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Serial Tomotherapy

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Outline

- Description of Tomotherapy
- Clinical Implementation
  - Commissioning
  - Clinical Setup and Treatment
  - Patient-Specific QA
- Clinical Issues
  - Abutment-region Dosimetry
  - Superficial Doses
  - Whole-Body Doses
  - Room Shielding

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Commercial Application

- NOMOS Corporation
  - Multileaf collimator (MIMiC)
  - “Indexing” hardware
  - Treatment planning software
  - QA tools
- >40 users worldwide

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MIMiC

- 20 pairs of leaves = 20 cm diameter cylinder
- Binary operation (pneumatic)
- Leaves subtend 0.84 ("1 cm") or 1.7 cm "(2 cm") width
  - Longer targets treated in successive abutted slices (indexes)
- Fluence modulated during arc
- Arcs subdivided into 5 degree bins
- Fluence nearly arbitrary each bin
- Up to 72 independent coplanar beams
- Patient indexed between slices

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Crane

- Couch repositioning and immobilization
- Attaches to couch rail
- Position read out using linear digital encoders

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Treatment Planning System

- Trade-name Corvus
- Structure delineation/import
- DVH-based optimization user interface
- Simulated annealing algorithm
- Multiple 2-D cross-section views
- DVHs
- Also supports DMLC

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Clinical Implementation

- Commissioning
  - Traditional
  - Dosimetric
- Patient setup and treatment
  - Immobilization
  - CT scan acquisition
  - Contour delineation and dose optimization
  - Treatment
- Patient-based QA
  - Dosimetric pre-treatment
  - Positioning verification

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Commissioning

- Traditional, e.g.
  - TG 53
  - Patient information
  - Printout accuracy
  - Data transfer
- IMRT
  - Dose distributions
  - Monitor unit determinations

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IMRT Dosimetry

- Dosimeters
  - Accuracy and dimensionality conflict
  - Point
    - Ionization chambers
    - TLD chips
    - Others
    - Poor spatial coverage
  - Size vs. dose heterogeneity
  - Response as function of incident fluence angle

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IMRT Dosimetry

- Dosimeters (cont'd)
  - Planar
    - Radiographic Film
      - Poor energy response
      - Convenient, inexpensive, large format
    - Radiochromic Film
      - Still difficult to use quantitatively
      - Possible to get 2% precision with 0.1 x 0.1 mm^2 resolution!!
      - Excellent for benchmarking

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IMRT Dosimetry

- Dosimeters (cont'd)
  - Volumetric
    - Polymerizing gel (Trade name BANG)
    - MRI or optical readout
    - Reasonable sensitivity (1-20 Gy)
    - MRI readout shown to be excellent as relative dosimeter (single experiment yields nearly 1,000,000 1 x 1 x 3 mm^3 data points!)
    - MRI readout still requires benchmarking for absolute IMRT dose measurements
    - Optical readout requires benchmarking for large volumes

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IMRT Dosimetry

- Phantoms
  - Anthropomorphic
    - Geometrically irregular
    - Patient-like structures including heterogeneities
    - Heterogeneities may yield unnecessary dosimetric uncertainties
    - Highly accurate spatial film registration difficult

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IMRT Dosimetry

- Phantoms (cont'd)
  - Geometrically regular
    - Easily aligned and registered
    - Precise internal construction
    - Homogeneous internal construction
    - Multiple dosimeters measuring in same dose distribution environment

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Patient Setup and Treatment

- Immobilization
  - Dose delivered in sequential slices
  - If patient moves perpendicular to arc during or between slice delivery, large dose heterogeneity results in abutment region
  - Immobilization system should concentrate on longitudinal direction
  - Don't forget localization to enable smallest possible margins

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Patient Setup and Treatment

- Volumetric anatomy measurement
  - Usually done with CT
  - Targets and critical structures delineated
- Optimization
  - Commercial system uses DVH-based system
  - Target and critical structure dose limits entered as 3-point DVHs
  - Pre-filtering of gantry angles
  - Simulated annealing determines individual beam fluences
  - Patient treatment plan written on a floppy disk which monitors number of delivered fractions

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Patient Setup and Treatment

- Laser alignment marks placed similar to conventional CT
- Intersection of alignment marks determines coordinate system "Origin"
- Gantry rotation axis usually passes through isocenter, but tool is provided to move axis if necessary
- Patient is aligned to marks, CRANE readouts zeroed
- Patient moved as required by treatment plan

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Patient Setup and Treatment

- Accelerator uses normal arc mode
- MIMiC leaves open and close as function of gantry angle (inclinometers)
- MIMiC controlling computer monitors gantry rotation rate and angles to determine of treatment proceeding correctly
- Monitor units or dose are not monitored by MIMiC controlling computer

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Patient-Based QA

- Treatment plan yields monitor units
- For same dose, MUs can vary by 40%
- How do we know the MUs are correct?
- MEASUREMENT!
- Patient fluence distribution transferred to QA phantom and dose measured at select points
- Ionization chambers for MU normalization
- Film used for spatial localization

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Patient-Based QA

- Patient Localization QA
  - How do we know the patient is in the correct location?
  - PORTAL FILMS
  - Compared against DRRs from commercial virtual simulation software using same CT dataset and radiopaque markers as treatment plan
  - Use double exposures when possible (with and without MIMiC)

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Clinical Issues

- Abutment-Region Dosimetry
  - CRANE indexing precision
  - Dosimetric consequences of indexing error
  - Intrinsic abutment dose distribution heterogeneity

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CRANE Indexing Precision

- Readout precision = 0.01 mm
- Readout made at rack and pinion gears, not at accelerator isocenter
- Couch bearing friction limits precision
- Measurement:
  - Radiographic using sequence of open MIMiC field images
  - Purposefully change index amount from overlap to underlap
  - Scan film and correlate hot and cold spots to intended couch index movement
  - Fabricate high precision system to provide baseline for relationship between hot and cold spots and couch index distance (“gold standard”
  - Also evaluate optical-based system: miniCRANE

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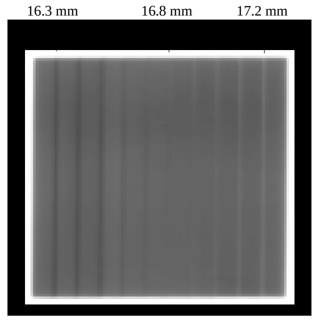

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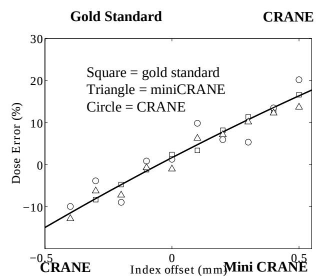

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Indexing Precision Results

- Standard deviation
  - CRANE = 0.10mm
  - miniCRANE = 0.08 mm
  - gold standard = 0.02 mm

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Consequences of Incorrect Indexing

- Either incorrect indexing or patient movement yields undesired overlap or underlap between successive abutments
- Carol determined dose error 10% mm^{-1}
- Measurement
  - 8 cm diameter target
  - Radiographic film (coronal)
  - Purposeful index error 0, ±1, ±2 mm

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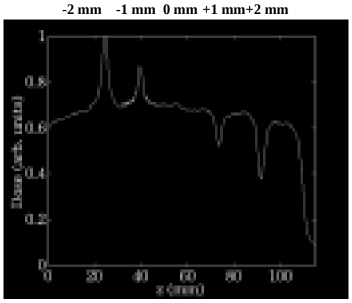
-2 mm -1 mm 0 mm +1 mm+2 mm



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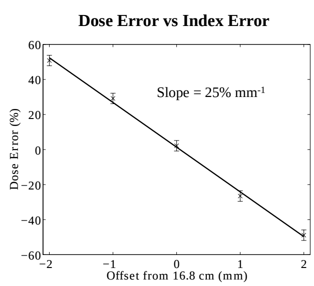

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Intrinsic Abutment Dosimetry

- Narrow but divergent beams
  - Unequal matching at abutments
  - Hot and cold spots created
  - Only narrow width
  - Dose heterogeneities are function of gantry angle rotation, off-axis distance, width of leaves (“1 cm” vs “2 cm” modes)
  - Random daily setup error may redistribute and reduce dose heterogeneity magnitude

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Intrinsic Dose Heterogeneity Measurement

- Treatment Plans
  - 8 cm cylindrical targets (head phantom)
  - Position relative to isocenter
  - 180°, 240°, 300° arcs
  - “1” and “2” cm modes
- Measurement
  - Radiographic film (coronal)
  - Precise indexing of phantom
  - Densitometry - 0.25 mm laser digitizer

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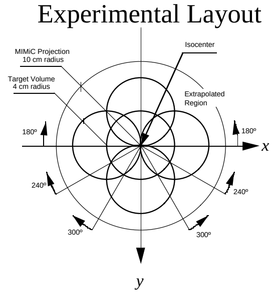
Experimental Layout



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Experimental Method

- Determine heterogeneity throughout 20 cm diameter volume
  - Apply smooth fit in x and y
- Position of abutment region in patient
  - Longitudinal position has random error
  - Smooths (distributes) abutment region
  - Model as Gaussian distribution
  - Convolve with abutment hot/cold spots

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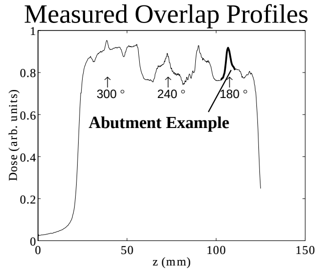
Measured Overlap Profiles



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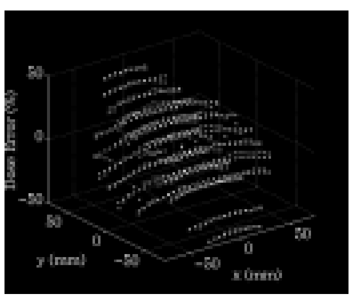

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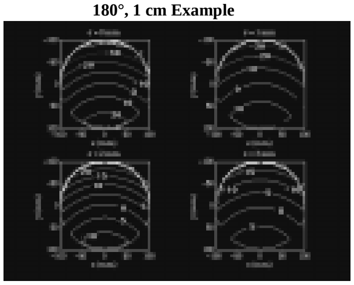
180°, 1 cm Example



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Result Presentation

- 2D contour plot difficult to interpret
- Largest variation in "y" direction
- Show 1-D plots of smoothed dose heterogeneity in "y" direction with superimposed measured data points

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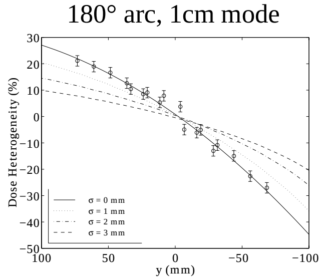
180° arc, 1cm mode



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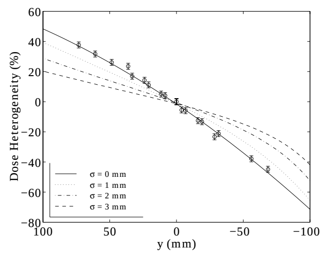
180° arc, 2cm mode



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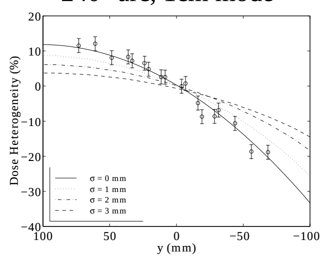
240° arc, 1cm mode



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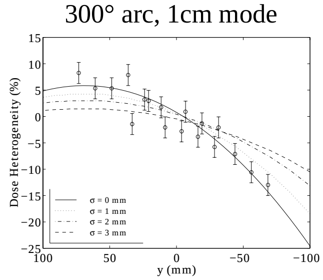
300° arc, 1cm mode



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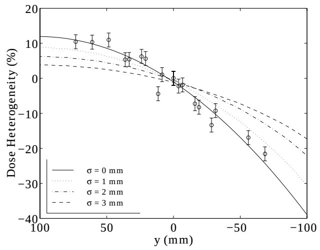
300° arc, 2cm mode



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Intrinsic Abutment Summary

Target off-axis distance along y axis required to achieve 10% dose homogeneity

1 cm mode

	σ=0mm		σ=2mm	
	ant	post	ant	post
300º	5	10	8	10
180º	3	3	5	6

2 cm mode

	ant	post	ant	post
300º	3	6	5	10
180º	1	2	3	4

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Recommendations

- 2 cm mode yields approx 70% greater heterogeneities than 1 cm, use 1 cm whenever practical
- Keep targets near isocenter
- Use as large a gantry angle as possible
- Periodically monitor couch indexing precision

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Future Implementation

- Spiral tomotherapy unit - Mackie
- Abutment region heterogeneities distributed throughout patient
- Improved patient throughput
- On-line images acquired during irradiation may yield tomographic information

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Acknowledgement

- This work was supported in part by a grant from the NOMOS corporation