On-line Imaging for Position and Dose Verification

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1.0 Introduction

The increased complexity of radiation therapy (RT) delivery systems combined with the desire to increase the precision and accuracy of radiation field placement have resulted in the substantial development in the area of "on-line" evaluation and correction in RT. These developments take a variety of forms and range from complex devices through to complex processes. The purpose of this lecture is to communicate the current technology available to the medical physics community and to inform them of trends in technology development as it relates to the "on-line" evaluation and correction of therapy. The lecture is structured to cover two components of verification in radiation therapy - (i) the positioning of the patient with respect to the treatment coordinate system, and (ii) the capacity of the treatment machine to reconstruct the desired dose distribution as intended in the planning process. It is clear that this separation is a simplification of the more realistic conditions that can occur, for example, during the delivery of dynamic intensity modulated therapy (IMRT) in a site influenced by breathing motion, however, for purposes of this lecture these two issues will remain separated as methods of verification are not, as yet, in the mainstream.

2.0 On-line Techniques for Target Position Detection, Correction and Verification

Significant effort has been invested in the manufacture of technologies for quantification of target position within the human body at the time of therapy. Traditionally, the patient has been aligned according to the projection of optical systems (such as lasers) on to the patient's skin and localizing tattoos. The use of external markers to infer target and normal structure location within the body obviously has its shortcomings. Up to the past 5 years, the primary method of measuring the location of internal targets was through acquisition of portal images. These images verify the relative position of the beam 'ports' with respect to the internal anatomy. Aside from improved portal imaging devices, these novel technologies have taken the alternative approach of detecting the position of target structures (or their surrogates) with respect to machine isocenter (as opposed to the central axis of the beam). These innovations are listed in generic form in Table 1.

Table 1: Technologies and Methods for Verification of Patient Positioning

		Strategy		
		Immobilization/Setup Aids	Off-line	On-line
Setup Errors	Inter-fraction	Alignment/Constraint Standard procedures Lasers/Light Field on Tattoos Thermoplast masks Tape Bite Blocks Vacu-Form molds/casts Thermoplast Body Casts Stereotactic Head Frame Stereotactic Body Frame	Conventional weekly port film practice Statistical Approaches: i) Population-based thresholds. ii) Individual-based thresholds.	MV-Radiographs (conventional pre-ports) EPID MV-Radiographs On-line kV Radiographs (with/without markers) Optical Video Monitoring
	Intra-fraction		(see note **)	MV Fluoroscopic kV Fluoroscopic Optical Video Monitoring Optical Reflectors/Markers
Organ Motion	Inter-fraction	Breath-hold Consistent Time-of-Day Active Breathing Control Specifications (bladder/rectum, full/empty) Patient position (prone/supine)	Off-line strategies based on repeat CT scans.	On-line Computed Tomography (CT-on-a-rail, Cone-Beam CT, Tomotherapy) Ultrasound Other imaging modalities (MRI, Ultrasound)
	Intra-fraction	Breath-hold Compression Plate Active Breathing Control	(see note **)	Respiratory Gating Cardiac Gating MV/kV Fluoroscopy of surrogates for organ motion

Notes:
**) Devices and procedures often serve not only to provide accurate interfraction alignment (setup aids) but also to constrain against intra-fraction motion (immobilization devices); hence, the distinction between inter- and intra-fraction strategies is blurred in this case.*
***) Although off-line correction strategies do not address intra-fraction variability directly, such strategies may provide margins which better accommodate such variability provided the inter- and intra-fraction motions are from the same distribution.*

3.0 On-line Techniques for Verification of Treatment Machine Operation

The increased complexity of delivery schemes has increased the concerns around maintaining delivery quality in external beam radiation therapy. The description of the radiation field at a given gantry angle has evolved from being fully described by 10 parameters (angles [gantry, collimator, table], modality, wedge, modifier, and four jaw positions) to being described by hundreds of parameters relating complex and changing field shapes for IMRT. The challenge of verifying the transfer of the desired prescription and its reproducible execution remains a substantial hurdle to broad implementation and, furthermore, hampers application in new sites. It is remarkable to note that the portal imaging system is beginning to play a new role in radiation therapy as a tool for verification of IMRT as well as conformal RT. Table 2 below embodies an attempt to layout the landscape of verification in treatment delivery. It should be noted that this verification is in addition to that being performed by the delivery system of the treatment systems itself. There is ample room for discussion in this area of verification. The need for verification is great, the challenge is to arrive at a system and distribution of responsibility (clinics/industry) that permits this valuable technology to be safely and confidently brought into the mainstream of radiation therapy practice.

Table 2: Technologies and Methods for Verification of Dose Construction

	Strategy		
	Off-line/Preparatory (Patient Absent)	On-line (beam-by-beam*) (Patient Present)	On-line (segment-by-segment*) (Patient Present)
Transfer/ Consistency with planning system	Visual Inspection of Graphical Print-out and Light Fields Pre-Tx course film (AgBr, GAFChromic) and chamber dosimetry (undersampled 3D) Pre-course film (AgBr) for BEV dosimetry Linear/Area BEV (diode/chamber arrays) Dosimetry Systems Volumetric Dosimetry Systems (Gels)	Verification Portal Films, EPIDs (SLIC, a-Si, CCD) (Conventional weekly port film/EPID practice Open-field segment verification for IMRT integrated with positional verification) Diodes (C/A or specific anatomical site on BEV) Record and Verify Systems	EPIDs (SLIC, a-Si, CCD) Tomotherapy MV linear array *Enhanced* Record and Verify Systems (Secondary logging systems for inferential verification of IMRT execution)
Intra-therapeutic Verification (reproducibility of execution /correct selection of treatment parameters)			

Notes:

**) Segments refer to specific positional targets within the course of a beam delivery. A beam typically refers to a group of segments applied at a specific gantry angle. However, beams may also refer to other groupings of segments and may therefore extend across multiple gantry angles (intensity modulated arc therapy, tomotherapy).*

***) Fully on-line imaging and delivery schemes will increase the pressure on the development of on-line verification methods. These methods will require verification in the presence of the patient, as removing the patient is not an option.*

Topics covered in the lecture:

MV Portal Imaging Systems for Target Positioning and Field Placement Verification

- commercial systems
- performance
- on-going research (radiographic and tomographic)

Kilovoltage (kV) Systems for Target Position Correction and Verification

- commercial systems (radiographic/fluoroscopic)
- performance
- research systems (tomographic)
- gantry mounted systems/room mounted systems

Optical Systems for Position Verification

- commercial systems
- point-based methods
- video-based methods

Methods for Off-line Verification of Beam's Eye View Dose Distribution

- visual inspection
- ion chamber point measurement
- distributions (film, linear array, two-dimensional arrays)

Methods for Off-line Verification of 3D Dose Distribution

- Point-based methods
  - chambers, diodes, MOSFET systems
- Stacked 2D methods
  - film (AgBr, GaFChromic)
- 3D methods
  - gels(BANG, Fricke)

Methods for On-line Verification of Field shaping and IMRT Execution

- Radiographic/Fluorographic monitoring of fluence and field edges
  - EPID
  - Linear array (MV – Tomotherapy)
- Enhanced Record and Verify Systems

Methods for On-line Verification of 3D Dose Distribution

- Point-based methods
  - Diodes, MOSFET systems