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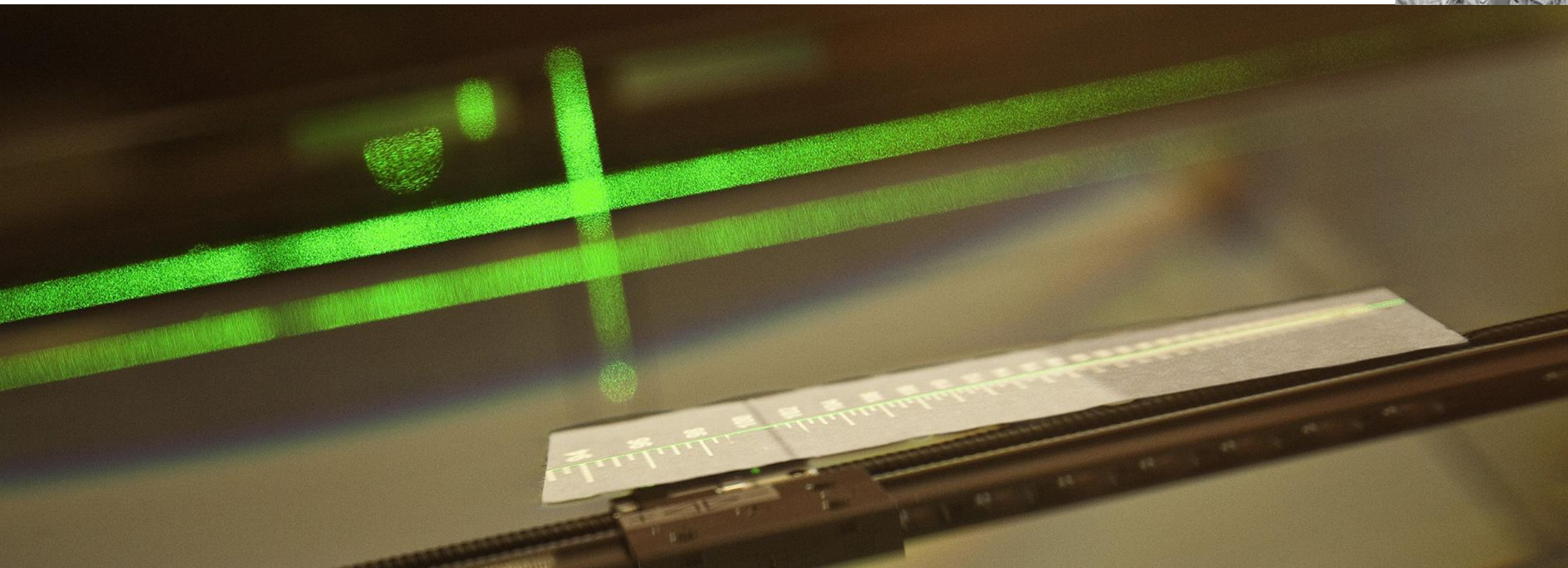
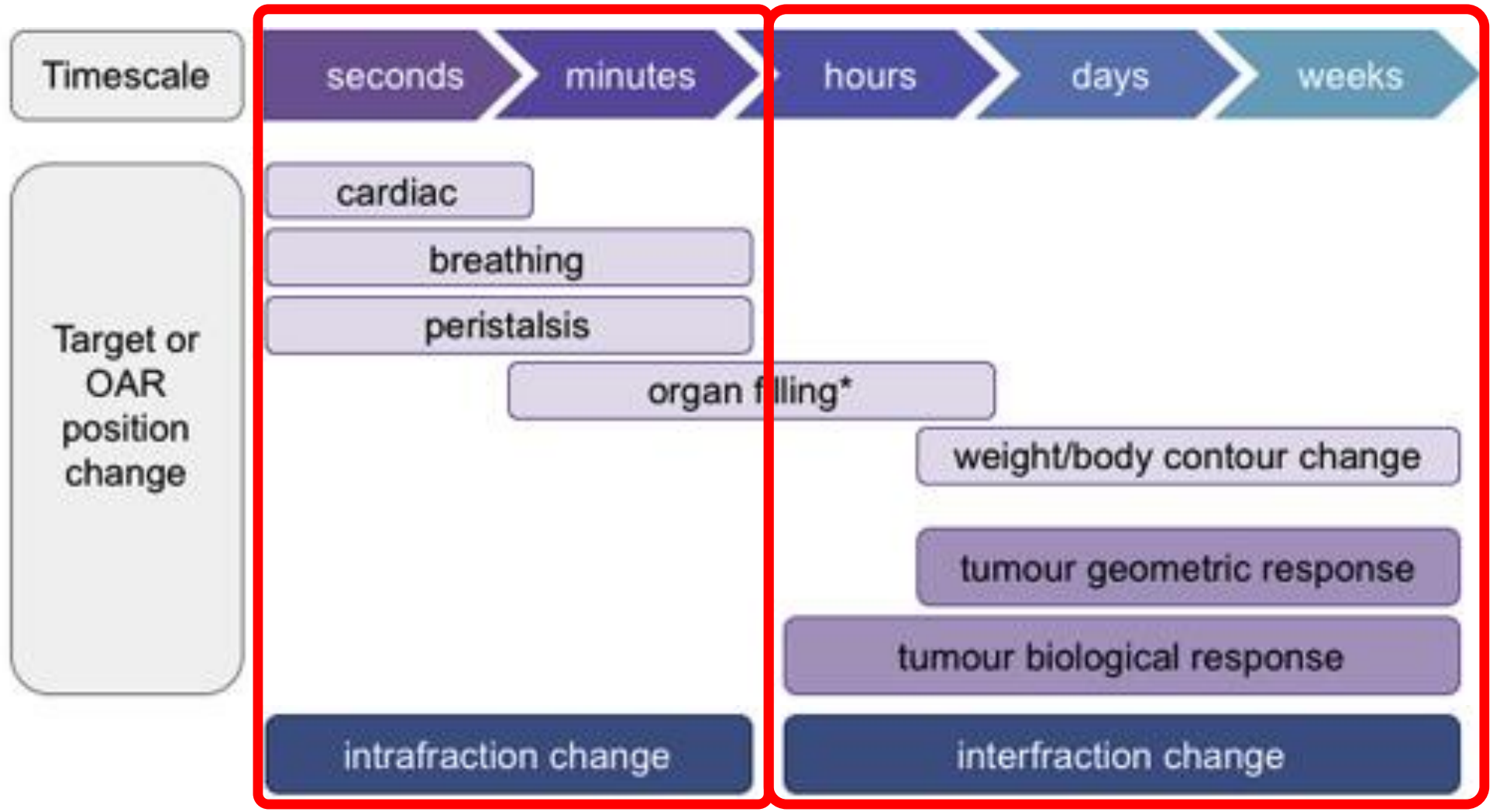
Division of Medical Radiation Physics

Real-time Intrafraction Motion Monitoring: Review of Available Methods

Jenny Bertholet, PhD



Anatomical changes in Radiotherapy

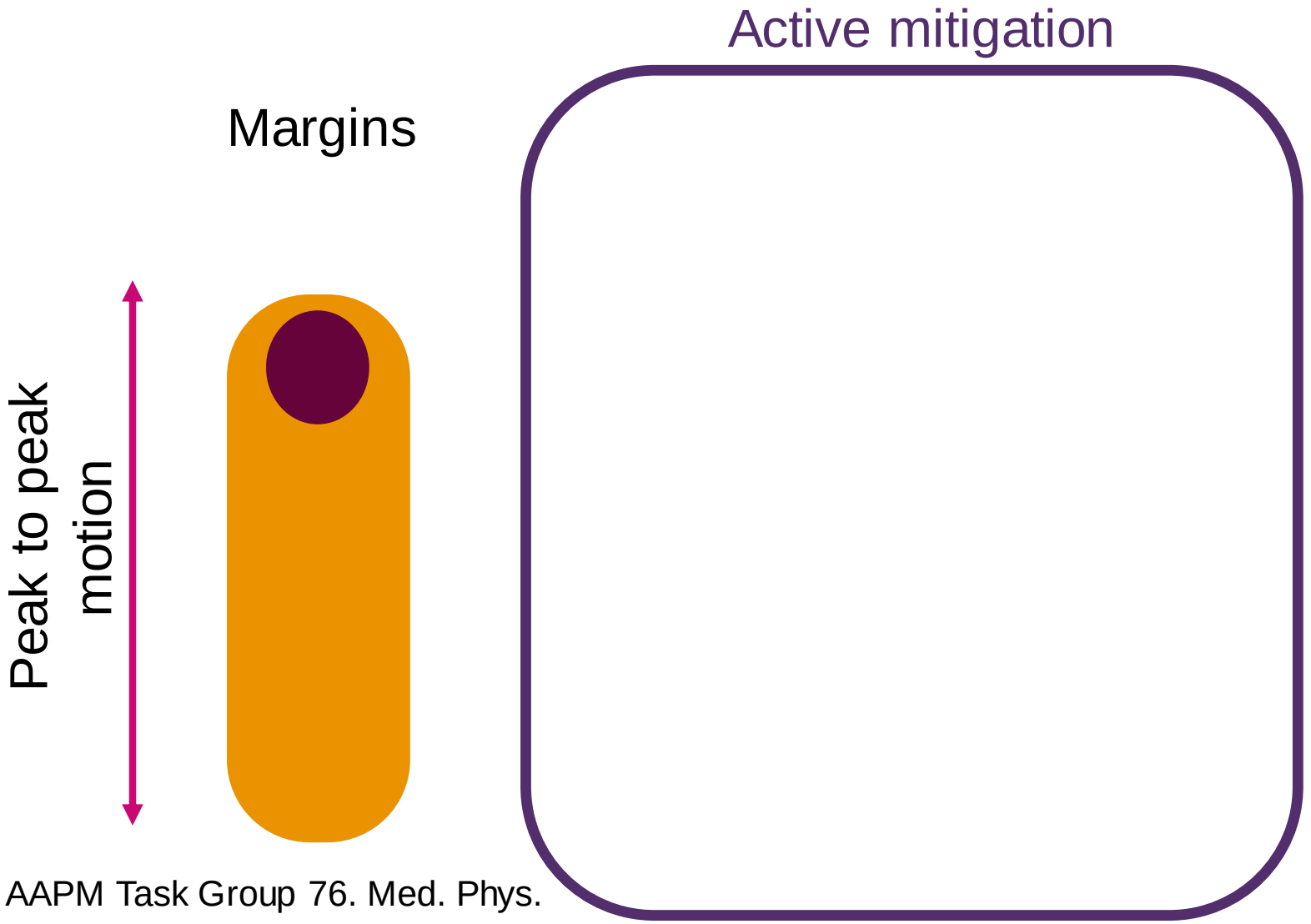


Hunt et al. Clin Onc 2018

Outline

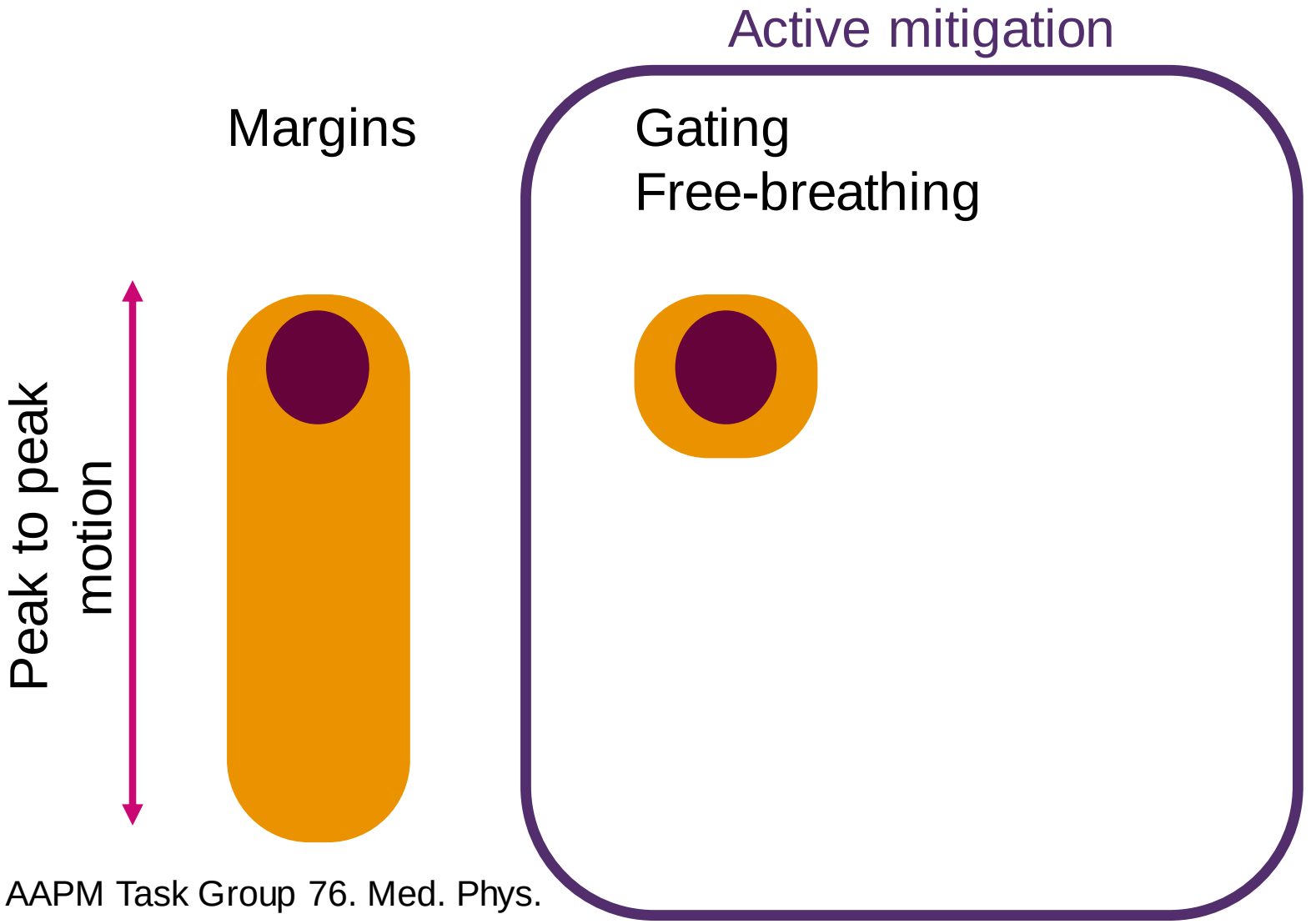
- Motion mitigation
- Monitoring methods
  - Dedicated monitoring/mitigation systems
  - Add-on monitoring equipment
  - Solutions on conventional linacs
- A look at current clinical practice

(Respiratory) motion management



Keall et al. 2006 AAPM Task Group 76. Med. Phys.

(Respiratory) motion management



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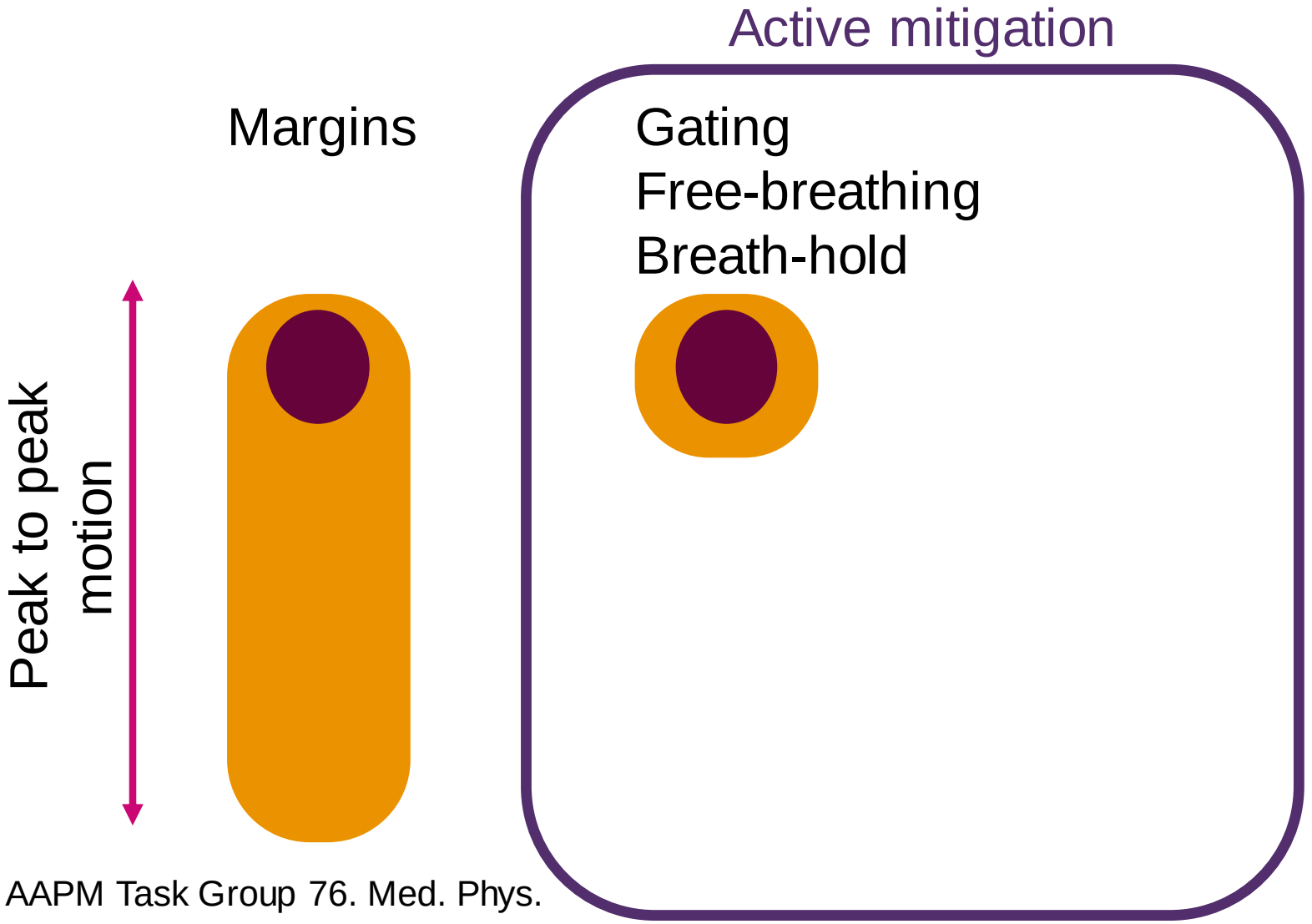

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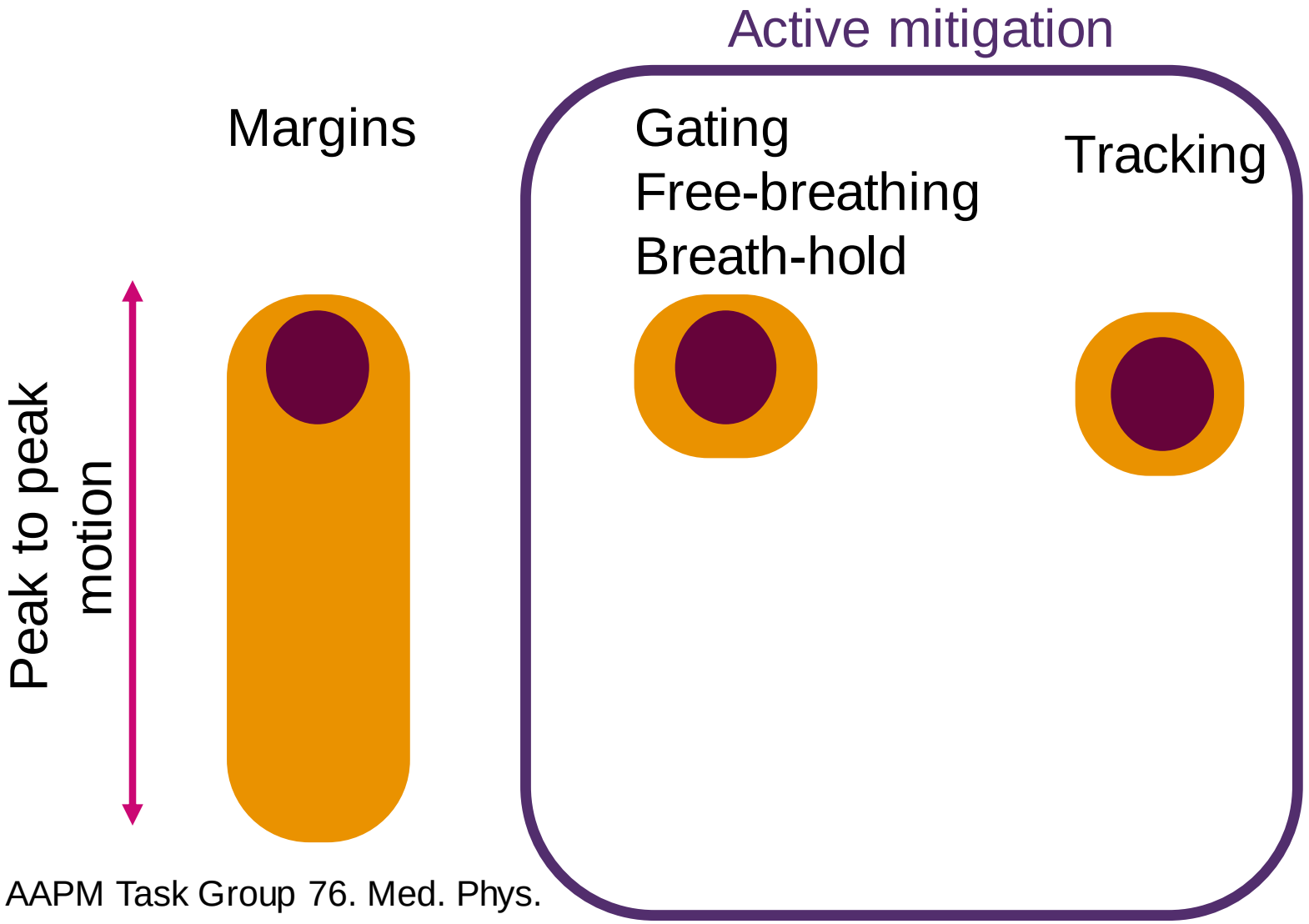

Keall et al. 2006 AAPM Task Group 76. Med. Phys.

(Respiratory) motion management

Active mitigation

Motion information also needed
to calculated margins!

A few definitions

- Monitoring: determination of target position as a function of time
- Gating: turning the beam on only when the target is in the reference position in free-breathing or breath-hold
- Tracking: active beam-target realignement[1]
- Real-time: measurement and processing of information **on the fly** with a frequency ≥ 2 Hz (i.e. time delay ≤ 0.5 s) (respiration)[2]

[1] using robotic, gimbal tracking, MLC or couch tracking
[2] AAPM TG76, 2006

Motion monitoring

- kV/MV imaging
- MR imaging
- US imaging (prostate)
- Surface imaging
- Electromagnetic transponders
- Breathing surrogates
- Hybrid methods

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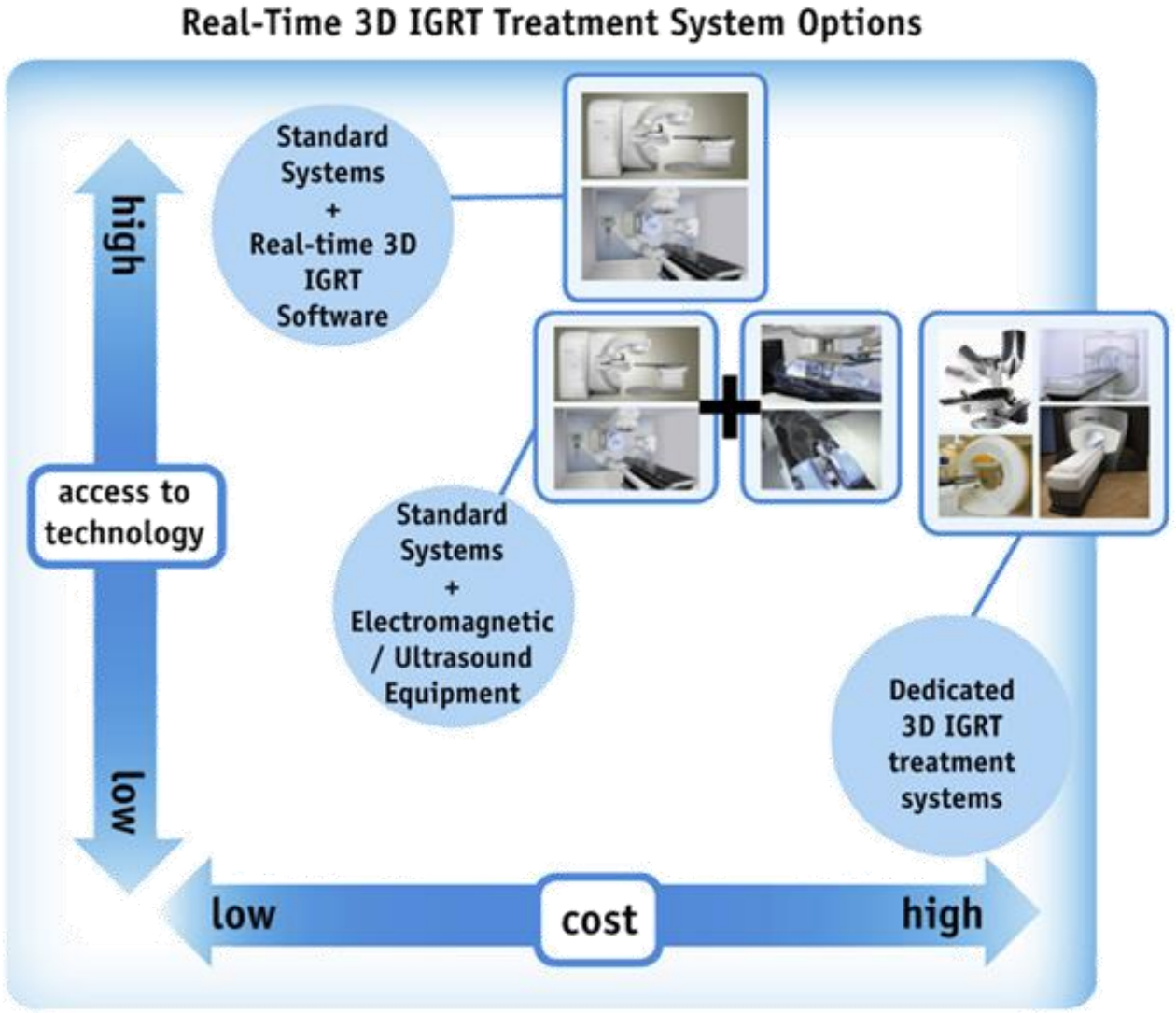
Physics in Medicine & Biology

IPEM Institute of Physics and Engineering in Medicine

TOPICAL REVIEW

Real-time intrafraction motion monitoring in external beam radiotherapy

Jenny Bertholet[1,7], Antje Knopf[2], Björn Eiben[3], Jamie McClelland[3], Alexander Grimwood[1], Emma Harris[4], Martin Menten[1], Per Poulsen[4], Doan Trang Nguyen[5,6], Paul Keall[5] and Uwe Oelfke[1]



Keall et al. IJROBP 102(4) 2018

Dedicated monitoring/mitigation systems

a)

b)

c)

Stereoscopic kV imaging (RTRT)

- Late 1990s in Japan (Shirato et al. IJROBP 2000)
- Two perpendicular images to triangulate the position of spherical marker (30 Hz)

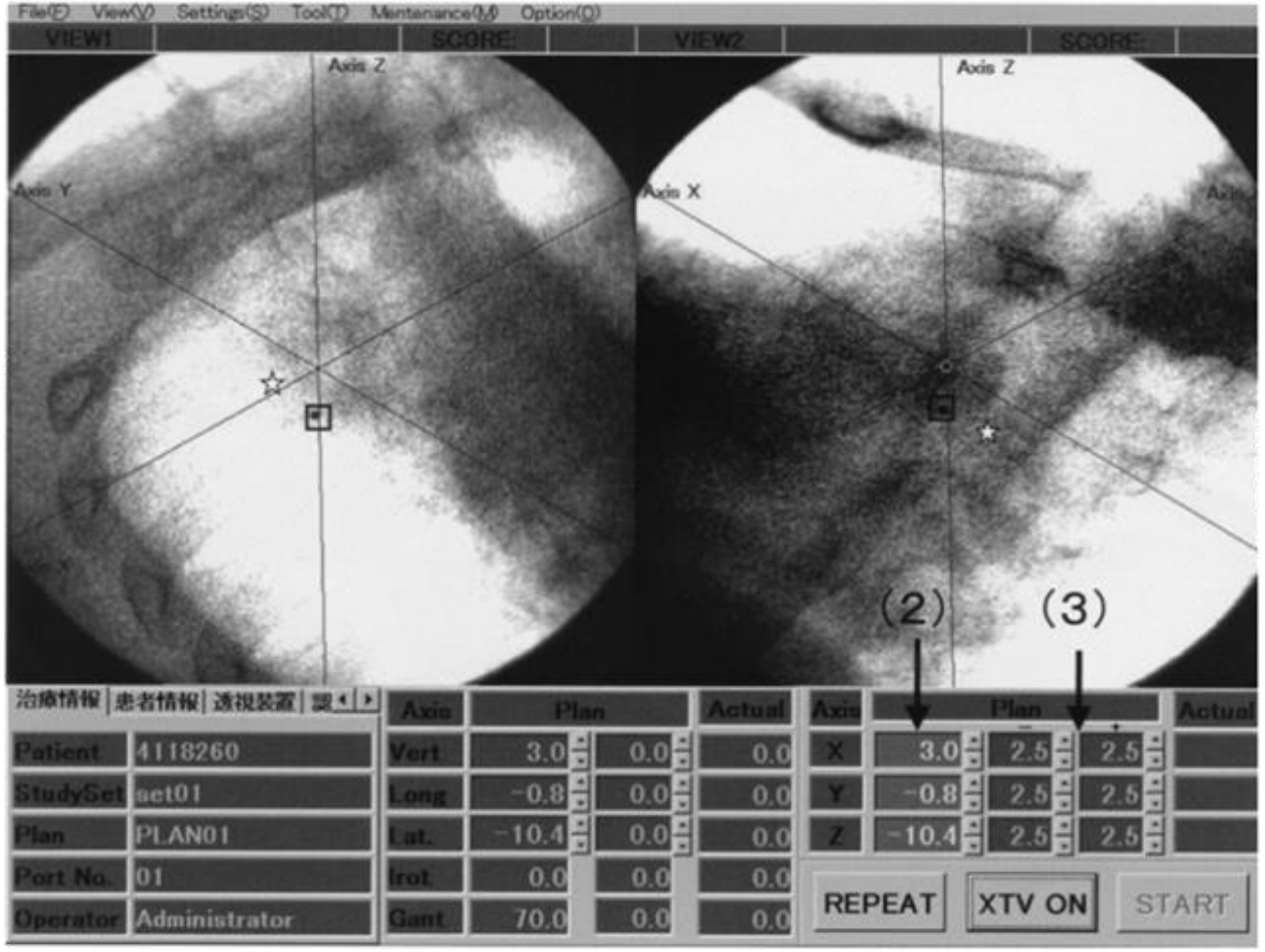
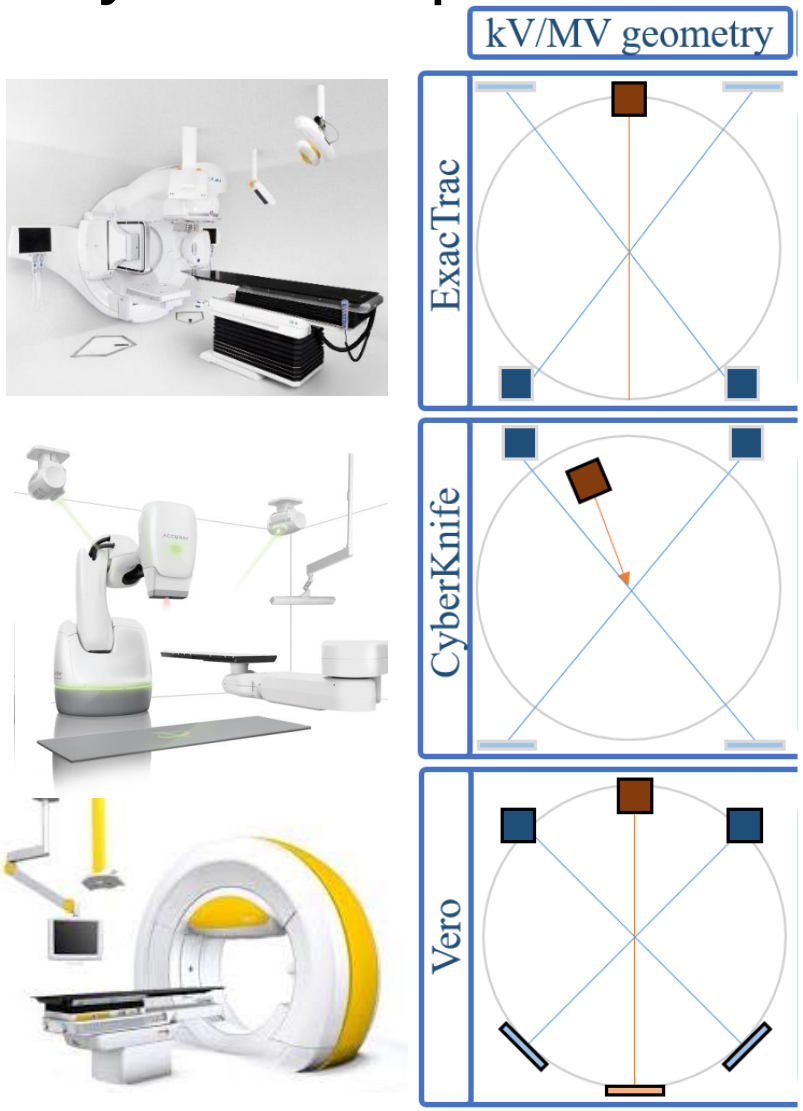


Fig. 2. Display on the monitor of the real-time tumor-tracking system in a patient with lung cancer. (1) A square centered on the marker and its planned position (star) superimposed on the X-ray image; (2) planned position in mm; (3) allowed displacement in mm.

Hybrid kV/optical monitoring



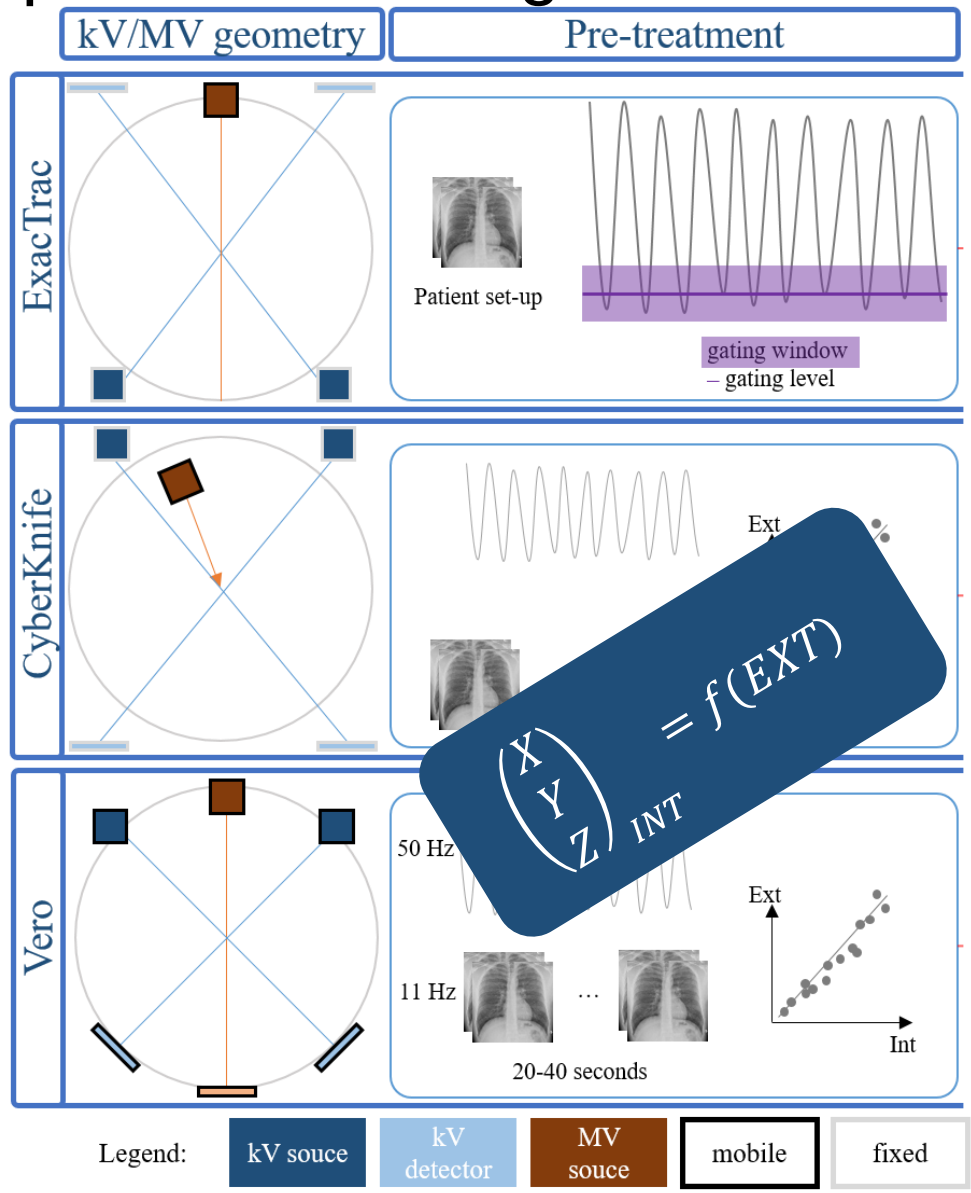
Mitigation

Gating / repositioning

Robotic tracking

Gimbal tracking

Hybrid kV/optical monitoring



Mitigation

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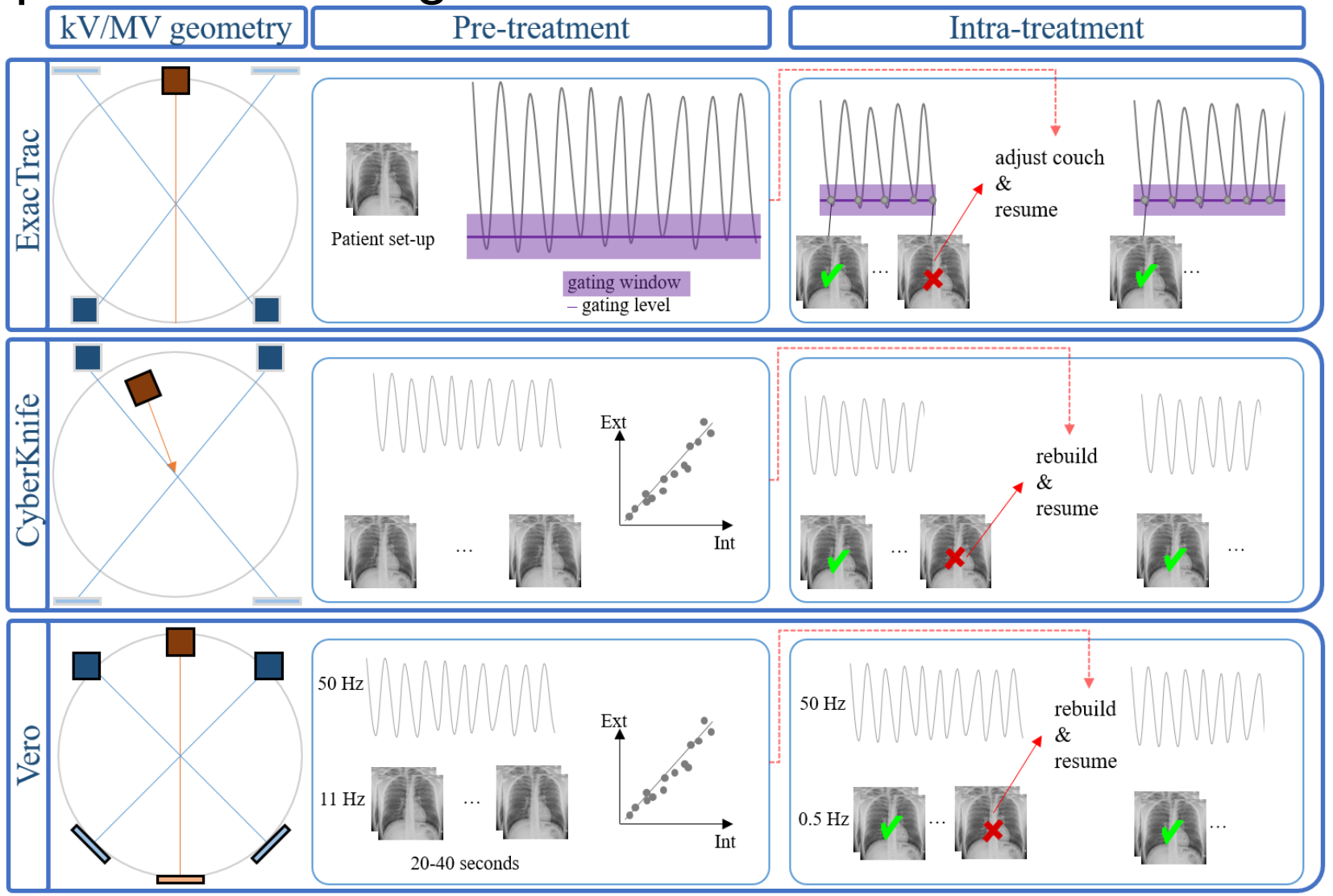


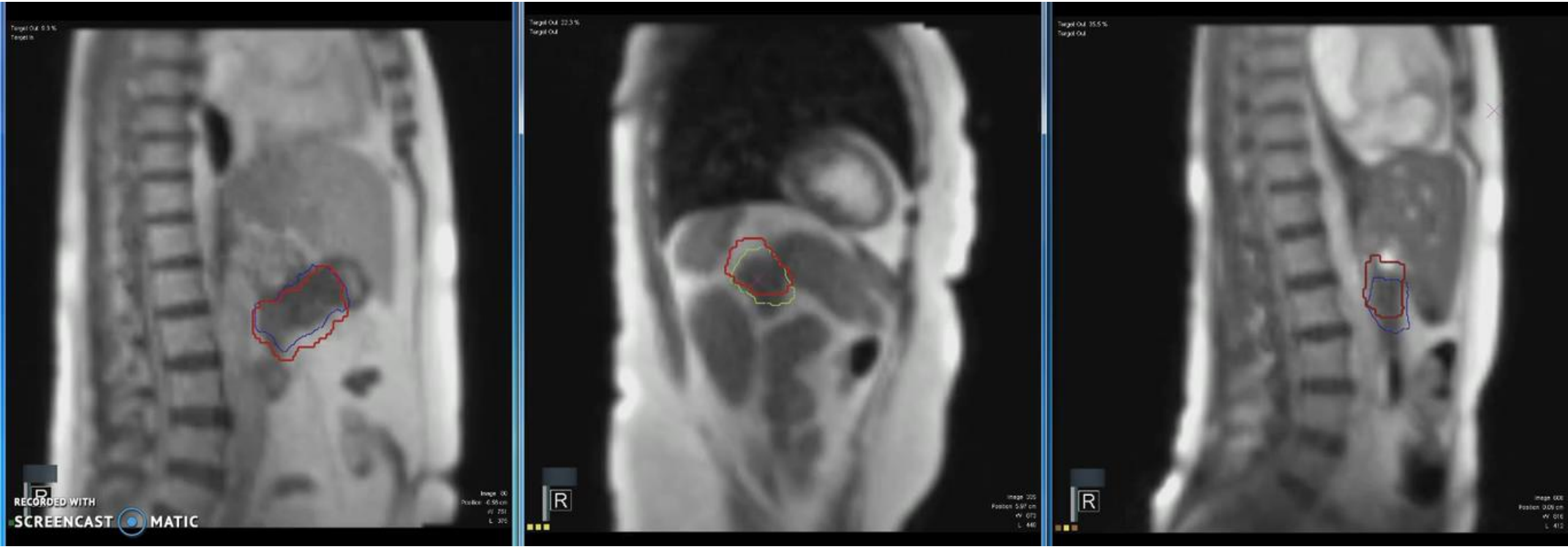
Mitigation

Gating / repositioning

Robotic tracking

Gimbal tracking

MR linac



Video Feedback System for MR-guided Radiotherapy Using Breath-hold Gated Treatment Delivery in Pancreatic Cancer Patients

This video shows three examples of what patients actually see during their treatment. They observe in real-time the gating target (in blue or green) within the gating boundary (in red) on a sagittal tracking image derived from the MRIdian console.

Tetar et al. Cureus 10(2)

Dedicated monitoring/mitigation systems

PROS

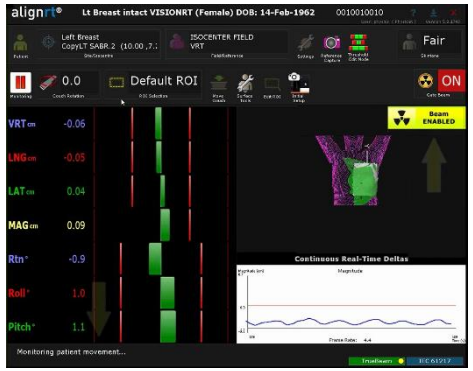
- Whole package: imaging, mitigation, recording…
- Tailored solution
- MR: no ionizing radiation

CONS

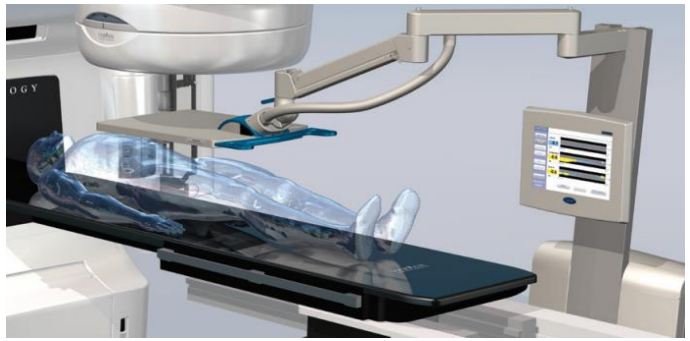
- Low availability
- High cost
- Hybrid monitoring only works for respiratory motion
- Markers (CyberKnife, Vero, RTRT, exacTrac)
- Imaging dose (RTRT)
- MR currently limited to 2D

Add-on monitoring equipment

a)



b)



c)

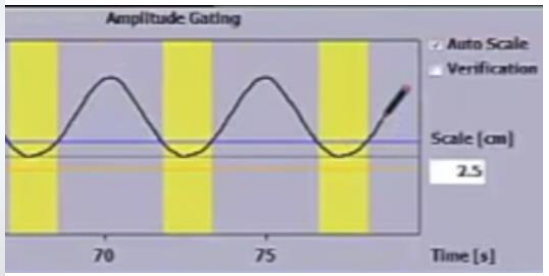
d)

Respiratory surrogates (conventional systems / add-on)

Proposed in 1996 for gating (Kubo and Hill, PMB 1996)

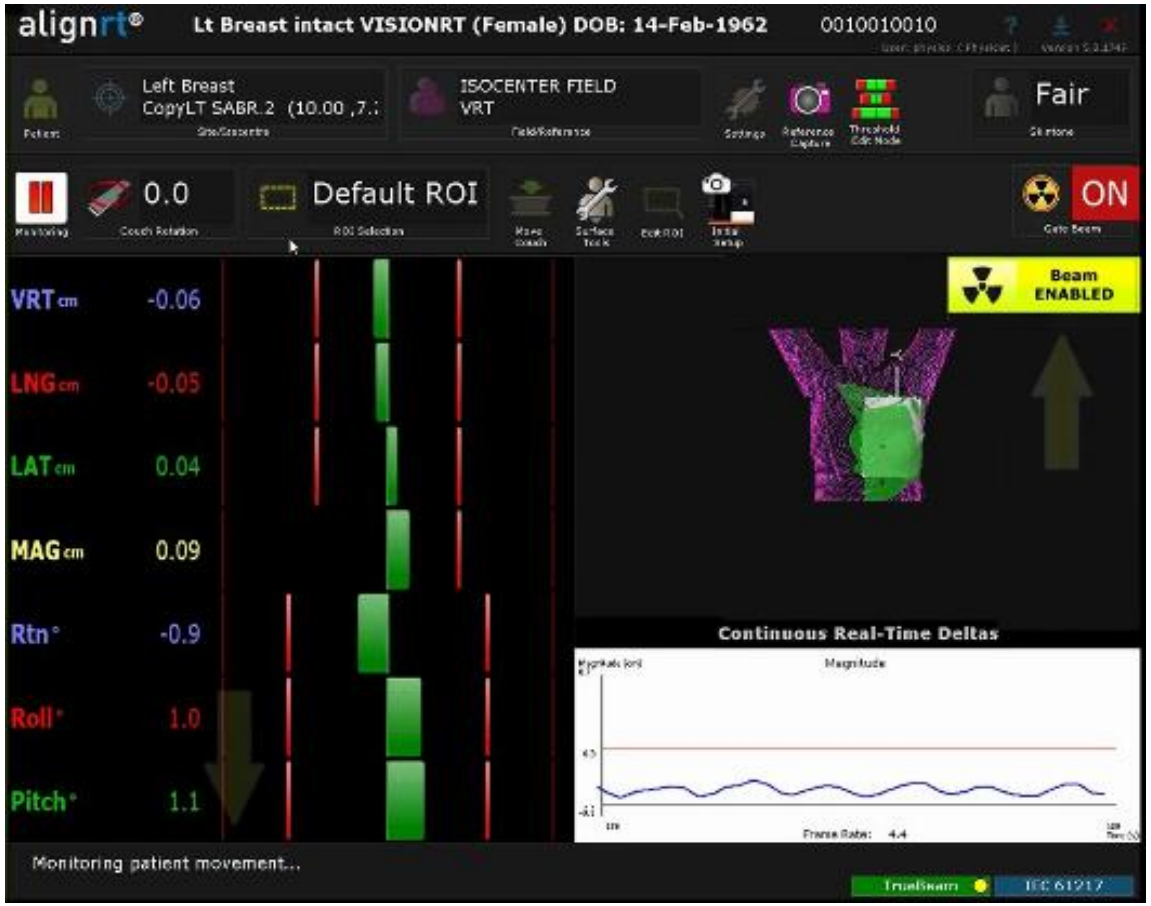
Optical marker on abdomen, lung volume change or abdomen perimeter changes

- Recommended to combine with intra-fraction imaging (e.g. auto-beam hold Vinogradskiy, IJROBP 2018)
- Spirometry can be used to enforce breath-hold



Surface monitoring

- Projects a light pattern on the patient
- Can detect 6D motion
- Can automatically trigger beam-hold
- Used mainly for cranial radiosurgery but also chest wall (direct target monitoring!), breast and breath-hold monitoring

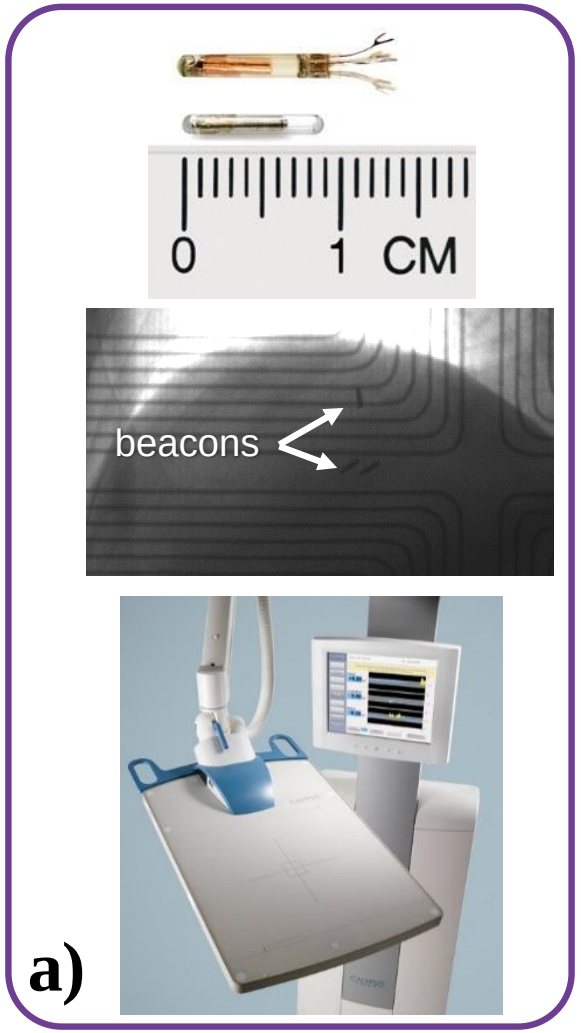


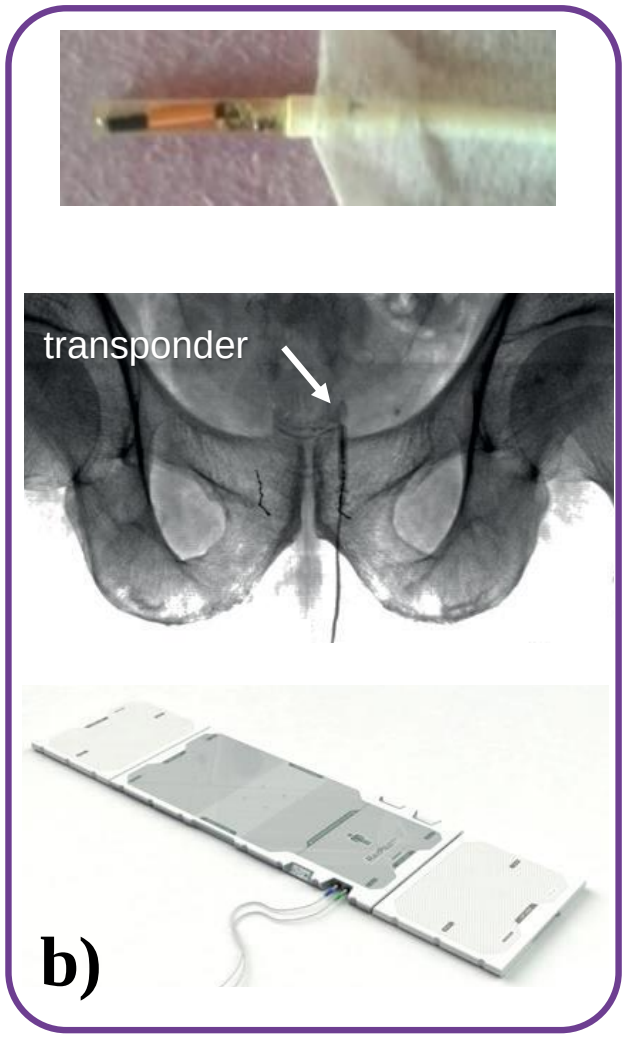
Electromagnetic transponders

a) Calypso (Varian): implantable beacons, any site

b) Raypilot: wired transmitters for prostate

- 3D internal monitoring
- No ionizing radiation





Ultrasound imaging (Clarity, Elekta)

- Currently only for prostate and prostate bed (direct target monitoring!)

- O'Shea et al. PMB, 61(8), 2016
- Grimwood et al. IJROBP 102(4) 2018

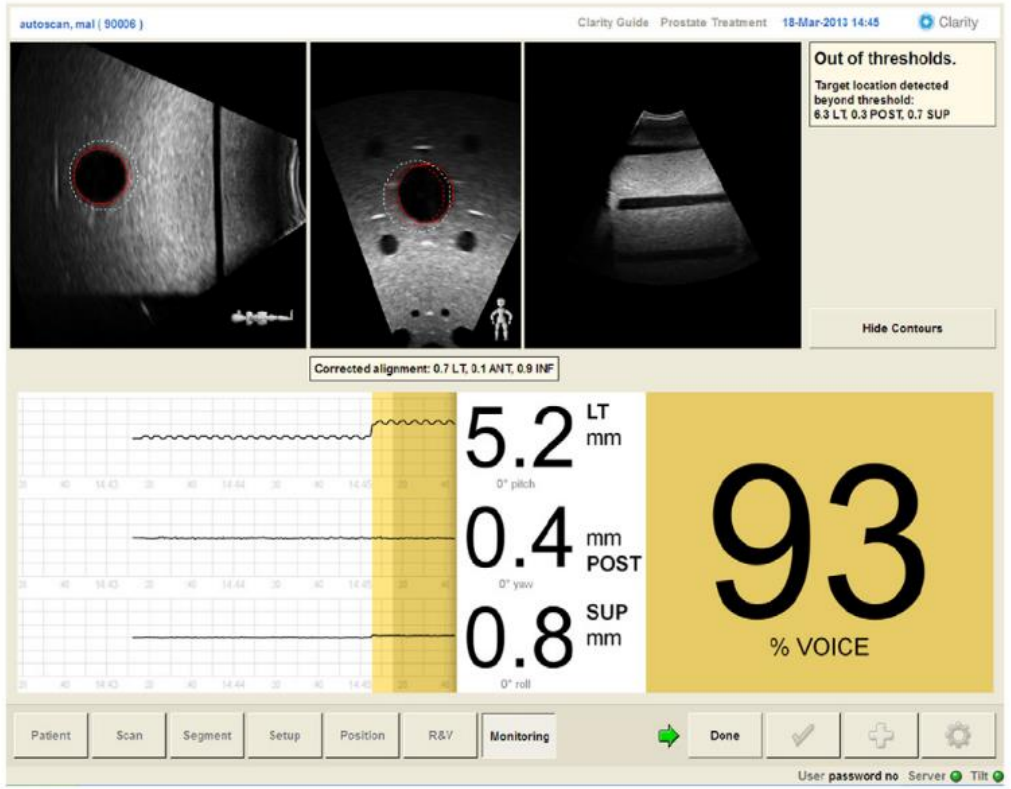
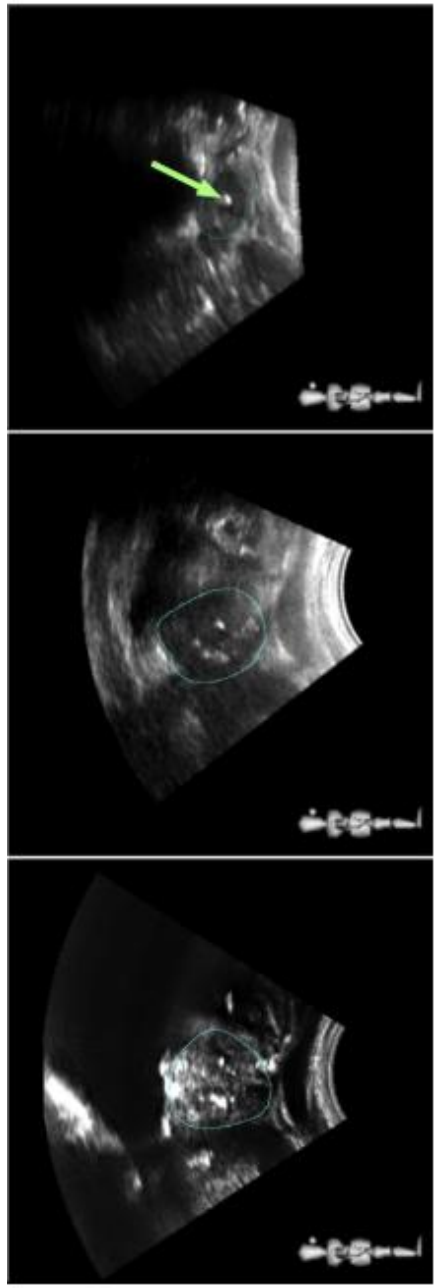


Figure 5. The Clarity Autoscan™ system with the monitoring interface showing a phantom used to simulate intra-fraction motion imaging. The dotted red contour is the reference target (reference planning volume, RPV). The solid red line indicates the current target contour. The dotted white line indicates the location of the VRV (VOICE reference volume). The % VOICE (volume of interest coverage estimate) is the percentage of target volume covered by the VRV contour (93% in this example). Courtesy of Martin Lachaine (Elekta Ltd).



Add-on monitoring equipment

PROS

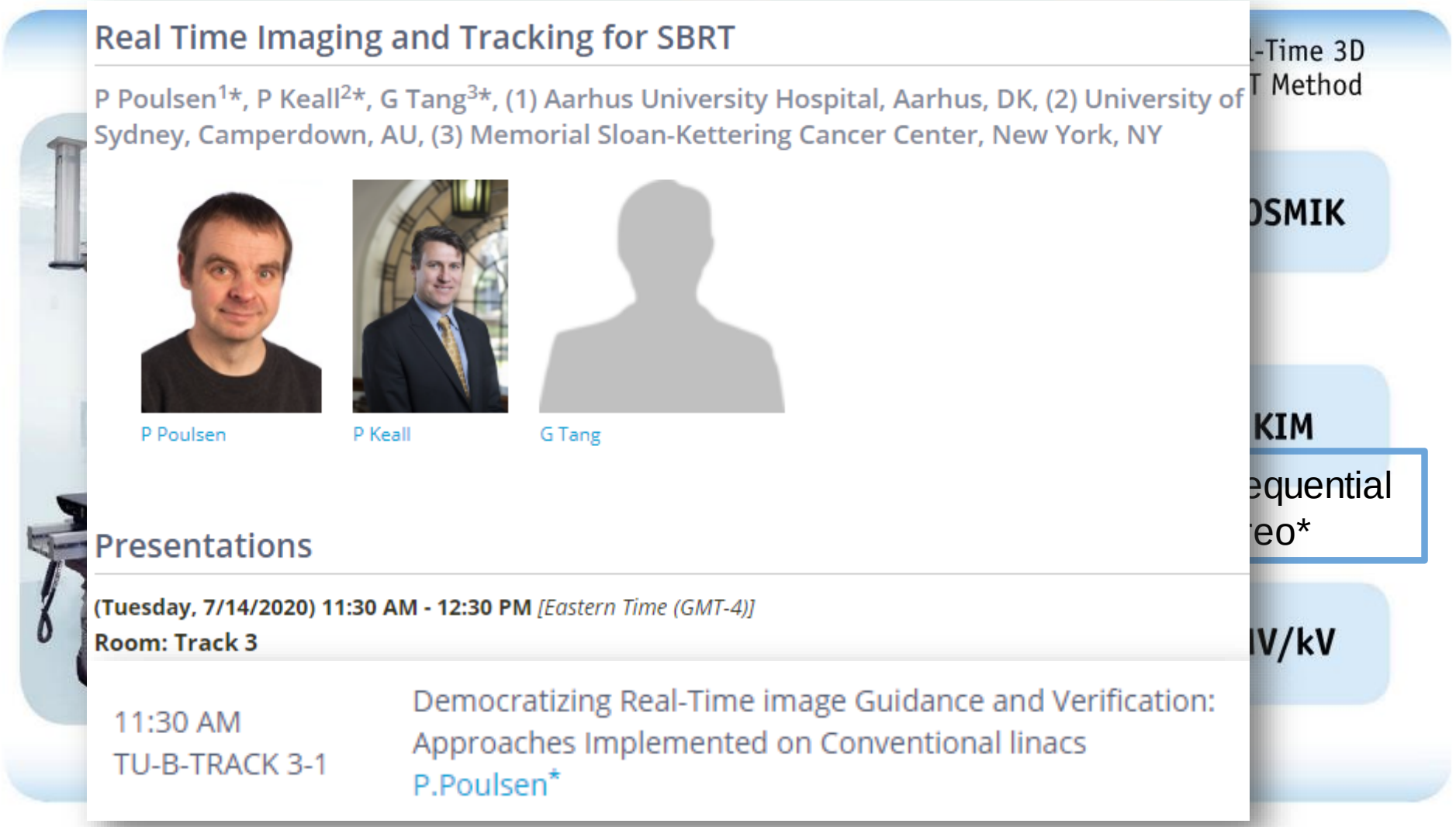
- Generally lower cost than dedicated machines
- Use on conventional linac
- Some are portable
- No ionizing radiation!

CONS

- Compatibility with treatment machine
- Extra QA
- Tends to be highly site specific
- Beacon implantation (Calypso, RayPilot)
- Surrogacy quality (respiratory surrogates / surface imaging)

Solutions on conventional linacs

- Implemented clinically
- But not (yet) commercially available
- Keall et al. IJROBP 102(4) 2018
- *Hazelaar et al. 2018 PMB 63(11), IJROBP 101(5), Radiother. Oncol. 129(2)



Solutions on conventional linacs

PROS

- High availability
- Software-based so low cost
- Integrated with the machine

CONS

- Not commercially available yet
- Marker implantation required (most sites)

Summary : intrafraction monitoring

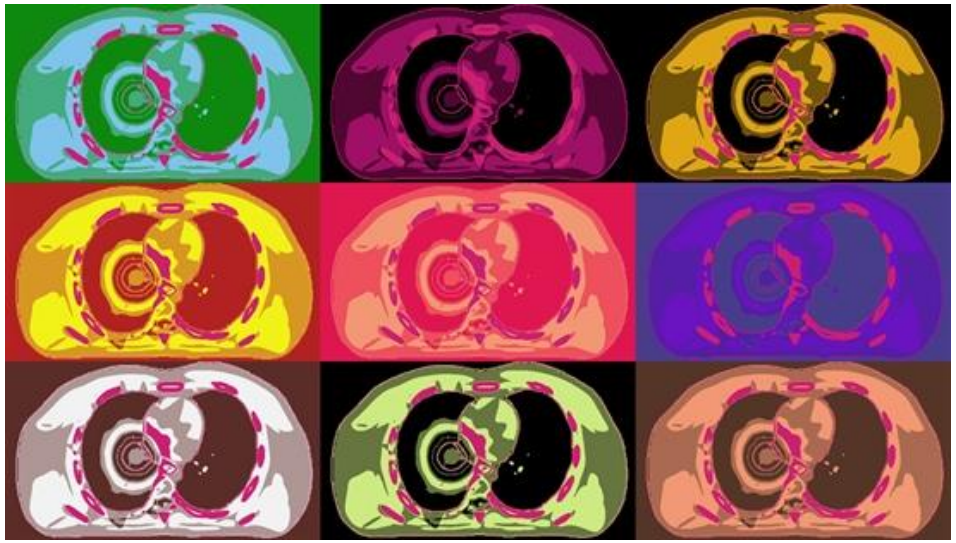
Many methods are available:

- No one size fits all solution
- Depends on the treatment site and the mitigation strategy
- Depends on the hospital's priorities, capacity, staff, training, …
- At the moment, additional equipment is required
- Consider also: QA, validation, … (Bertholet et al, PMB 2019 and ref. herein)

What about standard practice?

PHYSICS

Pattern Of Practice for Adaptive and Real Time Radiation Therapy (POP-ART RT)



ESTRO

Anastasi et al. Radiother. Oncol. Accepted

- Institutional practice for real-time respiratory motion management (RRMM)
- Wishes for increase use/change of technique or new implementation
- Barriers to increased use or implementation

- 200 centres from 41 countries responded

Main results – Patterns of Practice

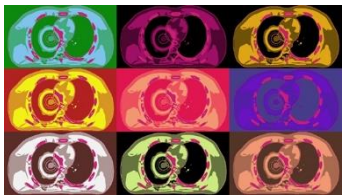
Breast

- Evidence of clinical benefit in inspiration breath-hold
- 56% of respondents used RRMM
- Monitoring with respiratory surrogates / surface imaging

Lung / Liver / Pancreas

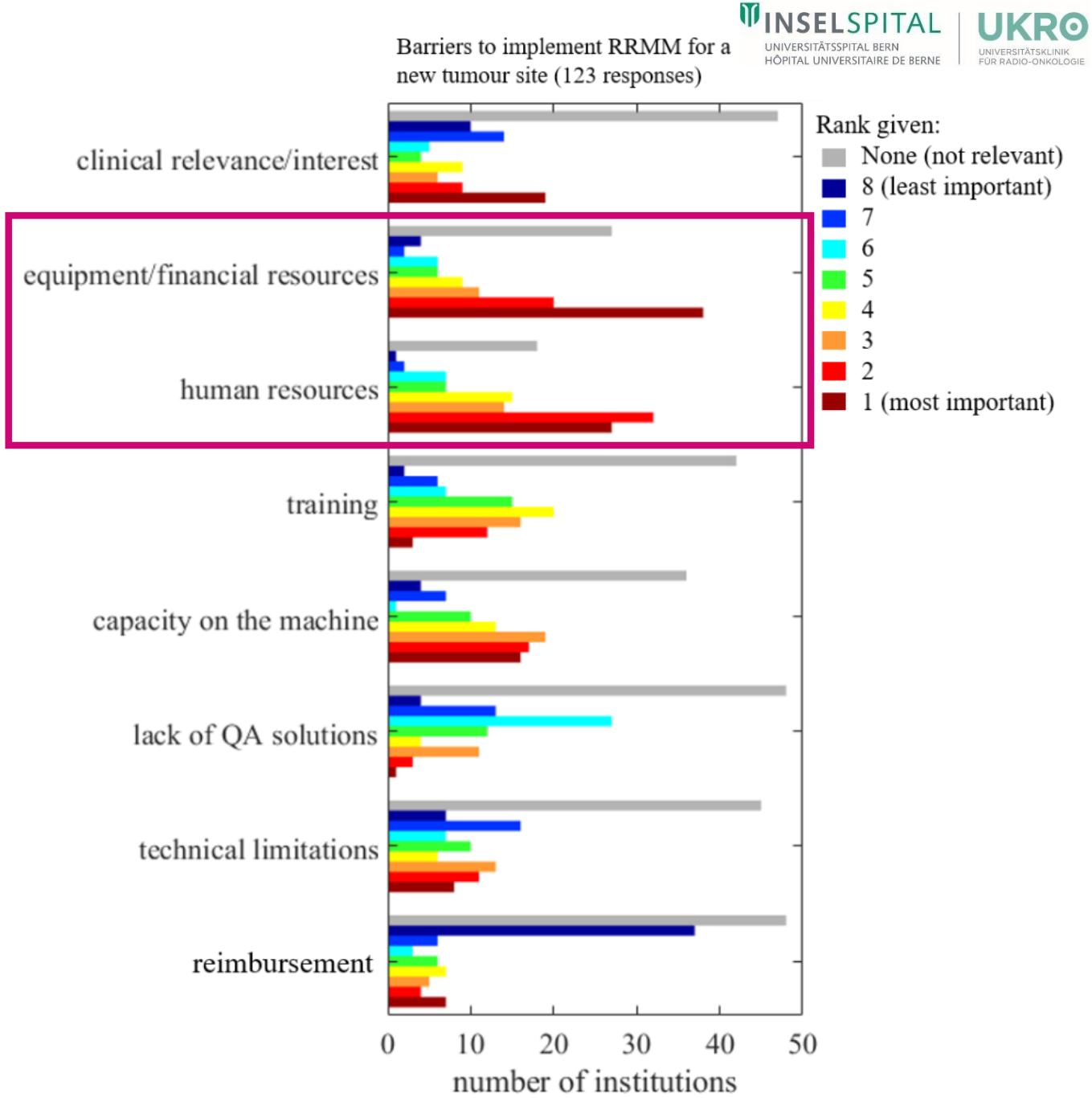
- Need for higher accuracy in SBRT
- 32% / 22% / 15% of respondents used gating
- Monitoring with breathing surrogate

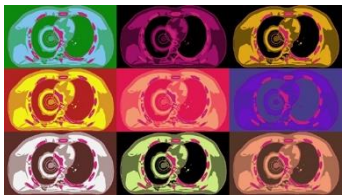
  (4 institutions with MR)
- 10% / 8% / 5% used tracking (Cyberknife except one)



Wishes for implementation

- 40% of respondents had plans to implement RRMM for a new treatment site in the next 2 years

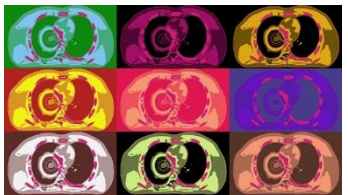




Summary: RRMM in clinical practice

- Mostly gating with respiratory surrogate
- Large interest in implementing RRMM (breast, lung)
- Limited by material/human resources

It is a fast evolving field with promising development…



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ESTRO
The AMS team

Thank you for your attention!