Motion Management in Radiotherapy: Choosing Wisely

Dr Jyotirup Goswami

Senior Consultant Radiation Oncologist

Ruby General Hospital, Kolkata

What are the common motions we encounter in radiotherapy?

- Thorax/ upper abdomen-Respiratory motion, Cardiac motion
- Lower abdomen/ pelvis-Peristalsis, Organ filling
- Head-neck-Deglutition

RESPIRATORY MOTION

Why?

- Enables more accurate and less toxic treatment

- Relevant for both early stage (stereotactic body radiotherapy) and locally advanced unresectable lung cancers

The problem with lung motion

- The lungs are continuously moving with respiration.
- The extent of this movement can be blurred during a fast helical CT scan.
- Movement is maximum in lower lobe tumors (close to the diaphragm), & less in upper lobe tumors.

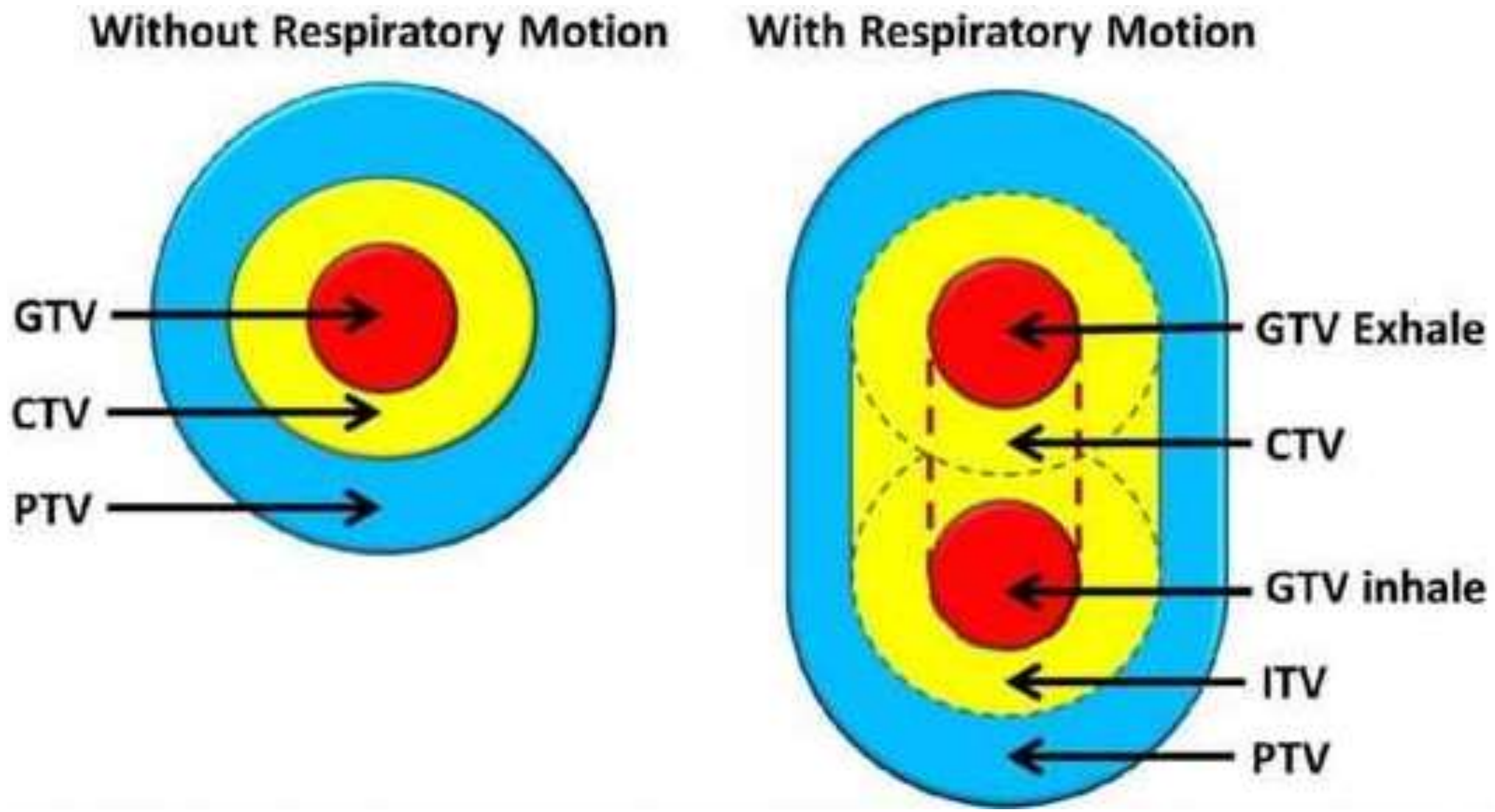
- **Average movement in normal breathing:**

Upper lobe = 0 - 0.5cm

Lower lobe = 1.5 - 4.0cm

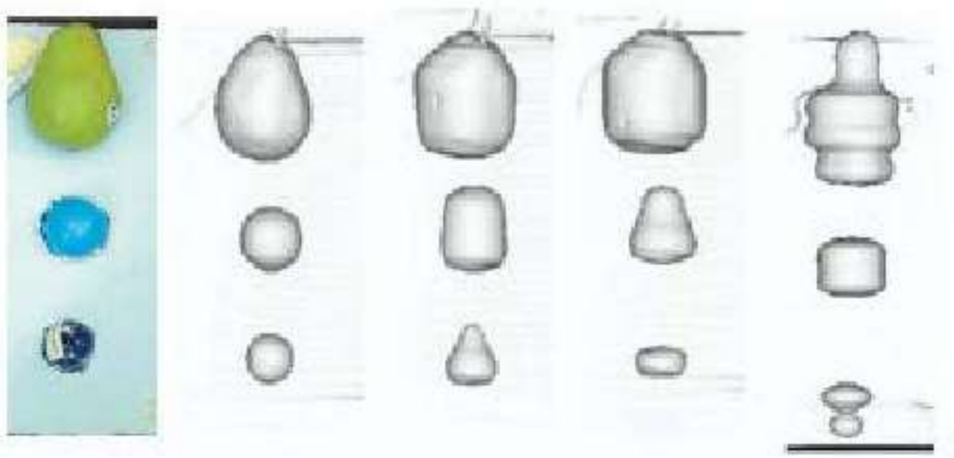
Middle lobe = 0.5 - 2.5cm

Hilum = 1.0 - 1.5cm


Without Respiratory Motion
With Respiratory Motion
GTV
CTV
PTV
GTV Exhale
CTV
GTV inhale
ITV
PTV

PROBLEMS WITH STANDARD APPROACHES

- Helical CT scans are very fast, hence like a snapshot of the tumor.
- Difficult to appreciate the full range of motion of the lungs.
- Also, there may be significant distortion of tumor shape & size (motion artefacts)



TECHNIQUES OF MOTION MANAGEMENT IN LUNG CANCER

Methods of Assessing Lung Motion

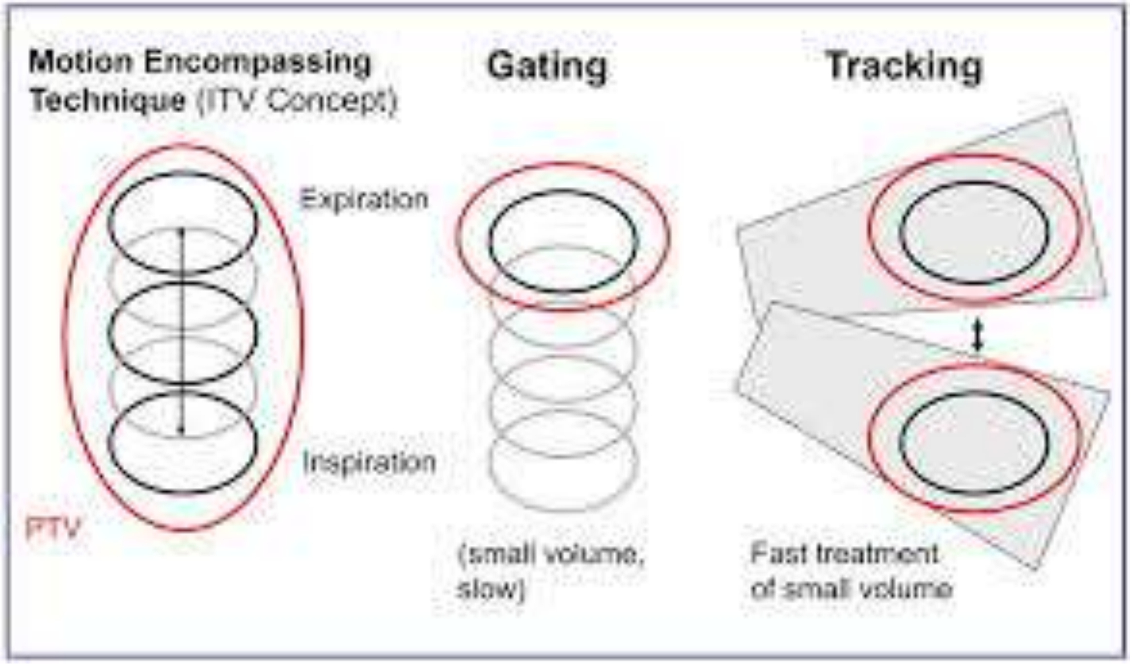
- Four dimensional computerised tomography (4DCT) / respiratory gated CT scans

- Slow CT scans

Methods to Control/ Compensate for Lung Motion during Respiration

Free Breathing Methods

- Internal Target Volume (ITV)-based treatment
- Gating
- Tracking



Breath hold methods

- Volumary DIBH
- ABC-DIBH

ITV-based treatment

- Generates a composite target volume for lung tumors, taking into account the different shape, size and position of the tumor in each phase of respiration

- Can be done on any LA with MLCs or on Tomotherapy , where there is no specialised motion management technology available for treatment delivery.

Gating

- Treatment delivery is done in the phase of respiration where the tumor motion & resulting treatment volume is minimum, by coupling the beam delivery with the phase of respiration

- Many centres use an internal fiducial, implanted within the tumor

- Others use external fiducial systems to correlate tumor & chest wall motions

Phase Selection

- Lung motion is minimum in end-expiration
- So the Internal Margin (IM) can be minimised

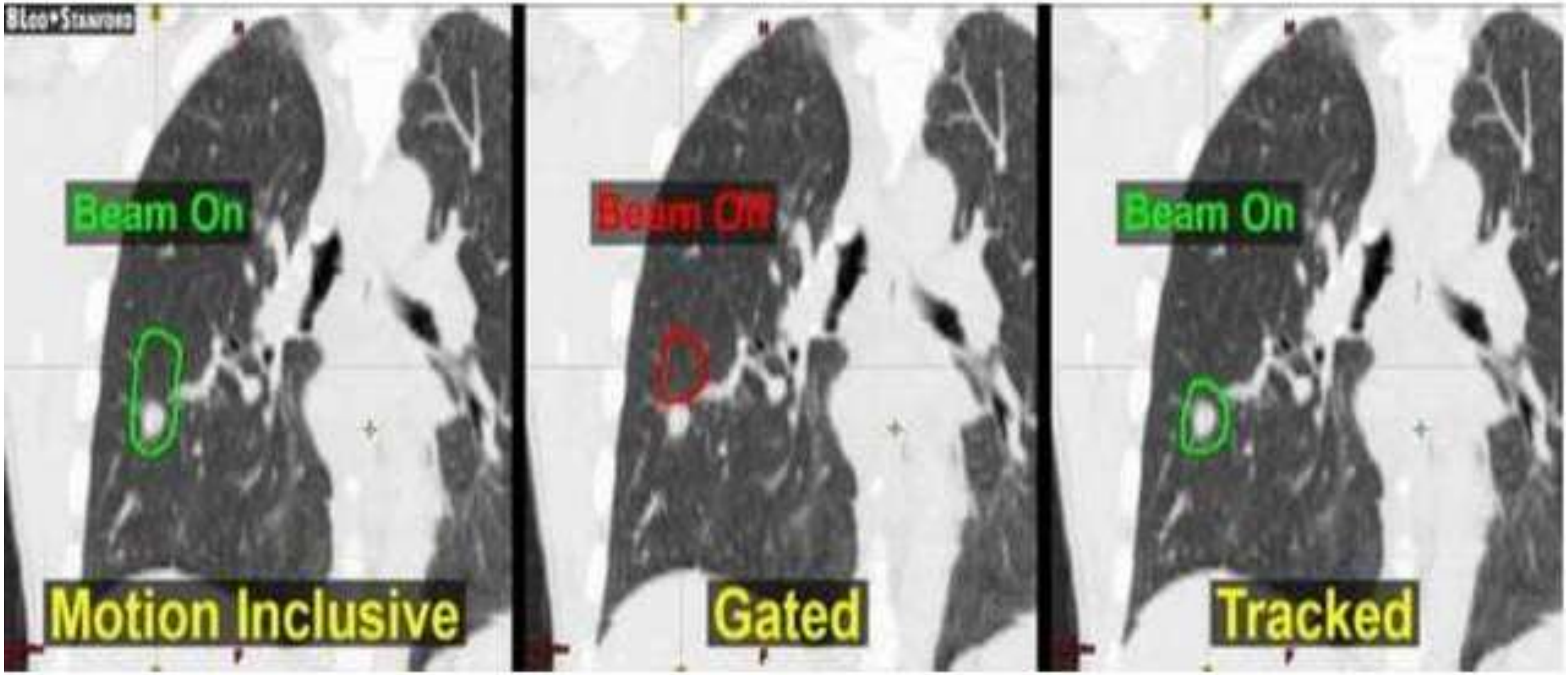
- The lung volume is more in end-inspiration
- So the V20 [volume of (bilateral lung-CTV) that receives 20Gy or more] is relatively lower

Tumor Tracking

- Imaging is used to track the actual tumor motion during treatment delivery and to move the treatment beam accordingly based on the varying position of the tumor.

- Usually requires an internal fiducial, implanted within the tumor.

- Can also be done non-invasively in some cases.



BLOO • STANFORD
Beam On
Motion Inclusive
Beam Off
Gated
Beam On
Tracked

Deep Inspiratory Breath hold

- The patient is coached to breath-hold in inspiration, to eliminate lung motion & treatment is delivered only in this state.
- The system minimizes anatomical movements making it possible to undertake processes such as imaging or beam delivery, with the lungs at a consistent and controllable volume.
- The patient is able to produce an accurate breath-hold to a known volume by observing their own respiratory information on a patient display monitor from the imaging or treatment table.

- Patient coaching prior to imaging or therapy instructs the patient on how to hold their breath at a predefined volume (threshold volume) which is clearly shown on the patient display monitor.
- Accurate and reproducible timing of the breath-hold period is aided by a patient controlled balloon valve that is directly connected to the flow meter device.
- Image acquisition and beam delivery are only performed while the patient is holding their breath to an identical lung volume.

Caveat

- The residual functional capacity is the amount of air that is in the lungs immediately following a normal unforced exhalation.
- The residual functional capacity has been shown to be an extremely stable point in the respiratory curve.
- Proper use of the system requires that the patient is undergoing normal breathing. If the patient is not breathing normally, then the residual functional capacity is no longer a stable point in the respiratory cycle.

Breath hold techniques

Active Breathing Coordinator (ABC-DIBH)

- Requires the ABC apparatus
- More complex
- More expensive

Voluntary (v-DIBH)

- Verified by use of surface optical markers
- Easier
- Cheaper

Comparable efficacy & reproducibility

Active breathing coordinator

Preparation

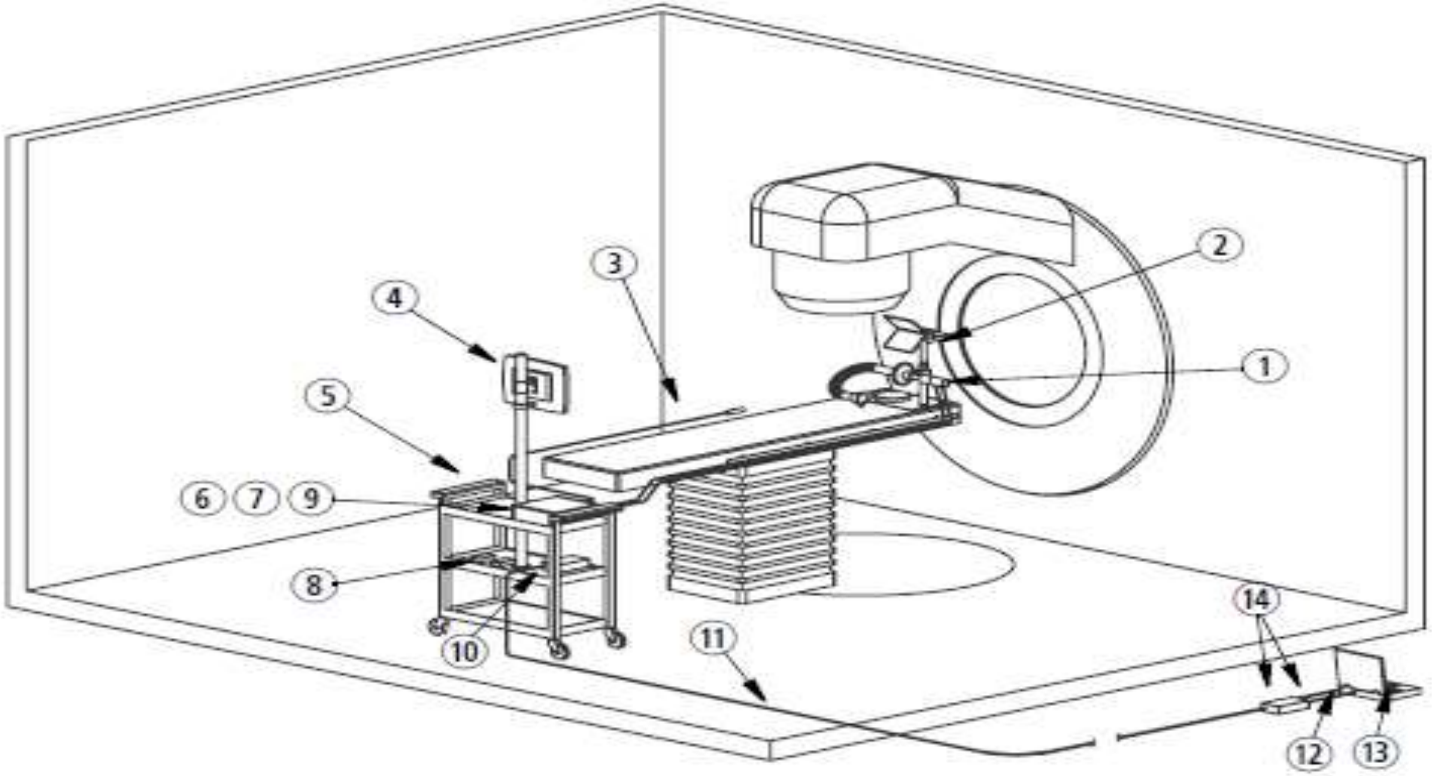
- Position the patient with their head comfortably on the patient head rest on the mirror support system base plate and position the arms according to the required treatment position.
- Rotate the mirrors in place until the patient can clearly see the LCD monitor.
- The patient should then be given the Patient Control Switch.

- With a single use filter kit fitted to the patient Respiratory System Mouthpiece, place the mouthpiece in the patient's mouth. Fit the nose clip over the bridge of the nose and instruct the patient to begin breath normally.

- When the patient reaches a steady breathing cycle the patient should depress the control switch indicating to the user that they are comfortable and ready to begin the treatment. The respiratory curve will then turn from red to blue.

Patient coaching

- During the patient coaching session the threshold volume and breath-hold duration need to be determined.
- The values obtained are unique to each patient and depends upon their individual capacity and ability to hold their breath.



① Patient respiratory system
② Mirror support system
③ Patient control switch
④ Patient feedback monitor
⑤ Cart system
⑥ Control module
⑦ RS-232 serial cable
⑧ Power supplies
⑨ Power cordset
⑩ PC Extender System-receiver
⑪ Category 5 UTP Cable
⑫ RS-232 serial cable (console area component)
⑬ Control computer (console area component)
⑭ PC Extender System-transmitter (console area component)

Figure 2.1 Typical treatment room layout

Process

- Once the ABC software has been turned ON, the patient begins breathing into the mouthpiece with the nose clip fitted.
- The patient should begin pressing the patient control switch indicating that they are comfortable and ready to begin the treatment
- The switch should remain pressed for the course of treatment and should not be released unless the patient is in need of assistance.
- The user observes the patient's breathing from outside the room and waits until the patient demonstrates normal breathing.
- Once normal breathing is observed, the user activates the system by pressing the space bar on the control computer.
- The patient receives the cue from the LCD monitor (green threshold region) that the system is active.
- During the next respiratory cycle, the patient takes a deep inspiration (trigger on inhalation example) which will bring their respiratory volume curve into the threshold region.
- The patient begins the breath-hold session at the same moment the balloon valve closes and the breath-hold duration countdown begins.

- Once the breath-hold session begins, the user begins delivering the pre-determined radiation dose.
- The user will observe the breath-hold countdown and would pause the beam delivery just before the end of the breath-hold (Manual ABC)
- Presently this is also available as an automated process (Gated ABC)
- The patient watches the breath-hold countdown on the LCD monitor and begins breathing again once the breath-hold session has terminated.
- The patient should breathe normally for a few cycles before the above procedure is repeated until the entire prescribed dose is delivered.

Clinical applications of DIBH

Breast Cancer

- Adjuvant radiotherapy is an integral component of multimodality management of breast cancer.

- The benefits derived from breast radiotherapy are compromised by an increase in non-breast cancer deaths, the majority of which are cardiovascular in origin

- Darby et al. estimated a relative 7.4% increase in the rate of major coronary events per 1 Gy increase in mean radiation dose to the heart (study period1958 to 2001)

- There is now mounting evidence that irradiation of the LAD is a key factor in the development of RRHD

Cardiac dose constraints-Traditional

Volume	Dose	Endpoint	Probability
1/3 organ	<50Gy	Pericarditis	5% at 5 years
2/3 organ	<45Gy		
3/3 organ	<40Gy		

Emami et al.Int J Radiat Oncol Biol Phys 1991; 21(1):109-122

The heart is both a serial & a parallel organ

Cardiac dose constraints-QUANTEC

Structure	Technique	Endpoint	Constraint	Rate of compli-cations	Comment
Pericardium	3DCRT	Pericarditis	Dmean<26Gy	<15%	Single study
Pericardium	3DCRT	Pericarditis	V30<46%	<15%	Single study
Whole organ	3DCRT	Long term cardiac mortality	V25<10%	<1%	Model prediction

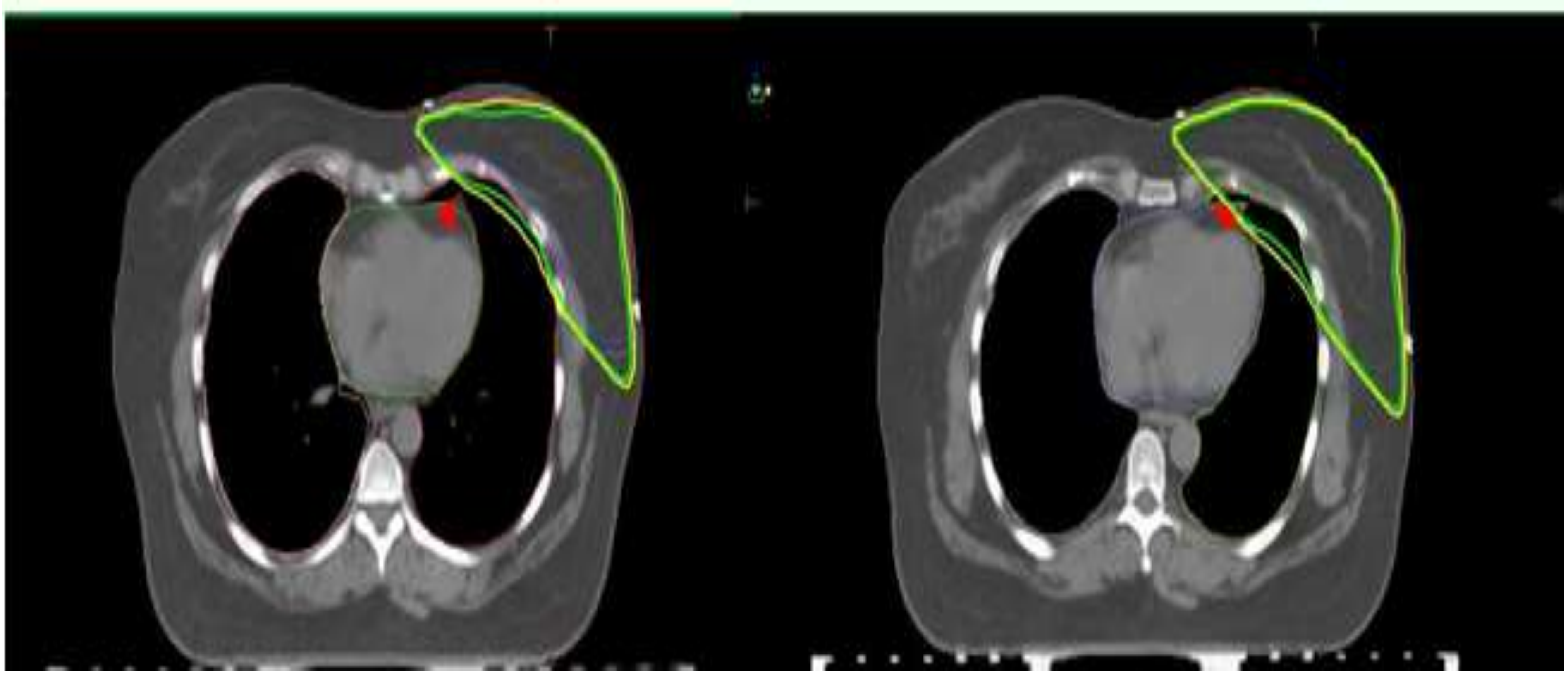
Int. J. Radiation Oncology Biol. Phys., Vol. 76, No. 3, Supplement, pp. S10–S19, 2010

Techniques to reduce heart dose

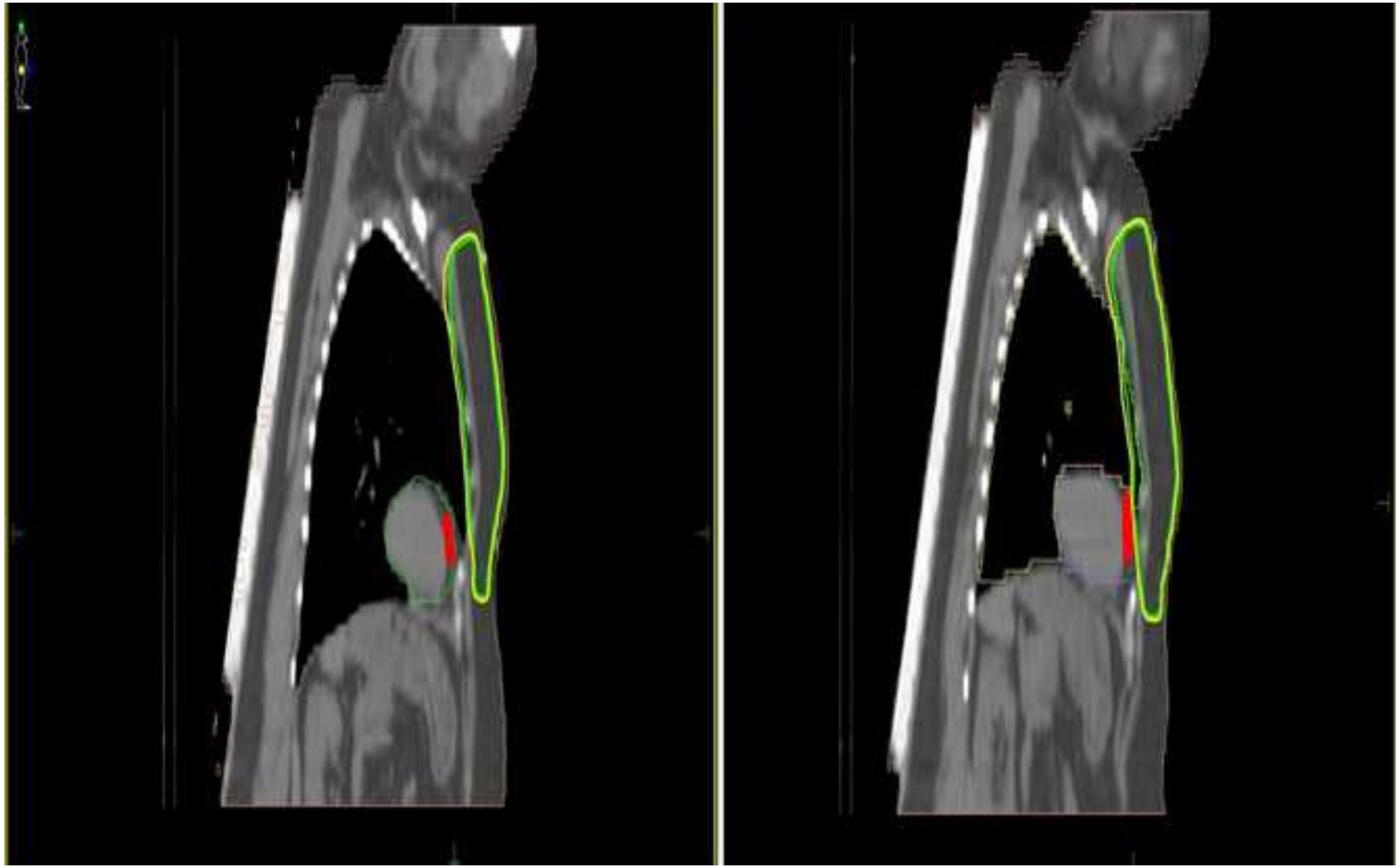
- Conformal delivery techniques [3DCRT/IMRT/VMAT/IMPT]

- Breath hold techniques [DIBH]

- Prone positioning

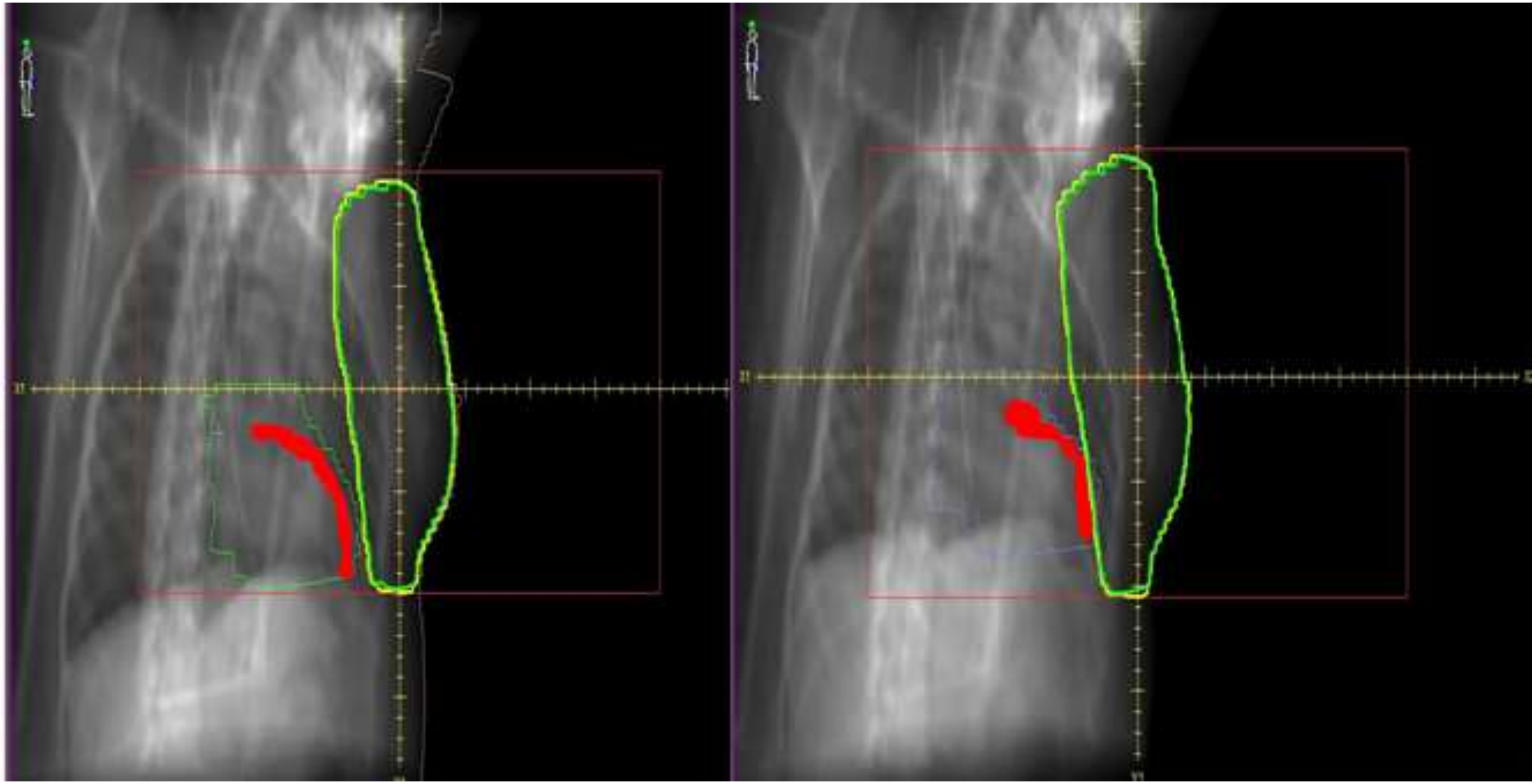


DIBH FB



DIBH

FB



DIBH

FB

An Interim Analysis of a Prospective Study to compare heart doses for Left Breast / Chest wall Radiotherapy using Conventional and Deep Inspiratory Breath Hold technique in Breast Carcinoma (DIBH STUDY)

PARAMETER	FREE BREATHING(Mean values)	DIBH(Mean values)	P value
Mean heart dose	4.8 Gy	2.4 Gy	0.001
Heart V30	4.9 %	0.3 %	0.001
Heart V5	16.2 %	7.8 %	0.002
Heart V10	11.6 %	3.3 %	0.001
LAD Max	35.9 Gy	25.6 Gy	0.0001
Lung V20	11.1 %	9.2 %	0.06
Lung V12	13.4 %	12 %	0.19
Ipsilateral lung V20	23 %	19.3 %	0.08

DIBH plans significantly decreased

- Mean Heart Dose
- V30 ,V5 and V10 of Heart
- Max dose to left anterior descending artery (LAD)
- Total lung V20 ,V12 and ipsilateral lung V20 .

Which patients?

- Patient characteristics cannot reliably predict for benefit with DIBH.
- These include age, PTV volume, BMI, cardiac contact distance , lung volume.
- Hence for the time being, no patients can absolutely be excluded for DIBH based on these criteria.

Selection of patients with left breast cancer for deep-inspiration breath-hold radiotherapy technique: Results of a prospective study

Beata Czeremszyńska[a,c], *Stanisław Drozda*[b], *Michał Górzyński*[a], *Lucyna Kępka*[a,c,*]

Practical Radiation Oncology 2017;22:341-348

Lung Cancer

- Breath hold techniques allow treatment of smaller target volumes compared to ITV-based technique, due to the elimination of an Internal Margin

- Reduces V20 & other lung dose-volume criteria

- Heart dose may/ may not be reduced

Hepatobiliary tumors

- Breath hold techniques allow treatment of smaller target volumes compared to ITV-based technique

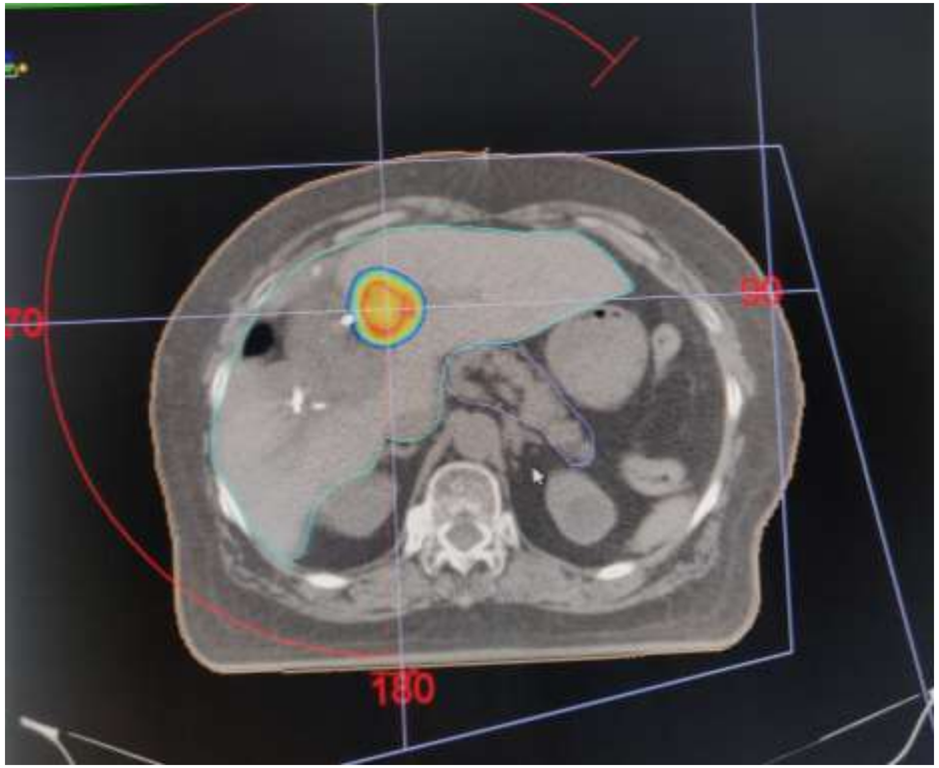
- Reduces liver dose-volume criteria, which are particularly important in the background of cirrhosis

ITV

- ITV volume=22.32ccc
- PTV=ITV +5mm
- PTV volume=58.33 cc

Breath-hold

- GTV volume=11.84 cc
- PTV=GTV+5mm
- PTV volume=28.12 cc



Pros and cons of DIBH

- Simple technique
- More predictable than other methods of motion management, which are free-breathing based & reliant on stereoscopic visualisation of tumor/ fiducial

- Requires significant coaching time for the patient
- Requires patient to cooperate
- Requires patient to be able to hold their breath for a reasonable time span
- There is still significant motion of the LAD in around 10% cases

Abdominal Compression Device

Radiotherapy and Oncology 201 (2024) 110581

Review Article

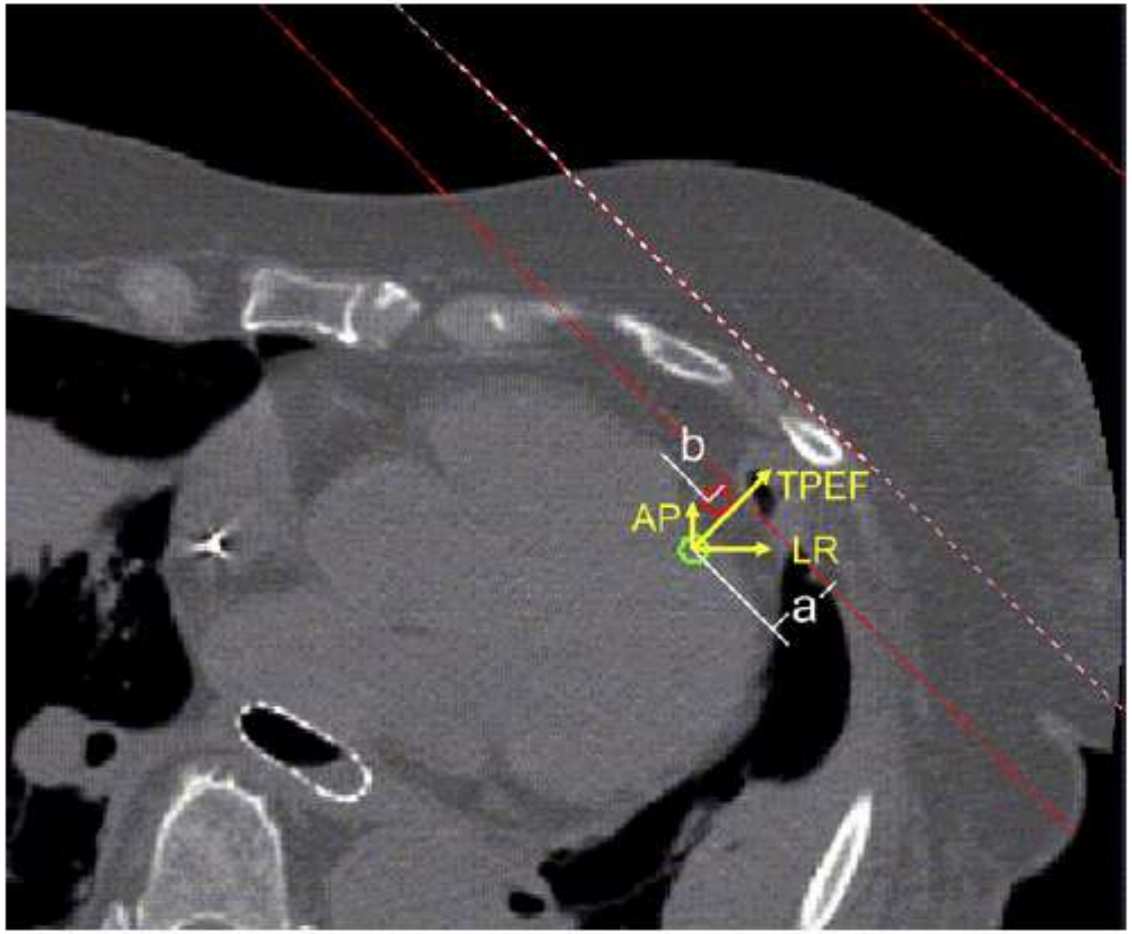
A systematic review of the impact of abdominal compression and breath-hold techniques on motion, inter-fraction set-up errors, and intra-fraction errors in patients with hepatobiliary and pancreatic malignancies

Amanda Webster [a,b,*], Yemurai Mundora [a], Catharine H. Clark [b,c,d], Maria A. Hawkins [a,b]

- Abdominal compression involves the application of external pressure to the abdominal region during pre-treatment and treatment sessions.
- This pressure aims to minimise organ motion, specifically by reducing respiratory motion .
- Different devices can be utilised for AC, including arches/plates, belts/bands, corsets, shells and immobilising the patient in the prone position.

Does DIBH eliminate all intra-thoracic motion?

- The mean displacement of the LAD from cardiac contraction without the influence of respiration was 2.3 mm toward the posterior edge of the treatment fields, 2.6 mm in the left–right direction, and 2.3 mm in the anteroposterior direction.
- At least 30% of the LAD volume was displaced >5 mm in any direction in 10% patients , and <10% of the LAD volume was displaced >5 mm in 50% patients.
- The extent of displacement of the heart periphery during cardiac motion was negligible near the treatment fields.
- The authors recommend maintaining 5 mm of distance between the LAD and the field edge for patients undergoing breast cancer radiotherapy during DIBH.



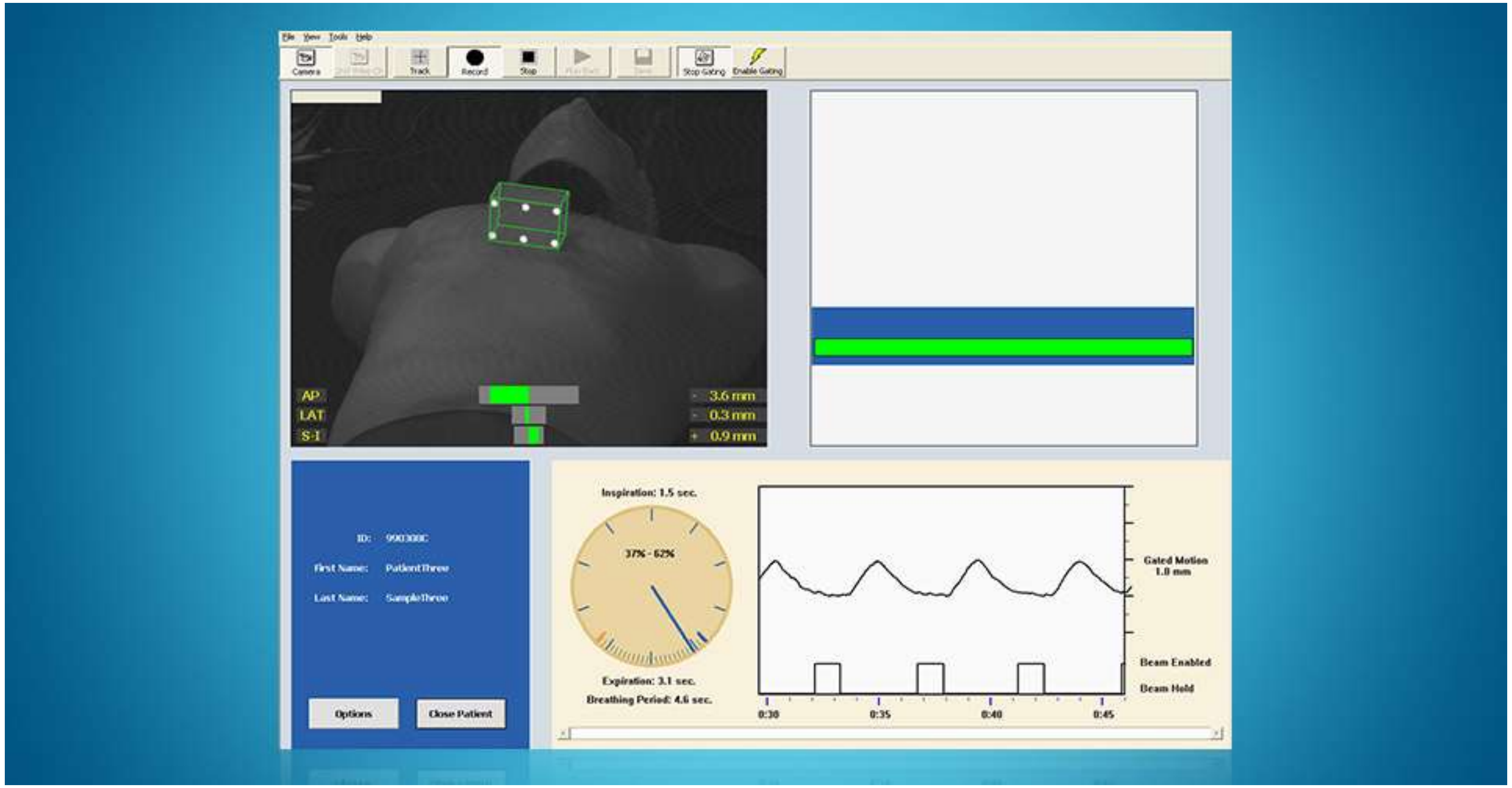
Want et al. Int. J. Radiation Oncology Biol. Phys., Vol. 82, No. 2, pp. 708–714, 2012

Simulation -Positioning

- For patients due for ITV-based treatment or ABC, conventional CT simulation is done using 3 LASER markers, with radio-opaque fiducials placed on the patient's skin.
- For gating/tracking, external fiducial system (infra-red reflectors) are placed over the patient's thorax and positions marked with indelible ink on the patient's skin.
- For good reproducibility, a photograph of the patient in this position, is then taken.

Positioning & Immobilisation

RPM™


File View Tools Help
Camera
Track
Record
Stop
Stop Gating
Enable Gating
AP
LAT
S-I
3.6 mm
0.3 mm
0.9 mm
First Name: PatientThree
Last Name: SampleThree
Options
Close Patient
Inspiration: 1.5 sec.
37% - 62%
Expiration: 3.1 sec.
Breathing Period: 4.6 sec.
Gated Motion
Beam Enabled
Beam Hold
0:30
0:35
0:40
0:45

Simulation-Imaging

- Patients for gating/ tracking/ITV-basedtreatment undergo plain 4DCT scan for planning (3mm slices), using Mayo belt/ Anzai belt/ RPM system to correlate the respiratory phases and corresponding CT images.
- Ten data sets are thereby generated.
- Patients for ABC need not undergo 4DCT scan.
- They can undergo an inhale breath-hold spiral CT scan with/ without contrast.

Delineation for lung tumors: GTV & ITV

- GTV is contoured using lung windows. Mediastinal windows may be suitable for defining tumours proximal to the chest wall.
- Where available, information from PET/CT should be incorporated into delineating the GTV.
- For gating/tracking, tumor delineation is done on the end-expiratory data -set. This is because, in this phase, lung motion is minimum.
- For ITV-based treatment, tumor delineation is done on the end-expiratory data set and extrapolated across the other data sets, OR on the Maximum Intensity Projection (MIP) data set to generate the ITV.

Delineation of OARs

- Organs at Risk are usually delineated on the Average Intensity Projection images
- This image set is also the one used for dose planning
- Alternatively, a separate helical CT scan can be taken, on which OARs are delineated and dose planning is done

MIP

- A maximum intensity projection (MIP) is a method for 3D data that projects in the visualization plane the voxels with maximum intensity that fall in the way of parallel rays traced from the viewpoint to the plane of projection.
- MIPs are a reliable clinical tool for rapidly generating ITVs from 4DCT data sets
- They permit rapid assessment of mobility for both gated and non-gated 4D radiotherapy in lung cancer.

CTV & PTV

- No CTV margin is given for stereotactic body radiotherapy
- For locally advanced disease, CTV margins between 0.6-0.8 cm are usually applied.
- Setup margins of 0.5 cm are normally applied (to the GTV/ CTV/ITV, as appropriate) to arrive at the PTV

Treatment setup

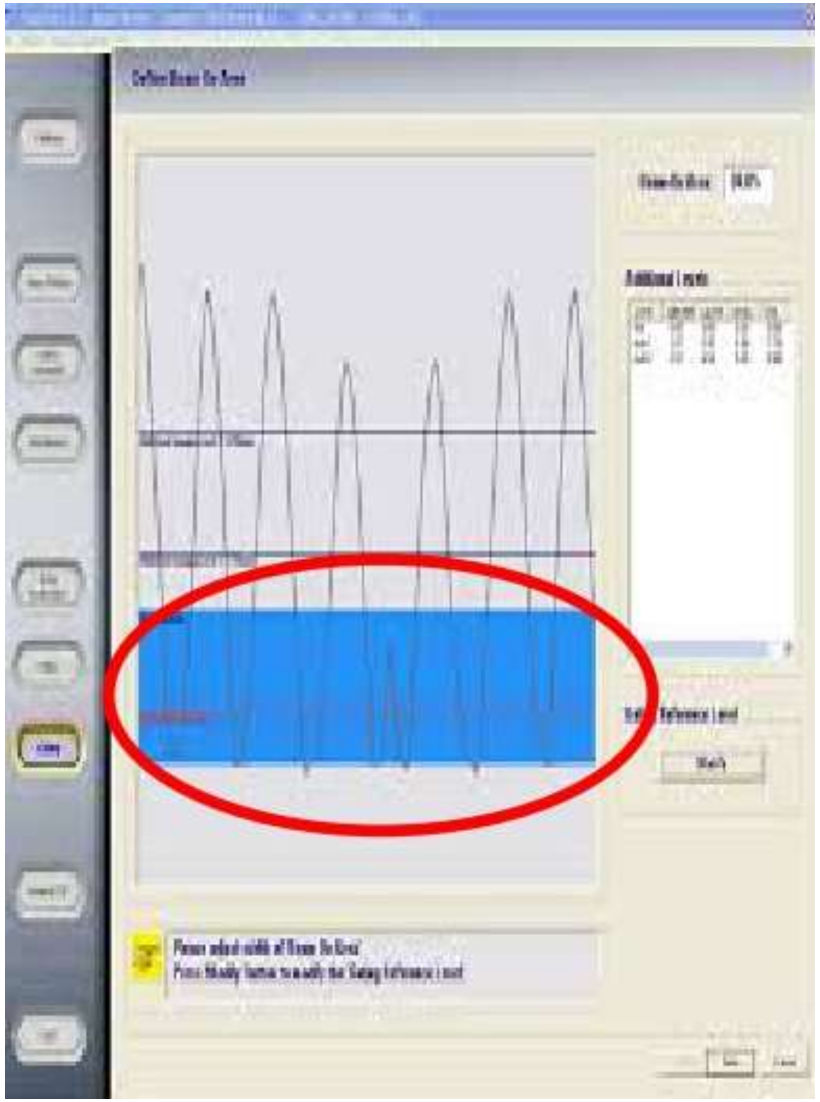
- The patients are positioned accurately by matching LASER fiducials OR Infra-red markers, as for initial simulation.

- Where available, pre-treatment Cone Beam/Fan Beam CT scans are taken & matched with the planning CT scan, for accurate patient positioning.

- Surface Guidance can be used wherever available.

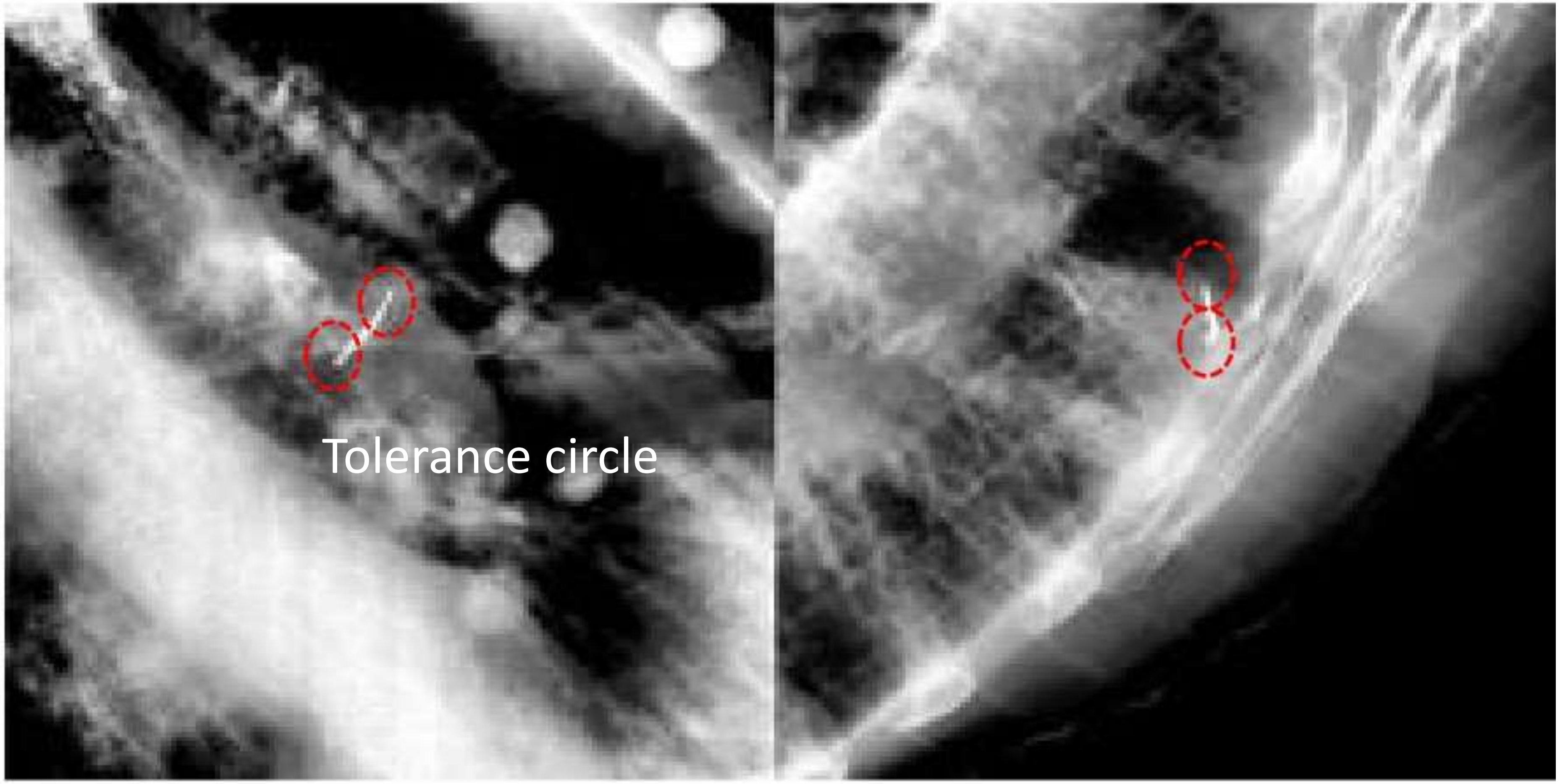
Gating: Workflow

- Respiratory signal is picked up using IR cameras to pick up the motion of infra-red markers on patient's body and once stable, is correlated with respiratory phase
- The gating window is then set at end-expiration

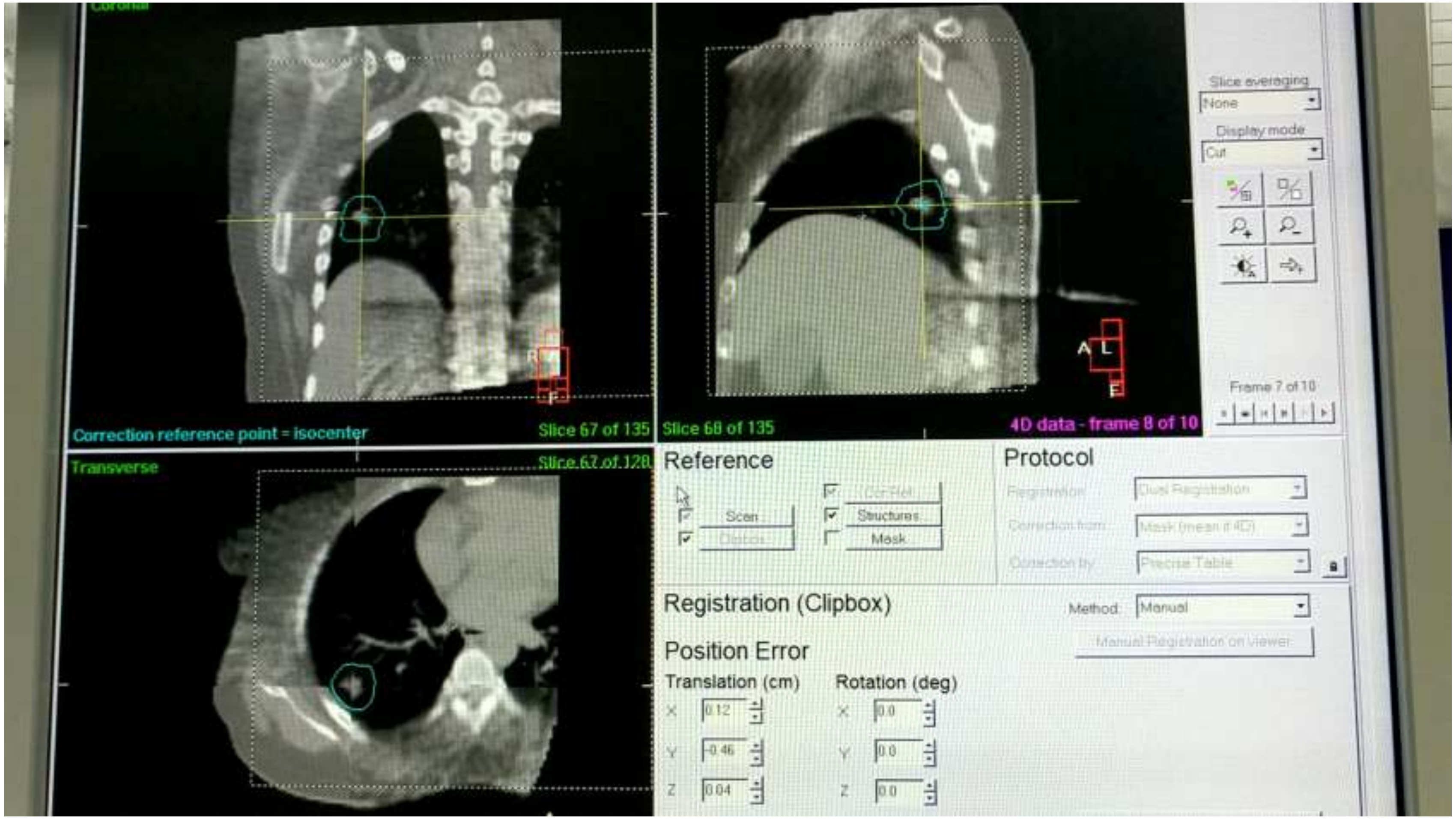


Gating with ExacTrac

- Oblique image pairs are taken by ExacTrac system's stereoscopic X ray imagers.
- Internal fiducial ends are identified to the system
- The system builds a correlation model between the end-positions and the respiratory phase (accuracy of correlation 3mm).
- The treatment beam is then turned on and is configured to treat ONLY in the gating window.

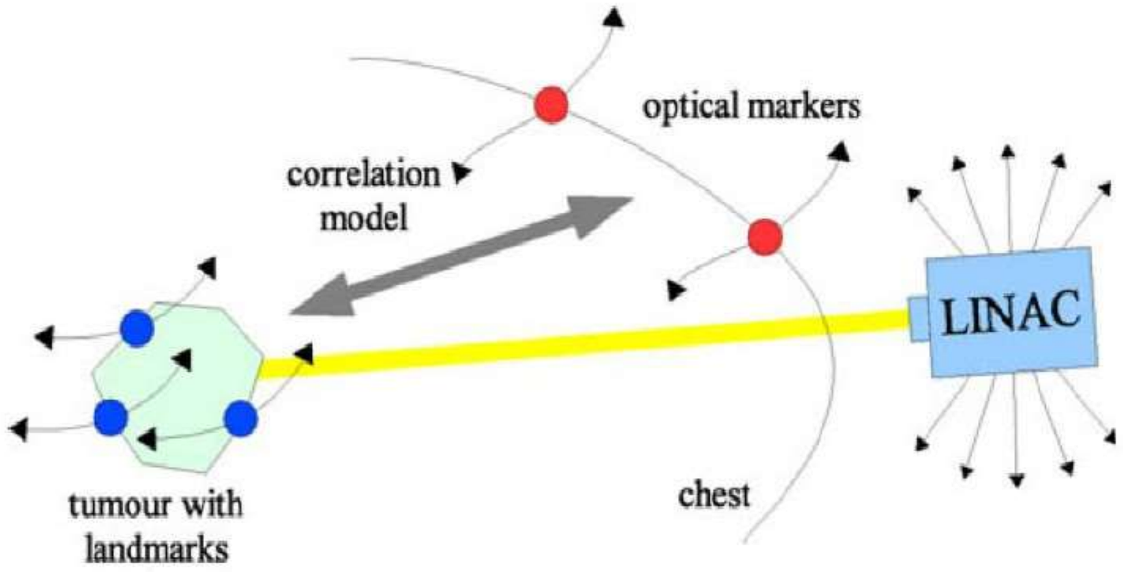

Tolerance circle

Gating/Gated ABC with 4D CBCT



Real Time Tumor Tracking

- ExacTrac system (VERO) ™
- Cyberknife ™



Requisites of Correlation Model

- Accuracy
- Speed
- Minimum imaging dose

Cyberknife: RTT Modes

- **Non-invasive**:

  Xsight lung

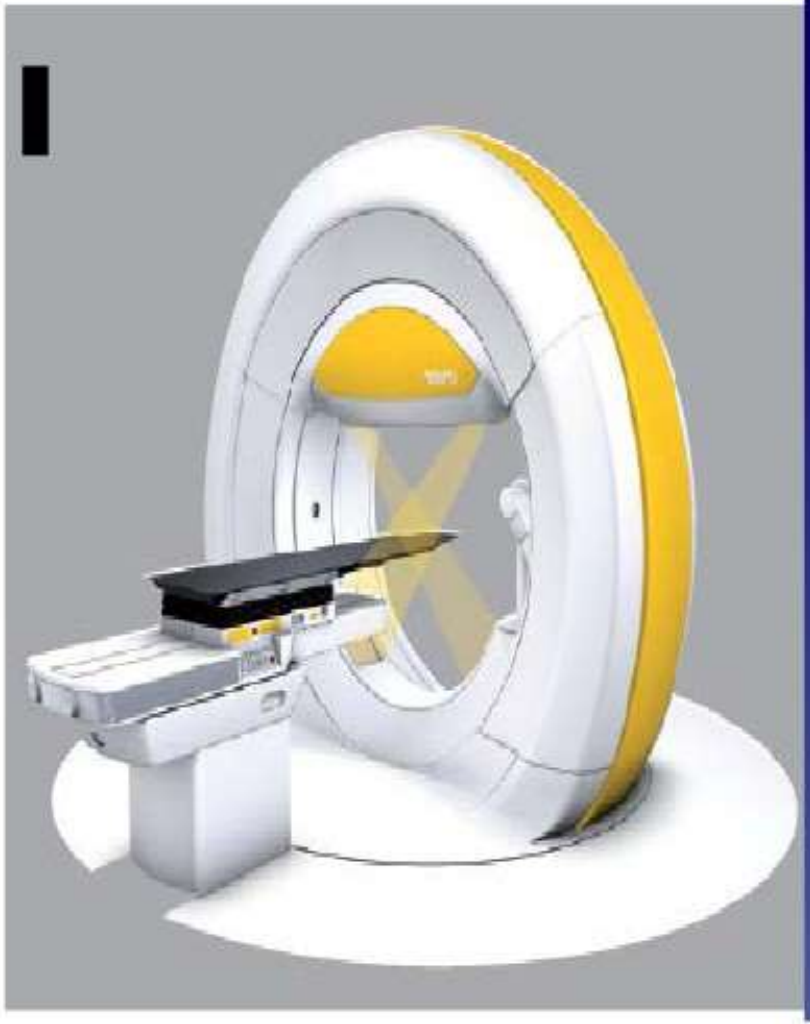
- Possible if:
- Tumour >1.5 cm, surrounded by air
- Tumour visible by imaging system

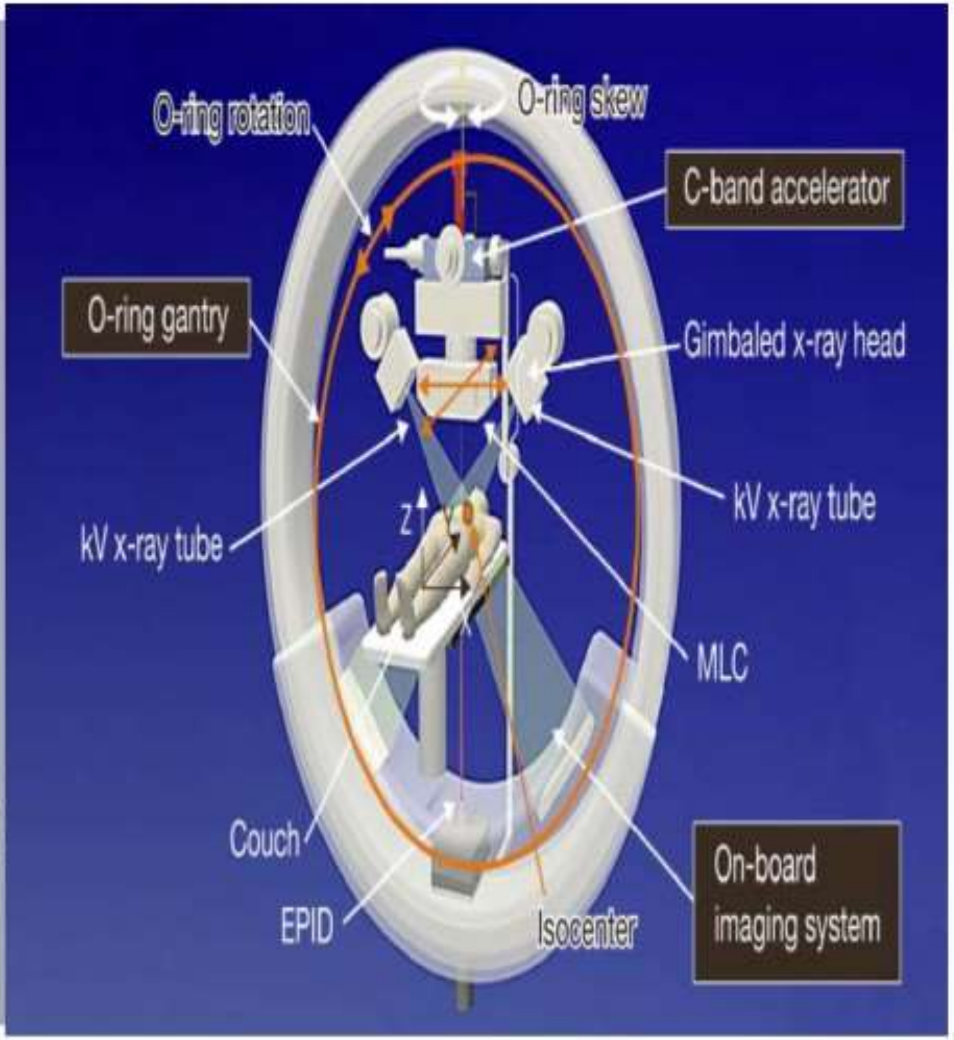
- **Invasive** (with implanted fiducial):

  Synchrony

- 3-5 fiducial markers need to be inserted in close proximity to the lesion
- They have to be well seperated (>2cm) and non-overlapping on oblique X ray image pairs


VERO (Brainlab-Mitsubishi)





- Has 6MV C-band LA mounted on O-ring gantry
- Gantry is mounted on

  gimbals
- Capable of pan & tilt motions
- Maximum motion allowed 2.5cm in isocentre plain / 2.5 degrees in each direction

- Has facility for **Cone Beam CT & Real Time Tumor Tracking** (based on Infrared & stereoscopic X rays) .
- **6 degrees of freedom**
- Patient repositioning **not** required as the system can move itself
- Image verification possible at any position during treatment

PERISTALSIS & ORGAN FILLING

Motion management strategies

- Bladder filling-Bladder protocol
- Rectal filling-Flatus tubes & enemas
- Adaptive strategies –Plan of the Day, MR Linac
- ITV-based planning
- Larger PTV margins

Optimal preparation

General preparation

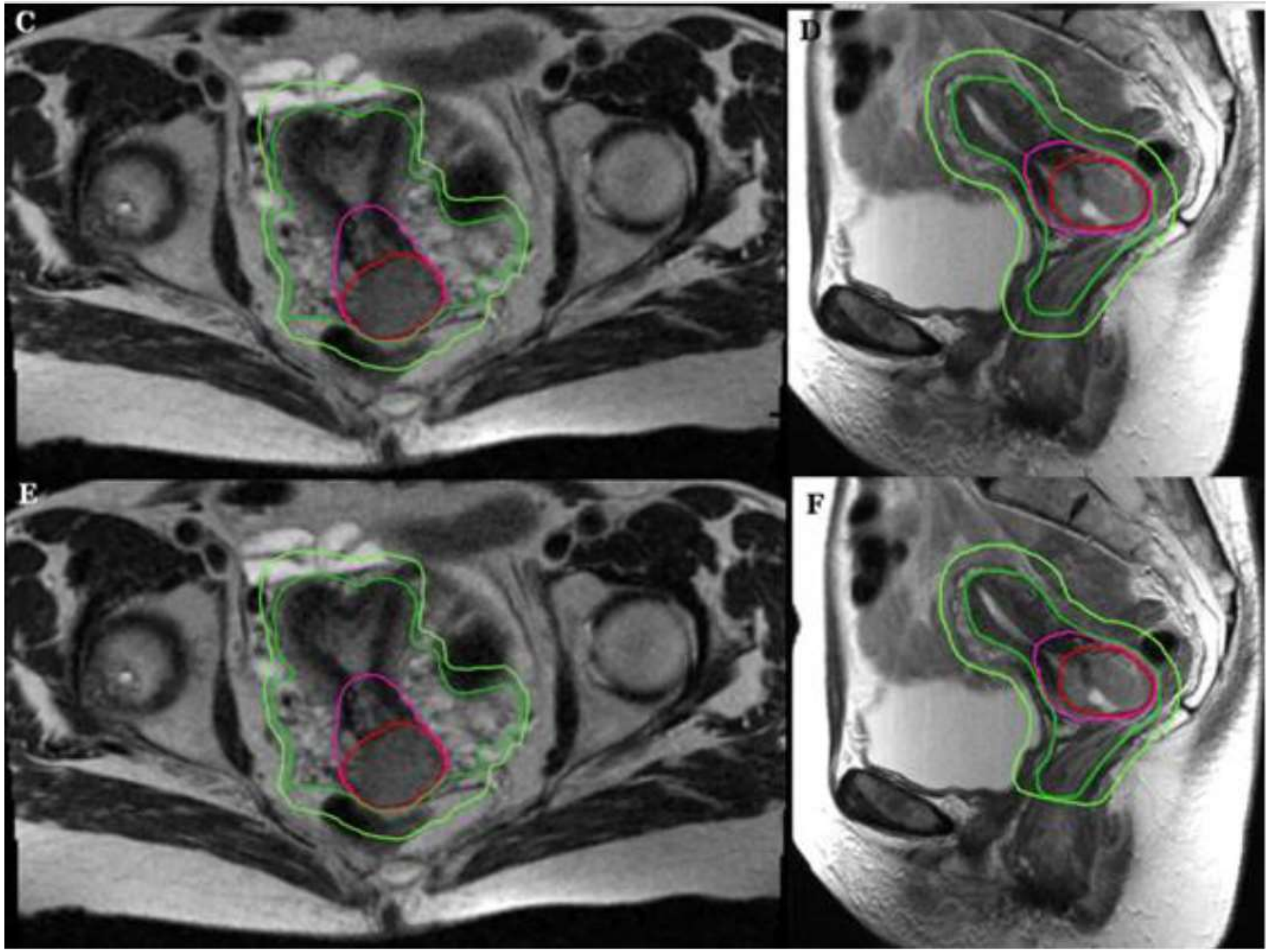
- Throughout the entire course of treatment and for at least 5 days before the planning computed tomography scan, maintain adequate hydration and drink 2 l of water spread throughout the day.
- Monitoring of organ motion is essential. Weekly cone beam computed tomography scans (CBCTs) are a minimum requirement

Rectal preparation

- Regular laxatives should be administered (sodium docusate preferred) if this is helpful for them.
- As patients progress through treatment they may develop diarrhoea and should be monitored carefully for this if taking laxatives.
- If the anterior-posterior diameter of the rectum is > 4 cm at planning, consider micro-enemas and if done, do this for all treatments.

Bladder preparation

- The volume of bladder achieved should ideally be 150-300 cc.
- If the bladder does not fall in that range at planning, especially if larger, consider rescanning having waited for a different time period, e.g. 10 min shorter.
- A bladder scanner can be used to facilitate this without extra radiation exposure for patients.
- On the day of and 1 day after when patients receive chemotherapy they should wait 10 min less than usual.
- As patients progress through treatment this will be less frequently required as bladder volume decreases and the individual preparation will become more adapted.



ITV (EMBRACE):

- Generate the ITV-T LR by adding a 10mm margin around the CTV-T LRinitial cranio-caudally and antero-posteriorly and 5 mm laterally
- On the ITV-T LR, erase the most caudal contours so that the most caudal delineation of the ITV-T LR correspond to the most caudal outline of the CTV-T Lrinitial
- The ITV-T LR should not go into the muscle and bony boundaries of the pelvis

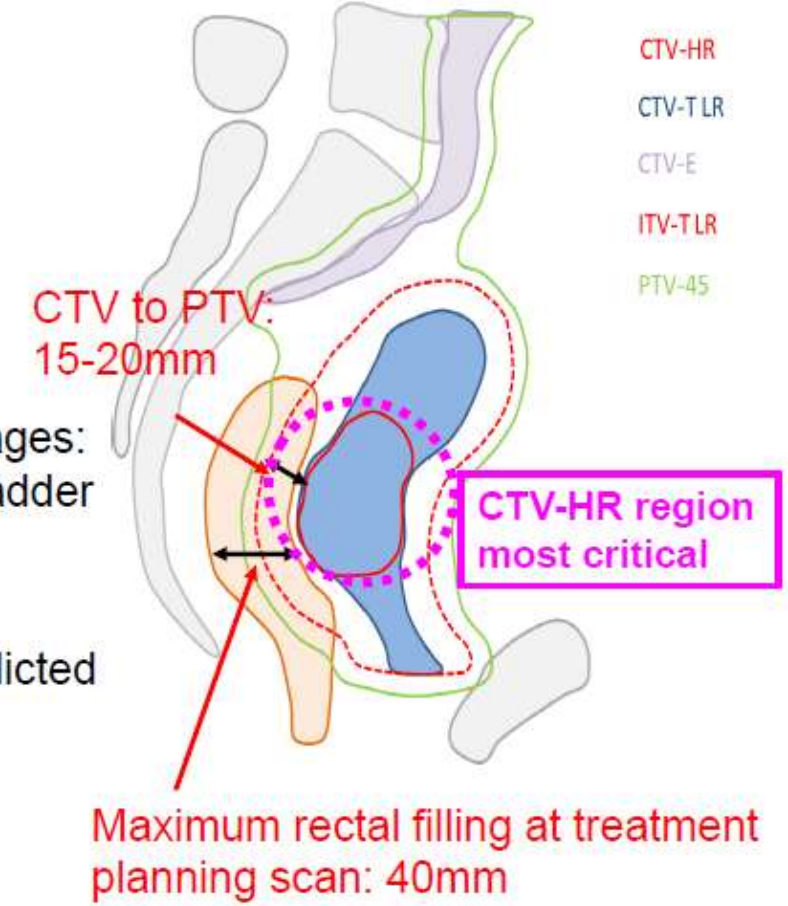
ITV-T LR and PTV-T LR

Standard:

- 10-15mm ITV margin
- 5mm PTV margin
- Total 15-20mm margin

Individualised approach:

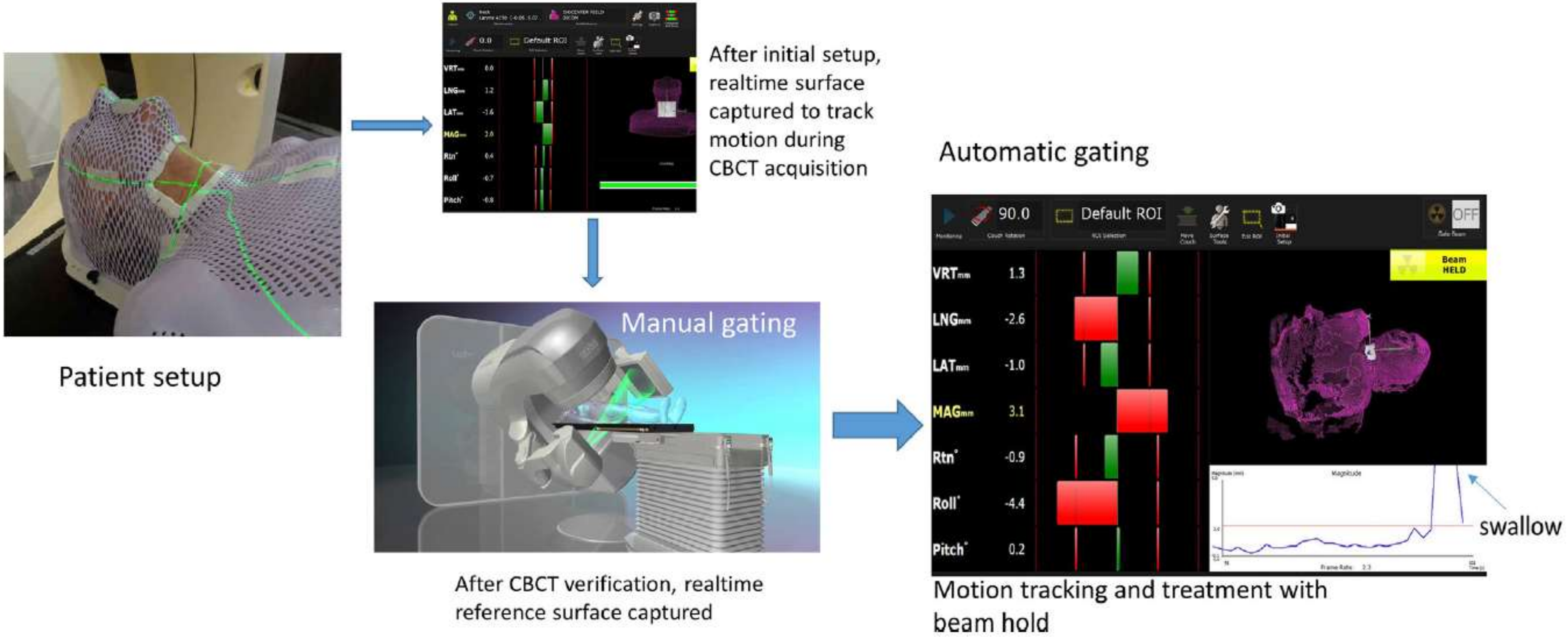
- Several treatment planning images: MRI, CT, full bladder, empty bladder
- Review anatomy on treatment planning images
- Apply margin according to predicted motion
- Monitor on daily CBCT



Courtesy Kari Tanderup

DEGLUTITION

- In a non-tracheostomized adult the larynx elevates approximately 2 cm during a swallow and moves anteriorly less than 1 cm.
- The normal frequency of swallowing in the supine position is once every l-2 min.
- During therapy, the likelihood of a swallow occurring during an irradiation interval depended on the duration of the interval.
- For irradiation intervals less than 2 min long the ratio of number of swallows to number of intervals was 0.27. For irradiation intervals between 2-3 min long the ratio was 1.76.
- In conventional radiotherapy, even using small fields, as for glottis, there is only 0.5% variation in radiation dose
- However, this may be accentuated when using highly conformal radiotherapy
- Surface guided radiotherapy may help to solve this issue



Patient setup
After initial setup, realtime surface captured to track motion during CBCT acquisition
Manual gating
After CBCT verification, realtime reference surface captured
Automatic gating
90.0
Default ROI
OFF
Beam HELD
VRTmm 1.3
LNGmm -2.6
LATmm -1.0
MAGmm 3.1
Rtn° -0.9
Roll° -4.4
Pitch° 0.2
Magnitude
swallow
Motion tracking and treatment with beam hold

Take Home Points

- Motion is inevitable & irregular
- Can be measured reasonably accurately
- Can be controlled/compensated for/partially eliminated
- Procedures demand sophisticated imaging & complex mathematics
- No single perfect method: free breathing methods aren’t the most accurate & breath-hold methods aren’t the most comfortable

Thank You

Email: jyotirup.goswami@gmail.com


Endorsed by
ASCO
AMERICAN SOCIETY OF CLINICAL ONCOLOGY
Narayana
Health
AROICON 2025
45th ANNUAL CONFERENCE OF
ASSOCIATION OF RADIATION ONCOLOGISTS OF INDIA
Hosted by AROI West Bengal Chapter
Date : 27th - 30th November 2025
Venue : Biswa Bangla Convention Centre