Self-sustained breath hold

- Deep Inspiration Breath Hold (DIBH)

Yuqing Xiong
June 09, 2020

Outline

1. Background Knowledge
   - The idea & research papers search
   - The Set up of DIBH
   - The required quantities

2. Clinical implementation
   - Clinical workflow
   - Verification of the DIBH plan

3. Discussion
   - Comparing with ABC
   - Advantages of DIBH
   - Challenges on DIBH
   - Outlook

1.Background Knowledge

1.1 The Idea — research papers search

Schönecker *et al. Radiation Oncology* (2016) 11:143
DOI 10.1186/s13014-016-0716-5

Radiation Oncology

RESEARCH | Open Access

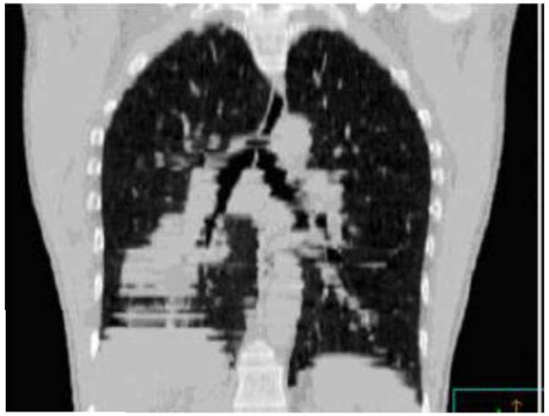
Treatment planning and evaluation of gated radiotherapy in left-sided breast cancer patients using the Catalyst™/Sentinel™ system for deep inspiration breath-hold (DIBH)

S. Schönecker[1], F. Walter[1], P. Freislederer[1], C. Marisch[2], H. Scheithauer[1], N. Harbeck[3], S. Corradini[1*] and C. Belka[1]

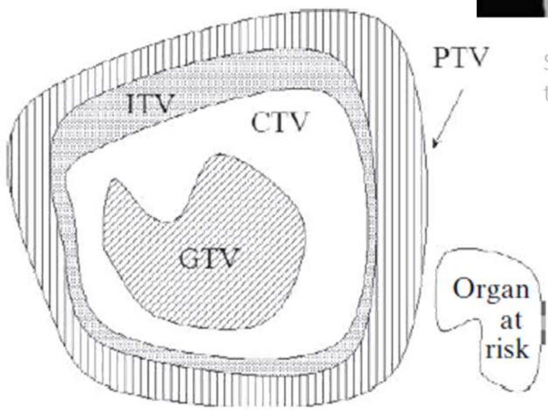
- Time frame: 2015-2020
- Keywords: DIBH, self-sustained breath hold, cardiac toxicity, lung expansion etc.
- **Focus: 1. latest studies**
  2. clinical implementation

1.1 The Idea

- Respiratory organ motion is a complicated factor
  - Imaging & treatment planning
  - Dose delivery
- Increasing safety margins can be very dangerous



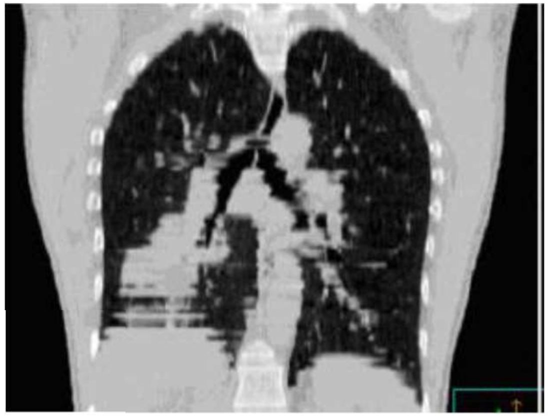
Source: Lecture Medical Imaging "4D X-ray tomography" Prof Riboldi, 13.05.2020



Source: Podgorsak, Radiation Oncology Phzysics

1.1 The Idea

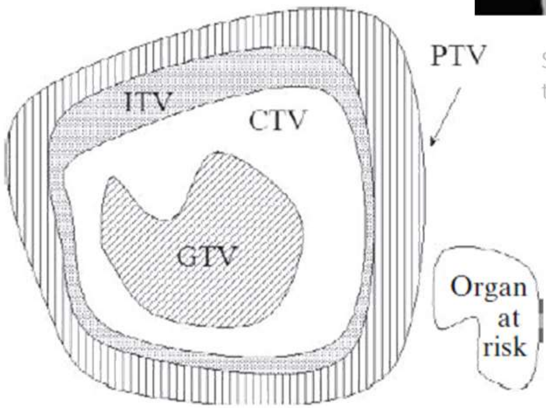
- Respiratory organ motion is a complicated factor
  - Imaging & treatment planning
  - Dose delivery
- Increasing safety margins can be very dangerous



Source: Lecture Medical Imaging “4D X-ray tomography” Prof Riboldi, 13.05.2020

Goal:

- To obtain a possibly static target in the beam’s eye of view, whenever the beam is on
- To protect the organ at risk better



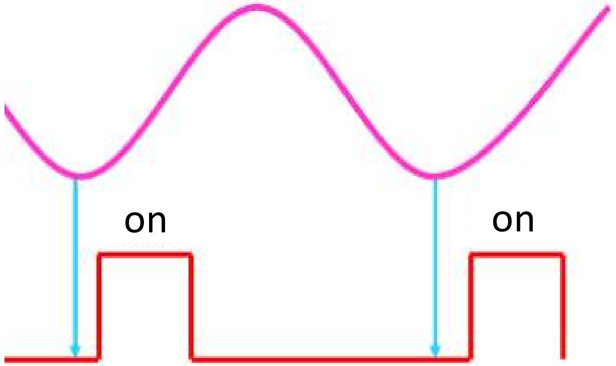
Source: Podgorsak, Radiation Oncology Phzysics

1.1 The Idea

There are three techniques:

1. Abdominal pressure	2. Predefining phase of the respiratory cycle	3. Special maneuvers of respiration

Source:https://blog.orfit.com/radiation-oncology/products/stereotactic-body-radiation-therapy/



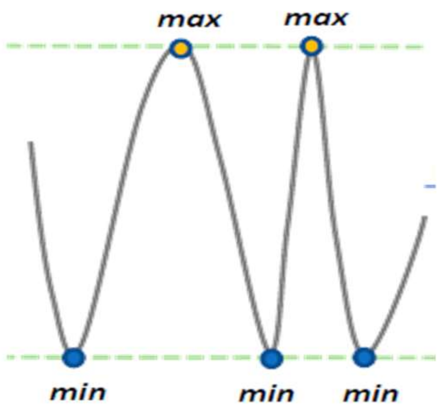
Source: Lecture Medical Imaging “4D X-ray tomography” Prof Riboldi, 13.05.2020

1.1 The Idea

There are three techniques:

1. Abdominal pressure	2. Predefining phase of the respiratory cycle	3. Special maneuvers of respiration

Source:https://blog.orfit.com/radiation-oncology/products/stereotactic-body-radiation-therapy/

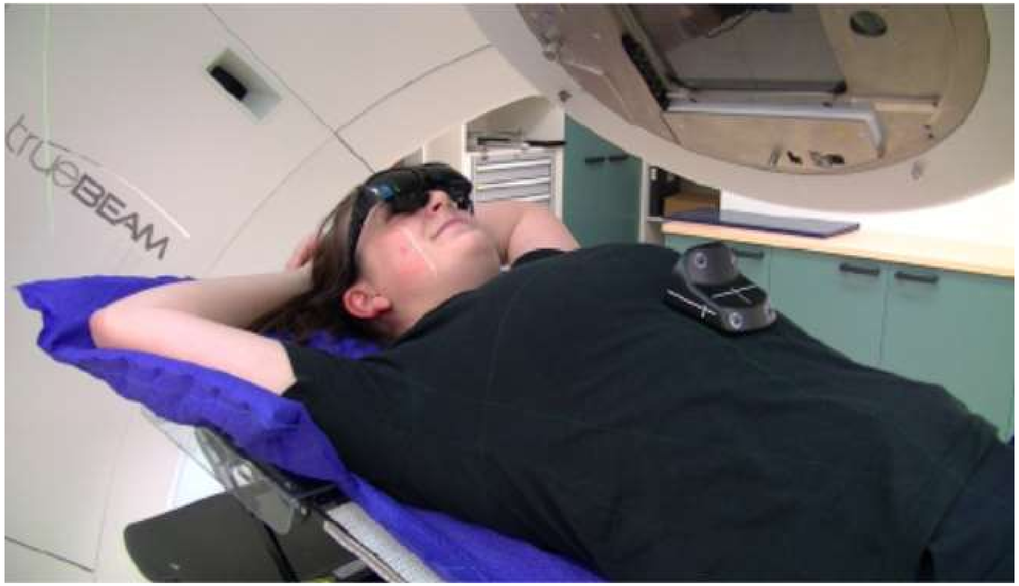


Source: Lecture Medical Imaging “4D X-ray tomography” Prof Riboldi, 13.05.2020

After couching

With feedback

1.2 The Set-up of DIBH



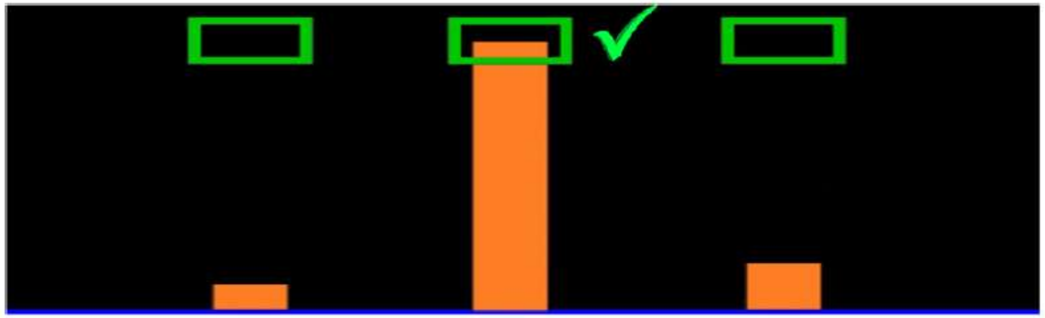
1. Audio-visual guidance

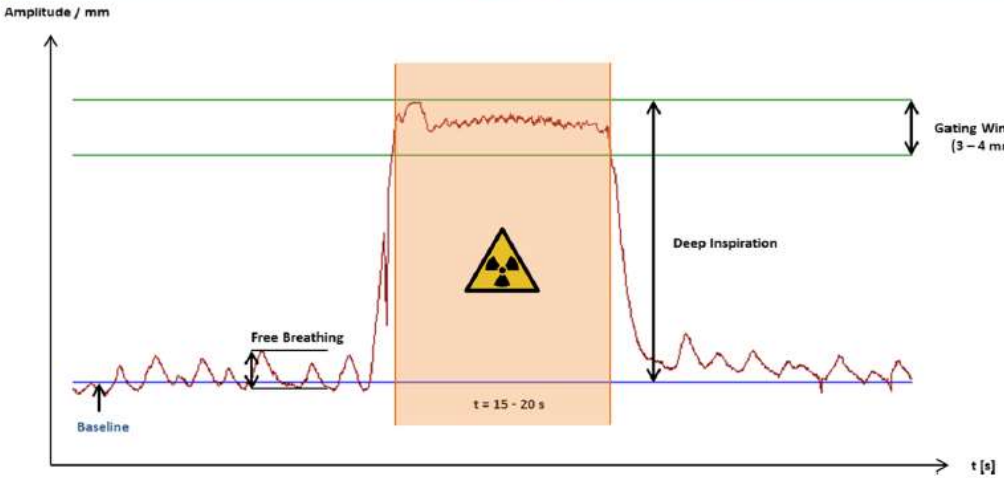
2. Breathing

3. Markers and detectors

4. Beam delivery

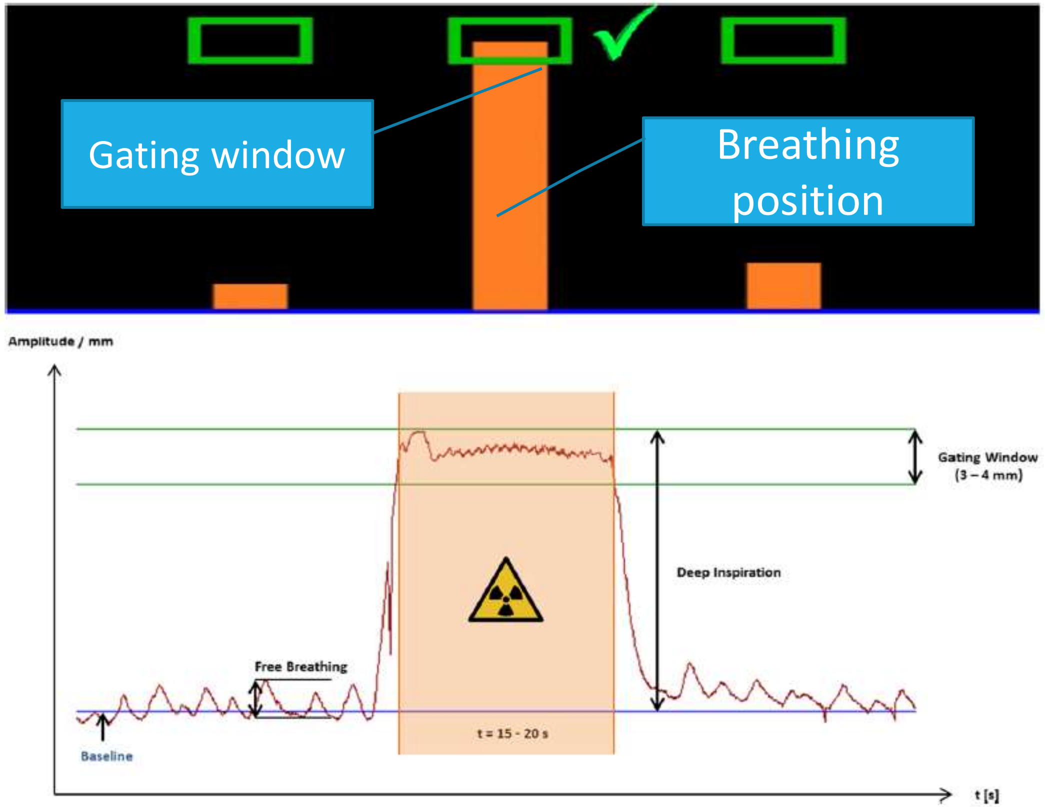
1.2 The Set-up





1. Audio-visual guidance

1.2 The Set-up



1. Audio-visual guidance

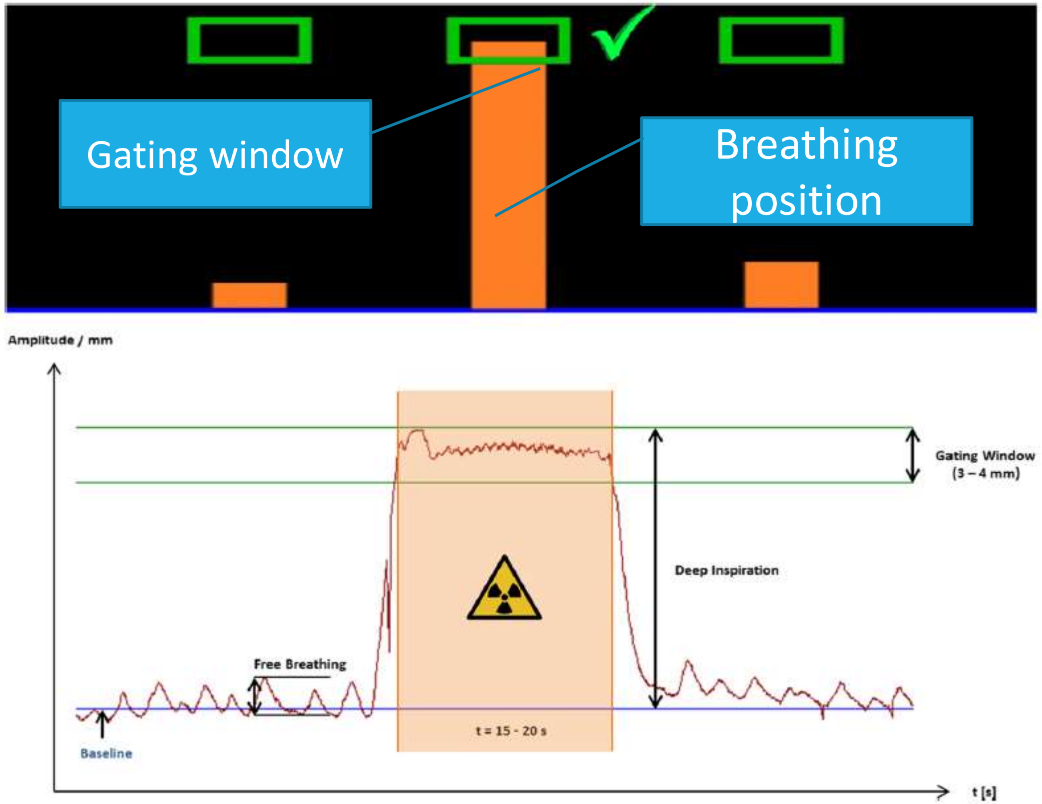
- Comparing with verbal instructions given by an operator

→ higher repeatability of surface localization during DIBH

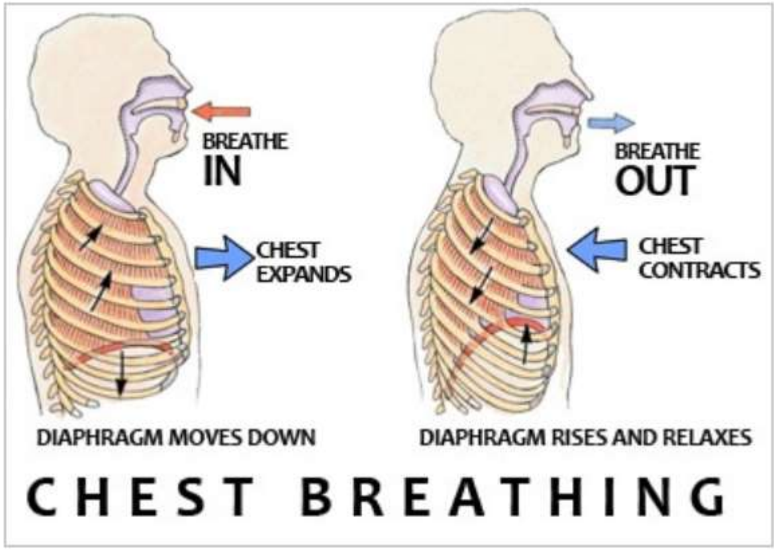
mean 3D displacement (2.2±0.8)mm vs. (3.2±1.1)mm

Data: Cristina Garibaldi et al.

1.2 The Set-up



2. Breathing



1.2 The Set-up

Type 1: 1D information

3. Markers and detectors

Spirometry

Source: Lecture Medical Imaging “4D X-ray tomography” Prof Riboldi, 13.05.2020

- Surface displacements ≠ variability of the inspiratory level
- Reduction of volumetric tolerance ≠ improvements

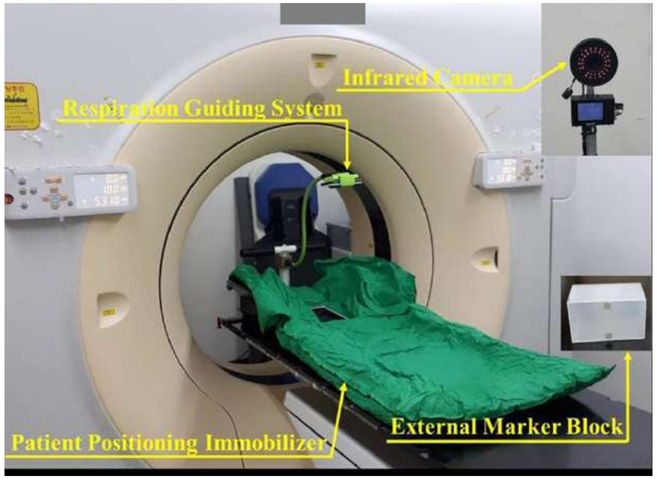
→ Volumetric invariance is **not** a reliable index of the **geometric stability and reproducibility** of patient’s thoraco-abdominal **surface**

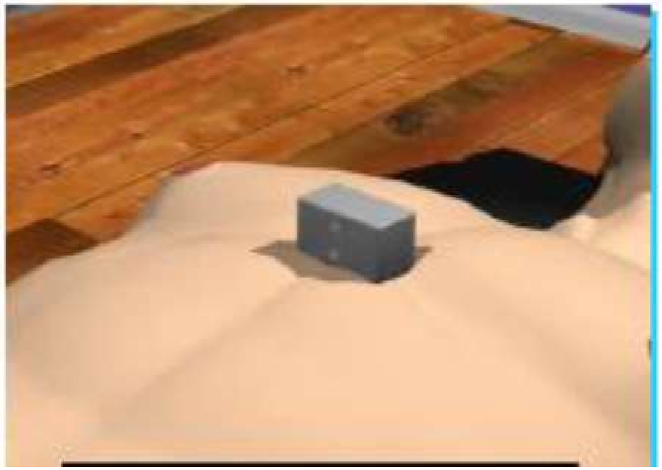
1.2 The Set-up

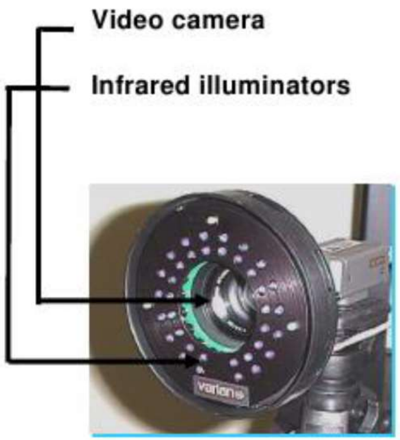
Type 2: 3D information

3. Markers and detectors

RPM (Real-time Position Management)







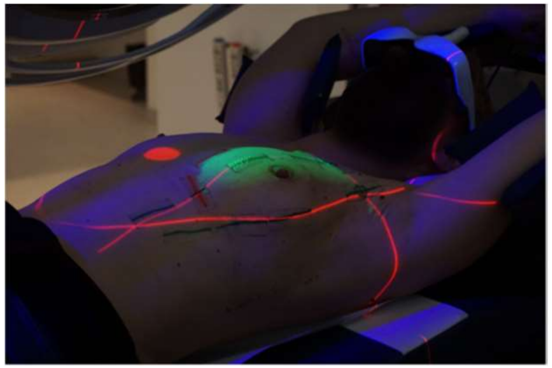
Source: Optimal Gating Window for respiratory-gated radiotherapy with real-time position management and respiration guiding system for liver cancer treatment

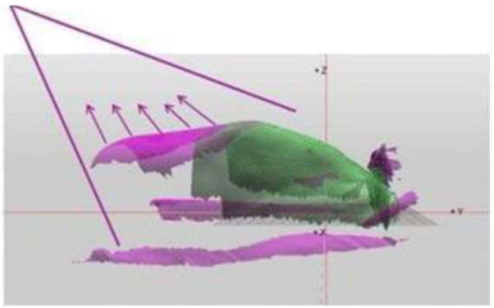
Source: Lecture Medical Imaging “4D X-ray tomography” Prof Riboldi, 13.05.2020

1.2 The Set-up

Type 2: 3D information

C-RAD

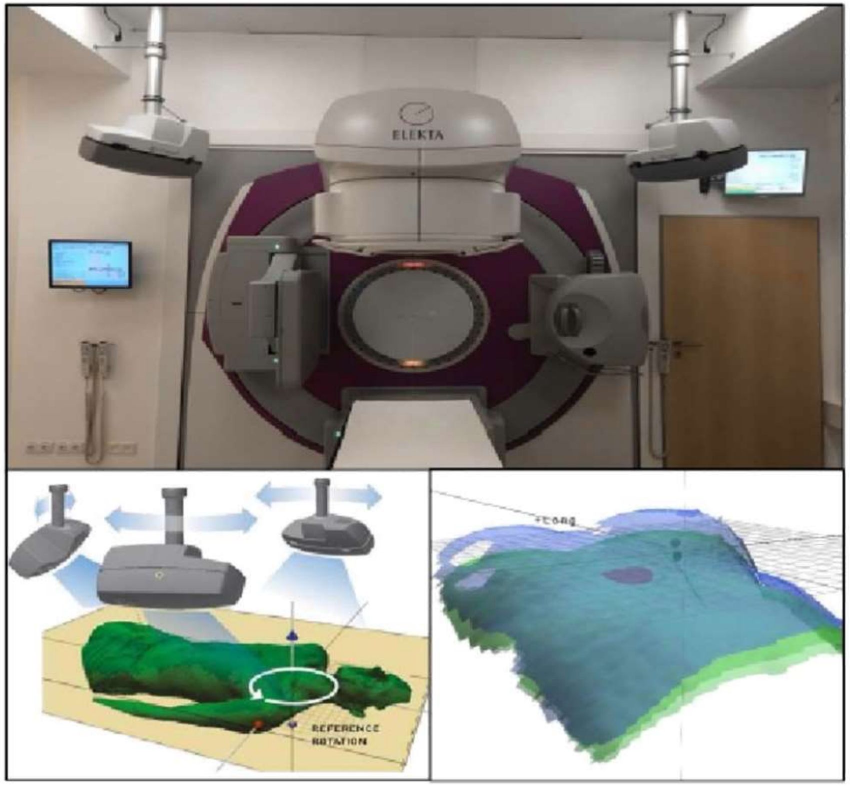




3. Markers and detectors

- Fast and reliable application
- No device or “box” on patient
- Continuous surface scanning
- Additionally: iView portal image

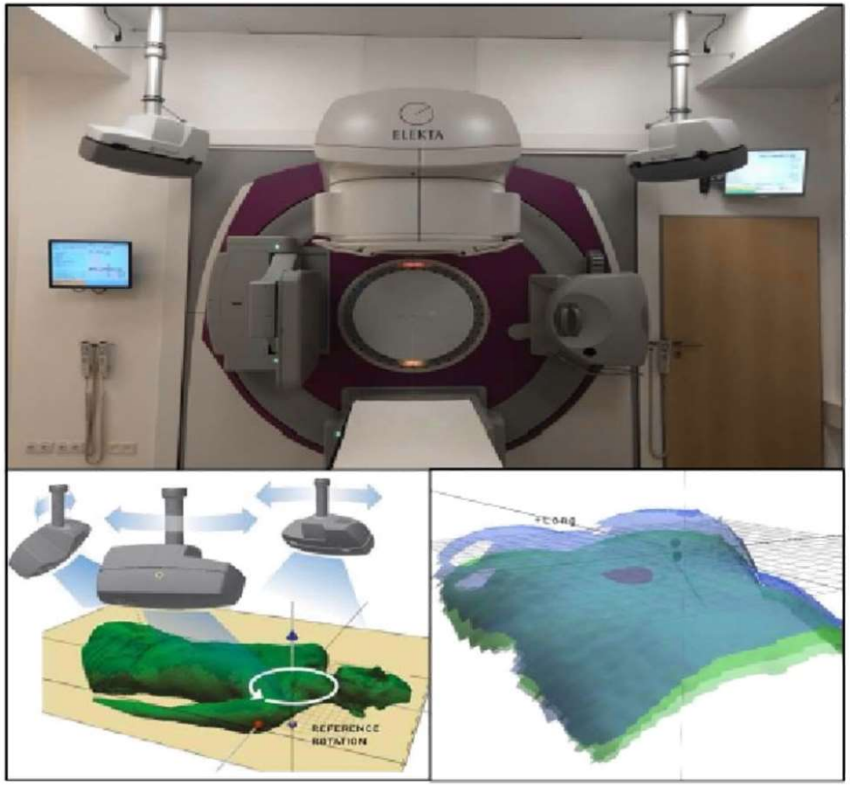
1.2 The Set-up



4. Beam delivery

- When the deep inspiration is detected in in the “gating window”, delivery starts
- The delivery stops immediately, when the breathing is out of the gating window

1.2 The Set-up



4. Beam delivery

- High dose rate required (i.e. 500-600 MU/min) in order to limit the delivery time per beam (i.e 20s)
- Routine is the same as conventional RT

1.3 The required quantities

Dose-Volume Histogram (DVH)

Definition:
- Graphical representation of received dose
- Information on the volume of a structure receiving a given dose over a range of doses

V_x
V: relative volume
x: received at least x Gy

i.e.: V_5, V_{25}, V_{45} relative volume receiving at least 5, 25 and 45 Gy

D_{max}, D_{mean}
the max and mean dose

$D_{2\%}$
dose D to 2% of the volume

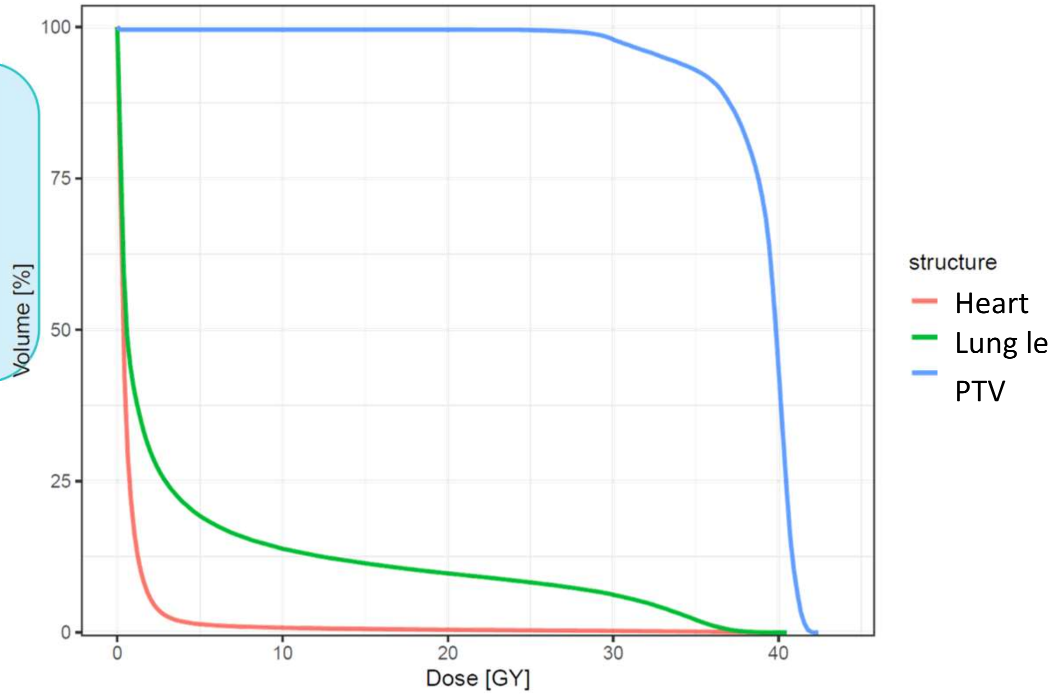
Definition Source: https://link.springer.com/referenceworkentry/10.1007%2F978-3-540-85516-3_659

1.3 The required quantities

Dose-Volume Histogram (DVH)

Definition:

- Graphical representation of received dose
- Information on the volume of a structure receiving a given dose over a range of doses



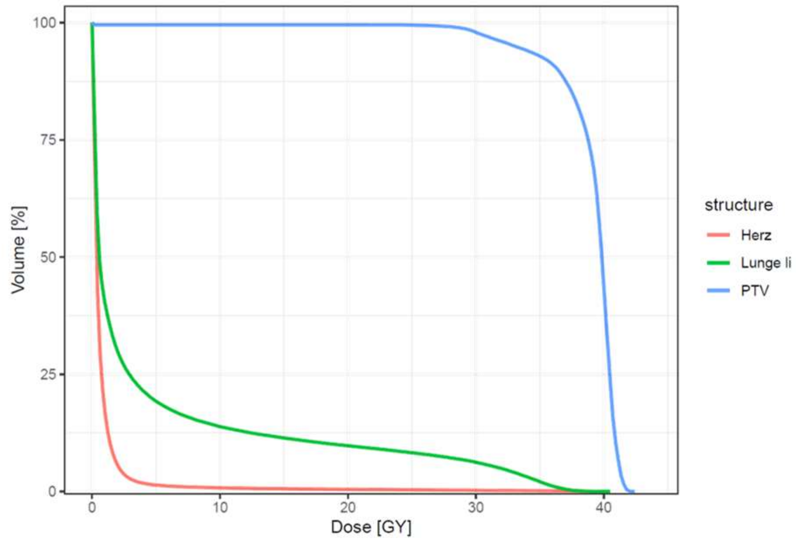
Example: cumulative DVH for left-breast cancer radiation

Definition Source: https://link.springer.com/referenceworkentry/10.1007%2F978-3-540-85516-3_659

1.3 The required quantities

DVH Versus *DMH (Dose-Mass Histogram)*

DVH	DMH
Uses volume elements (voxels)	Accounts for density changes inside voxels
Voxels remain unchanged between FB and DIBH	More accurate for organs with significant local density changes
In commercial treatment planning system	No option in TPS, approximation with mean density inside the volume



Example: cumulative DVH for left-breast cancer radiation

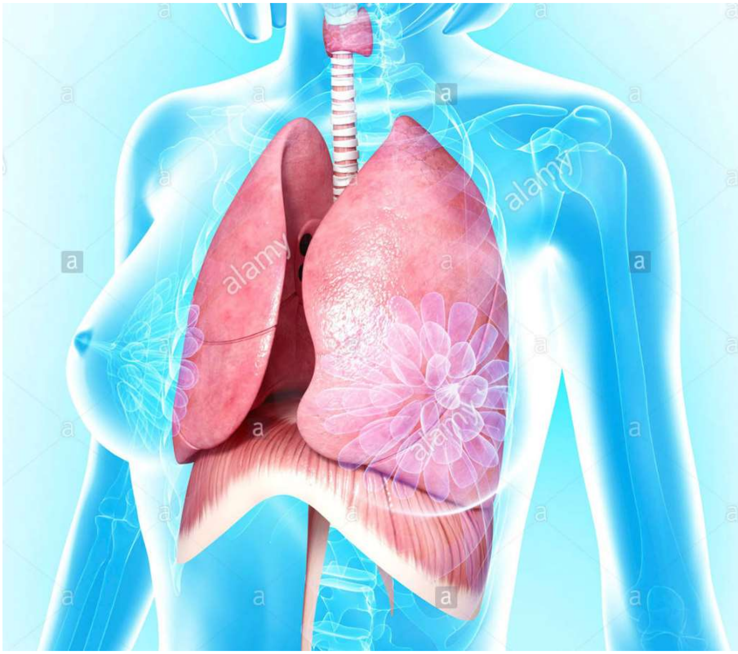
2. Clinical Implementation

- Irradiation of left-sided breast cancer

2.1 Clinical Workflow

Background and purpose

- Breast cancer is the most common cancer among women worldwide
- Radiotherapy is important **adjuvant** treatment
- Dose received by the **<u>heart</u>** can cause **late toxicity**



Source: https://www.alamy.com/stock-photo-female-chest-anatomy-artwork-55436736.html

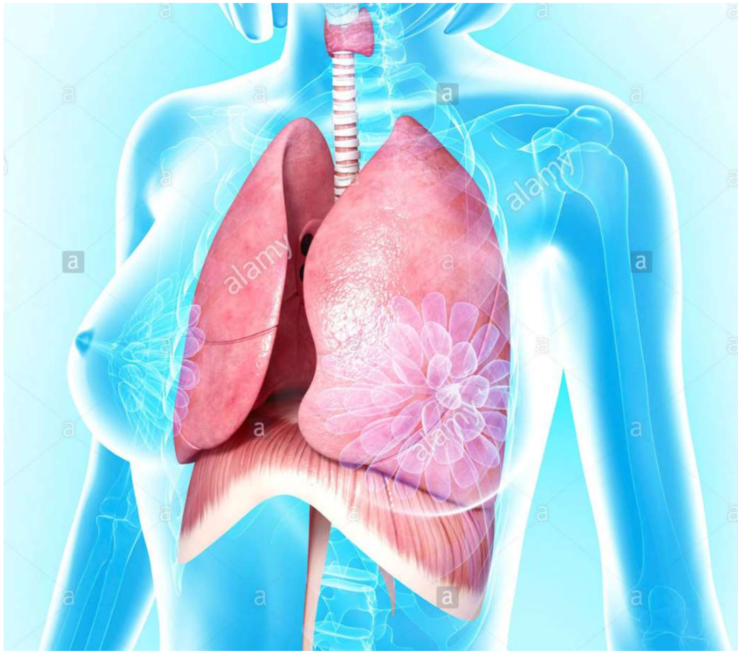
2.1 Clinical Workflow

Background and purpose

- Breast cancer is the most common cancer among women worldwide
- Radiotherapy is important **adjuvant** treatment
- Dose received by the <u>**heart**</u> can cause **late toxicity**

BUT: - no deterministic threshold
- The rate of ischemic heart disease increases linearly by 7.4% per 1Gy increase in the mean heart dose

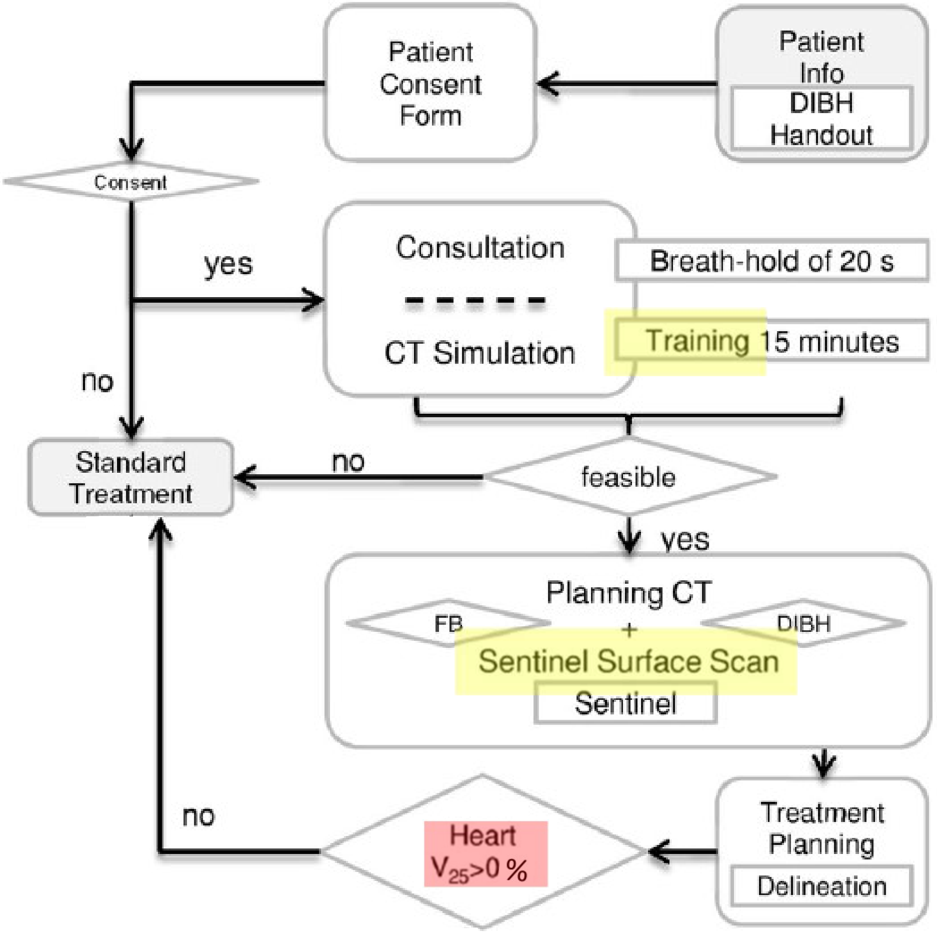
→ Minimization of dose to the heart is crucial



Source: https://www.alamy.com/stock-photo-female-chest-anatomy-artwork-55436736.html

2.1 Clinical Workflow

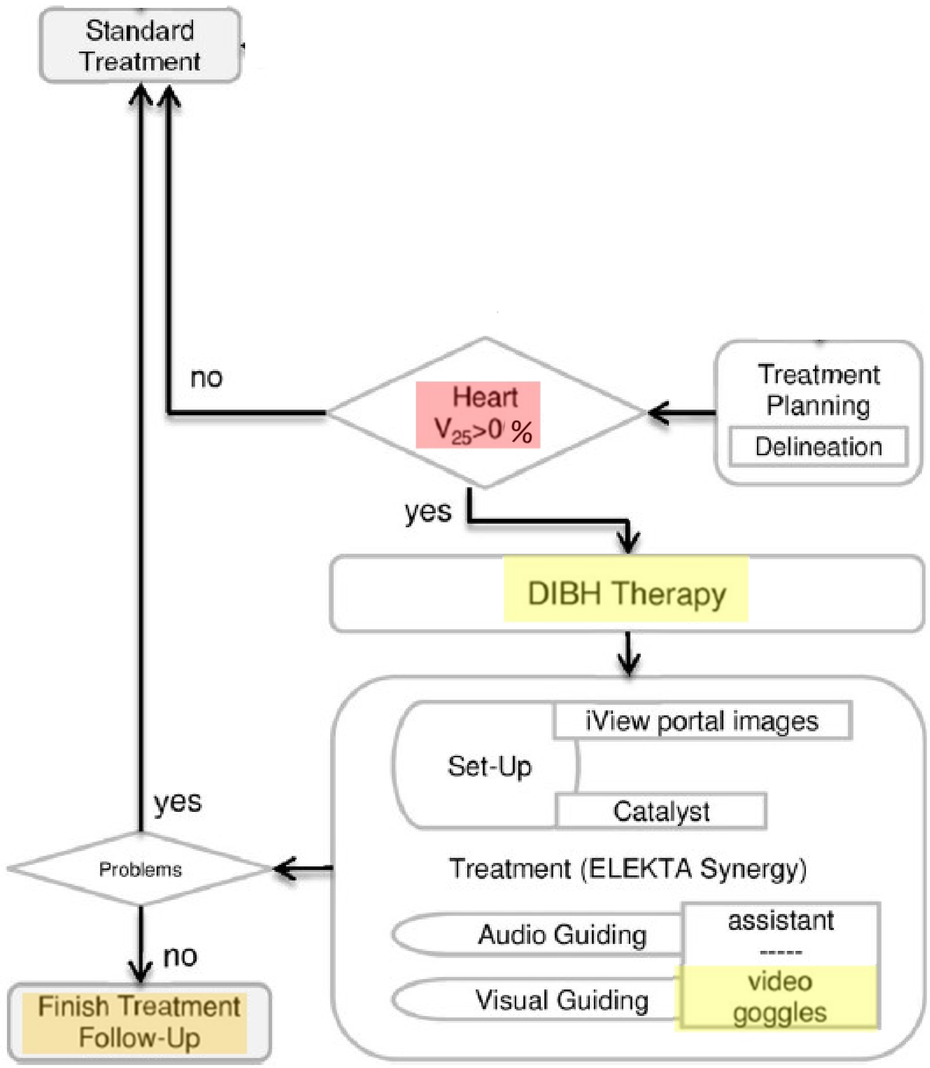
Part 1



Source:Schönecker et al. Radiation Oncology (2016) 11:143
DOI 10.1186/s13014-016-0716-5

2.1 Clinical Workflow

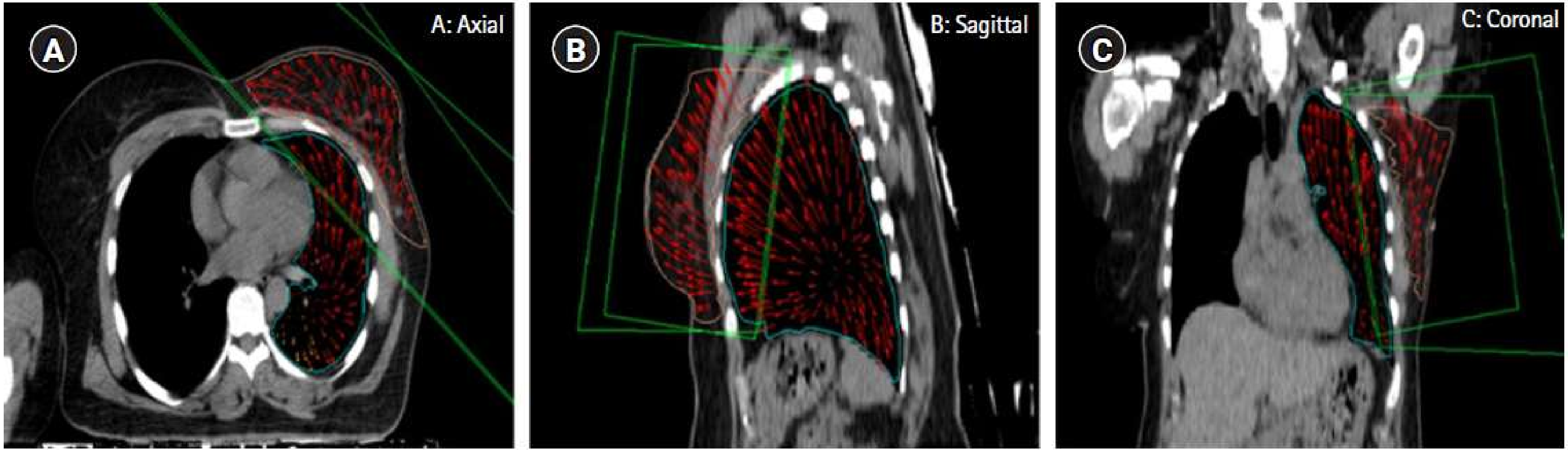
Part 2



Source:Schönecker et al. Radiation Oncology (2016) 11:143
DOI 10.1186/s13014-016-0716-5

2.2 Verification of the DIBH plan

1. CT comparisons



Representation of displacement vectors during the DIBH

2.2 Verification of the DIBH plan

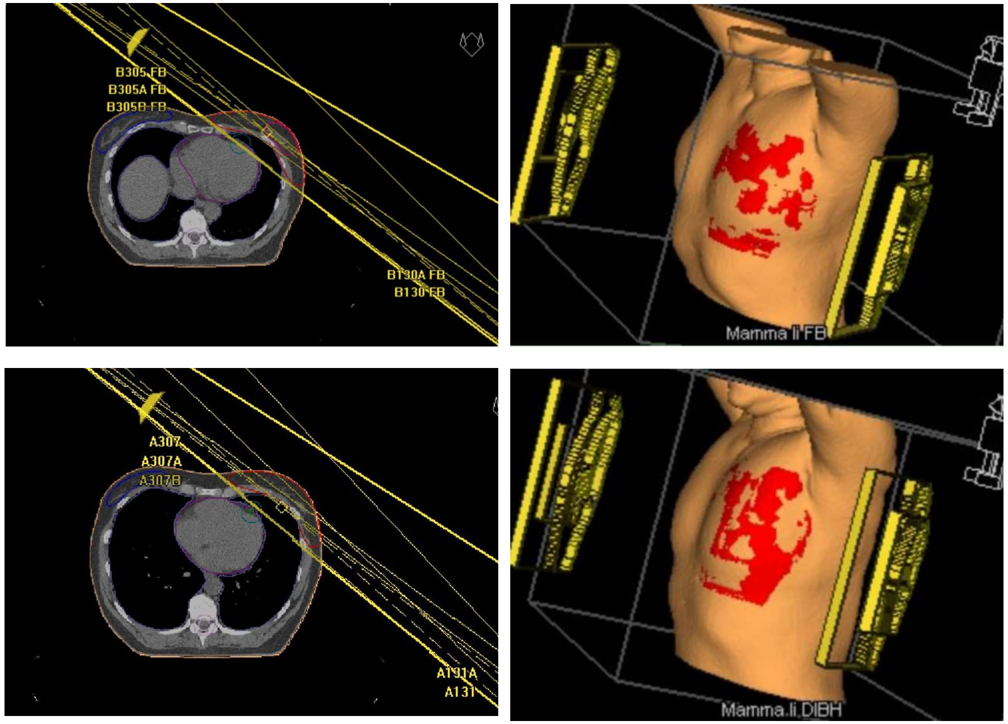
1. CT comparisons

Changes of anatomical conditions:

Red: thoractic diameter and volume in DIBH

Blue: during FB

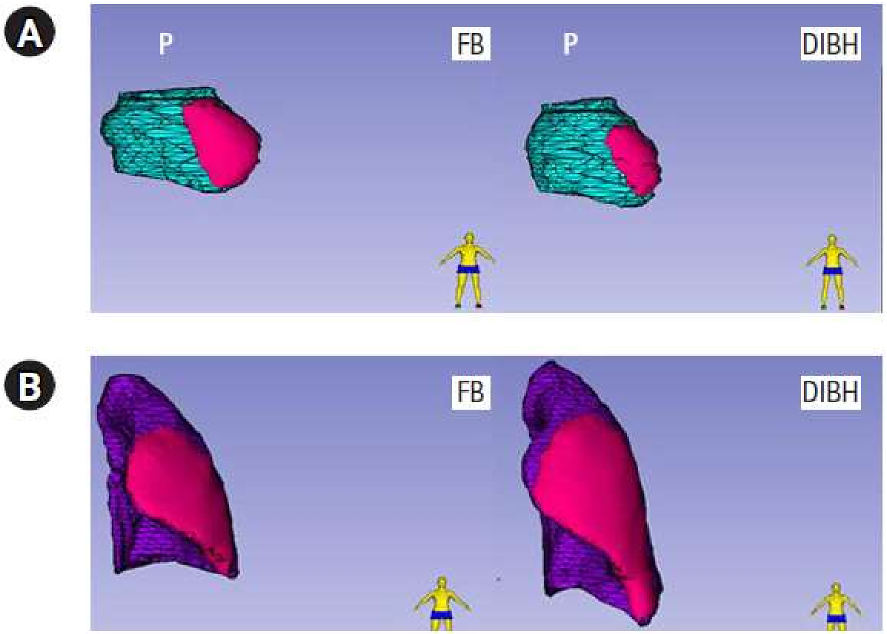
2.2 Verification of the DIBH plan



1. CT comparisons – treatment planning

- 3D conformal radiation therapy (3D-CRT)
- 2 opposing tangential beams
- All treatment plans were calculated on both CT datasets
- All DVH-parameters are determined with the plans
- *Example prescribed dose*: 50 Gy, 2Gy per fraction

2.2 Verification of the DIBH plan



Irradiated volumes in tangential fields: (A) heart (B) left lung

1. CT comparisons – treatment planning

- 3D conformal radiation therapy (3D-CRT)
- 2 opposing tangential beams
- All treatment plans were calculated on both CT datasets
- All DVH-parameters are determined with the plans
- *Example prescribed dose*: 50 Gy, 2Gy per fraction

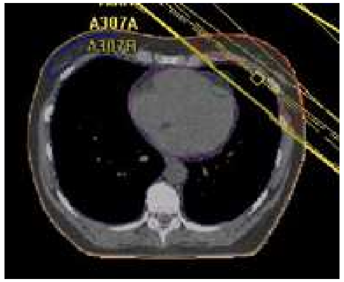
2.2 Verification of the DIBH plan

2. Parameters comparisons

- 2016, 9 patients

Heart	FB	DIBH
$D_{\mathrm{max}}\ (Gy)$	47.90 ± 1.39	19.74 ± 15.52
$D_{\mathrm{mean}}\ (Gy)$	2.73 ± 1.40	1.31 ± 0.15
$V_5\ (\%)$	6.75 ± 4.39	1.18 ± 0.77
$V_{25}\ (\%)$	2.55 ± 2.74	0.06 ± 0.14

LAD	FB	DIBH
$D_{mean}\ (Gy)$	18.91 ± 9.78	4.19 ± 1.52
$D_{2\%}\ (Gy)$	38.55 ± 12.40	9.66 ± 6.30



2.2 Verification of the DIBH plan

2. Parameters comparisons

- 2016, 9 patients

Heart	FB	DIBH
$D_{\max}\ (Gy)$	47.90 ± 1.39	19.74 ± 15.52
$D_{\text{mean}}\ (Gy)$	2.73 ± 1.40	1.31 ± 0.15
$V_5\ (\%)$	6.75 ± 4.39	1.18 ± 0.77
$V_{25}\ (\%)$	2.55 ± 2.74	0.06 ± 0.14

Decrease by 52 %

LAD	FB	DIBH
$D_{mean}\ (Gy)$	18.91 ± 9.78	4.19 ± 1.52
$D_{2\%}\ (Gy)$	38.55 ± 12.40	9.66 ± 6.30

Decrease by 78%

2.2 Verification of the DIBH plan

2. Parameters comparisons

- 2019, 17 patients

Heart	FB	DIBH
$D_{\text{mean}}\ (Gy)$	5.97 ± 2.0	3.83 ± 1.40
$V_{25}\ (\%)$	7.60 ± 4.10	3.29 ± 2.64
$V_{abs}\ (\text{mL})$	42.12 ± 29.54	15.82 ± 15.46

Decrease by 36%

- Studies agree on the dose reduction effect of DIBH in heart during left breast irradiation
- BUT: **discrepancies** in **the left lung** dosimetric parameters

Source: Azam Eskandari et al. *Evaluation of the heart and lung dosimetric parameters in deep inspiration breath hold using 3D slicer, 2019*

2.2 Verification of the DIBH plan

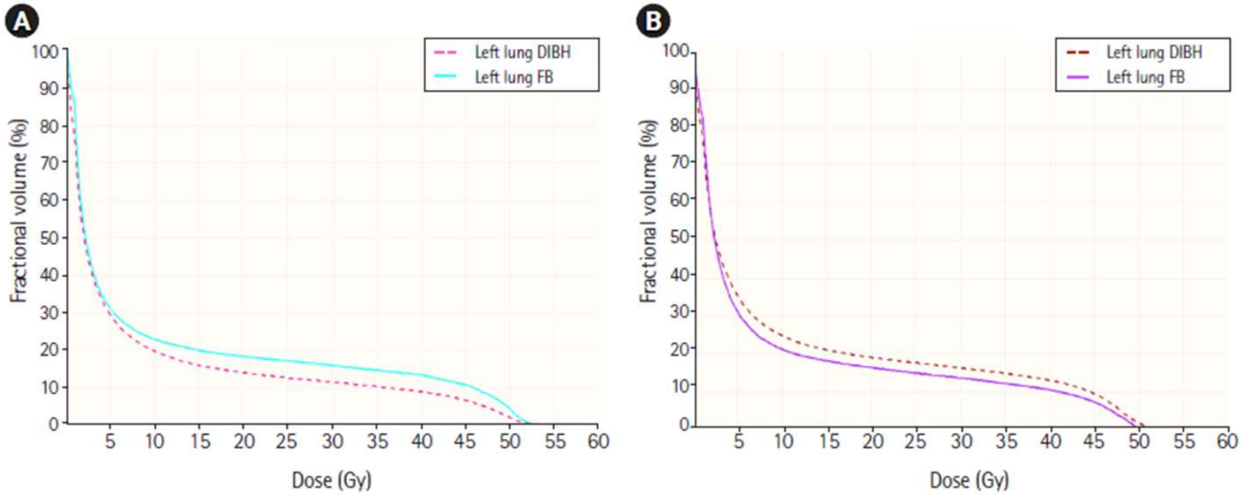
2. Parameters comparisons

- 2016, 9 patients

Left lung	FB	DIBH
$D_{\text{mean}}\ (Gy)$	8.01±2.02	6.45±1.31
$V_{20}\ (\%)$	14.87±4.41	10.96±3.10

- V_{20} could be decreased by 26%
- For all 9 patients, both parameters reduces in DIBH

- 2019, 17 patients

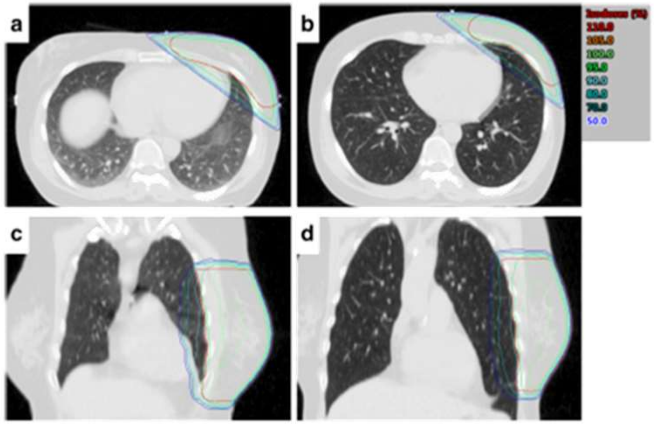


- Results vary from patient to patient and relative irradiated volume increased in some patients
- Patient anatomy, contouring, treatment planning and methods dependent

2.2 Verification of the DIBH plan

2. Parameters comparisons

- Another paper from 2019, 31 patients



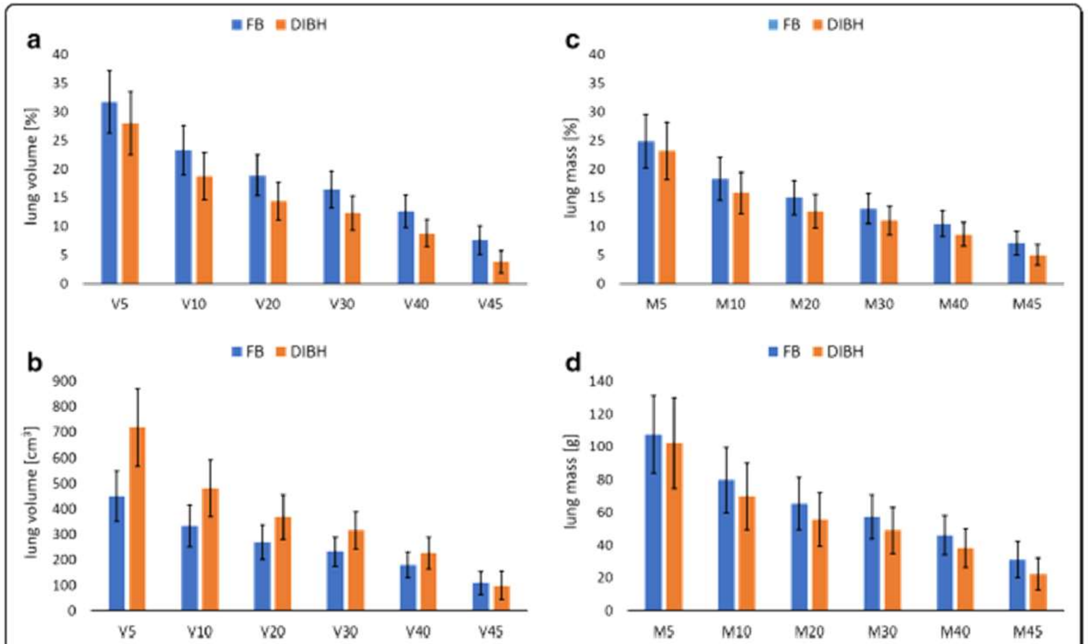


Fig. 1 Mean volumes (V5–45, **a**, **b**) and masses (M5–45, **c**, **d**) of the left lung receiving a certain dose, presented as relative and absolute values ± SD. *FB* free breathing, *DIBH* deep inspiration breath-hold

- 4 patients have higher radiated lung mass

3. Discussion

3.1 Comparing with ABC (Active Breath Control)

Comparing with DIBH, ABC has…

- **drawbacks, because:**
  - More invasive, patient discomfort
  - No positional information
  - external devices could increase the cost and complexity of QA
- **advantages, because:**
  - In many cases, ABC shows a better consistency
  - ABC reduces left lung dose significantly

Source:https://www.youtube.com/watch?v=33gva9denGQ

3.1 Comparing with ABC (Active Breath Control)

Comparing with DIBH, ABC has…

- **drawbacks, because:**
  - More invasive, patient discomfort
  - No positional information
  - external devices could increase the cost and complexity of QA
- **advantages, because:**
  - In many cases, ABC shows a better consistency
  - ABC reduces left lung dose significantly (2015, **81 patients**)

Left lung (ABC)	FB (95% CI)	DIBH (95% CI)
$D_{\text{mean}}\ (Gy)$	6.4	5.9
$V_{20}\ (\%)$	12.0	10.4

Decrease by 9% and 10%

Source:https://www.youtube.com/watch?v=33gva9denGQ

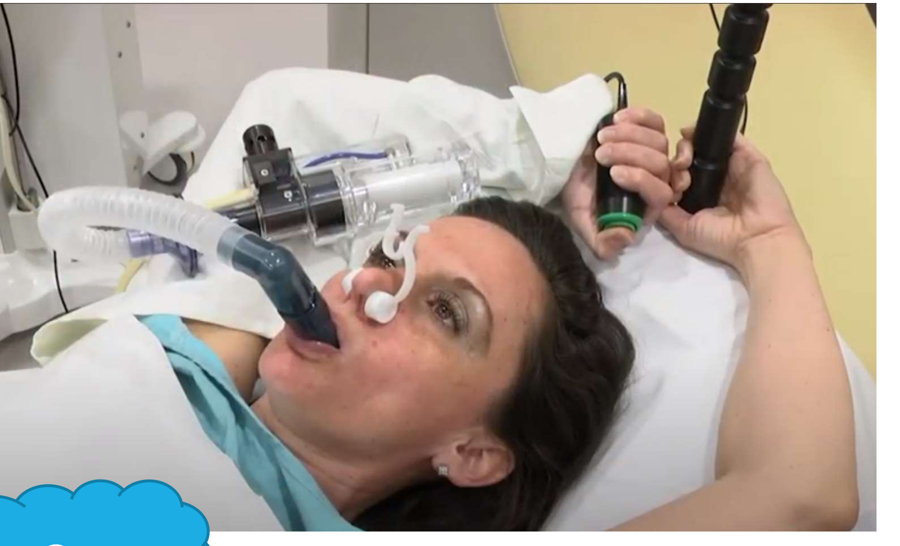
3.1 Comparing with ABC (Active Breath Control)

Comparing with DIBH, ABC has…

- **drawbacks, because:**
  - More invasive, patient discomfort
  - No positional information
  - external devices could increase the cost and complexity of QA
- **advantages, because:**
  - In many cases, ABC shows a better consistency
  - ABC reduces left lung dose significantly (2015, **81 patients**)

Left lung (ABC)	FB (95% CI)	DIBH (95% CI)
$D_{\text{mean}}\ (Gy)$	6.4	5.9
$V_{20}\ (\%)$	12.0	10.4

Decrease by 9% and 10%



utube.com/watch?v=33gva9denGQ

?

3.2 Advantages of DIBH

1. **Possibility to image under DIBH**

   → complete volume dataset under DIBH

   → possible in both MRI and CT

3.2 Advantages of DIBH

1. **Possibility to image under DIBH**
2. **DIBH immobilizes the diaphragm movement less invasively**

→ good reproducibility, more comfortable

→ reduces intra- and interfraction organ motion (mm-range offset)

→ immobilization of PTV allows reduction of PTV margins

→ beneficial also for liver, lung etc.

3.2 Advantages of DIBH

1. **Possibility to image under DIBH**
2. **DIBH immobilizes the diaphragm movement less invasively**
3. **Dosimetric advantages for OAR**

   → reduction of cardiac damage at breast RT & thoractic esophageal cancer
4. **Standard treatment**

3.2 Challenges on DIBH

- No universal standard for patient selection
- Patient anatomy dependent
- Health condition dependent (i.e. longer breath-hold)
- It could take longer than FB
- Due to variable standards, the comparison of dose distributions from different studies need to be done with caution
- Require further follow-up
  - Study of late effect
  - Reassessment of the risk of cardiac diseases

3.3 Outlook

Improvements

- Develop a better standard for patient selection
- Study on the protection of lungs (left AND right)
- Follow-up

Other possibilities?

- With MRI as online guidance?
- IMPT with DIBH?

Comparative Study > Acta Oncol. 2019 Jan;58(1):95-104.
doi: 10.1080/0284186X.2018.1512153. Epub 2018 Oct 3.

Comparative Treatment Planning Study for Mediastinal Hodgkin's Lymphoma: Impact on Normal Tissue Dose Using Deep Inspiration Breath Hold Proton and Photon Therapy

Anneli Edvardsson [1], Malin Kügele [1, 2], Sara Alkner [2], Marika Enmark [2], Joakim Nilsson [2], Ingrid Kristensen [2], Elisabeth Kjellén [2], Silke Engelholm [2], Sofie Ceberg [1, 2]

Affiliations + expand

PMID: 30280626
DOI: 10.1080/0284186X.2018.1512153

Thank you for your attention!

Sources

Papers:

Active Breathing Coordinator Reduces Radiation Dose to the Heart and Preserves Local Control in Patients with Left Breast Cancer: Report of a Prospective Trial, Harriet Eldredge-Hindy et al. Published in final edited form as: *Pract Radiat Oncol*. 2015 ; 5(1): 4–10. doi:10.1016/j.prro.2014.06.004

Experience with an abdominal compression band for radiotherapy of upper abdominal tumours, Rebecca Van Gelder et al. doi: 10.1002/jmrs.254

Deep inspiration breath-hold for left-sided breast irradiation: Analysis of dose-mass histograms and the impact of lung expansion, Markus Oechsner et al. Oechsner et al. Radiation Oncology (2019) 14:109 https://doi.org/10.1186/s13014-019-1293-1

Treatment planning and evaluation of gated radiotherapy in left-sided breast cancer patients using the Catalyst/Sentinel system for deep inspiration breath-hold (DIBH), Stephan Schönecker et al. DOI 10.1186/s13014-016-0716-5

Sources

Deep Inspiration Breath Hold: techniques and advantages for cardiac sparing during breast cancer irradiation, Carmen Bergom et al. *doi: 10.3389/fonc.2018.00087*

Dose reduction to organs at risk with deep-inspiration breath-hold during right breast radiotherapy: a treatment planning study, Chloe Pandeli et al. https://doi.org/10.1186/s13014-019-1430-x

Deep Inspiration Breath Hold – based radiation therapy: a clinical review, Judit Boda-Heggemann et al. Inc. All rights reserved. http://dx.doi.org/10.1016/j.ijrobp.2015.11.049

Reproducibility of the external surface position in left-breast DIBH radiotherapy with spirometer-based monitoring, Aurora Fassi et al. JOURNAL OF APPLIED CLINICAL MEDICAL PHYSICS, VOLUME 15, NUMBER 1, 2014

Recent advances in radiotherapy of breast cancer, Jan Haussmann et al. https://doi.org/10.1186/s13014-020-01501-x

Lung volume reproducibility under ABC control and self-sustained breath-holding, Evangelia Kaza et al., DOI: 10.1002/acm2.12034

Sources

Reduction of cardiac and coronary artery doses in irradiation of left-sided breast cancer during inspiration breath hold – a planning study, Stephan Schönecker et al. DOI 10.1007/s00066-016-1039-z

Evaluation of the heart and lung dosimetric parameters in deep inspiration breath hold using 3D Slicer, Azam Eskandari et al. Radiat Oncol J 2020;38(1):68-76 https://doi.org/10.3857/roj.2019.00654

Deep inspiration breath-hold radiotherapy for lung cancer: impact on image quality and registration uncertainty in CBCT image guidance, Mirjana Josipovic et al, https://doi.org/10.1259/bjr.20160544

Deep inspiration breath-hold technique guided by an opto-electronic system for extracranial stereotactic treatments, Cristina Garibaldi et al., JOURNAL OF APPLIED CLINICAL MEDICAL PHYSICS, VOLUME 14, NUMBER4, 2013

Sources

Websites:

Swedish Cancer institute: https://www.swedish.org/services/cancer-institute/our-services/radiation-therapy/types-of-radiation-therapy/active-breathing-coordinator

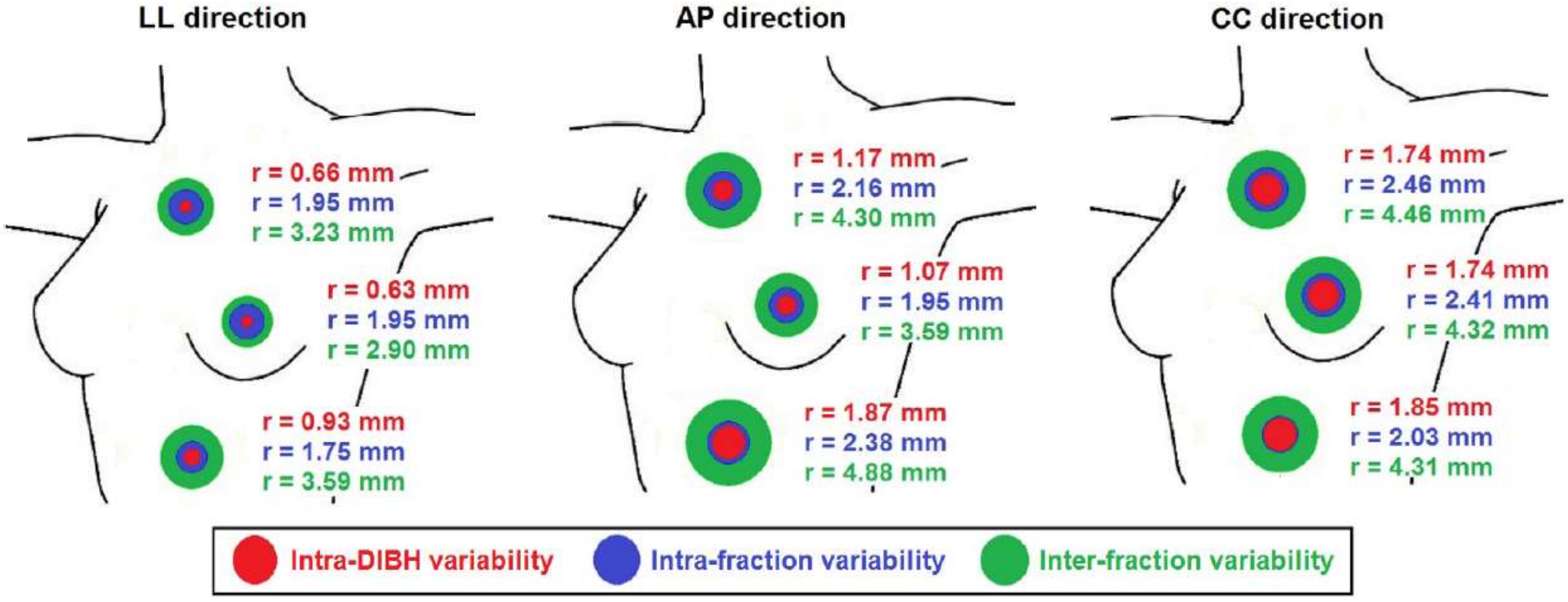
To understand ABC: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5893752/
https://www.youtube.com/watch?v=33gva9denGQ

Breathing: https://www.healnaturesway.com/what-is-yogic-breathing/

DVH definition: https://link.springer.com/referenceworkentry/10.1007%2F978-3-540-85516-3_659

C-RAD: https://c-rad.se/catalyst/
https://c-rad.se/sentinel-4d-ct/

Appendix

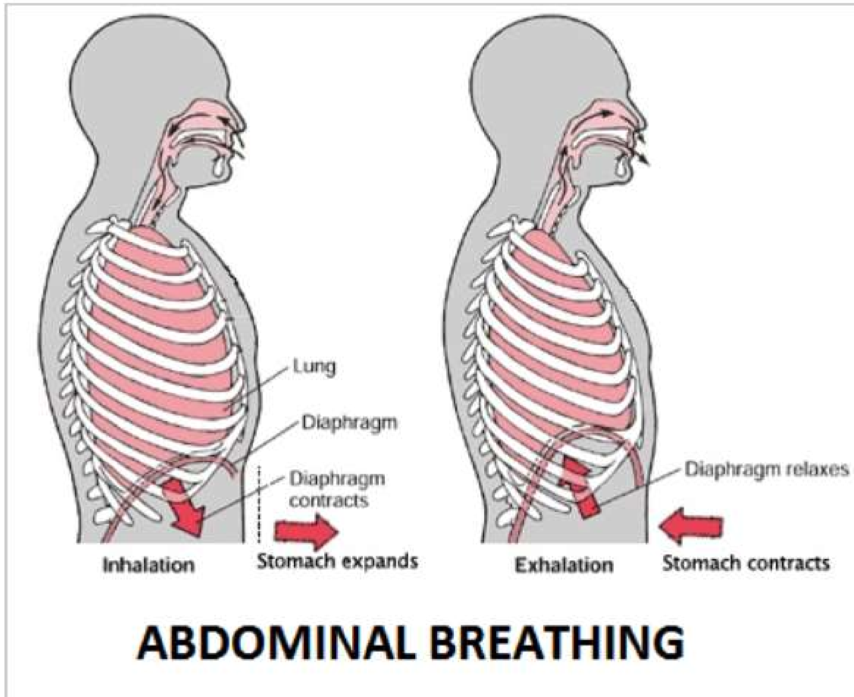


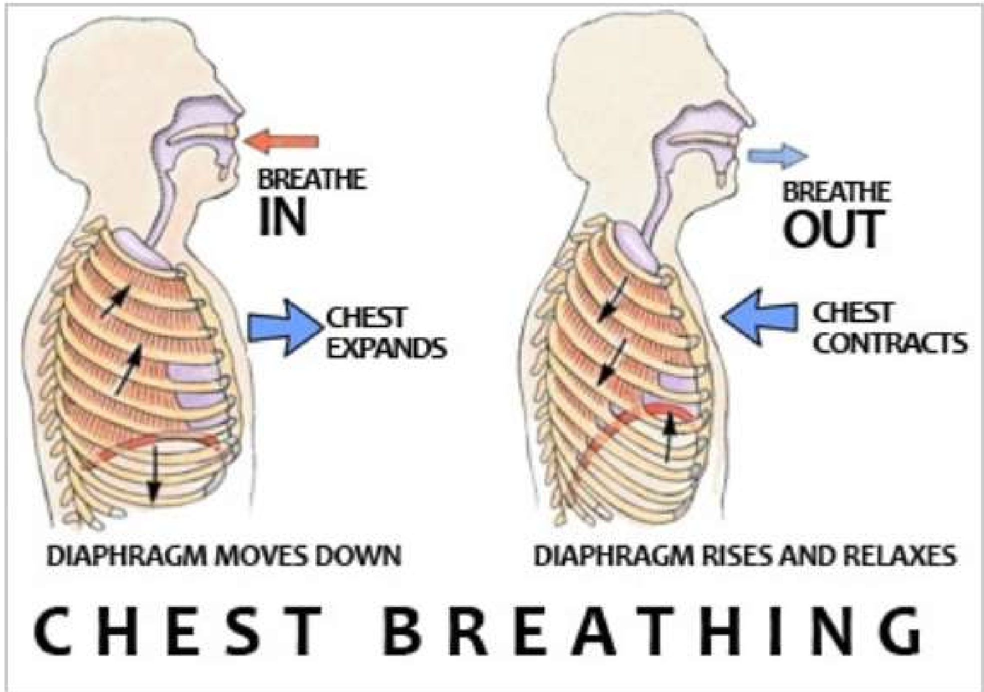
Source :**Reproducibility of the external surface position in left-breast DIBH radiotherapy with spirometer-based monitoring**

Aurora Fassi,1a Giovanni B. Ivaldi,2 Ilaria Meaglia,2 Patrizia Porcu,2 Paola Tabarelli de Fatis,3 Marco Liotta,3 Marco Riboldi,1,4 Guido Baroni1,4

Dipartimento di Elettronica, Informazione e Bioingegneria,1 Politecnico di Milano, Milano, Italy; Department of Radiation Oncology,2 Fondazione Salvatore Maugeri, Pavia, Italy; Medical Physics,3 Fondazione Salvatore Maugeri, Pavia, Italy; Bioengineering Unit,4 CNAO Foundation, Pavia, Italy

aurora.fassi@polimi.it


Lung
Diaphragm
Diaphragm contracts
Diaphragm relaxes
Inhalation
Stomach expands
Exhalation
Stomach contracts
ABDOMINAL BREATHING


BREATHE IN
CHEST EXPANDS
BREATHE OUT
CHEST CONTRACTS
DIAPHRAGM MOVES DOWN
DIAPHRAGM RISES AND RELAXES
CHEST BREATHING