Pelvis Therapy Education Symposium:
Planning, QA & Imaging

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Vancouver, Canada

Disclosures

- Jennifer L Johnson, M.S.
  - Nothing to disclose
- Ann Lawyer, M.S.
  - Nothing to disclose

Prostate Radiotherapy

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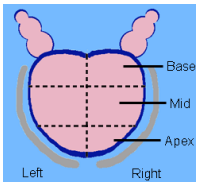
Prostate Cancer

- Incidence rate ~ 1 in 6 men in U.S. will be diagnosed
- Estimated deaths in U.S. in 2008: 28,660
- Median age diagnosis: 72 yrs
  - prevalence likely increases with age
  - 64% cases in men ≥ 65 yrs
- Present with urination symptoms
- Risk factors include age, ethnicity, family history, diet & obesity

Prostate Cancer

- Most common noncutaneous cancer in men
- Usually adenocarcinoma (>90%)
  - ~4% transitional cell, thought arise urothelial lining
- Multifocal
  - 70% peripheral zone
    - ejaculatory ducts & SV
  - 15-20% central zone
  - 10-15% transitional zone
    - spread bladder neck

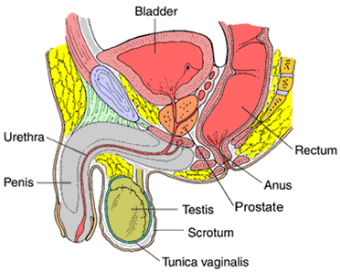


Prostate Cancer

- Rate of tumor growth
  - Very slow to moderately rapid
  - Early-stage doubling time ~ 2-4 yrs

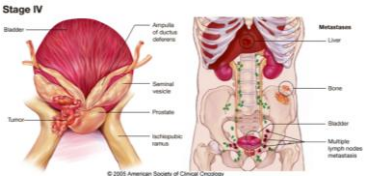
Relative survival rates (1996-2003)	All stages (5 yr) %	Local & Regional (5 yr) %	Distant (5 yr) %	All stages (10 yr) %	All stages (15 yr) %
Prostate	98.4	100.0	31.9	91	76

Prostate Anatomy



Prognostic Factors

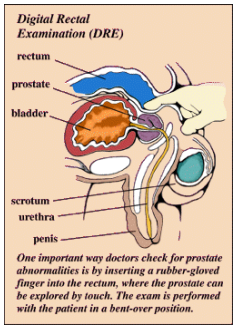
- Organ-confined - (Low; Intermediate; High) risk
- Locally-advanced (outside prostate)
- Node positive
- Metastatic (bone, liver, lung)



Diagnosis

- DRE
- PSA
- Gleason score
- Other imaging
  - CT – Lymph nodal involvement
  - MRI – SV involvement
  - Bone scan – bone metastasis

Digital Rectal Exam (DRE)



Prostate Specific Antigen (PSA)

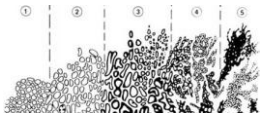
- Antigen released by normal prostate tissue and tumor cells arising from the prostate
  - PSA normal range ≤ 4 ng/mL (≤ 2.5 ng/mL ≤ 60 yrs)
  - Normal prostatic growth: 0.04ng/mL increase per year
- PSA elevation may indicate the presence of prostatic disease

Approximate chance of having prostate cancer on biopsy:

Below 4 ng/mL	Between 4-10 ng/mL	Greater than 10 ng/mL
2%	25%	50% to 67%

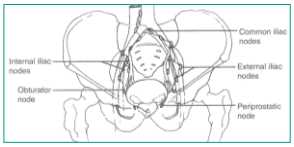
Gleason Score

- Gleason grade (1-5)
  - Histologic variation – 5 patterns
  - Based on degree of glandular differentiation and overall pattern of tumor growth at low microscopic magnification
  - Primary grade (>50%) and secondary grade (5-50%) characteristics



- Gleason score (2-10) = sum of Gleason grades
  - Low 2-4, Mid 5-7, High 8-10
  - E.g. Gleason 3+4 = 7

Prostate Lymphatics



- Prostate cancer first progresses locally and invades the local lymphatics in an orderly fashion:
  - periprostatic and obturator nodes
  - external iliac
  - hypogastric
  - common iliac
  - periaortic

Prognosis

Favorable

As nodal involvement increases, prognosis decreases.

Unfavorable

2002 American Joint Committee on Cancer (AJCC) Staging

- T1 Clinically inapparent tumor
  - T1a,b Found incidentally during TURP*
  - T1c Needle biopsy due elevated PSA
- T2a,b,c Palpable (one or both lobes)
- T3a,b Extracapsular extension, Seminal vesicle involvement
- T4 Invasion other structures

*TURP – Transurethral resection of the prostate

Risk Stratification

Table 1. Risk scoring schemes

	Seattle Risk Group (n = 232)	Mt. Sinai Risk Group (n = 232)	D'Amico Risk Group (n = 212)
Low	iPSA ≤10.0 Gleason Score 2–6 Stage T1a–T2b	iPSA ≤10.0 Gleason Score 2–6 Stage T1a–T2a	iPSA ≤10.0 Gleason Score 2–6 Stage T1c–T2a
Intermediate	iPSA >10.0 or Gleason Score ≥7 or Stage ≥T2c	iPSA = 10.1–20.0 or Gleason Score = 7 or Stage = T2b	iPSA = 10.1–20.0 and/or Gleason Score = 7 and/or Stage = T2b
High	2 or 3 of intermediate risk factors	2 or 3 of intermediate risk factors or Gleason Score 8–10 or iPSA >20.0 or Stage ≥T2c	iPSA >20.0 and/or Gleason Score = 8–10 and/or Stage = T2c

Abbreviation: iPSA = initial prostate specific antigen.

MDACC

Organ Confined Disease

	Radiation Dose	Radiation Target	Hormones
Low-risk	78 Gy in 39 fractions	Prostate alone	None
Intermediate risk	78 Gy in 39 fractions	Prostate and proximal SV	6 mos 2 mos before, 2 during and 2 after.
High-risk	78 Gy in 39 fractions (SV 45-54 Gy)	Prostate and SV as dose constraints allow	28 mos of hormone ablation, starting 2 mos before treatment

Post-Operative EBRT

- Adjuvant treatment – 60-70 Gy
  - Adverse pathology post RRP
    - + margins (> 10mm or ≥3 sites), ECE, SV involvement
    - + lymph nodes
  - Used after surgical recuperation
  - Detectable PSA (≤ 1.5 ng/mL)
- Salvage – 70 Gy
  - Biochemical recurrence/progression post RRP (- margins)
    - PSA not fall to undetectable
    - Detectable PSA increase 2 consecutive times
  - Post RT
    - Rising PSA ≅ ≥ 2 ng/mL above nadir PSA after EBRT ± ADT
    - Positive DRE

Alternatives to Standard EBRT

- Brachytherapy Seed Implantation
  - I-125 or Pd-103

ABS Rx doses

Isotope	No EB (Gy)	EB (40-50Gy)
I-125	144	100-110 Gy
Pd-103	115-120	80-90 Gy

100 Gy + 45 Gy = 145 Gy
80 Gy + 45 Gy = 125 Gy

- Hormonal Therapy

Hypofractionation

- Alpha/beta values debate
- Prostate may have low α/β
  - Therapeutic ratio may be enhanced by delivering fewer, larger fractions
  - Maintain normal tissue toxicities
  - May benefit intermediate risk patients
- SBRT
  - 32-38 Gy in 4 – 5 fractions; (~7-8 Gy per fraction)
- Results inconclusive

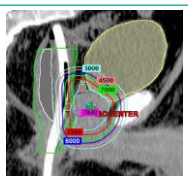
CT Simulation: External Immobilization

- Empty rectum (Fleet's enema 1 hour before sim)
- "Semi-full" bladder (18-24 oz 30 mins before sim)
- Supine, pillow under head, arms across chest
- Legs in immobilization device (indexed)
  - Patient's pelvis straight!
  - Relaxed muscles

CT Simulation: Scan Process

- Inferior border of the treatment field set at the bottom of the ischial tuberosities
- Longitudinal axis should split symphysis pubis
- 2.5mm slices, 2.5mm spacing
- Mini-scan – bladder fullness, sigmoid & small bowel
- Select isocenter (prostate)
- Look at skin contours
- Full scan

CT Simulation: Internal Immobilization



- Water or air filling
- Immobilization of the prostate
  - Bony alignment for prostate treatment – protons
- Displacement of sigmoid/small bowel away from prostate / sv

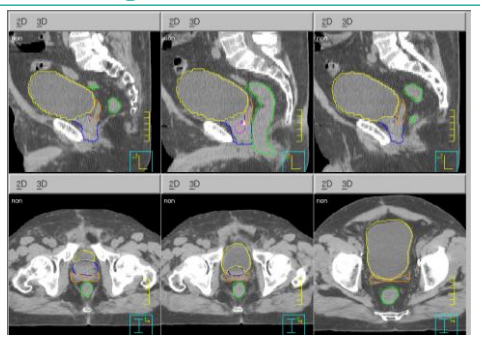
Target Structures

- Prostate
  - inf border/apex defined using sagittal imaging on treatment planning CT (1 slice above GU diaphragm)
- Seminal Vesicles
  - "Proximal SV" ~ 1.5cm (6 slices)
  - Distal SV – remainder
- Involved Lymph Nodes

Critical Avoidance Structures

- Rectum
  - inf border at bottom of ischial tuberosities
  - sup border at the rectosigmoid junction (~11 cm)
- Bladder
- Sigmoid & Small Bowel
- Femoral Heads

Contouring



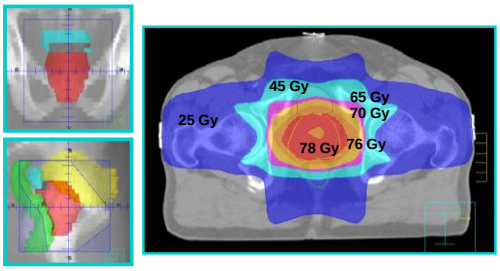
Margins for PTV

- PTV = CTV plus margin
- Setup uncertainty – aka localization
- Organ motion
  - Interfraction motion
  - Intrafaction motion
- 5mm posterior, 7mm for the rest

MDACC EBRT

- 4-Field Box
  - < 1995
  - Conventional 4-Field Box + 4-Field Boost (70 Gy)
- 3D Conformal Radiation Therapy (3D-CRT)
  - 1995
  - 4-Field Box + 6-Field 3D-CRT Boost (78 Gy)

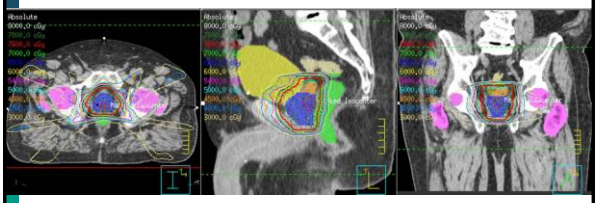
3D-CRT: 78 Gy to Isocenter



MDACC IMRT

- Intact prostate cases
  - 1998
    - 4-Field Box + IMRT Boost (75.6 Gy)
    - MIMiC (Dec 1998 - 2001)
  - May 2000 - Present
    - Prostate (75.6 Gy / 76 Gy / 78 Gy mean); SV (45 – 54 Gy)
    - Step-and-Shoot MLC (sMLC)
- Prostatectomy cases
  - 2005?
    - Prostatic fossa (70 Gy); SV fossa (57.75 Gy)
    - sMLC

IMRT: 80 Gy to Isocenter

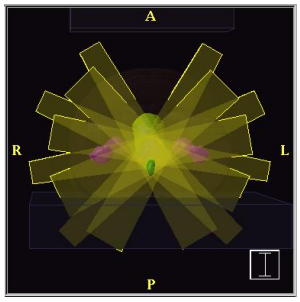


IMRT Beam Angles

Gantry Start / Stop	Couch	Coll
225 / 225	0	0
260 / 260	0	0
295 / 295	0	0
330 / 330	0	0
30 / 30	0	0
65 / 65	0	0
100 / 100	0	0
135 / 135	0	0

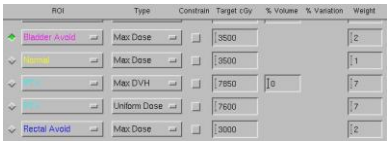
Old-IEC Scale

Occasionally 180° post-op



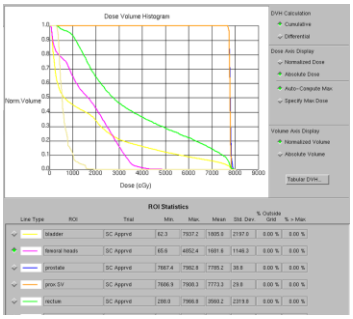
IMRT Dose Objectives

Structure	Type	Target (cGy)	%volume
PTV	Max Dose	7850	
PTV	Uniform Dose	7600	100
Rectum	Max DVH	1500	80
Rectum	Max DVH	3000	60
Rectum	Max DVH	4500	45
Rectum	Max DVH	7000	10
Bladder	Max DVH	1500	85
Bladder	Max DVH	3000	60
Bladder	Max DVH	4500	40
Bladder	Max DVH	7000	10
Normal tissue	Max Dose	3500	



IMRT Dose Volume Histogram

- Prostate:
  - >98%V@78Gy
- SV:
  - >95%V@78Gy
- Rectum:
  - <20%V@70Gy
  - <40%V@60Gy
  - <60%V@40Gy
- Bladder:
  - <20%V@70Gy
  - <35%V@60Gy
- Femoral Heads:
  - <10%V@50Gy

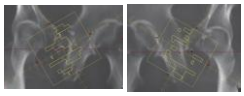


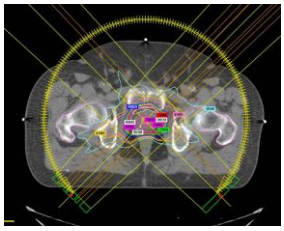
IMRT Evaluation

- Peripheral dose < 50 Gy
- Plan Total MUs < 700
- Rectum
  - 45 Gy should always split the rectum
  - 30 Gy not cover entire posterior wall but conformal
- Sigmoid
  - Distance from sigmoid to 76 Gy ≥ 1cm
  - 54 Gy spots, 50 Gy entirety ok
  - May need two IMRT plans get SV coverage
- Small bowel at 45-54 Gy

VMAT

- Volumetric Modulated Arc Therapy
- Three parameters are modulated simultaneously:
  - Gantry rotation
  - Dose rate
  - Leaf speed

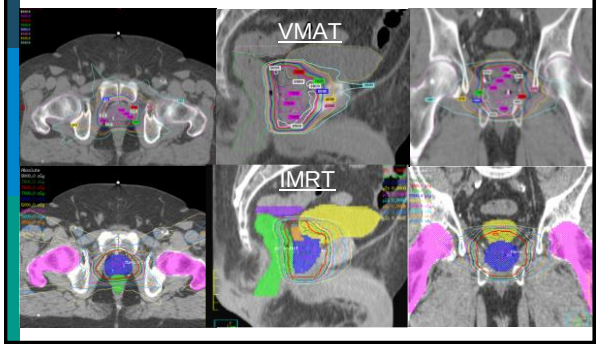




VMAT

- Arc optimization
  - MLC leaf positions & dose per degree are calculated for a # of cp in an arc field
  - Resulting MLC leaf positions & dose per degree are stored in a # of cp in the field
- Treatment machine control system determines how the dose rate & gantry speed need to be modulated in order to deliver the cp sequence in the plan

MDACC VMAT



MDACC VMAT

VMAT (Eclipse)

- 2 arcs
  - 225 – 135 CW
  - 135 – 225 CCW
- Total MU = 1119
  - (562 + 557)
- Total control points = 354
- Dose rate ~ 600MU/min
- Treatment time ~ 3min (75 sec per arc)

IMRT (Pinnacle)

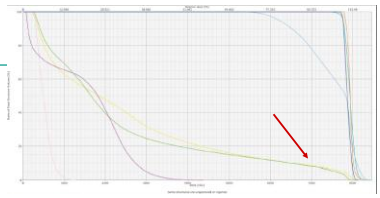
- 8 step-and-shoot fields
  - 225, 260, 295, 330, 30, 65, 100, 135
- Total MU = 706
- Total control points = 49
- Dose rate = 400MU/min
- Treatment time ~4.5min

*NB: Pinnacle SmartArc recently commissioned but not delivered for prostate treatments. MUs lower than Eclipse plans

DVH

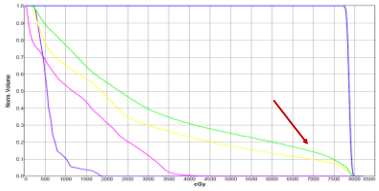
VMAT

- Bladder, rectum 8% volume @ 70Gy

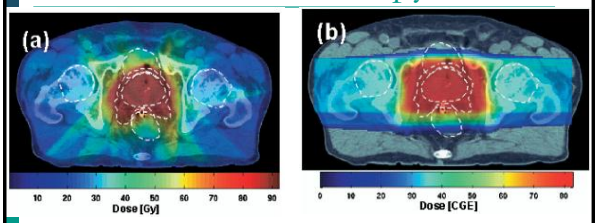


IMRT

- Bladder 10% volume @ 70G
- Rectum 15% volume @ 70G



Proton Radiation Therapy



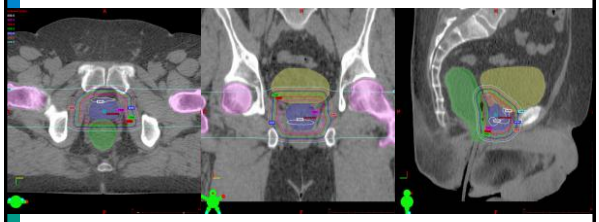
IMRT 3-D Conformal Proton Therapy

- Reduces damage to surrounding tissues
- Greatly reduces side effects
- Treatment of choice for lesions close to sensitive areas of the body

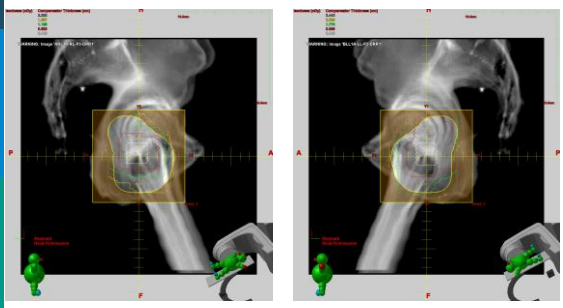
Trofimov *et al*, *IJROBP*, 2007, 69 (2), pp 444-453

MDACC Proton Therapy

- Protons 2-Field – Passive Scattering Beams
  - May 4, 2006

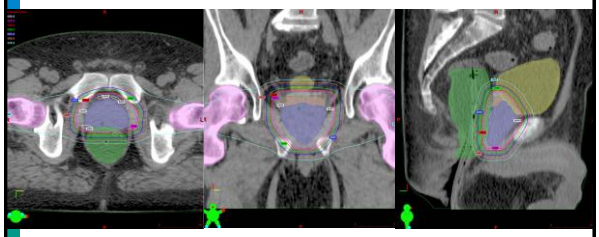


MDACC Proton Therapy



MDACC Proton Therapy

- Protons 2-Field – Scanning Beam
  - May 5, 2008

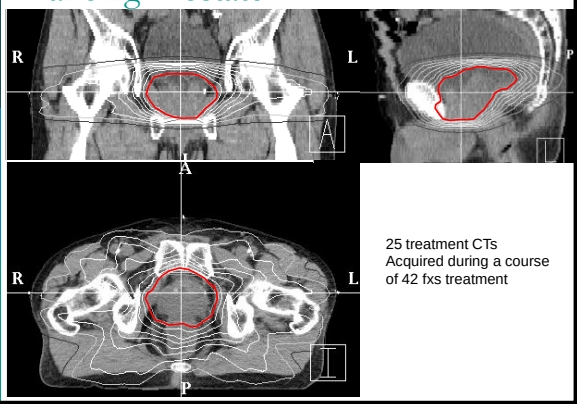


Imaging for Setup, Localization, & Re-planning*

Image-Guided Radiation Therapy (IGRT)

- Setup / Localization
- Organ motion
  - Interfraction & intrafraction
  - Bladder volumes and rectal filling
- Re-planning
  - Prostate setup confirmation – e.g. rectal balloon, sigmoid/small bowel toxicities

Dancing Prostate

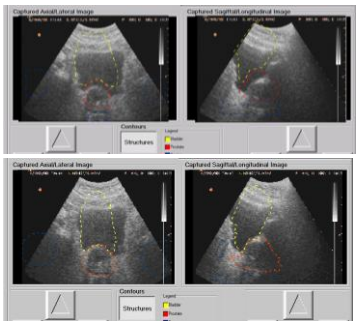


25 treatment CTs Acquired during a course of 42 fxs treatment

Target Localization

- Ultrasound guidance
  - Soft tissue alignment
  - No dose (NOMOS B-Mode Acquisition and Targeting System)
- Implanted fiducials (kV)
  - Soft tissue alignment
- Bony anatomy (kV)
  - Prostate moves relative to bone
- Cone beam CT (CBCT)
  - Image quality needs to improve
  - Spot-check endorectal balloon placement

Ultrasound Guidance



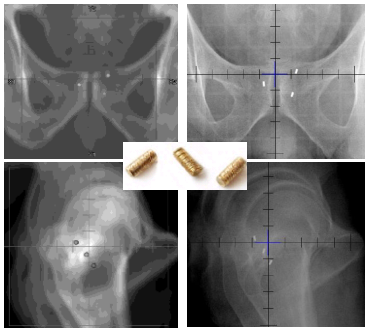
Before alignment

Required Couch Movements

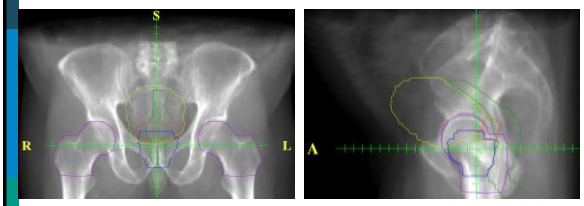
Couch Left	1.68 cm
Couch Down	0.36 cm
Couch Out	0.13 cm

After alignment

Fiducial Markers



Bony Alignment



Setup Reference DRR (AP)

Setup Reference DRR (L_LAT)

Bladder volumes

Differences from CT Prostate Registration

	x = DOWN (+) [Ant]		y = IN (+) [INF]		z = RIGHT (+)	
	delta x	delta sd x	delta y	delta sd y	delta z	delta sd z
implanted fiducials						
mean	-0.02		0.02		0.02	
std dev Sigma	0.12		0.11		0.06	
RMS random error		0.20		0.22		0.19
overall error	**0.18**		**0.19**		**0.16**	
BAT shifts						
mean	-0.27		-0.10		0.12	
std dev Sigma	0.33		0.30		0.16	
RMS random error		0.40		0.38		0.35
overall error	**0.38**		**0.36**		**0.30**	
Bony Registration						
mean	-0.01		0.00		-0.01	
std dev Sigma	0.19		0.20		0.05	
RMS random error		0.22		0.20		0.07
overall error	**0.21**		**0.20**		**0.07**	

Imaging

- CBCT
  - Image quality can be an issue
  - Can be used for positioning
  - Critical organ localization
  - Can visualize changes to consider re-planning

Introduction

- Gynecological Cancer
  - Introduction
- Cervical Cancer for Intact and Post-operative Cases
  - Diagnosis, Evaluation, History
  - Anatomy and disease progression
  - Staging
  - Treatment Planning, simulation and QA
  - Examples

Gynecological Epidemiology - US

- ~80,000 new cases of gynecological cancer annually
  - Cervical – 11,070
  - Endometrial – 40,100
  - Ovarian – 21,650
  - Other (vulvar, vaginal)
- 27,000 deaths account for 10% of overall cancer mortality
  - Cervical – 2%
  - Endometrial – 18.6%
  - Ovarian – leading cause of cancer death in gynecological malignancies,

Cervical Cancer Epidemiology

- Cervical intraepithelial neoplasia prevalent in younger women
- Invasive cervical cancer rates appear at a later age (50-60)
  - Squamous cell carcinoma – 75%
  - Adenocarcinoma (seen in increasing numbers of women <40)
- Cervical cancer is on the decline in the US
  - Cytologic Screening
- Black women, Hispanic and Vietnamese women
  - Recent immigration, sexual activity history
  - Birth control - adenocarcinoma
- Epidemiologic studies and molecular studies have shown that HPV plays a causative role but there is evidence – multi-factorial

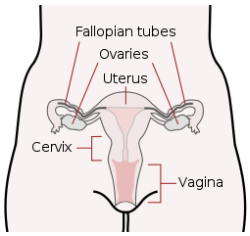
Radiation Therapy Text, Cox and Ang, 2010

Clinical Presentation

- Asymptomatic
- Detected during routine cytologic screening
- Discharge and bleeding most common symptoms – dependent on tumor
  - Exophytic
  - Endophytic and endocervical
- Urinary frequency, constipation, heaviness
- Advanced stages – abdominal swelling and pain and nausea but…
- Pain is rare
- Note: Currently no blood test for detection except for ovarian (Ca-125)

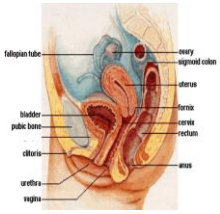
Cervix Anatomy and Tumor Progression

- 2.5 cm long, projects into anterior vaginal wall
- Divided into the supravaginal and vaginal regions
- Most cervical carcinomas arise between endocervix (IO) and exocervix (EO)
- Invasion into the muscular stroma may still remain confined to the cervix



Anatomy and Tumor Progression

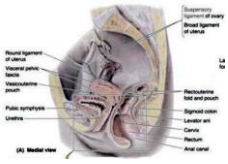
- Exterior to the smooth muscle of the uterus and cervix is a layer of viseral pelvic fascia - parametrium and paracervix
- The uterine fundus is covered by the peritoneum which covers the upper cervix and vaginal fornices to anterior rectal wall
- Large tumors may grow into this area but rarely invade the rectum
- Anteriorly the peritoneum reflects from the fundus to bladder but in only 5% of cases with large invasive tumors will the bladder be involved. (by cystoscopy)



Gray's Anatomy. Philadelphia WB Saunders 1980

Anatomy and Tumor Progression

- The uterus is connected to surrounding structures by a number of **peritoneal folds and ligaments** and are continuous with the paracervix tissue.
- These serve as conduits for direct extension of cancer of the cervix
- Tumors that invade the paracervical fascia can involve **broad ligaments or rectouterine space** and gain access to these regions by lymphatic extension

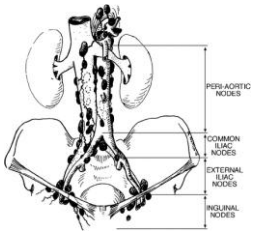


Tumor Progression Synopsis

- Squamous cell – arises in epithlium and spread laterally
- Adenocarcinoma's – arise in endocervical canal and are exophytic in nature
- Local extension of cervical tumors are common
  - Involving the uterus, vagina ad pelvic ligaments
  - Disease progresses into the lymphatic system
    - Late Spread will involve nerves, pelvic bones, peritoneal cavity, vulva and then other organs

Pelvis Lymphatics

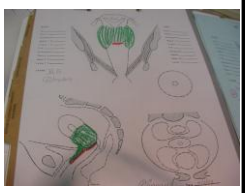
- Lymphatic's of the cervix drain to internal, external and common iliac nodes
- Uterus drain laterally to external iliac nodes
- Fundus drain with those from the ovary to para-aortic nodes
- Drainage from the external genitalia goes to the inguinal nodes



MDACC Dosimetry Planning Guidelines

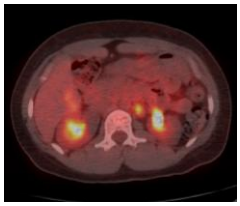
Original Staging Workup

- Cervical cancer traditionally has been staged clinically
- Physical examination
- Imaging
  - Originally limited role – film
  - Advances lymphangiography, ultrasonography, CT, MRI, PET, and lymphatic mapping



Current Staging Workup

- Physical examination
- Imaging Modalities
  - lymphangiography, ultrasonography, and lymphatic mapping
- CT is very useful but has limits, failure to detect small metastases
- MRI – soft tissue evaluation but also has limits in detection of positive nodes
- PET CT – lymph node identification and tumor size
- Biopsies for lymph nodes >1.0-1.5 cm



Pet Positive Node

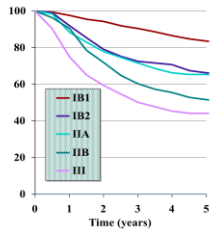
FIGO Cervical Staging

- FIGO (International Federation of Gynecology and Obstetrics) system
- Stage I – Cancer confined to the cervix
  - Stage IA – IA2 – Microinvasion disease, 3->7mm stromal invasion
  - Stage IB – Lesions greater than 7mm in horizontal spread
- Stage II – Involvement beyond cervix, including vagina except for the lowest third , or infiltration of parametrium but not extending to pelvic sidewall
- Stage III – Involvement of the lowest third of the vagina or pelvic sidewall
- Stage IV – Cancer extends beyond reproductive tract

Prognostic Factors

- Tumor size
- Lymph Node involvement
- Histologic Type and Tumor grade
- Patient related Factors

Disease-Specific Survival



Treatment Options

- Based on the staging
  - Surgery alone or Radiation therapy alone
  - Lesion size >3 cm and vaginal involvement – RT (recommended)
  - With 6 cm or "barrel" shaped tumors - RT – either alone or before hysterectomy
  - Definitive RT: EBRT and intracavitary implants

Tumor Size (cm)	Number of Patients	Central Tumor Control Rate (%)	Pelvic Tumor Control Rate (%)	Disease-Specific Survival Rate (%)
<5	701	99	98	90
5–5.9	200	93	85	69
6–6.9	99	92	79	69
7–7.9	55	90	81	58
≥8	48	69	57	40

Radiation Therapy Alone - Eifel PJ, Morris M, Wharton JJ, et al Int J Radiat Oncol Biol Phys 29:9, 1994.

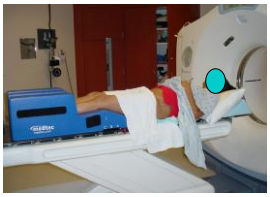
EBRT for the Cervix

Intact Cervix
- Conventional 2-Field AP-PA
- 3D Conformal Radiation Therapy (3D-CRT)
  - 4-Field Box

Post-operative cervix
- IMRT
- IMRT/IGRT

CT Simulation

Standard Pelvis Setup
- Supine
- Regular head holder or pillow
- Arms high on chest holding A-bar, with or without vacloc
- Legs
  - Relaxed in lower vacloc cradle
  - Med-Tec leg device



CT Simulation

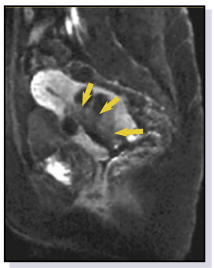
- All Gyn patients will need an anal verge marker (small metal BB) for the CT scan which will mark the inferior extent of the disease
- Full bladder
- The isocenter is usually placed midline, mid-depth and 2 cm above the femoral heads unless otherwise specified
- Scan from either T12 or L2 down through mid-femur
- 2.5 - 3mm slices
- Mini-scan
- Select isocenter

CT Simulation

- Patients with large extension into the vagina may also be treated frog legged.
- Using the frog legged position:
  - Prevents the skin from to much dose
  - Provides adequate dose to the vagina

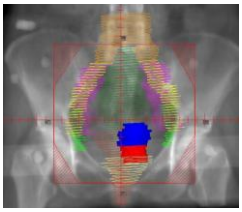
Role of EBRT for Intact Cervix

- Shrink tumor to improve geometry
  - Endocervical
  - Exophytic
- Sterilize disease beyond the high dose rate ICBT region
  - Paracervical
  - Nodal



AP/PA
Pelvic RT for Intact Cervix

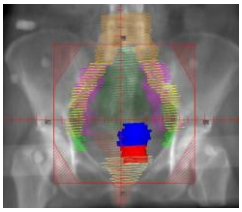
- Post-op for locoregional advanced disease
- Problem – treatment of normal tissue to provide adequate tumor control
- Must cover common, external and iliac nodes
- Superior border - L4-L5
- Inferior border cover the upper portion of the vagina
- Laterally the fields must cover the iliac nodes > 15 cm wide



45 Gy in 25 FX

AP/PA
Pelvic RT for Intact Cervix

- Block the femoral heads but should not compromise the pelvic ligaments
- Care must be taken covering the posterior border so that the uterosacral ligaments are covered
- And finally anteriorly - there is adequate coverage of the external iliac nodes



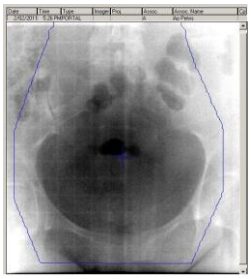
45 Gy in 25 FX

AP/PA
Pelvic RT for Intact Cervix

- Fields are limited to the pelvis 45Gy in 25 fractions
  - If with chemotherapy, then 40 Gy in 20 fractions
- In all cases the external beam should be completed in 5 weeks
  - Compliance issue
- If LDR ICBT is being done the total treatment time should not extend beyond 7-8 weeks

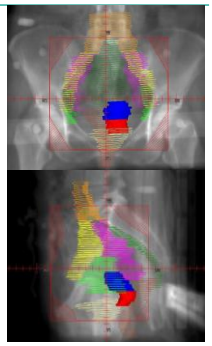
Localization

- MV imaging weekly
- AP/PA
- SSD's should be verified as well
- All patient marks should be assessed and improved if necessary



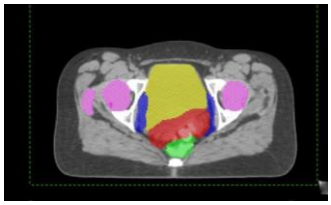
4 Field Technique
Pelvic RT for the Intact Cervix

- This technique will reduce the dose to the anterior small bowel or rectum
- Upper borders L4-L5 or at least be two vertebral bodies above known disease
- Inferior border: superior edge of pubic ramus
- Lateral borders: ~2cm lateral to bony pelvic, in order to cover lymph nodes
- If the tumor is bulky the and lateral fields are used relatively little pelvis can be spared

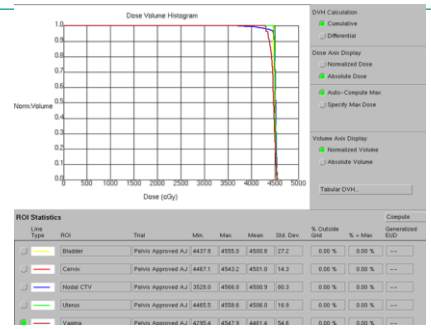


Contouring Intact Cervix

- Nodes
- Bladder
- Rectum
- Bowel
- Uterus, cervix, vagina

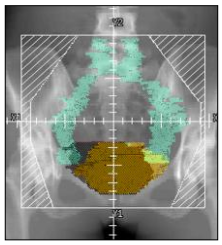


DVH Intact Cervix



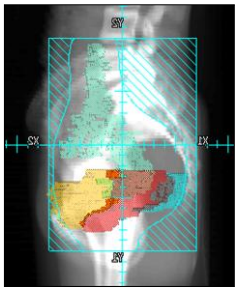
Post operative Radiation Therapy

- Planning similar to intact
- More consideration of small bowel
- Bladder fill is important



Conventional Radiation Therapy in the Post-operative Setting

- Laterals shield very little small bowel
- Small Bowel complications limit whole pelvis dose –
  - 10 – 12% Grade 3-4
  - Higher Grade 1-2
- High–risk post-op CX patients 45–50 Gy
  - prevents only 50–70% of pelvic recurrences



Conformality by MLC

Localization

- These patients should have imaging weekly – kV or MV
- AP/PA and RT/LT Lat
- Bladder fill should be assessed ± 10 - 20%

IMRT for Post Operative Cervix

CONSENSUS GUIDELINES FOR DELINEATION OF CLINICALTARGET VOLUME FOR INTENSITY-MODULATED PELVIC RADIOTHERAPY

Int. J. Radiation Oncology Biol. Phys., Vol. 71, No. 2, pp. 428–434, 2008

Common iliac lymph nodes -From **7 mm** below L4–L5 interspace to level of bifurcation of common iliac arteries into external and internal iliac arteries

External iliac lymph nodes -From level of bifurcation of common iliac artery into external artery to level of superior aspect of femoral head where it becomes femoral artery

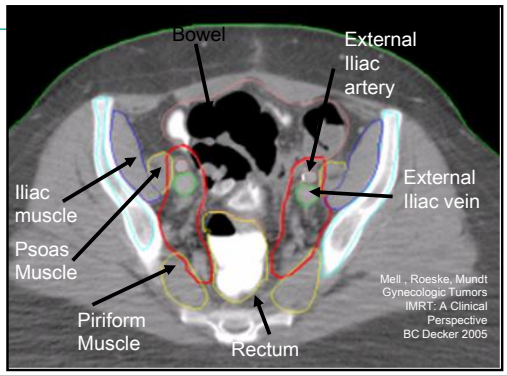
Internal iliac lymph nodes -From level of bifurcation of common iliac artery into internal artery, along its branches (obturator,hypogastric) terminating in paravaginal tissues at level of vaginal cuff

Upper vagina - Vaginal cuff and 3 cm of vagina inferior to cuff

Parametrial/paravaginal tissue - From vaginal cuff to medial edge of internal obturator muscle/ischial ramus on each side

Presacral lymph nodes* - Lymph node region anterior to S1and S2 region

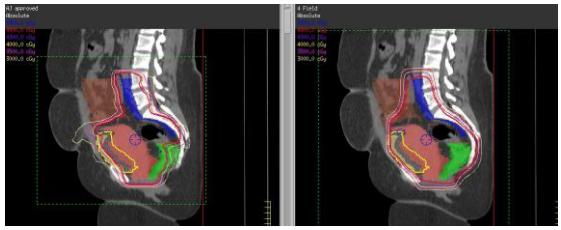
CTV Delineation



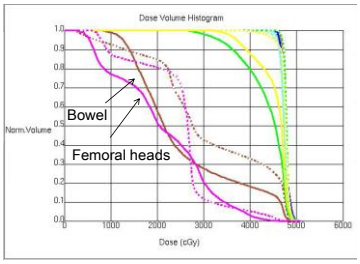
Critical Structure Doses

- Spinal Cord – 45 Gy (extended field L3 and above)
- Kidney – V 20 < 30%
- Pelvis Bones - > 60 Gy necrosis
- Duodenum – V60< 2cc
- Rectum – V45 < 60%
- Bladder – V40 < 35%, Bladder > 50 Gy fibrosis-hematuria
- Femoral Heads – V30 < 15%
- Small Bowel – 20-25 Gy enteritis, > 45Gy increases probability of injury

IMRT comparison with 4 Field



DVH IMRT vs. 4 Field

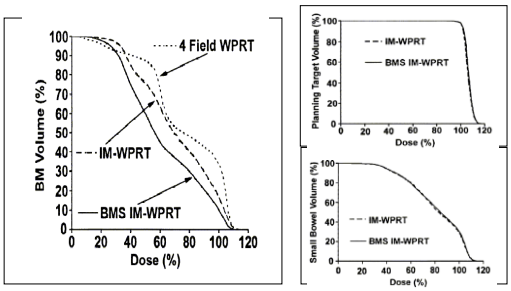


Dashed – 4 FLD, Solid - IMRT

Comparative Studies: Instensity-modulated Pelvic RT vs. Conventional Pelvic RT (Kochanski et al, Clin Adv Hematol Oncol, May 2006)

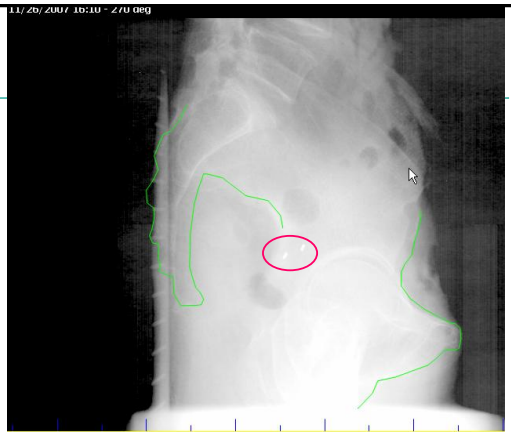
Authors	↓ Volume Receiving Prescription Dose		
	Small Bowel	Bladder	Rectum
Roeske et al	↓50%	↓23%	↓23%
Heron et al	↓51%	↓31%	↓66%
Chen et al	↓70%	↓Not-stated	↓Not-stated
Ahamad et al	↓40-63%	↓Not-stated	↓Not-stated
Wong et al	↓95%	NS	NS

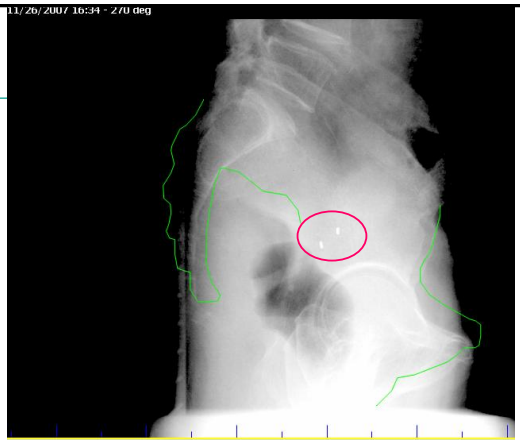
Bone Marrow Sparing – Lujan et al. 2003, Int. J Radiation Oncology Biol Phys

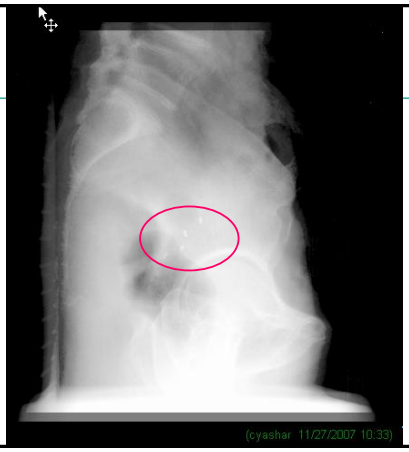


IMRT – Intact Cervix

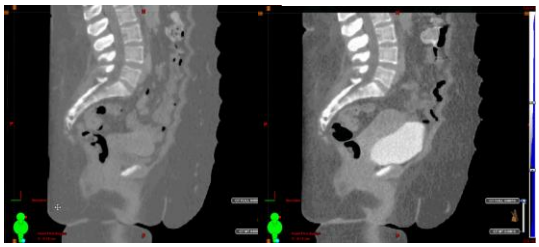
- IMRT for cervical cancer may be beneficial however need to account for:
  - Organ motion – both bladder and rectal filling
  - Accurate knowledge of the areas of risk
  - Tumor regression when there is gross disease







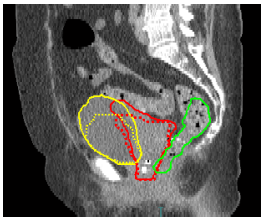
Organ Motion - Bladder



CT-on Rails – Yu, H, 2011

Reference

Daily



Bladder volume increased from 204 cc to 331 cc, a 62% increase!

Organ Motion

VAGINAL MOTION AND BLADDER AND RECTAL VOLUMES DURING PELVIC INTENSITY-MODULATED RADIATION THERAPY AFTER HYSTERECTOMY

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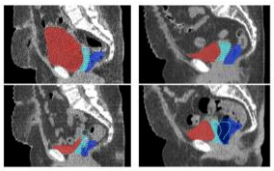
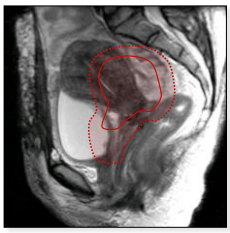
Departments of *Radiation Oncology and †Radiation Physics, The University of Texas M. D. Anderson Cancer Center, Houston, TX

Int. J. Radiation Oncology Biol. Phys., Vol. -, No. -, pp. 1–7, 2010



Internal Pelvic Organ Motion – Beyond Bladder

- More complex
- Tumor response
  - Shifts in position of critical structures
- Internal motion
  - Bladder filling
  - Rectal filling
- Contour changes



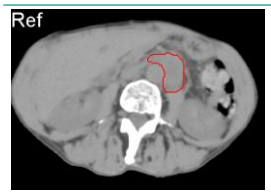
Treatment Response Variation

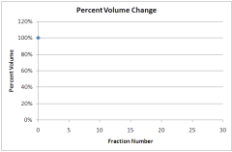
Beadle et al

- 16 pts - weekly serial ct scans and one with implant
  - Mean start cervical volume - 97 cc (range 37-302 cc
  - Mean end cervical volume - 32 cc (range 11.8-83.3)
  - Reduction of 62% no matter what stage
  - Median change in 20 days

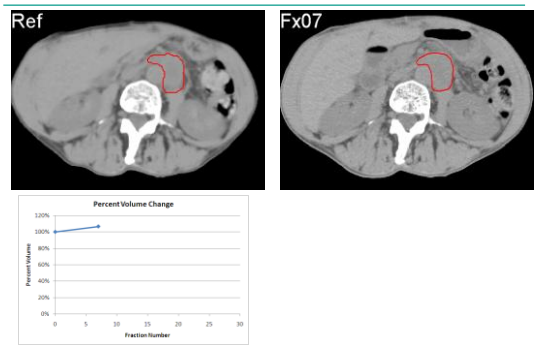
Tumor Regression & Re-plan

Yu, Henry, 2011, MDACC





Tumor Regression & Re-plan
Yu, Henry, 2011, MDACC



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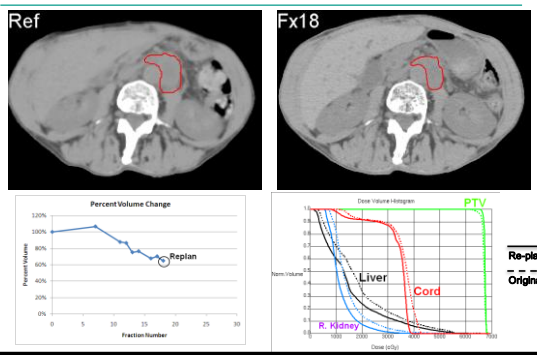

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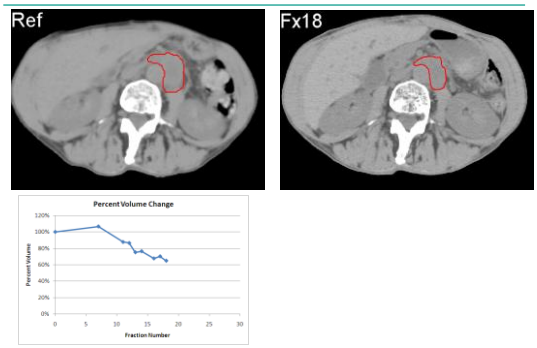


IMRT Considerations

- Need Daily imaging due to organ motion/tumor response
  - Rectal filling
  - Bladder filling
  - Movement of the fundus
- No clear definition on what should be included
  - Should the entire fundus be included in ctv
  - When to include para-rectal nodes
  - When should all the sacral nodes be treated
- How often should you replan?
- Should be done only in a protocol setting!!!!

Conclusions

- Treats less small bowel
- Results in lower acute bowel toxicity as well as chronic bowel toxicity
- Results in less bone marrow treated – may lead to better tolerance of concurrent chemotherapy
- May be able to dose-escalation without increase bowel toxicity leading to better local control
- Needs larger studies

Quality Assurance

Quality Assurance

- TPS
  - Quality assurance for clinical radiotherapy treatment planning (AAPM TG 53)
- Patient-specific treatment plan
  - Prescription, dose constraints, & plan parameters
  - Verification of monitor unit calculations for non-IMRT clinical radiotherapy (AAPM TG 114)
  - IMRT commissioning: Multiple institution planning and dosimetry comparisons (AAPM TG 119)
- R&V
  - Quality assurance of external beam radiotherapy data transfer (AAPM Task Group 201)

Machine-Specific QA

- CT Simulator
  - Quality assurance for computed-tomography simulators and the computed- tomography-simulation process: (AAPM TG 66)
- "Classic" Accelerator
  - AAPM Code of Practice for Radiotherapy Accelerators (AAPM TG 45)
  - Comprehensive QA for Radiation Oncology (AAPM TG 40)
  - Quality assurance of medical accelerators (AAPM TG 142)
  - Protocol for clinical reference dosimetry of high-energy photon and electron beams (AAPM TG 51)

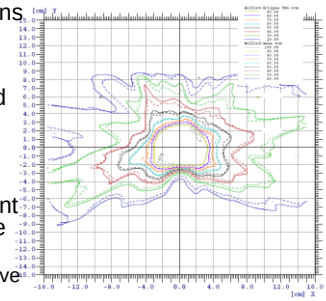
Machine-Specific QA

- IAEA Code of Practice for proton beams
- Basic Applications of Multileaf Collimators (AAPM TG 50)

- Modality-specific
  - Guidance document on delivery, treatment planning, and clinical implementation of IMRT: Report of the IMRT subcommittee of the AAPM radiation therapy committee
  - VMAT
  - (e.g., dynalog files)

Patient-Specific QA

- IMRT, VMAT, Protons
- **Ion chamber** measured dose is ±5% than calculated dose
- **2D measurement** Results are in qualitative agreement with calculated dose distribution
  - Passes for 5% relative dose/ 3mm criteria



Dynalog Results

Dynamic Leaf Deviation Error Histogram Data

225 CW

Bin No.	Error (cm)	10/12/2009 VMAT QA	10/14/2009 Fraction 1	10/15/2009 Fraction 2	10/16/2009 Fraction 3	Mean %	Std Dev %
		Percent					
1	0.000 - +0.005	19.95	20.09	19.94	19.94	19.98	0.07
2	0.005 - + 0.050	41.83	42.00	42.04	42.41	42.07	0.24
3	0.050 - +0.100	32.44	31.99	31.98	31.75	31.94	0.27
4	0.100 - +0.150	5.70	6.25	6.06	5.84	5.95	0.24
5	0.150 - +0.200	0.09	0.07	0.06	0.06	0.07	0.01
6	0.200 - +0.250	0.00	0.00	0.00	0.00	0.00	0.00

135 CCW

Bin No.	Error (cm)	10/12/2009 VMAT QA	10/14/2009 Fraction 1	10/15/2009 Fraction 2	10/16/2009 Fraction 3	Mean %	Std Dev %
		Percent					
1	0.000 - +0.005	19.63	19.42	19.22	19.32	19.45	0.21
2	0.005 - + 0.050	41.27	41.14	41.28	41.07	41.19	0.10
3	0.050 - +0.100	32.54	32.58	32.76	33.66	32.89	0.53
4	0.100 - +0.150	6.43	6.60	6.70	5.85	6.40	0.38
5	0.150 - +0.200	0.13	0.06	0.05	0.10	0.09	0.03
6	0.200 - +0.250	0.00	0.00	0.00	0.00	0.00	0.00

- 99% within error < 1.5 mm
- 94% within error <1.0 mm

Dynamic Leaf Deviation RMS Data

225 CW

Leaf No.	Crs	10/12/2009 VMAT QA	10/14/2009 Fraction 1	10/15/2009 Fraction 2	10/16/2009 Fraction 3	Mean (cm)	Std Dev (cm)
		cm					
Average	A	0.047	0.047	0.047	0.046	0.047	0.001
Maximum	A	0.057	0.058	0.057	0.057	0.057	0.001
Average	B	0.053	0.053	0.053	0.053	0.053	0.000
Maximum	B	0.063	0.063	0.063	0.063	0.063	0.000

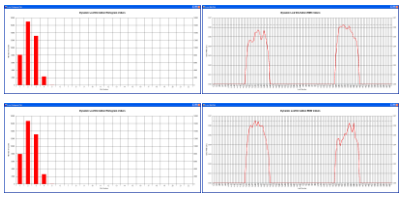
135 CCW

Leaf No.	Crs	10/12/2009 VMAT QA	10/14/2009 Fraction 1	10/15/2009 Fraction 2	10/16/2009 Fraction 3	Mean (cm)	Std Dev (cm)
		cm					
Average	A	0.053	0.053	0.053	0.052	0.053	0.001
Maximum	A	0.065	0.066	0.065	0.064	0.065	0.001
Average	B	0.049	0.049	0.049	0.048	0.049	0.001
Maximum	B	0.063	0.063	0.063	0.062	0.063	0.001

- Average RMS deviation = 0.5 mm
- Average Maximum = 0.6 mm
  - Global max = 0.66 mm

Dynalog Results

- Field A 225 CW
- Field B 135 CC



- Wijesooriya et. al., "Development of An Independent, Real-Time Software Algorithm to Ensure Patient Safety (SU-D-214-1)

Imaging QA

- Localization
  - ACR–ASTRO PRACTICE GUIDELINE FOR IMAGE-GUIDED RADIATION THERAPY (IGRT)
  - ACR TECHNICAL STANDARD FOR MEDICAL PHYSICS PERFORMANCE MONITORING OF IMAGE-GUIDED EXTERNAL BEAM RADIATION THERAPY (IGRT)
  - Quality assurance of U.S.-guided external beam radiotherapy for prostate cancer (AAPM TG 154)
  - The Role of In-Room kV X-Ray Imaging for Patient Setup and Target Localization (AAPM TG 104)
  - Clinical use of electronic portal imaging: (AAPM TG 58)

Quality Assurance

- Imaging dose
  - The management of imaging dose during image-guided radiotherapy (AAPM TG 75)
- Practice QA
  - AAPM Task Group 103 report on peer review in clinical radiation oncology physics
  - ACR/ASTRO Accreditation