Out-of-Field Dose Reconstruction for Studies of Health Risks Following Photon Radiotherapy When DICOM-RT Files Are Available

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NCI Investigating Late Effects Following Radiotherapy

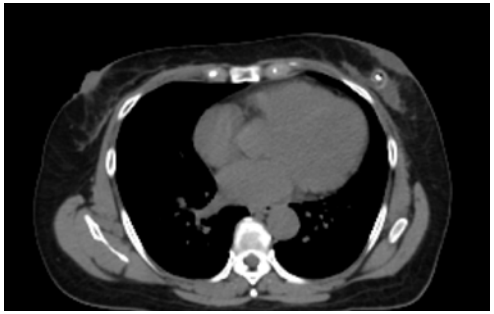
- Epidemiological studies correlate organ dose with incidence of new disease in a cohort of patients
- Cohorts can be observed retrospectively or prospectively
- Individualized dosimetry is critical, but challenging…
  - Studies last many years because of long latency of cancer
  - Large number of patients needed for statistical power
  - Expensive to access patient records & link to cancer registries
  - Detailed radiotherapy records (DICOM-RT) may not be available

This talks focuses on case when DICOM-RT are available to individualize the dosimetry

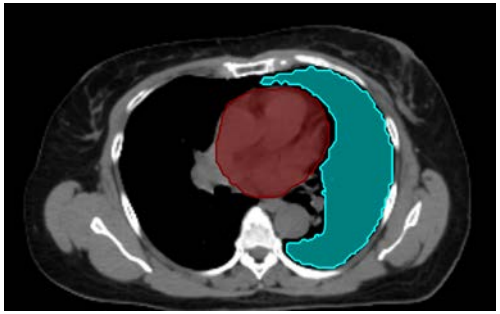
What is DICOM-RT?

- Digital Imaging and Communications in Medicine (DICOM)
- 1980's *became* clear need for standardization to facilitate interoperability amongst medical equipment and software
- Meeting held at RSNA 1994 to discuss need for standardization of radiotherapy specific data
- 4 DICOM RT objects ratified in 1997
  - RT Structure Set, RT Plan, RT Dose, RT Image
  - More objects added later

DICOM CT



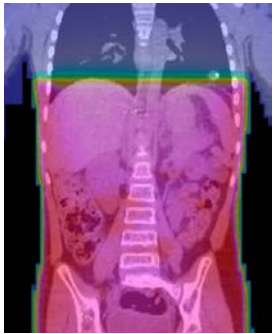
RT Structure Set



RT Plan

Geometric and Dosimetric Data Specifying Treatment

RT Dose

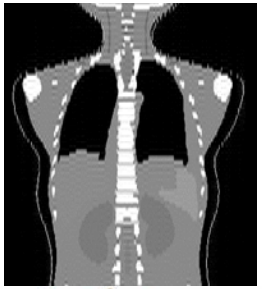


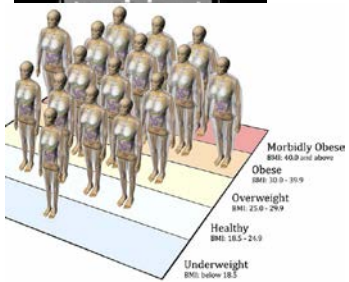
Individualized Dosimetry Using NCIRT

- Estimate dose to point or tissue location (in-field or out-of-field)

Patient Anatomy + Organ Contours

Patient CT or Phantom CT





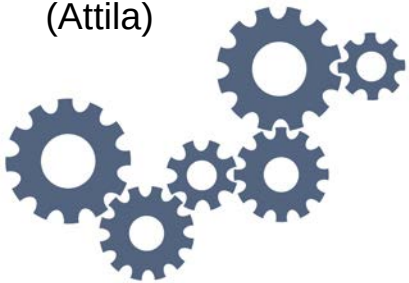
Radiotherapy Plan

DICOM
Digital Imaging and Communications in Medicine

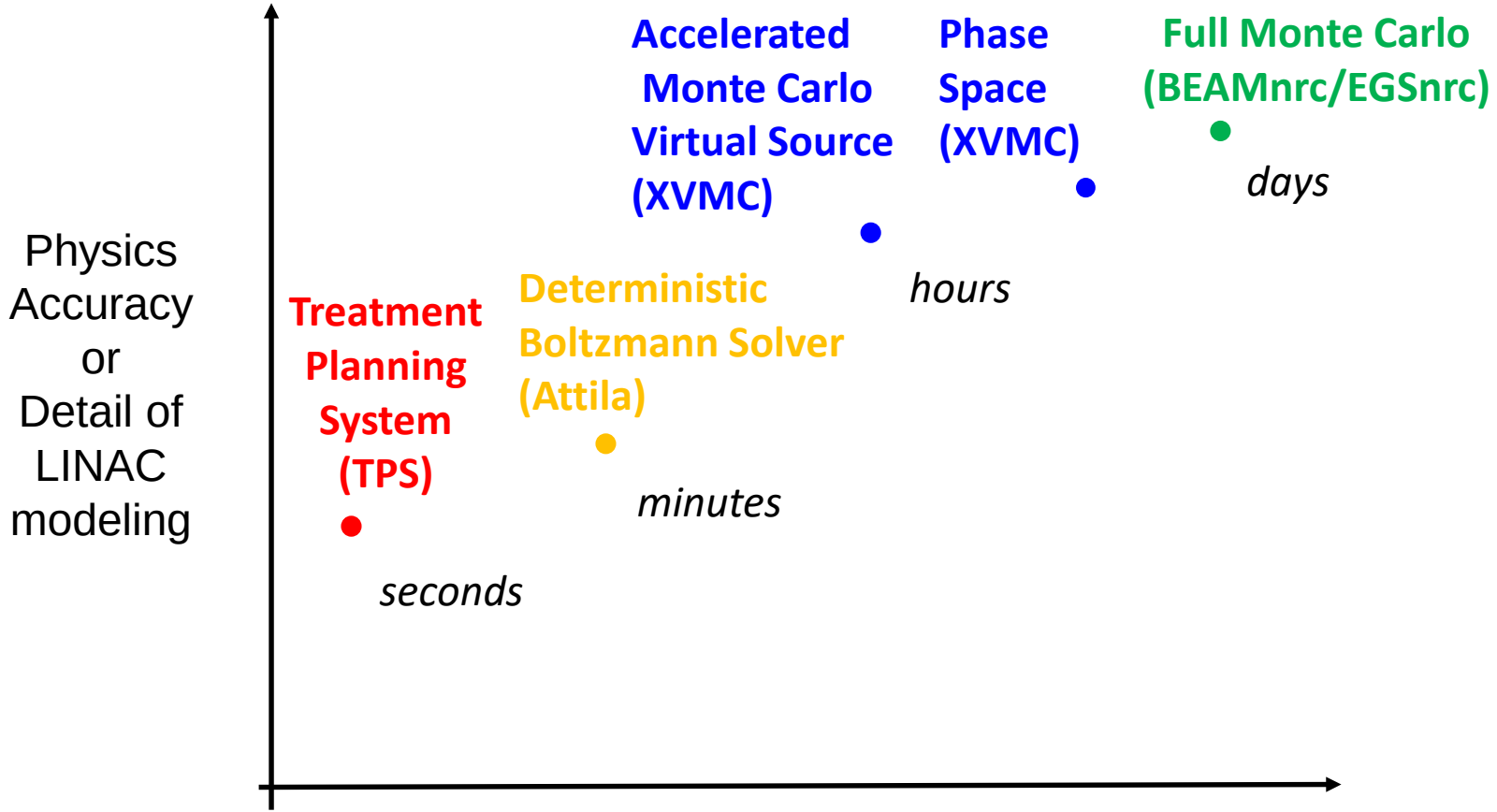
Acquire DICOM-RT Files From Patient Archive
OR
Recreate From Medical Records

Dose Calculation Engine

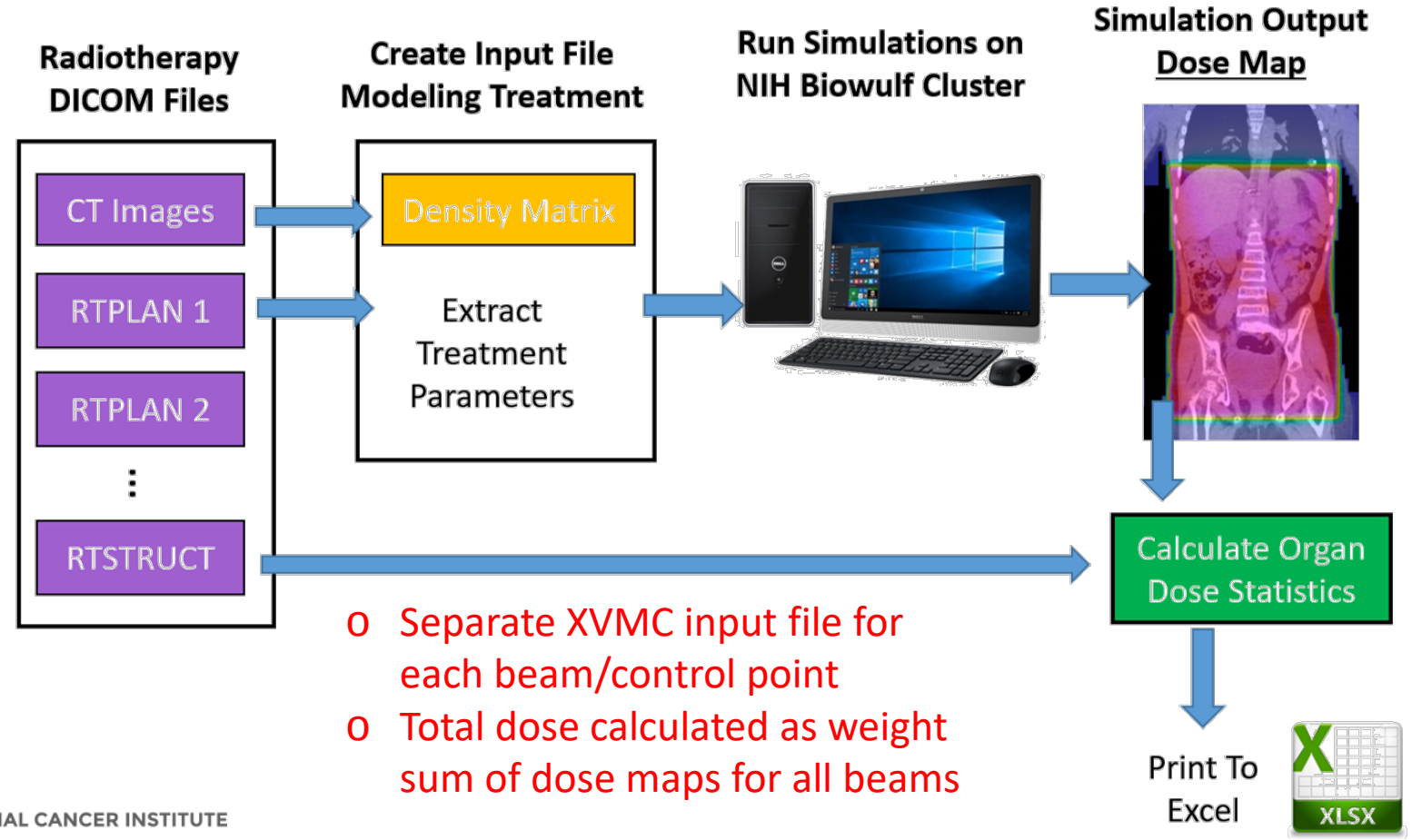
1. Treatment Planning System (AAA)
2. Accelerated Monte Carlo (XVMC)
3. Full Monte Carlo (BEAMnrc/EGSnrc)
4. Deterministic Approach (Attila)



Comparison of Dose Calculation Engines

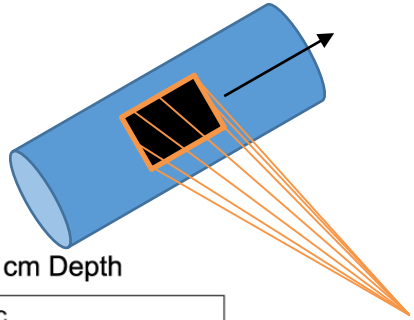


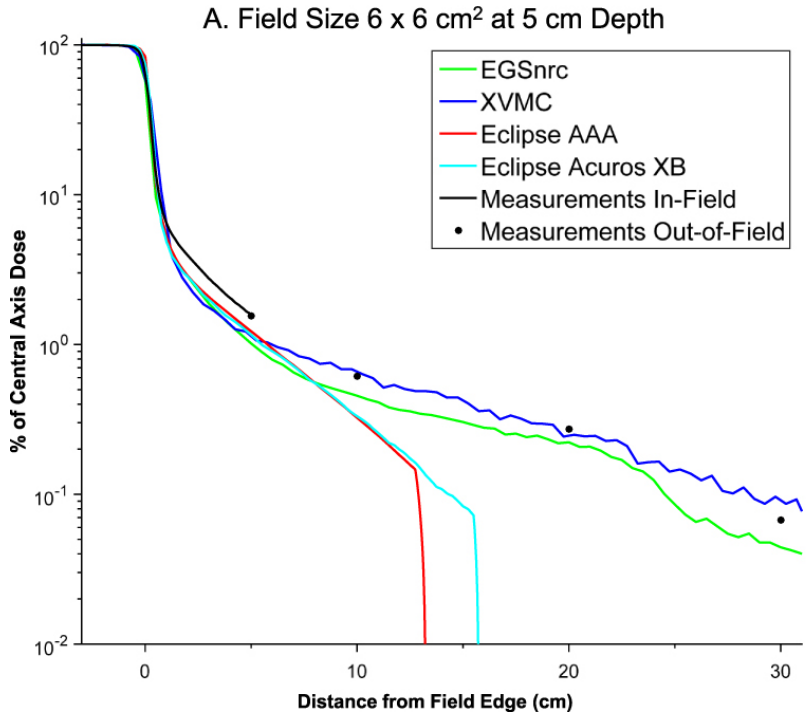
NCIRT Method (XVMC Approach)

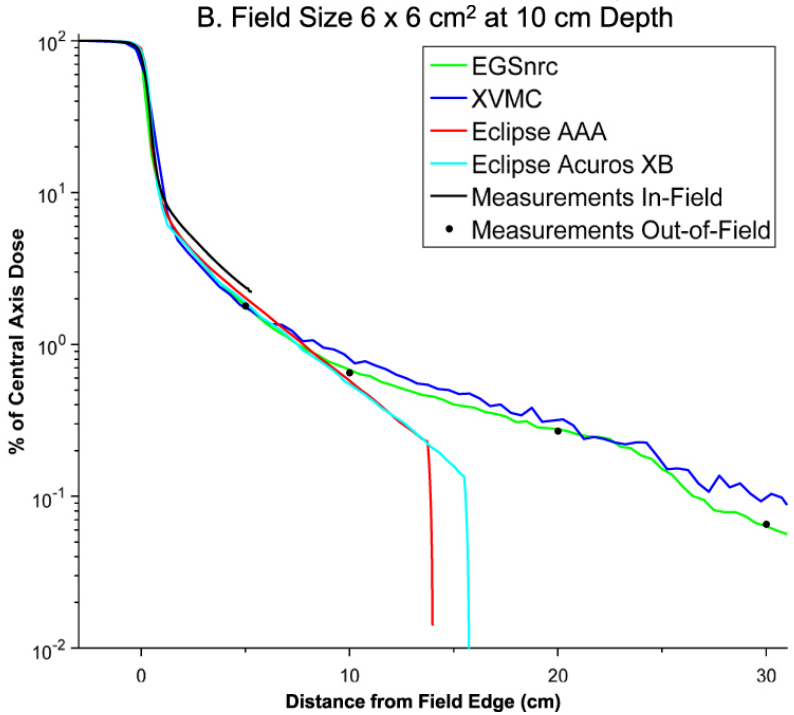


- Separate XVMC input file for each beam/control point
- Total dose calculated as weight sum of dose maps for all beams

Crossplane Dose Profiles For Homogeneous Water Phantom

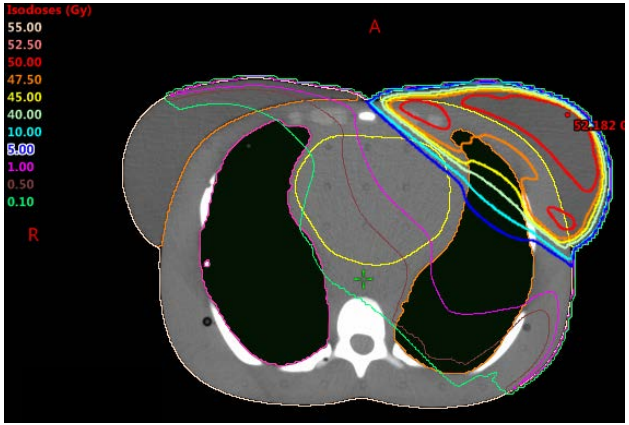




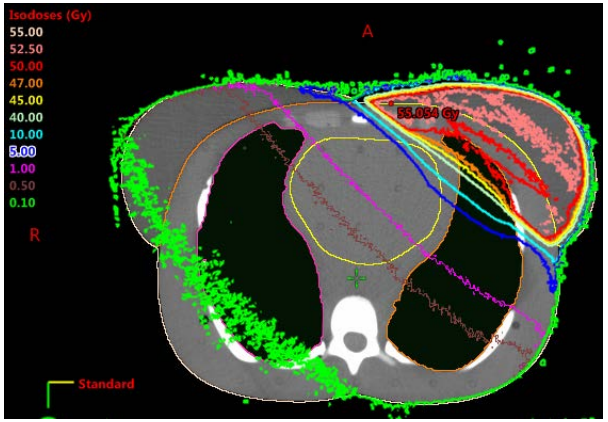


CIRS Physical Phantom (50 Gy Rx)

Treatment Planning System (AAA)



Accelerated Monte Carlo (XVMC)



	Mean Dose (Gy)		Max Dose (Gy)	
	AAA	XVMC	AAA	XVMC
L Breast	47.4	47.5	52.5	56.5
R Breast	0.26	0.48	5.1	12.0
Heart	1.19	1.70	50.2	50.9
L Lung	5.81	5.85	51.2	53.9
R Lung	0.01	0.16	0.21	1.68

ECU Confirmed XVMC By Radiochromic Film

Example Applications of NCIRT

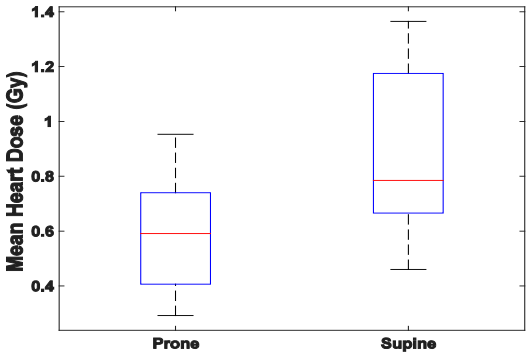
1) **Clinical study comparing normal tissue doses for breast cancers treated in the prone versus supine position**
   - Convenience sample of 30 patients having both prone and supine CT
   - Full DICOM-RT available for all patients

2) **Retrospective dosimetry analysis on ~5,000 children who received radiotherapy (1969-2002) for Wilms Tumor**
   - No patient CT available → phantoms used as a surrogate
   - DICOM-RT reconstructed for detailed paper medical records
   - Radiotherapy portal films available for some patients

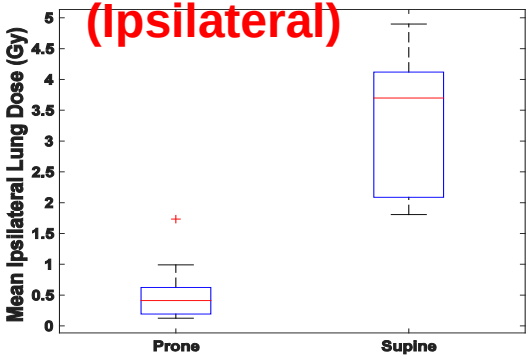
Example Applications of NCIRT

- Radiotherapy records for 30 left breast cancer patients and who had both prone/supine CT images
- Tangential photon plans developed using field-in-field technique
- Compare organ doses for 45 Gy Rx
  - Heart, left and right lunch, esophagus, thyroid, contralateral breast

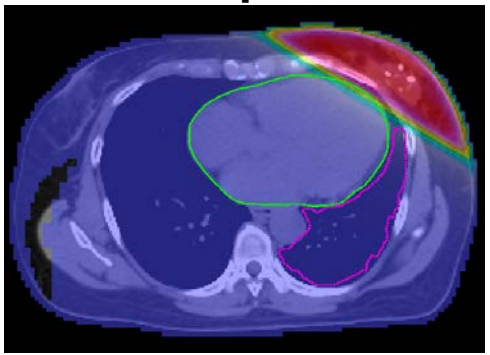
Heart



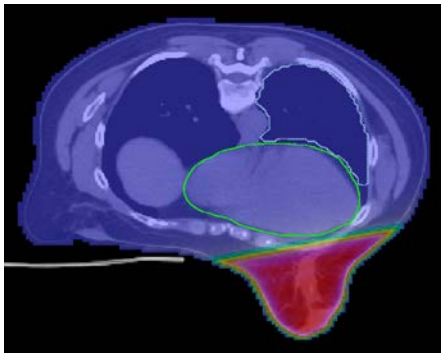
Left Lung Dose (Ipsilateral)



Supine

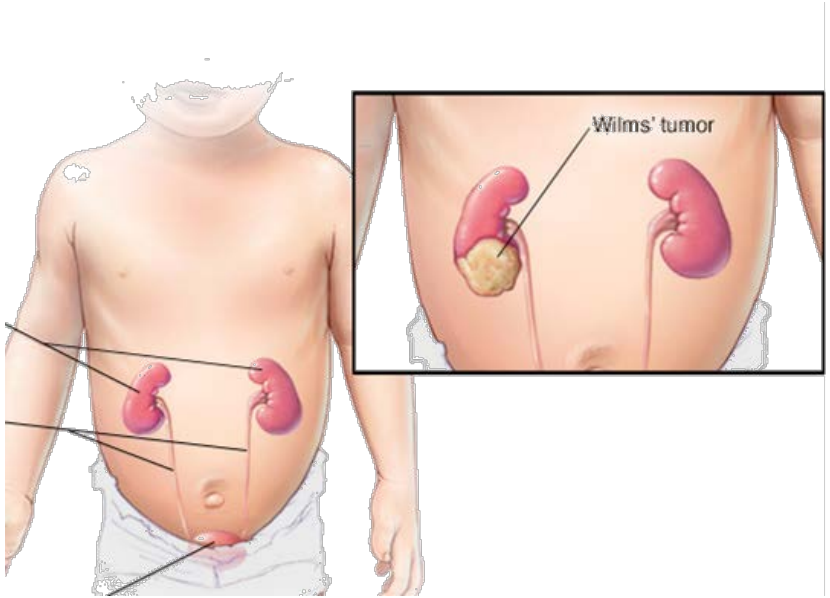


Prone



Retrospective dosimetry analysis on children who received radiotherapy for Wilms Tumor

- **Wilms Tumor** – Cancer of the kidney that occurs most often in children
  - 500 cases diagnosed in U.S. annually.
  - 75% cases occur in otherwise normal children
  - Highly responsive to treatment
- **National Wilms Tumor Study (NWTS)**
  - 5 clinical trials during 1969 to 2002
  - Overriding principle was “Cure is not enough”
  - 5000 patients contributed data to the late effects study.
  - 2600 patients followed for 20+ years



NWTS Retrospective Study Aims

Aim 1: Estimate 3D RT doses to specific organs of exposed members of the NWTS studies using NCI Phantoms and Monte Carlo simulation

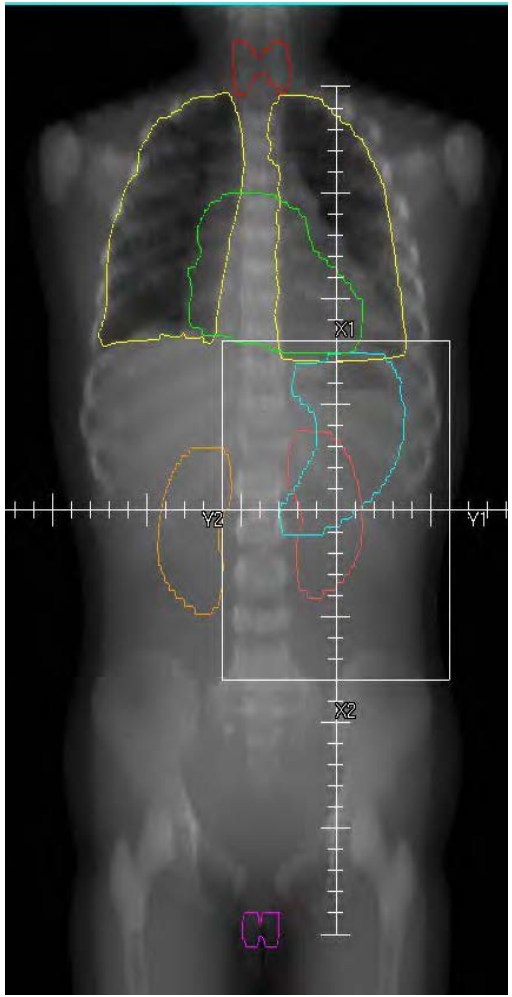
- heart, ventricles, kidneys, lungs, chest wall, breasts, thyroid, liver, stomach, colon, ovaries, uterus, pelvis, testicles, pancreas

Aim 2: Conduct a prospective questionnaire-based cohort study to determine prevalence of male/female reproductive late effects (hypogonadism and infertility) among NWTS survivors

Aim 3: Study the association between RT dose and late effects ascertained in the NWTS

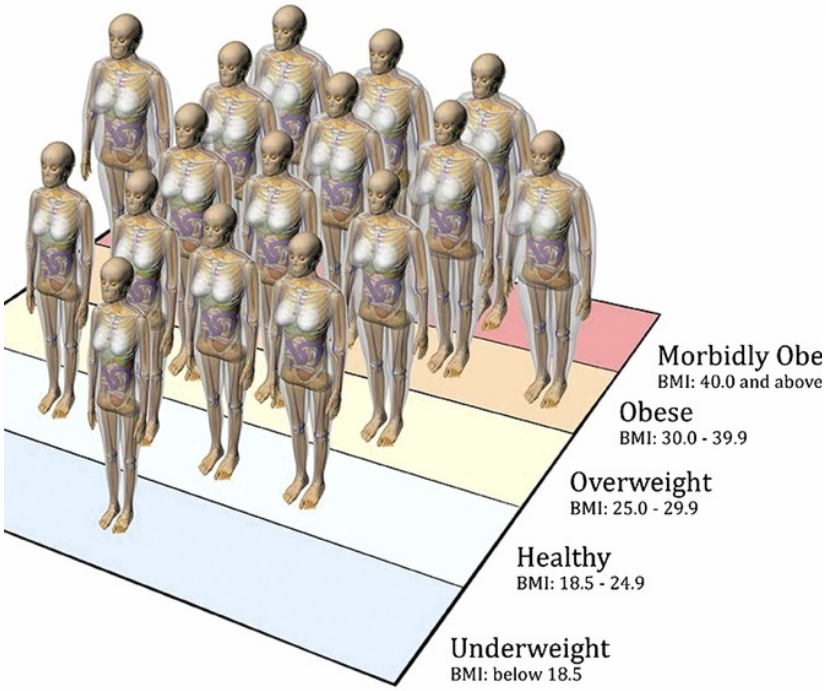
Dosimetry Approach

- No patient CT or DICOM-RT available
- NCI phantoms will be used as a surrogate for missing anatomy (matched on gender, height, weight)
- All organs of interest (and many others) are pre-contoured in phantom
- Load phantom into treatment planning system (TPS) to reconstruct plan from paper records
- Treatments consist of simple AP-PA beams relatively easy to reconstruct based on bony and soft tissue anatomy
- RT portal films for about 500 (10%) of NWTS-3 which can be used for confirmation

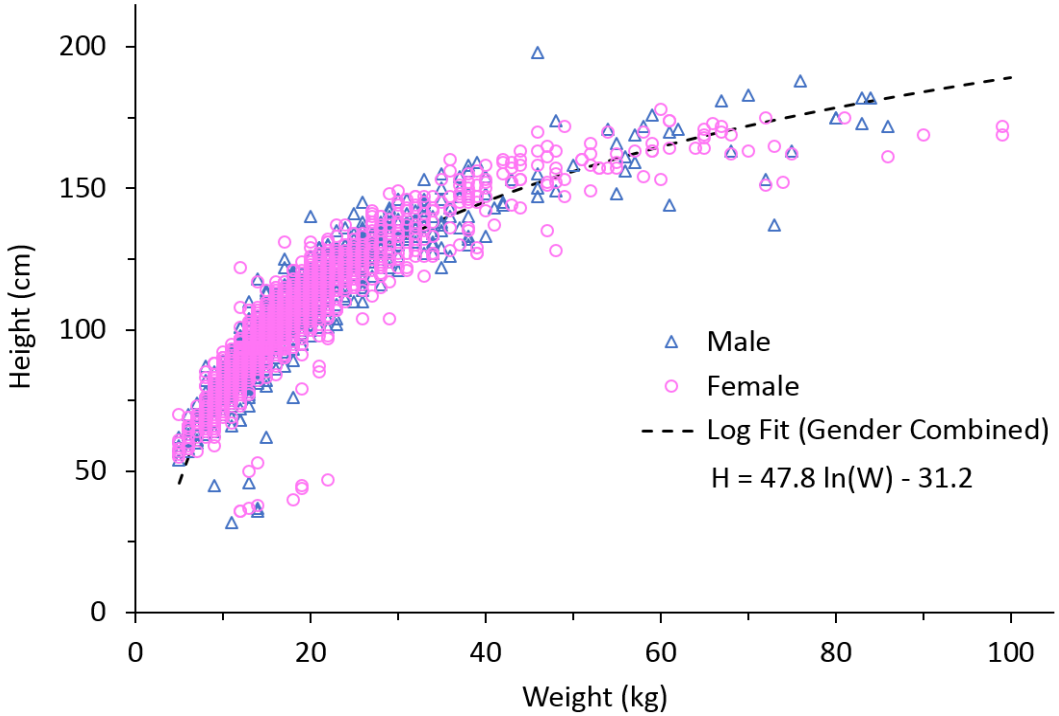


Phantoms As Surrogate for Patient CT

Match on gender, height, weight



Height or Weight imputed for 7% of patients using WHO/CDC Growth Curves



Nearly Complete Phantom Matching

Phantom in NCI Library
Missing phantom

Height (cm)	5	10	15	20	25	30	35	40	45	50	55	60	65	70
195	0	0	0	0	0	0	0	0	0	0	0	0	0	0
185	0	0	0	0	0	0	0	0	0	0	1	0	1	1
175	0	0	0	0	0	0	0	0	0	3	2	9	4	2
165	0	0	0	0	0	0	0	2	6	7	6	4	4	4
155	0	0	0	0	0	0	9	16	15	7	7	2	0	2
145	0	0	0	0	0	28	27	15	4	3	1	1	1	0
135	0	0	0	0	61	88	19	7	1	1	0	0	0	0
125	0	0	0	122	235	40	10	3	0	0	0	0	0	0
115	0	0	80	504	96	6	0	0	0	0	0	0	0	0
105	0	0	652	381	10	0	0	0	0	0	0	0	0	0
95	0	118	885	29	0	0	0	0	0	0	0	0	0	0
85	0	443	231	0	0	0	0	0	0	0	0	0	0	0
75	0	366	0	0	0	0	0	0	0	0	0	0	0	0
65	59	74	0	0	0	0	0	0	0	0	0	0	0	0
55	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0	0	13	0	0	0	0	0	0	0	0	0	0	0

Weight (kg)

Study Workflow

NCI

Generate Phantom CT and Structure Set

NW

Reconstruct Treatment In TPS

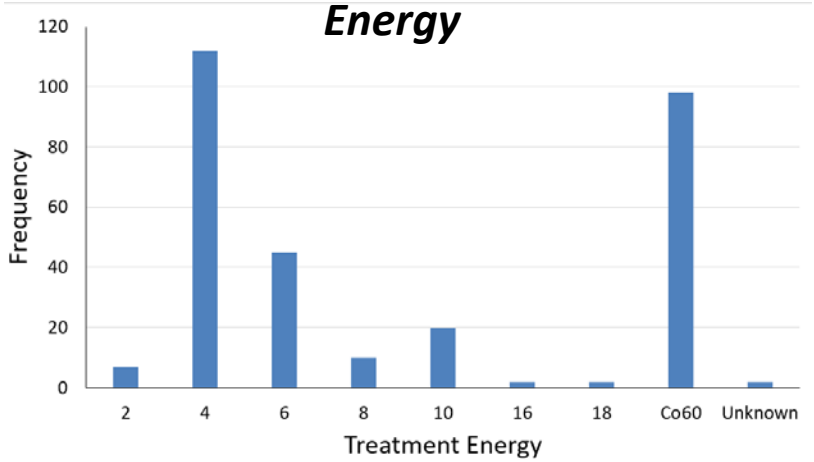
individually checked by RO

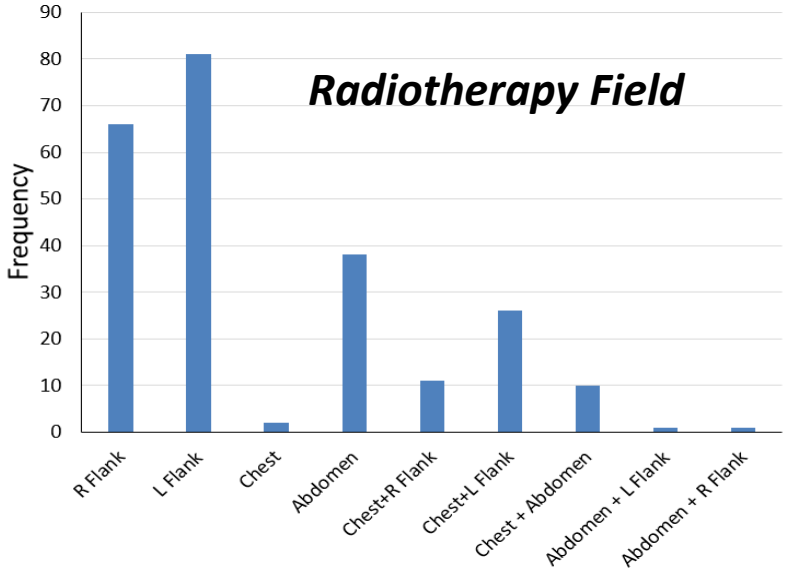
NCI

XVMC Simulation and Save Result in DICOM RT DOSE Format

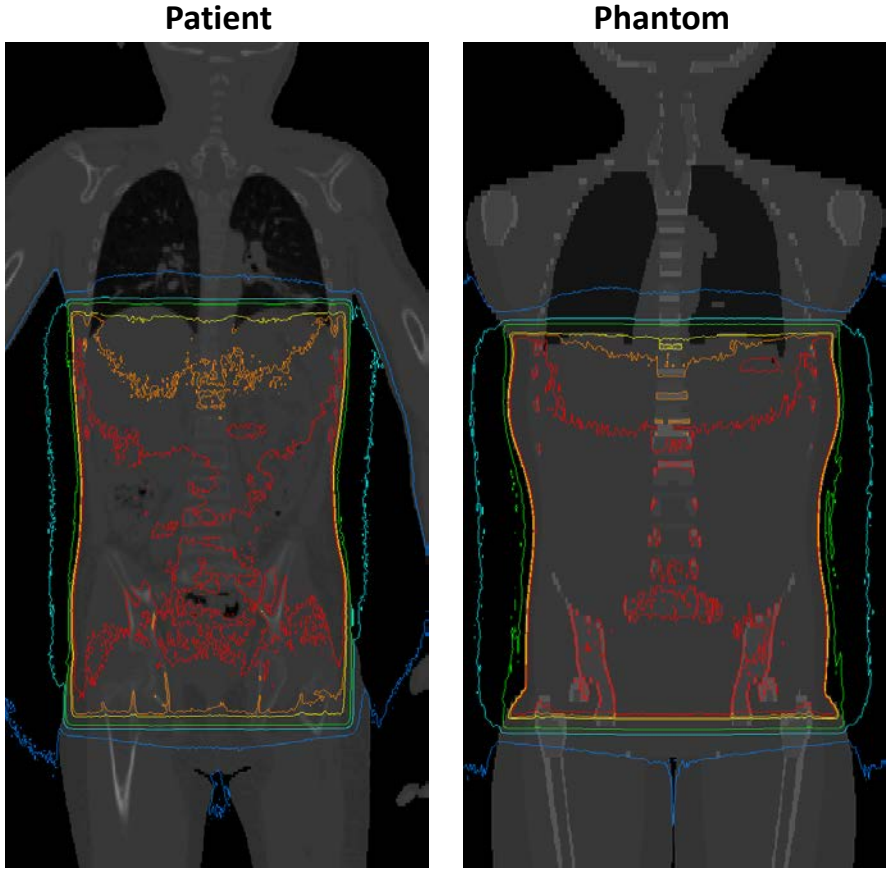
NW

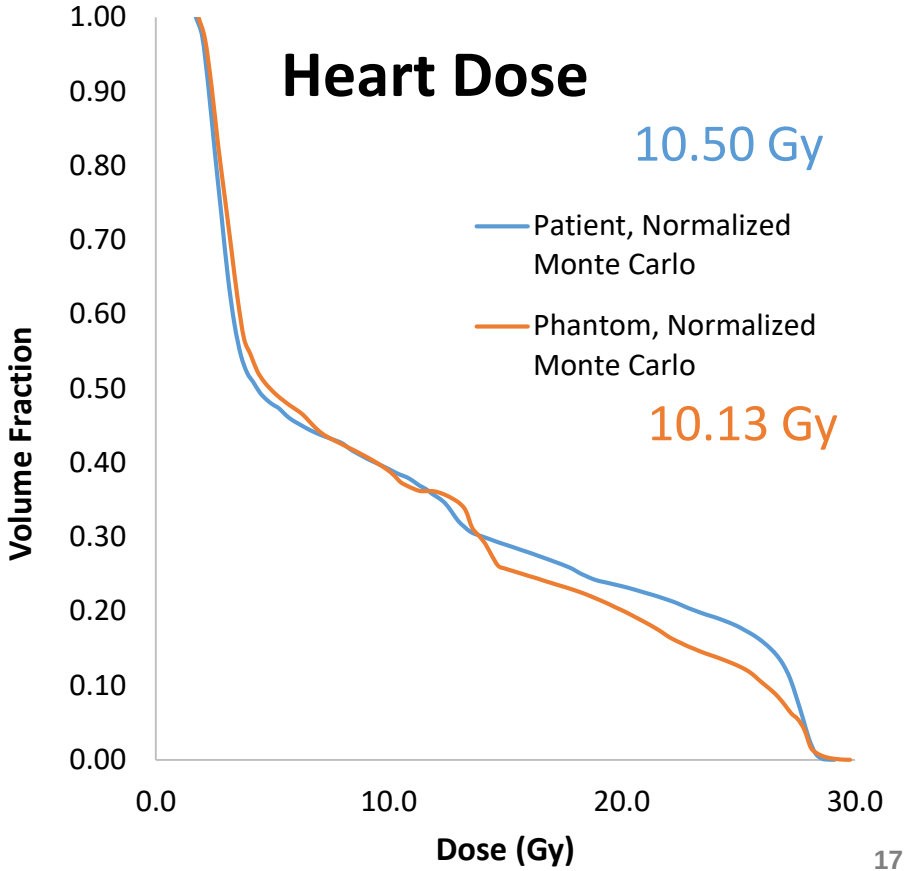
Late Effects Study





Example Case: Patient 107, Male, Abdomen = 30 Gy





Needs Statement

- Auto segmentation methods to contour organs of interest not typically delineated as part of clinical practice
- Develop and validate LINAC (various energies) and Co-60 irradiator models
  - Out-of-field dose data for benchmarking MC simulation
  - Develop phase space files for various manufacturer/energies for MC simulation

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