

# Clinical Experience with Gold Anchor in Proton Therapy

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# Disclosure

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Nothing to Disclose

# Content

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01

## Foundations

*基础*

- IGRT context
- Why fiducials?
- What is Gold Anchor?

02

## Photon / Proton experience

*质子经验*

Based on prostate  
SBRT and prostate /  
liver / lung IMPT  
patients

03

## Proton RGPT

*质子门控*

Workflow from marker  
insertion to treatment —  
prostate / liver / lung

04

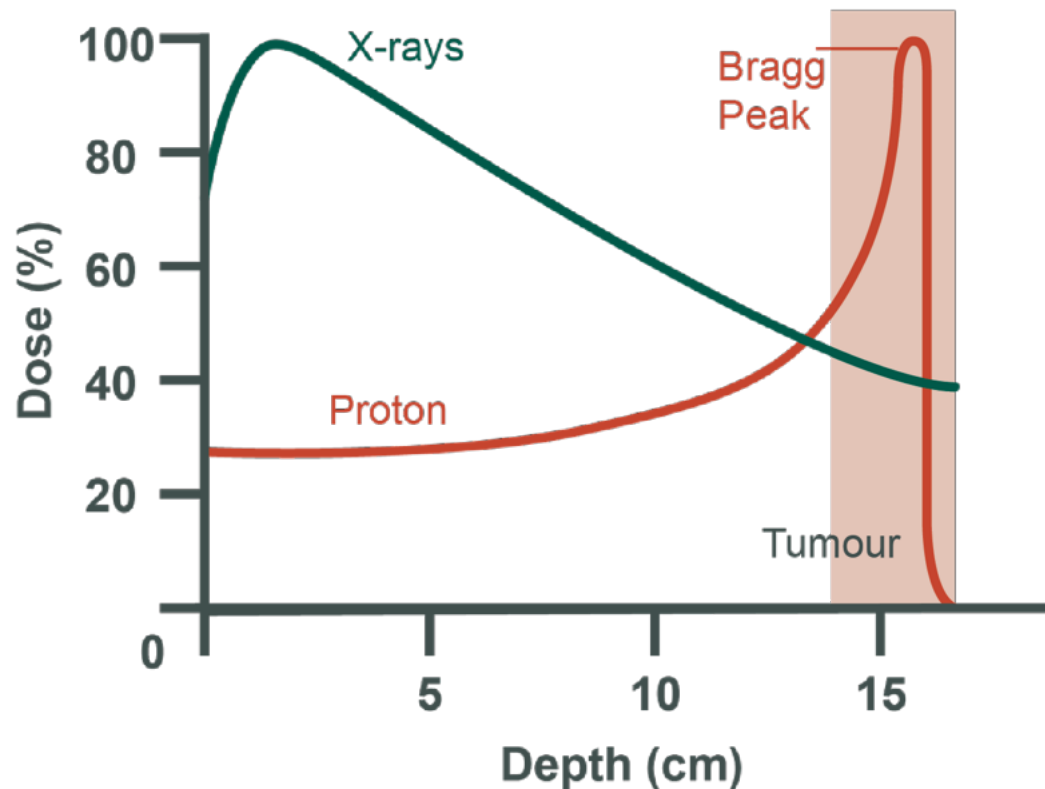
## Lessons & Takeaways

*经验总结*

What we learned · what  
we'd recommend to  
new proton centres

# Why precision matters more for proton therapy?

## 为什么质子治疗对精度要求更高?



### X-rays 光子

- ▶ Gradual dose fall-off
- ▶ Exit dose to normal tissue; conformity from many beam angles
- ▶ Sub-mm setup helps, but is not catastrophic

### Protons 质子

- ▶ Sharp distal fall-off — 1–2 mm shift can drop CTV coverage
- ▶ Range uncertainty interacts with anatomy and motion
- ▶ Sub-mm precision is a clinical requirement

# What is a fiducial marker?

## DEFINITION · 定义

*A small radio-opaque object implanted in or near the tumour, used as a surrogate of target position for imaging-based guidance.*

### **Pre-treatment alignment** 治疗前对位

- kV/CBCT match to fiducial structure

### **Intra-fraction monitoring** 治疗中监控

- Triggered imaging, gating, tracking

### **Inter-fraction trending** 分次间趋势

- Detect organ deformation / migration

*In proton therapy, the marker also enables real-time gating (RGPT 实时门控质子治疗) — beam ON only when target is in correct position.*

# Why we chose Gold Anchor™?

## Flexible thin wire

柔性细丝

0.28 – 0.40 mm diameter

## Anchors against migration

防止移位

Coiled shape grips tissue — reduces post-implant drift

## Small enough for fine needles

兼容细针

Implanted through 22G / 25G needle — well tolerated, low haemorrhage risk.

## Folds into a ball / line

球形或线形

Urologist controls the shape during deployment; ball-form anchors mechanically.

## Multiple sizes available

多种规格

0.28×10, 0.28×20, 0.40×10, 0.40×20 mm — dependent on physics recommendation, center specific

## Good visibility

良好可视性

Gold = high Z → strong CT, kV and CBCT contrast even at small volume.

# Shape matters

## RIGID CYLINDRICAL SEED · 传统圆柱型金粒



≈ 0.4–1.0 mm diameter · smooth surface

- ▶ Higher migration rate
- ▶ Smooth, rigid body — slides along needle track
- ▶ Bleeding channel can carry seed back out
- ▶ Larger needle gauge required (typically 18–20G)

## GOLD ANCHOR™ · 锚形金标



0.28–0.40 mm wire · folds into ball/line shape on deployment

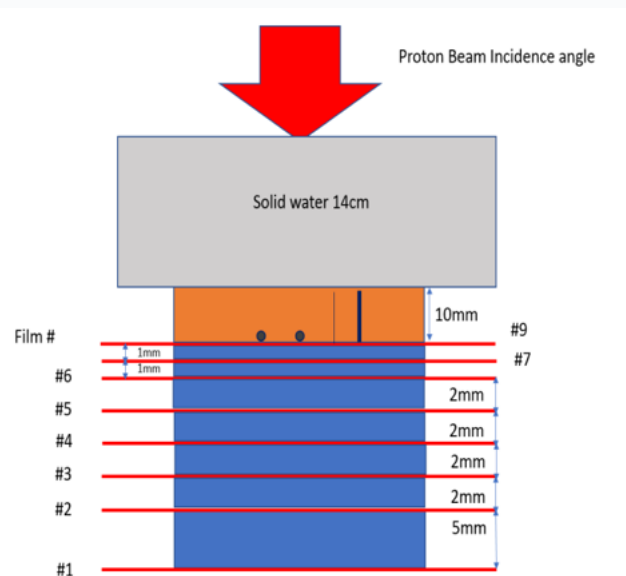
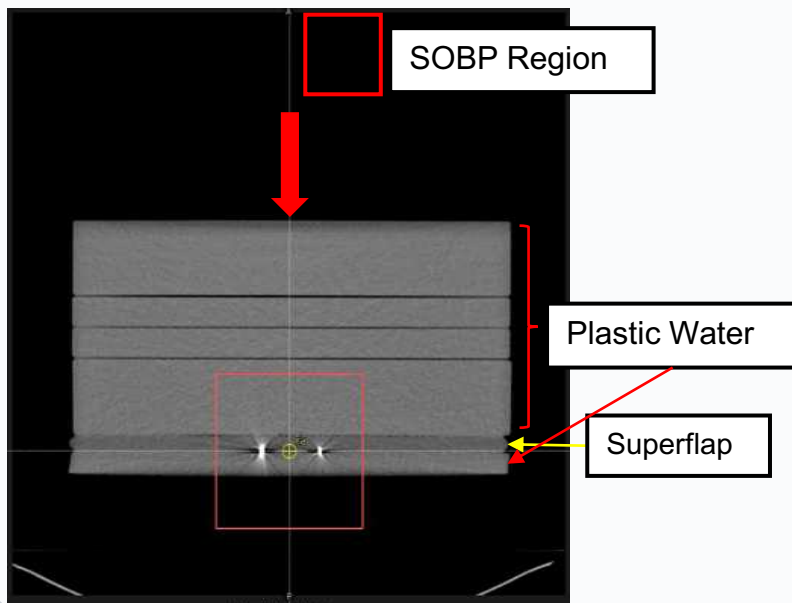
- ▶ Reported lesser migration
- ▶ Coiled shape mechanically anchors — does not slide
- ▶ Fine needle (22G/25G) — well tolerated, low bleed

# Commissioning film study — methods

委托测量 · 实验设置

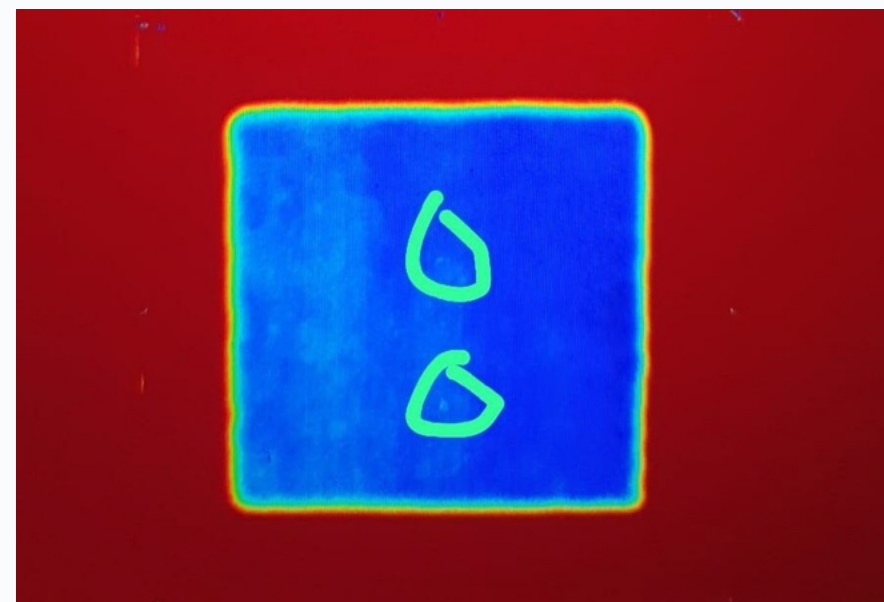
## SETUP · 实验参数

- ▶ Two Gold Anchor sizes:  $0.28 \times 10$  mm and  $0.40 \times 10$  mm
- ▶ Markers placed below 14 cm solid water + 1 cm Superflab
- ▶ EBT3 radiochromic films stacked immediately downstream
- ▶ Film–marker offsets: 0, 1, 2, 4, 6, 8, 10, 15, 20 mm



## FILM CALIBRATION · 胶片标定

- ▶ 8-point calibration: 0, 0.5, 1, 2, 3, 4, 6, 8 Gy
- ▶ Readout: Epson 12000 XL flatbed
- ▶ Each film scanned twice for repeatability



# Film results — measured under-dose

胶片测量结果 · 实测剂量降低

## -6.8%

0.28 × 10 mm Gold Anchor

- max under-dose at ~ 1 cm depth (within target)

## -7.5%

0.40 × 10 mm Gold Anchor

- max under-dose at ~ 1 cm depth (within target)

### WHEN IT GETS WORSE

- ▶ Single-field worst case → 10 % if all markers align in beam path
- ▶ Contouring error < 1 mm → 5 % dose perturbation error in the TPS estimate
- ▶ 1 – 5 mm Range pull back (实测射程回拉)

### CLINICAL IMPACT · 临床影响

- ▶ Two-field prostate plan halves the perturbation → 3–4 % target under-dose
- ▶ Range pull back (实测射程回拉) → Covered by 3.5 % range uncertainty in pelvis treatment

# Gold Anchor in a proton beam — two effects

## 金标对质子束的两种物理效应

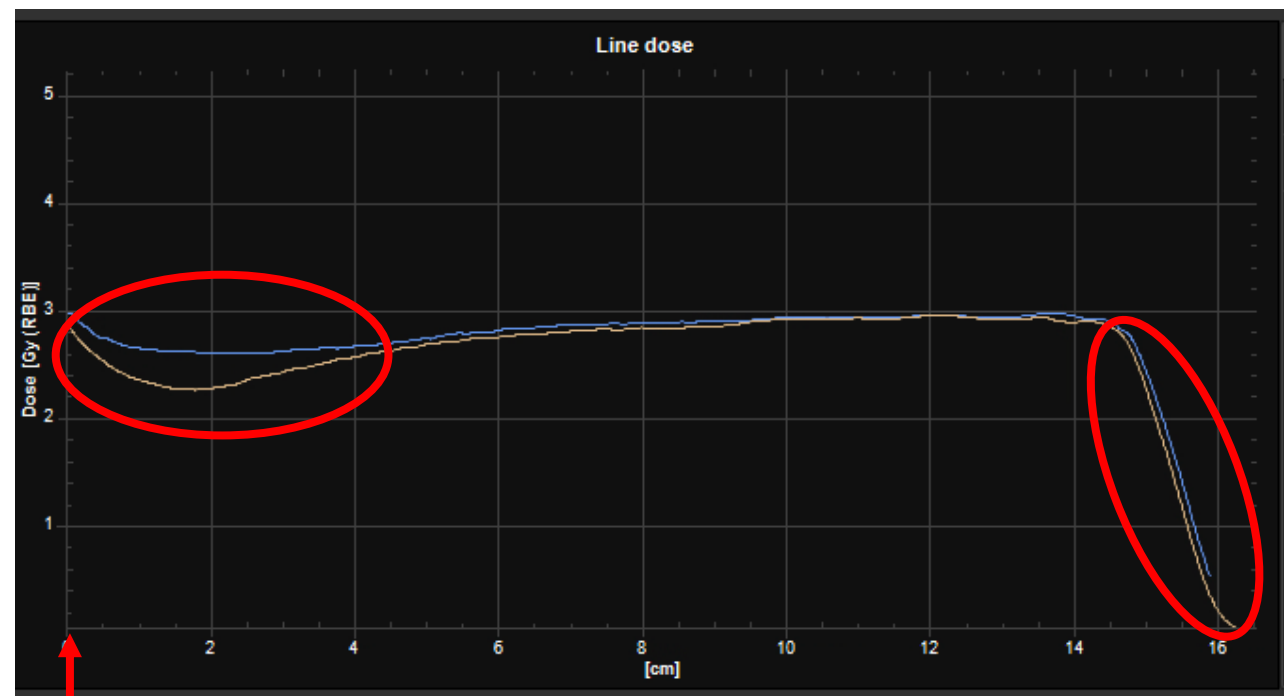
### 1. DOSE PERTURBATION · 剂量扰动

- ▶ Higher atomic number (gold,  $Z = 79$ ) → larger Multiple Coulomb Scattering
- ▶ Lateral scatter creates an under-dose region distal to the marker
- ▶ Maximum effect 1 – 4 cm behind the marker
- ▶ Equivalent to a localised cold spot in the target volume

### 2. RANGE PULL-BACK · 射程回拉

- ▶ Higher Water-Equivalent Thickness (WET) than water
- ▶ Protons lose more energy traversing the marker
- ▶ Bragg peak shifts proximally by 1–5 mm
- ▶ Usually absorbed by the 3.5 % pelvic range uncertainty

Actual line dose profile behind the fiducial in a SOBP  
Blue – without fiducial, orange – with fiducial



Fiducial  
placed here

# TPS challenges with fiducials

## TPS 三大挑战

1

### Contouring accuracy 勾画精度

Gold Anchor takes variable shapes after deployment; CT scatter makes the marker appear larger than its physical size.  $\leq 1$  mm contouring error  $\rightarrow$   $\sim 5$  % perturbation error.

2

### Material assignment 材料指定

Gold Anchor is  $> 90$  % gold. Overriding to pure gold is physically truer, but TPS calibration curves are built for tissue. We override to water/prostate during optimisation.

3

### Dose transport in sub-mm objects *mm* 物体剂量输运

TPS dose engines are not validated for very small, high-Z volumes. Hard to quantify without highly precise experimental setup. Film commissioning is the practical answer.

# Physics recommendations

## 物理师建议

### Expect 3–4 % distal under-dose

预计 3-4 % 远端剂量降低

Documented baseline for Gold Anchor  
0.28 / 0.40 mm in 2-field prostate plans.

### Override to water/prostate during optimisation

优化时使用水/前列腺密度覆盖

Gold override gives unreliable dose  
because TPS is not commissioned for  
high-Z sub-mm volumes.

### Re-evaluate final plan with gold override

用纯金覆盖重新评估终版计划

Approximate check only — interpret with  
awareness of TPS limitations.

### Restrict the recommendation to commissioned markers

建议仅适用于已委托的金标

Only valid for Gold Anchor 0.28 × 5.0 mm  
and 0.40 × 5.0 mm. New markers → re-  
commission.

### Route beams to avoid lining up markers

避免金标共线

Worst case > 10 % under-dose if multiple  
markers align in the same beam path.

### Document and verify CTV D95 % ≥ 95 %

记录并验证 CTV D95 %

Patient-specific QA confirms target  
coverage before treatment starts.



PART 03 · From marker insertion to gated delivery

# Real-time gated proton therapy

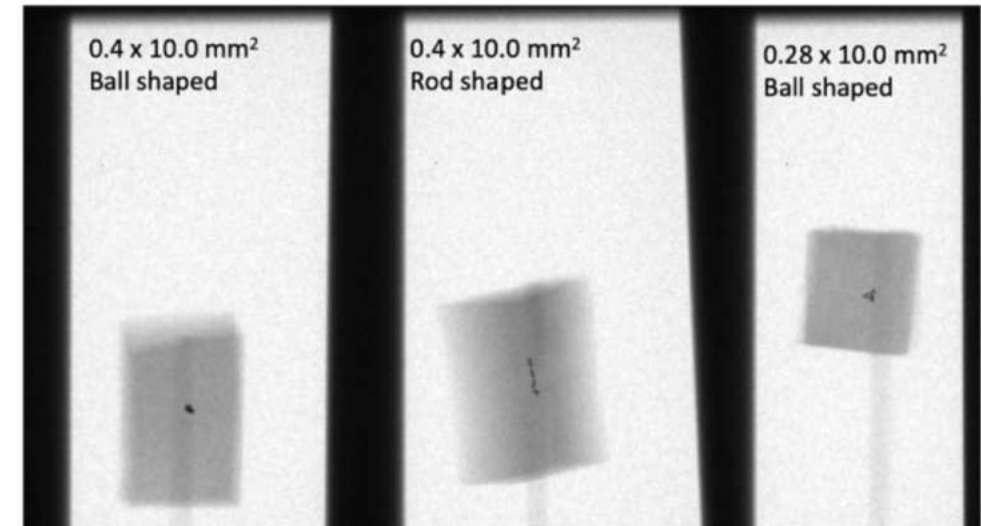
实时门控质子治疗 · RGPT at NCCS

# Proton Beam Therapy



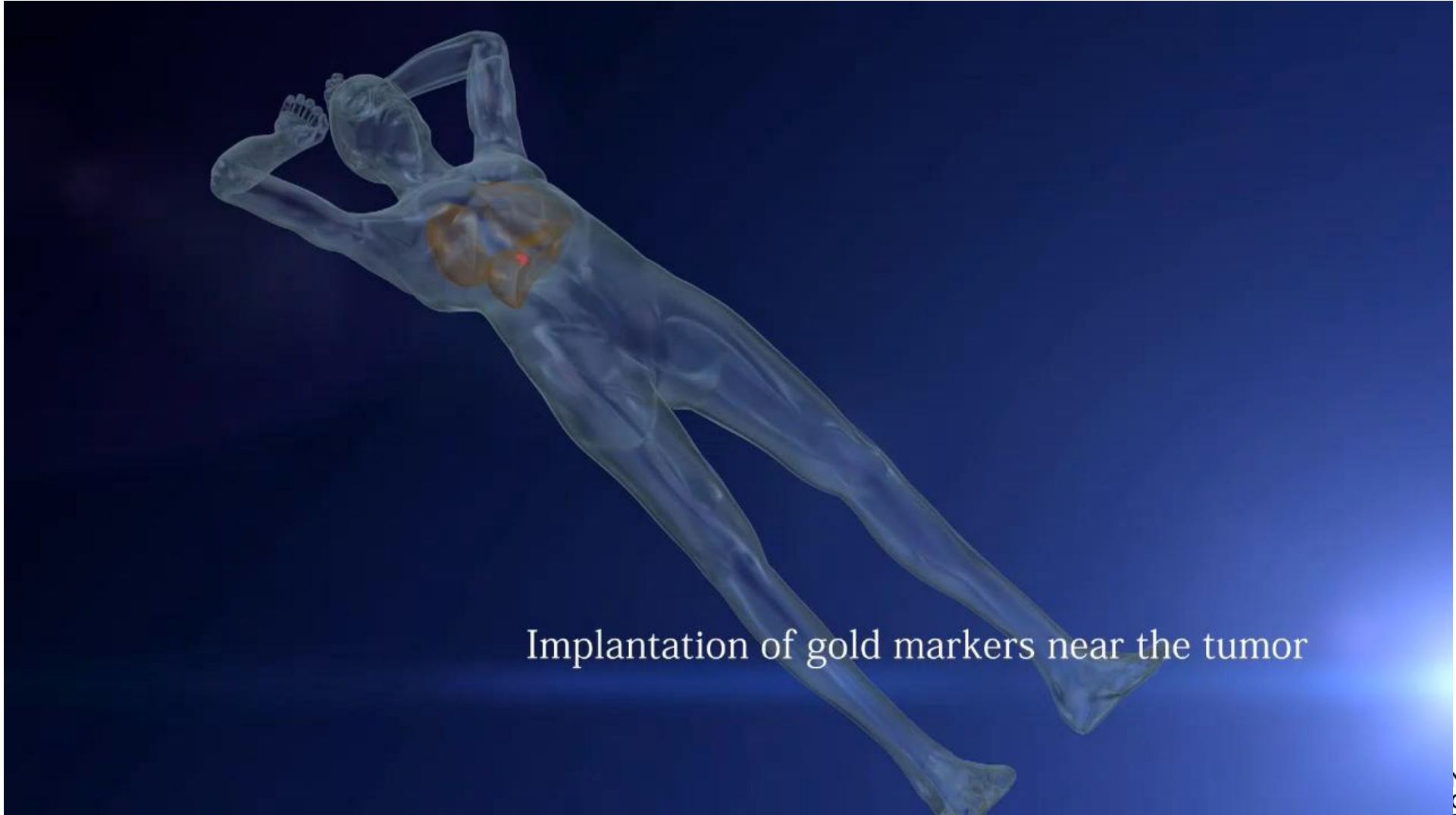
Smallest source to imager distance (1.6 m) in the world!

This figure shows the pulsed fluoroscopy images taken for the two different sizes and orientations Gold Anchor™ fiducial markers. The images are taken under the same exposure settings.



# Real-Time Image Gated Proton Beam Therapy

实时影像门控质子治疗



Implantation of gold markers near the tumor

National Cancer  
Centre Singapore  
SingHealth

# RGPT Patient Treatment Workflow

## RGPT 患者治疗流程图



# Fiducial Marker Insertion 金标植入要求

- 1 Marker size: at least 0.4 × 10 mm Gold Anchor™ fiducial markers  
金标尺寸
- 2 Placed not more than 10 cm from centre of patient (within FOV)  
距患者中心
- 3 Inserted as a ball shape (better visibility & tracking)  
球形植入
- 4 At least 2 markers inserted (3 recommended for rotation correction)  
≥ 2 个标记 (建议 3 个)
- 5 Markers must be in different axial planes and 2 cm apart  
不同轴向层面, 间距 ≥ 2 cm
- 6 Markers are 1 cm away from tumour and away from proton beam path  
距肿瘤 ≥ 1 cm, 避开束流路径

**Oncologist provides surgeon with marker type & placement instructions | Scheduled before  
RGPT assessment & CT simulation**

# RGPT Tracking Assessment

## RGPT 追踪评估 · 治疗前可视性确认

### Radiation Therapist

- Position patient and set up fluoroscopy
- Take fluoroscopy at gantry 315° and 270°
- Assess marker visibility for 5s or 2–3 breathing cycles
- Assess marker tracking stability
- Adjust kV / mA / PPS settings if needed
- Record ideal marker & settings in checklist

### Medical Physicist

- Verify marker insertion criteria met (type, size, placement)
- Confirm correct marker selected (closest to isocentre, no migration)
- Evaluate matching score & tracking quality
- Determine if patient is suitable for RGPT
- If unsuitable → advise on alternative motion management

**Settings | Prostate: 1 PPS | Liver/Lung: 15–30 PPS | kV: 125 | mA: 50–80 | Matching Score  $\geq$  30**

# CT Simulation – Physics Perspective

## CT 模拟定位 · 物理师检查要点

### General CT Sim Checks

*Scheduled same day as RGPT assessment*

- Verify correct patient ID and protocol  
*核对患者身份与方案*
- Confirm correct scan phase (especially for liver/lung — exhale phase)  
*正确扫描相位 (肝/肺: 呼气相)*
- Check immobilisation device setup  
*固定装置确认*
- Ensure adequate scan range for proton planning  
*扫描范围充足*
- Confirm marker presence and count on CT images  
*金标可视性与数量*
- Assess for marker migration from assessment session  
*评估标记物移位*

# Treatment Planning Checks

## 治疗计划检查

### Contour & Structure Review

- Verify correct CT phase selected for planning
- Check that marker contours are correctly identified
- Review overwriting of fiducial markers (density override)
- Confirm CTV, PTV and OAR contours are appropriate
- Ensure isocentre placement relative to markers

### Plan Quality & RGPT-Specific Items

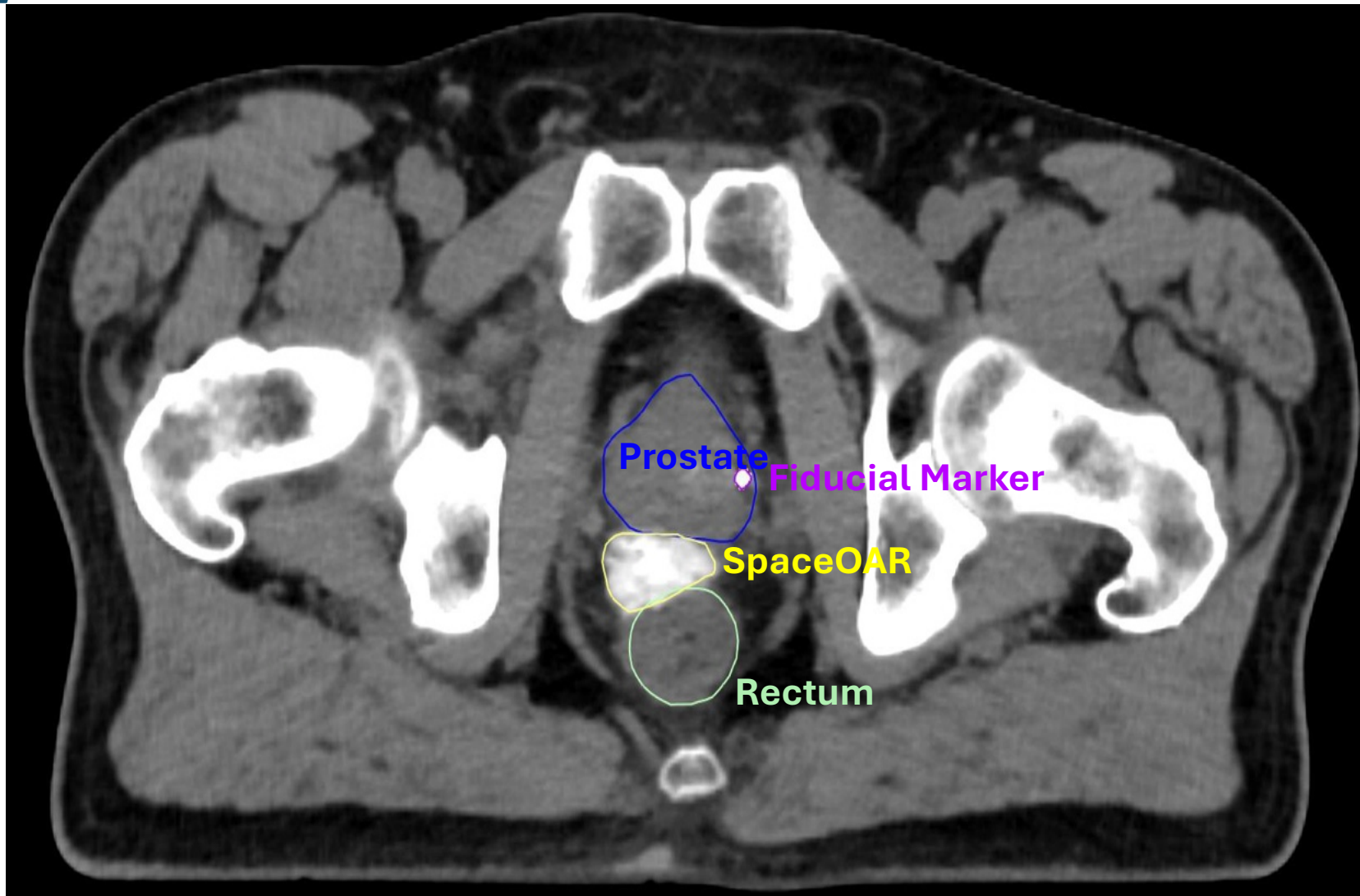
- Marker not in the proton beam path (dose perturbation)
- Robustness evaluation with setup & range uncertainties
- Confirm treatment fields compatible with RGPT couch angles
- Achieved clinical goal
- Dosimetrist review + physicist sign-off

# Pelvis

## 盆腔计划 · 金标 + 水凝胶处理

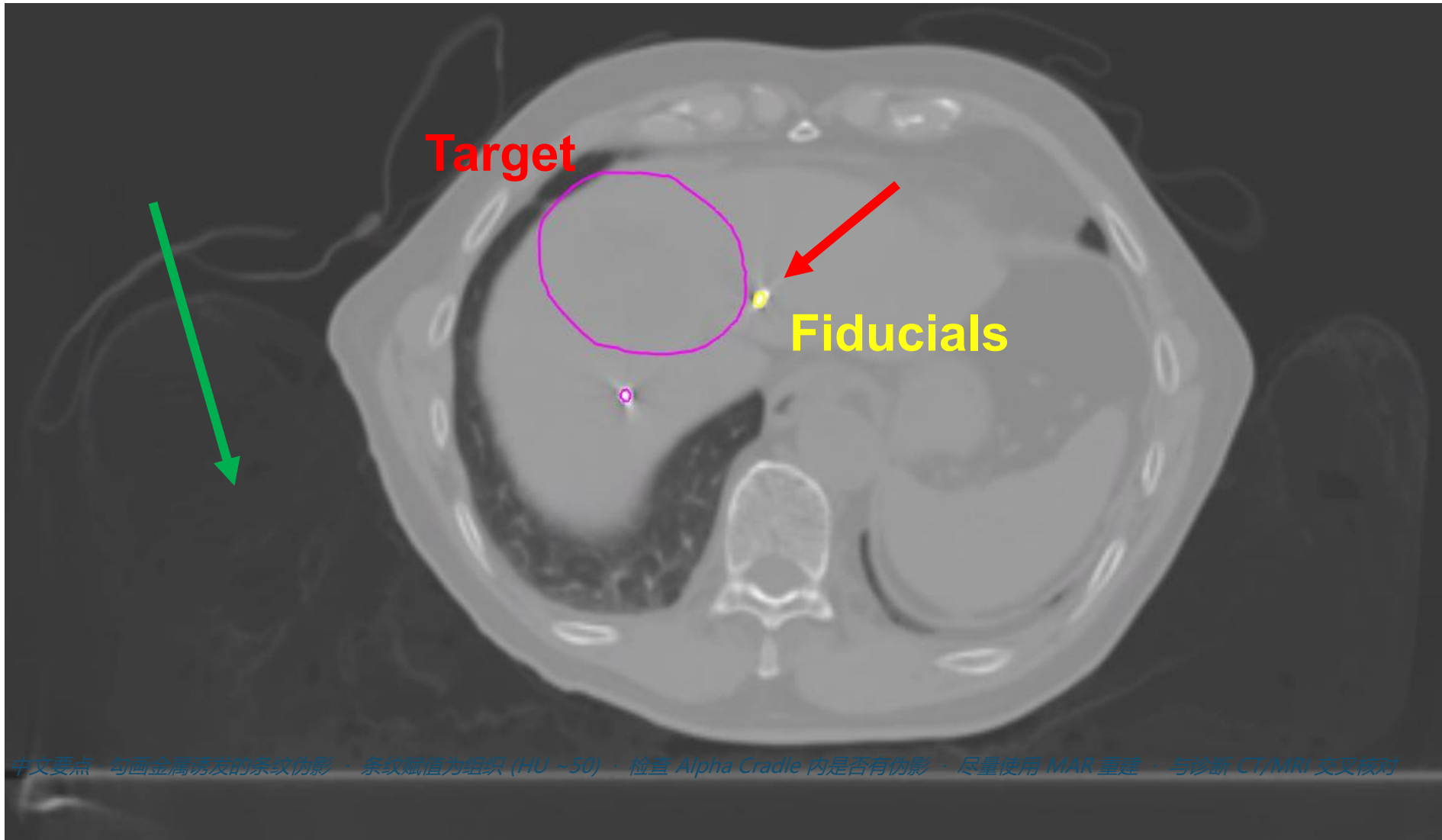
### Gold Anchor

- 0.4 x 10 mm
- Dose Perturbation 6-7%
- Contour and assign to water
- Accept a 3% underdose just behind the marker



# Fiducials Image Artifact

伪影处理 · 确保 Alpha Cradle 质量



- **Artifact**  
Contour and assign to Tissue
- Ensure Alpha Cradle quality

中文要点 · 勾画金属诱发的条纹伪影 · 条纹赋值为组织 (HU ~50) · 检查 Alpha Cradle 内是否有伪影 · 尽量使用 MAR 重建 · 与诊断 CT/MRI 交叉核对

# Treatment Planning

## Contour & Structure Review

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# Physics Checks / QA

物理检查 / QA · 含 RGPT 专项最大允许位移

## Standard Physics Plan Check (same as other proton plans)

Independent dose calculation verification, beam parameter checks, OIS transfer verification, patient-specific QA (PSQA) measurement

## RGPT-Specific: Maximum Allowable Marker Shifts (High RPN from FMEA)

- Create new structure and isocentre for shift calculation — verify correct selection
- Calculate maximum allowable RGPT shifts per axis (X, Y, Z) using in-house algorithm
- CTV D95% > 95% of prescribed dose at the defined shift limits
- Secondary review by another physicist to mitigate selection errors
- Document shift tolerances for RT team to use during treatment

# Treatment - Prostate

## 治疗 — 前列腺 • *Static / non-respiratory*

- 1 Bladder Protocol & Setup** Patient adheres to bladder protocol. Immobilisation and positioning.
- 2 CBCT & Bone Match** Day 1/Mid: Large FOV. Subsequent: Small FOV.
- 3 RGPT Marker Match (3 DoF)** Matching score > 30. No tracking loss for 5s.  
Record marker shifts — must be within max allowable shifts.
- 4 Irradiation with Gating** Monitor gating: matching score, marker tracking loss, actual marker deviation.
- 5 Repeat for All Fields** Marker match + shift check per field. Complete treatment.

$\sum \Delta M_{\text{marker},i} < \text{Maximum allowable marker shifts}$  — if exceeded, re-setup with CBCT is required

# Treatment – Liver/Lung

## 治疗 — 肝 / 肺 · 呼吸门控

### Template at Exhale Phase

The RGPT tracking template must be created at the exhalation phase of the breathing cycle to enhance treatment reproducibility and extend the dwell time for irradiation.

### Higher PPS Required

15–30 PPS for liver/lung (vs 1 PPS for prostate) to capture respiratory motion and reduce gating latency for moving tumours. *更高透视率 PPS 15–30*

### Breathing Cycle Assessment

Marker must be tracked stably for 2–3 breathing cycles before each field. No tracking loss is acceptable during this assessment window.

### Irregular Breathing — Highest RPN

Patient breathing irregularity is the highest-risk failure mode (average RPN: 142–207).  
*FMEA 最高 RPN: 呼吸不规律*

# RGPT for liver cancer



# Treatment – Monitoring and Troubleshooting

## 实时监控与故障处理

### Marker Tracking Loss

- Continuously re-select marker during gating
- Pause irradiation and change collimator window
- Increase kV / mA fluoroscopy settings for better contrast

### Actual Marker Deviation

- Organ deformation / slight movement → Repeat marker match
- Large movement exceeding max shifts → Full re-setup with CBCT

## Physics Role During Treatment

- Be present to judge RGPT marker matching quality — is the correct marker being tracked?
- Verify marker match shifts are within the calculated maximum allowable shifts
- Assess if tracking instability warrants treatment pause or re-setup
- Advise on fluoroscopy setting changes (kV, mA, PPS, collimator window)
- Escalate if persistent issues suggest RGPT is no longer feasible for the patient

# NCCS clinical experience to date

## NCCS 临床数据汇总

**50+**

RGPT prostate patients · 前列腺

**<10**

RGPT liver/lung/pancreas patients ·  
肝 / 肺 / 胰腺

**0**

Marker-related grade  $\geq 2$  events ·  
严重不良事件

## WHAT WE OBSERVED · 临床观察

- ▶ Marker migration  $< 2$  mm in  $> 95$  % of cases - anchoring shape is the key driver
- ▶ Tracking failures most often from breathing irregularity, not from the marker itself
- ▶ Treatment time per fraction: prostate  $\sim 10$  min, liver/lung  $\sim 20$  min including gating
- ▶ Stable performance across operator changes after dedicated RGPT training programme

# Key takeaways for new proton centres

## 对新建质子中心的建议

### 01 Pick the right marker shape

#### 选对金标形状

Coiled / ball-shape (Gold Anchor) - measurable reduction in migration vs rigid seeds.

### 02 Commission, then plan around perturbation

#### 委托测量 + 计划规避

Film commissioning gives the real numbers; route beams accordingly.

### 03 Build an FMEA-driven QA programme

#### 用FMEA 驱动QA

Max allowable shift calculation per-plan; 2nd-physicist review; clear treatment-day rules.

### 04 Coach the patient - especially thoracic/abdomen

#### 充分培训病人呼吸

Irregular breathing is the top FMEA risk for liver/lung RGPT - invest in coaching protocols.

### 05 Train the team end-to-end

#### 团队全流程培训

Oncologist, surgeon/IR, physicist, RT therapist - one shared SOP from insertion to delivery.

# Conclusion

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- Marker insertion criteria and assessment workflow are critical gatekeepers for RGPT suitability
- CT simulation: verify fiducial marker visibility, position, and correct scan phase
- Treatment planning: watch for wrong CT phase (highest severity) and marker density overwriting
- Physics QA: standard plan checks plus RGPT-specific maximum allowable shift calculations
- Treatment: physics present to evaluate marker matching quality and advise on troubleshooting
- FMEA identified irregular breathing as the highest RPN — patient coaching is essential

# Thank you

谢谢

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