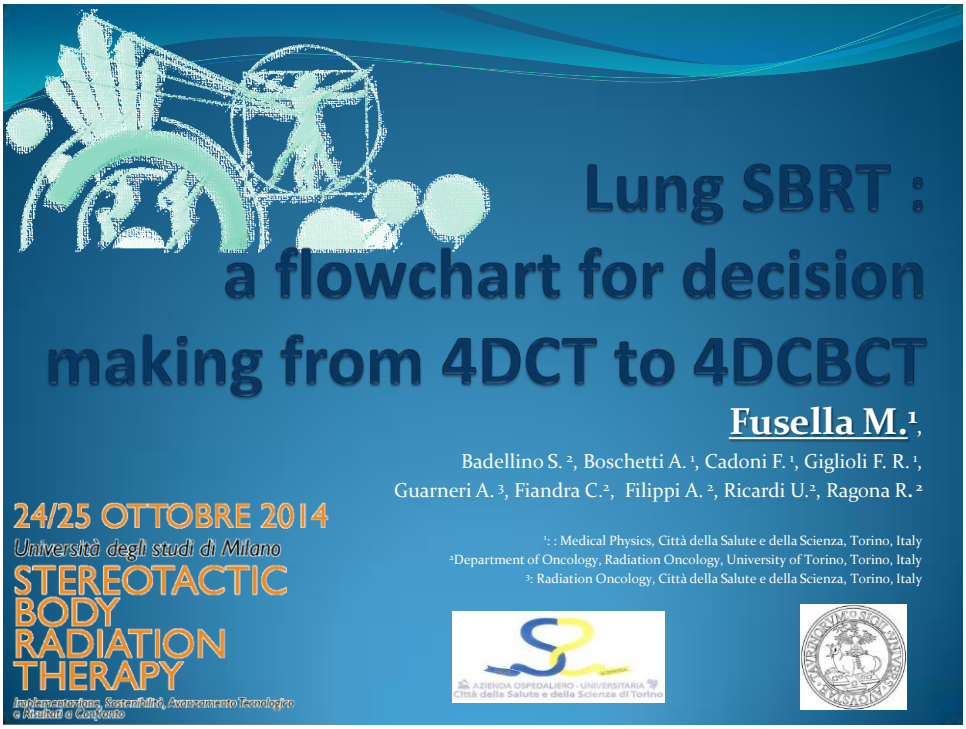
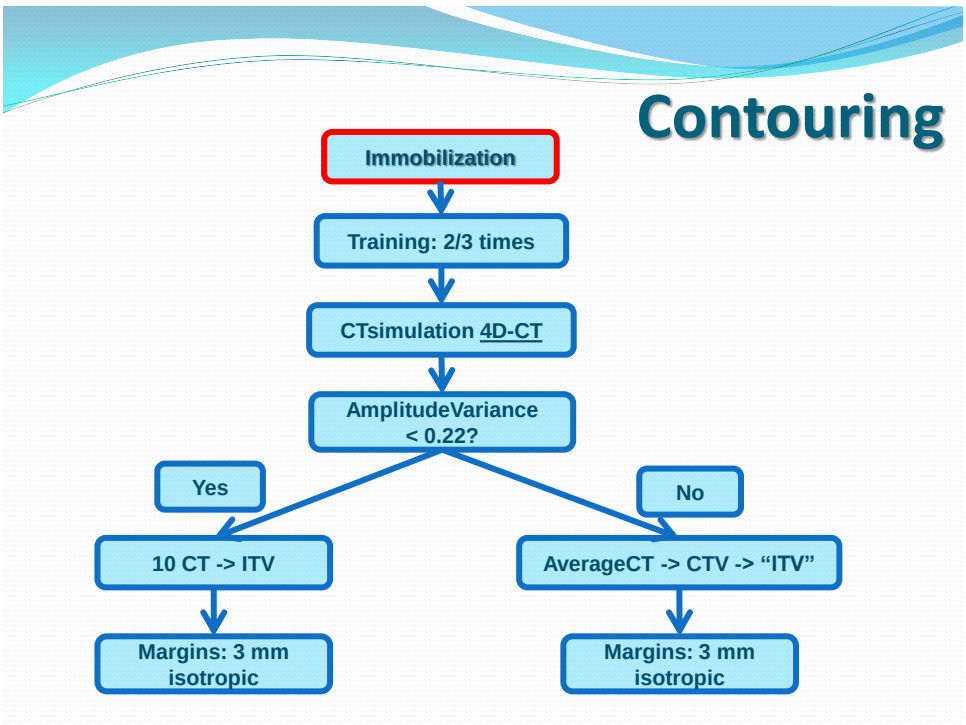
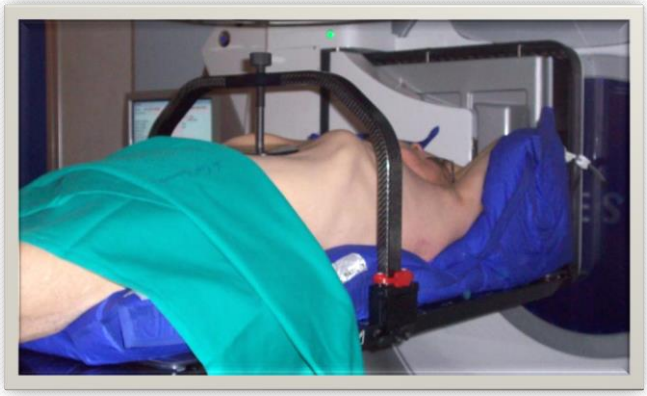

Lung SBRT :
a flowchart for decision making from 4DCT to 4DCBCT
Fusella M.[1],
Badellino S.[2], Boschetti A.[1], Cadoni F.[1], Giglioli F. R.[1],
Guarneri A.[3], Fiandra C.[2], Filippi A.[2], Ricardi U.[2], Ragona R.[2]
[1]: : Medical Physics, Città della Salute e della Scienza, Torino, Italy
[2]Department of Oncology, Radiation Oncology, University of Torino, Torino, Italy
[3]: Radiation Oncology, Città della Salute e della Scienza, Torino, Italy
24/25 OTTOBRE 2014
Università degli studi di Milano
STEREOTACTIC BODY RADIATION THERAPY
Implementazione, Sostenibilità, Avanzamento Tecnologico e Risultati a Confronto
AZIENDA OSPEDALIERO - UNIVERSITARIA
Città della Salute e della Scienza di Torino

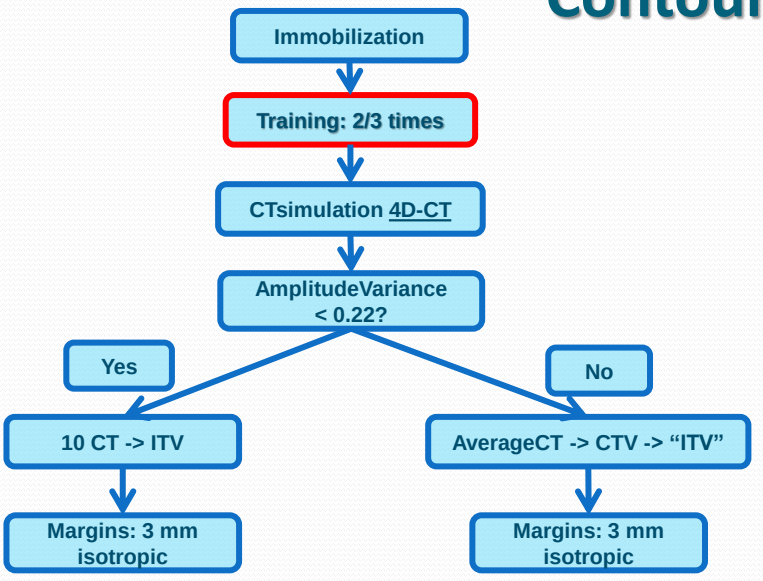

Contouring
Immobilization
Training: 2/3 times
CTsimulation 4D-CT
AmplitudeVariance < 0.22?
Yes
No
10 CT -> ITV
AverageCT -> CTV -> "ITV"
Margins: 3 mm isotropic
Margins: 3 mm isotropic

Immobilization



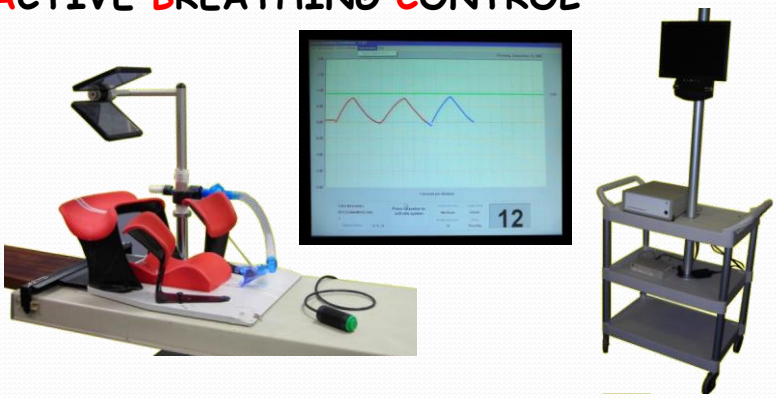
Vacuum immobilisation reduces tumour excursion and minimizes intrafraction error in a cohort study of stereotactic ablative body radiotherapy for pulmonary metastases (Shankar Siva et al 2014)

Contouring



Training

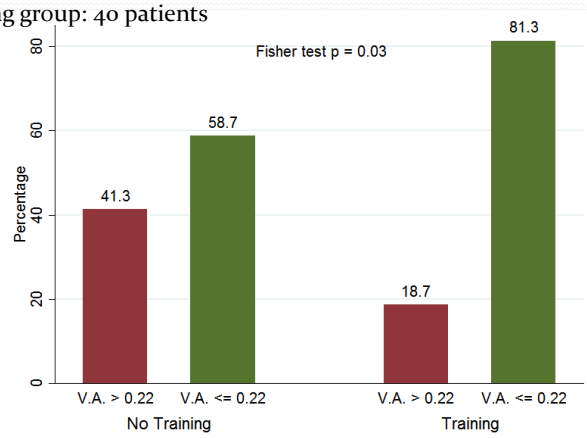
ACTIVE BREATHING CONTROL



To reduce variability of respiratory movements
during the radiotherapy treatment

Training: results

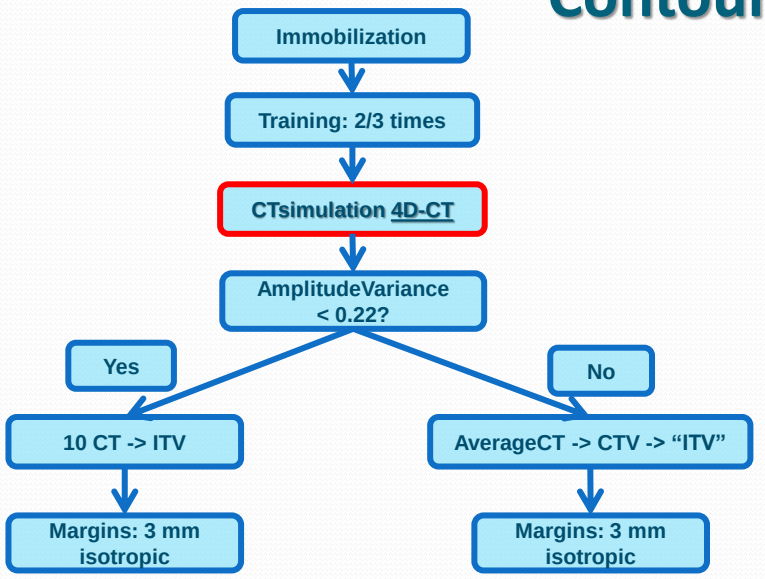
2 groups: Control group: 50 patients
Training group: 40 patients



A significantly higher proportion of patients in the training group had an acceptable amplitude variance (Fisher test p=0.03).

Poster #M4 : Breath training in lung SABR

Contouring



CT-Simulation 4D-CT

Radiotherapy and Oncology 93 (2009) 419–423

Contents lists available at ScienceDirect

Radiotherapy and Oncology

journal homepage: www.thegreenjournal.com

Lung cancer SBRT

4D-CT-based target volume definition in stereotactic radiotherapy of lung tumours: Comparison with a conventional technique using individual margins

Holger Hof [a,*], Bernhard Rhein [b], Peter Haering [b], Annette Kopp-Schneider [c], Jürgen Debus [a], Klaus Herfarth [a]

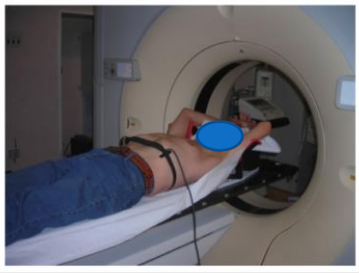
[a] University of Heidelberg, Department of Radiation Oncology, Heidelberg, Germany; [b] German Cancer Research Center (DKFZ), Department of Medical Physics, Heidelberg, Germany; [c] German Cancer Research Center (DKFZ), Division of Biostatistics, Heidelberg, Germany

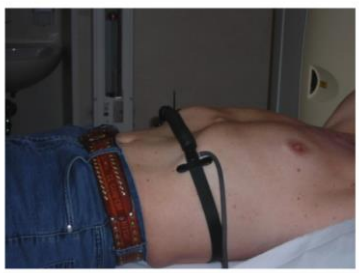
Results: Volumetric examinations revealed a significant reduction of the mean PTV by 4D-CT from 57.7 to 40.7 cm^3 (31%) ($p < 0.001$). A significant inverse correlation was found for the motion vector and the amount of inclusion of PTV_{4D} in PTV_{conv} ($r = -0.69$, 90% confidence limits: -0.87 and -0.34, $p = 0.007$). Mean lung dose (MLD) was decreased significantly by 17% ($p < 0.001$).

Conclusions: In SBRT of lung tumours the mere use of individual margins for target volume definition cannot compensate for the additional effects that the implementation of 4D-CT phases can offer.

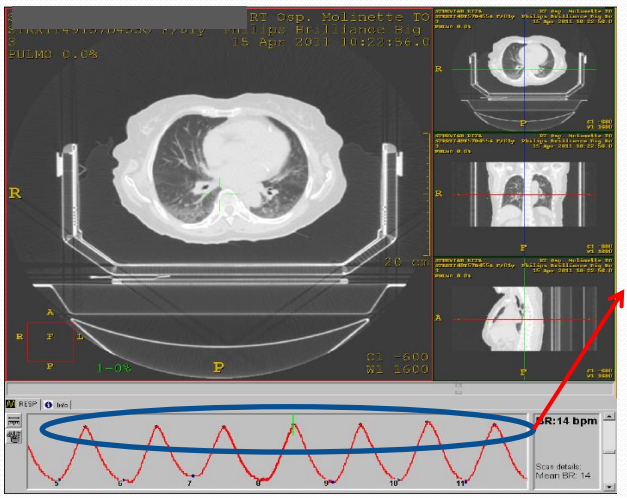
CT-Simulation 4D-CT

Measurement of abdominal diameter





CT-Simulation 4D-CT

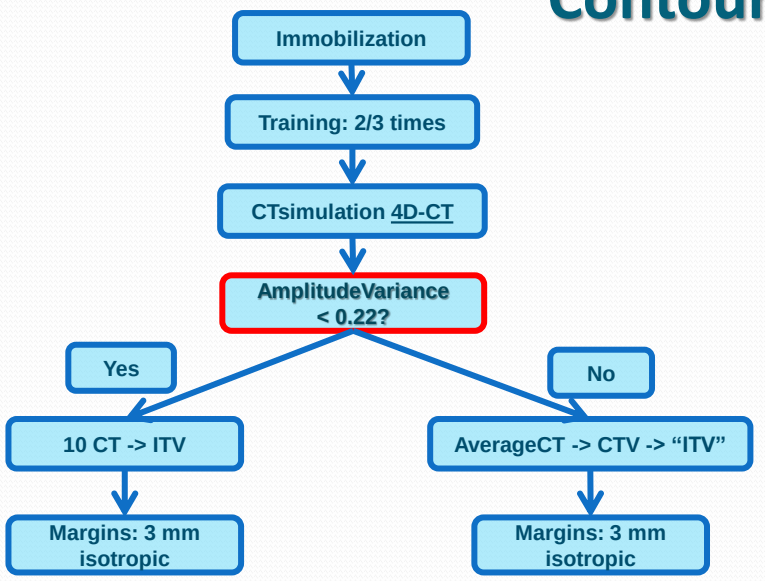


After an analysis of amplitude variance:

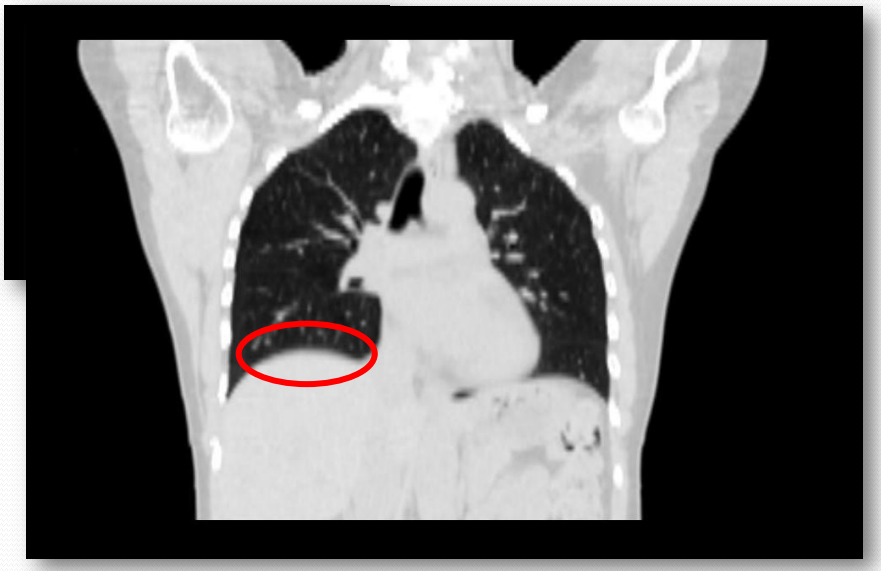
We choose as suitable for an accurate 4D-CT the threshold value of **20%** (±10%)

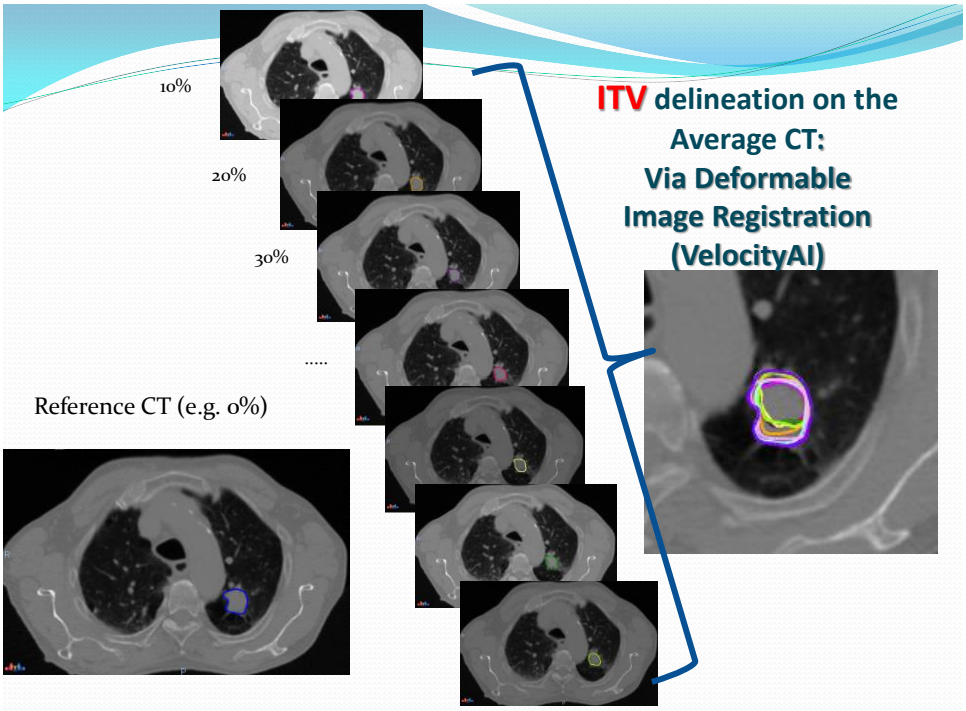
- ***Phase binning***:
10 series of images corresponding to 10 phases of respiratory cycle

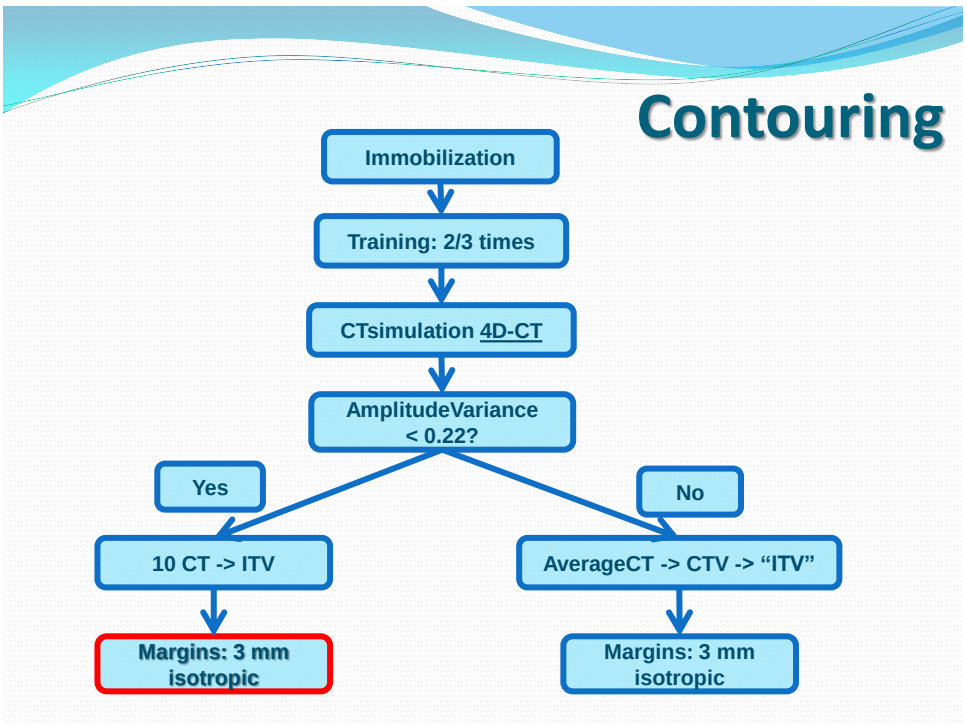
Contouring



AV < 0.22




10%
20%
30%
.....
Reference CT (e.g. 0%)
ITV delineation on the Average CT: Via Deformable Image Registration (VelocityAI)


Contouring
Immobilization
Training: 2/3 times
CTsimulation 4D-CT
AmplitudeVariance < 0.22?
Yes
No
10 CT -> ITV
AverageCT -> CTV -> "ITV"
Margins: 3 mm isotropic
Margins: 3 mm isotropic

Margins

Localization accuracy was quantified by the residual tumor misalignment measured in the second 4D-CBCT scan acquired for validation and expressed in terms of systematic (Σ), and random (σ) errors.

For dose prescription at 80% instead of 95%, for a lung target(σ_p = 0.64):

$$M = 2.5\Sigma + 0.84\sqrt{(\sigma_p^2 + \sigma^2)} - 0.84\sigma_p^2$$

Margins

We calculated:

LL: 1.6 mm

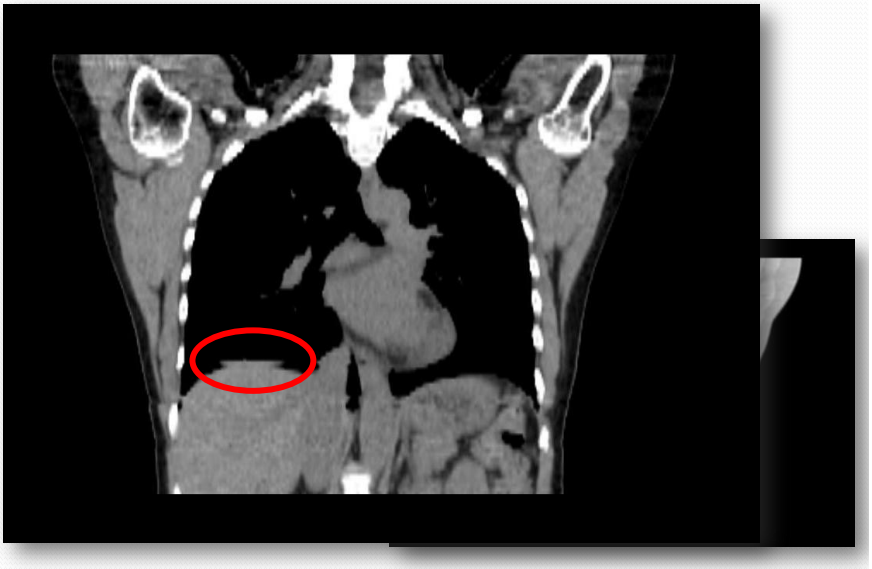
AP: 1.9 mm

CC: 2.4 mm

We choose:

3 mm isotropic (from ITV)

AV > 0.22



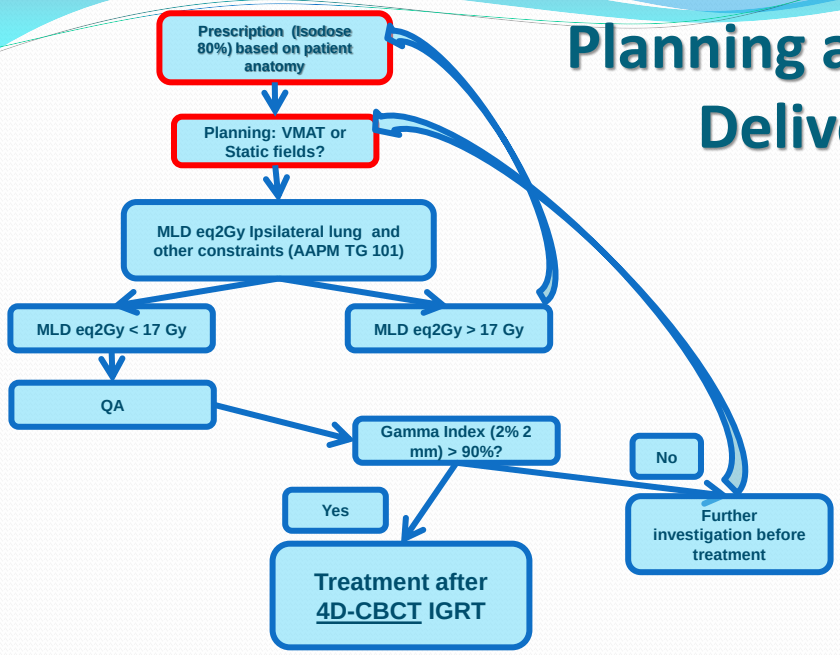
Contouring: 'statistic ITV'

- Contour of CTV on the Average CT obtained from the 4D-CT scan.
- Obtain a 'statistic ITV' (sITV) by adding margins related to the location of the tumor. We based the amplitude of these margins on a statistical analysis of the tumor motion. Then we used the mean value and 2 SD to define margins for each lobe and for each axis:

➢ Inferior lobe(cm):	LL: **0.11**	AP: **0.43**	CC: **0.65**
➢ Medium lobe(cm):	LL: **0.10**	AP: **0.35**	CC: **0.60**
➢ Superior lobe(cm):	LL: **0.10**	AP: 0.**34**	CC: **0.58**

- Then we add **3 mm isotropic** (from sITV) to obtain PTV

Planning and Delivery



Prescriptions

Clinical routine: "risk-adapted" SBRT protocol

- **Peripheral lesions (T1a-T1b):**

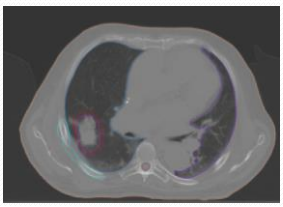
- 45-54 Gy/ 3 fractions

- **Peripheral lesions, with extensive contact with the chest wall, or larger tumors (T2a):**

- 55 Gy/ 5 fractions

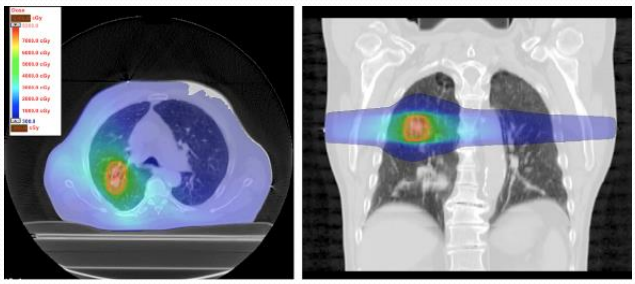
- **Central lesions:**

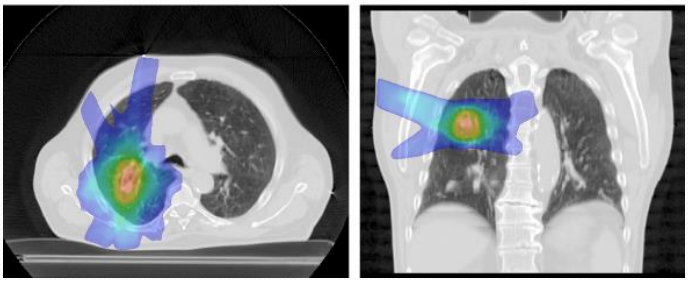
- 60 Gy/ 8 fractions



DEPARTMENT OF ONCOLOGY
UNIVERSITY OF TURIN

Step & Shoot or VMAT?

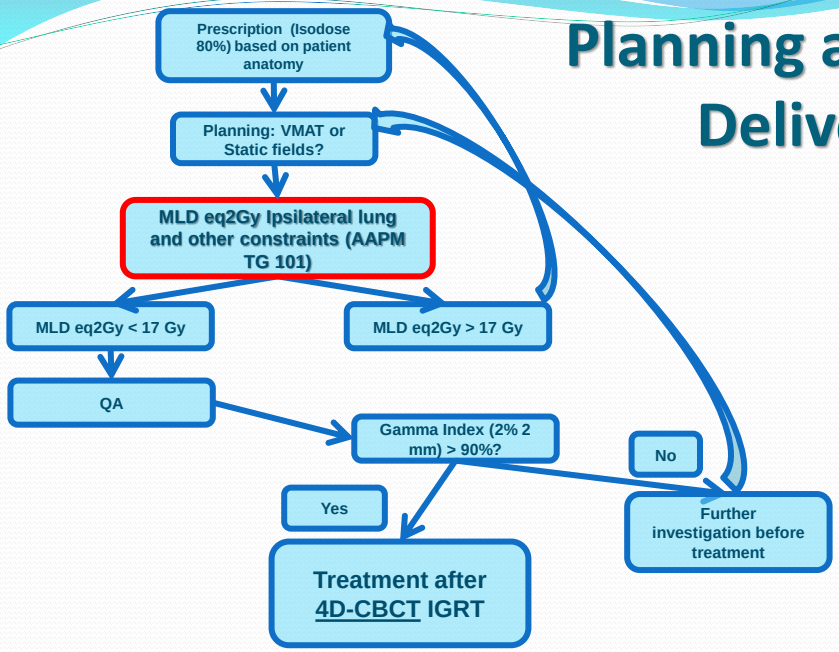




Planning with:
Elekta CMS
Monaco v.3.2/3.3

Grid calculation 2 mm,
Montecarlo Variance 1.5%

Planning and Delivery



MLD_{2Gy} Ipsilateral Lung

Table IV. Logistic regression analysis (correlation with RTOG grade 2-3 pulmonary toxicity)

	Odds Ratio	Std. Err.	z	p	95% Confidence Interval	
MLD_2	**1.52**	0.24	2.66	**0.008**	1.12	2.08
Primary/ Metastatic	3.03	3.98	0.84	0.399	0.23	39.79
Central/Peripheral	0.54	0.70	−0.48	0.634	0.04	6.75
Superior/Median/Inferior Lobe	1.53	0.89	0.73	0.464	0.49	4.79
PTV	1.03	0.03	1.05	0.293	0.98	1.08

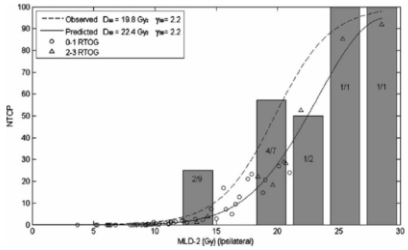


Table III. MLD_2 and NTCP mean values according to RTOG lung toxicity score

	Grade 0-1	Grade 2-3
MLD_2	**11.2 Gy** (95% CI 10.1-12.3 Gy)	**20.3 Gy** (95% CI 16.6-23.9 Gy)
NTCP	**4%** (95% CI 2-5.9%)	**37%** (95% CI 11.6-62.3%)

Dosimetric predictors of radiation-induced lung injury in stereotactic body radiation therapy

Acta Oncologica, 2009; 48: 571–577

MLD_{2Gy} Ipsilateral Lung

Decomposition analysis of differential dose volume histograms

Frank Van den Heuvel Ph.D.[a)]
Department of Oncology and Experimental Radiation Therapy
Universiteit Leuven, Belgium

Dose volume histograms are a common tool to assess the value of a treatment plan for various forms of radiation therapy treatment. The purpose of this work is to introduce, validate, and apply a set of tools to analyze differential dose volume histograms by decomposing them into physically and clinically meaningful normal distributions. A weighted sum of the decomposed normal distributions (e.g. weighted dose) is proposed as a new measure of target dose, rather than the more unstable point dose.

The method and its theory are presented and validated using simulated distributions. Additional validation is performed by analyzing simple four field box techniques encompassing a pre–defined target, using different treatment energies inside a waterphantom.

Furthermore, two clinical situations are analyzed using this methodology to illustrate practical usefulness. A comparison of a treatment plan for a breast patient using a tangential field setup with wedges is compared to a comparable geometry using dose compensators. Finally, a normal tissue complication probability (NTCP) calculation is refined using this decomposition. The NTCP calculation is performed on a liver as organ at risk in a treatment of a mesothelioma patient with involvement of the right lung.

The comparison of the wedged breast treatment versus the compensator technique yields comparable classical dose parameters (e.g Conformity Index ≈ 1 and equal dose at the ICRU dose point). The methodology proposed here shows a 4% difference in weighted dose outlining the difference in treatment using a single parameter instead of at least two in a classical analysis (e.g. mean dose, and maximal dose, or total dose variance). NTCP–calculations for the mesothelioma case are generated automatically and show a 3% decrease with respect to the classical calculation. The decrease is slightly dependant on the fractionation and on the α/β–value utilized.

In conclusion, this method is able to distinguish clinically important differences between treatment plans using a single parameter. This methodology shows promise as an objective tool for analyzing NTCP and doses in larger studies, as the only information needed is the dose volume histogram.

Constraints

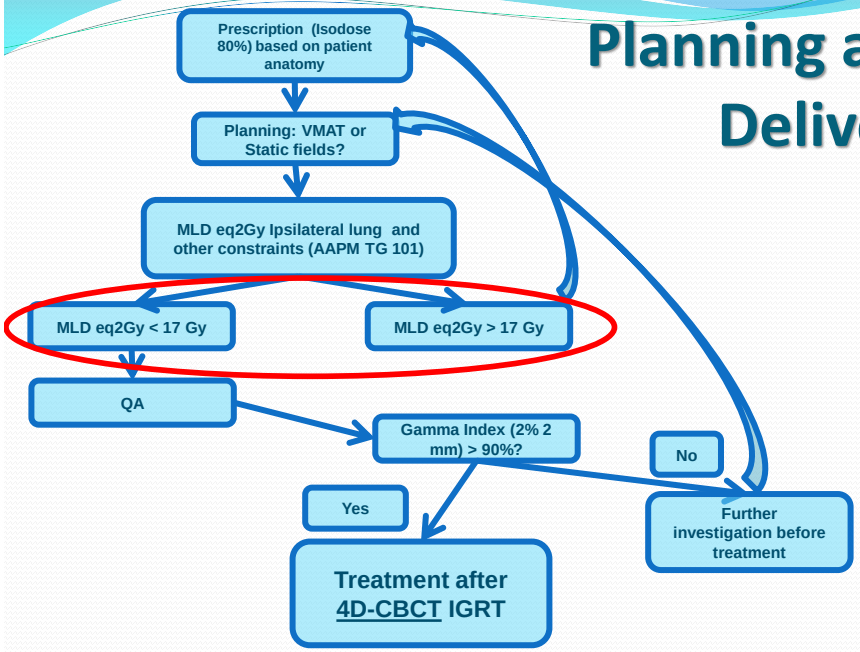
Stereotactic body radiation therapy: The report of AAPM Task Group 101

Stanley H. Benedict, Chairman[a)]
University of Virginia Health System, Charlottesville, Virginia 22908

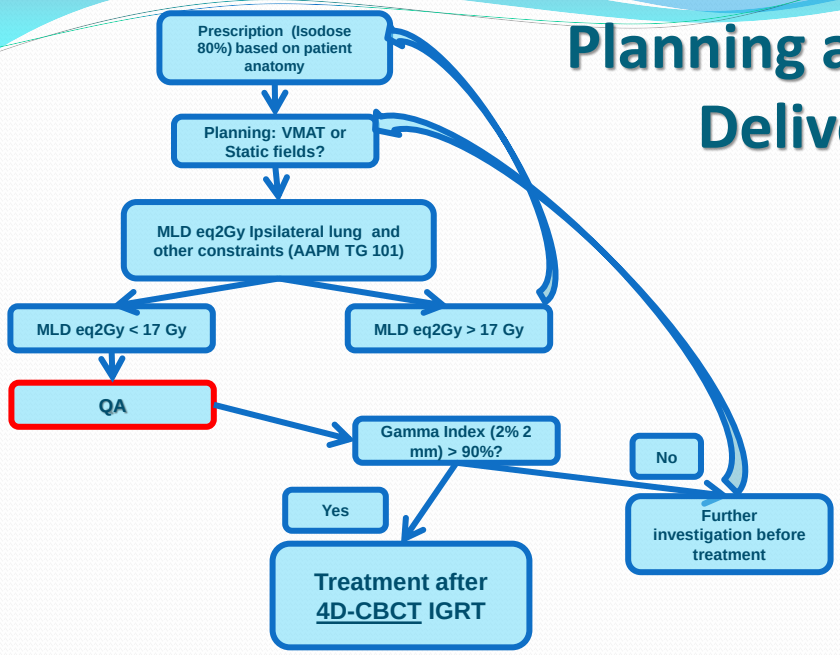
TABLE III. Summary of suggested dose constraints for various critical organs. Note that for serial tissues, the volume-dose constraints are given in terms of the critical maximum tissue volume that should receive a dose equal or greater than the indicated threshold dose for the given number of fractions used. For parallel tissues, the volume-dose constraints are based on a critical minimum volume of tissue that should receive a dose equal to or less than the indicated threshold dose for the given number of fractions used.

		One fraction		Three fractions		Five fractions		
Serial tissue	Max critical volume above threshold	Threshold dose (Gy)	Max point dose (Gy)[a]	Threshold dose (Gy)	Max point dose (Gy)[a]	Threshold dose (Gy)	Max point dose (Gy)[a]	End point (n/Grade3)
Optic pathway	<0.2 cc	8	10	15.3 (5.1 Gy/fx)	17.4 (5.8 Gy/fx)	23 (4.6 Gy/fx)	25 (5 Gy/fx)	Neuritis/ Hearing loss
Cochlea			9		17.1 (5.7 Gy/fx)		25 (5 Gy/fx)	Cranial neuropathy
Brainstem (not medulla)	<0.5 cc	10	15	1.8 (6 Gy/fx)	23.1 (7.7 Gy/fx)	23 (4.6 Gy/fx)	31 (6.2 Gy/fx)	Myelitis
Spinal cord and medulla	<0.35 cc	10	14	1.8 (6 Gy/fx)	21.9 (7.3 Gy/fx)	23 (4.6 Gy/fx)	30 (6 Gy/fx)	
	<1.2 cc	7		12.3 (4.1 Gy/fx)		14.5 (2.9 Gy/fx)		
Spinal cord sub-volume (5–6 mm above and below level treated per Rx)	< 10% of sub-volume	10	14	1.8 (6 Gy/fx)	21.9 (7.3 Gy/fx)	23 (4.6 Gy/fx)	30 (6 Gy/fx)	Myelitis
Cauda equina	<5 cc	14	16	21.9 (7.3 Gy/fx)	24 (8 Gy/fx)	30 (6 Gy/fx)	32 (6.4 Gy/fx)	Neuritis
Sacral plexus	<5 cc	14.4	16	22.5 (7.5 Gy/fx)	24 (8 Gy/fx)	30 (6 Gy/fx)	32 (6.4 Gy/fx)	Neuropathy
Esophagus	<5 cc	11.9	15.4	17.7 (5.9 Gy/fx)	25.2 (8.4 Gy/fx)	19.5 (3.9 Gy/fx)	35 (7 Gy/fx)	Stenosis/fistula
Brachial plexus	<3 cc	14	17.5	20.4 (6.8 Gy/fx)	24 (8 Gy/fx)	27 (5.4 Gy/fx)	30.5 (6.1 Gy/fx)	Neuropathy
Heart/pericardium	<15 cc	16	22	24 (8 Gy/fx)	30 (10 Gy/fx)	32 (6.4 Gy/fx)	38 (7.6 Gy/fx)	Pericarditis
Great vessels	<10 cc	31	37	39 (13 Gy/fx)	45 (15 Gy/fx)	47 (9.4 Gy/fx)	53 (10.6 Gy/fx)	Aneurysm
Trachea and large bronchus[b]	<4 cc	10.5	20.2	1.5 (5 Gy/fx)	30 (10 Gy/fx)	16.5 (3.3 Gy/fx)	40 (8 Gy/fx)	Stenosis/fistula
Bronchus-smaller airways	<0.5 cc	12.4	13.3	18.9 (6.3 Gy/fx)	23.1 (7.7 Gy/fx)	21 (4.2 Gy/fx)	33 (6.6 Gy/fx)	Stenosis with atelectasis
Rib	<1 cc	22	30	28.8 (9.6 Gy/fx)	36.9 (12.3 Gy/fx)	35 (7 Gy/fx)	43 (8.6 Gy/fx)	Pain or fracture
	<30 cc			30.0 (10.0Gy/fx)				
Skin	<10 cc	23	26	30 (10 Gy/fx)	33 (11 Gy/fx)	36.5 (7.3 Gy/fx)	39.5 (7.9 Gy/fx)	Ulceration
Stomach	<10 cc	11.2	12.4	16.5 (5.5 Gy/fx)	22.2 (7.4 Gy/fx)	18 (3.6 Gy/fx)	32 (6.4 Gy/fx)	Ulceration/fistula
Duodenum[b]	<3 cc	11.2	12.4	16.5 (5.5 Gy/fx)	22.2 (7.4 Gy/fx)	18 (3.6 Gy/fx)	32 (6.4 Gy/fx)	Ulceration
	<10 cc	9		11.4 (3.8 Gy/fx)		12.5 (2.5 Gy/fx)		
Jejunum/ileum[b]	<5 cc	11.9	15.4	17.7 (5.9 Gy/fx)	25.2 (8.4 Gy/fx)	19.5 (3.9 Gy/fx)	35 (7 Gy/fx)	Enteritis/ obstruction
Colon[b]	<20 cc	14.2	18.4	24 (8 Gy/fx)	28.2 (9.4 Gy/fx)	25 (5 Gy/fx)	38 (7.6 Gy/fx)	Colitis/fistula
Rectum[b]	<20 cc	14.2	18.4	24 (8 Gy/fx)	28.2 (9.4 Gy/fx)	25 (5 Gy/fx)	38 (7.6 Gy/fx)	Proctitis/fistula
Bladder wall	<15 cc	11.4	18.4	16.8 (5.6 Gy/fx)	28.2 (9.4 Gy/fx)	18.3 (3.65 Gy/fx)	38 (7.6 Gy/fx)	Cystitis/fistula
Penile bulb	<3 cc	14	34	21.9 (7.3 Gy/fx)	42 (14 Gy/fx)	30 (6 Gy/fx)	50 (10 Gy/fx)	Impotence
Femoral heads (right and left)	<10 cc	14		21.9 (7.3 Gy/fx)		30 (6 Gy/fx)		Necrosis
Renal tissue/vascular trunk	<2/3 volume	10.6	18.6 (6.2 Gy/fx)			23 (4.6 Gy/fx)		Malignant hypertension

Planning and Delivery



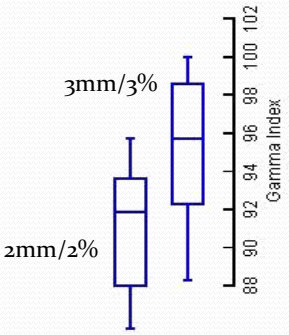
Planning and Delivery

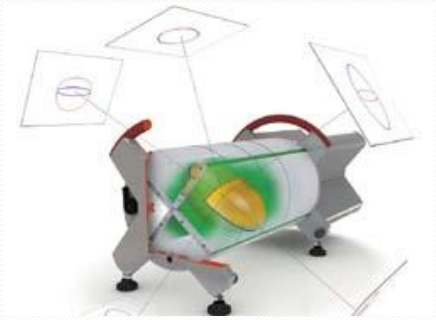


Patient Specific pre-treatment QA: Delta 4

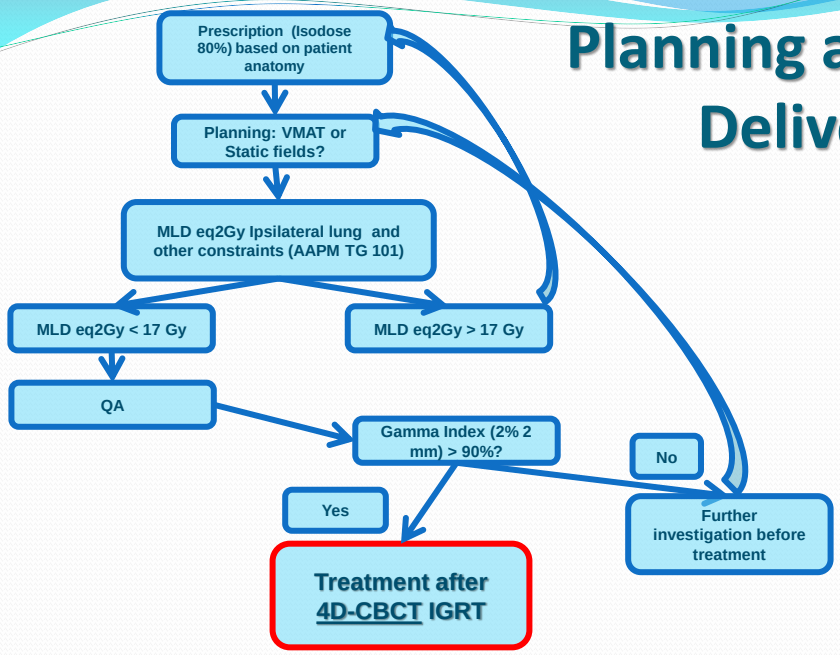
Acceptance level:

- 1 step: 2mm/2% > 90%
- 2 step 3mm/3% > 95%

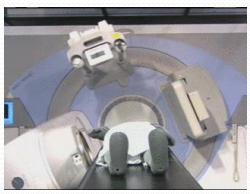




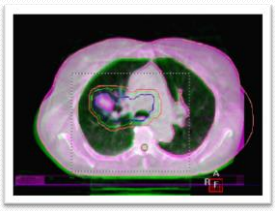
Planning and Delivery

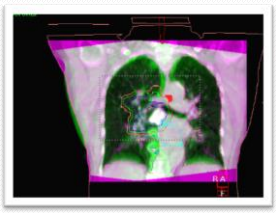


4D –CBCT (XVI v 4.5) at Axesse®,Elekta



Robotic Couch 6-D:
Hexapod



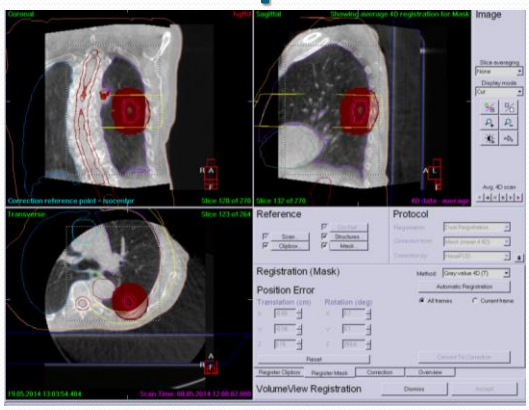


4D-CBCT: correction protocol

First, the bony anatomy was rigidly registered using a user-defined 3D rectangular-shaped **ROI**.
We correct <u>set-up</u> of the patient.

4D-CBCT: correction protocol

- Second, tumor motion analysis was performed using a local rigid registration , based on a 3D-shaped ROI (**PTV expanded by 1.5 cm**)
- This ROI was automatically registered (<u>translations only</u>) to each phase of a 4D-CBCT scan yielding the tumor trajectory relative to the planned tumor position.



Rotation and translation corrected by:
Robotic Couch 6-D: **Hexapod**

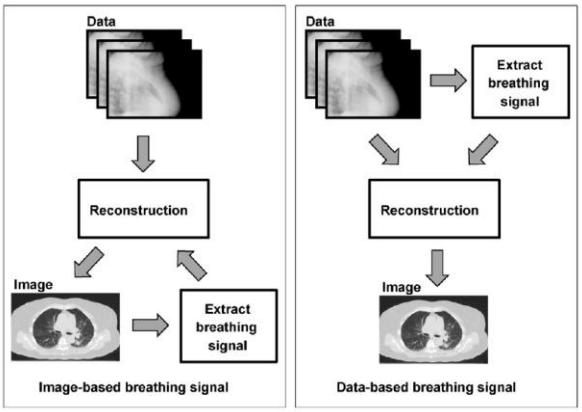
Baseline shift

The measured tumor trajectory was averaged (time-weighted) to quantify displacements of the mean tumor position. Corrections for **baseline shifts** were validated.

Abdominal compression was effective for reducing the amplitude of tumor motion. However the use of abdominal compression seemed to increase the **interfraction variation** in tumor position, despite reducing lung tumor motion. The daily tumor position deviated more systematically from the tumor position in the planning CT. Therefore, **target matching is required to correct or minimize the interfraction variation**.

Grazie dell'attenzione

Correlate 4D-CT and 4D-CBCT phase binning



Via DIR (VelocityAI) analysis