Quality assurance and workflow considerations for adaptive radiotherapy

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Adaptive Radiotherapy (ART)

- A close-loop process involving systematic monitoring of treatment variations (anatomic or biological) and altering treatment plan to account for:
  - Systematic or progressive changes (offline ART)
  - Stochastic changes (online ART)

*Organ: subject to filling and deformation including bladder, rectum, cervix, and stomach etc.*
Offline and online ART

• Complex workflow and decision-making
• Compressed time frame
• Key components:
  • Imaging for monitoring
  • Assessment
  • Re-planning and evaluation
  • Quality Assurance (QA)

Green et al. Semin Radiat Oncol 29, 2019
Offline ART - Risk and failure mode

- Failure mode and effects analysis (FMEA) indicated:
  - ART risk priority numbers (PRN) increased by 38%
  - 75% attributed to segmentation and planning processes
  - 13 unique critical failures for offline ART
  - Largely due to increased time constraints, user inattention and inadequate training

Process-based quality management is essential for ART

Noel et al. Medical Physics, 41(8), 2014
Online MR guided ART

- Complex workflow involving several critical clinical decisions
- Multidisciplinary teamwork similar to surgical operation
- Requires high quality on-board imaging guidance and automated planning tools
- Time and efficiency management
- Safety and QA
Monitoring and Assessment - Imaging

- Image quality directly impacts assessment and decision-making
- Optimal image sequence for soft tissue contrast
- Image artifacts (motion, metal...)

Images:
- 25s free breathing
- 25s breath hold
- 17s breath hold
- TrueFISP
- T1
Daily MR QA tests

- Traditional ACR phantom based QA tests are too time-consuming to be performed on a daily basis
- Automated phantom image analysis can expedite the process for daily QA

Uniformity test detected failure in one of the MR coil elements

Courtesy of Dr. Yingli Yang, UCLA
Accelerated 3D Balanced SSFP imaging

- Variable-density Poisson-Disk (VDPD) technique with 15x under-sampling (12.5s)

Courtesy of Dr. Yingli Yang, UCLA
Assessment - Decision making

• To adapt or not:
  • Visual evaluation can be subjective
  • Uncertainties in direct deformable registration of dose and structures
• Dose prediction with manually refined contours is accurate, but time-consuming

Retrospective dosimetric analysis indicated that more fractions need adaptive than online visual assessment

Tyran M et al. Radiother Oncol. 129.2 (2018)
Quality and Efficiency of Contouring

- Relies on quality of deformable image registration
- Usually requires labor-intensive manual correction
- Advanced auto-segmentation approaches (statistical shape, deep-learning, biomechanical models…)
- QA tools for checking contour integrity (empty, incomplete, size/shape change, etc.)
Re-planning / optimization

• Speed and efficiency
  • Forward adaption (beam weighting, aperture shape, MUs)
  • Using initial plan parameters for optimization
  • Automated tools: structure expansion and Boolean, dosimetric evaluation etc.

• Plan quality:
  • Robust planning
  • Beam angle optimization
  • Knowledge based planning

Patient specific QA

- Traditional measurement based QA is not feasible for online ART
- Alternative methods:
  - Independent dose calculation
  - Retrospective post-treatment measurement or delivery log analysis
  - “Simulated” treatment delivery without beam-on
  - Real-time monitoring (EPID, real-time tracking of machine delivery…)

Li et al, Medical Physics, 42,1, 2015
Physics plan and chart review

• Most effective QC procedure, but actual sensitivity varies depending on the design of checks and workload stress

• Risk analysis (FEMA) and incident learning system can be used to develop the checklist

• Automated plan check tools to improve efficiency

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Ford et al. IJROB, 84, 2012
End-to-end test

- A simple and effective method to validate the entire workflow
- Require phantoms capable of simulating anatomical change (displacement or deformation)
- Periodic (daily) E2E to test functionality and connectivity of all the major components of ART
Communication and documentation

• Complex workflow and decision-making require well documented directives and communication

• A “hand-off” procedure with clear documentation to ensure consistency in decision-making
Process management and improvement

• Compressing many days of work in a much shorter setting
• Require robust process-based quality management
• Areas for improvement
  • Improve image acquisition speed and quality
  • Contouring accuracy and efficiency
  • Fast and robust re-planning and effective QA
  • Staff training, coordination and communication

Automation to maximize efficiency, quality and safety

Minimizing errors through application of risk analysis
ART - an evolving process
ART - an adapting process

- Control console
- Planner planning
- Remote Access
- MD review plan
Summary

• ART holds great promise for personalized patient care, but involves complex workflows in compressed timeframe.

• Robust and comprehensive process-based quality management is necessary:
  • Automation to maximize efficiency, quality and safety
  • Well-documented procedure and well-integrated team work with sufficient training
  • Prospective quality management (process map, FMEA analysis, fault tree..)
Thank you!