Clinical implementation of **breath-hold** with **nasal high flow therapy** for photons & protons at Maastro

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Device used at Maastro: AIRVO®

- Delivery of high flow of humidified heated air and supplemental oxygen through a nasal interface
- **Nasal High Flow therapy (NHFT)** (AIRVO®) to support **voluntary breath hold**
  - Nasal cannula
  - High flow 40L/min (2-60L/min)
  - Heated (31-34-37°C)
  - Insulated tube
  - Humidified
  - Oxygen 21%-80%
- Easy set-up

New taxonomy: HFNC

- Combined with surface scanning with visual feedback

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Use of NHFT in non-RT setting

Is used in hospitals, but also at home

Website vendor →

Recommendations for NHF use

Clinical applications/ scenarios	ESICM[2,9]	ACP[1]	SSC[3]	AARC[4]	ERS[5]	TSANZ[6]	JSICM JRS JSRCM[7]	WHO[8]	SRLF SFMU[10]	ACEP[11]	NICE[12]	GOLD[13]
PRIMARY SUPPORT - MEDICAL												
Undifferentiated or moderate respiratory distress										[a]		
Acute hypoxemic respiratory failure (AHRF)	[b,c]	[d]			[e]	[f]			[g]			
Respiratory failure due to pneumonia											[h]	
Acute respiratory distress syndrome (ARDS)	[c]						[i]					
Acute hypercapnic respiratory failure					[j]							
Exacerbation of COPD												[k]
Sepsis-induced AHRF			[l]									
Patients with severe or critical COVID-19	[c]							[m]				
Patients who are immuno-compromised with AHRF				[n]								
PRIMARY SUPPORT - SURGICAL												
Low risk post-operative patients					[o]							
High risk post-operative patients					[p]							
High risk post-cardiothoracic surgery patients	[q]											
PRE-ESCALATION SUPPORT												
Pre-oxygenation for peri-intubation patients	[r]											
DE-ESCALATION SUPPORT												
Post-extubation	[s]	[t]		[u]								
Low risk, extubated patients					[v]							
High risk, extubated patients	[w]				[x]							
COMPLEMENTARY RESPIRATORY SUPPORT												
Rest breaks off NIV					[y]							
PROPHYLACTIC RESPIRATORY SUPPORT												
Patients requiring supplemental oxygen for any reason				[z]								

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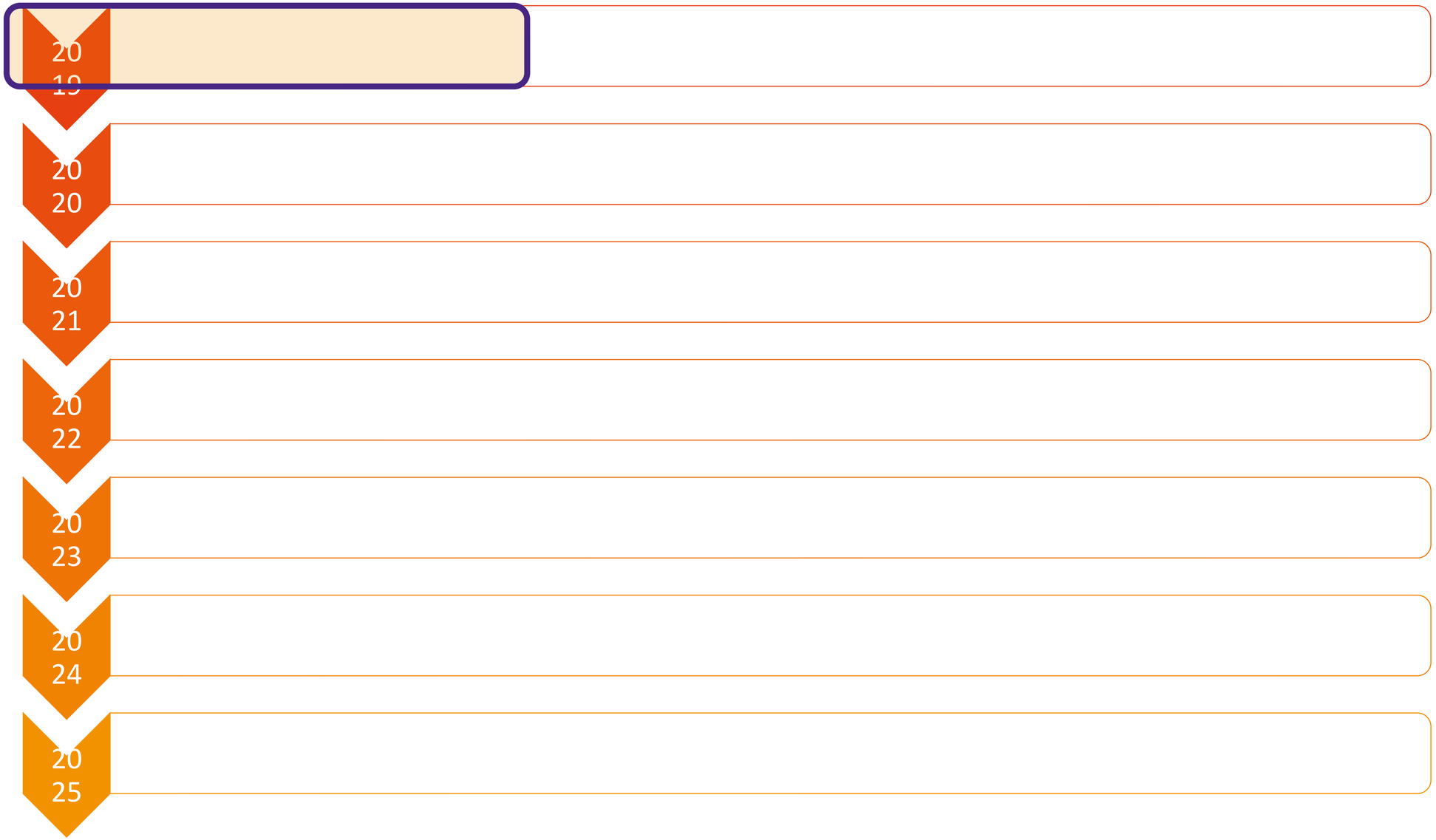
NHFT in radiotherapy under breath hold: Maastro experience



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Lung cancer, photons

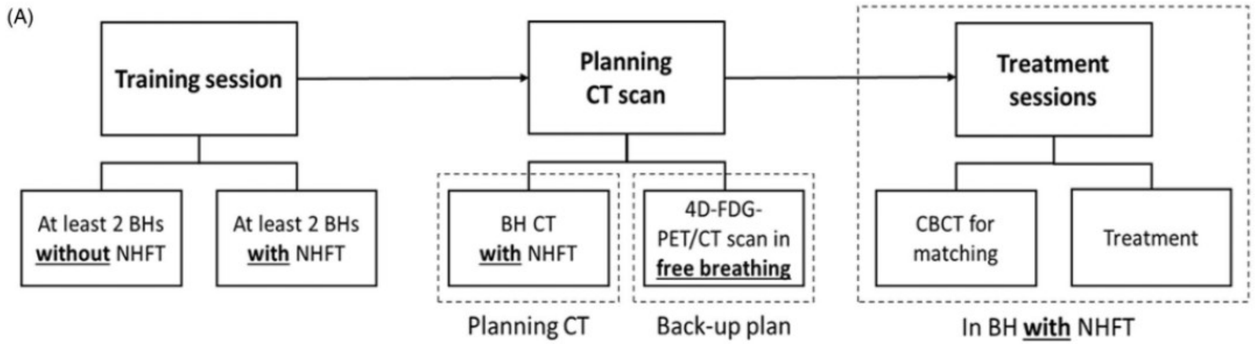
First experience: ENTheR study

Treated with NHFT

- with 80% O2

- Flow 40 L/min

Inclusion	10 consecutive locally advanced NSCLC patients undergoing radical photon RT
Methods	Prospective, NHFT, surface scanning, CO2-meter, 2019
Endpoints	Tolerability of the treatment **Breath hold length** Stability & reproducibility (Surface scanning) Subjective tolerance Dose difference between standard treatment plan and treatment plan in BH with NHFT.



Lung cancer, photons

First experience: ENTheR study

Results	9/10 included patients treated within study
	7/9 completed treatment as planned (2 pts had 2 fractions in FB)
	Training session: mean BH duration (p=0.005) - Without NHFT: 39 s (range 15-86) - With NHFT: 78 s (range 29-223) - Factor 2.1 (range 1.1-3.9)
	Intra- and inter-BH variability were both minimal, with submillimeter variability
	Mean inter-fraction tumor position variability: 1.8mm (-1.1–8.1;SD 2.4)

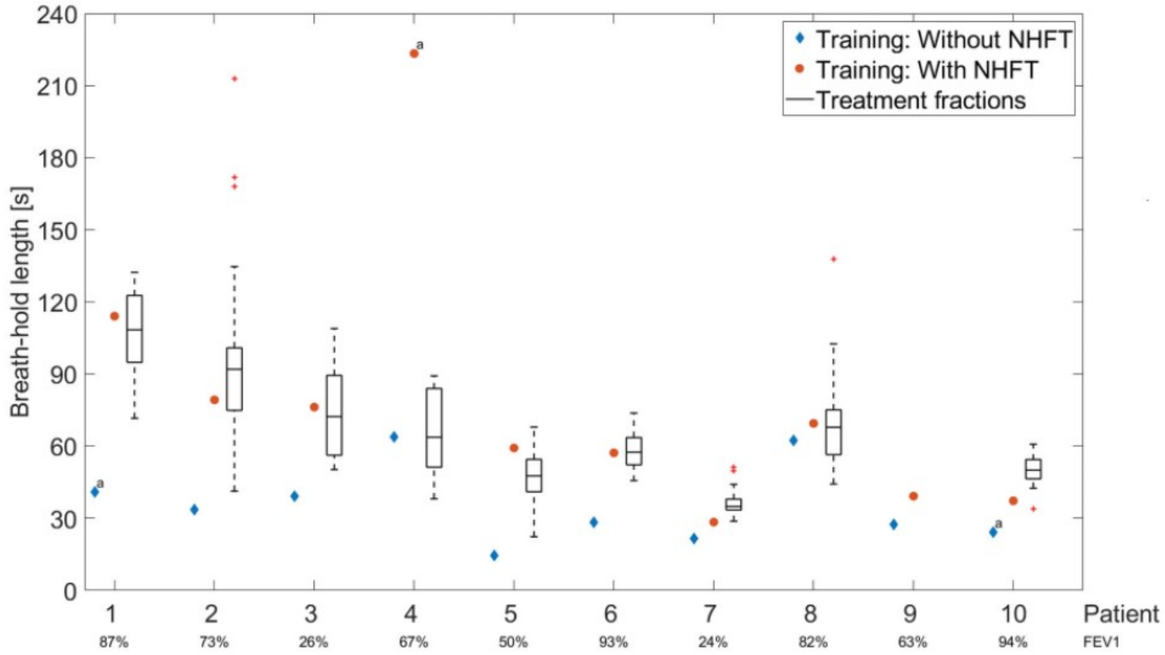


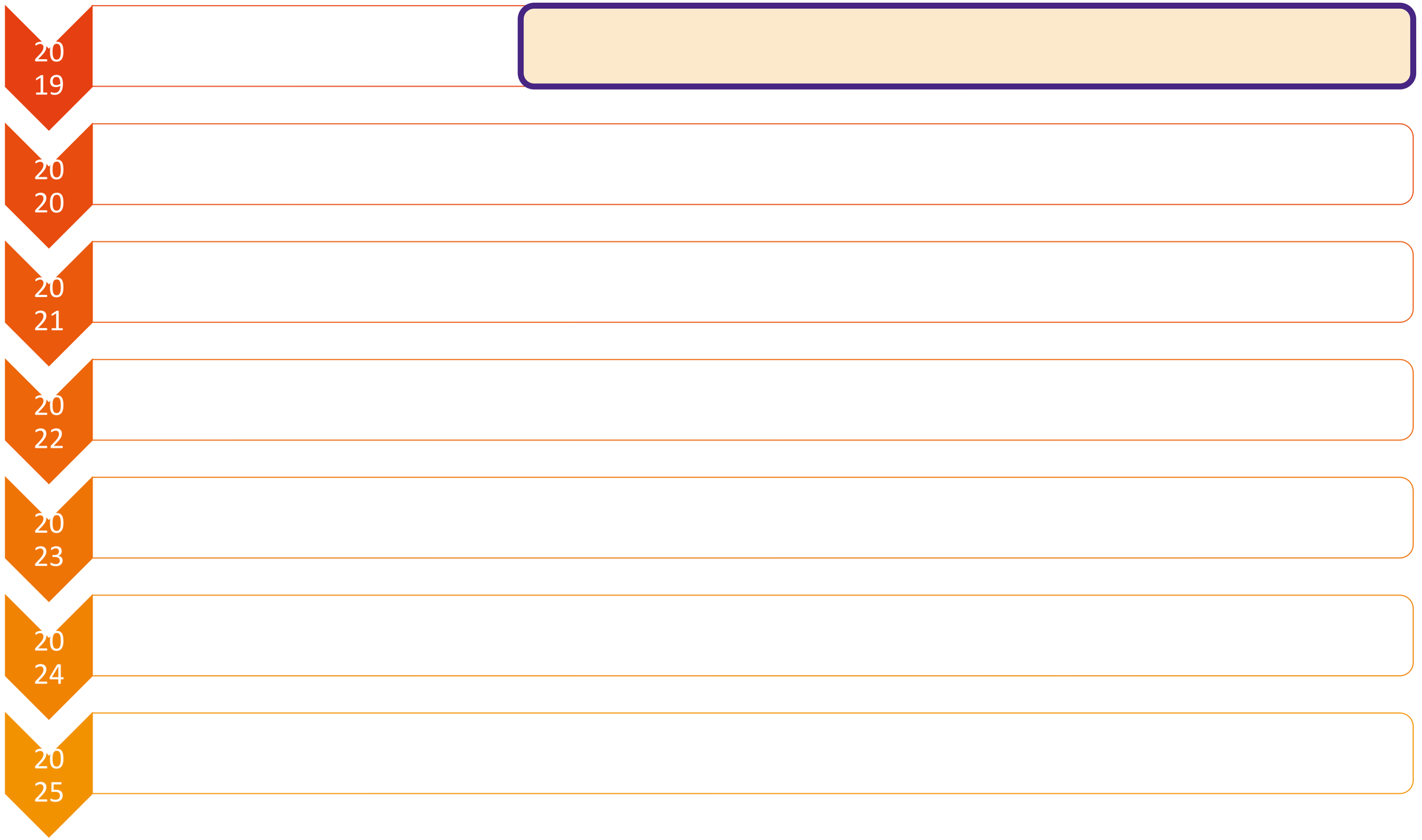
Table 1. Patients' characteristics.

	$N = 10$
Mean age (years) (range)	67 (60–74)
Gender	
Male	6
Female	4
WHO performance status	
0	3
1	5
2	2
Stage (TNM 8)	
Stage IIIA	3
Stage IIIB	3
Stage IIIC	2
Stage IVA	1
Stage IVb	1
Primary tumor location	
Upper lobe	8
Middle lobe	0
Lower lobe	2
FEV1 (%pred): mean (range)	66 (24–94)
Smoking status	
Never smoker	0
Former smoker	6
Active smoker	4
Treatment ($n = 9$)[a]	
Concurrent chemoradiotherapy	6
Sequential chemoradiotherapy	2
Radiotherapy alone	1
Lung volume ($n = 9$)[a]	
Free breathing (L) (mean) (range)	4.1 (2.1–5.7)
Breath hold (L) (mean) (range)	6.1 (4.1–8.0)
Relative increase (%) (mean) (range)	150 (114–200)

FEV1: Forced expiratory volume in 1 s.
[a]1 patient was upstaged to stage IVc at planningCT and was not treated with RT.

Peeters et al. Acta Oncol 2020

NHFT in radiotherapy under breath hold: Maastro experience



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Lymphoma, photons

11 mediastinal lymphoma pts included

Treated with photons in BH: 6 with NHFT (pts 1-6), 5 without NHFT (pts 7-11)

Flow of 40 L/min, with 80% O2

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Original Article

Radiotherapy for mediastinal lymphoma in breath hold using surface monitoring and nasal high flow oxygen: Clinical experiences and breath hold stability

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	NHFT (n)	No NHFT (n)
Number of patients	6	5
Age Median (range) (years)	36 (21–54)	22 (19–33)
Gender		
Male	4	3
Female	2	2
Cardiac risk factors		
Yes	3	1
No	3	4
Stage		
IIA	5	5
IIB	1	0
Histology		
Classic Hodgkin lymphoma	6	5
Chemotherapy regimen		
A(B)VD courses		
2	1 (+2x escBEACOP)	1
3	2	
4	2	0
5	0	3
Other chemotherapy regimen	1 (3x GDP + BEAM)	1 (reduced dose)
		0
Fractionation schedule		
10x2Gy	2	1
15x2Gy	3	4
20x2Gy	1	0
Extra mediastinal involvement		
Axilla	2	2
Neck	5	4
Periclavicular	5	2
Internal mammary chain	1	0

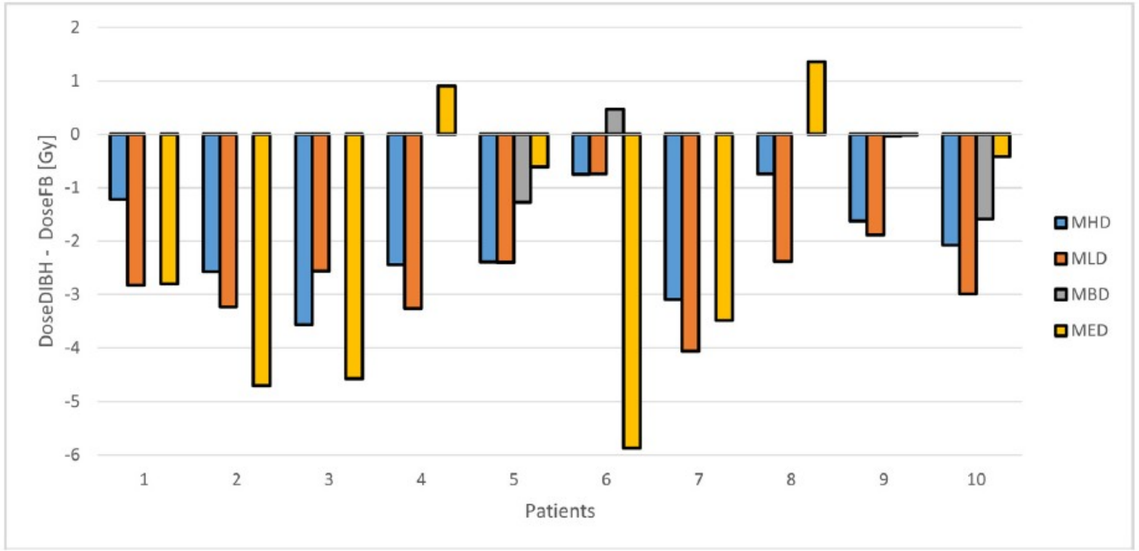

Fig. 4. Dose in breath hold plan minus dose in free breating plan for mean dose in heart (MHD), lung (MLD), breast (MBD), and esophagus (MED).

Canters et al. Radioth Oncol 2023

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Lymphoma, photons

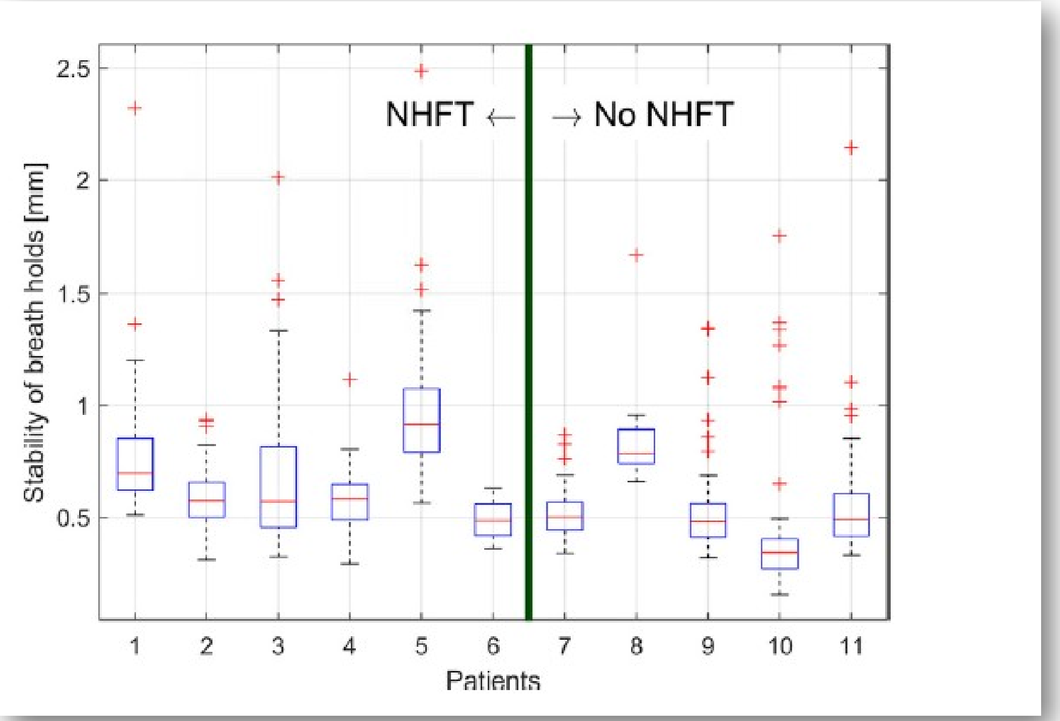
Breath holds were stable

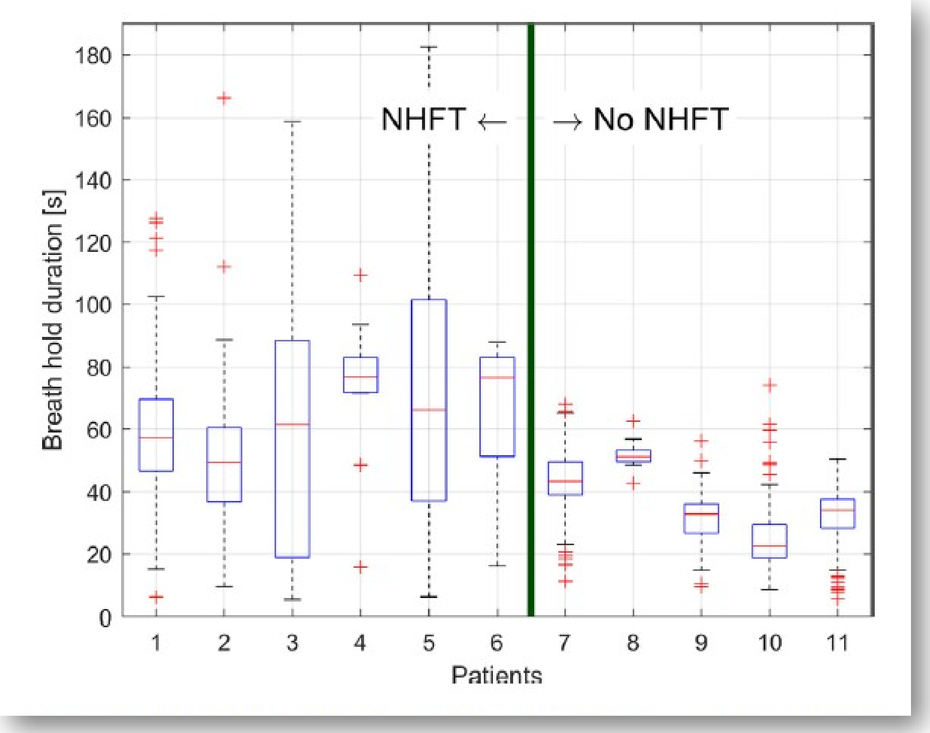
Similar stability with and without NHFT

NHFT +/- doubled BH duration

Table 2
Overview of inter and intra fraction random (σ) and systematic (Σ) setup errors in left–right (LR), craniocaudal (CC), and anterior-posterior (AP) direction as well as the resulting margins, both for free breathing as well as breath hold.

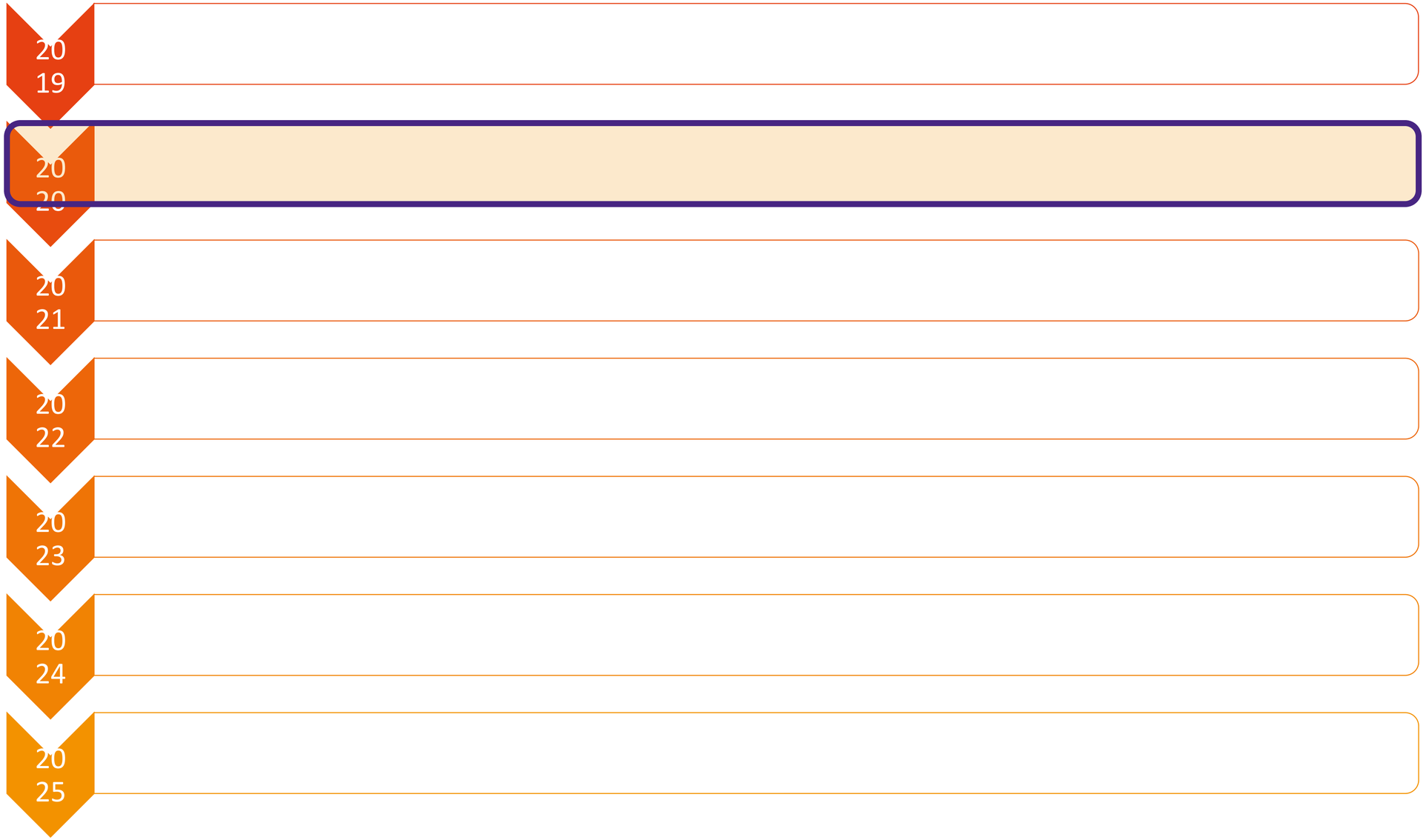
	Inter fraction motion DIBH [mm]	Intra fraction motion DIBH [mm]	Inter fraction motion free breathing [mm]
Σ_LR	0.9	0.8	0.7
Σ_CC	1.3	0.7	2.1
Σ_AP	1.1	0.5	1
σ_LR	1.2	1.0	0.6
σ_CC	1.9	1.7	1.8
σ_AP	1.3	1.2	1.1
Margins [mm]			
LR	4		3
CC	5		7
AP	4		4





Canters et al. Radioth Oncol 2023

NHFT in radiotherapy under breath hold: Maastro experience



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Liver SBRT

- 11 pts treated for liver mets with SBRT

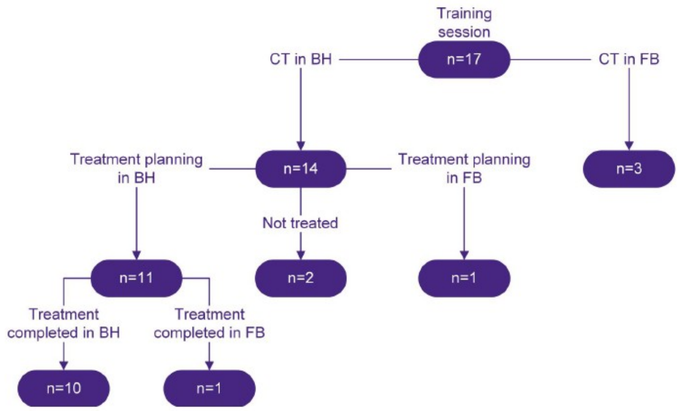

Figure 3. Flowchart showing the number of breath-hold (BH) patients and patients who continued in free-breathing (FB) for each step of the workflow.

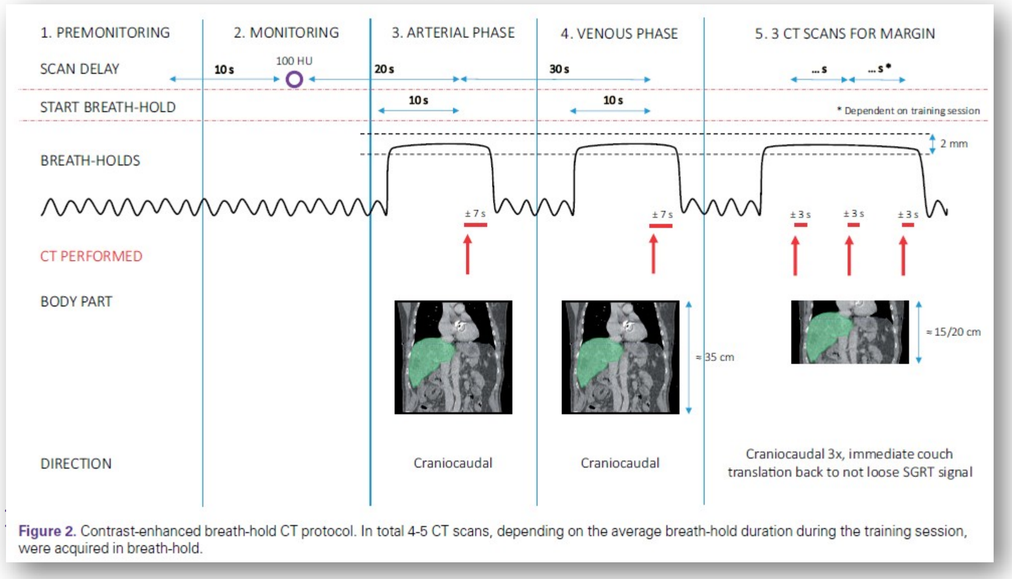

Figure 2. Contrast-enhanced breath-hold CT protocol. In total 4-5 CT scans, depending on the average breath-hold duration during the training session, were acquired in breath-hold.

BJR, 2024, **97**, 1950–1958
https://doi.org/10.1093/bjr/tqae177
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Research Article

Clinical implementation and evaluation of stereotactic liver radiotherapy in inspiration breath-hold using nasal high-flow therapy and surface guidance

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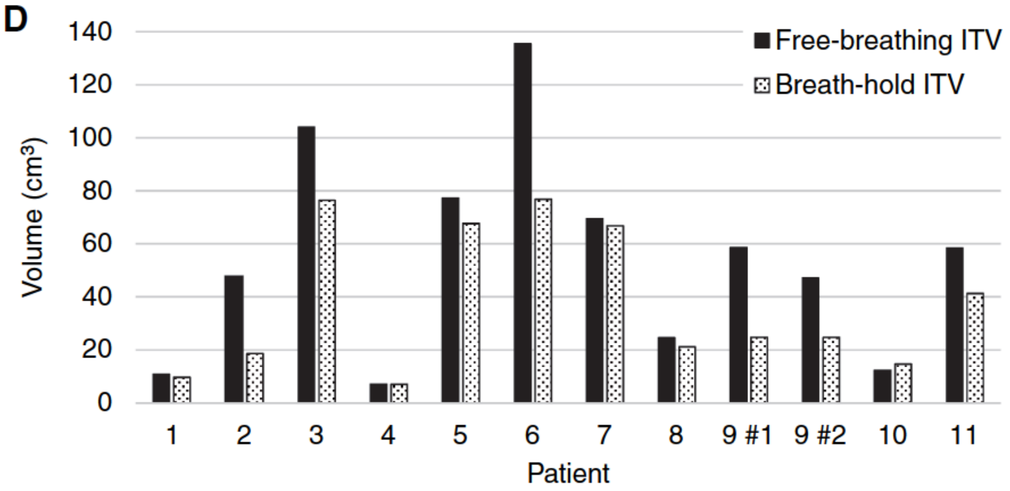

Hazelaar et al. BIR 2024

Liver SBRT

Table 1. Patient and treatment characteristics.

Patient	Sex	Age (y)	PTV (cm^3)	Dose prescription (fractions × Gy)	Energy	Maximum dose rate (MU/min)	MU/arc	Median number of BHs performed during CBCT imaging (range)	Median number of BHs performed during treatment (range)
1	F	55	58.7	5 × 12	6X-FFF	1400	965/945/865	1 (1-5)[f]	3 (2-8)
2	F	80	95.5	3 × 20	10X-FFF	1600	1832/1614/1514	1 (1-2)	7 (5-10)
3	M	73	177.4	8 × 7.5	10X-FFF	2400	1000/1165[d] 960/1118	2 (1-4)	6.5 (3-19)
4[a]	F	72	38.9	5 × 12	10X-FFF[d] 6X-FFF	2400[d] 1400	1936/1912[d] 1312/1717	1 (1-2)	6 (4-7)
5	M	73	182.4	5 × 12	6X-FFF	1400	1325/1524	2.5 (1-4)	19[g]
6	M	67	190.9	5 × 12	6X-FFF	1400	1218/1497	2 (1-3)	8 (4-13)
7[a]	M	80	242.8	8 × 7.5	6X-FFF	1400	817/859	2 (1-4)	4 (3-8)
8	M	68	91.2 18.5[b]	5 × 12	6X-FFF	1400	1776/1824	1 (1-5)	5 (3-5)
9	M	76	225.2[c]	3 × 8	6X-FFF	1400	1232/1136	2 (1-4)	5 (4-14)
10	M	32	72.9	3 × 20	6X-FFF	1400	3065/3065	1.5 (1-4)	9 (6-17)
11	M	70	151.7	3 × 8	6X-FFF	1400	313/783/723/305[e]	2.5 (1-3)	5 (4-6)

Abbreviations: PTV=planning target volume, MU=monitor unit, BH=breath-hold, CBCT=cone-beam CT, F=female, M=male, FFF=flattening filter free.
[a]These patients did not have a metastasis in the liver itself but close to the liver: patient 4 had a metastasis next to/below the liver, and patient 7 between the liver and thoracic wall.
[b]Two PTVs treated in a single plan, of which one was located within the liver and one between the ribs.
[c]This PTV consisted of multiple GTVs.
[d]After the first fraction, these patients were treated using a new treatment plan.
[e]This patient was positioned with the arms alongside the body. More treatment arcs were used to avoid irradiation through the arms.
[f]CBCT information of one fraction was missing and is therefore not included.
[g]This patient received only one fraction in breath-hold.

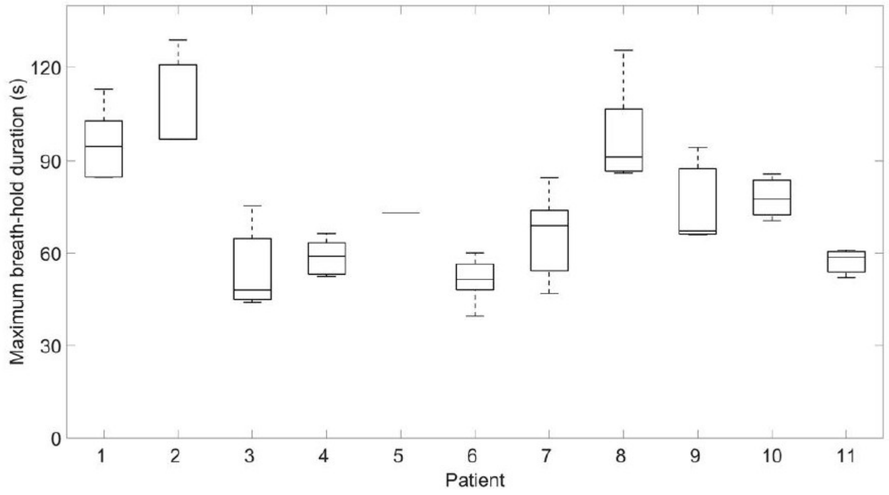

Figure 4. Boxplot showing for each patient the longest breath-hold per fraction during the treatment phase.

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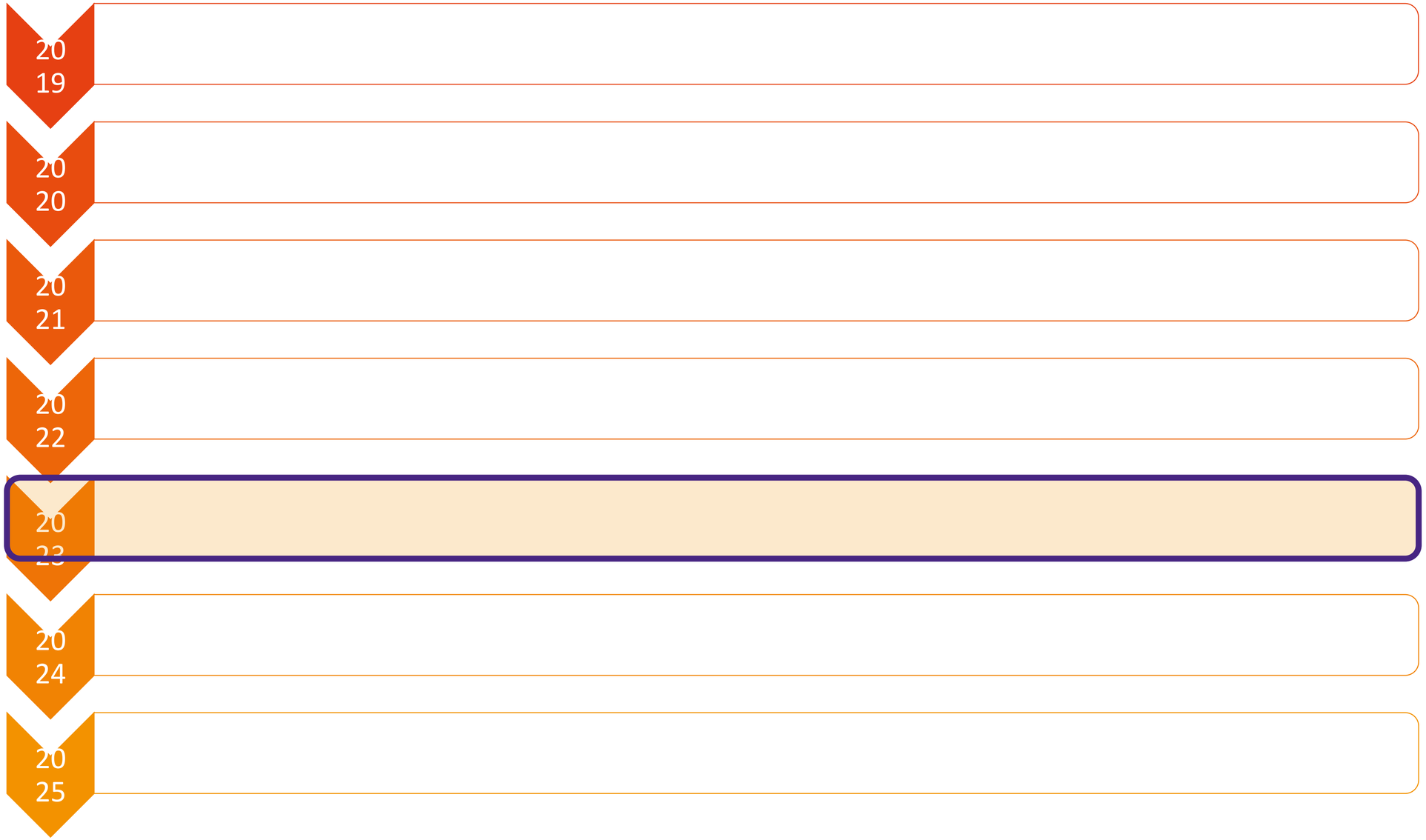
NHFT in radiotherapy under breath hold: Maastro experience



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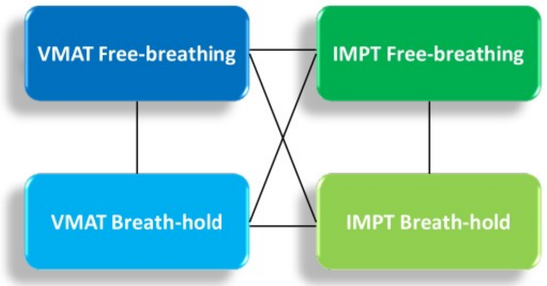
Lymphoma, protons

Background

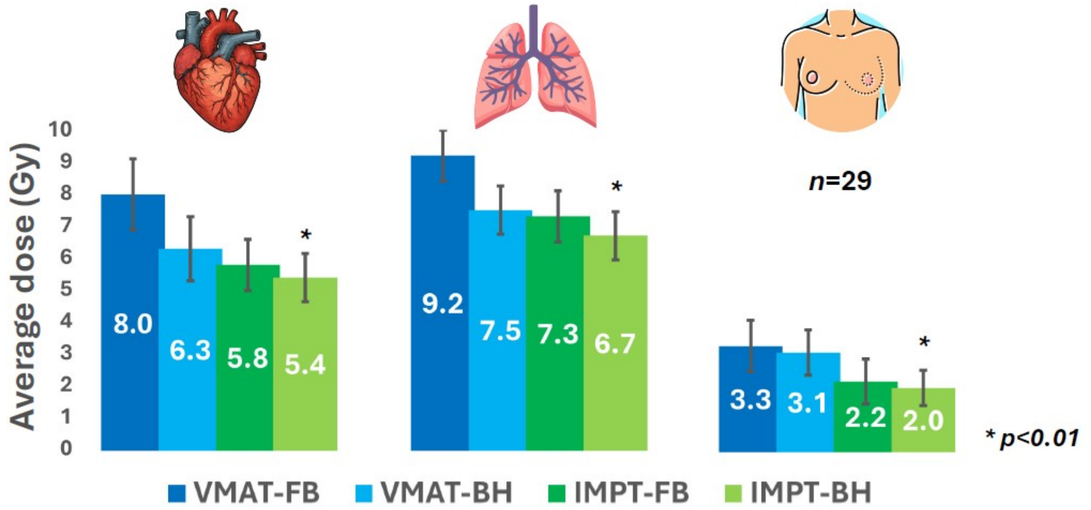
Comparative data is limited on **IMPT-BH** *vs* other techniques for **mediastinal lymphoma** (ML) patients.

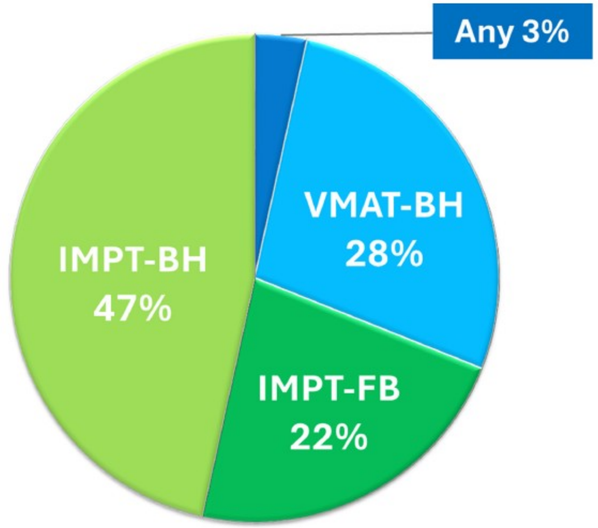
Material & Methods



- **58** ML patients
- **4 plans** per patient: clinical + in silico
- **DVH metrics**

Results





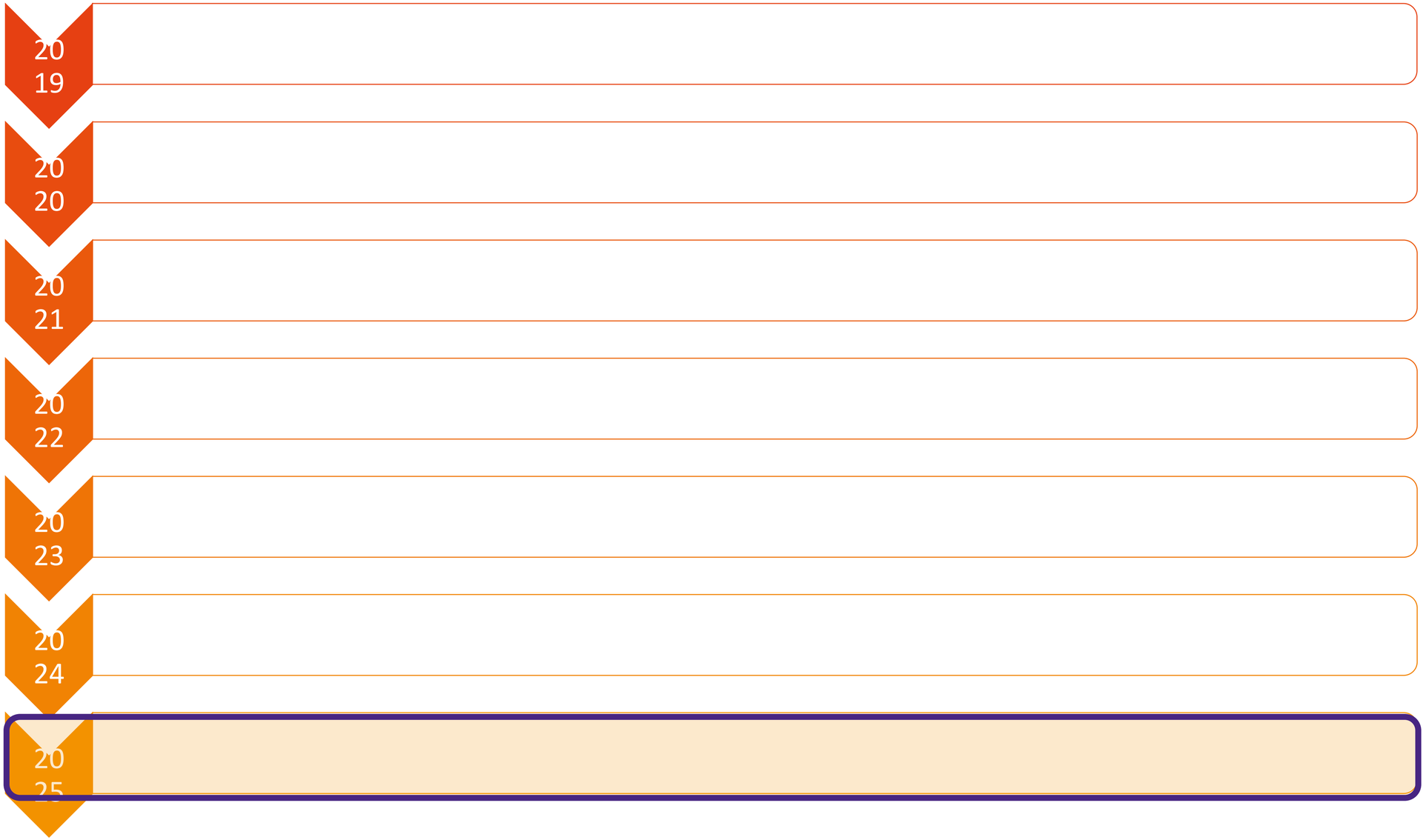
ΔDose ≥1 Gy = clinically relevant
Patients assigned to overall optimal technique

Conclusion

- **IMPT-BH reduced mean heart and lung doses *vs* other techniques ($p<0.01$)**
- **IMPT reduced average bilateral mean breast dose *vs* VMAT ($p<0.01$)**
- **IMPT was the most optimal technique for ≥69% of ML patients**

Ta et al. PhiRO submitted

NHFT in radiotherapy under breath hold: Maastro experience



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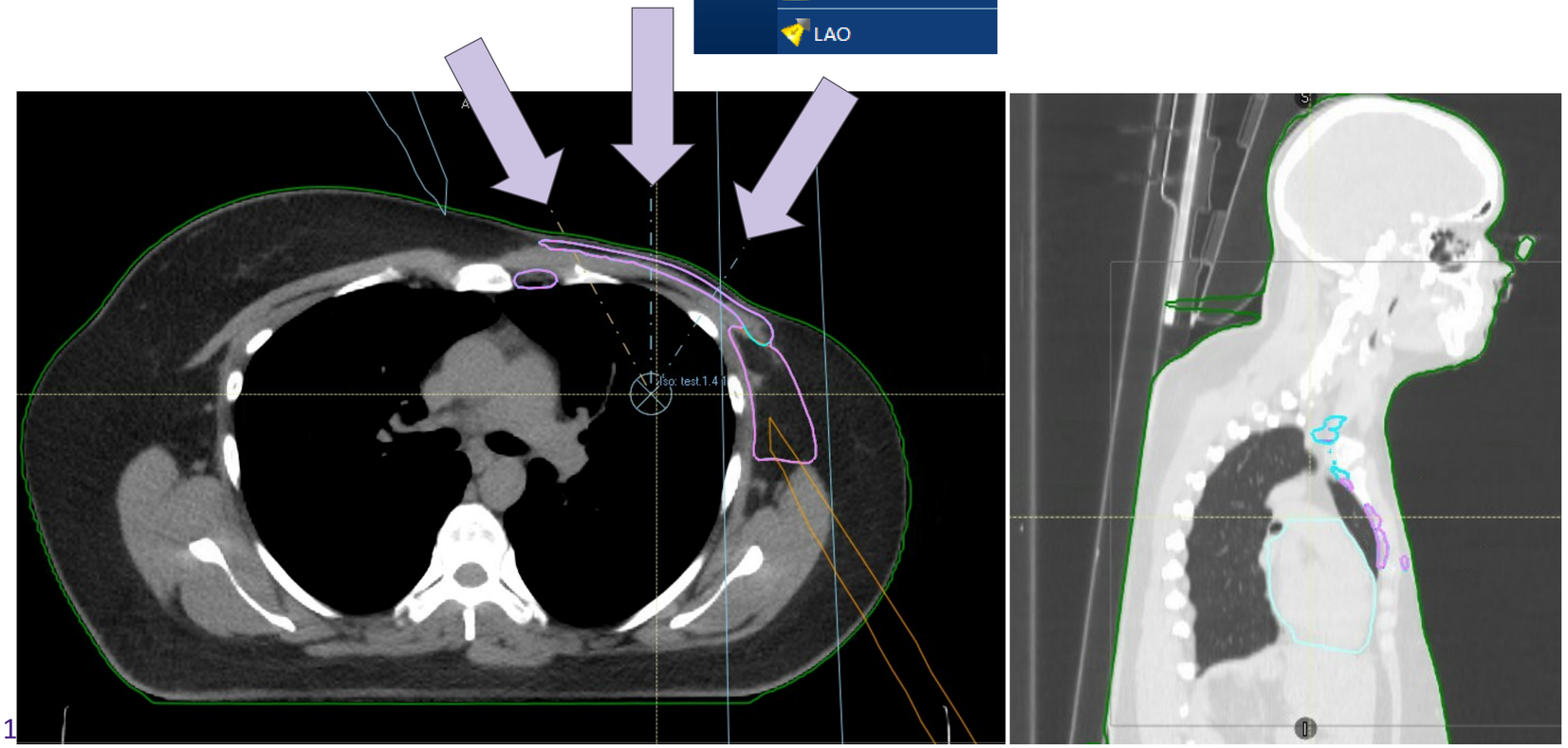
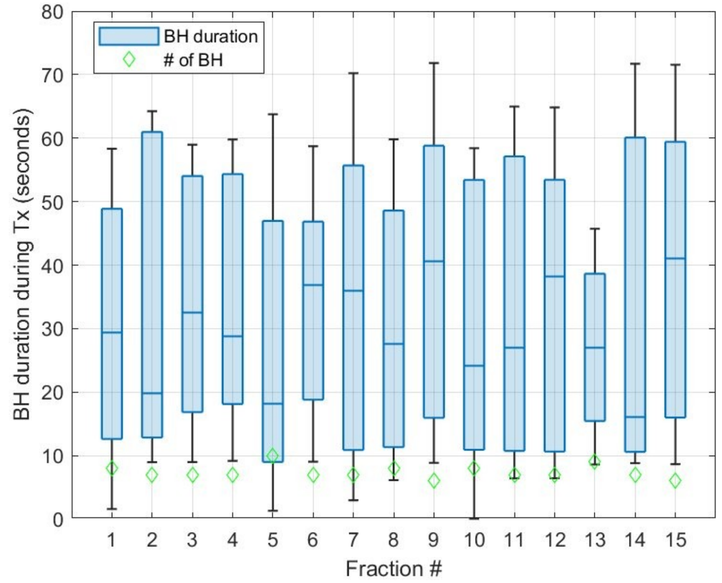
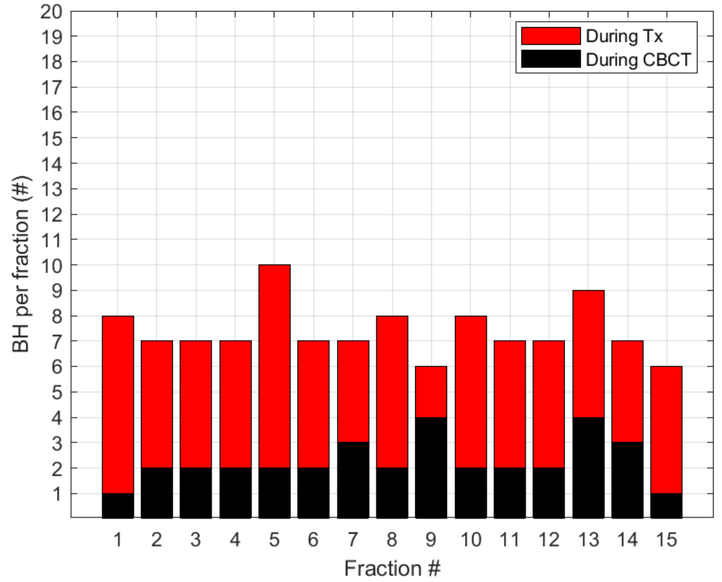
Breast cancer, protons

- 1st patient (March 2025): 5 beams (3 directions), 15 fx







Future work: ProThorac

KWF

Dose optimized positioning

PROTONS
OAR dose reduction in thoracic tumors

NIMV breath hold/ regularized breathing

Probabilistic optimization

umcg

HollandPTC
Protonen Therapie Centrum

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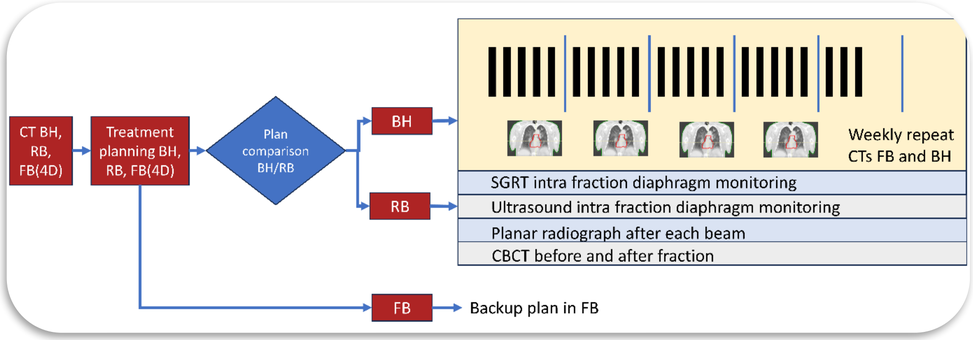
Work packages

- In silico study to define most preferable tumor sites
- Develop a method for NIMV breath hold or regularized breathing
- Volunteer study
- Patient feasibility trial



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Maastricht University

Maastricht UMC+

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