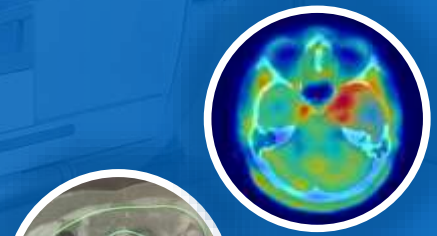
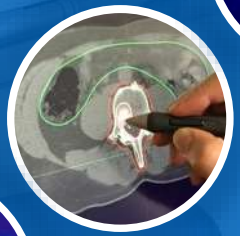
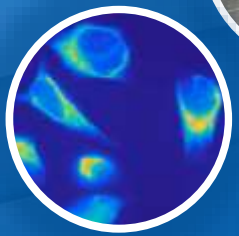
RadioOnkologie und Strahlentherapie
Fakultät für Medizin
Technische Universität München

Implantate und andere Unsicherheiten in der SBRT der Wirbelsäule







Christoph Straube

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Institut für Strahlenmedizin (IRM)

München, 22.11.2019

RadioOnkologie und Strahlentherapie
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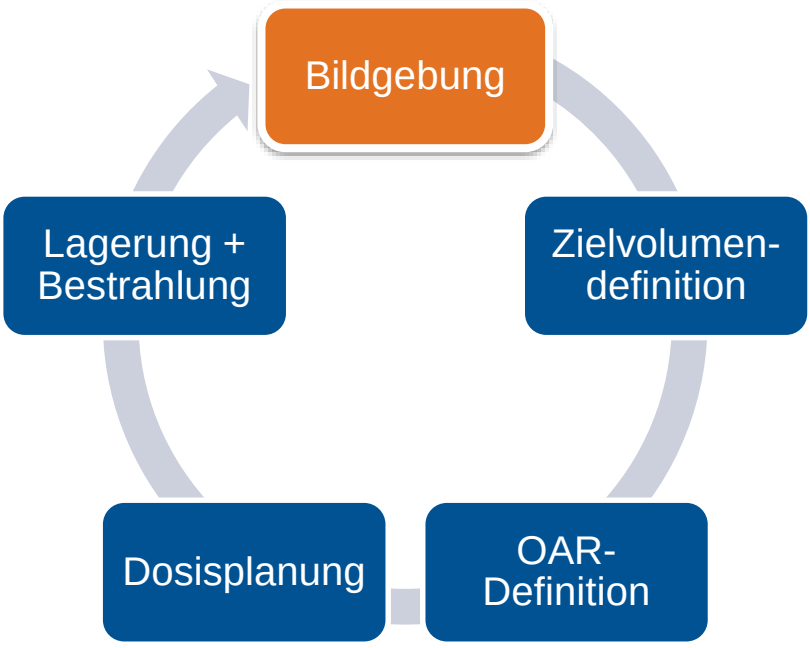
Technische Universität München

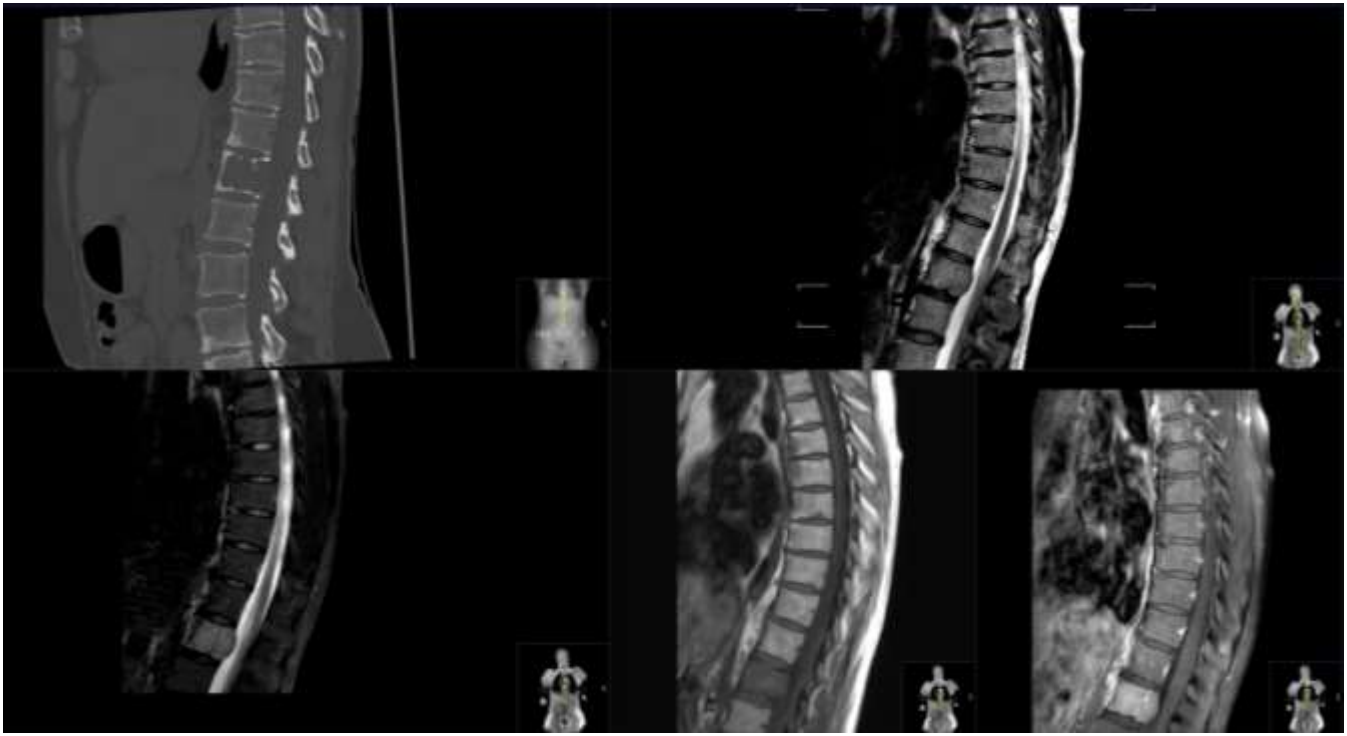
IRM MRI TUM

SBRT spinaler Metastasen – Implantate und andere Unsicherheiten

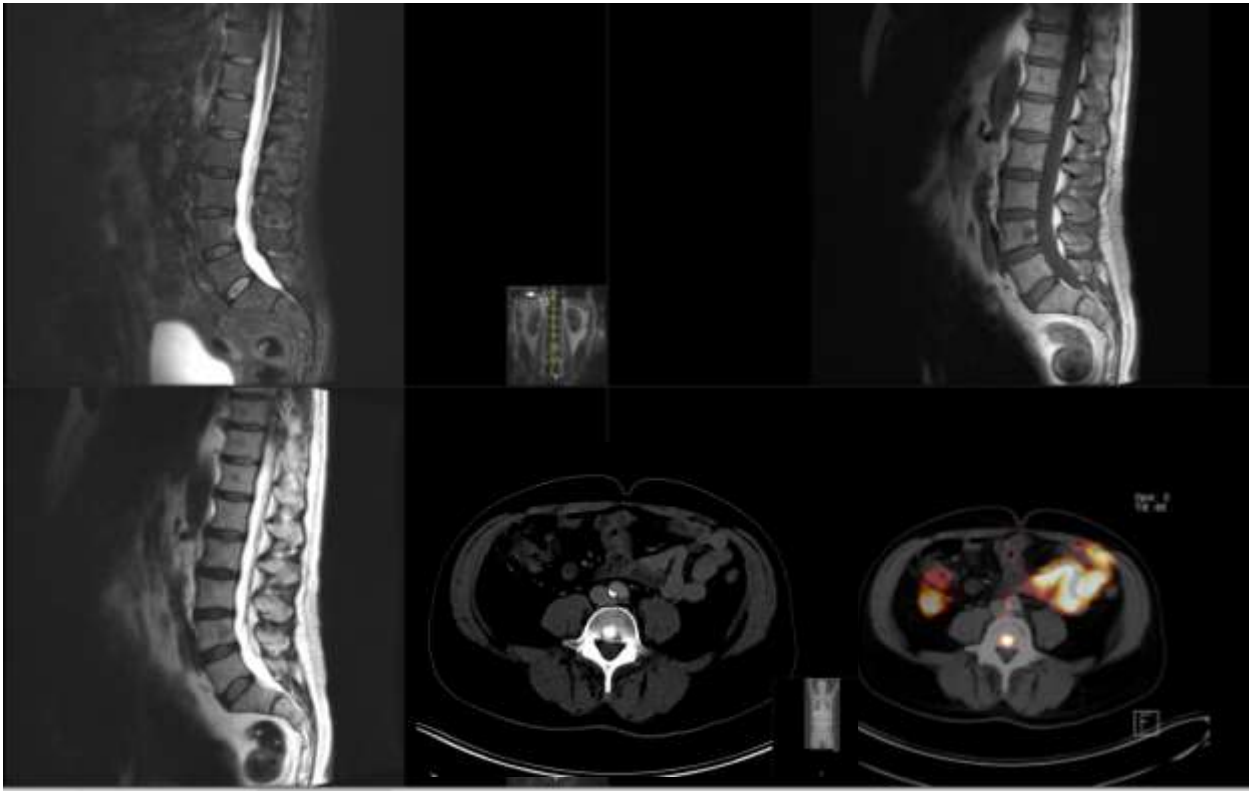
Um was wird es gehen?



Bildgebung– lytische Metastase



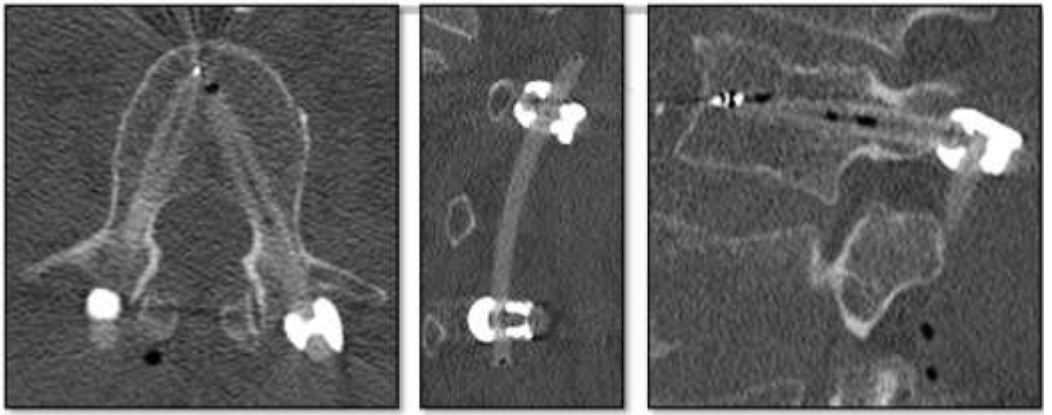
Bildgebung – osteoplastische Metastase



CT bei Implantaten

Fig. 2. Comparison of computed tomography images taken at the disc level. (Left) Stainless steel; (Middle) titanium; and (Right) vitallium.

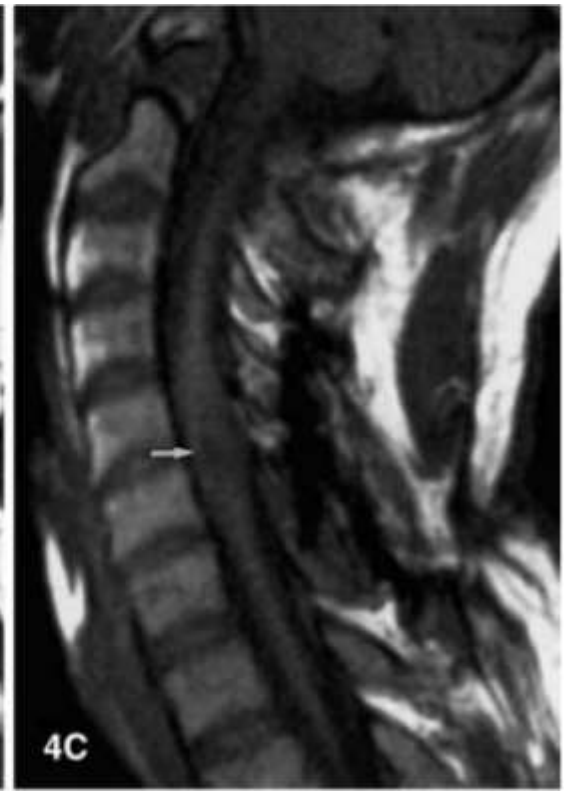
Stahl
Titan
Vitallium

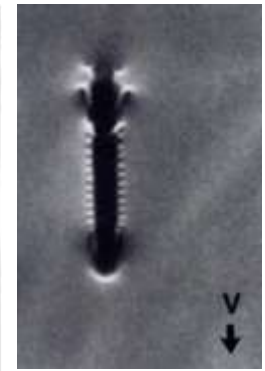


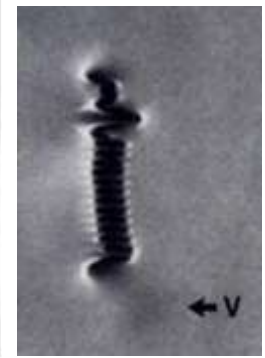
PEEK

Knott PT, The Spine Journal, 2010 | Ringel F, World Neurosurgery 2016

Limitationen des MRT: Verzerrung durch Implantate

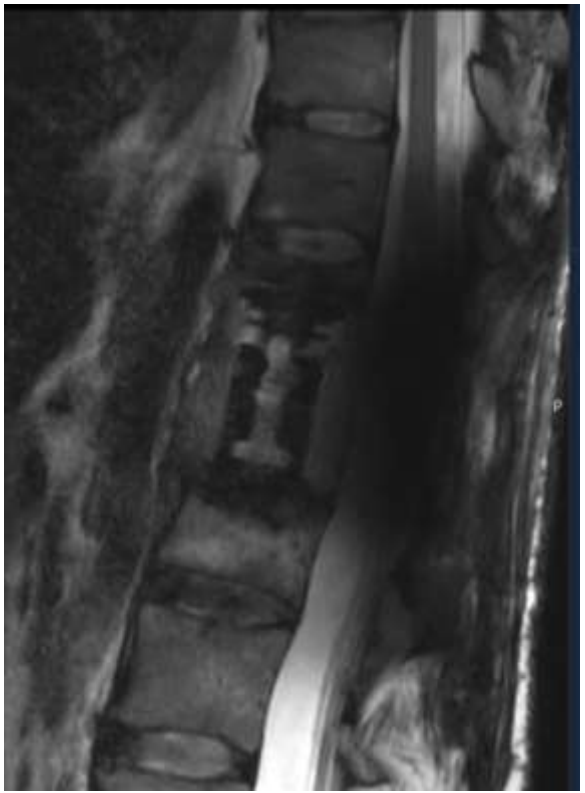


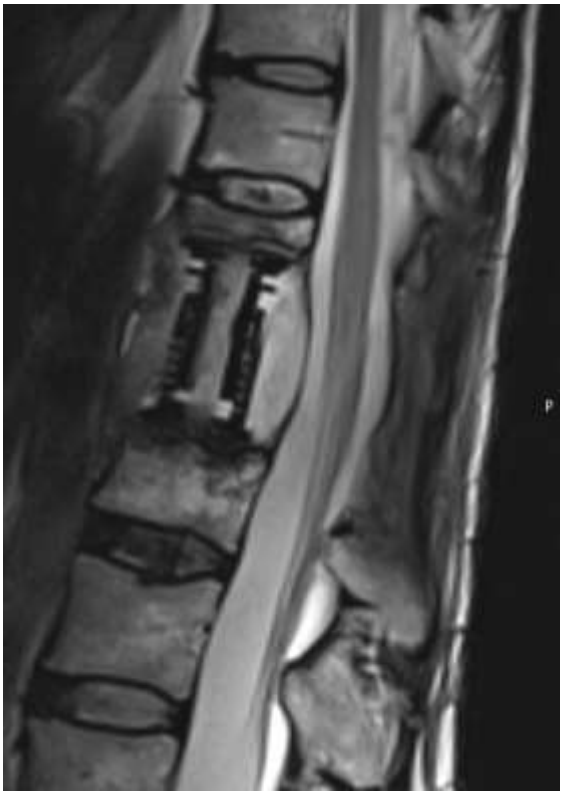




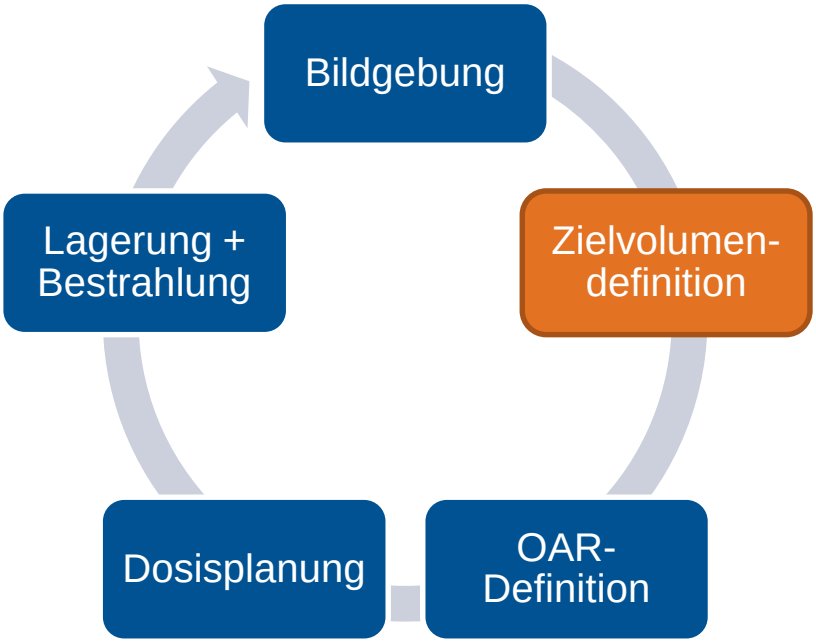
Chang SD, Skeletal Radiol 2001 | Links: T1 – Rechts: T1-MARS - beides 1,5 T MRT | ganz rechts: Frazzini VI 1997

Limitationen des MRT: Signalverlust durch Artefakte





Lokalrezidiv bei Osteosarkom – PEEK-WKE + Icotec-Schrauben | Links T2 auf 3T-MRT; Rechts T2-WARP 1,5T

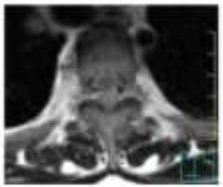
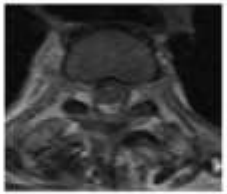
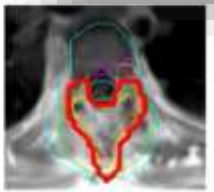
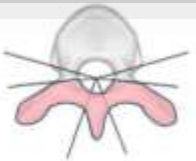
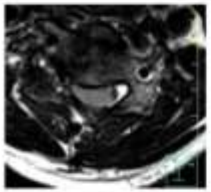
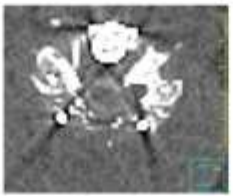
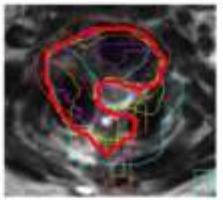
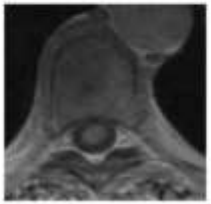
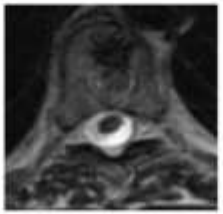
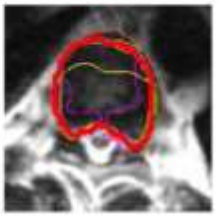
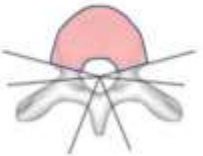

Bildgebung
Zielvolumen-definition
OAR-Definition
Dosisplanung
Lagerung + Bestrahlung

Inter-Observer-Heterogenität

Int J Radiat Oncol Biol Phys 2017 January 01; 97(1): 64–74. doi:10.1016/j.ijrobp.2016.09.014.

Consensus Contouring Guidelines for Post-Operative Stereotactic Body Radiation Therapy (SBRT) for Metastatic Solid Tumor Malignancies to the Spine

Kristin J. Redmond, M.D., M.P.H.[1], Scott Robertson, Ph.D.[1], Simon S. Lo, M.D., F.A.C.R.[2], Scott G. Soltys, M.D.[3], Samuel Ryu, M.D.[4], Todd McNutt, Ph.D.[1], Samuel T. Chao, M.D.[5], Yoshiya Yamada, M.D.[6], Amol Ghia, M.D.[7], Eric L. Chang, M.D.[8], Jason Sheehan, M.D., Ph.D.[9], and Arjun Sahgal, M.D., F.R.C.P.C.[10]

Patient number	Pre-operative axial MRI	Post-operative axial CT myelogram or T2 MRI	Simula	
7				
8				
9				

Redmond KJ, Int J Radiat Oncol Biol Phys, 2017

Inter-Observer-Heterogenität

Absolute kappa agreement, sensitivity and specificity for CTV target delineation between participating spinal oncology specialists based on the STAPLE analysis.

	CTV				PTV			
Case	Mean sensitivity (average +/− SD)	Mean specificity (average +/− SD)	Kappa measure	P value	Mean sensitivity (average +/− SD)	Mean specificity (average +/− SD)	Kappa measure	P value
1	0.74 +/− 0.22	0.95 +/− 0.07	0.57	<0.001	0.74 +/− 0.20	0.96 +/− 0.06	0.59	<0.001
2	0.76 +/− 0.23	0.93 +/− 0.09	0.52	<0.001	0.75 +/− 0.24	0.92 +/− 0.12	0.53	<0.001
3	0.77 +/− 0.26	0.99 +/− 0.02	0.70	<0.001	0.70 +/− 0.24	0.99 +/− 0.02	0.66	<0.001
4	0.86 +/− 0.16	0.91 +/− 0.12	0.63	<0.001	0.87 +/− 0.12	0.88 +/− 0.19	0.60	<0.001
5	0.86 +/− 0.16	0.94 +/− 0.07	0.67	<0.001	0.86 +/− 0.12	0.93 +/− 0.10	0.67	<0.001
6	0.78 +/− 0.28	0.95 +/− 0.05	0.60	<0.001	0.77 +/− 0.22	0.94 +/− 0.10	0.59	<0.001
7	0.71 +/− 0.29	0.93 +/− 0.12	0.43	<0.001	0.71 +/− 0.29	0.90 +/− 0.15	0.37	<0.001
8	0.75 +/− 0.16	0.93 +/− 0.09	0.52	<0.001	0.78 +/− 0.16	0.91 +/− 0.14	0.51	<0.001
9	0.89 +/− 0.20	0.93 +/− 0.07	0.70	<0.001	0.95 +/− 0.04	0.90 +/− 0.11	0.76	<0.001
10	0.77 +/− 0.30	0.90 +/− 0.15	0.46	<0.001	0.80 +/− 0.20	0.87 +/− 0.18	0.47	<0.001

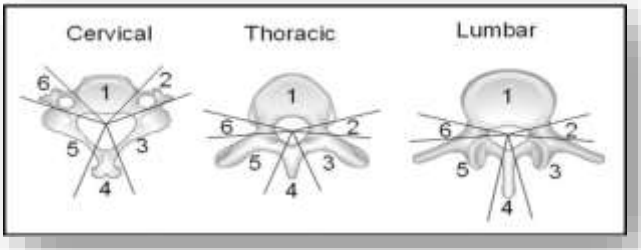
Sensitivität: Voxel in Experten-TV = Voxel im Konsensus-TV

Spezifität: Voxel außerhalb Experten-TV = Voxel außerhalb Konsensus-TV

Kappa: Überlapp Experten-TV vs. Konsensus-TV > Zufall

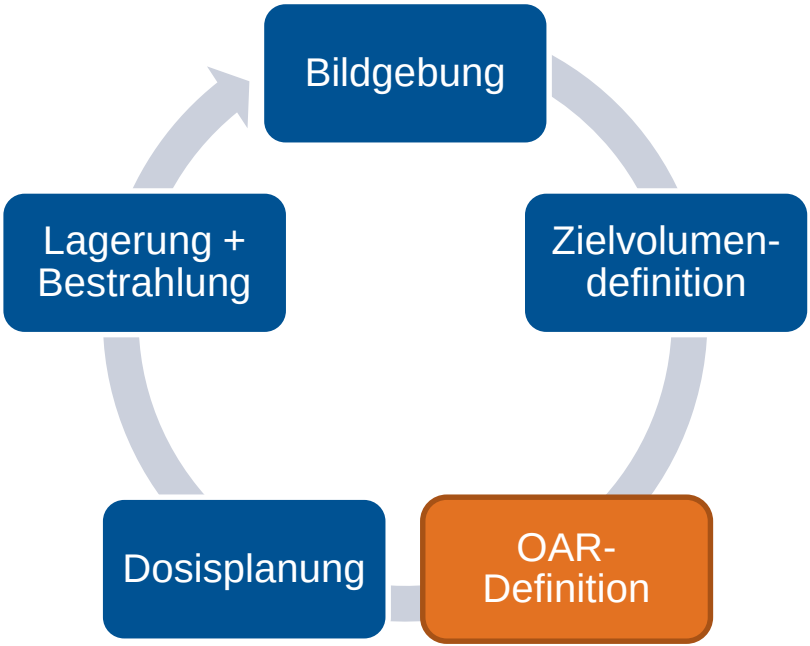
Redmond KJ, Int J Radiat Oncol Biol Phys, 2017

Empfehlungen für Post-OP-SBRT



Target volume	Guidelines
GTV	• Gross tumor based on post-operative CT and MRI with attention to residual epidural or paraspinal disease
	• Include post-operative residual epidural and para-spinal components of tumor
CTV	• Include the post-operative region and entire anatomic compartment corresponding to all pre-operative MRI abnormalities suspicious for tumor involvement
	• Include entire GTV
	• Surgical instrumentation and incision not included unless involved
	• Judicious use of circumferential CTVs limited to cases of pre-operative circumferential osseous and/or epidural involvement; however, can be considered for near-circumferential epidural disease involvement
	• Modified at reconstructed dural space and to account for changes in anatomy following surgery at discretion of treating physician
	• Consider additional anatomic expansions of up to 5 mm beyond para-spinal extension and cranio-caudally for epidural disease
PTV	• Uniform CTV to PTV expansion of up to 2.5 mm
	• Treating physician may modify expansion at the interface with critical organs-at-risk
	• May subtract cord avoidance structure from PTV as a modified PTV for planning and dose reporting purposes
	• Include entire GTV and CTV

Redmond KJ, Int J Radiat Oncol Biol Phys, 2017


Bildgebung
Zielvolumen-definition
OAR-Definition
Dosisplanung
Lagerung + Bestrahlung

Unsicherheit bei der Lokalisation der OAR

„Critical Neural Structures“

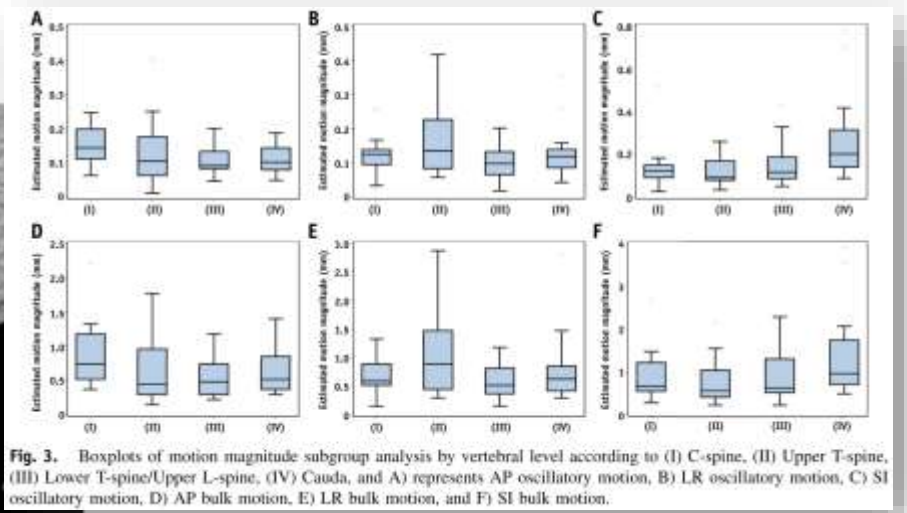


Fig. 3. Boxplots of motion magnitude subgroup analysis by vertebral level according to (I) C-spine, (II) Upper T-spine, (III) Lower T-spine/Upper L-spine, (IV) Cauda, and A) represents AP oscillatory motion, B) LR oscillatory motion, C) SI oscillatory motion, D) AP bulk motion, E) LR bulk motion, and F) SI bulk motion.

Bsp. Ösophagus

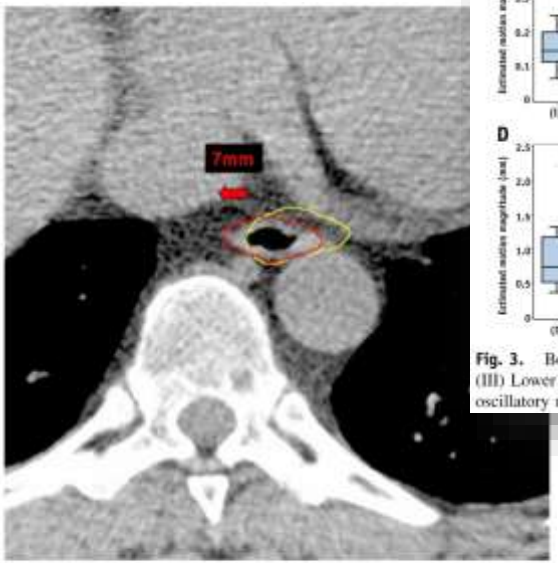
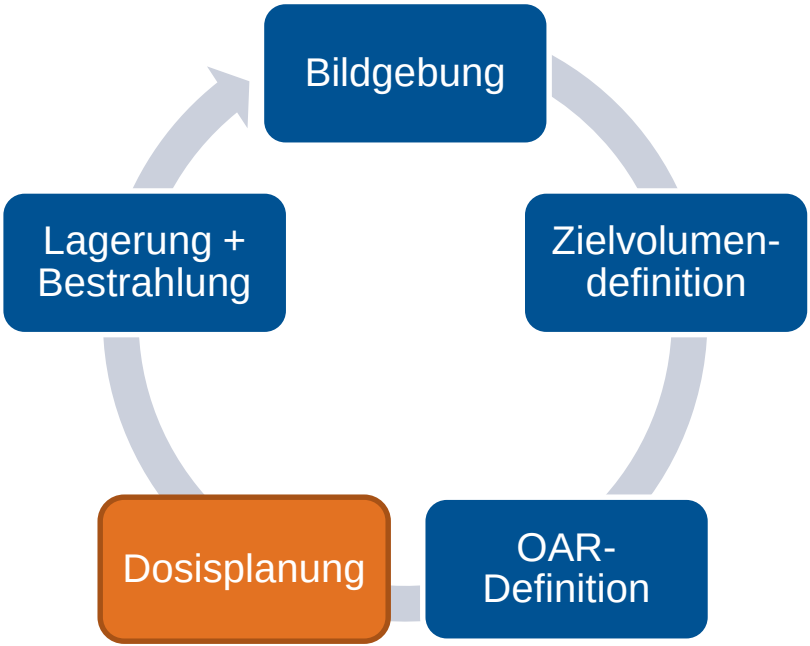


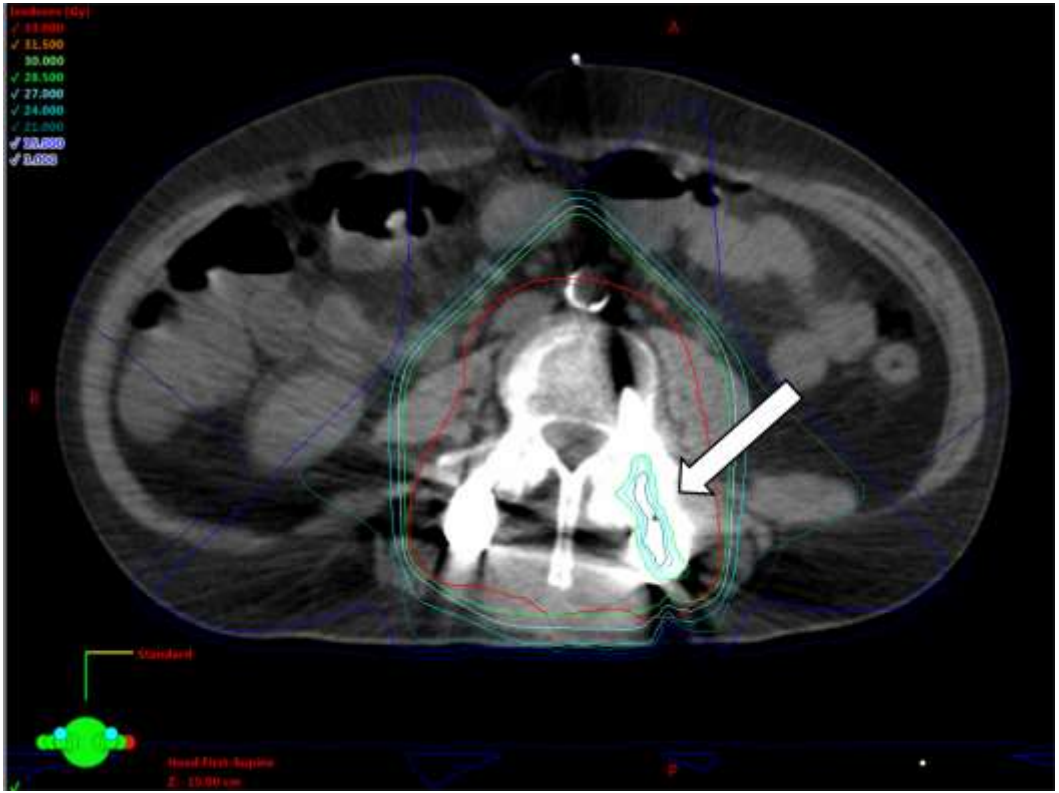
Fig. 5. Extent of esophageal motion illustrated by organ contours in two separate phases of a 4D CT scan is shown, demonstrating 7-mm mediolateral motion during respiration.

Dahele, Int J. Radiat Oncol Biol Phys 2011 | C Tsien

- → PRV ca. +2mm
- → 4D-CT erwägen
- → T2 TSE (ggf. WARP) für neurale Strukturen
- → Ultima Ratio: Myelo-CT


Bildgebung
Zielvolumen-definition
OAR-Definition
Dosisplanung
Lagerung + Bestrahlung

Hochdichtes Material bei spinalen Metastasen



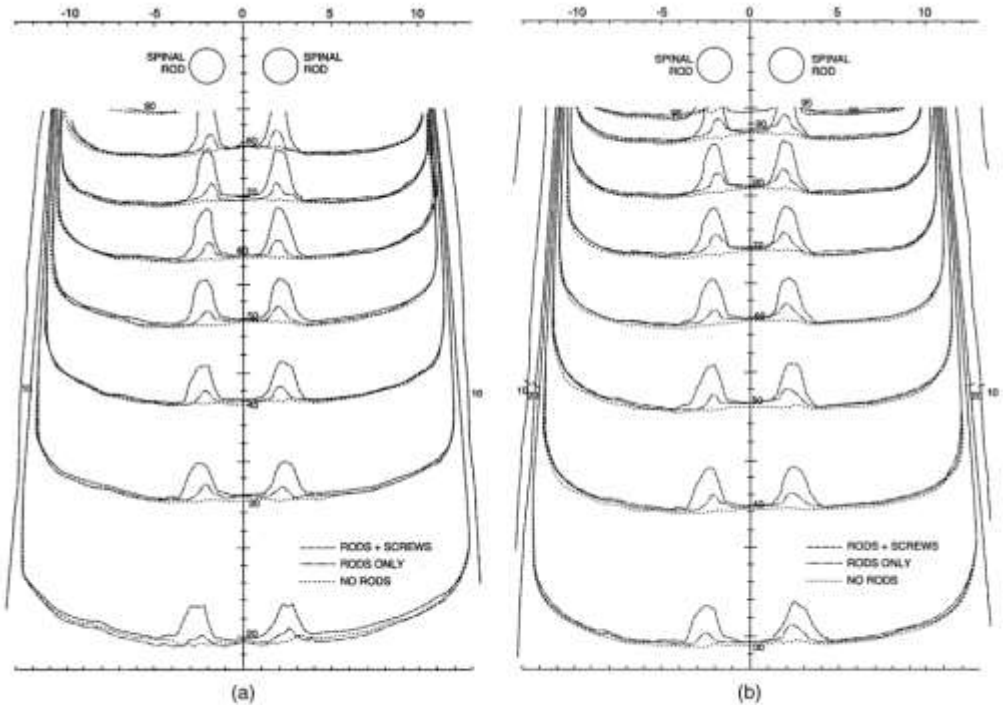
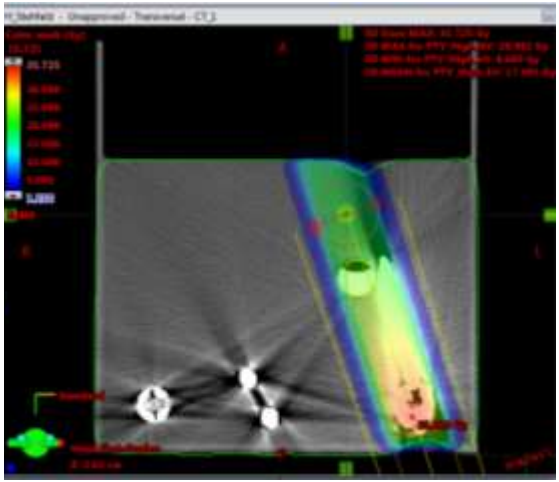
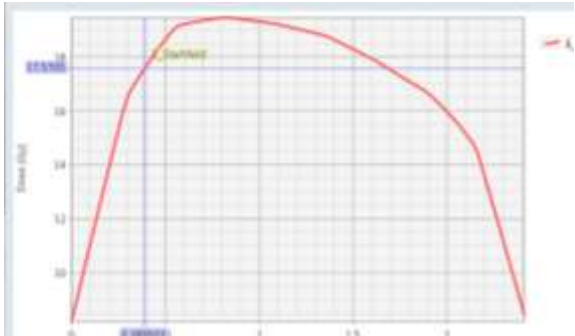


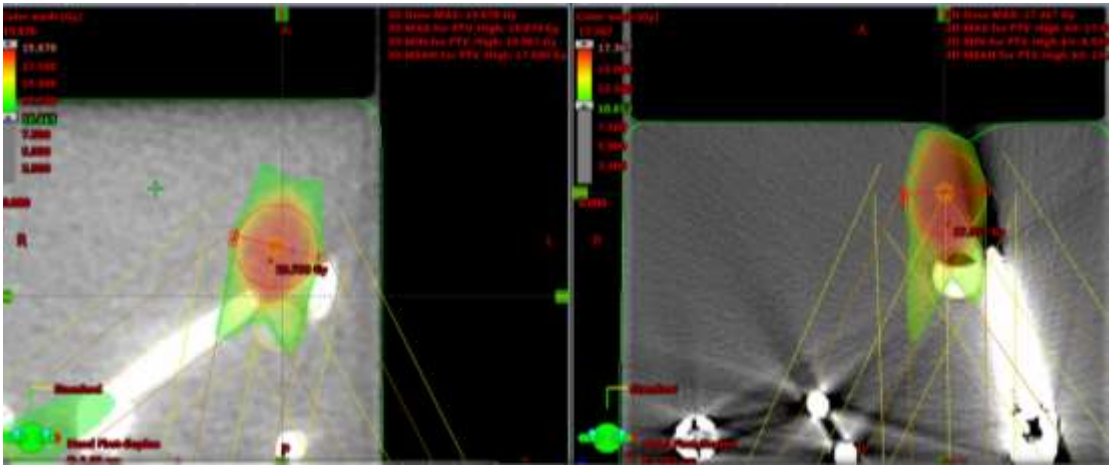
Fig. 3. Isodose curves generated from profile measurements in the water phantom at a source-to-surface distance of 100 cm for (a) 6-MV and (b) 18-MV beam with no rods, rods alone, and rods with screws.

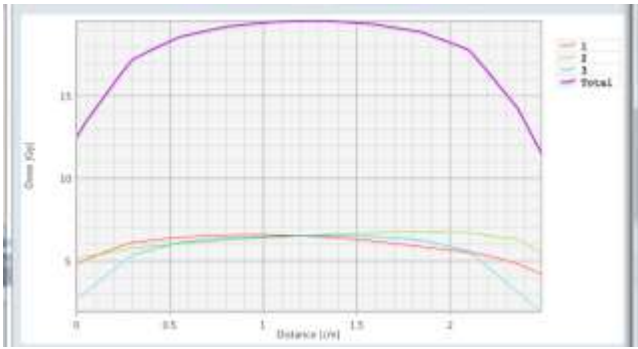
Stehfelder MV-CT vs. kV-CT

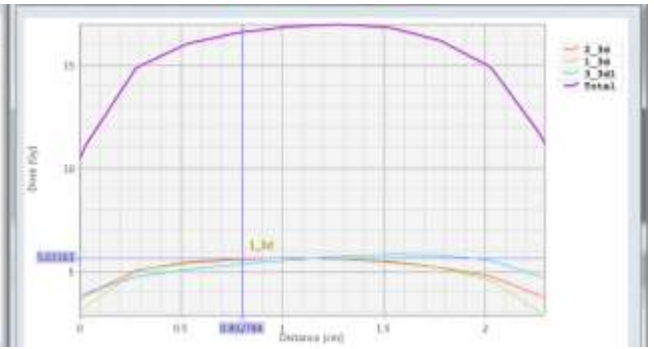




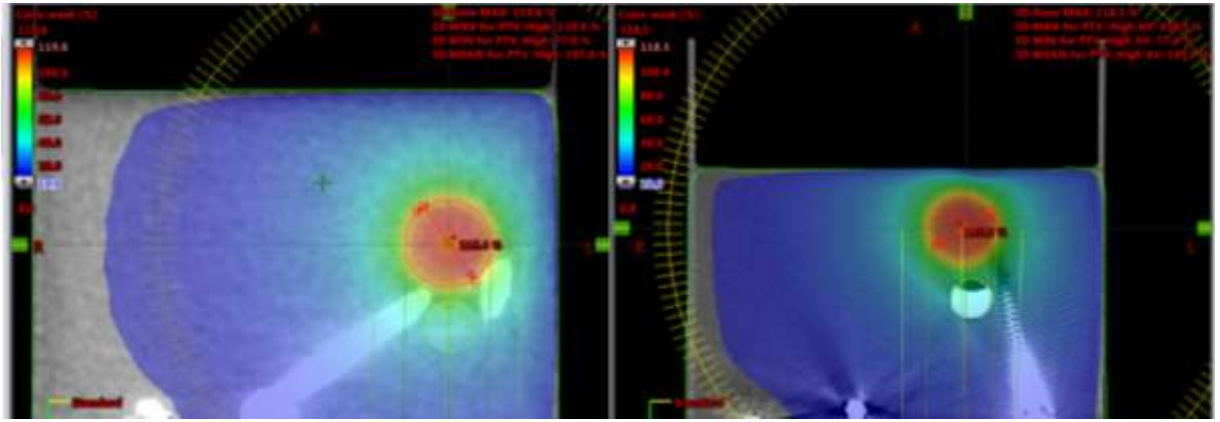
3D – MV-CT vs. kV-CT

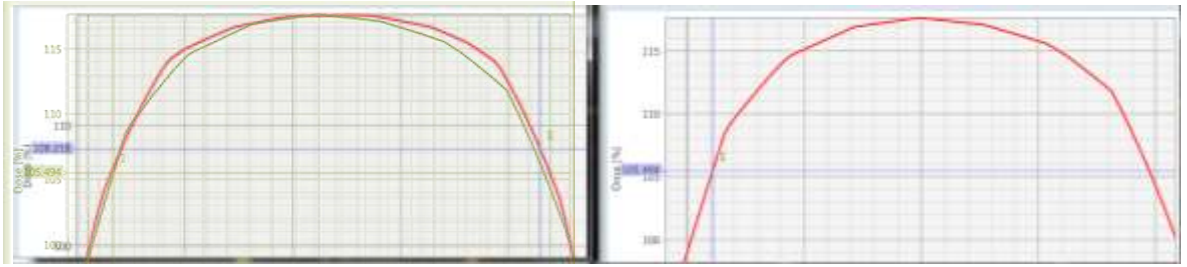




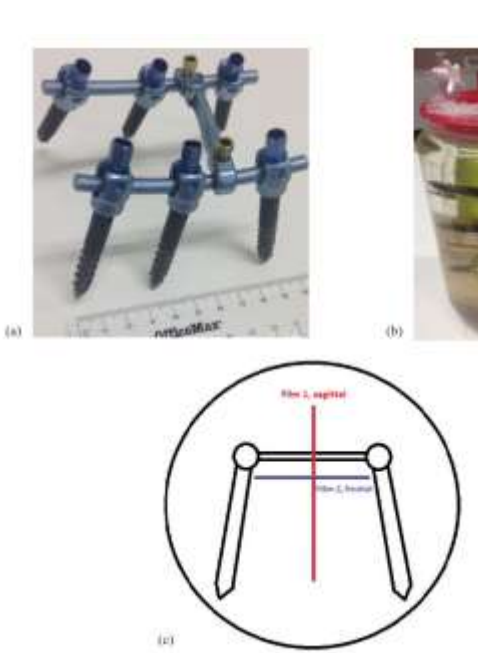


Rotations-Bestrahlung: MV-CT vs. kV-CT





Genauigkeit der Dosisberechnung mit AAA und Acuros



Titan-Implantate

Cheng Z, JOURNAL OF APPLIED CLINICAL MEDICAL PHYSICS, 2016

Genauigkeit der Dosisberechnung mit AAA und Acuros

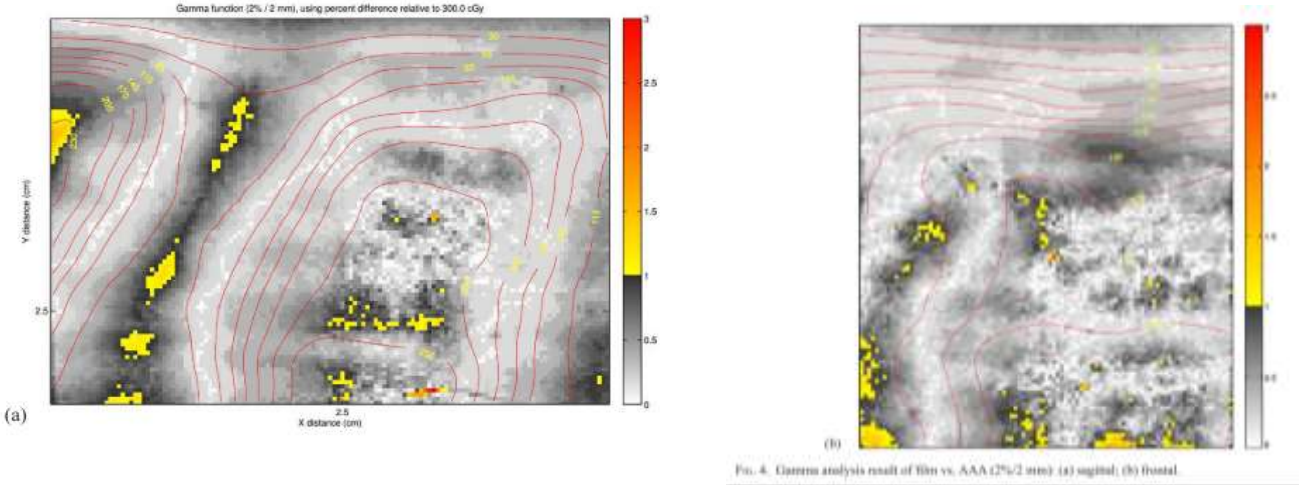


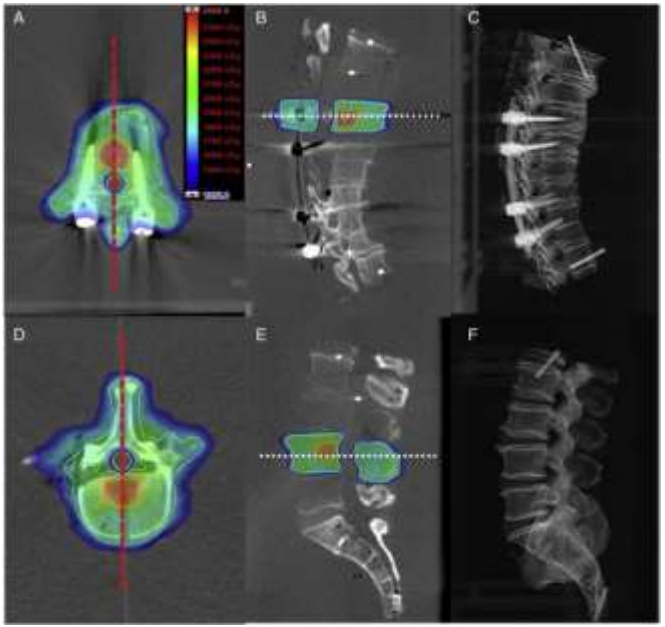
FIG. 4. Gamma analysis result of film vs. AAA (2%/2 mm): (a) sagittal; (b) frontal.

TABLE 1. Gamma pass rate for IMRT plan.

	Sagittal		*Frontal*	
	2%/2 mm	*3%/3 mm*	*2%/2 mm*	*3%/3 mm*
Film vs. Acuros XB	97.9%±1.0%	100%	97.8%±1.0%	100%
Film vs. AAA	98.5%±1.0%	100%	97.8%±1.0%	100%
Film vs. MC	93.7%±2.0%	99.0%±0.5%	92.5%±3.0%	98.8%±0.5%
Acuros XB vs. AAA	99.2%±0.5%	99.8%	99.5%	99.8%

Cheng Z, JOURNAL OF APPLIED CLINICAL MEDICAL PHYSICS, 2016

Genauigkeit von AAA:



Grams MP, Practical Radiation Oncology 2016

Genauigkeit von AAA:

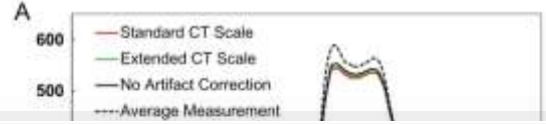
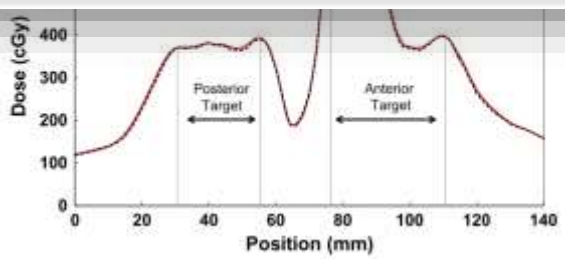
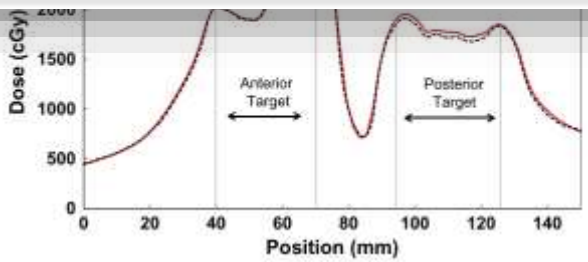


Table 1 Summary of comparison statistics

	Average (SD) percentage difference between TPS calculations and measurement											
	Thoracic spine								Lumbar spine			
	6-MV std				6-MV FFF				6-MV std		6-MV FFF	
Planning scenario	Std CT	Ext CT	No Corr	QA	Std CT	Ext CT	No Corr	QA	Std CT	Ext CT	QA	Std CT	Ext CT	QA
Posterior target	2% (1%)	2% (1%)	1% (1%)	1% (1%)	1% (1%)				1% (1%)			2% (1%)		
Anterior target	5% (2%)	4% (2%)	3% (2%)	1% (1%)	1% (1%)				1% (1%)			1% (1%)		

Corr, correction; CT, computed tomography; ext, extended; FFF, flattening filter-free; QA, quality assurance; SD, standard deviation; std, standard.





Grams MP, Practical Radiation Oncology 2016 | links Thorax, rechts lumbal

Erheblicher Effekt von Implantaten auf Partikel

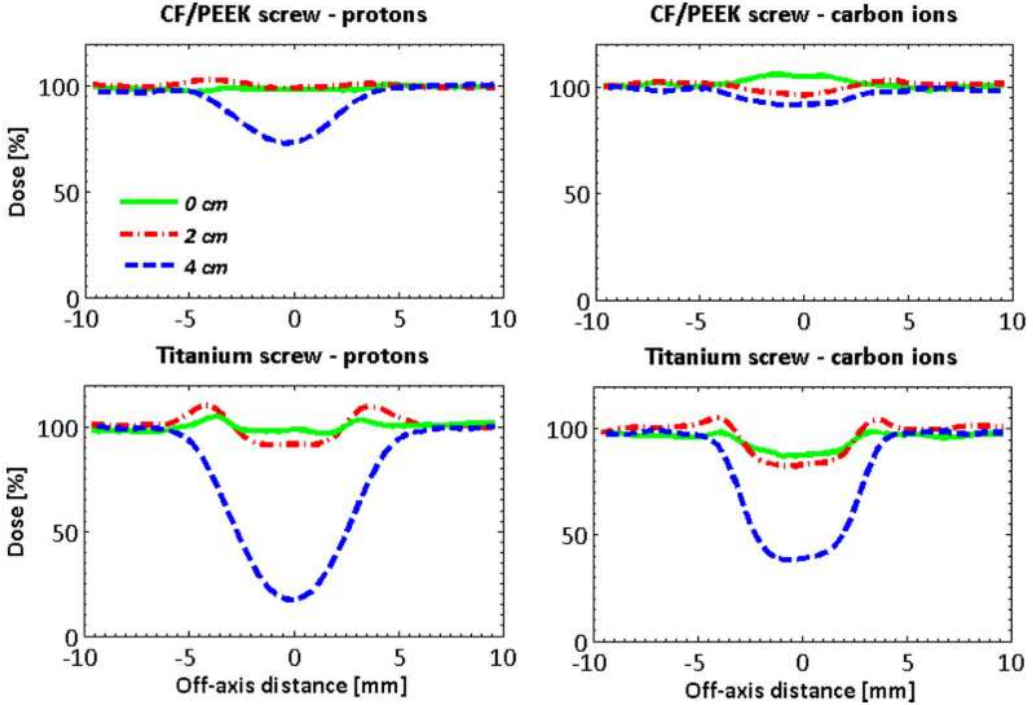
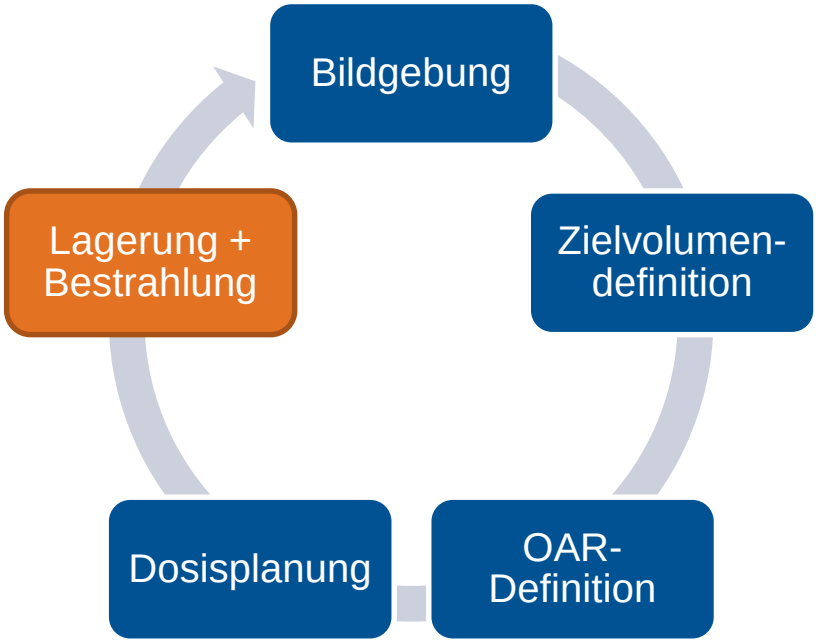


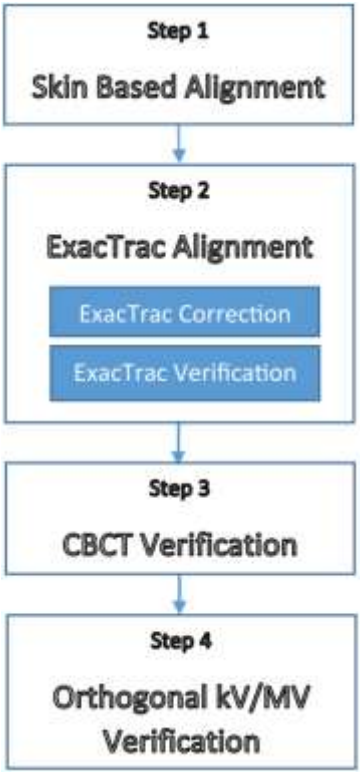
Fig. 5. Transversal dose profiles measured with EBT3 films for carbon fiber (on the top) and titanium screws (on the bottom). The EBT3 films were positioned at distances of 0 (green continuous line), 2 (red dotted line) and 4 (blue dotted line) cm from the screws. Left panels: proton SOBP; right panels: carbon ion SOBP. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Mastella E, Phyisca Medica 2107

Um was wird es gehen?



Setup-Genauigkeit am nicht-robotischen LINAC



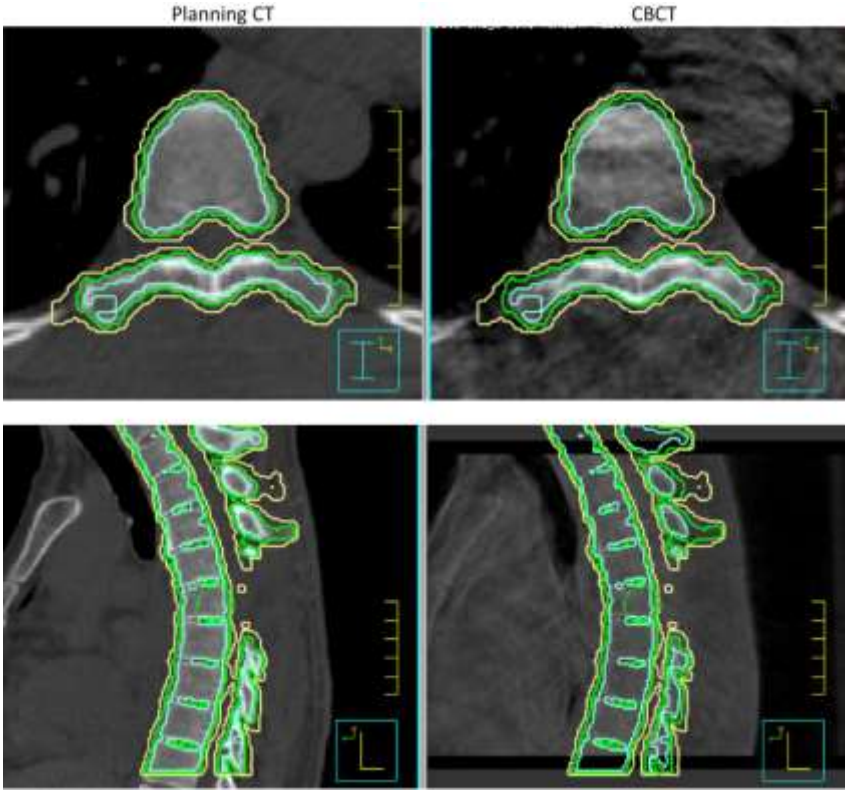


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TABLE 3 Residual error in millimeter integrals of vertebrae visible in the CBCT of each case.

#	C1	C2	C3	C4	C5	C6	C7	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	L1	L2	L3	L4	L5	S1	S2	S3	S4	S5
1	1	1	1	3	3																								
2	1	1	1	1	3																								
3	1	1	1	1	1	1	1	1																					
4		1	1	1	1	1	3	3																					
5		3	1	1	1	1	1	1	1	1	1																		
6			3	3	3	1	1	1	1	1																			
7			3	1	3	1	1	1	1	1	1																		
8			1	1	1	1	1	1	1	1	1	1																	
9					1	1	1	1	1	1	1	1	1																
10						3	3	3	1	1	1	1	1																
11							1	1	1	1	1	1	1																
12							1	1	1	1	1	1	1																
13						3	3	1	1	1	1	1	1	1															
14					1	1	1	1	1	1	1	1	1	1															
15									1	1	1	1	1	1	1														
16										1	1	1	1	1	1	1													
17										1	1	1	1	1	1	1													
18										1	1	1	1	1	1	1													
19										1	1	1	1	1	1	1													
20											1	1	1	1	1	1													
21												1	1	1	1	1	1												
22													1	1	1	1	1	1	1										
23													1	1	1	1	1	1	1										
24														1	1	1	1	1	1										
25														1	1	1	1	1	1										
26															1	1	1	1	1	1									
27																1	1	1	1	1	1								
28																	1	1	1	1	1								
29																	1	1	1	1	1								
30																	1	1	1	1	1								
31																		1	1	1	1	1							
32																		1	1	1	1	1							
33																	1	1	1	1	1	1	1						

98% mit <1mm und <1°

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Setup-Genauigkeit am nicht-robotischen LINAC

TABLE 4 Dosimetric values to the spinal cord of case # 16. The spinal cord volumes include the total volume (T5 to T8) over the target area and sub volume in each individual vertebra level. Misalignment is a vertical shift in isocenter of clinical plan. Dose pertubation is the average of dose value changes from 0 to 1 and 1 to 2 mm misalignment.

Vertebrae level	Spinal cord volume (cm^3)	Misalignment (mm)	D_{max} (Gy)	$D_{1\ cc}$ (Gy)	$D_{2\ cc}$ (Gy)
T5	0.90	0	16.3		
		1	16.9		
		2	18.4		
		Dose perturbation (Gy/mm)	0.6		
T6	0.99	0	16.7		
		1	18.8		
		2	21.2		
		Dose perturbation (Gy/mm)	2.2		
T7	0.98	0	15.0		
		1	15.9		
		2	17.8		
		Dose perturbation (Gy/mm)	0.9		
T8	0.98	0	14.9		
		1	14.8		
		2	14.7		
		Dose perturbation (Gy/mm)	−0.1		
T5 to T8	3.85	0	16.7	13.8	12.6
		1	18.8	14.0	13.0
		2	21.2	14.3	13.4
		Dose perturbation (Gy/mm)	2.2	0.3	0.4

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Intrafraktionelle Beweglichkeit

Li W, Intern. J. Radiol Biol Phys 2012 | Foster R, Intern. J. Radiol Biol Phys 2013

Intrafraktionelle Beweglichkeit

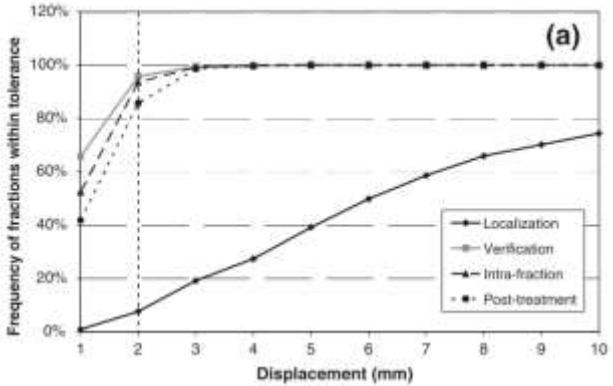

Table 2 Mean pretreatment and intrafraction shifts for all patients

	Mean intrafraction errors (mm)			
	AP	SI	Lateral	3D
Lung: compressed	0.58 ± 1.75	−0.36 ± 1.29	0.08 ± 1.31	1.72 ± 1.98
Lung: uncompressed	0.25 ± 1.25	0.03 ± 1.24	0.05 ± 0.90	1.28 ± 1.53
Liver	0.17 ± 0.82	0.13 ± 1.62	0.08 ± 1.07	1.21 ± 1.74
Prostate	0.46 ± 1.26	0.73 ± 1.65	−0.28 ± 1.42	1.95 ± 1.76
Spine	−0.10 ± 1.04	0.38 ± 1.23	0.06 ± 1.05	1.29 ± 1.45

Abbreviations: 3D =

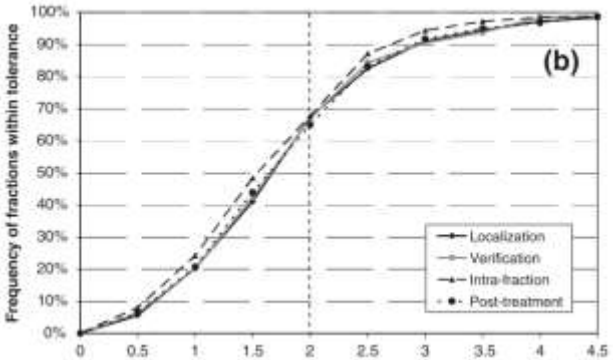

Table 4 Margins calculated from pretreatment and intrafraction errors

	Margins		
	Intrafraction (mm)		
	Anteroposterior	Superoinferior	Lateral
Lung: compressed	3.25	1.93	2.24
Lung: uncompressed	2.04	2.05	1.74
Liver	1.27	2.57	2.36
Prostate	2.71	3.50	2.98
Spine	2.09	2.46	2.10

Li W, Intern. J. Radiol Biol Phys 2012 | Foster R, Intern. J. Radiol Biol Phys 2013

Mögliche Schlussfolgerungen

- Implantate beeinflussen die Bildqualität (Stahl>Vitallium>Titan>PEEK)
- Bestmögliche Bildgebung: 1-3mm CT, 1,5T mit WARP/MARS, T1+T2
- Zielvolumendefinition entsprechend Consensus-Guidelines
- OAR-Konturierung und PRV-Konzept
- Photonen bei Implantaten bevorzugen
- Maximal rigide Lagerung, möglichst kurze Pläne
- Erwägung von interfraktionellem CBCT (oder anderem Tracking)