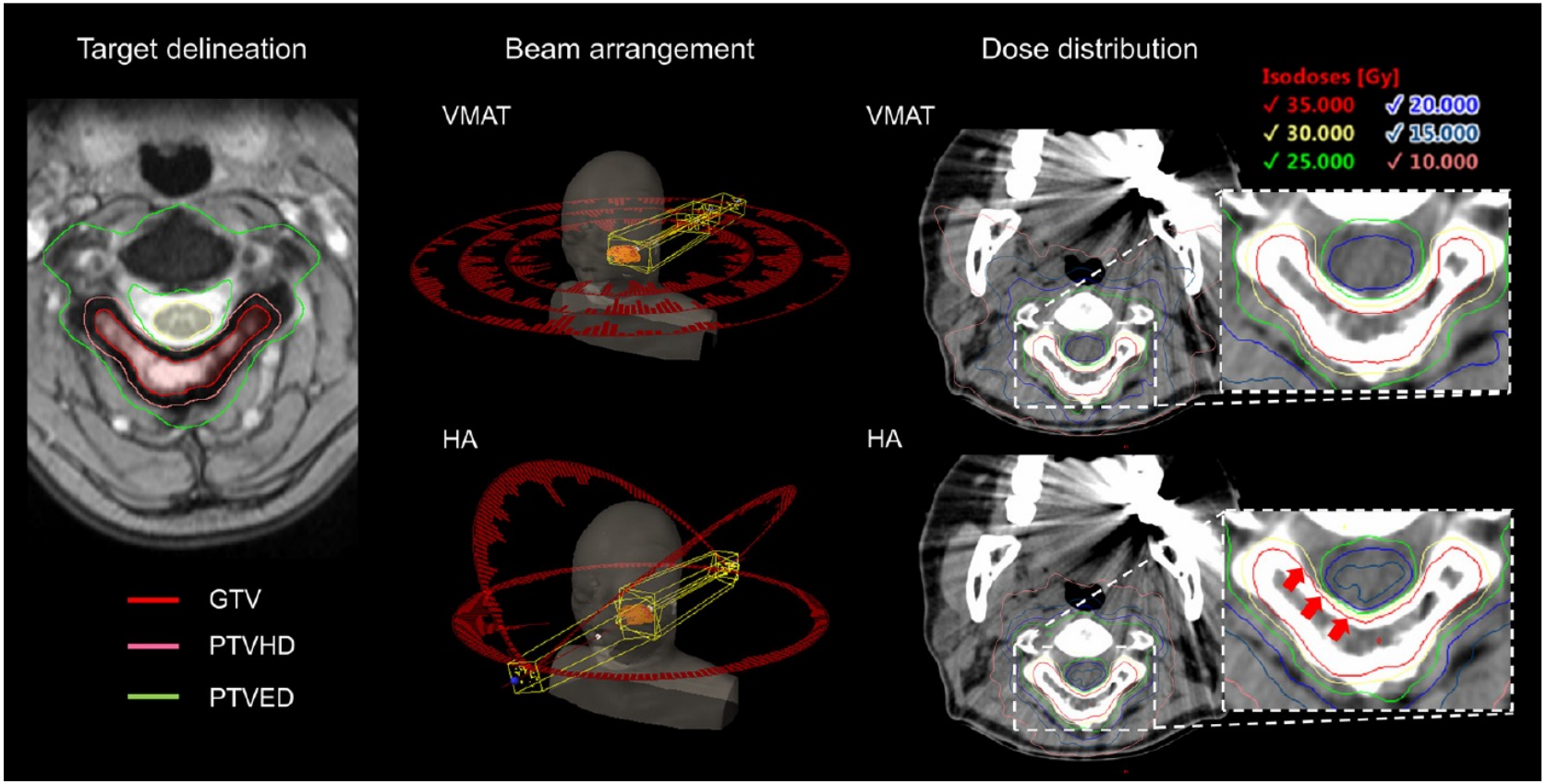


- IMPT bessere CTV Homogenität und Max Dosis bei OAR´s
- 4π bessere mittlere Rektum und Blasendosis.
- 4π im Vergl. VMAT dosimetrisch überlegen.

Tran A., Sheng K Radiat Oncol 2017

Klinisches Szenario 4: Spinale SBRT

n = 11 Knochenmetastasen, SIB Technik 35-40Gy (PTVHD) und 20-25 Gy (PTVED)



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Klinisches Szenario 4: Spinale SBRT

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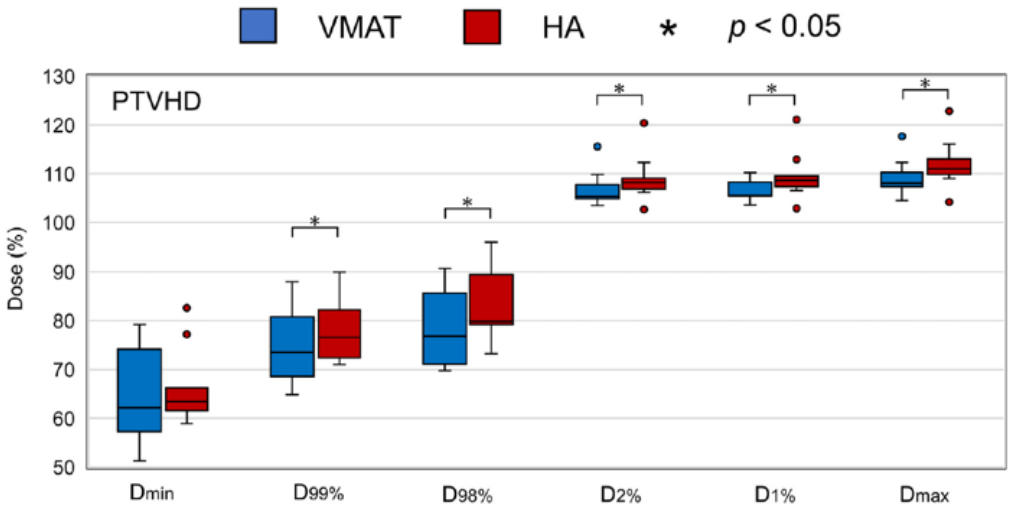

Dosimetric parameters for OARs

Structure	Dosimetric parameter	VMAT		HA		*p*-value
		Mean	SD	Mean	SD	
Spinal cord ($n = 11$)	Dmax (Gy)	24.3	2.7	24.5	2.6	n.s.
Esophagus ($n = 6$)	Dma			24.1	4.2	n.s.
Brachial plexus ($n = 6$)	Dma			30.7	2.5	n.s.
Larynx ($n = 11$)	Dme			3.0	1.8	n.s.
Pharyngeal constrictor ($n = 11$)	Dmean (Gy)	9.1	6.4	8.1	5.3	n.s.
Thyroid ($n = 11$)	Dmean (Gy)	3.3	4.0	3.3	3.6	n.s.
Parotid grand (left) ($n = 11$)	Dmean (Gy)	1.2	2.0	1.8	1.2	n.s.
Parotid grand (right) ($n = 11$)	Dmean (Gy)	1.4	2.4	1.6	0.8	n.s.
Submandibular gland (left) ($n = 11$)	Dmean (Gy)	1.6	2.1	2.3	1.0	n.s.
Submandibular gland (right) ($n = 11$)	Dmean (Gy)	1.9	2.5	2.4	1.0	n.s.
Entire body ($n = 11$)	V_{20Gy} (cm^3)	87.0	53.3	74.4	47.7	0.004
	V_{15Gy} (cm^3)	150.9	88.3	113.1	73.1	0.003
	V_{10Gy} (cm^3)	288.3	160.0	199.6	129.6	0.003

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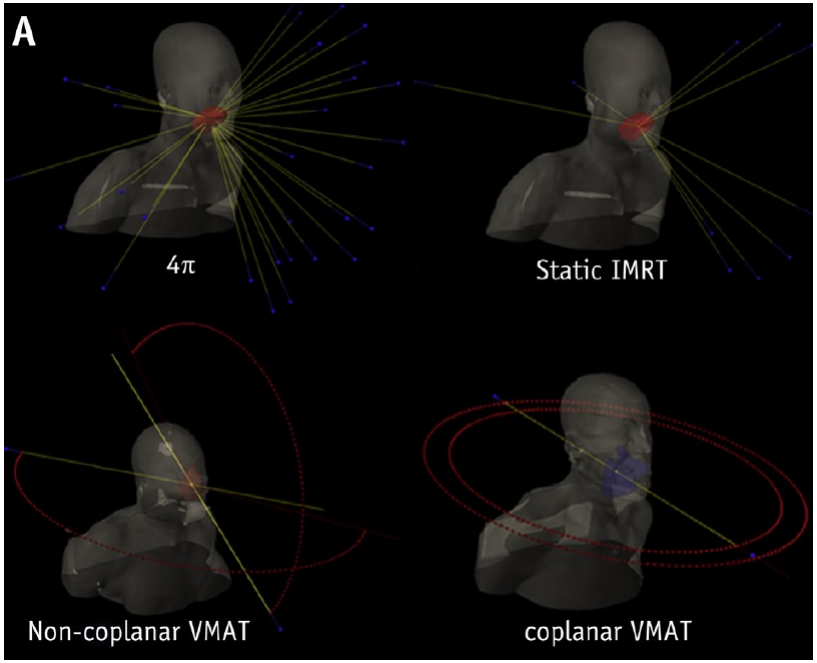
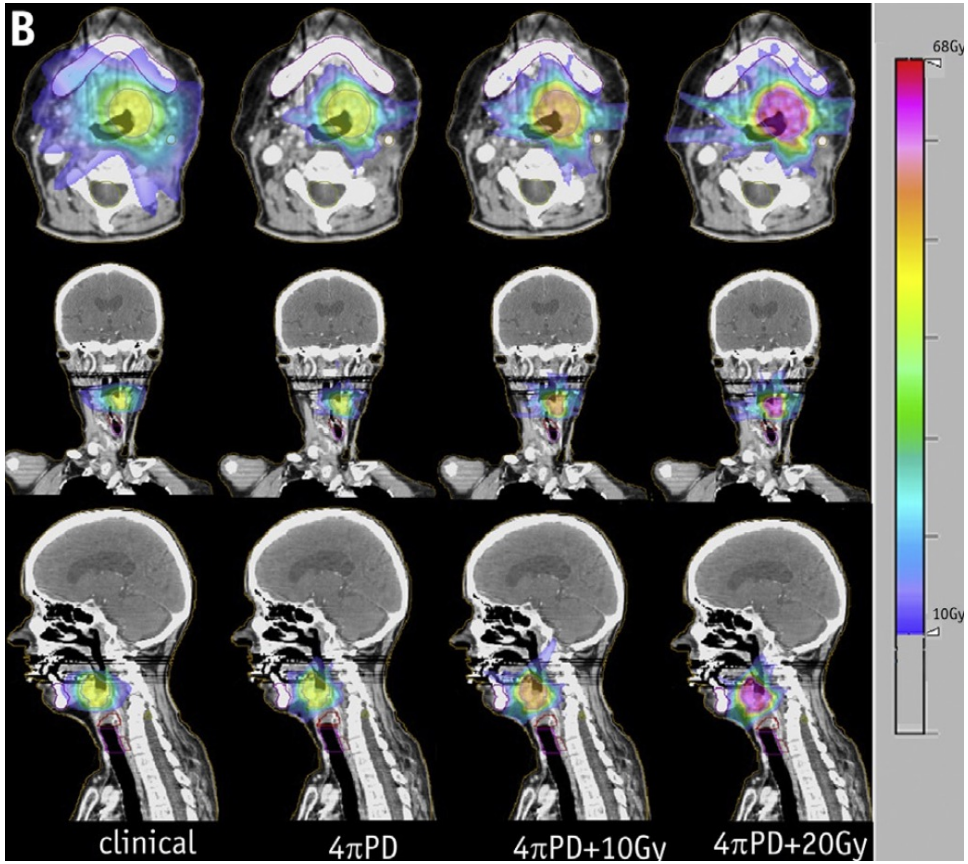
Klinisches Szenario 5: Head and Neck SBRT

n = 27 (29 Rezidivtumore) Kopf-Hals, SIB Technik 35-44 in 5#Gy,





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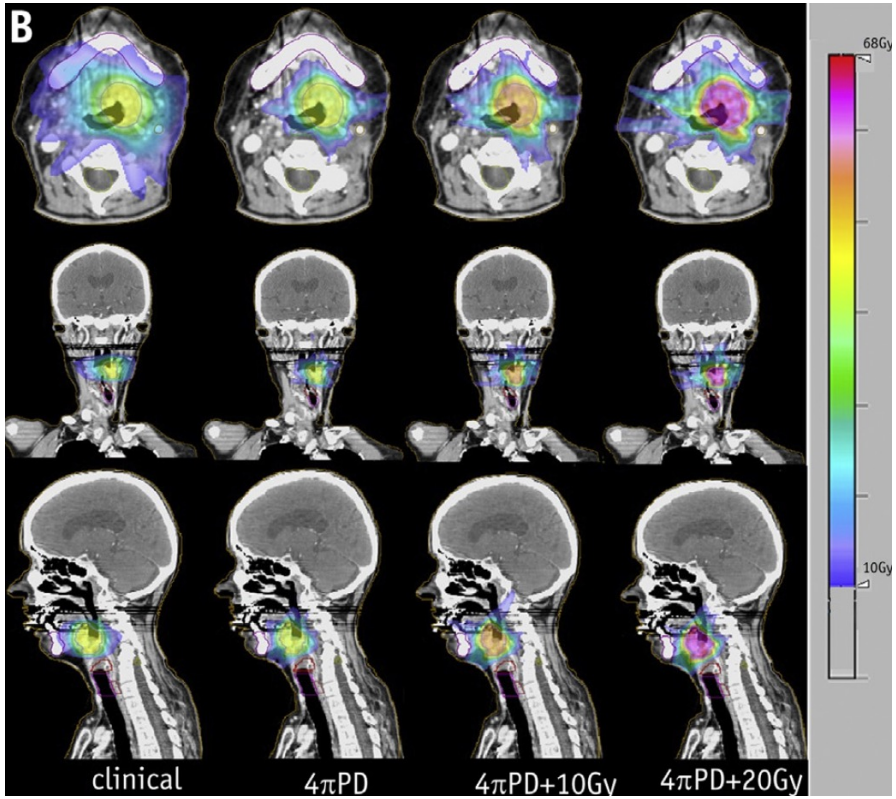
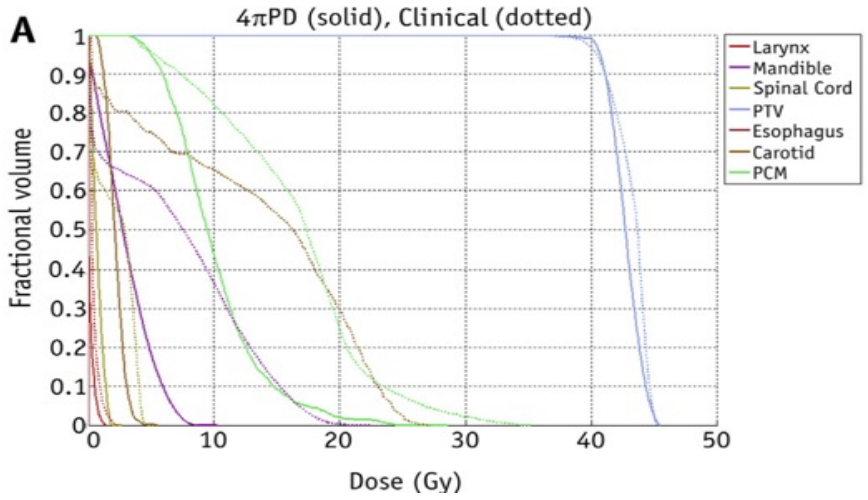
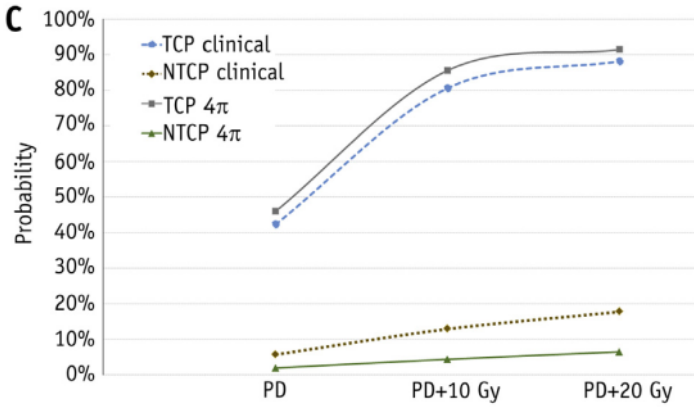
Klinisches Szenario 5: Head and Neck SBRT

n = 27 (29 Rezidivtumore) Kopf-Hals, SIB Technik 35-44 in 5#Gy,







Rwigema JC et al. IJROB 2014

Extrakranielle non-coplanare Bestrahlung
– Zusammenfassung –

Besondere Bedeutung bei stereotaktischen Hochpräzisionstherapien, extremer Hypofraktionierung, Schonung von OAR´S, Dosiseskalation

Con´s

- Komplexe Planung
- Höheres Risiko für Einstellungsfehler
- Erhöhtes Kollisionsrisiko
- Behandlungszeit
- Nur geringe Planverbesserung

Pro´s

- **steilerer Dosisabfall**
- **bessere Konformität**
- **bessere Schonung OAR´s**
- **weniger Nebenwirkungen**
- **Dosiseskalation**
- **bessere lokale Kontrolle**

Realität? Praxis?

KlinikumDarmstadt GmbH
Akademisches Lehrkrankenhaus

Extrakranielle non-coplanare Bestrahlung – Muss oder Spielerei –

Extrakranielle non-coplanare Bestrahlung

Nutzung in der Routine

in Ausnahmefällen vorstellbar

eher Spielerei

KlinikumDarmstadt GmbH
Akademisches Lehrkrankenhaus

DKG KREBSGESELLSCHAFT
Zertifiziertes Onkologisches Zentrum

Gemeinsam fürs