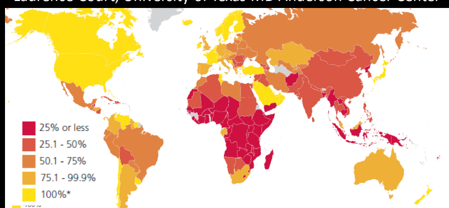
Automated treatment planning for low-resource settings

Laurence Court, University of Texas MD Anderson Cancer Center



Percentage of patients with access to radiotherapy.
Global Cancer Facts & Figures 3rd edition (2015)

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Conflicts of Interest

- Funded by NCI UH2 CA202665
- Equipment provided by:
  - Varian Medical Systems
  - Mobius Medical Systems
- Other, not related projects funded by CPRIT, Elekta

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Project team

MD Anderson Cancer Center, Houston

- Laurence Court, PhD - PI
- Beth Beadle, MD/PhD - PI
- Joy Zhang, PhD – algorithms and integration
- Peter Balter, PhD – radiation physics
- Jinzhong Yang, PhD - atlas segmentation
- Rachel McCarroll – H&N algorithms
- Kelly Kisling, MS – GYN, breast algorithms
- Brian Anderson – positive node detection
- Ann Klopp, MD/PhD
- David Followill, PhD

- Santo Tomas University, Manila:
  - Michael Mejia, MD
  - Maureen Bojador, MS
  - Teresa Sy Ortin, MD
- Stellenbosch University, Cape Town
  - Hannah Simonds, MD
  - Monique Du Toit – physics
  - Vikash Sewram, PhD
- University of Botswana
  - Surbhi Grover
  - Remigio Makufa
  - Talkmore Kurumekayi
- Varian Medical Systems
- Mobius Medical Systems
- National Cancer Institute
  - Bhadrasain Vikram

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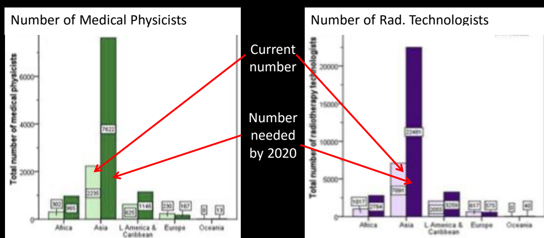
Radiation therapy staff shortages in LMICs



Datta NR et al. IJROBP 89:448-457 (2014).

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Country	Additional number of radiotherapy infrastructure and staffing required by 2020			
	Treatment units	Radiation oncologists	Medical physicists	Radiation therapy technologists
Philippines	140	141	133	382
South Africa	56	93	82	82
All LMI regions	9169	12,147	9,915	29,140

*Datta NR, Samiei M, Bodis S. Radiation Therapy Infrastructure and Human Resources in Low- and Middle-Income Countries: Present Status and Projections for 2020. International Journal of Radiation Oncology*Biology*Physics. 2014;89(3):448-57.*

- Large deficit – including current physicists, need around 13,000 physicists in 2020
- Many international guidelines suggest that medical physicists needs 2+ years residency, typically following graduate school.
- Staff retention is also a problem (anecdotal)
- Approximately 50% of physicist time is spent doing treatment planning
- So, if planning was automated, then the number of medical physicists needed could be reduced by 50%

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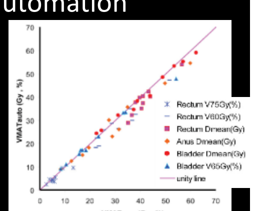
We can build on the extensive history and advances in plan automation

- Treatment planning systems are complicated
- Many publications on plan automation
- Plan automation has been shown to significantly reduce hands-on time
  - E.g. Voet et al showed savings of at least 1 hour of hands-on-time
- Vendors have implemented some of this
- Vendors have also improved our ability to control these features
- We need to implement for non-IMRT techniques also



Voet et al., Fully Automated Volume Modulated Arc Therapy Plan Generation for Prostate Cancer Patients, IJROBP 88(5),1175-1179, 2014

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Bugando Medical Center Cancer Center, Tanzania

- Simulation:
  - 1 CT, 1 conventional simulator
- Treatment units:
  - 1 Elekta, 1 Varian, 1 Cobalt

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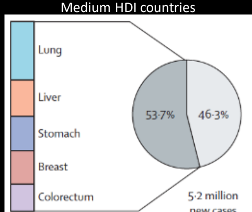
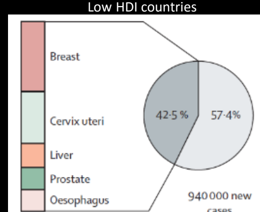
Which cancers should we focus on?

Total incidence of cancer (2012)

Medium HDI countries



Low HDI countries



HDI = Human Development Index

Atun et al, Expanding global access to radiotherapy, Lancet Oncol 16, 1153-86, 2015

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Specific goals of the Radiotherapy Planning Assistant.

- Automatically create plans for cervix, breast (chest wall), head and neck (including naso-pharynx, larynx…..) cancers
- A person educated to the level of a high-school diploma can be fully trained (using video and online tutorials) to use the system in ½ a day.
- Once trained, treatment plans can be created in less than 30minutes.
- Compatible with all treatment units / record-and-verify systems
- Automatic QA of all processes
- Begin clinical testing in 2018.

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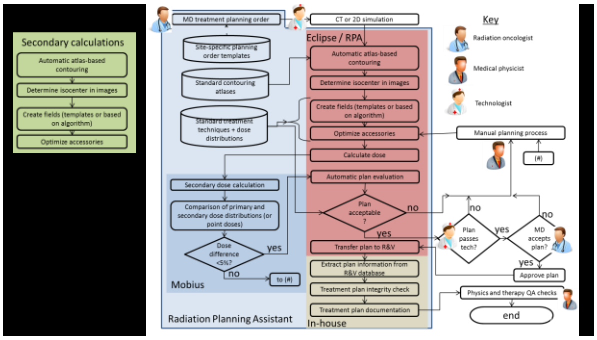


Big Picture of Auto Planner V1.0 Workflow

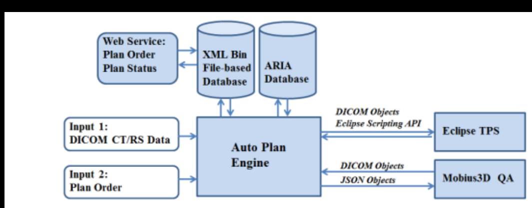
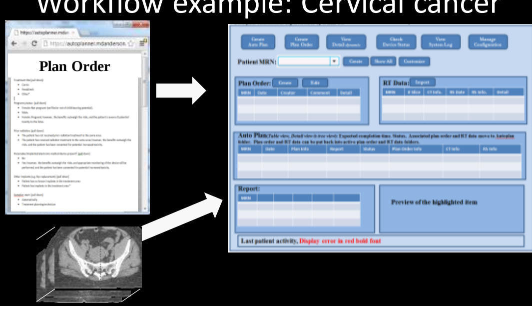


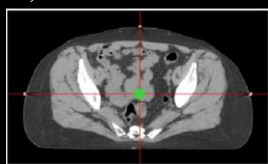
Figure by Lifei Zhang

Workflow example: Cervical cancer



Identify marked isocenter

- Assume use of fiducials
- Two independent algorithms
- Additional sanity checks (e.g. position relative to specific bony structures)



Work by Lifei Zhang

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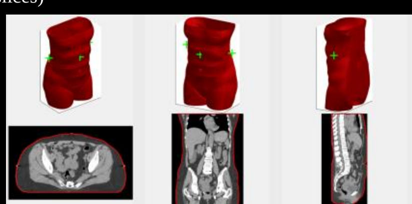
Remove couch and segment the body

- Two independent algorithms
- Additional sanity checks (e.g. smooth changes between slices)



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Determine the field aperture

- Two independent algorithms were developed
- The results of one can be used as an independent verification of the other
  - The 3D Method
    - Uses auto-segmentation of bony anatomy on CT
  - The 2D Method
    - Uses deformable image registration (DIR) of an atlas of standards plans to patient DRRs

Kelly Kisling, Automated Treatment Planning for Cervical Cancer in Low- and Middle-Income Countries, SU-F-T-423

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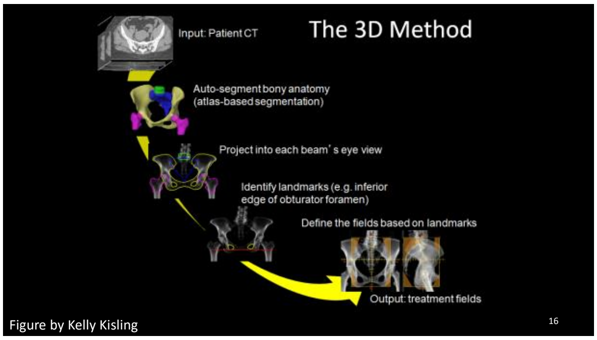
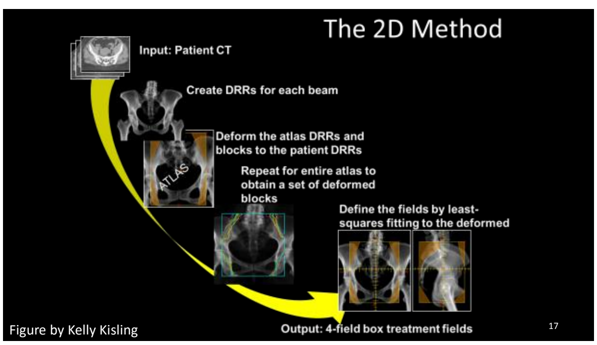




Initial Results

- 39 patient treatment fields rated by a radiation oncologist

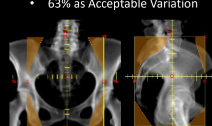
3D Method

- 96% passed
  - 62% as Per Protocol
  - 34% as Acceptable Variation
  - 4% failures were all same (jaw at incorrect vertebrae)

- Now deployed this to clinical practice

2D Method

- 79% passed – still working on improvements
  - 17% as Per Protocol
  - 63% as Acceptable Variation



Figures by Kelly Kisling

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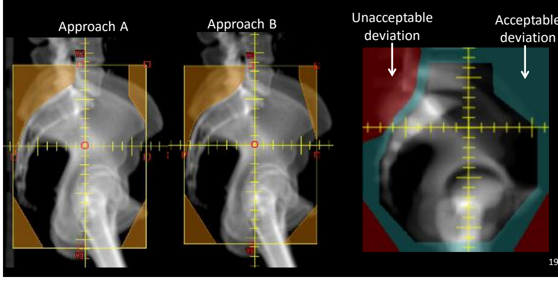
Use of approach B to QA approach A



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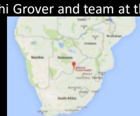
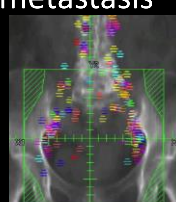
Treating lymph node metastasis

- Lymph node metastasis – common, and predictable location
- May require a change in superior border
- Curative treatment requires a boost dose
- Many centers lack resources to identify these, so they are not treated
- Project to automatically identify LN metastases in collaboration with Surbhi Grover and team at the University of Botswana





Location of PET positive lymph nodes in a cohort of patients with locally advanced cervical cancers

Fontanilla et al. Anatomic distribution of FDG-avid lymph nodes in patients with cervical cancer, PRO 3(1), 45-53, 2013

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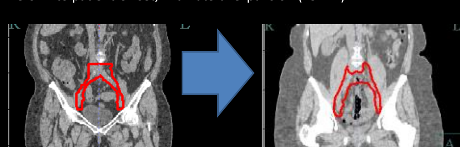
Step 1: Identify region where positive nodes likely to be

- Volume based on probability map
- Deform to patient CT set, with lateral expansion (25mm)



Work by Brian Anderson

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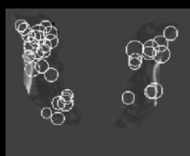
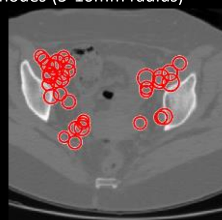
Step 2: identify multiple regions with:
- circular shape (2D)
- size characteristic of positive nodes (5-10mm radius)





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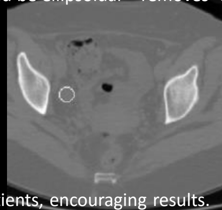
Step 3: Further processing to remove false results based on
- Connectivity
- 3D shape - should be ellipsoidal – removes 'traveling arteries'



So far:
- Tested on 30 patients, encouraging results.

Work by Brian Anderson

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Plan QA: Comparison with population ranges

- Some ranges are quite tight, so provide reasonable QA
- E.g. Total range of MU is 10%
- Range of jaw positions is ~2.5cm in lateral and AP directions, 6cm in SI direction

Jaw positions – population statistics

	gantry: 0deg	
	x	y
average	16.8	21.3
St. dev.	0.9	1.9
min	15.7	18.5
max	18.2	23.1

Total MU – population statistics

average	208
St. dev.	9
min	200
max	220

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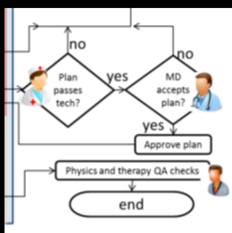
Plan QA: Manual checks



- Initial tech review
- MD approval
- Physics, therapy review

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Initial technical review

- Double check of vital plan check functions
- Only get to this point if passes all internal QA checks
- Technical items checked:
  - Marked isocenter
  - Patient orientation, laterality and site
  - Body contour
  - CT processing (couch removal)
  - Field apertures
  - Any significant artifacts or differences
  - Dose calculation complete
- Purpose designed document to lead the user through the checks

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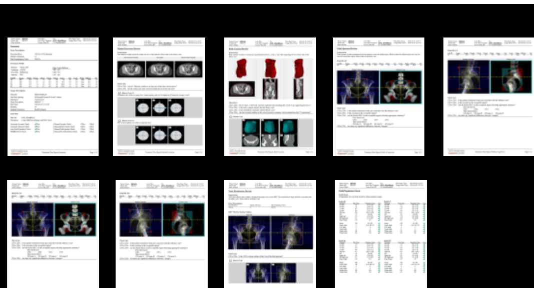

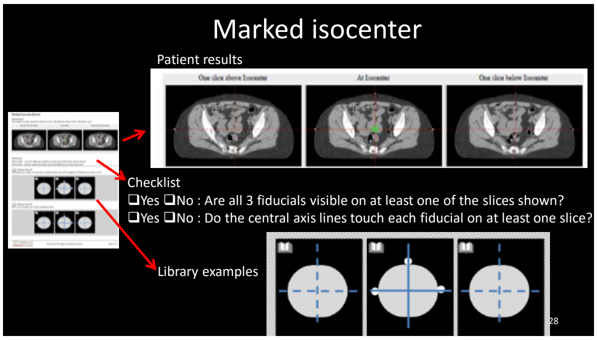
Marked isocenter
Patient results
One slice above Isocenter
At Isocenter
One slice below Isocenter
Checklist
❑Yes ❑No : Are all 3 fiducials visible on at least one of the slices shown?
❑Yes ❑No : Do the central axis lines touch each fiducial on at least one slice?
Library examples
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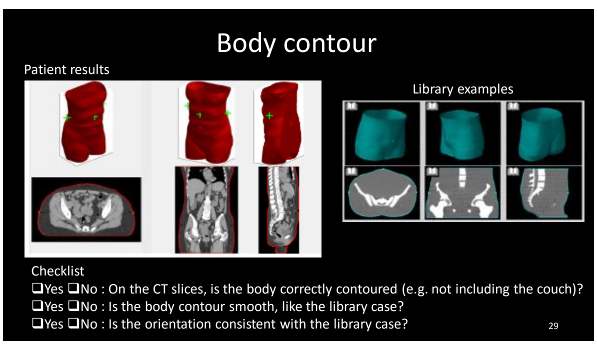
Body contour
Patient results
Library examples
Checklist
❑Yes ❑No : On the CT slices, is the body correctly contoured (e.g. not including the couch)?
❑Yes ❑No : Is the body contour smooth, like the library case?
❑Yes ❑No : Is the orientation consistent with the library case?
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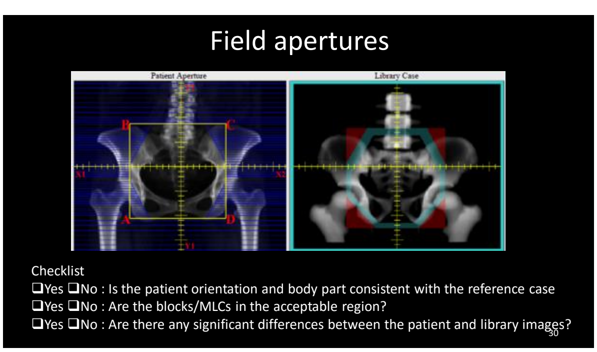
Field apertures
Patient Aperture
Library Case
Checklist
❑Yes ❑No : Is the patient orientation and body part consistent with the reference case
❑Yes ❑No : Are the blocks/MLCs in the acceptable region?
❑Yes ❑No : Are there any significant differences between the patient and library images?
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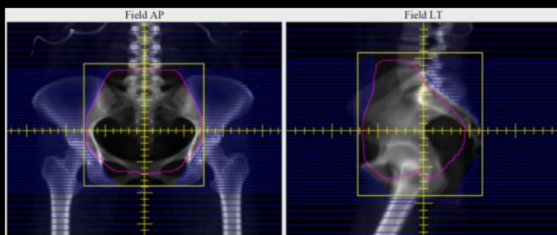
Dose calculation complete



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Lessons learned

- Total 7 pages, 23 questions
- Initial tests: 3 physics undergraduates, 15 patient plans with intentional errors
- Time taken to check each plan: Average 4 min (range: 1 - 10min)
- Techs can identify well defined issues, e.g. marked isocenter
- Testing is essential to optimize questions, and to give realistic expectations
  - e.g. what is an acceptable body contour
  - Is marked isocenter correctly identified
- Likely to be difficult for them to assess clinical tasks
  - e.g. field apertures
- Unlikely to catch issues not associated with a specific question
  - e.g. missing fields
- Credentialing of Planning Technologists will be necessary
- More work needed…..

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Head and neck treatments

- Range of complexities in treatments:
  - VMAT or IMRT
  - Opposed laterals / off-cord cone-downs
  - Complex conformal plans
- Starting with VMAT because easiest for us to integrate
  - Auto-contouring normal tissue
  - Auto-contouring low-risk CTV
  - Manual contouring of GTV
  - RapidPlan (Eclipse)

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Normal tissue auto-contouring

Multi-atlas segmentation – deformable registration (accelerated "Demon") followed by STAPLE algorithm to fuse contours

Structure	Number	Average	Stdev
Brain	128	4.1	0.5
Brainstem	128	4.2	0.4
Cochleas	256	4.0	0.8
Esophagus	116	3.4	1.0
Eyes	236	4.2	0.6
Lung	113	3.9	0.5
Mandible	128	4.3	0.5
Parotids	254	4.4	0.7
SpinalCord	128	5.0	0.2

- Tested pm 128 patients
- Scored by Radiation oncologist. 4+ is acceptable without edit
- Fails for non-standard head positions
- Otherwise all pass, except esophagus and cochlea
- Now deployed this to clinical practice

Rachel McCarroll, Fully automatic verification of automatically contoured normal tissues in the head and neck, TU-H-CAMPUS-JeP1-2

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Validation of Models

- Bagged Classification Tree Model
- Physician Rated Contours (Pass/Fail)
- 10 fold validation
- Minimize false negatives (maximize specificity)
- More testing needed……

	Sensitivity	Specificity
Brain	0.97	0.93
Brainstem	0.88	0.96
Cochlea	0.79	0.89
Eye	0.80	0.92
Lung	0.63	0.89
Mandible	0.88	0.96
Parotid	0.84	0.95
Spinal Cord	0.99	0.95

RPA Deployment process

- Need to ensure that patients treated with RPA receive correct treatment
- Receive commissioning data + commission RPA (Eclipse)
- Radiotherapy Beam Audit Device + TLD output
- Remote planning audit of current planning system (comparison with standard beams)
- End-to-end tests (on-site)

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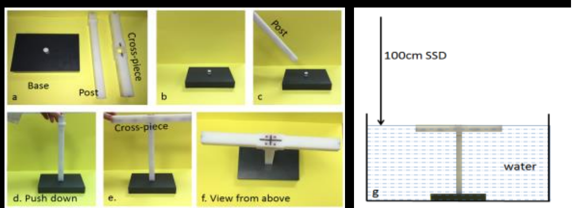
Radiotherapy Beam Audit Device

- Use together with TLD output checks



Phantom built at IROC-Houston, with David Followill

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End-to-end tests

- Will create tests based on IAEA-TECDOC-1583

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Summary

- Automatic treatment planning may help reduce the planning burden, reducing staff shortages in LMICs
- Many approaches to ensure plan quality
  - Secondary independent algorithms
  - Additional ‘sanity’ checks
  - Population comparisons
  - Structured plan checks
- Limited testing starting in South Africa in September
- Then the Philippines….
- Aiming to start use of the complete system in LMIC setting in 2018
- (and also work on 2D plans, not mentioned today……)

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