Leids Universitair Medisch Centrum

QA for Excellent Radiotherapy

ESTRO Technical Guideline: IMRT & IGRT for rectal cancer



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On behalf of
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MRO.ART MODERN RADIATION ONCOLOGY 36° RESIDENTIAL COURSE

Gemelli
Fondazione Policlinico Universitario Agostino Gemelli IRCCS
Università Cattolica del Sacro Cuore

GART Advanced Radiation Therapy

Introduction

Radiotherapy integral part of treatment of rectal cancer

- SCRT: 25Gy in 5 fractions
- LCRT: 45-50.4 Gy in 25-28 fractions w/o tumour boost
  - Combined with chemotherapy and surgery
  - Most commonly, but not exclusively, in pre-operative setting

Goal of radiotherapy

- Improve local control for intermediate resectable disease
- Downstaging high risk borderline resectable & unresectable disease

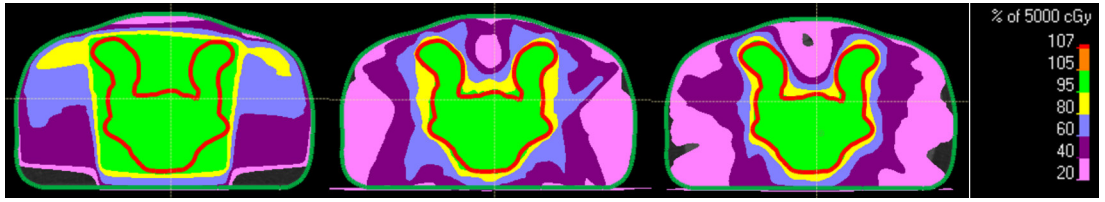
Recent development:

- Radiotherapy combined with chemotherapy to avoid surgery for early disease

Introduction

Reducing dose to healthy tissue (bladder and bowel) without compromising target coverage

1) Precise dose shaping with steep dose gradients: IMRT/VMAT



3 field conformal IMRT VMAT

2) Improved accuracy through the visualisation of patients' anatomy: IGRT

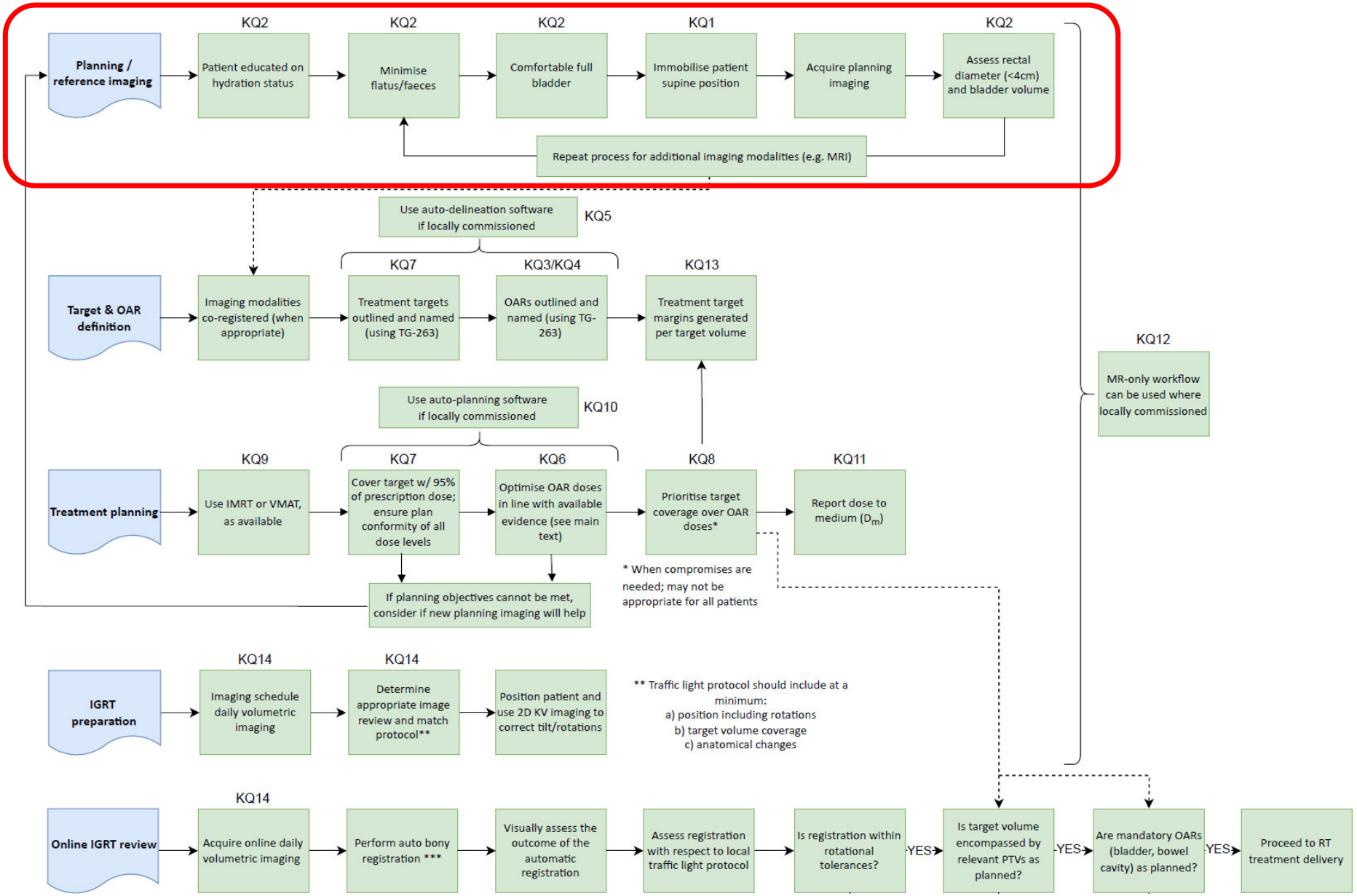


3D kV iConebeamCT

- ESTRO's Lower GI Guideline Committee:

ESTRO technical guideline: intensity modulated radiotherapy and image guided radiotherapy for rectal cancer

ELSEVIER
Radiotherapy and Oncology 218 (2026)


Planning / reference imaging
KQ2
Patient educated on hydration status
KQ2
Minimise flatus/faeces
KQ2
Comfortable full bladder
KQ1
Immobilise patient supine position
Acquire planning imaging
KQ2
Assess rectal diameter (<4cm) and bladder volume
Repeat process for additional imaging modalities (e.g. MRI)
Use auto-delineation software if locally commissioned
KQ5
Target & OAR definition
Imaging modalities co-registered (when appropriate)
KQ7
Treatment targets outlined and named (using TG-263)
KQ3/KQ4
OARs outlined and named (using TG-263)
KQ13
Treatment target margins generated per target volume
KQ12
MR-only workflow can be used where locally commissioned
Use auto-planning software if locally commissioned
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Treatment planning
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Use IMRT or VMAT, as available
KQ7
Cover target w/ 95% of prescription dose; ensure plan conformity of all dose levels
KQ6
Optimise OAR doses in line with available evidence (see main text)
KQ8
Prioritise target coverage over OAR doses*
KQ11
Report dose to medium (D_m)
* When compromises are needed; may not be appropriate for all patients
If planning objectives cannot be met, consider if new planning imaging will help
IGRT preparation
KQ14
Imaging schedule daily volumetric imaging
KQ14
Determine appropriate image review and match protocol**
Position patient and use 2D KV imaging to correct tilt/rotations
** Traffic light protocol should include at a minimum:
a) position including rotations
b) target volume coverage
c) anatomical changes
Online IGRT review
KQ14
Acquire online daily volumetric imaging
Perform auto bony registration ***
Visually assess the outcome of the automatic registration
Assess registration with respect to local traffic light protocol
Is registration within rotational tolerances?
YES
Is target volume encompassed by relevant PTVs as planned?
YES
Are mandatory OARs (bladder, bowel cavity) as planned?
YES
Proceed to RT treatment delivery

Planning / reference imaging

Patient immobilization for reproducibility, stability & dose to organs at risk

Prone vs Supine in context of IGRT+IMRT

Prone

- Small bowel dose reduction especially with bellyboard

Supine

- Improved setup reproducibility
- Improved intrafraction stability
- Greater patient comfort
- More suitable for frail, post-surgical, and stoma patients

✅ Supine should be the first option
⚠️ Prone with a bellyboard could be an option when maximal small bowel sparing is the primary treatment objective

Planning / reference imaging

Patient preparation: bladder

Context:
Large interfraction variation of bladder volume due to
- Hydration
- Medication
- Treatment related changes
- Compliance

Decrease of volume over course of treatment
Full bladder displaces small bowel from the target region -> reduces dose to small bowel & anterior bladder

Goal: Consistent and comfortable full bladder

- Structured patient education and drinking instructions
  - 300 to 500 ml fluid
  - 30-45 minutes before planning and treatment
- Catheter irrigation
- Volumetric imaging (and optionally bladder ultrasound) can support assessment of bladder volume on refCT and/or CBCT

✅ Use protocol for a *comfortable* full bladder for planning and treatment
✅ Patients should be educated on maintaining hydration status for both planning and treatment

Planning / reference imaging

Patient preparation: bowel

Context:
Large interfraction variation of target shape and volume

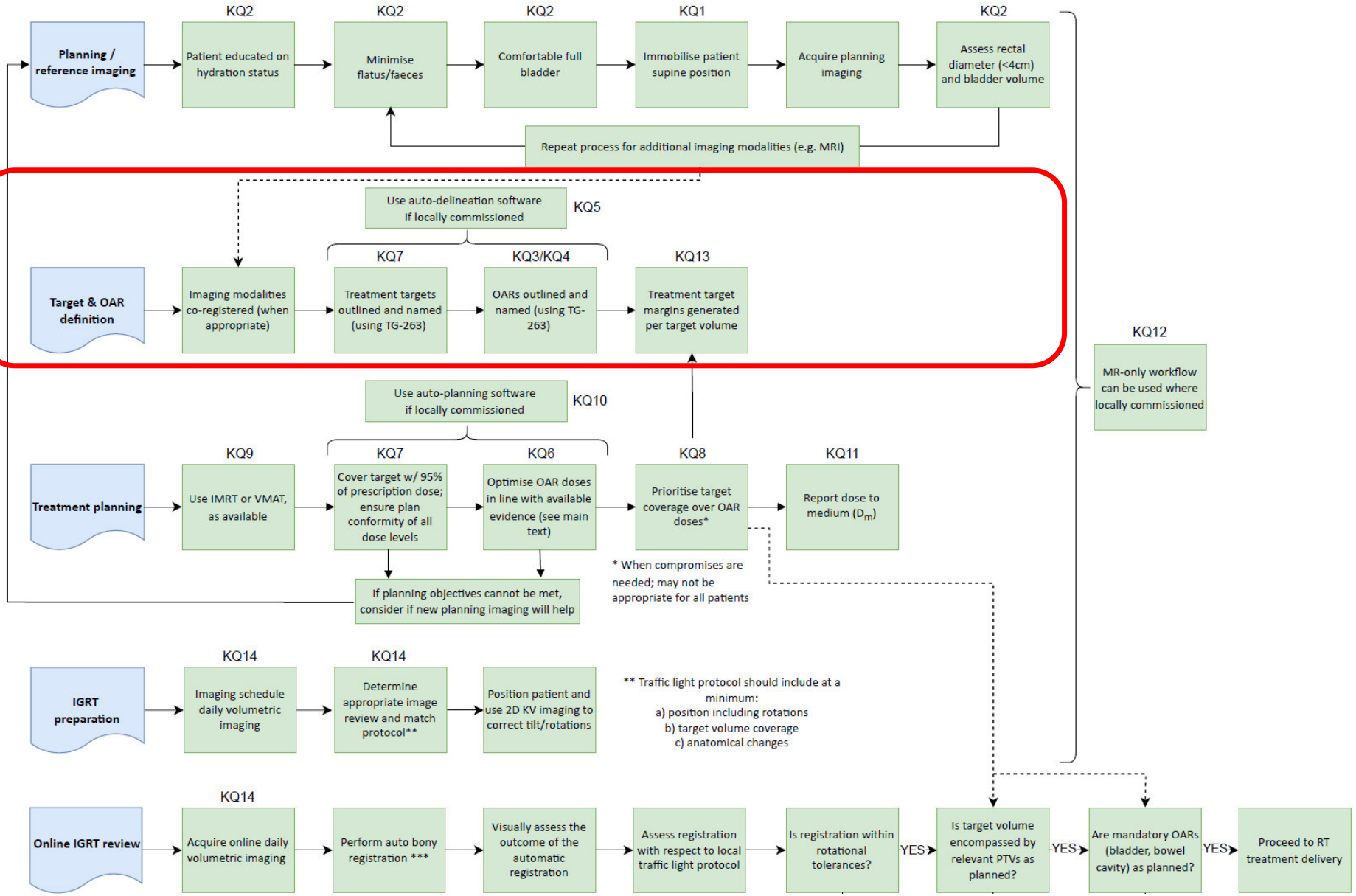
- Diet
- Medication
- Treatment related changes
- Compliance

Decrease of volume over course of treatment

Goal: Consistent (empty) rectum

- Encourage patients to empty bowels before CT simulation and treatment if possible
- Planning scans should be acquired without an excessively distended rectum (gas and/or faeces): Rectal diameter ≤4 cm
- Review rectal filling on scout before proceeding
- Review rectal filling on diagnostic imaging before proceeding when rectum is distended

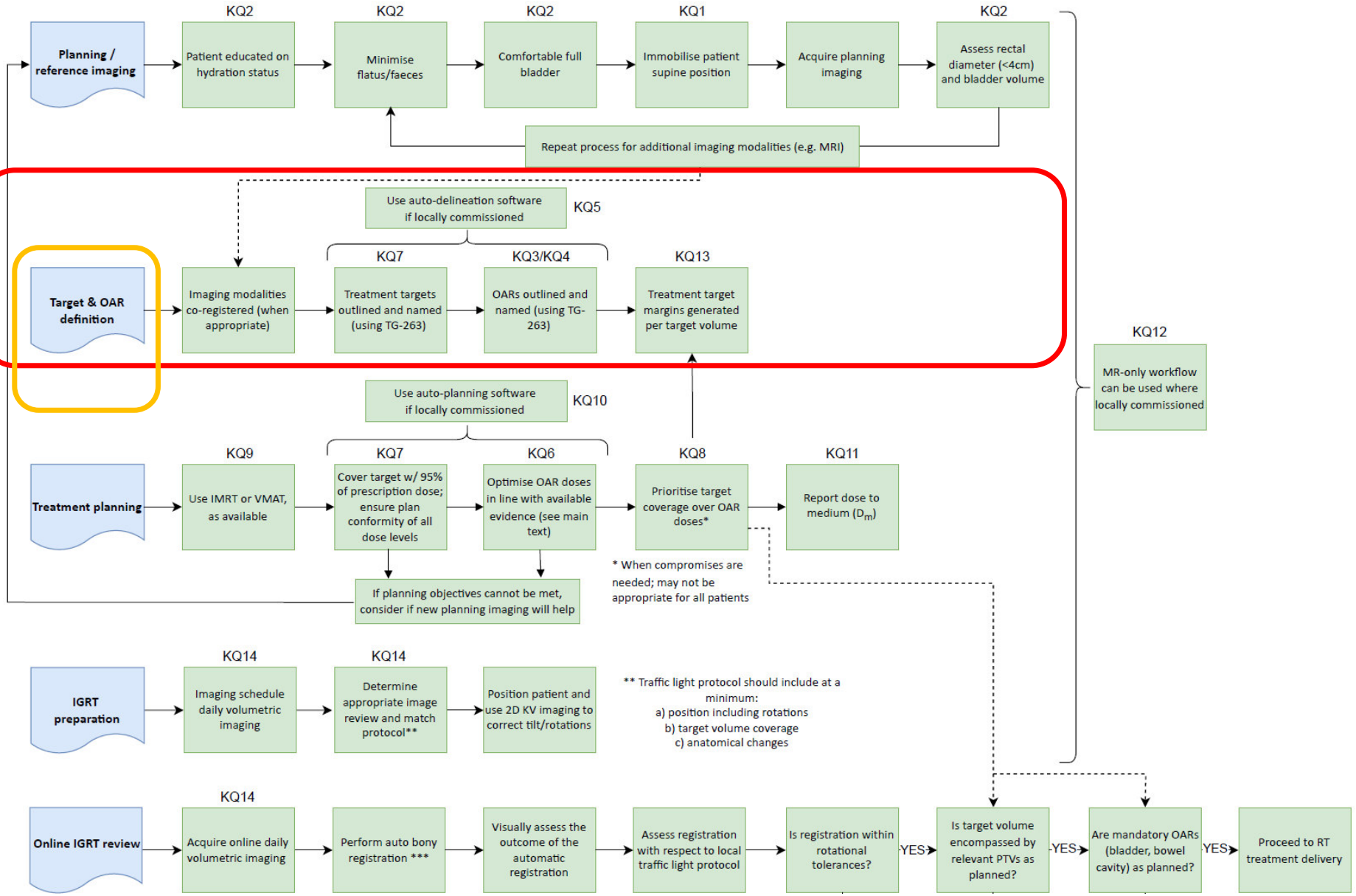
✅ Minimize flatus/faeces in the rectum for planning and treatment
✅ Ensure the CT planning scan is representative of patient anatomy


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Not part of these guidelines:

CTV delineation:
✓ *Valentini et al 2016*

GTV delineation:
✓ *Under construction*



Target & OAR definition

Organs at Risk (OAR) to be outlined

(Consistent) OAR delineations are necessary for

- plan optimisation and evaluation
- reporting of OAR dose for individual patient
- to support long-term evidence generation for our RT community; variability in delineation across clinical practice /research

Literature insufficient & inconsistent

- Expert consensus by voting process of writing panel

✅ Mandatory

- Bladder
- Bowel Cavity
- Femoral Heads

✅ Recommended

- Vagina
- External Genitalia
- Penile Bulb
- Anal Sphincter
- Sacral Bones
- Stoma (when within 1 cm of PTV)

✅ Optional

- Prostate & seminal vesicles
- Ovaries
- Uterus & cervix
- Lumbosacral plexus
- Diverticulum (bowel segment ending in the stoma)
- Inguinal area

✅ Specific scenario's suggestions

- Primary tumor (GTV) boost: Vagina, anal sphincter
- Nodal boost: Sacral bones, lumbosacral plexus
- Organ preservation strategy: Anal sphincter, rectal wall
- Total Neoadjuvant Treatment (TNT): Bone marrow

➢ Use consensus guidelines, see paper for guidelines available
➢ Use standardized nomenclature AAPM TG263 (and color coding)
➢ May need to be adapted for individual patient factors like age, frailty, fertility preservation

Target & OAR definition

Auto segmentation for targets and OAR

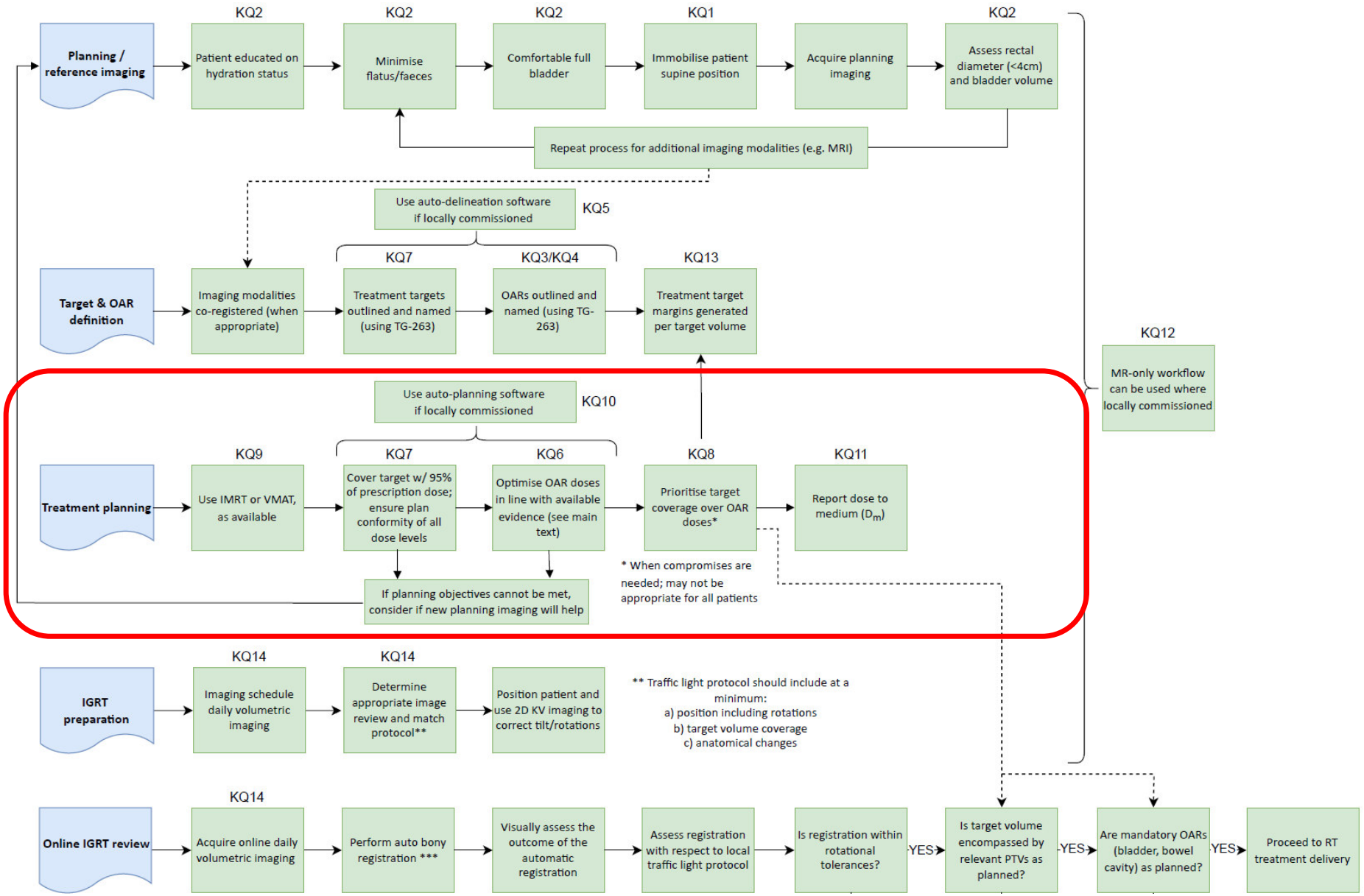
Goal: Improved consistency and reduced contouring time

Literature is limited:
- Retrospective
- Single center
- Inhouse models

Good results:
- Acceptable accuracy
- Time saving

⚠️
- Commercial solution may not reflect local practice
- Always review and edit when necessary:
  - Consider qualitative acceptability criteria e.g. geometric accuracy, dosimetric impact
  - Consider outcomes assessments e.g. actions to be taken for corrections

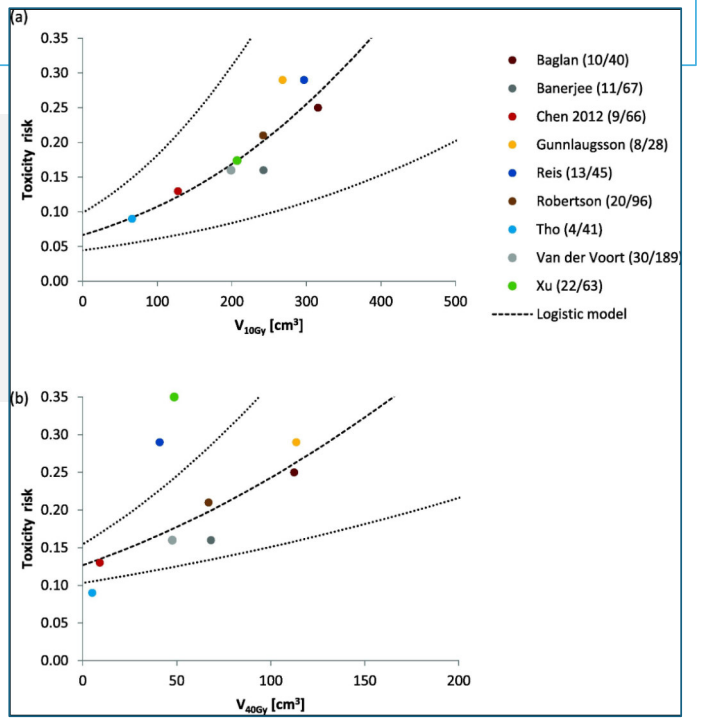
✅ Auto-delineation can be used for OAR for time-reduction benefit
✅ Auto-delineation can be considered for target volume


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Dose levels and metrics for OAR

Bowel

- Acute diarrhea V5-V45Gy, no single dose threshold
  - 3D-CRT studies suggest lower dose volumes to be more relevant
  - VMAT studies suggest higher dose volumes may be more relevant
- Late GI toxicity, the strongest evidence supports limiting:
  - Small bowel V30Gy < 200 cc or V30Gy < 300 cc



Holyoake et al. 2019

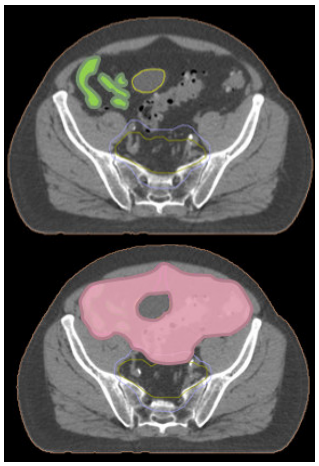
Treatment planning

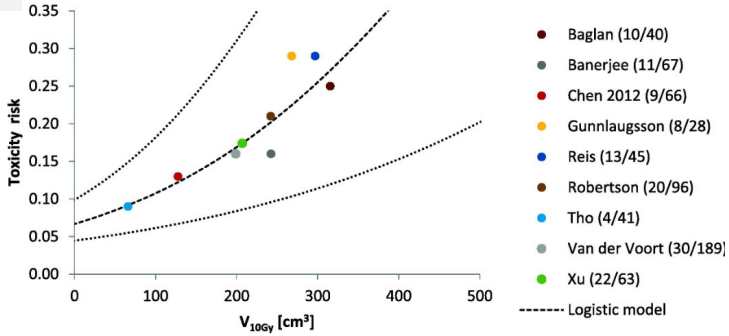
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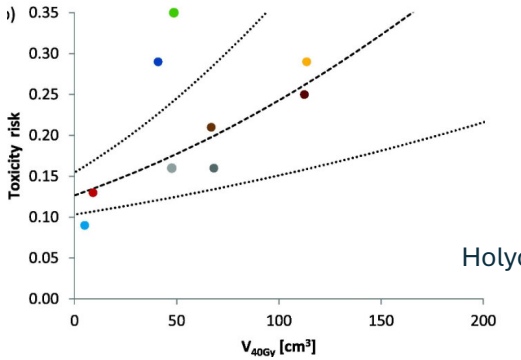
Limited literature: Based mainly on 3D-CRT; limited IMRT/VMAT data, no data on SCRT

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Holyoake et al. 2019

- Individual bowel loops exhibit significant interfractional movement
  - ➢ Bowel loop dose on planning imaging will not accurately reflect the actual dose delivered
- IMRT plans optimized with bowel / peritoneal space OAR more robust to interfractional bowel position variation
  - ➢ Planning DVH more reflective of actually delivered dose
- But might need to consider individual bowel loops when delivering boost!
  - ➢ Solution: Outline both for optimisation & plan evaluation

⚠️ Rectal wall may be an 'new' OAR in the context of organ preservation

✅ Limit dose to bowel to prevent acute and late GI toxicity using a range of low to high dose levels
✅ Use bowel cavity, or a comparable volume, for plan optimization, irrespective of the volume used for plan evaluation and reporting

Treatment planning

Dose levels and metrics for OAR

Limited literature: Based mainly on 3D-CRT; limited IMRT/VMAT data, no data on SCRT

Bladder

- Acute cystitis V30-35Gy
- Late toxicity thresholds, insufficient data

Other

- Evidence is sparse for most additional OARs
- Bone marrow is the best studied; findings are inconsistent
- Any other OAR outlined, dose should be reviewed as part of plan evaluation and prescription, and any given patient specific considerations should be recorded

⚠️ OAR dose constraints are highly dependent on clinical scenario and the acceptable risk for a giving patient/patient group
⚠️ Dose-response and dose-volume effects may be impacted by changing multimodality regimens (TNT/Immuno and/of Targeted therapy)

✅ Limit dose to bladder, with a particular focus on limiting V30-35Gy to prevent acute toxicity
✅ For any other OAR outlined for an individual patient, dose should be reviewed as part of plan evaluation and prescription, and any patient-specific considerations should be recorded.

Dose metrics target volume

Target volume	Standardised nomenclature (TG-263)	Dose metric	Objective†
Gross tumour, involved nodes, and clinical target volumes	GTVp, GTVn, CTVp, CTVn, CTVe*	Avoid cold spots in GTV / CTV target volumes; e.g. keep these volumes covered by 95% isodose. For plan evaluation, e.g. use V95%≥99%	
Planning target volume for primary tumour and involved lymph nodes (where relevant)	PTVp, PTVn	$D_{99\%}$	≥90%
		$D_{95\%}$	≥95%
		$D_{50\%}$	= 100% ± 2%
		$D_{2\%}$	≤105%
Planning target volume for elective targets	PTVe*	$D_{99\%}$	≥90%
		$D_{95\%}$	≥95%
		$D_{50\%}$	= 100% ± 2%
		Avoid dose ≥105% away from any SIB volumes	
Evaluation structure when delivering simultaneously integrated boost (SIB)	PTVe minus (PTVp&n + 5mm)	Minimise volume receiving 107% of the elective volume prescription dose. For plan evaluation, e.g. use $V_{107\%}$<15%	

Treatment planning

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Planning target volume for elective targets	PTVe*	$D_{99\%}$	≥90%
		$D_{95\%}$	≥95%

✅ Use standardized nomenclature AAPM TG263 and comply to ICRU Report 83
✅ Cover the PTV for primary tumour, involved lymph nodes and elective volumes with 95% of the prescription dose, *minimise hotspots*
✅ Dose *as conformal as possible* for SIB to tumour or involved nodes
✅ For individual patients it is at the treating physician discretion to prioritize an OAR over the target volume

⚠️ If OAR constraints cannot be met due to unfavourable anatomy, assess if repeat planning imaging can help
⚠️ The IGRT protocol should be in line with the planning prioritizations

Treatment planning

IMRT & VMAT planning

- Decision between 3D CRT and IMRT is not part of the guideline
- That decision is best made once IMRT has been developed allowing clinical practice to inform the comparison

IMRT and VMAT comparable plan quality

- Some studies reported slightly lower OAR doses with IMRT
- Others found VMAT improved target coverage and normal tissue sparing
- Consistent finding substantial reduction delivery time for VMAT compared to IMRT

Planning variability

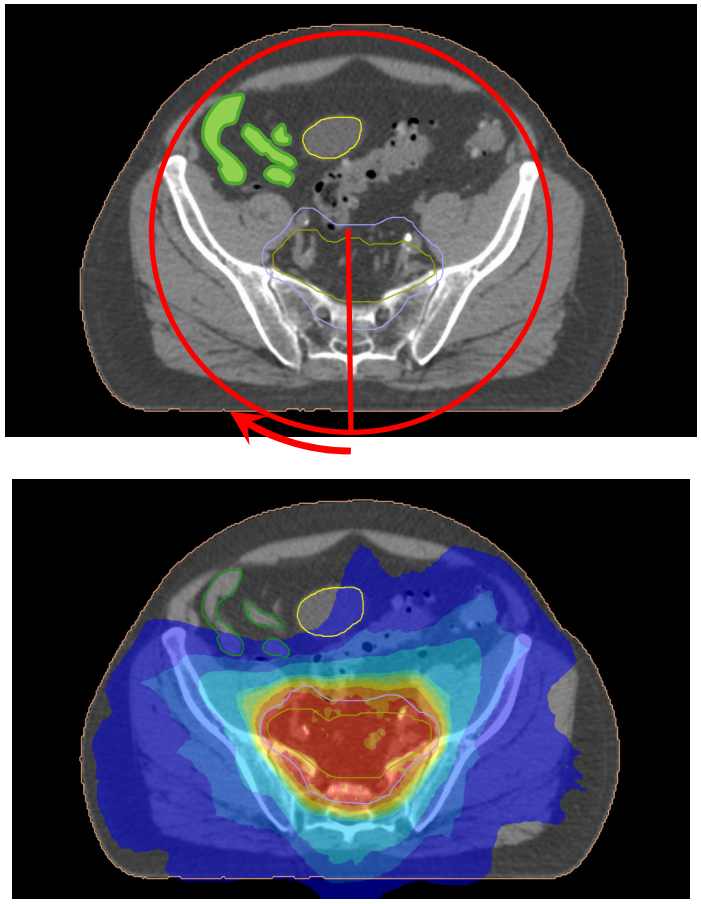
- No direct comparisons for different TPS using the same modality, technique, and planners
  - Isolated benefit of newer optimization engines unclear
- Multi-centre benchmarking show substantial inter-centre variability despite strict planning guidelines
  - More inter-centre benchmarking, peer-reviewed quality assurance (QA) and robust planning QA in clinical trials
- Both IMRT and VMAT can deliver SIB without a substantial increase in OAR dose
  - When evaluating SIB plans, high-dose conformity metrics should be included as an important quality measure

✅ Tips and tricks in the paper:

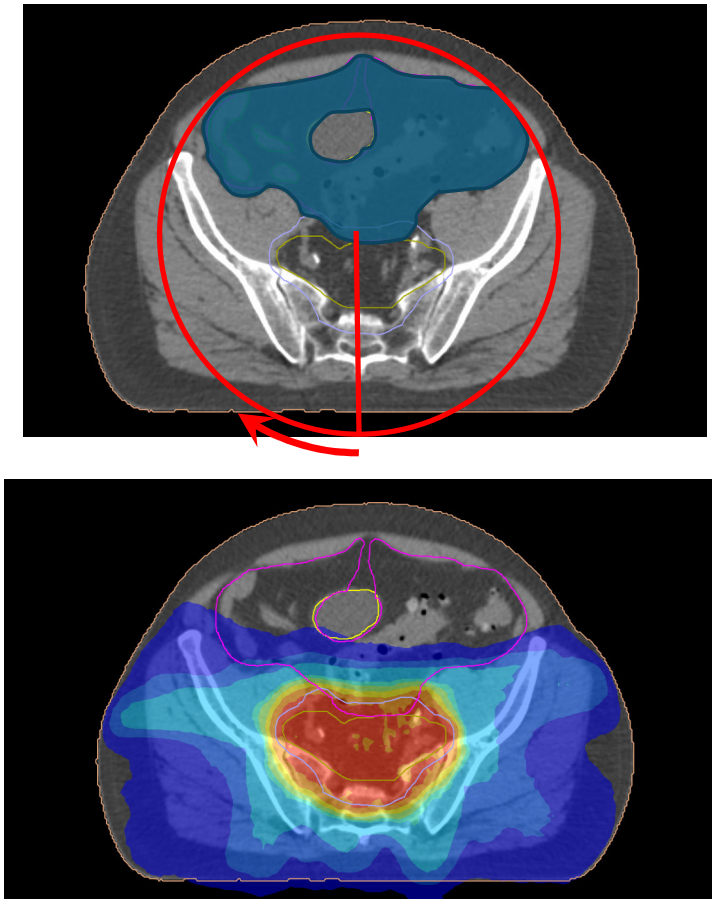
- IMRT/VMAT and OAR optimisation: beam arrangement, number of arcs, planning techniques, rectal cancer specific optimisation tricks etc
- Contrast and density corrections

OAR definition and plan optimisation

Small bowel loops

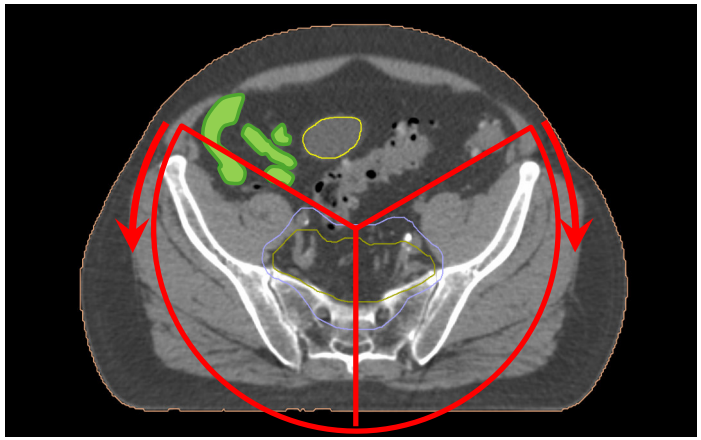


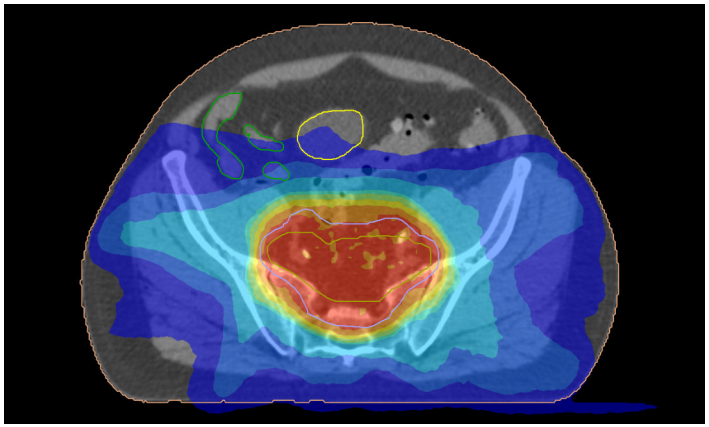
Bowel space / cavity



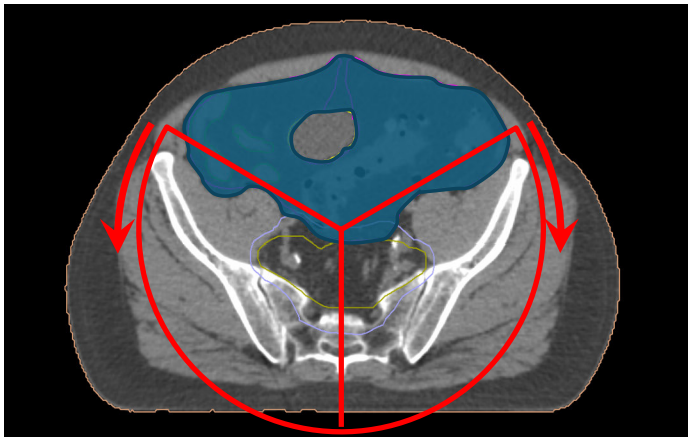
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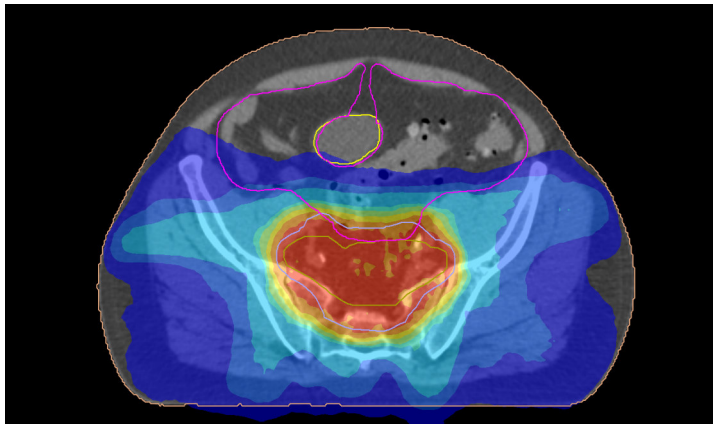
Small bowel loops





Bowel space / cavity





Treatment planning

Auto planning solutions

Literature shows

- Improved bladder and small bowel sparing (LCRT studies)
  - ✓ Lower mean dose
  - ✓ V30Gy
  - ✓ V40Gy
- Improved time efficiency
- Improved consistency

- Knowledge-Based Planning (KBP) is the most used approach, followed by template-based and script-based optimization
- Successful implementation requires local configuration, validation, and continuous quality monitoring
  - ➢ KBP additionally depends on a sufficiently large dataset of high-quality training plans
- Current evidence is limited to predominantly retrospective, single-centre studies

✅ Commercially available auto-planning solutions can be used to
- ✓ improve the OOI sparing
- ✓ increase the time efficiency & consistency of IMRT planning

✅ When used, verify and monitor local clinical performance continuously

Treatment planning

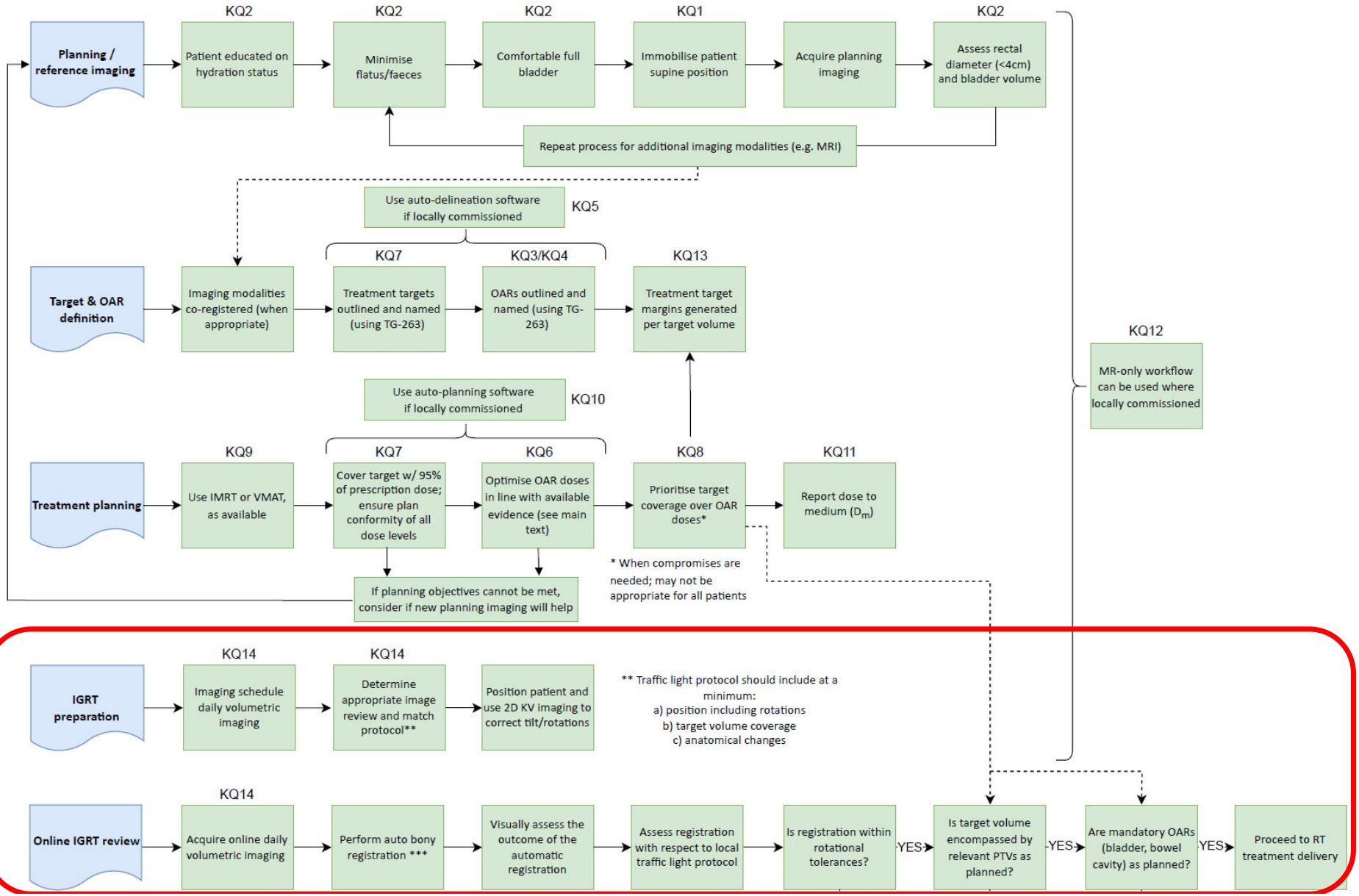
MR-only workflows

- MRI offers superior soft-tissue contrast
- Omitting CT scan + its registration uncertainties
- Dedicated acquisition protocols are required:
  - ➢ Additional sequences for sCT generation
  - ➢ Full planning anatomy coverage (FOV CC)
  - ➢ Geometric distortion minimization and verification
- Recent studies support the use of synthetic CT (sCT) generated from MRI for dose calculation
  - Across multiple commercial sCT solutions, dose differences versus planning CT are generally <1%
  - Special care needed for
    - ➢ Handling of rectal air pockets
    - ➢ sCT electron density assignment
- MRI/sCT can also be used for image guidance, with registration differences typically <1 mm and <0.5° compared with CT
  - Lacks commercial support

⚠️ Patient comfort during MRI simulation should be optimized to reduce motion:

- Earplugs/headphones and music
- Blankets for warmth
- Feet-first positioning
- Clear explanation of scan duration and procedure

✅ Commercially available sCT generation software can be used to generate sCT for dose calculation
✅ MRI or sCT can be used as reference image for position verification in an MR-only workflow for rectal cancer

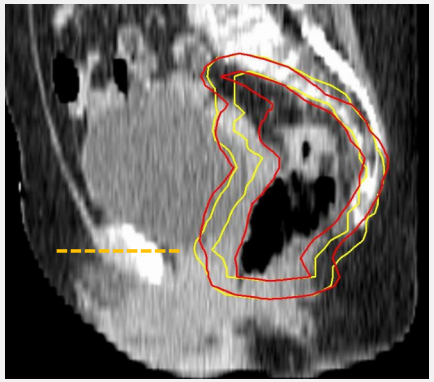

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Delineation uncertainty

Delineation not part of these guidelines

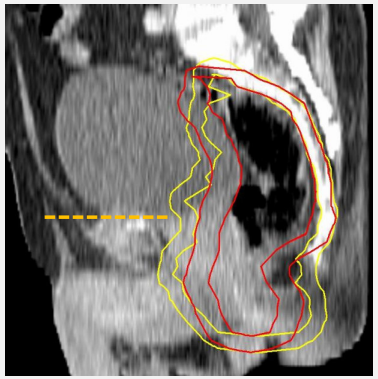
Delineate the actual target volume: Valentini et al.



Clinical CTV

"Real" CTV

Female

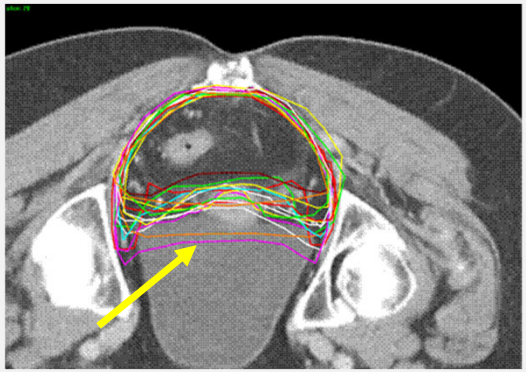


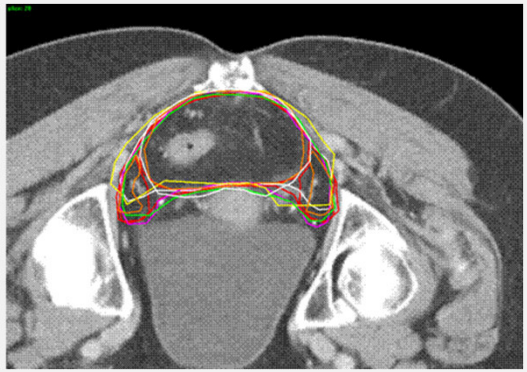
Male

---- Base of bladder

Margins based in this image based on:
Nijkamp et al. 2009 1
Nijkamp et al. 2009 2
Nijkamp et al. 2012

Delineation uncertainty





Phase 1

Phase 2

- ✓ Optimize imaging inputs (MRI)
- ✓ Use consensus atlas-based delineation guidelines
- ✓ Training program (protocol compliance)
  - ✓ Peer review!

✅ Use iniform nomenclature TG-163 (and color-coding)

✅ Delineate the 'real' CTV

Valentini et al. Radiother Oncol. 2016 International consensus guidelines on Clinical Target Volume delineation in rectal cancer
Mayo et al. 2018 American Association of Physicists in Medicine Task Group 263: Standardizing Nomenclatures in Radiation Oncology
Nijkamp et al. Radiother Oncol 2012 Target Volume delineation variation in radiotherapy for early stage rectal cancer in the Netherlands
Fuller et al. IJROPB 2011 Prospective randomized double-blind pilot study of site specific consensus atlas implementation for rectal cancer target volume delineation in the cooperative group setting

Online IGRT review

Daily set up and anatomy changes

Intrafraction motion

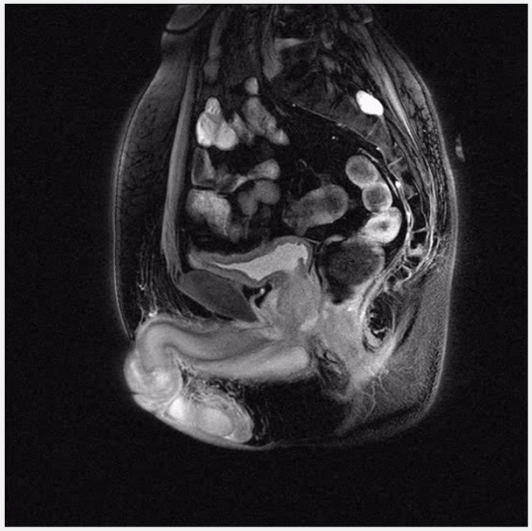
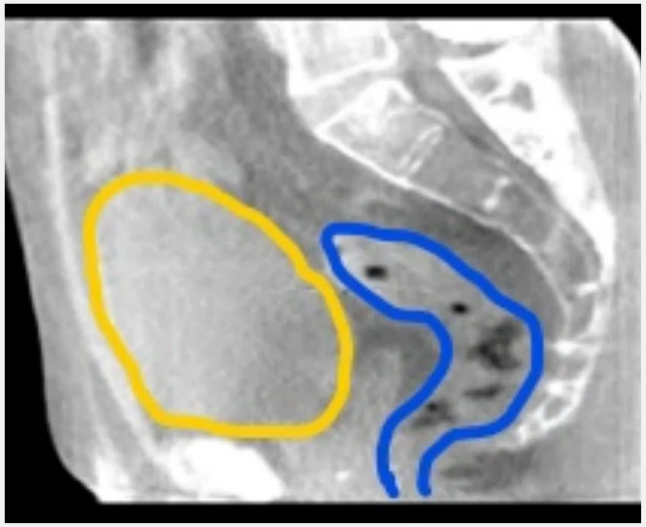


Image Courtesy Beaumont Hospital

Interfraction motion



Target volume shape variation

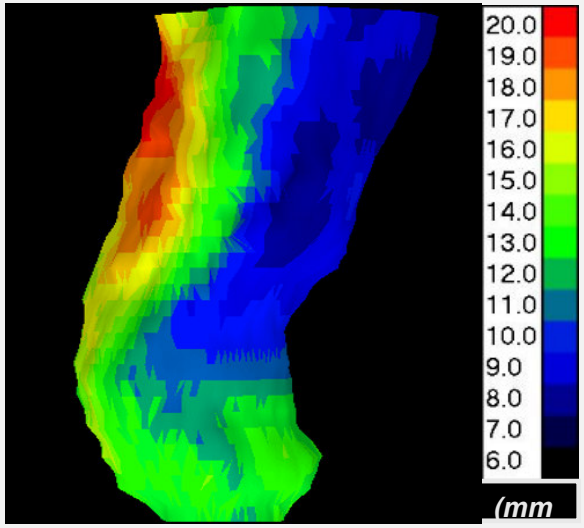


Image Courtesy Jasper Nijkamp

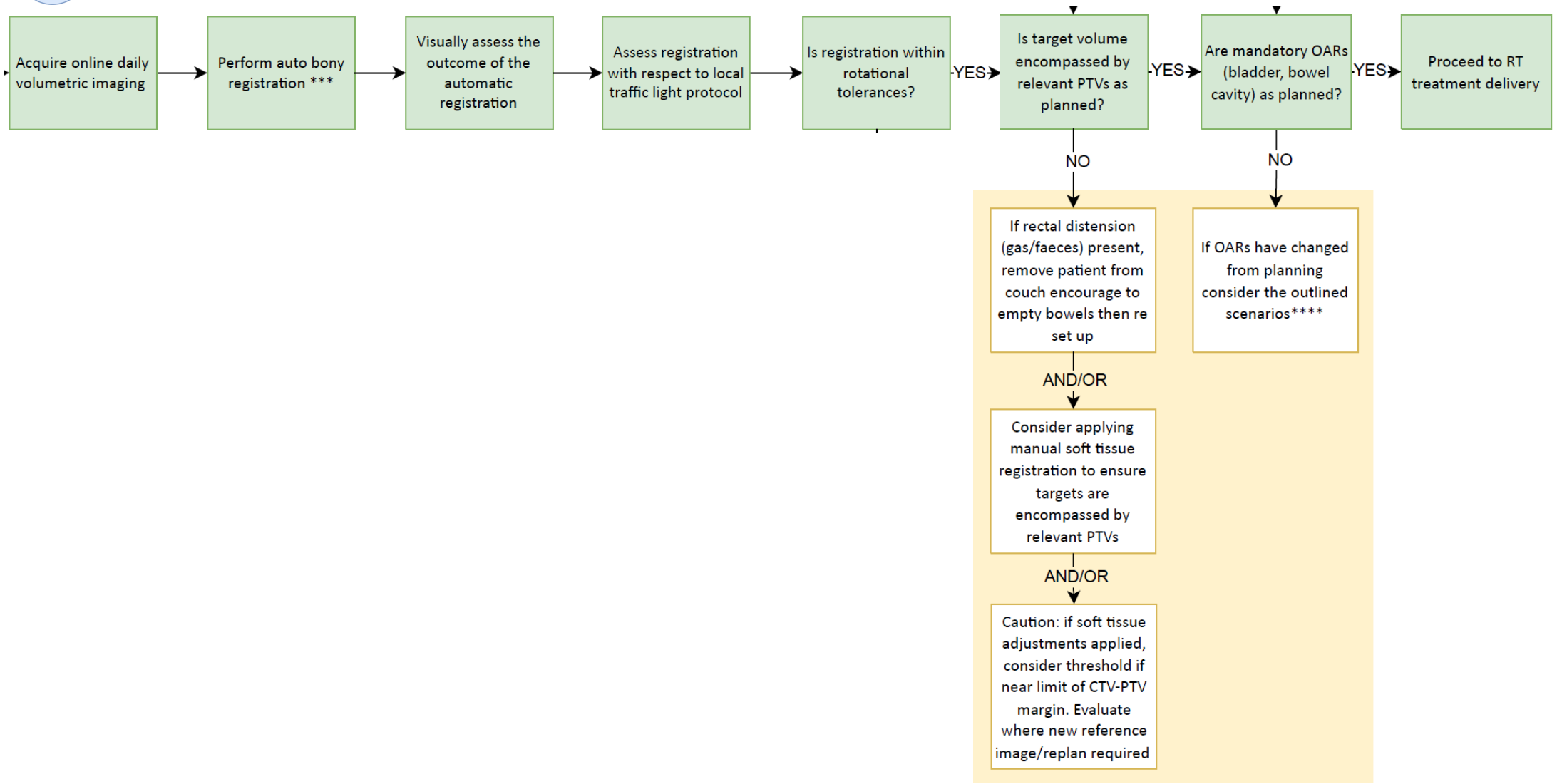
- ✅ Systematic & random errors in setup & target volume shape are large -> use appropriate margins
- ✅ Margins should be defined separately for the primary tumour, involved lymph nodes, mesorectum & elective volumes
- ✅ Use daily 3D imaging:
  - Match to bony structures
  - Evaluate target volume
- ✅ Use decision support tools for image evaluation and decision making

Setup and target volume shape variation in rectal cancer radiotherapy: a systematic literature review

Giovanna Mantello [a], Elena Galofaro [a,*], Cihan Gani [b], Daniel Portik [c,d], Lynsey Devlin [e,f], Robin De Roover [g], Ane Appelt [h,1], Rianne de Jong [i,1]

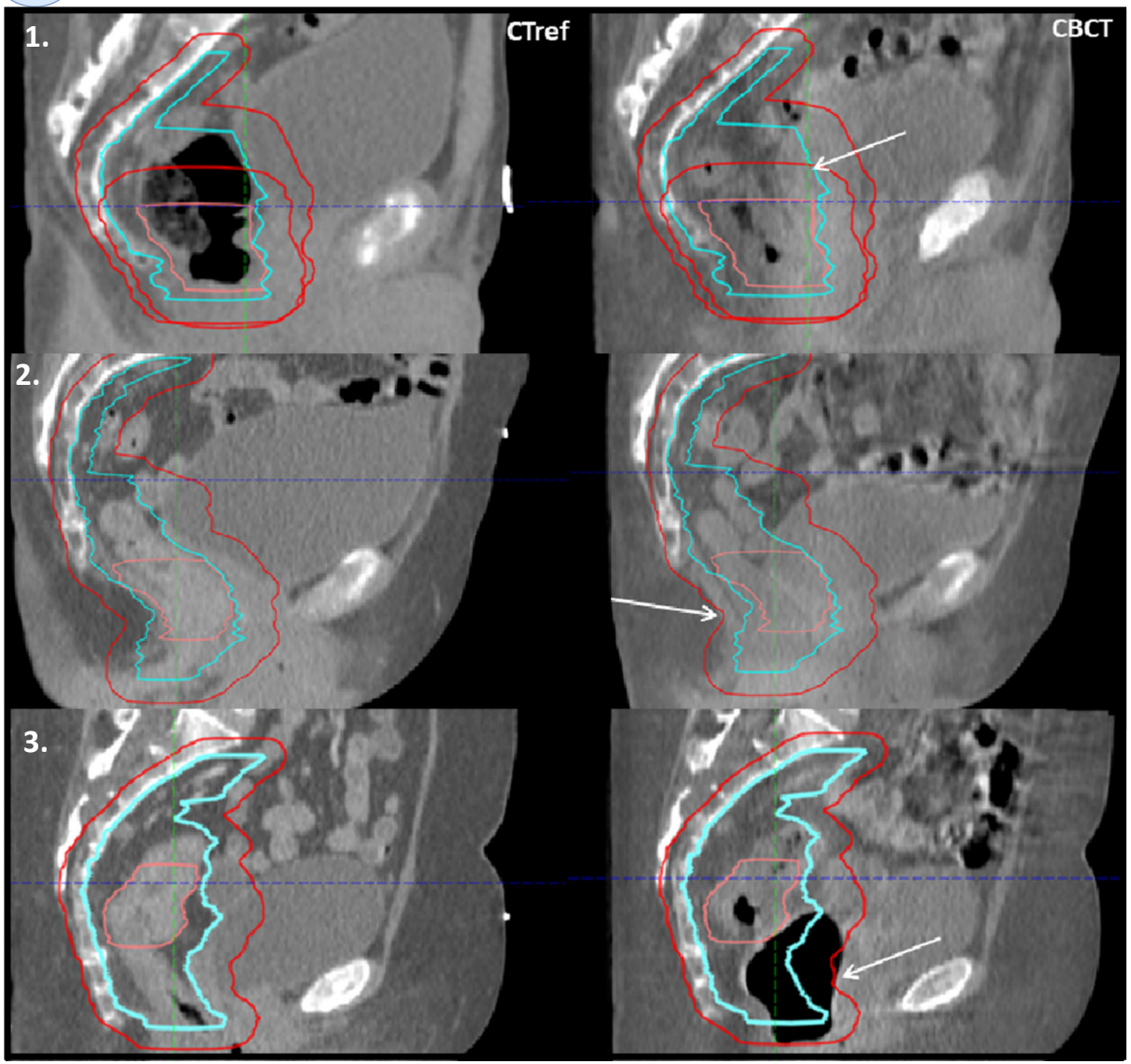
Online IGRT review

Daily set up and anatomy changes



Online IGRT review

Daily set up and anatomy changes



Display only structures needed for evaluation:
→ Target volume and its PTV
Bony anatomy registration
→ Elective lymph nodes

1. **CTref:** Rectal diameter too large
   CBCT: Too much bladder within PTV with full bladder
   Too much bowel within PTV with empty bladder
   ToDo: *- New CTref*

2. **CTref:** Bladder very full
   CBCT: Bladder comfortable full
   Different muscle tension (bladder too full CTref?)
   Target not completely in PTV
   ToDo: *- Manual/soft tissue adjustment WITH CARE!*
   -> consider local margin total TV
   - Re-set up patient

3. **CTref:** *Perfect!* : Comfortable bladder & empty rectum
   CBCT: Extended rectum
   Target volume not within PTV
   ToDo: *- Manual/soft tissue adjustment WITH CARE!*
   -> consider local margin total TV
   - Patient off couch and re-set up patient
   - New CTref

Online IGRT review

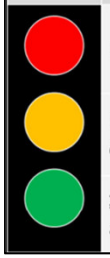
Daily set up and anatomy changes

Decision support tools are department specific; they depend on margins and treatment planning technique used

Seek immediate advice

Intervene before next fraction

No action

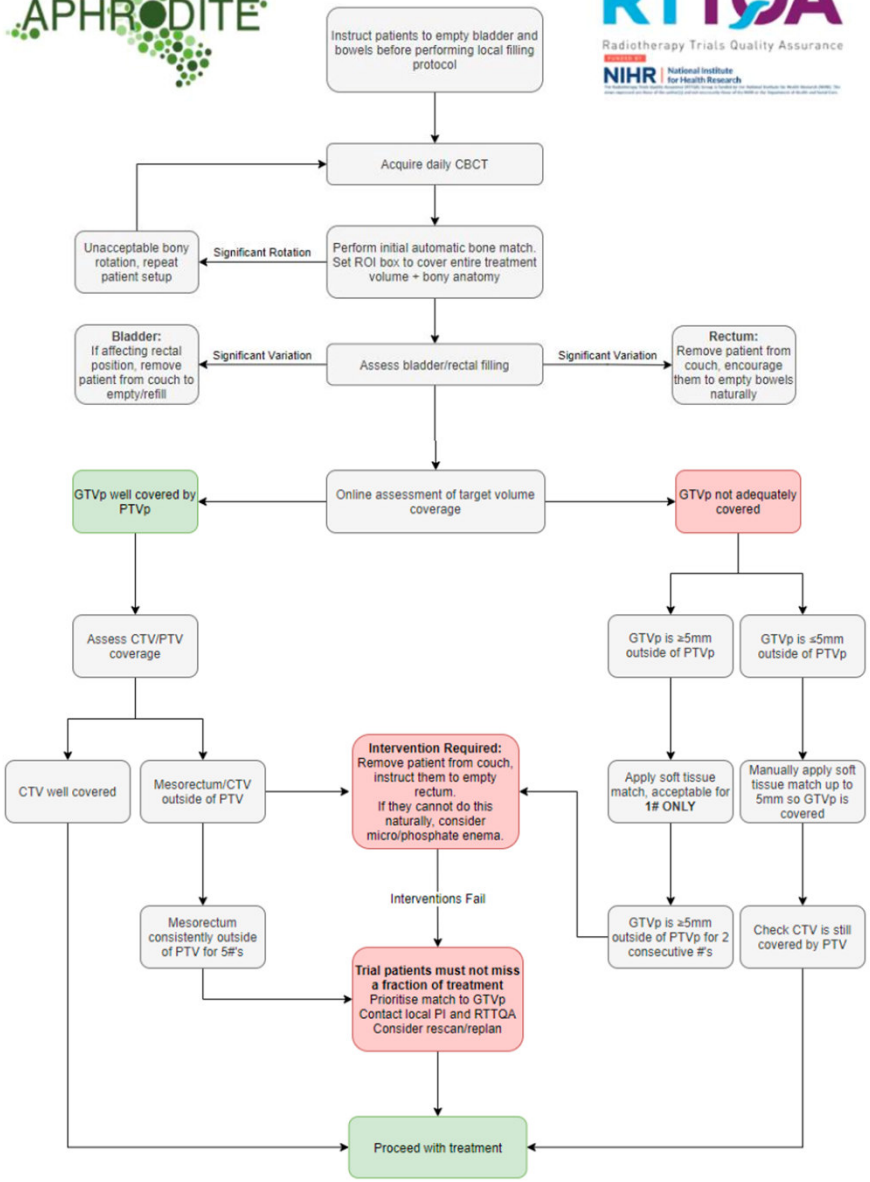


	PTV COVERAGE OF PRIMARY CTV	BLADDER VOLUME	RECTAL VOLUME	PITCH	CHANGE IN BODY CONTOUR
	Not covering	Under/over full; causing poor coverage	Under/over full; causing poor coverage	> 4°	≥ 1 cm at all field entry points
	Primary CTV at edge of PTV contour	Under/over full; not affecting coverage	Under/over full; not affecting coverage	3° – 4°	≥ 1 cm at one field entry point
	≥ 3 mm margin around primary CTV	Similar to planned volume	Similar to planned volume	< 3°	< 1 cm

✅ Traffic light protocol should include

- Rotational tolerance
- Target volume requirements
- OAR requirements (when any)
- Anatomical changes guidance -> triggered adaptation

Alexander et al. TipsRo, 2019 RTT-led IGRT for cervix cancer; training, implementation and validation


Instruct patients to empty bladder and bowels before performing local filling protocol
Acquire daily CBCT
Perform initial automatic bone match. Set ROI box to cover entire treatment volume + bony anatomy
Significant Rotation
Unacceptable bony rotation, repeat patient setup
Assess bladder/rectal filling
Significant Variation
Bladder: If affecting rectal position, remove patient from couch to empty/refill
Significant Variation
Rectum: Remove patient from couch, encourage them to empty bowels naturally
Online assessment of target volume coverage
GTVp well covered by PTVp
GTVp not adequately covered
Assess CTV/PTV coverage
GTVp is ≥5mm outside of PTVp
GTVp is ≤5mm outside of PTVp
CTV well covered
Mesorectum/CTV outside of PTV
Intervention Required: Remove patient from couch, instruct them to empty rectum. If they cannot do this naturally, consider micro/phosphate enema.
Apply soft tissue match, acceptable for 1# ONLY
Manually apply soft tissue match up to 5mm so GTVp is covered
Interventions Fail
Mesorectum consistently outside of PTV for 5#'s
GTVp is ≥5mm outside of PTVp for 2 consecutive #'s
Check CTV is still covered by PTV
Trial patients must not miss a fraction of treatment
Prioritise match to GTVp
Contact local PI and RTTQA
Consider rescan/replan
Proceed with treatment

Leids Universitair Medisch Centrum



Rianne de Jong
RTT
Leiden, NL



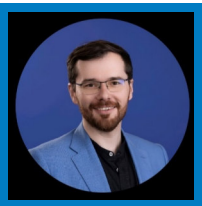
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MRO.ART
MODERN RADIATION ONCOLOGY
36° RESIDENTIAL COURSE

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Fondazione Policlinico Universitario Agostino Gemelli IRCCS
Università Cattolica del Sacro Cuore

GART
Advanced Radiation Therapy

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Treatment planning

Calculation and reporting dose

- Type-B and Type-C dose calculation algorithms enable dose calculation in reasonable time frame; the use of older Type-A algorithms is no longer justified
- Current consensus guidelines recommend Dose-to-Medium (D_m) as the standard for dose reporting
- Although many historical OAR constraints were developed using Dose-to-Water (D_w), reporting in D_m is preferred to ensure consistency with current and future clinical trials
- Comparison with historical data using D_w may be useful, but routine conversion of D_m to $D_{w,m}$ is not recommended due to reduced accuracy
- Differences between D_m and D_w are generally small, whereas $D_{w,m}$ can overestimate dose in some tissues (e.g., cortical bone by up to ~10%)

✅ Use modern Type-B/Type-C calculation algorithms and report in dose-to-medium (D_m)
✅ Special care should be taken when comparing D_m with dose-to-water (D_w) in cortical bone
✅ It is not recommended to convert D_m to D_w (dose to water in medium, $D_{w,m}$) as this will result in poorer agreement with either D_w and D_m.