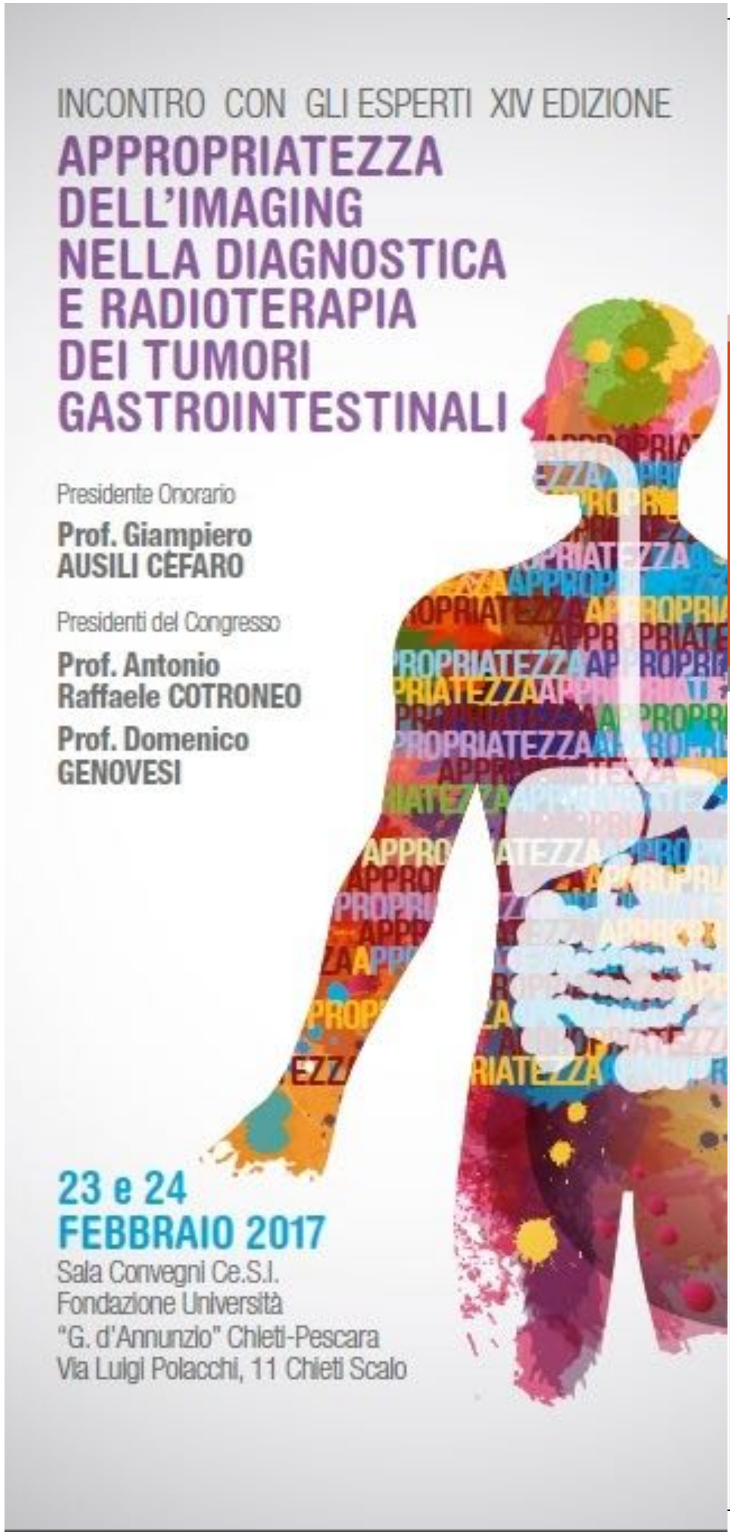


Azienda Sanitaria Locale
Lanciano Vasto Chieti

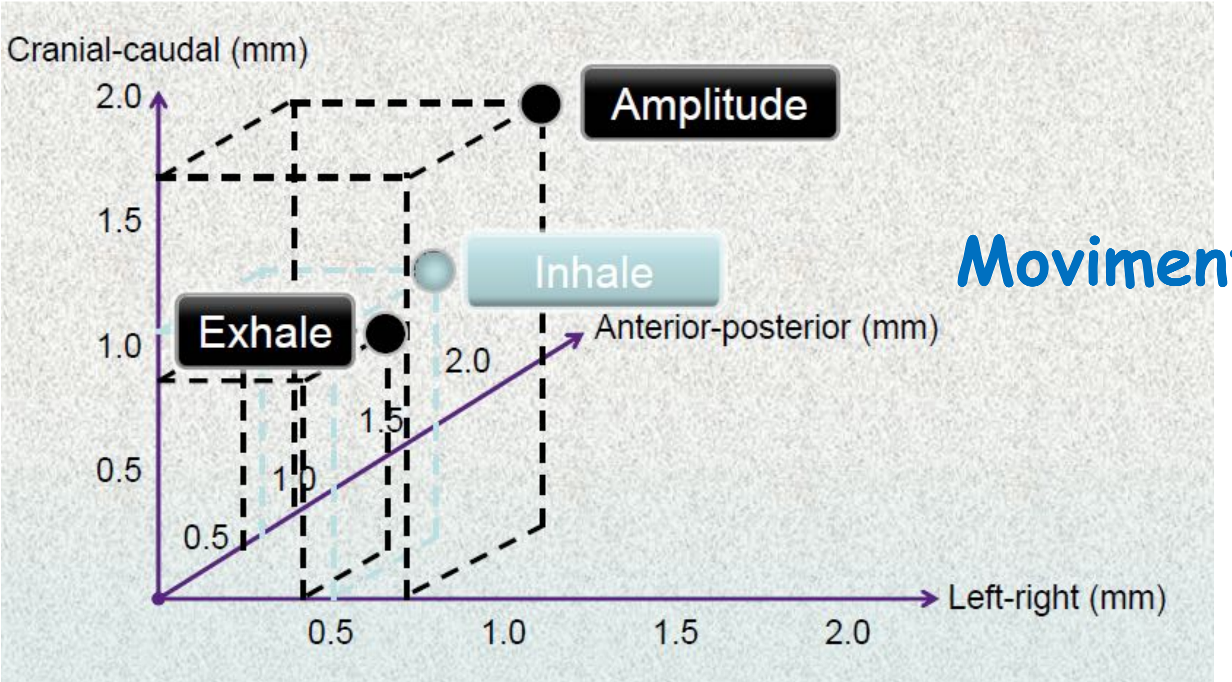
Radioterapia 4-D: "evidence" e metodologie applicative

Maria Daniela Falco

Università degli Studi "G. D'Annunzio"

Radioterapia 4D

Esplicita inclusione dei cambiamenti temporali dovuti ai movimenti respiratori durante l'imaging, il planning e delivery



Movimento dovuto al respiro

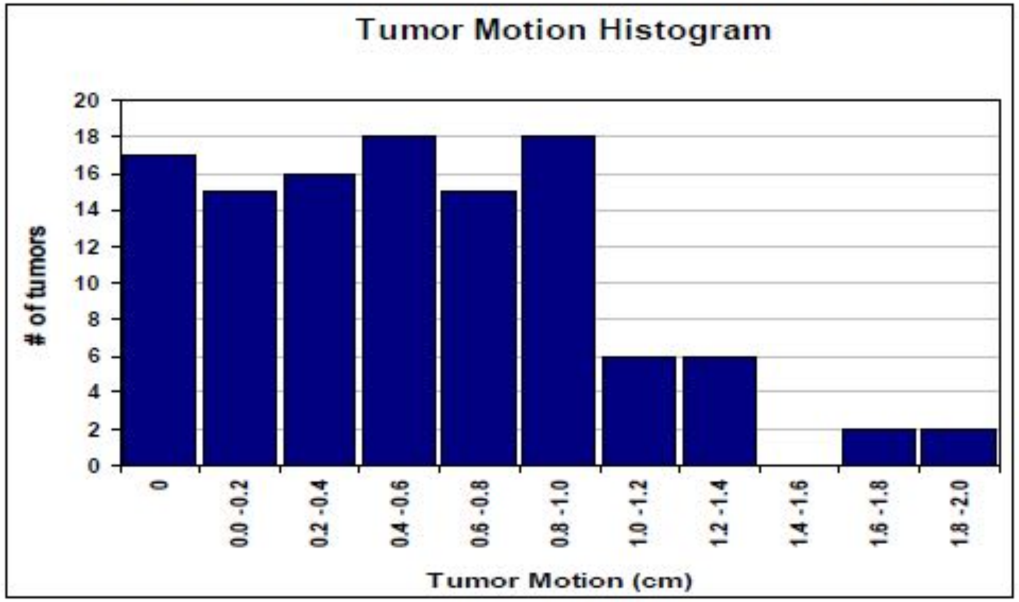
Il movimento è principalmente correlato allo spostamento del diaframma

PHYSICS CONTRIBUTION

ASSESSING RESPIRATION-INDUCED TUMOR MOTION AND INTERNAL TARGET VOLUME USING FOUR-DIMENSIONAL COMPUTED TOMOGRAPHY FOR RADIOTHERAPY OF LUNG CANCER

H. Helen Liu, Ph.D.,* Peter Balter, Ph.D.,* Teresa Tutt,* Bum Choi, Ph.D.,*

How much do thoracic tumors move ?

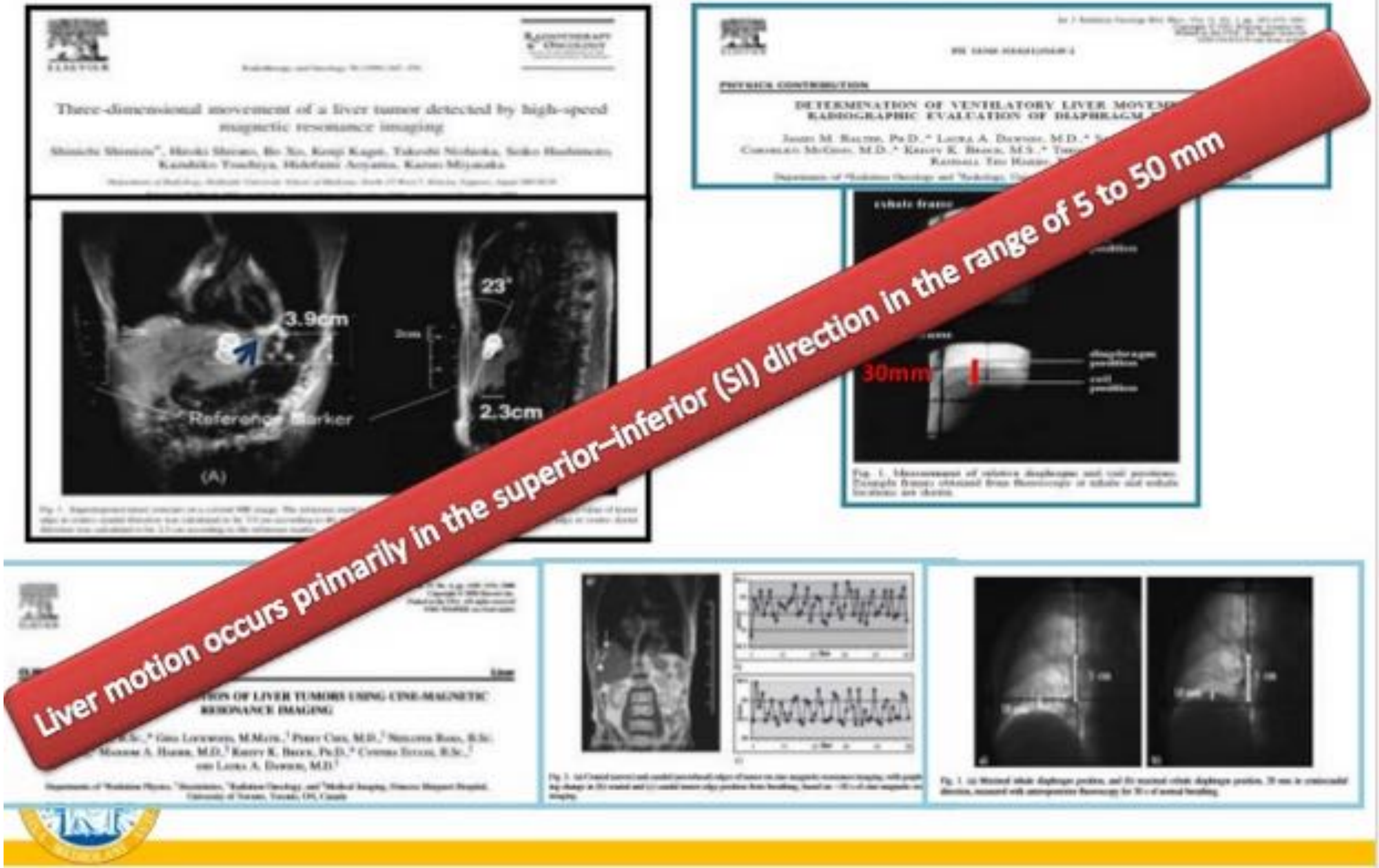


Conclusions: Lung tumor motion is primarily driven by diaphragm motion. The motion of locally advanced lung tumors is unlikely to exceed 1.0 cm during quiet normal breathing except for small lesions located in the lower half of the lung.

Direzione di maggior spostamento → CRANIO-CAUDALE (95% dei tumori < 1.34 cm)

Distribuzione **anisotropa dei movimenti**

How much does liver move?



Strategie: quali?

- **NON CONSIDERARLO?**

- **CONTENERLO :** BREATH HOLD, BODY FIX, COMPRESSORE

- **TRACCIARLO : CYBERKNIFE,** EXACTRACK

4DCT - GATING

The management of respiratory motion in radiation oncology report of AAPM Task Group 76[a]

Paul J. Keall[b]
Virginia Commonwealth University (Chair)

2006

C. Scope

Methods that are used in the management of respiratory motion in radiation oncology and that are covered by this report include:

- Motion-encompassing methods;
- respiratory gated techniques;
- breath-hold techniques;
- forced shallow-breathing methods;
- respiration-synchronized techniques.

Int J Radiat Oncol Biol Phys. 2012 Jul 15;83(4):1338-43. doi: 10.1016/j.ijrobp.2011.09.010. Epub 2012 Jan 13.

Respiration-correlated image guidance is the most important radiotherapy motion management strategy for most lung cancer patients.

Korreman S[1], Persson G, Nygaard D, Brink C, Juhler-Nøttrup T.

PURPOSE: The purpose of this study was to quantify the effects of four-dimensional computed tomography (4DCT), 4D image guidance (4D-IG), and beam gating on calculated treatment field margins in a lung cancer patient population.

46 cancer patients

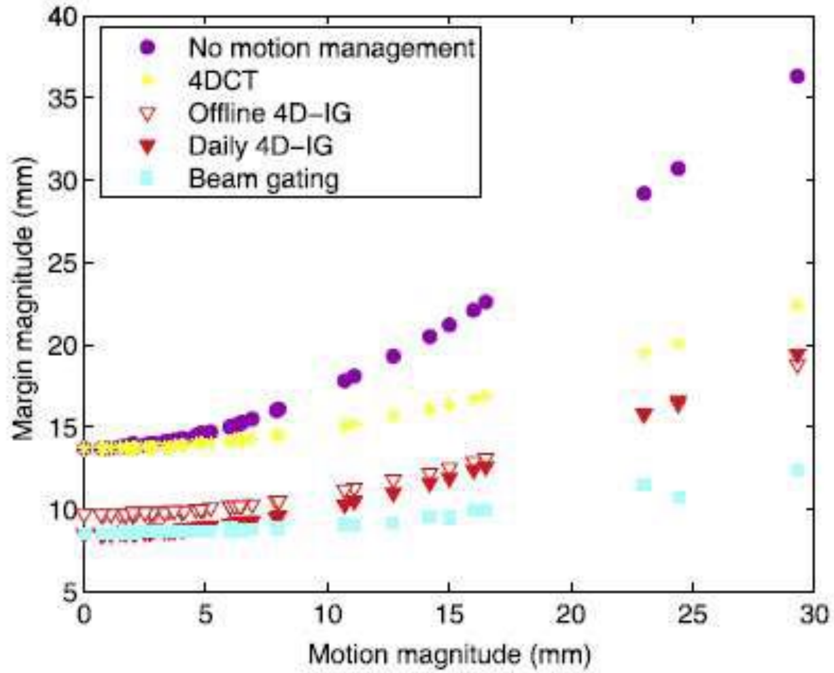


Fig. 2. The required calculated margins for the four motion management strategies are shown versus motion magnitude.

CONCLUSION: A respiratory management strategy for lung cancer radiotherapy including planning on 4DCT scans and daily image guidance provides a potential reduction of 37% to 47% in treatment field margins. The 4D image guidance strategy was the most effective strategy for >85% of the patients.

Int J Radiat Oncol Biol Phys. 2009 Jun 1;74(2):567-74. doi: 10.1016/j.ijrobp.2008.08.004. Epub 2008 Nov 27.

Frameless stereotactic body radiotherapy for lung cancer using four-dimensional cone beam CT guidance.

Sonke JJ[1], Rossi M, Wolthaus J, van Herk M, Damen E, Belderbos J.

PURPOSE: To quantify the localization accuracy and intrafraction stability of lung cancer patients treated with frameless, four-dimensional (4D) cone beam computed tomography (CBCT)-guided stereotactic body radiotherapy (SBRT) and to calculate and validate planning target volume (PTV) margins to account for the residual geometric uncertainties.

MATERIALS AND METHODS: Sixty-five patients with small peripheral lung tumors were treated with SBRT without a body frame to 54 Gy in three fractions. For each fraction, three 4D-CBCT scans were acquired: before treatment to measure and correct the time-weighted mean tumor position, after correction to validate the correction applied, and after treatment to estimate the intrafraction stability. Patient-specific PTV margins were computed and subsequently validated using Monte Carlo error simulations.

RESULTS: Systematic tumor localization inaccuracies (1 SD) were 0.8, 0.8, and 0.9 mm for the left-right, craniocaudal, and anteroposterior direction, respectively. Random localization inaccuracies were 1.1, 1.1, and 1.4 mm. Baseline variations were 1.8, 2.9, and 3.0 mm (systematic) and 1.1, 1.5, and 2.0 mm (random), indicating the importance of image guidance. Intrafraction stability of the target was 1.2, 1.2, and 1.8 mm (systematic) and 1.3, 1.5, and 1.8 mm (random). Monte Carlo error simulations showed that patient-specific PTV margins (5.8-10.5 mm) were adequate for 94% of the evaluated cases (2-28 mm peak-to-peak breathing amplitude).

CONCLUSIONS: Frameless SBRT can be safely administered using 4D-CBCT guidance. Even with considerable breathing motion, the PTV margins can safely be kept small, allowing patients with larger tumors to benefit from the advantages of SBRT. In case bony anatomy would be used as a surrogate for tumor position, considerably larger PTV margins would be required.

Metodi motion-encompassing

❖ **Slow CT scanning**: acquisizione TC lenta

-Vantaggi: media delle fasi respiratorie
-Svantaggi: perdita di risoluzione dovuta a "motion-blurring"

❖ **Inalation-exhalation breath-hold CT**: acquisizione delle fasi respiratorie di inalazione ed espirazione

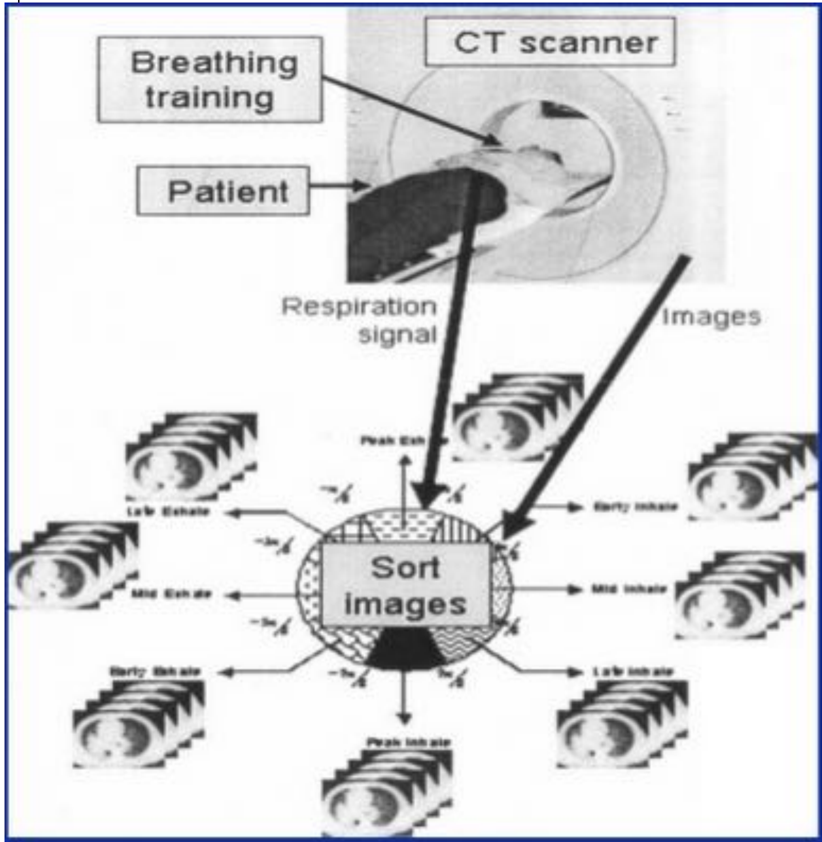
-Vantaggi: riduzione dell'effetto blurring legato al respiro libero
-Svantaggi: aumento considerevole del tempo di acquisizione TC, dipende dalla capacità del paziente di mantenere il respiro,volumi del target molto grandi

❖ **Four-Dimensional CT/CT respiro-correlata**

Aumento dei margini di contornazione

+ dose OAR
- dose target

Imaging/Target definition: 4D-CT



A diagram showing a 4D CT acquisition process. Images are acquired and then sorted by the patient's respiratory phase at the time the image was acquired to create 3D CT images at discrete phases of the respiratory cycle.

8 – 10x

si ottengono 10 serie di immagini che rappresentano l'anatomia e la posizione del tumore in uno specifico momento del ciclo respiratorio

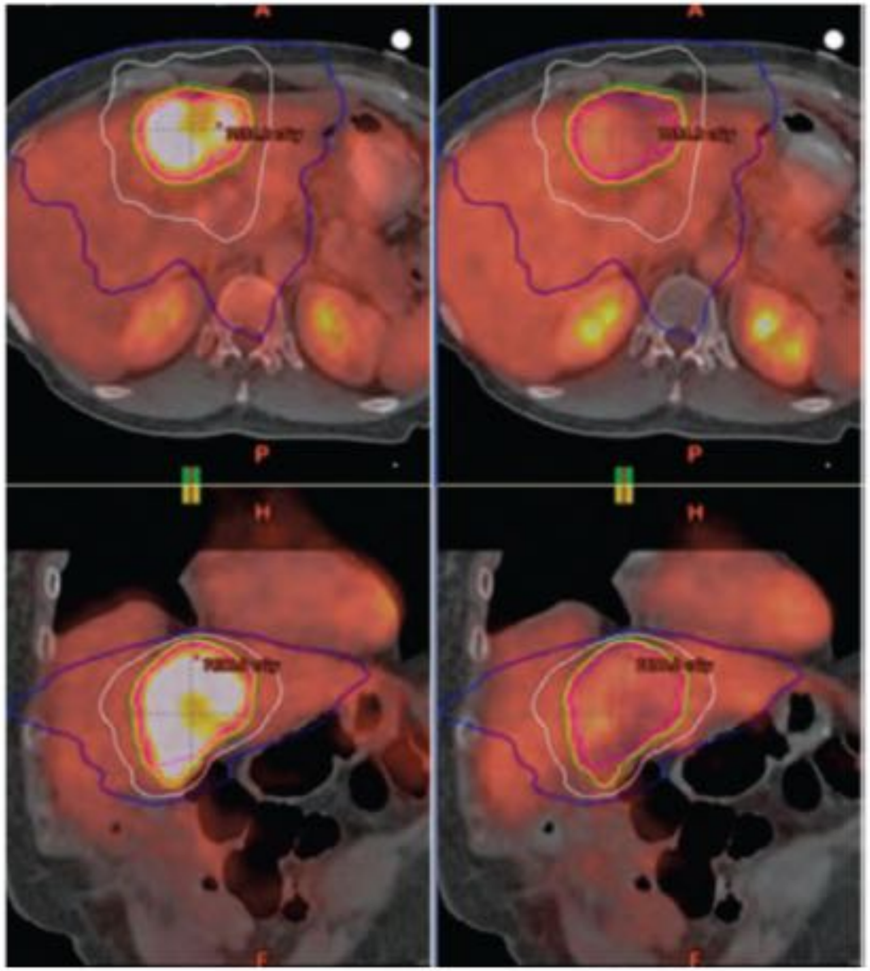
Le immagini vengono successivamente esportate al software di fusione per il matching delle 10 serie + serie average ricostruita

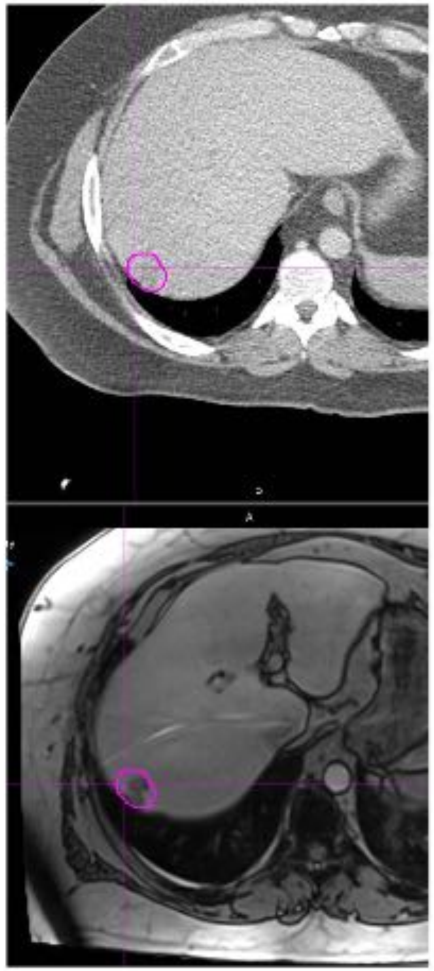
Is 4D-CT adequate? No!

- 4DCT margin compared with intra-fractional tumor motion tracked by fiducial markers:
  - Geometrical miss could be larger than 10% for 16 out of 20 pancreas patients (Minn. et. al., A J Clinc Oncol, V32, 2009)
  - 4DCT overestimated tumor motion in 39% of the fractions in 7 of 10 patients and underestimated it in 53% fractions in 8 of 10 patients (Ge. et. al., IJROBP V85(4) 2013)
- Real-time verification of tumor position during treatment delivery is important

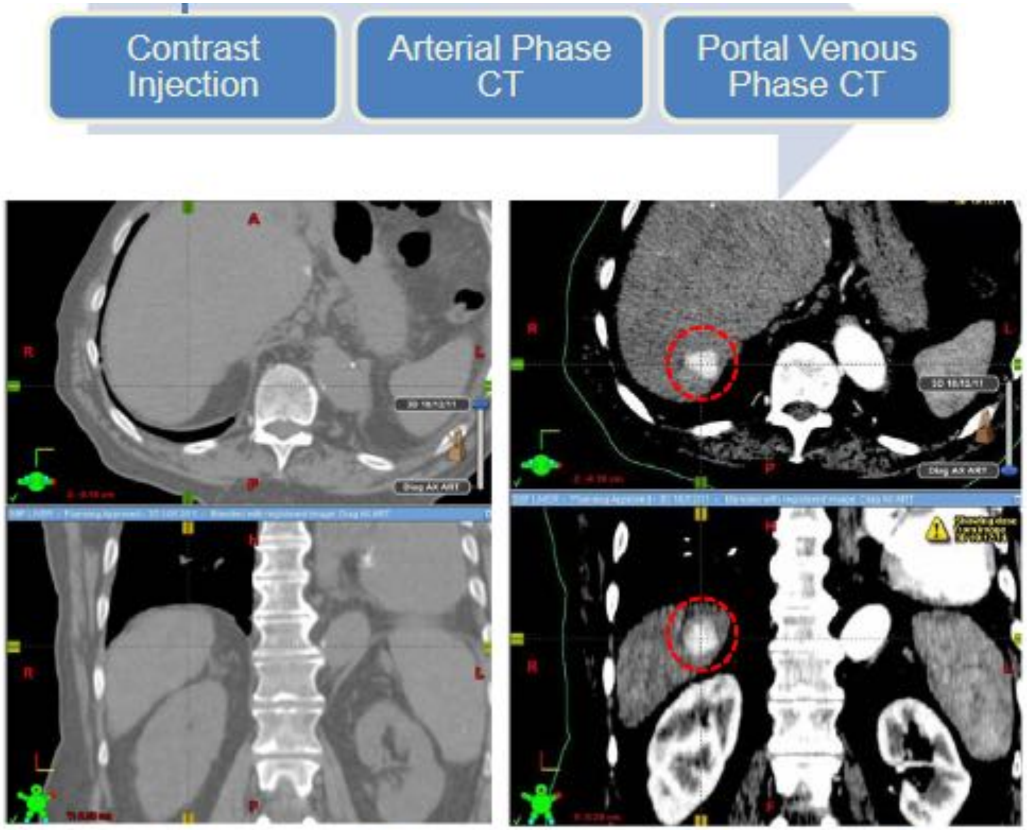
Delineazione del target

IMAGING MULTIMODALE





4D-CT → Mezzo di contrasto



Planning CT Dual phase CT

4D-CT scan analysis of tumor and organ motion at varying levels of abdominal compression during stereotactic treatment of lung and liver

Heinzerling J, Anderson J, Papiez L, Boike T, Chien S, Zhang G, Abdulrahman R, Timmerman R

Purpose

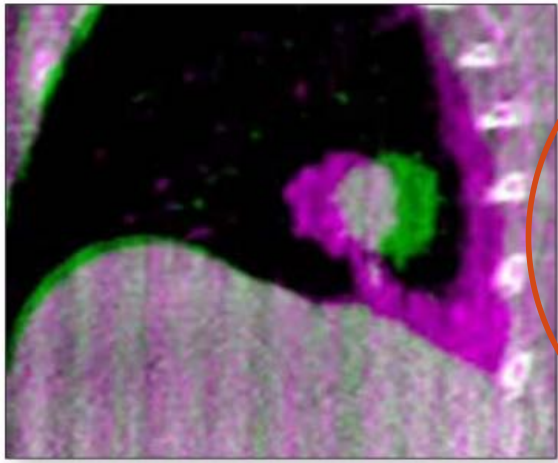
To investigate the effectiveness of different abdominal compression levels on tumor and organ motion during stereotactic body radiotherapy of lower lobe lung and liver tumors using four-dimensional (4D)-CT scan analysis.

Conclusions

Four-dimensional CT shows significant control of both lower lobe lung and liver tumors using abdominal compression. High levels of compression improve SI tumor motion when compared with MC.

Imaging/ Target definition: 4D CBCT

XVI Symmetry™
Managing respiratory motion



Baseline shift
Images courtesy of NKI-AvL Hospital, Amsterdam

- Helps achieve symmetrical dose distribution
- Uninterrupted patient set-up and treatment delivery
- Accounts for baseline shift for a variety of planning techniques, including ITV
- Enables margin reduction
- Simple intuitive workflow

Accuratezza??

Br J Radiol. 2016;89(1060):20150870. doi: 10.1259/bjr.20150870. Epub 2016 Feb 26.

Evaluating the four-dimensional cone beam computed tomography with varying gantry rotation speed.

Yoganathan SA[1], Maria Das KJ[1], Mohamed Ali S[2], Agarwal A[1], Mishra SP[2], Kumar S[1].

Author information

Abstract

OBJECTIVE: The purpose of this work was to evaluate the four-dimensional cone beam CT (4DCBCT) imaging with different gantry rotation speed.

METHODS: All the 4DCBCT image acquisitions were carried out in Elekta XVI Symmetry™ system (Elekta AB, Stockholm, Sweden). A dynamic thorax phantom with tumour mimicking inserts of diameter 1, 2 and 3 cm was programmed to simulate the respiratory motion (4 s) of the target. 4DCBCT images were acquired with different gantry rotation speeds (36°, 50°, 75°, 100°, 150° and 200° min(-1)). Owing to the technical limitation of 4DCBCT system, average cone beam CT (CBCT) images derived from the 10 phases of 4DCBCT were used for the internal target volume (ITV) contouring. ITVs obtained from average CBCT were compared with the four-dimensional CT (4DCT). In addition, the image quality of 4DCBCT was also evaluated for various gantry rotation speeds using Catphan(®) 600 (The Phantom Laboratory Inc., Salem, NY).

RESULTS: Compared to 4DCT, the average CBCT underestimated the ITV. The ITV deviation increased with increasing gantry speed (-10.8% vs -17.8% for 36° and 200° min(-1) in 3-cm target) and decreasing target size (-17.8% vs -26.8% for target diameter 3 and 1 cm in 200° min(-1)). Similarly, the image quality indicators such as spatial resolution, contrast-to-noise ratio and uniformity also degraded with increasing gantry rotation speed.

CONCLUSION: The impact of gantry rotation speed has to be considered when using 4DCBCT for ITV definition. The phantom study demonstrated that 4DCBCT with slow gantry rotation showed better image quality and less ITV deviation.

ADVANCES IN KNOWLEDGE: Usually, the gantry rotation period of Elekta 4DCBCT system is kept constant at 4 min (50° min(-1)) for acquisition, and any attempt of decreasing/increasing the acquisition duration requires careful investigation. In this study, the 4DCBCT images with different gantry rotation speed were evaluated.

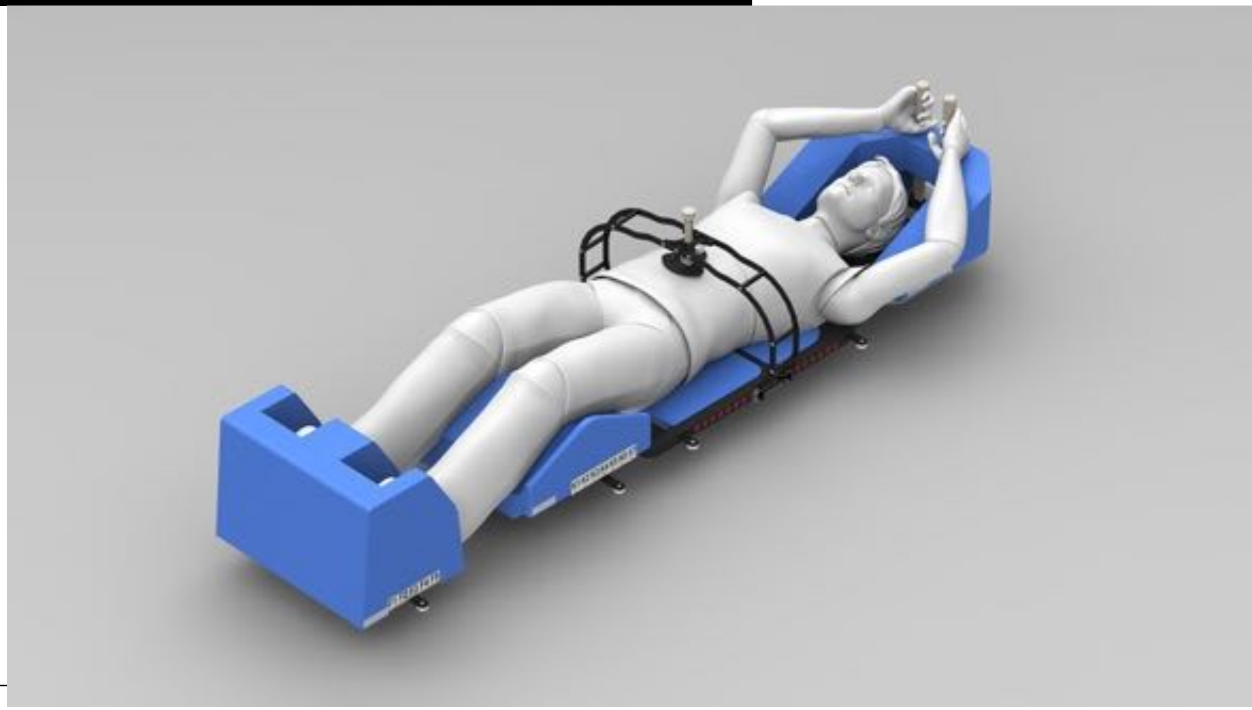
Sistemi di immobilizzazione

Measurement of abdominal height

Measurement of abdominal diameter

La fascia registra il respiro del paziente e ricostruisce il suo ciclo respiratorio

Richiede sistemi hardware e software complessi



Definizioni: Volumi di trattamento

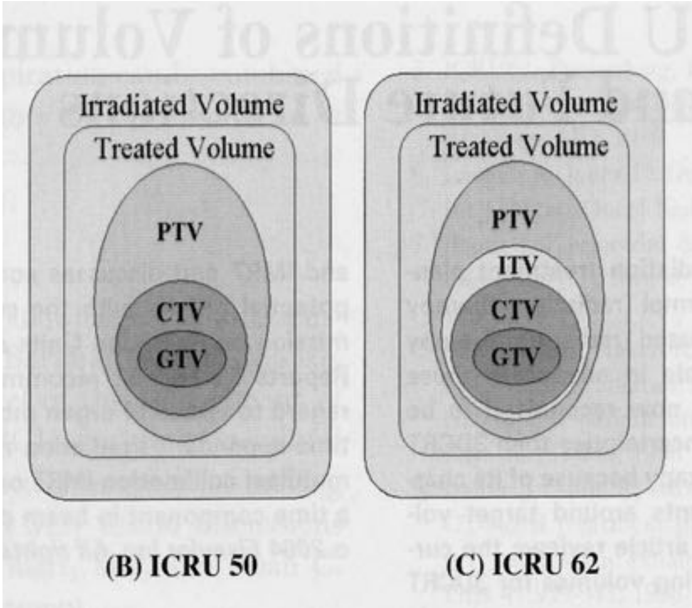
GTV = estensione macroscopica del tumore (GTV-P e GTV-N)

CTV = GTV + circostanti infiltrazioni tumorali microscopiche (CTV-P e CTV-N)

ITV = CTV + IM (introdotto da ICRU report 62)

IM (Internal Margin): definito in base a punti di riferimento interni (reperi ossei), considera i possibili movimenti fisiologici di tumori / tessuti sani causati da respirazione, pulsazioni, cambiamenti di forma e dimensioni dei tumori, attività viscerali, …

PTV = CTV + IM + SM (in Radioterapia, i campi o archi radianti sono conformati al PTV, il quale incorpora nel modo qui descritto le tipiche incertezze geometriche della Radioterapia)



ICRU 50, 1993 e ICRU 62, 1999

4 D

Breath Hold

Gating

Tracking

Riduzione sul PTV

Dose Escalation

Minor tossicità

Metodo BREATH-HOLD

➢Deep-inspiration breath hold

-respiro trattenuto 10-20 s attraverso un tubo flessibile connesso ad uno spirometro sia in fase di simulazione che di erogazione del trattamento radiante

-profilo spirometrico del ciclo respiratorio in funzione del tempo registrato da un computer

-circa il 60% dei soggetti affetti da neoplasia polmonare non è suscettibile di questa metodica

➢Self-healed breath hold with respiratory monitoring

- tecnica che sfrutta un device (RPM System) per monitorare il respiro del paziente e controllare la delivery della dose
- irradiazione continua nella fase di breath-hold sotto costante monitoraggio

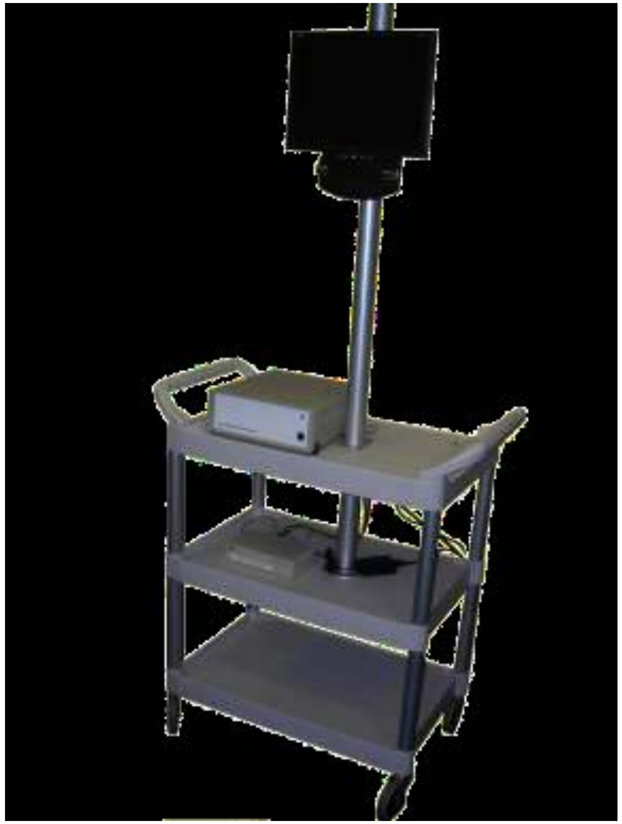
➢Active-breathing control (ABC)

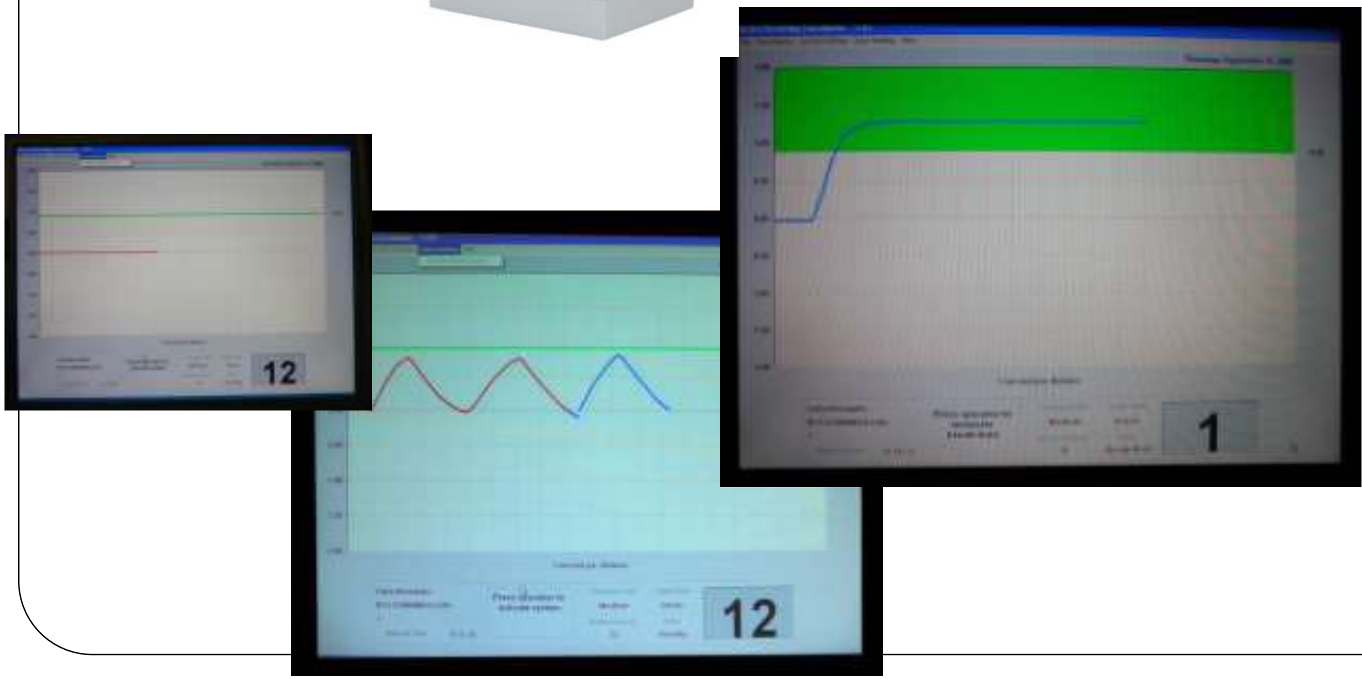
Active-breathing control (ABC)

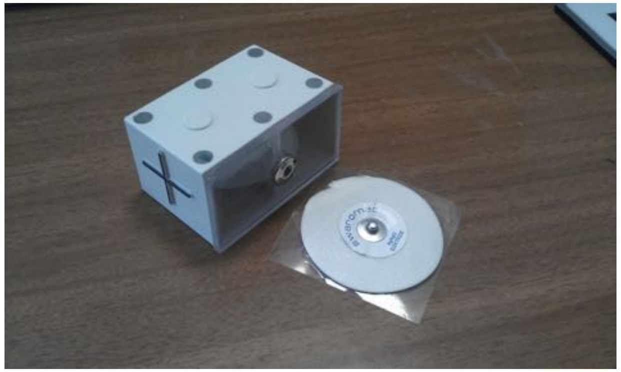
- Paziente istruito a respirare attraverso uno spirometro digitale connesso ad una ballon-valve adatto a registrare la traccia respiratoria
- La respirazione può essere sospesa a qualunque predeterminata posizione → preferibile fase di moderata o profonda inspirazione
- L'operatore sceglierà il volume polmonare e lo stadio del ciclo respiratorio al quale "attivare il sistema" che chiude il balloon-valve

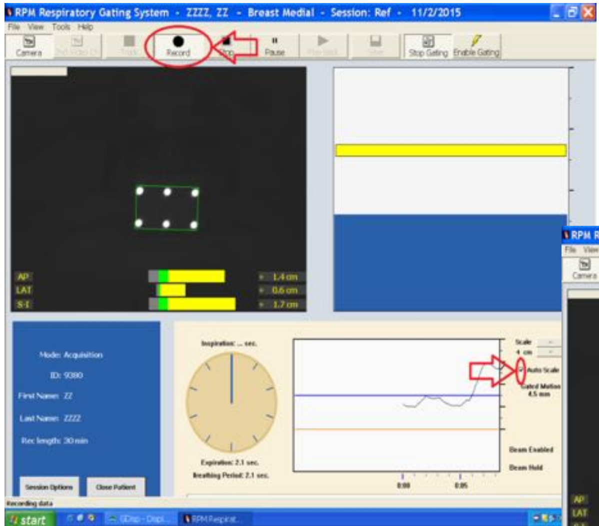
Non particolarmente confortevole per il paziente

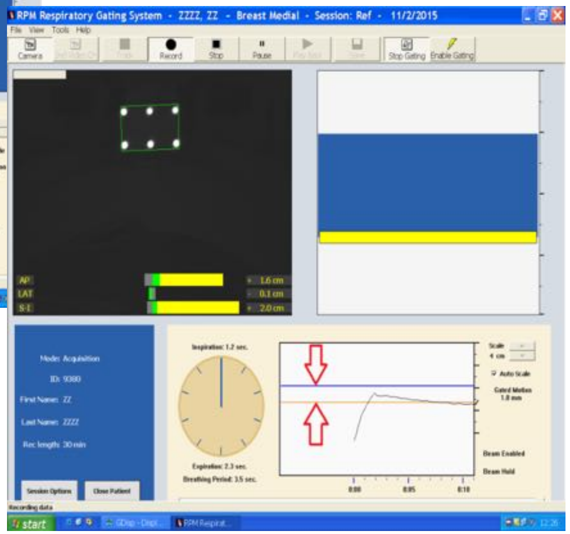
Allunga il tempo di trattamento




12
12
1




RPM Respiratory Gating System - ZZZZ, ZZ - Breast Medial - Session: Ref - 11/2/2015
File View Tools Help
Camera
Record
Pause
Stop Gating
Enable Gating
AP
LAT
S-I
1.4 cm
0.6 cm
1.7 cm
Mode: Acquisition
ID: 9380
First Name: ZZ
Last Name: ZZZZ
Rec length: 30 min
Session Options
Close Patient
Expiration: 2.1 sec.
Breathing Period: 2.1 sec.
Beam Enabled
Beam Hold
Recording data
start


RPM Respiratory Gating System - ZZZZ, ZZ - Breast Medial - Session: Ref - 11/2/2015
File View Tools Help
Camera
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Pause
Stop Gating
Enable Gating
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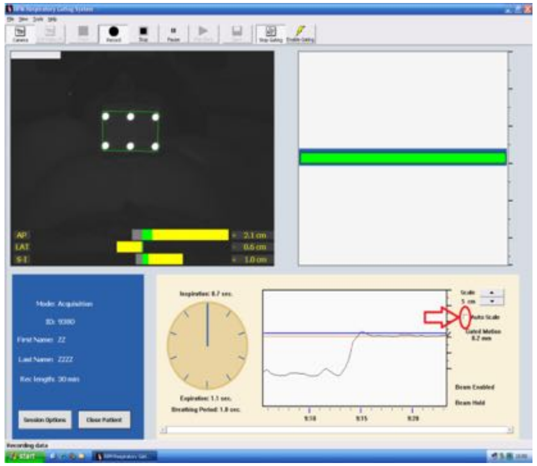
1.6 cm
0.1 cm
2.0 cm
Mode: Acquisition
ID: 9380
First Name: ZZ
Last Name: ZZZZ
Rec length: 30 min
Inspiration: 1.2 sec.
Expiration: 2.3 sec.
Breathing Period: 3.5 sec.
Auto Scale
Beam Enabled
Beam Hold
Session Options
Close Patient
Recording data
start



E' sufficiente il breath hold?

Radiother Oncol. 2016 Nov;121(2):268-275. doi: 10.1016/j.radonc.2016.09.012. Epub 2016 Oct 20.

Abdominal organ motion during inhalation and exhalation breath-holds: pancreatic motion at different lung volumes compared.

Lens E[1], Gurney-Champion OJ[2], Tekelenburg DR[3], van Kesteren Z[3], Parkes MJ[4], van Tienhoven G[3], Nederveen AJ[5], van der Horst A[3], Bel A[3].

⊕ Author information

Abstract

PURPOSE: Contrary to what is commonly assumed, organs continue to move during breath-holding. We investigated the influence of lung volume on motion magnitude during breath-holding and changes in velocity over the duration of breath-holding.

MATERIALS AND METHODS: Sixteen healthy subjects performed 60-second inhalation breath-holds in room-air, with lung volumes of ~100% and ~70% of the inspiratory capacity, and exhalation breath-holds, with lung volumes of ~30% and ~0% of the inspiratory capacity. During breath-holding, we obtained dynamic single-slice magnetic-resonance images with a time-resolution of 0.6s. We used 2-dimensional image correlation to obtain the diaphragmatic and pancreatic velocity and displacement during breath-holding.

RESULTS: Organ velocity was largest in the inferior-superior direction and was greatest during the first 10s of breath-holding, with diaphragm velocities of 0.41mm/s, 0.29mm/s, 0.16mm/s and 0.15mm/s during $BH_{100\%}$, $BH_{70\%}$, $BH_{30\%}$ and $BH_{0\%}$, respectively. Organ motion magnitudes were larger during inhalation breath-holds (diaphragm moved 9.8 and 9.0mm during $BH_{100\%}$ and $BH_{70\%}$, respectively) than during exhalation breath-holds (5.6 and 4.3mm during $BH_{30\%}$ and $BH_{0\%}$, respectively).

CONCLUSION: Using exhalation breath-holds rather than inhalation breath-holds and delaying irradiation until after the first 10s of breath-holding may be advantageous for irradiation of abdominal tumors.

Gating e Tracking

Tecnica di trattamento in cui il paziente respira liberamente e l'irradiazione avviene solo in corrispondenza di una fase del cilco respiratorio

Gating: il fascio è on o off a seconda della posizione in real time del target →

Segnale esterno

Internal fiducial marker → invasivo

Tracking: il fascio di radiazione è sempre on e segue il movimento del target

Esperienza di CHIETI

CT +TPS → XVI-SYMMETRY

CT+TPS

XVI-SYMMETRY

Casistica 7 pazienti

1 pz lesione epatica

2 pz con linfonodo mediastinico

4 pz SBRT su nodulo polmonare

TPS= Oncentra MasterPlan

Tecnica=VMAT (6 MV)

Acceleratore lineare = Elekta Synergy Agility

Sistema di immobilizzazione

Compressione addominale

Maschera termoplastica

Poggiatesta

Poggiagambe

Lettino fibra di carbonio

Imaging/target Definition

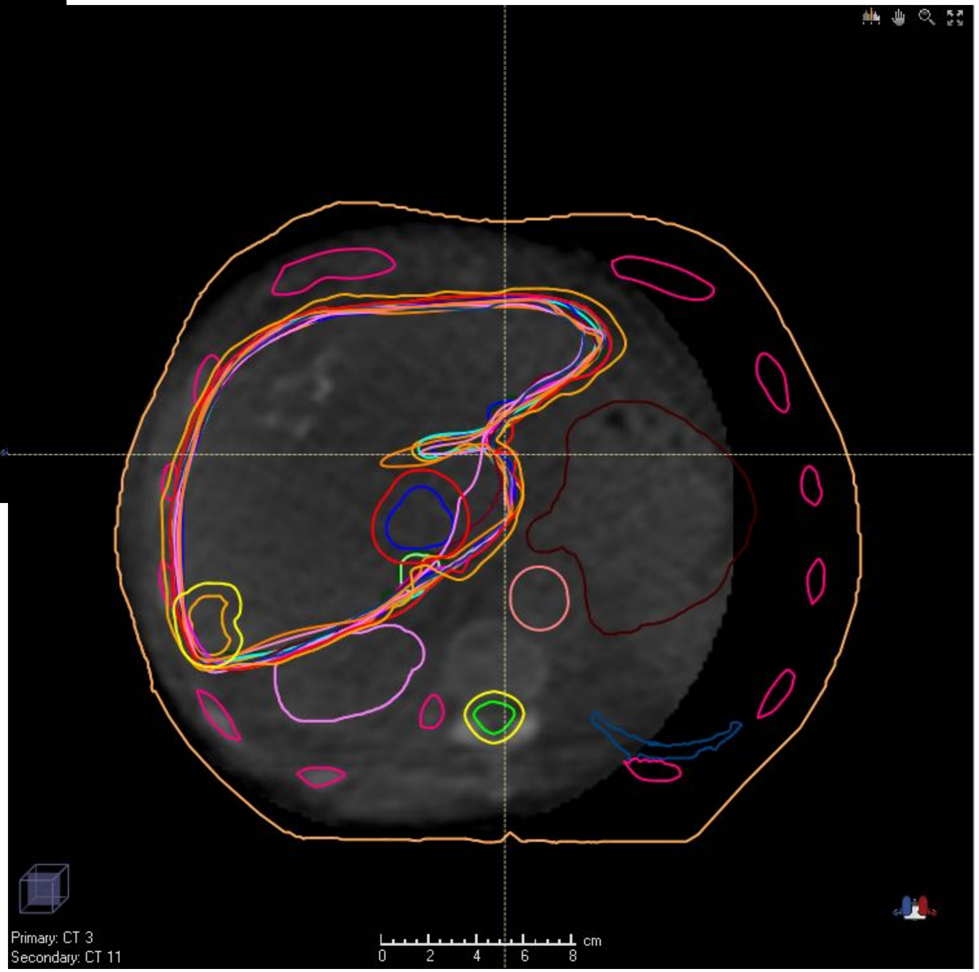
CT con respiro libero

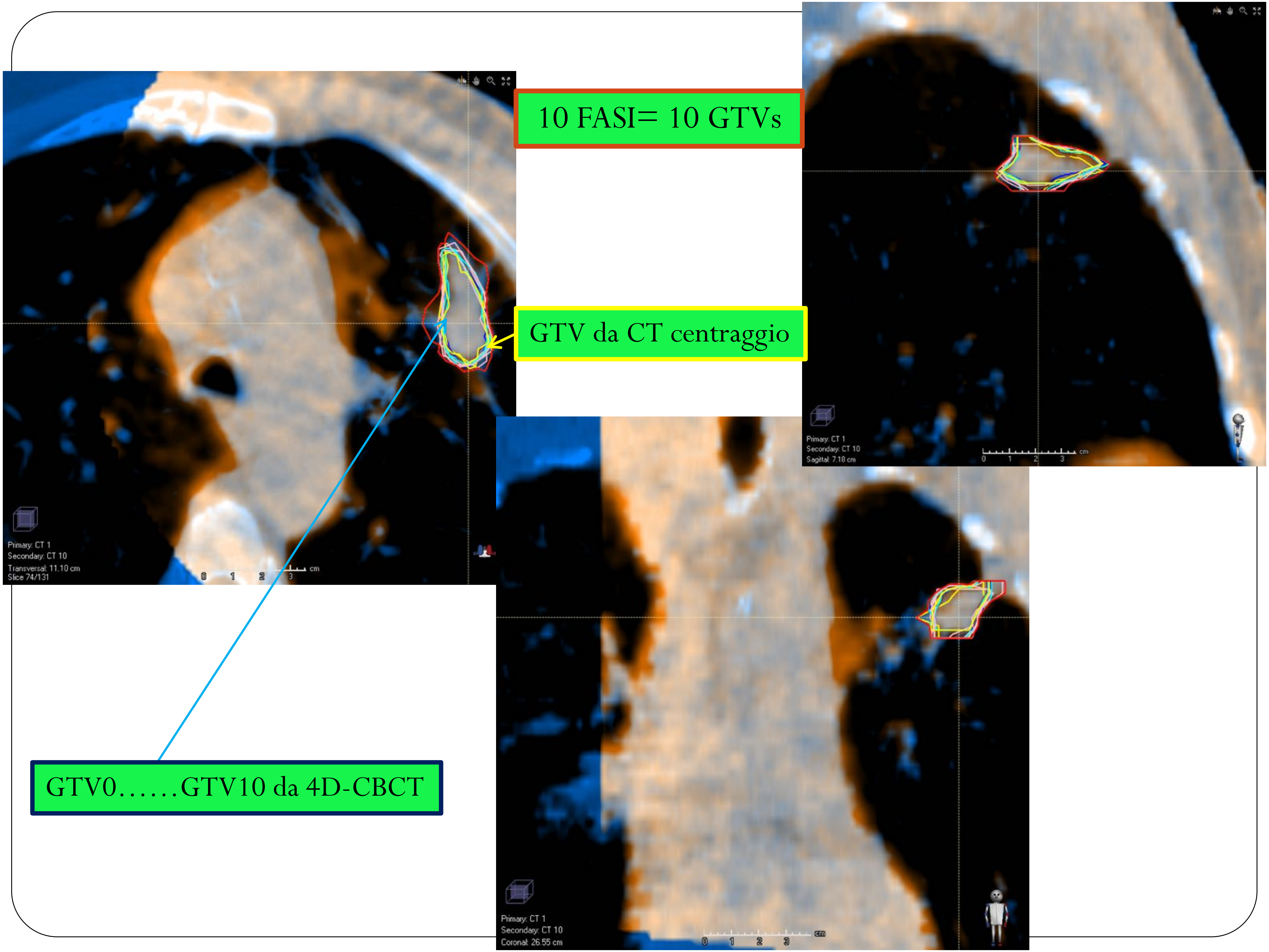
1. CT: Slice thickness = 3 mm
   FOV= tutti gli organi a rischio
2. TPS RayStation: contornazione GTV e outline e posizionamento iso provvisorio
3. Esportazione su MOSAIQ dell'iso, GTV e un fascio
4. XVI: acquisizione 4D-CBCT con Symmetry ("traccia respiratoria" ottenuta utilizzando la posizione del diaframma come "internal marker")

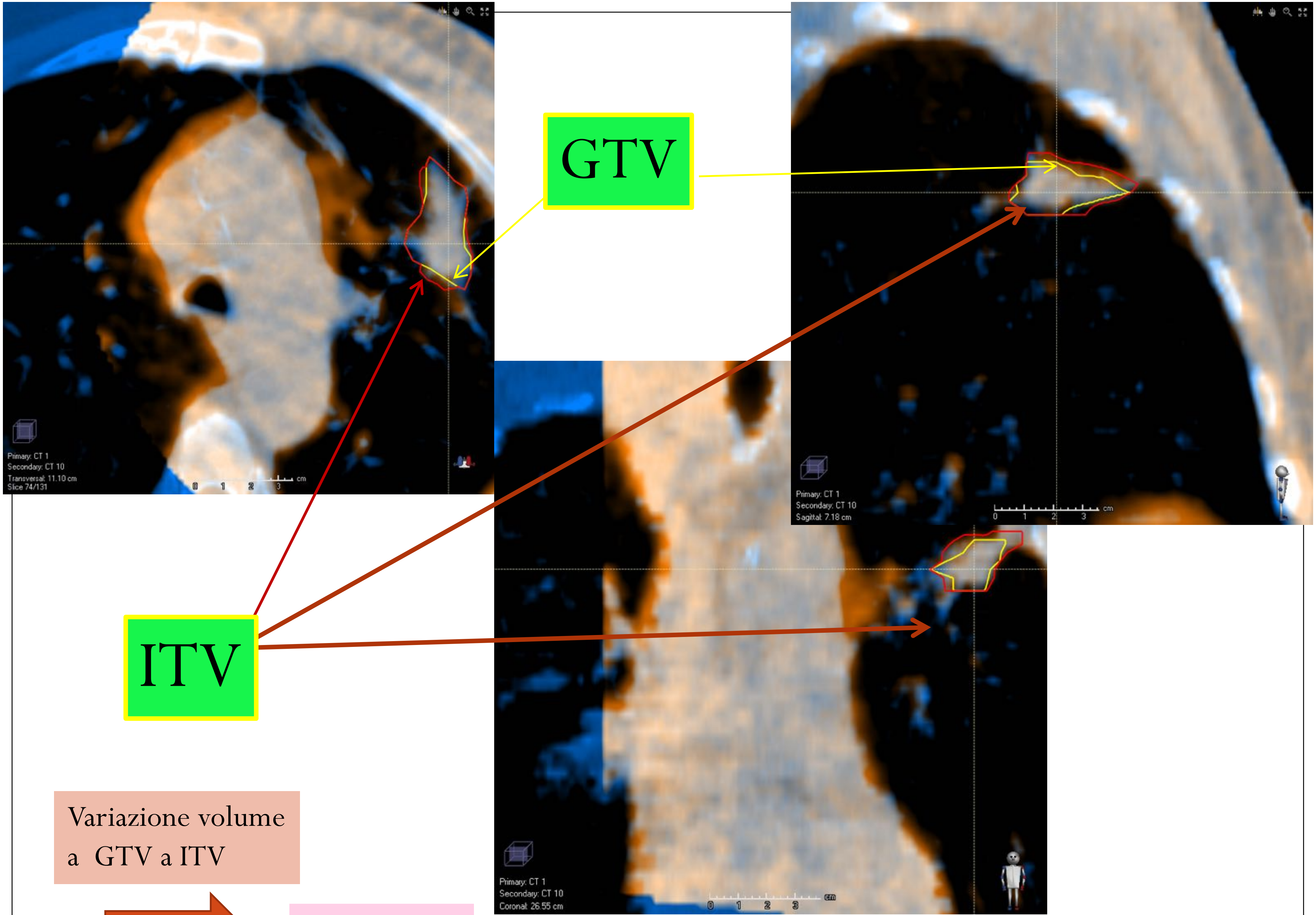
5. Esportazione dei singoli pacchetti (Mini-Volume View) corrispondenti alle varie fasi respiratorie (10) a WS di contornazione (TPS raystation)
6. Registrazione di 4D-CBCT corrispondente ad ogni fase respiratoria con la CT di centraggio
7. Contornazione di 10 GTVs
9. Volume di unione dei 10 GTV → ITV
10. Esportazione piano a MOSAIQ, approvazione dei fasci e creazione della 4D-CBCT

Margini da ITV a PTV 5 mm ….


Primary: CT 3
Secondary: CT 11
Transversal: 14.40 cm
Slice 81/165
0 2 4 6 8 cm


Primary: CT 3
Secondary: CT 11
0 2 4 6 8 cm

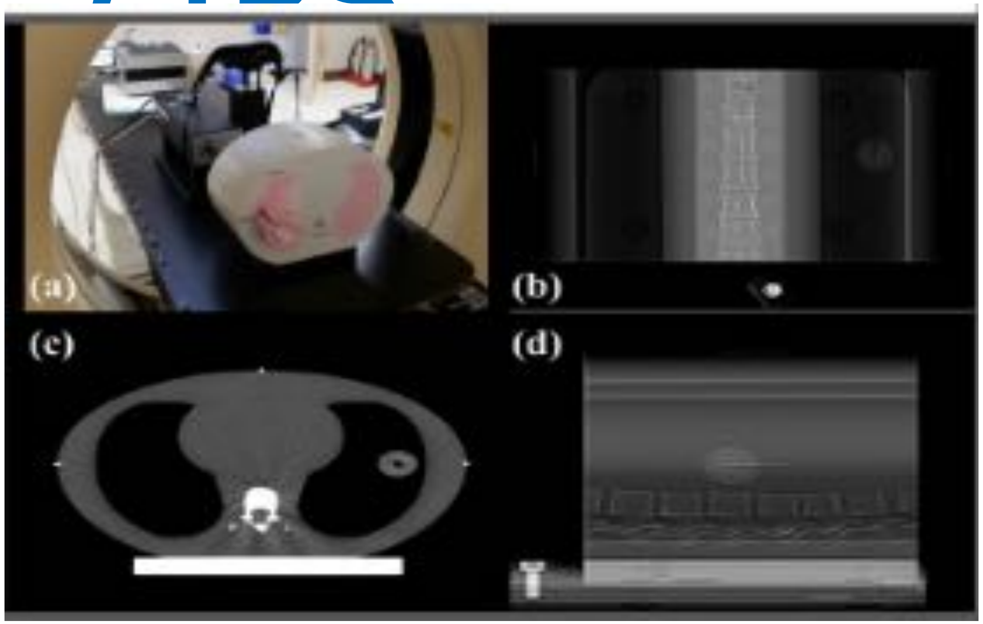

10 FASI= 10 GTVs
GTV da CT centraggio
GTV0……GTV10 da 4D-CBCT
Primary: CT 1
Secondary: CT 10
Transversal: 11.10 cm
Slice 74/131
Primary: CT 1
Secondary: CT 10
Sagittal: 7.18 cm
Primary: CT 1
Secondary: CT 10
Coronal: 26.55 cm



Variazione volume
a GTV a ITV

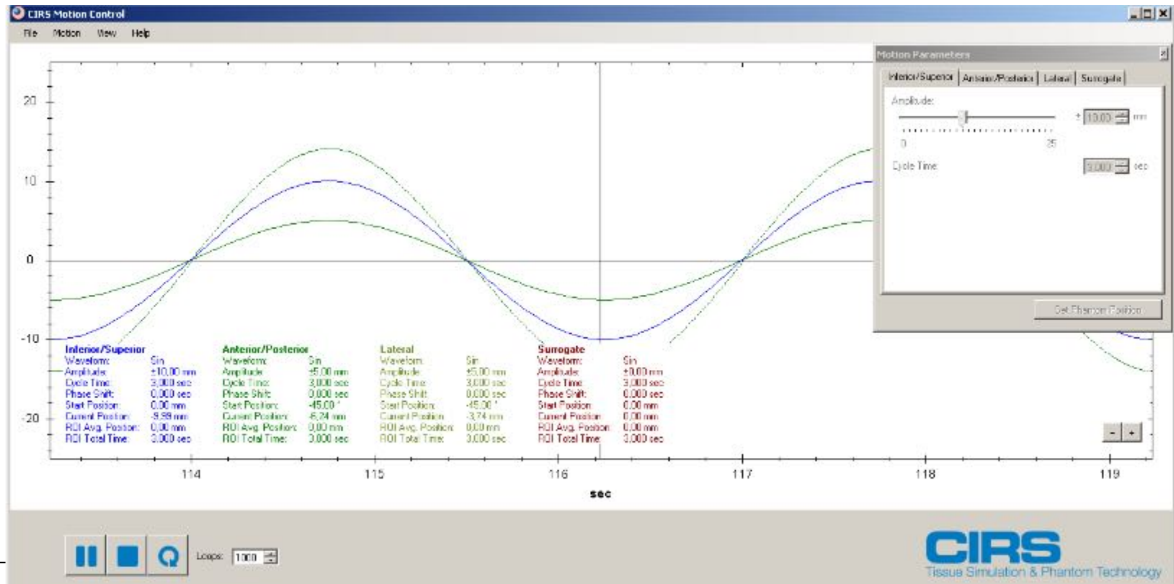
18% - 63%

Commissioning Symmetry: CIRS



Sfera target 3 cm
Movimento: ± 5 mm in direzione antero-posteriore; ± 5 mm in direzione latero-laterale; ± 10 mm in direzione supero-inferiore

frequenza di cicli respiratori impostata è stata di 1 ciclo/3 secondi



- Slice thickness = 3 mm
- Esportazione TPS Oncentra Masterplan
- Contornazione

•**GTV_1**: "sfera target" più effetto blurring secondario al movimento. Contornazione eseguita mediante utilizzo della finestra TC per parenchima polmonare
•**PTV_1**: GTV_1 + 0.5 cm di espansione isotropica
•**GTV_2** :"sfera target" senza effetto blurring secondario al movimento. Contornazione eseguita mediante utilizzo della finestra TC per parenchima polmonare
•**PTV_2** : GTV_2 + 0.8 cm di espansione isotropica

- Piano di trattamento VMAT

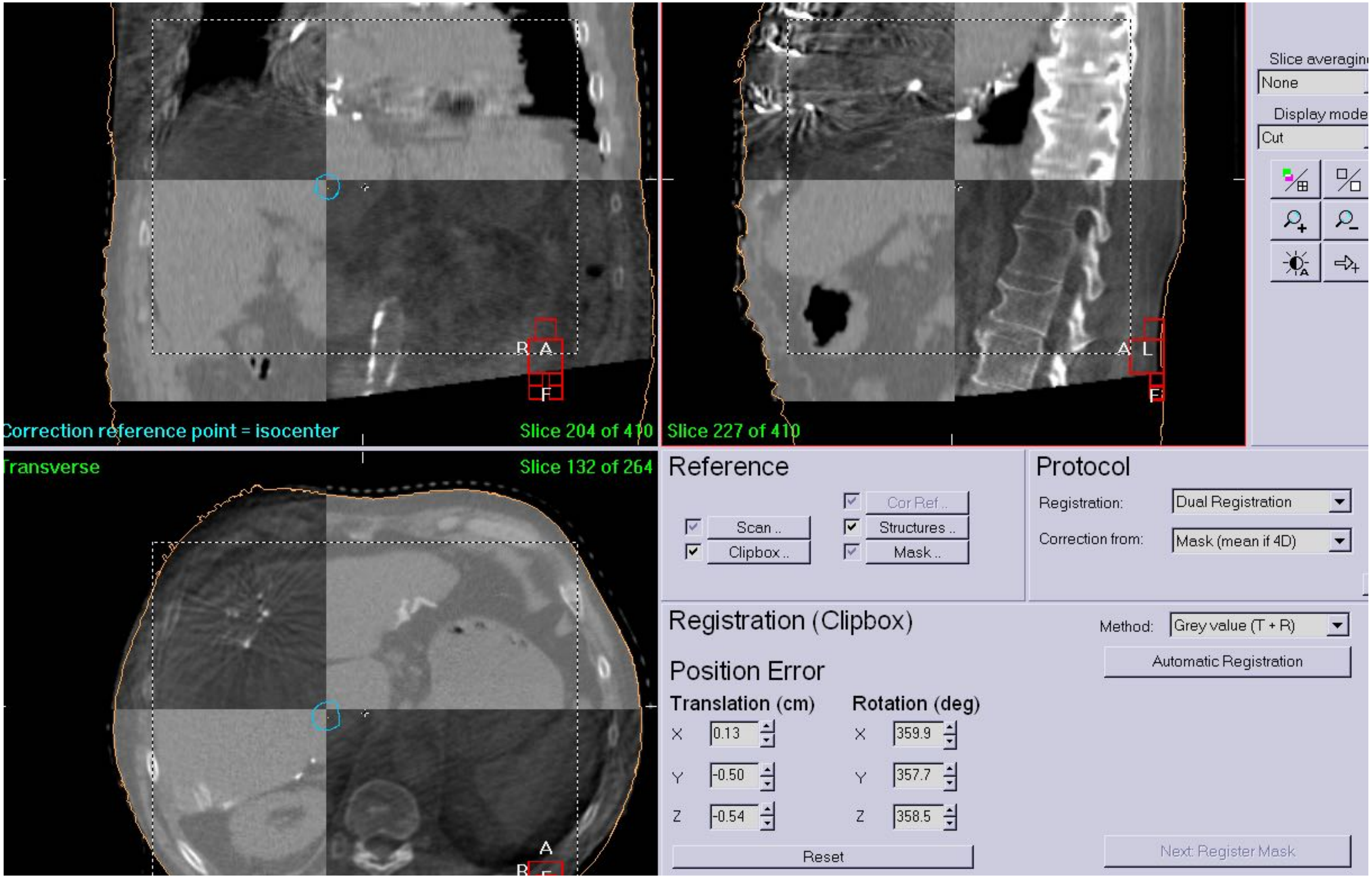
- Verifica con Symmetry

Valore assoluto errori (differenza rispetto i movimenti pre-stabiliti in fase di acquisizione delle CTs) ≤ *0.15 cm*

La 4D-CBCT inviata al TPS per la verifica della concordanza tra volumi contornati sulla base della TC di centratura e quelli definibili alla CBCT 4D

$ITV_{4D\text{-}CBCT}$ e $PTV_{4D\text{-}CBCT}$ sovrapponibile a ITV e PTV contornati nella CT iniziale

Trattamento-XVI Symmetry

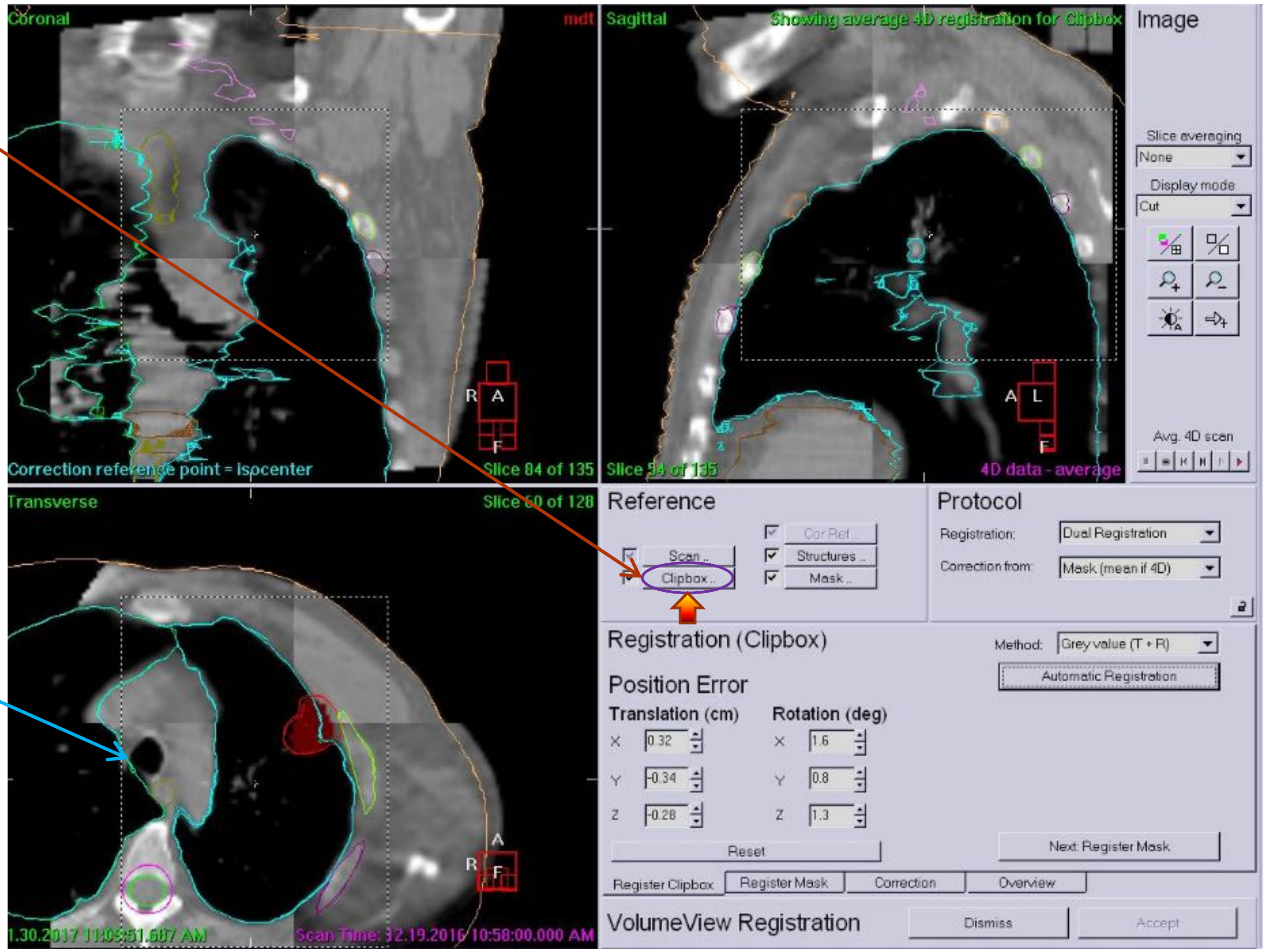


SENZA MEZZO DI CONTRASTO NON SI VEDE LESIONE IN CBCT4D

Trattamento-XVI Symmetry

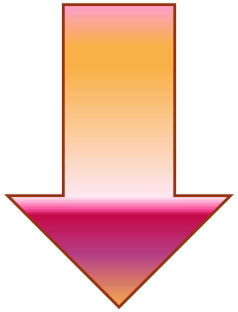
Correzione set-up

Clipbox



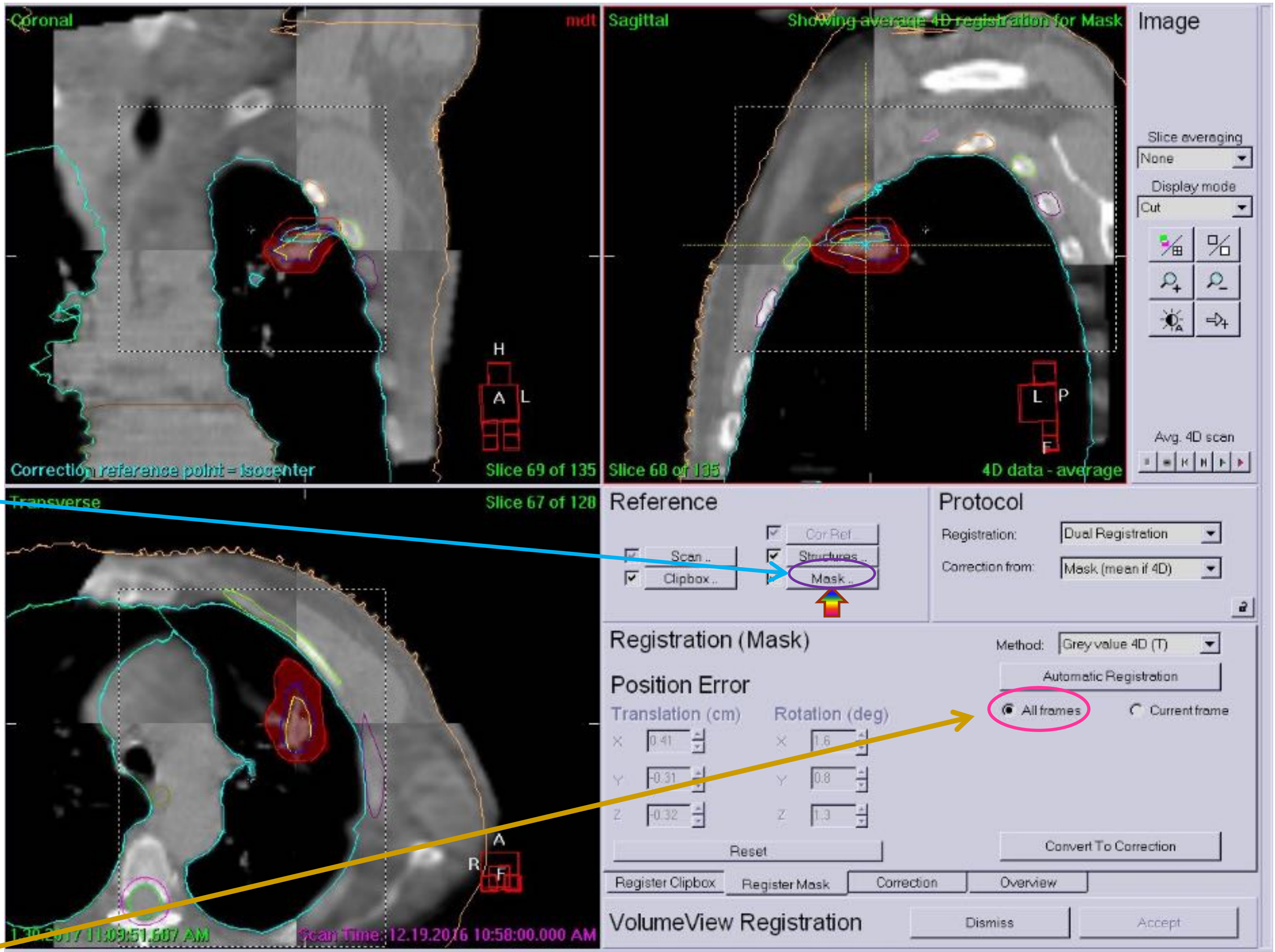
Metodo di co-registrazione:"**GREY VALUE T+R**"

Correzione su movimento target



Mask

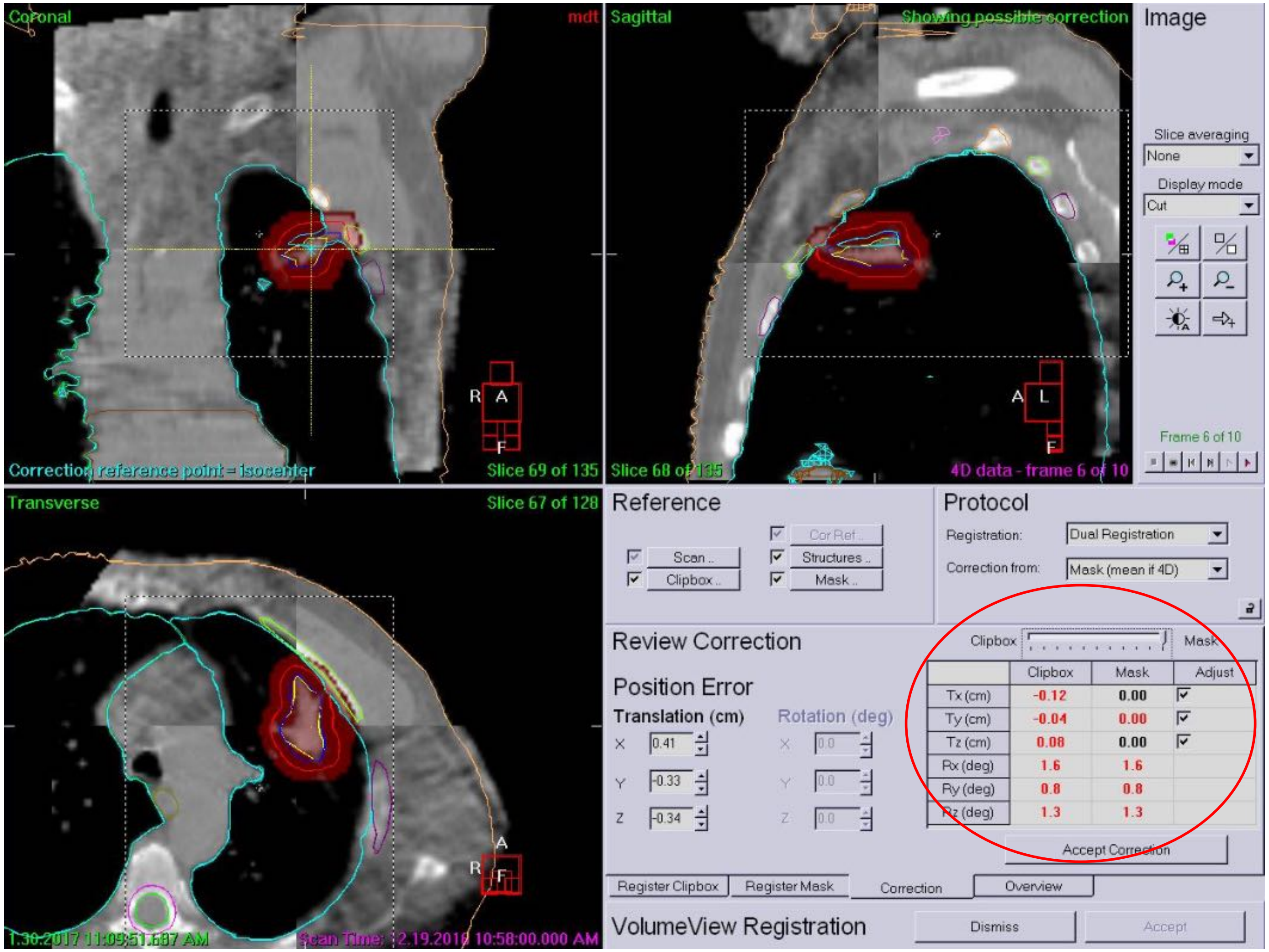
All frames



Metodo di co-registrazione:“**GREY VALUE 4D(T)**”

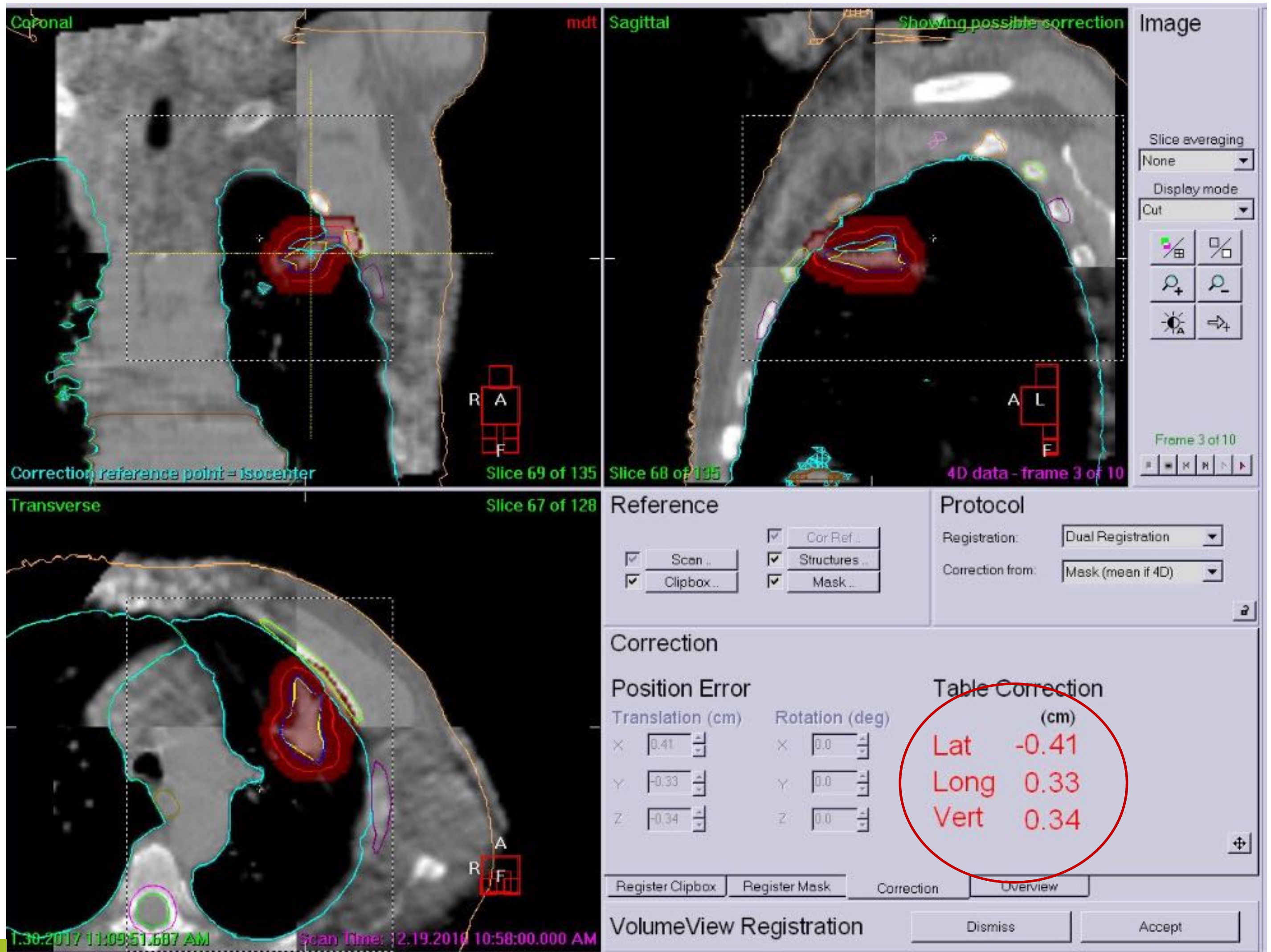
Spostamenti relativi alla clip box e alla mask

CONVERT TO CORRECT



Visualizzazione spostamenti

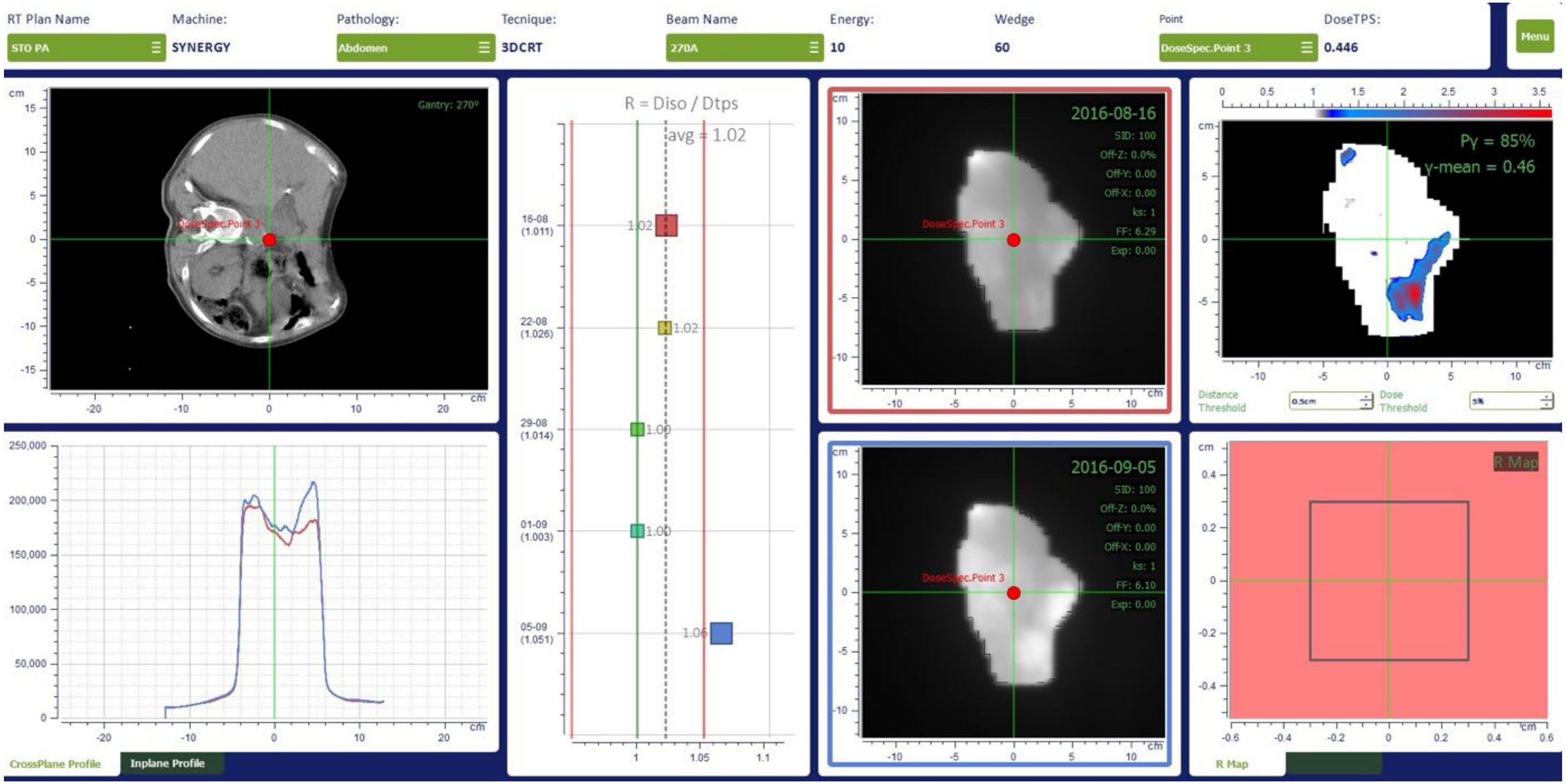
Accept



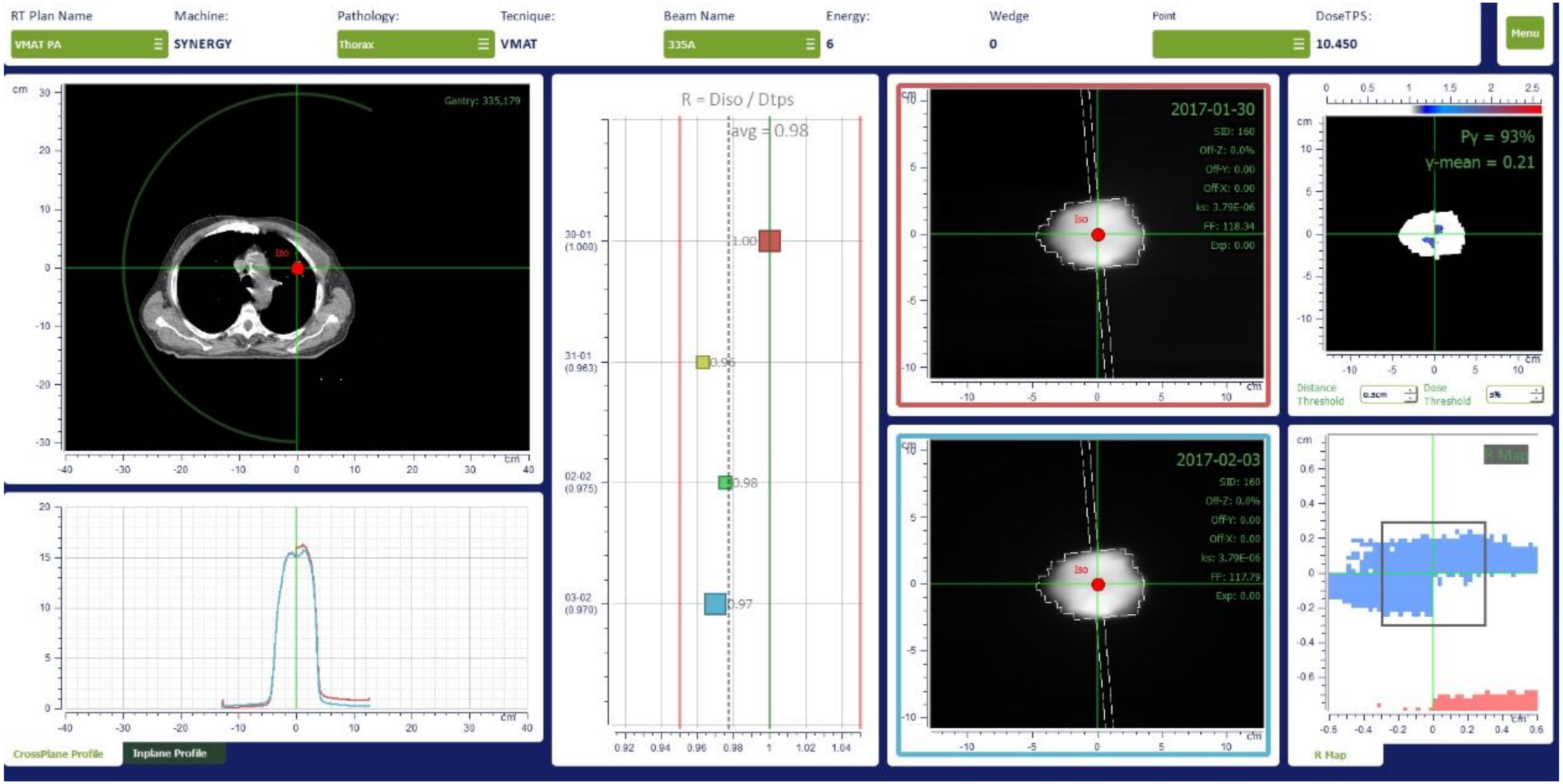
Medie spostamenti

	Media X	Media Y	Media Z	DEV.ST X	DEV.ST Y	DEV.ST Z
Medie	-0,20	0,42	0,59	0,13	0,52	0,29

Dosimetria in Vivo : Pancreas



Dosimetria in Vivo : polmone



Conclusioni

- Radioterapia 4D nuovi scenari

- Diverse metodologie e pochi dati (gastro-intestinali) per gestire il movimento e integrazione con altre tecniche di imaging

- Trattamenti simil-chirurgici ma tecnologia avanzata

Grazie per l’attenzione