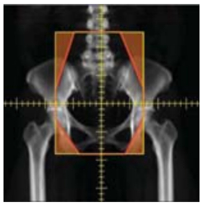
Automation in Therapy: The Future is Now

Automated treatment planning



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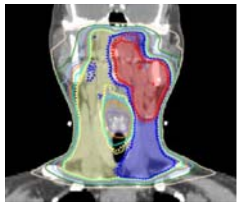

Conflicts of Interest

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

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- MD Anderson Cancer Center, Houston
- Laurence Court, PhD
- Joy Zhang, PhD – algorithms and integration
- Rachel McCarroll – H&N algorithms
- Kelly Kisling, MS – GYN, breast algorithms
- Jinzhong Yang, PhD - atlas segmentation
- Peter Balter, PhD – radiation physics
- Ryan Williamson, MS – software tools
- Ann Klopp, MD/PhD – GYN planning
- Anuja Jhingram, MD – GYN planning
- Simona Shaitemman, MD – breast
- David Followill, PhD – audits/deployment
- James Kanke and dosimetry team

Stanford
- Beth Beadle, MD/PhD – head/neck

Commercial Partners
- Varian Medical Systems
- Mobius Medical Systems

Primary Global Partners
- Stellenbosch University, Cape Town
  - Hannah Simonds, MD
  - Monique Du Toit – physics
  - Chris Trauernicht - physics
  - Vikash Sewram, PhD
- University of Cape Town
  - Hester Berger, PhD
  - David Anderson, MD
  - Jeannette Parkes, MD
- Santo Tomas University, Manila
  - Michael Mejia, MD
  - Maureen Bojador, MS (physics)
  - Teresa Sy Ortin, MD

Global testing sites
- University of the Free State
  - William Shaw, PhD
  - Alicia Sherriff, MD

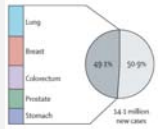
Cancer across the world

- Low and Middle Income Countries (LMICs)
  - Population: 5.625 billion (84%)
  - Global Burden of Disease (97%)
    - 29.4% Communicable diseases
    - 70.6% Non-communicable diseases
      - 66% of global cancer mortality
      - 15% of radiation facilities
- Affordable Cancer Techologies (NCI) projects

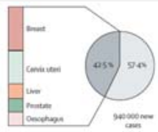
Phase 1 (UH2): Development Phase – 2 years – to April 2018
  - System development at MDACC, initial testing at partner sites

Phase 2 (UH3): Validation Phase – 3 years
  - Full patient testing

Cancer incidence in high HDI countries



Cancer incidence in low HDI countries



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

IAEA: The Advisory Group on increasing access to Radiotherapy Technology [AGaRT] in low and middle income countries.
Samiei, Massoud.. Challenges of making radiotherapy accessible in developing countries. *Cancer Control* 2013: 85.

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Motivation for automated planning 1: Staff shortages

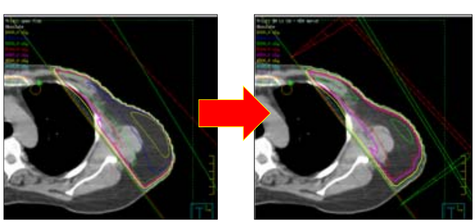
Country	Additional number of radiotherapy infrastructure and staffing required by 2020			
	Treatment units	Radiation oncologists	Medical physicists	Radiation therapy technologists
Philippines	140	141	133	382
South Africa	56	93	82	82
All LMI regions	9169	12,147	9,915	29,140

*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 in resources – including medical physicists and technologists
- Staff retention is also a problem (anecdotal)
- Many international guidelines suggest that medical physicists need 2+ years residency, typically following graduate school – so 4+ years per person.
- Approximately 50% of physicist time is spent doing treatment planning
- If planning was automated, then the deficit of medical physicists could be reduced to ~5000.

Motivation 2: 3D planning

- All our partner institutions are treating chest walls using standard opposed oblique open fields (i.e. not optimized for the individual patient's geometry)
- Automated planning could change this



Comparison of the dose distribution for a chest wall treatment with optimized wedges (right) and with open fields (left). The non-optimized plan has a large region of soft tissue receiving 60Gy (6000cGy), compared with 52Gy (5200cGy) in the optimized plan.

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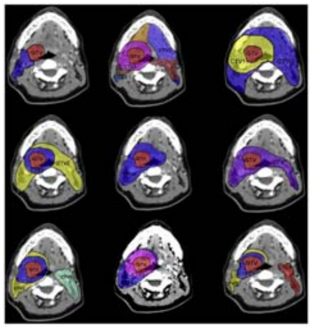
Motivation 3: Consistency

- Head and neck (H&N) tumors are typically surrounded by a large number of OARs
  - CTV delineation a particularly difficult and time consuming task
  - Several reports of high inter-observer variability
  - Automating this process:
    - Reduced contouring time
    - Potentially reduce contouring variability



Hong TS, et al. "Heterogeneity in head and neck IMRT target design and clinical practice." *Radiotherapy and Oncology* 103.1 (2012): 92-98.

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Specific goals of the Radiotherapy Planning Assistant (RPA)

- Automatically create high quality radiation plans for cancers of the:
  - Uterine Cervix
  - Breast (intact and chest wall)
  - Head and neck (nasopharynx, oropharynx, oral cavity, larynx, etc.)
- Generate treatment plans that are:
  - Generated from scratch (including transfer to the local machine) in less than 30 minutes.
  - Compatible with all treatment units and record-and-verify systems.
  - Internally QA'd in an automated fashion within the system.
- Limit need for the radiation oncology physician to:
  - Delineate the target (location).
  - Provide the radiation prescription.
  - Approve the final plan.
- Create a system that can be used by an individual with:
  - A high school education.
  - ½ day of training (online and video) on the RPA itself.
  - (dosimetrists still needed for unusual/complex cases)

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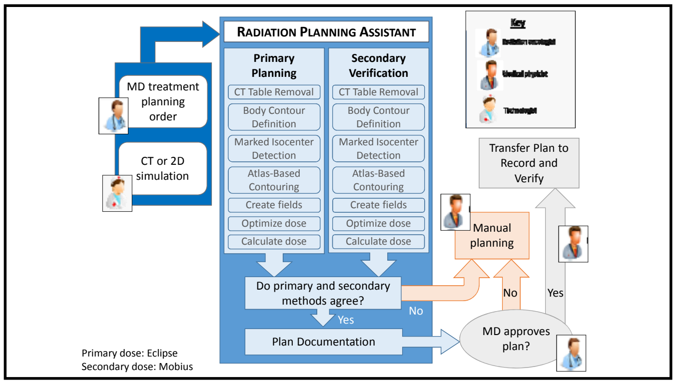
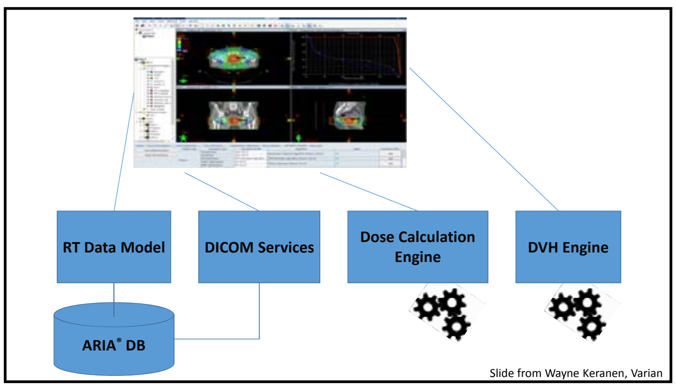
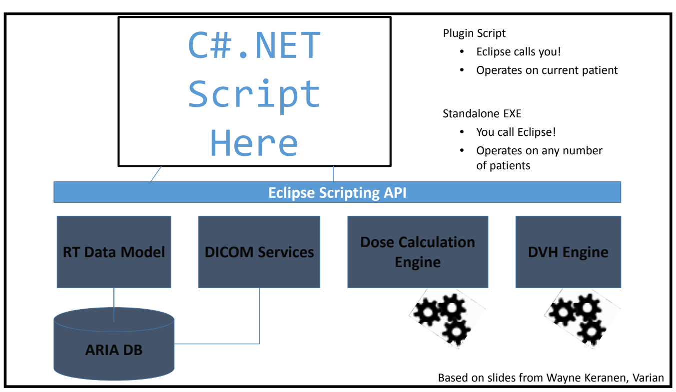
A comment about Treatment Planning Systems

- Our experience is based on the Eclipse TPS
- Similar automation tasks can be achieved with other TPS – and I will try to highlight some of these
- Several (TPS agnostic) tools have been deployed into our clinic (Pinnacle and Raystation)

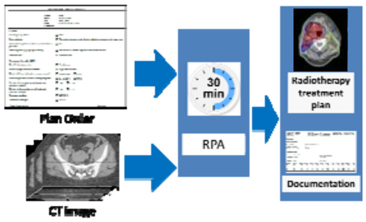

Radiation Planning Assistant
Key
MD treatment planning order
CT or 2D simulation
Primary Planning
Secondary Verification
CT Table Removal
Body Contour Definition
Marked Isocenter Detection
Atlas-Based Contouring
Create fields
Optimize dose
Calculate dose
CT Table Removal
Body Contour Definition
Marked Isocenter Detection
Atlas-Based Contouring
Create fields
Optimize dose
Calculate dose
Do primary and secondary methods agree?
No
Yes
Plan Documentation
Transfer Plan to Record and Verify
Manual planning
No
Yes
MD approves plan?
Primary dose: Eclipse
Secondary dose: Mobius

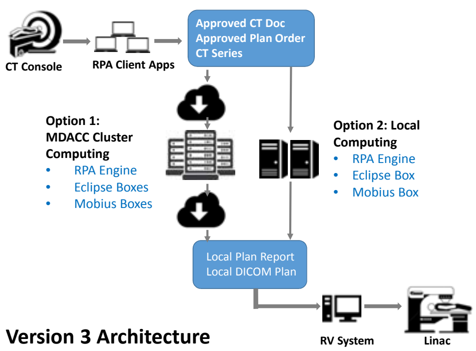

RT Data Model
DICOM Services
Dose Calculation Engine
DVH Engine
ARIA® DB
Slide from Wayne Keranen, Varian


C#.NET Script Here
Plugin Script
• Eclipse calls you!
• Operates on current patient
Standalone EXE
• You call Eclipse!
• Operates on any number of patients
Eclipse Scripting API
RT Data Model
DICOM Services
Dose Calculation Engine
DVH Engine
ARIA DB
Based on slides from Wayne Keranen, Varian

General philosophy

- Take advantage of Eclipse, but avoid the need for the user to actually use Eclipse
- Use Eclipse functions whenever possible (API)
- Combine with purpose-written tools (extensive use of DICOM)
- Internal verification for everything
- Work closely with eventual users
- Deploy at MDACC whenever possible





Version 3 Architecture

Pre-processing

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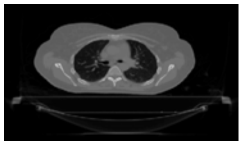
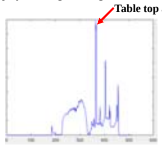
CT Table Removal



Method 1: ***Peak Detection***
By finding peaks slice by slice at sum projection signal along lateral direction.



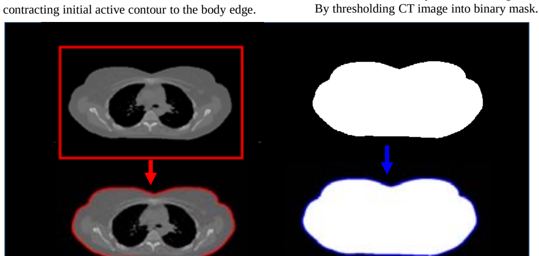
Method 2: ***Line Detection***
By detecting Hough lines at maximum intensity projection image.

- Average difference between two approaches: 2.6 ± 1.6mm (max: 4.9mm)

Body Contour

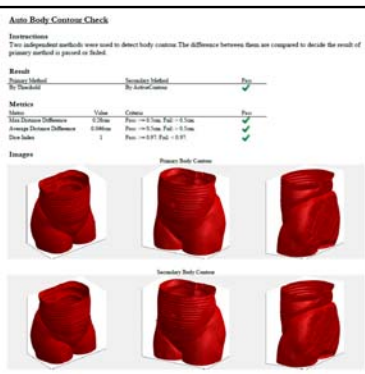
Method 1: ***Active Contour***
By contracting initial active contour to the body edge.

Method 2: ***Intensity Thresholding***
By thresholding CT image into binary mask.



- Average agreement = 0.6mm, Average max: 7.6mm

(paperwork design to improve efficiency of plan checks)



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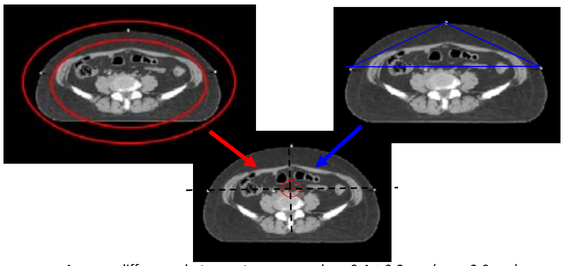
Marked Isocenter Detection

Method 1: ***Body Ring Method***
By searching BB candidates in the body ring domain.

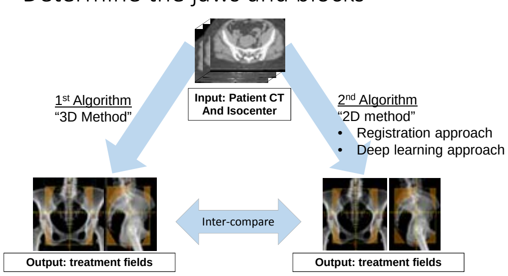
Method 2: ***BB Topology Method***
By searching BBs that constitute the triangle topology.



- Average difference between two approaches: 0.4 ± 0.8mm (max: 3.0mm)

Cervix

For cervical cancer treatment: Determine the jaws and blocks



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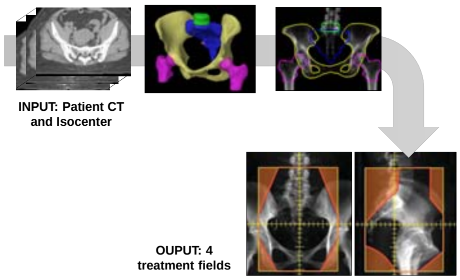
Create Treatment Beams (3D method)



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Iterations of testing

Tested on 469 unique patients!

Feb 2016	Initial Test (v1)	n = 39 patients	Reviewed by MDA physician
Jun 2016	MD Anderson clinical implementation (vMDA.1)	n = 18 patients	Compared beams after physician edits
Dec 2016	2nd physician review of initial test (v1)	n = 39 patients	Reviewed by Tygerberg physician
Jan 2017	Test on 1st set of Stellenbosch patients (v2)	n = 9 patients	With clinical target contours
Jan-Feb 2017	1st large test of full automation (v3)	n = 228 patients	Reviewed by MDA physician
Mar 2017	2nd large test of full automation (v4)	n = 150 patients	Reviewed by MDA and Tygerberg physicians
Apr 2017	Test on 2nd set of Stellenbosch patients (v4)	n = 8 patients	With clinical target contours
May 2017	MD Anderson clinical implementation (vMDA.2)	n = 20 patients (as of March 2018)	Compared beams after physician edits
Sep 2017	Onsite test - South Africa (v5)	n = 23 patients	Reviewed by Groote Schuur and Tygerberg physicians

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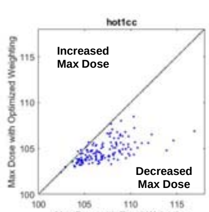
Optimized beam weights

- Compared dose distributions using optimized beam weights to equal beam weights
  - n=149
  - Wilcoxon signed-rank test
- Reduced maximum dose
  - Hottest 1cc
  - Median change: -1.9%
    - $p < 0.001$
  - Range: -10.0% to +0.4%
- Coverage maintained
  - % volume covered by 95% of Rx
  - Median change: +0.6%
    - $p < 0.001$
  - Range: -2.8% - +2.8%



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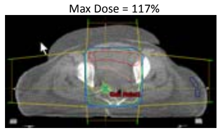
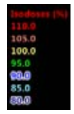
Greatest effect for hotter doses

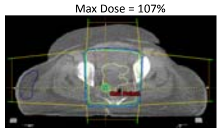
- Looking at patients with higher maximum doses
  - >= 107% of Rx
- Reduced maximum dose
  - Hottest 1cc
  - Median change: -3.5%
- Percent of patients
  - Equal weights: 44%
  - Optimized weights: 3%

Equal Beam Weights
Max Dose = 117%





Optimized Beam Weights
Max Dose = 107%



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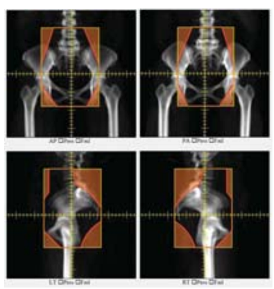
The Big Test

- Retrospective
- MDACC patients (n=150)
- Radiation Oncologist rates fields as acceptable for treatment or not (pass/fail)
  - Target pass rate is 95%
- 2 Radiation Oncologists (MDACC and Stellenbosch U)
- Pass rate
  - 89% of patients
  - (round 1 = 78%)
- #1 cause of rejection: superior border
  - Otherwise, 99% of plans are acceptable



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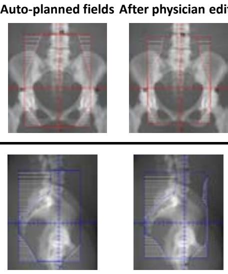
Clinical Version Deployed at MD Anderson



24 patients so far

~10 minutes per patient

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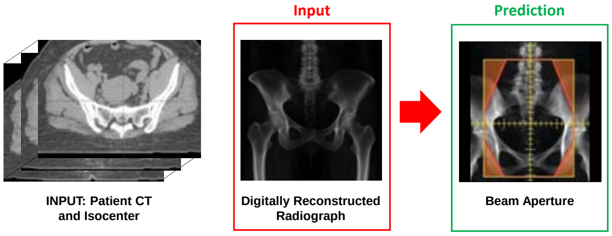
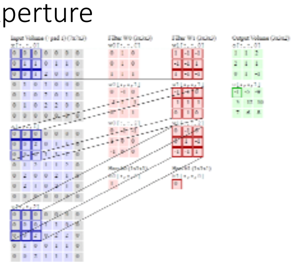
Deep Learning Solution?



Cervical Cancer Beam Aperture

- Convolutional Neural Networks
  - Local connectivity
  - Provides spatial context
  - Shift invariant
- Great for
  - Image segmentation
    - VGG-16, U-Net, etc.
  - Image classification
    - AlexNet, VGG, etc.
- CNNs have become very popular in medical imaging research

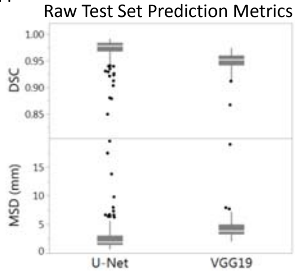


http://cs231n.github.io/convolutional-networks/

Deep Learning Approach

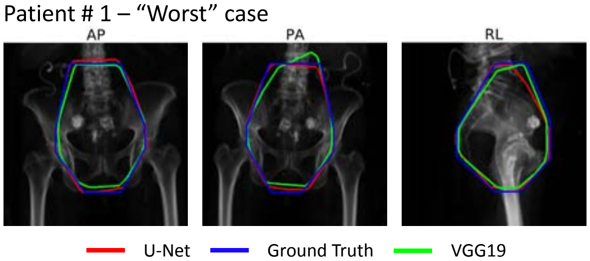
- We chose two image segmentation architectures
  - VGG19
  - U-Net
- Comparison between results

Raw Test Set Prediction Metrics



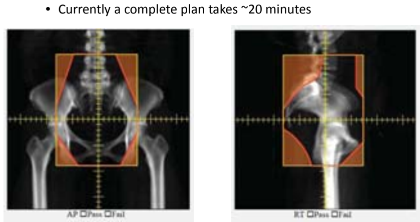
Test Set Results

Patient # 1 – "Worst" case



Cervical cancer 4-field box plans - summary

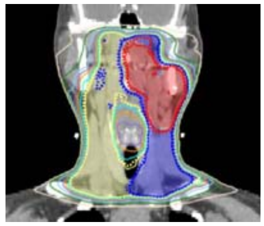
- Automatic generation of field apertures – used in our clinic
- Automatic beam-weight optimization
- Secondary calculations to check quality
- Currently a complete plan takes ~20 minutes



Head and neck

Head and neck treatments

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



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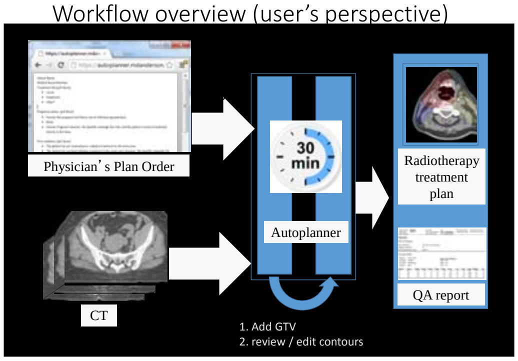
Workflow overview (user's perspective)



Normal tissue contouring

The search for a good contouring algorithm

Eight Contouring algorithms options evaluated:

1. Eclipse Smart Detection (Heuristic)
2. Eclipse Smart Segmentation (DIR)
   a) Single Atlas
   b) Fused Atlas
3. Varian Deeds (DIR)
   a) Varian Atlas
      Two fusion techniques:
      - Majority voting
      - STAPLE fusion
   b) MDACC Atlas
4. In-house multi-atlas technique - MACS (DIR) [STAPLE fusion]
   a) MDACC Atlas
   b) Original Varian Atlas

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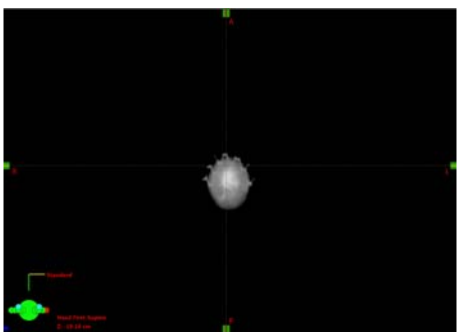
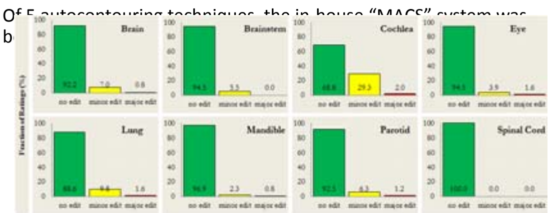
Case #3: Normal Tissue Autocontouring



Results – Physician Review

- Of 5 autocontouring techniques, the in-house “MACS” system was
  b



In submission: Retrospective Validation and Clinical Implementation of Automated Contouring of Organs at Risk in the Head and Neck: A Step toward Automated Radiation Treatment Planning for Low- and Middle-Income Countries JGO.18.00055

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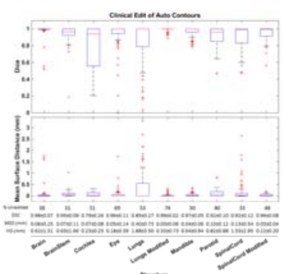
In-house and commercial solution (RayStation) vs. manual contours

Structures	Commercial solution			In-house solution		
	Dice	MSD (mm)	HD (mm)	Dice	MSD (mm)	HD (mm)
Brain	0.99±0.00	0.8±0.3	16.3±28.3	0.99±0.00	0.8±0.3	16.1±28.5
Brainstem	0.84±0.04	1.8±0.5	6.1±1.9	0.89±0.02	1.4±0.3	6.0±1.9
Spinal Cord	0.85±0.02	1.1±0.2	8.6±3.7	0.84±0.04	1.1±0.2	9.1±4.7
Parotids	0.81±0.05	2.2±0.6	11.8±5.8	0.83±0.05	2.0±0.5	11.9±5.5
Mandible	0.90±0.03	0.9±0.2	8.0±2.8	0.90±0.02	0.9±0.1	7.9±2.6
Cochleae	0.78±0.05	0.7±0.1	2.2±0.5	0.73±0.06	0.8±0.2	2.7±0.4
Eyes	0.88±0.04	1.1±0.3	3.4±0.9	0.89±0.03	1.0±0.2	3.5±0.9
Lungs	0.87±0.11	3.8±3.2	21.5±13.3	0.87±0.12	3.8±3.3	24.3±12.5

Data from Jinzhong Yang and Peter Balter (submitted to ASTRO 2018)

Clinical use of OAR autocontouring

Analysis of 228 patients (18 months)



Possible use of margins to account for contouring uncertainties

	Patient population			
	90%		95%	
	Contour coverage			
Structure	95%	100%	95%	100%
Brain	0	7.53	0	10.64
Brainstem	3.55	7.22	4.51	8.88
Cochlea	2.28	3.02	3.42	4
Eye	1.64	3.34	2.06	5.28
Lung	0.64	>15	4.2	>15
Mandible	1.74	12.8	3.59	>15
Parotid gland	4.67	>15	9.05	>15
Spinal cord	0.98	3.74	1.63	4.81

In submission: Retrospective Validation and Clinical Implementation of Automated Contouring of Organs at Risk in the Head and Neck: A Step toward Automated Radiation Treatment Planning for Low- and Middle-Income Countries JGO.18.00055

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Dosimetric impact of OAR autocontouring

- 54 patients with clinically edited autocontours
  - Use (1) unedited original and (2) edited contours for planning
  - Evaluate the plan on physician edited “true” structures

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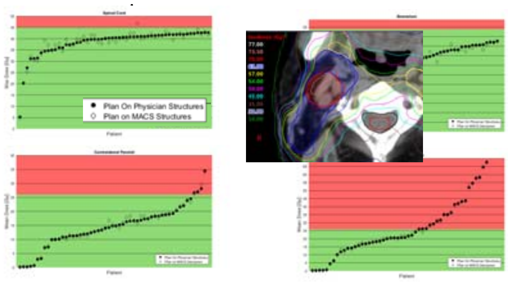
Results – Dosimetric impact of OAR a



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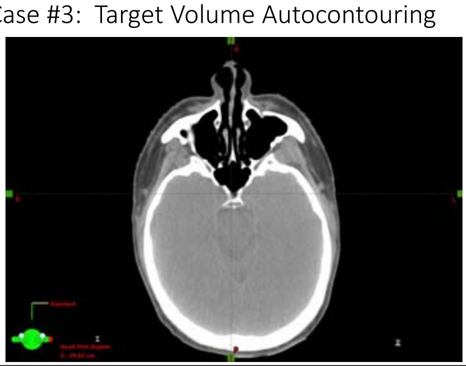
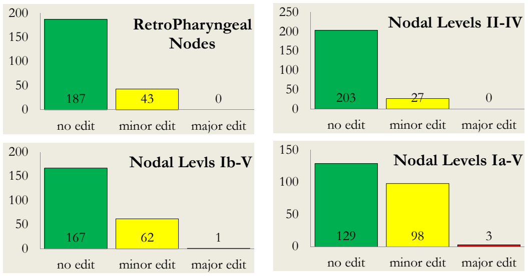
Target contouring

Case #3: Target Volume Autocontouring



Results – Primary Physician Review (n=115)



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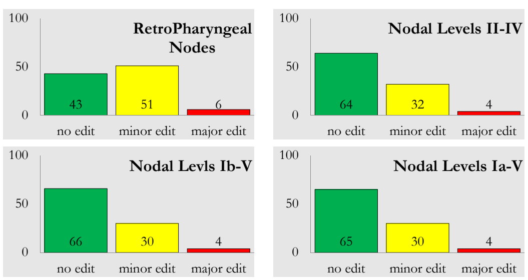
Results – International Review (5 physicians, n=10)



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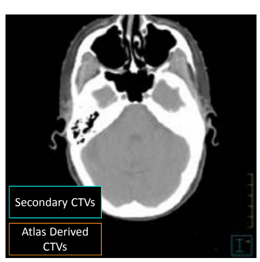
Deep learning for contour QA?

- Secondary technique
  - Two channel U-Net architecture (3D variant)
    - Trained on 210 bilateral oropharynx patients
  - Requires CT, GTV contour(s), external contour
  - Tested on 85 independent cases: Dice 0.78±0.05



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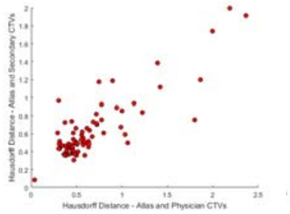
Results – Assessment of autocontour quality

"Disagreement" with secondary check is correlated to disagreement with physician CTVs



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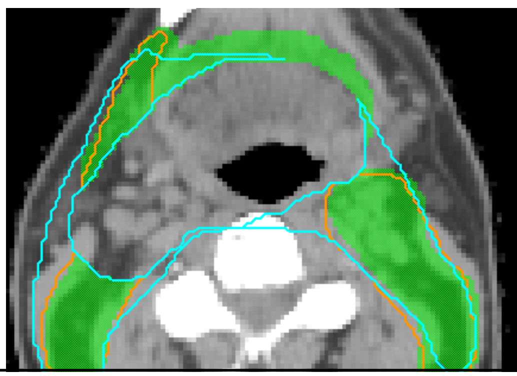


Plan optimization

Plan automation has been demonstrated to save time:

Fully Automated Volumetric Modulated Arc Therapy Plan Generation for Prostate Cancer Patients

Peter W.J. Voet, RTT, Maarten L.P. Dirkx, PhD, Sebastiaan Breedveld, PhD, Abrahim Al-Mamgani, MD, PhD, Luca Incrocci, MD, PhD, and Ben J.M. Heijmen, PhD

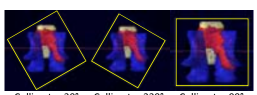
Department of Radiation Oncology, Erasmus MC—Daniel den Hoed Cancer Center, Rotterdam, The Netherlands

Int J Radiation Oncol Biol Phys, Vol. 88, No. 5, pp. 1175–1179, 2014

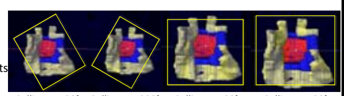
- Purpose – single-run optimization, avoiding manual tweaking
- Commercial TPS linked to in-house optimizer for pre-optimization
- Demonstrated fully automated VMAT planning for prostate plans
- Plans were clinically acceptable – and saved 1+ hours of hands on time

Methods – Single optimization treatment plans

- Planning Approach
  - Physician drawn targets and OARs
  - Supplement with autocontoured structures
    - Missing normal structures
    - Various planning structures
  - Isocenter at target center
  - Collimator size/angle based on targets
    - 30° and 330° collimator angles, symmetric fields, 18cm max
    - 90° collimator angle, split field if Superior-Inferior dimension exceeds 18cm
  - WUSTL Rapid Plan Model + Population Constraints
  - Normalize such that all PTVs receive ≥98% of prescribed dose to 95% volume



Collimator 30° X field: 17.8cm | Collimator 330° X field: 17.8cm | Collimator 90° X field: 16.4cm



Collimator 30° X field: 18cm | Collimator 330° X field: 18cm | Collimator 90° X field: 18cm | Collimator 90° X field: 18cm

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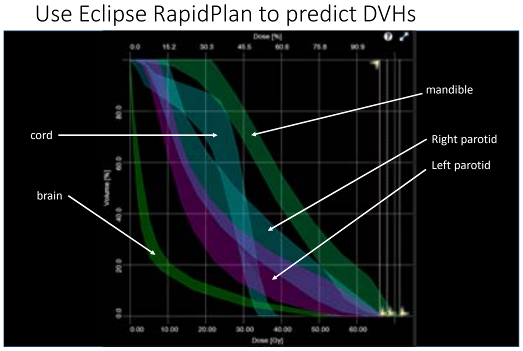
Use Eclipse RapidPlan to predict DVHs



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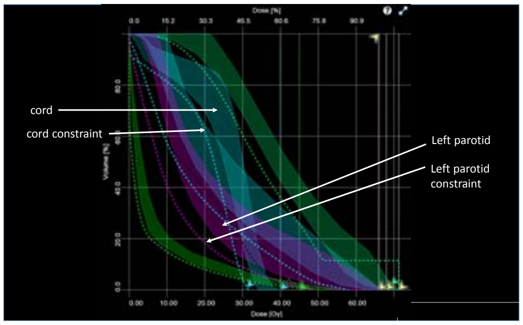
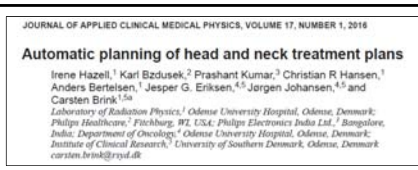
And optimization constraints

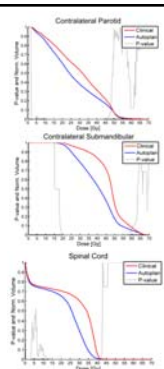



JOURNAL OF APPLIED CLINICAL MEDICAL PHYSICS, VOLUME 17, NUMBER 1, 2016

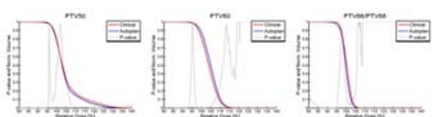
Automatic planning of head and neck treatment plans

Irene Hazell,[1] Karl Bzdusek,[2] Prashant Kumar,[3] Christian R Hansen,[1] Anders Bertelsen,[1] Jesper G. Eriksen,[4,5] Jørgen Johansen,[4,5] and Carsten Brink[1,5a]

Laboratory of Radiation Physics,[1] Odense University Hospital, Odense, Denmark; Philips Healthcare,[2] Fitchburg, WI, USA; Philips Electronics India Ltd.,[3] Bangalore, India; Department of Oncology,[4] Odense University Hospital, Odense, Denmark; Institute of Clinical Research,[5] University of Southern Denmark, Odense, Denmark carsten.brink@rsyd.dk

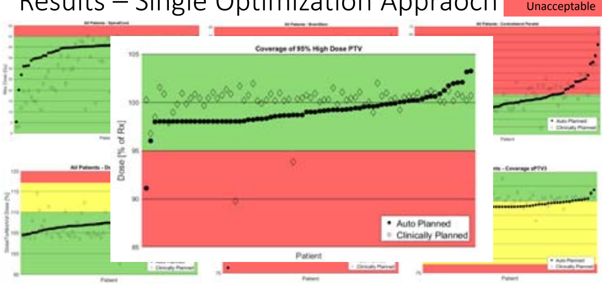


- Pinnacle Auto-Planning module
- Created clinically acceptable treatment plans in 26/26 cases



Results – Single Optimization Appraoch

Per Protocol
Acceptable Variation
Unacceptable



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Results – Clinical vs RPA plans

		p value, Wilcoxon Rank Sum				p value, Wilcoxon Rank Sum			% plans meeting	
Structure	Test Point	All (74)	RTOG (20)	MDACC (54)	Test Point	All (74)	RTOG (20)	MDACC (54)	RPA	Clinical
Spinal Cord	D_max	0.00	0.17	0.00	V_45Gy	0.63	0.25	1.00	100%	99%
Brainstem	D_max	0.00	0.01	0.00	V_50 Gy	1.00	1.00	1.00	100%	99%
Ipsilateral Parotid	D_mean	0.00	0.00	0.10	V_30Gy	0.00	0.00	0.00	56%	50%
Contralateral Parotid	D_mean	0.02	0.00	0.00	V_30Gy	0.01	0.00	0.76	88%	86%
Ipsilateral SMG	D_mean	0.00	0.31	0.01					10%	25%
Contralateral SMG	D_mean	0.00	0.81	0.00					32%	46%
Cochleae	D_max	0.00	0.00	0.00	V_35Gy	0.01	0.25	0.00	86%	93%
Optic Chiasm	D_max	0.02	0.75	0.03	V_54Gy	1.00	1.00	1.00	95%	100%
Optic Nerves	D_max	0.00	1.00	0.00	V_54Gy	0.03	1.00	0.03	90%	96%
Lens	D max	0.00	0.13	0.00	V_7Gy	0.00	1.00	0.00	82%	88%
High Dose PTV	V_1cc	0.00	0.22	0.00					99%	100%
High Dose PTV	V_95%	1.00	1.00	1.00					97%	97%
Intermediate Dose PTV	V_95%	0.00	0.26	0.00					97%	100%
Low Dose PTV	V_95%	0.00	0.02	0.02					100%	100%

RPA plans are better

Clinical plans are better

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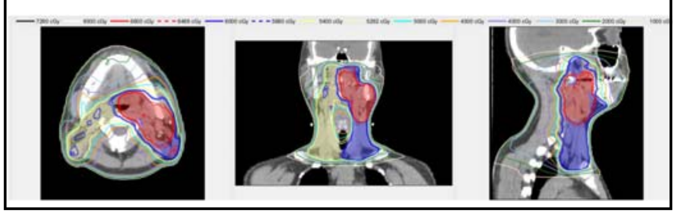
Head and neck automated planning summary

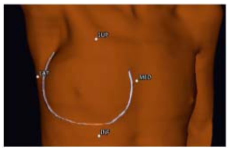
- Automated contouring of normal tissues – deployed into clinic
- Automated contouring of targets – works (not deployed)
- Automated VMAT plans
- Currently, the entire automated process takes ~40minutes



Breast

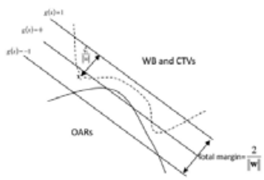
Automated breast planning

- Purdie: Princess Margaret approach
- Wire placed around the breast tissue or along chest wall
- Markers used to denote margins (4)
- Heuristic optimization to place beams (based on lung, heart contours)
- Originally integrated into Pinnacle. Now available in RayStation



Raysearchlabs.com

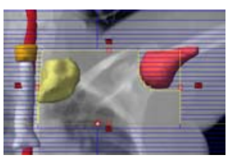
- Zhao et al: Support vector machine algorithm to determine beam placement

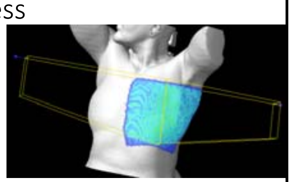


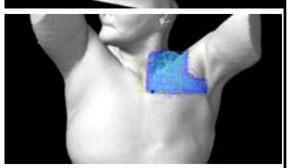
Zhao et al, Automated beam placement for breast radiotherapy using a support vector machine based algorithm, Med. Phys. 39(5), 2536, 2012

Chest wall – works-in-progress

- Autocontour chest wall, lung, heart, SCV, humeral head, spinal canal, trachea and cricoid
- SVM for gantry, collimator angles, and medial border for SCV field (tangents first, then SCV)
- BEV of cricoid and humeral head for rest
- Field-in-field apertures/weight optimization







Physician feedback

Primary Partners

Data gathering trips, 9/2017, 1/2018, 3/2018

Santo Tomas University, Manila

- **Head/neck treatments**
  - Reviewed 20 patient RPA plans with radiation oncologist
  - They approved all plans
  - Ran 3 patients through RPA, and reviewed – approved
  - Plans for which V105 > 8% are flagged to the user

Tygerberg Hostpital, Stellenbosch University

- **Cervical cancer treatments**
  - Ran 10 cervical cancer patients through the RPA and reviewed with rad onc (~1hour)
    - She approved all 10 plans
- **Head/neck treatments**
  - Ran 5 + 3 H/N patients through the RPA and reviewed with radiation oncologist
  - She approved all plans

UNIVERSITEIT • STELLENBOSCH • UNIVERSITY

Groote Schuur Hospital, University of Cape Town

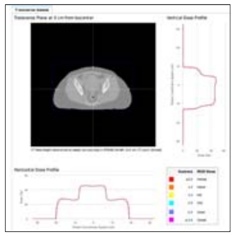
- **Cervical cancer treatments**
  - Ran 13 cervical cancer patients through the RPA and reviewed 4 rad onc ~1hour
    - She approved all 4 plans
- **Head/neck treatments**
  - Reviewed 3 patient RPA plans with radiation oncologist
  - They approved all plans

Quality Assurance

Quality Assurance

- Basic QA of input data
  - Does the site match?
    - H/N vs. pelvis
  - Is the orientation correct?
  - CT scan length sufficient?
- Comparison of primary and secondary algorithms
  - Dose calculation: Eclipse vs. Mobius
  - Other independent algorithms for all other functions
    - Couch removal
    - Contours
    - Beam apertures

Simple image registration



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Quality Assurance

- Comparison with population values
  - MU
  - Jaw positions
  - ....
- Data transfer checks (automatic)
- Manual plan checks
  - Planning technician
  - Physics
  - Radiation oncology

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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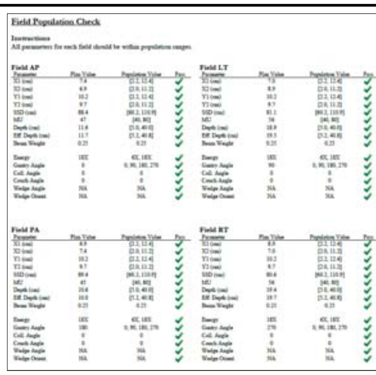

Field Population Check

Instructions

All parameters for each field should be within population ranges.

Field AP

Field LT

Field PA

Field RT

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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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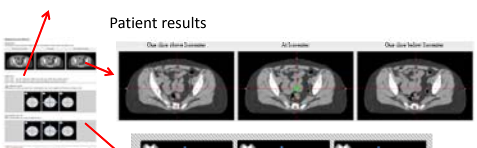
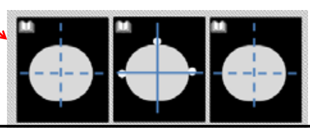
Marked isocenter

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?

Patient results



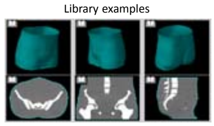
Library examples



Body contour

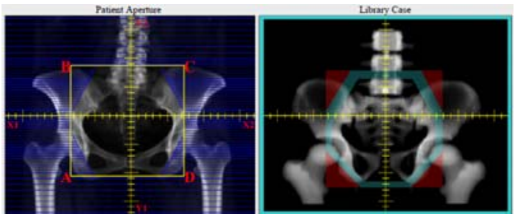
Patient results

Library examples



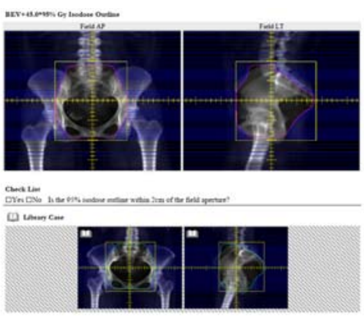
Checklist
❑Yes ❑No : On the CT slices, is the body correctly contoured (e.g. not including the couch)?
❑Yes ❑No : Is the body contour smooth, like the library case?
❑Yes ❑No : Is the orientation consistent with the library case?

Field apertures



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?

Completeness of dose calculation



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How well can the planning technologist evaluate plans?

- Total 7 pages, 23 questions
- Training video (for technical plan checks)
- 4 physics undergraduates, 16 patient plans with intentional errors
- Time taken to check each plan: Average 8 min

	Correctly identified errors
Marked isocenter	Yes
Body contour	Yes
Field apertures	NO
Differences in images (including orientation)	Yes
Unanticipated error type (missing field)	NO

Court et al. Radiation Planning Assistant – A streamlined, fully automated radiotherapy treatment planning system, Jove 2018 (accepted)

Automation of treatment planning: Summary

- Automatic treatment planning may help reduce the planning burden, reducing staff shortages
- Fully automated cervical cancer 4-field box treatments – done (20min per plan)
  - Field aperture task already at MDA
- Fully automated H/N IMRT/VMAT treatment planning – mostly done (40min per plan)
  - Normal tissue contouring task deployed at MDA
- Breast / chest wall – next
- Start deploying (if funded) late 2018.

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