


# Standardization and Automation of HDR Brachytherapy Plan QA with API

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## Disclosures

- None

## Objective

To learn about the latest in cutting edge tools for script-based automated plan checkers in brachytherapy

## Outline

- HDR brachytherapy & events
- Need for treatment plan QA and role for automation
- Scripting-based checker for HDR brachytherapy plan QA
  - Development, implementation, and validation
  - Potential enhancements

## HDR Brachytherapy

- HDR BT treatments demand high efficiency:
  - applicator placement, planning, and treatment
  - short time-frames (the same day!)
  - leaving limited time for plan QA
- HDR BT treatments demand high accuracy:
  - delivery of dose in few fractions & high dose rates
  - prevent severe dosimetric errors and medical events
- HDR BT is a mature modality
  - Published guidance documents to help establish safety and quality management programs (TG-56 in 1997, TG-59 in 1998)

# Events in HDR Brachytherapy

However, near-misses and medical events do happen (ICRP 97 in 2004)

- ~ 2 decades of HDR brachytherapy
- Estimated that accidents or events are greatly underreported
- Identified > 500 recorded events
- Most events due to human failures/errors (ICRP 97)

Prevention of high-dose-rate brachytherapy accidents

ICRP Publication 97

Approved by the Commission in August 2004

# ME in HDR Brachytherapy

HDR brachytherapy medical events recorded for 2010-2011:

- Not due to a lack of guidance documents
- Failure to follow recommendations
- Human failures in performance of tasks
- 4 out of 10 major error categories leading to ME were related to the treatment planning process

1. Sources entered into the computer database in the wrong units at the time of assay
2. Wrong step size entered either during treatment planning or treatment-unit programming
3. Wrong dose entered during treatment planning
4. Wrong isodose value selected for dose prescription
5. Wrong length or default length incorrectly used
6. Applicator length measured incorrectly
7. Different transfer tubes used during treatment than assumed during treatment planning
8. Wrong magnification used during treatment planning or other general treatment planning errors
9. Source retracting failures
10. Applicator failure through poor construction, poor maintenance, or misuse

*Thomadsen et al, PRO, 4, 65-70, 2014.*

# ME in HDR Brachytherapy

Events related to the treatment planning (TP) process:

- 44 NRC-reported ME related to HDR Planning from 1999-2012

Table 3
NRC-reported medical events related to HDR planning (1999–2012)

| Event | Number | % |
|---|---|---|
| Wrong indexer length | 20 | 45 |
| Dose points | 6 | 15 |
| Catheter reconstruction | 5 | 11 |
| Misidentified first dwell position | 4 | 9 |
| Not specified | 8 | 20 |
| Total | 44 | |

NRC = Nuclear Regulatory Commission (United States).

- FMEA on TP process
  - Most common failure mode was due to human error
  - Most often with actions having the least time available
    - treatment planning vs. source strength calibration/machine QA
  - Possible solutions: lower workload stress & more experience

*Wilkinson DA, Kolar MD. Brachytherapy 2013;12:382–6.*

# Treatment Plan QA

- Plan QA typically includes an evaluation of plan quality and a check of plan parameters
- Plan quality assurance (Plan QA) can increase the detectability of planning errors, with some caveats:
  - often manually performed → subject to errors
  - relies on the reviewer's expertise → inconsistencies
  - can be iterative: customized plans → further plan optimization → repeat plan QA → repeat retrieval of plan parameters & plan evaluation → takes time

*Wilkinson et al., Brachytherapy, 12, 382-386, 2013.*
*Fraass et al., TG-53, Medical Physics, 25, 1773-1829, 1998.*

# Role for Automation

- Automation and safety barriers have been recognized as being more effective than implementing policies/procedures for safety & quality
- Many aspects of treatment plan QA can be automated using software
- "Pre-treatment plan check" is one aspect, & has been shown to be the most effective individual check to prevent errors*

*Safety is no accident: a framework for quality radiation oncology and care. Arlington, VA: ASTRO; 2012.*
**Ford E et al., Int J Radiat Oncol Biol Phys 2012;84:e263–99.*

- # of investigators have created automated plan check programs:
  - Halabi T and Lu H. Automating checks of plan check automation. J Appl Clin Med Phys. 2014;15(4):1–8
  - Olsen LA, Robinson CG, He GR, et al. Automated radiation therapy treatment plan workflow using a commercial application programming interface. Pract Radiat Oncol. 2013;4(6):358–67.
  - Moore KL, Kagadis GC, McNutt TR, Moiseenko V, Mutic S. Vision 20/20: automation and advanced computing in clinical radiation oncology. Med Phys. 2014;41(1):010901.
  - Li HH, Ms YW, Yang D, Mutic S. Software tool for physics chart checks. Pract Radiat Oncol. 2014;4(6):e217–e225.
  - Yang D and Moore KL. Automated radiotherapy treatment plan integrity verification. Med Phys 2012;39(3):1542–51.
  - Breen SL and Zhang B. Audit of an automated checklist for quality control of radiotherapy treatment plans, Radiother Oncol. 2010;97(3):579–84.
  - Furhang EE, Dolan J, Sillanpaa JK, Harrison LB. Automating the initial physics chart checking process. J Appl Clin Med Phys. 2009;10(1):2855.
  - Dewhurst JM, Lowe M, Hardy MJ, Christopher J, Whitehurst P, Rowbottom CG. AutoLock: a semiautomated system for radiotherapy treatment plan quality control. J Appl Clin Med Phys. 2015;16(3):339–50.
  - Covington et al., Improving treatment plan evaluation with automation. J Appl Clin Med Phys. 2016;17(6):16-31.
- Trend in last 10 years: Focused on external beam (EB) RT
- HDR brachy team to be efficient, accurate, and consistent → need for automated plan QA tools
- BrachyVerifier by Damato et al in 2014– Java-based custom software that functions as a GUI *external to the treatment planning system* (TPS), user uploads info from R&V and documents

*Damato et al., R&O, 113, 420–424, 2014.*

## Cutting Edge in Scripting for RT

- What if we could reduce the # of workspaces by creating a plan checker WITHIN the TPS → ideal for convenience
- Can be done with scripting
- Scripting: Programming via a vendor-supported format or interface to access treatment planning information from TPS
- Supported by several major TPS vendors (Eclipse, Pinnacle, RayStation, etc.)
- Many groups have studied and developed scripting tools for RT
  - Auto planning, plan QA, DVH generation, data mining, etc.
  - Again, mainly for EBRT

*Cai et al., Brachytherapy, 18, 108-114.e1, 2019.*

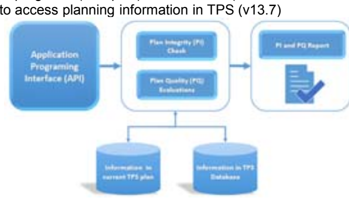
## Cai et al 2019: Scripting for Brachy

- Designed QA tools for standardized & automated checking of HDR brachytherapy plans using scripting in a commercially available TPS (Eclipse)
- Plan QA was divided into 2 major categories:
  - Plan quality (PQ) evaluations
  - Plan integrity (PI) checks
- PQ: focuses on dosimetric information and checks plan meets D-V constraints, and also performs a manual verification of dwell time
- PI: checks plan parameters against tolerances/specs of the RAU and applicator
- Checks/Evals based on published guidelines, clinical protocols, institutional experience

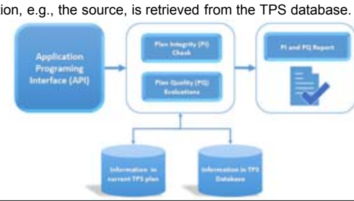
*Cai et al., Brachytherapy, 18, 108-114.e1, 2019.*
*Mooney et al., Brachytherapy, 15, 616-624, 2016.*
*NSABP B-39/ROTG 0413 protocol*
*RTOG 0321 protocol*

## Script Design in Eclipse (ESAPI)

- The Eclipse Scripting Application Programming Interface (Eclipse Scripting API or ESAPI): a programming interface and software library for Eclipse.
- The scripts can be integrated into the Eclipse user interface, or they can be run as standalone executables.
- User designed C# programs ("scripts") were created (PI check & PQ check) and executed through the API to access planning information in TPS (v13.7)



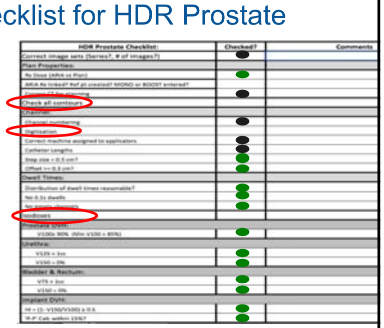

- Two quality control reports were generated on
  - PI report specific to the applicator
  - PQ report designed to be site dependent (SAVI-Breast, HDR Prostate)
- Information for PI checks & PQ evaluations retrieved mainly from two places: the current plan and the TPS database.
- Dynamic information, e.g., individual plan's planning parameters, retrieved from information and data structure within current plan
- Static information, e.g., the source, is retrieved from the TPS database.



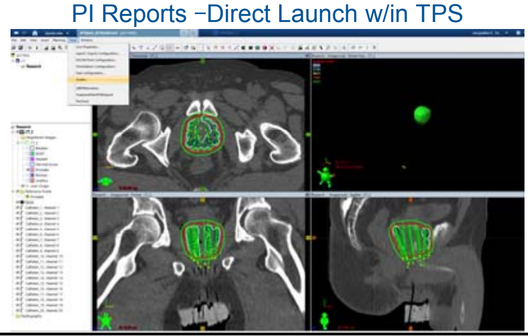

## Plan QA Checklist for HDR Prostate

- Use of checklists in RO recommended to standardize processes & increase compliance w/policies
- Sample plan QA checklist for HDR prostate (manual process)
- Goal: to automatically pull information from TPS and mimic human checking process – *as much as possible using scripting*
  - ❑ Report items
  - ❑ Check items
  - ❑ Leave items for manual check (still need a checklist!)

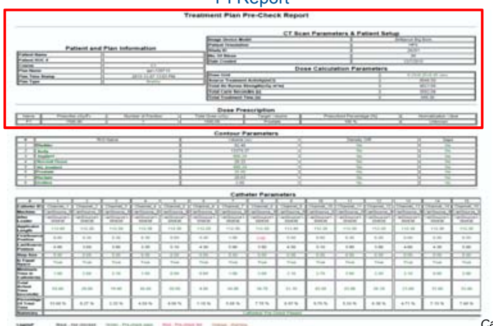
*Thomadsen et al, PRO, 4, 65-70, 2014.*




## PI Reports −Direct Launch w/in TPS

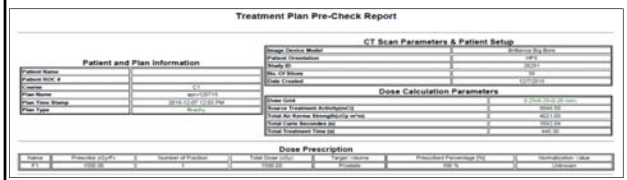


## PI Report



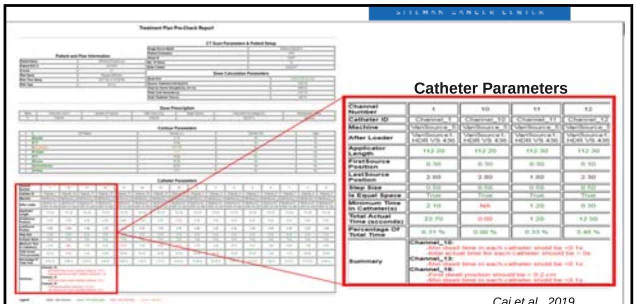
*Cai et al., 2019.*

## PI Report = “Precheck Report”




- Used as a “precheck” & “final check” tool (e.g., after opt)
- Some information simply reported (black)
- Other information compared against predetermined QA metrics with color-coded pass (green) or flagged (red) or warning (yellow) indicators
- Forty-one parameters reported/checked

*Cai et al., 2019.*



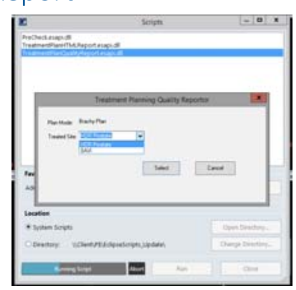

*Cai et al., 2019.*

## PQ Report

Manual inputs required by the PQ report:

•What site? Manually selected

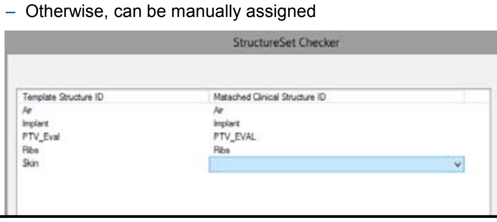
- SAVI
- Prostate



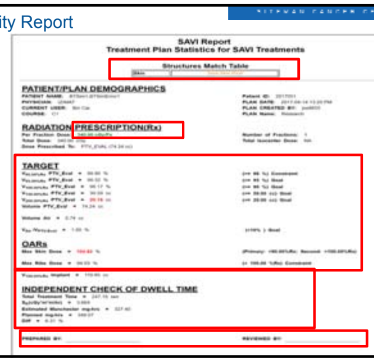
## PQ Report

•What structures for D-V stats?

- Script will automatically assign contours in plan to these structures based on a set naming convention, e.g., “PTV_Eval”
- Otherwise, can be manually assigned




## Plan Quality Report




*Cai et al., 2019.*

## PQ Report

**TARGET**

| | | |
|---|---|---|
| V[illegible] PTV_Eval = 99.80 % | | (>= 98 %) Constraint |
| V[illegible] PTV_Eval = 99.32 % | | (>= 95 %) Goal |
| V[illegible] PTV_Eval = 98.17 % | | (>= 90 %) Goal |
| V[illegible] PTV_Eval = 39.59 cc | | (<= 50.00 cc) Goal |
| V[illegible] PTV_Eval = 20.18 cc | | (<= 20.00 cc) Goal |
| Volume PTV_Eval = 74.24 cc | | |
| Volume Air = 0.74 cc | | |
| $V_{Air}/V_{PTV\text{-}Eval}$ = 1.00 % | | (<10% ) Goal |

- Customizable report
  - D-V indices
  - Also evaluates % air in PTV_EVAL
  - Could also re-execute report with a different target contour structure—for example PTV_EVAL_air (simply re-assign)
- Report can be re-generated during planning & re-opt (Dos & Phys)

*Cai et al., 2019.*

## Evaluation of the Plan QA Scripts

- Tested clinical implementation of these QA tools for SAVI breast and HDR prostate
  - High volumes (1-2 week) in an already busy clinic (stressful)
  - Customized planning (requiring more experienced teams)
  - Established planning criteria (rules -- scripted)
- Carried out an observer study
  - Validate QA tools
  - Evaluate gain (if any) in efficiency

*Cai et al., Brachytherapy 2019.*

## Observer Study

- 5 blinded observers
  - experienced authorized medical physicists [AMPs]
  - 2 junior physicists with limited HDR-BT experience
- 4 mock plans (2 SAVIs + 2 HDR Prostates) with added deficiencies

| Item | Simulated Errors or Suboptimal Plan Parameters (detected via PI script) | Simulated Deficiencies in Plan Quality (detected via PQ script) |
|---|---|---|
| (1) | Wrong prescription | OAR max dose constraints not met |
| (2) | Wrong planning image dataset | Compromised target coverage |
| (3) | Wrong step size | Difference of more than 15% in independent dwell time check |
| (4) | Minimum dwell time < 0.2s | |
| (5) | Offset of first dwell position < 0.3cm | |
| (6) | Heavily weighted single channel (> 40%) | |

*Cai et al., 2019.*

## Observer Study

- Check mock plans using a condensed checklist
- Perform 2 rounds:
  - 1st withOUT scripts,
  - 2nd with scripts, run it first, check off list, and manually check remaining items
- In-house software
  - Track time with pausing
  - To record all detected errors/comments along the way

| SAVI Checklist: | Checked? |
|---|---|
| **Plan Properties** | |
| Rx is entered for 1 Fraction? | |
| Air Volume (<10% of PTV_Eval?) | |
| Objectives for Vol Opt | |
| **Channel:** | |
| Channel Numbering | |
| Catheter Lengths | |
| Step size = 0.5 cm? | |
| Offset >0.2? | |
| **Dwell times:** | |
| Distribution of Dwell Times Reasonable? | |
| Channel 1 < 50%? | |
| No 0.1 Seconds | |
| No Empty Channels | |
| **DVHs for PTV_EVAL:** | |
| V90 ≥ 98% | |
| V95 ≥ 95% | |
| V100 ≥ 90% | |
| V150 ≤ 50cc | |
| V200 ≤ 20cc | |
| **DVHs for OARs:** | |
| Skin Dmax < 90% (at least <100%) | |
| Ribs Dmax < 100% (at least not transecting rib) | |
| **P-P' Calc within 15%?** | |

*Cai et al., 2019.*

## Results of Observer Study

| Average over all physicists | Plan1 | | | Plan 2* | | | Plan 3 | | | Plan 4 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | %Errors detected | | Time reduction (min) | %Errors detected | | Time reduction (min) | %Errors detected | | Time reduction (min) | %Errors detected | | Time reduction (min) |
| | Manual | Auto | | Manual | Auto | | Manual | Auto | | Manual | Auto | |
| | 80.0 | 100 | 22.1±16.4 | 100 | 100 | 12.8±9.0 | 90 | 100 | 15.7±12 | 83.3 | 100 | 14.3±5.0 |

*Please note Plan 2 had no simulated errors.

- 100% of simulated errors were detected by the PI script
- Values failing to meet the planning constraints were red-flagged successfully in the PQ reports
- Appropriate warning messages displayed in both reports
- An average time reduction of 16 mins for plan review was observed when using the scripts

*Cai et al., 2019.*

## Our Findings...

- API scripting-based plan QA was designed and implemented for HDR SAVI & prostate plans
- Helpful in terms of error catching and efficiency improvement
- Scripts have been in use in our clinic since 2015 (for brachy)
- Some notable benefits:
  - 10 s → Comprehensive summary → avoid some manual checking steps → saves time, helps prevent misses
  - Maintain some level of consistency between planners/checkers
  - As a precheck tool—quickly identify problems and identify them all at once & upfront
  - Customizable – can check D-V stats, report other metrics (% air, DHI), quickly verify dwell times
  - Reports saved to pdf, has location for AMP/AU signature and part of patient's chart → concise plan report (happy dosimetrists)

## Potential Enhancements of Scripting for HDR Brachy Plan QA

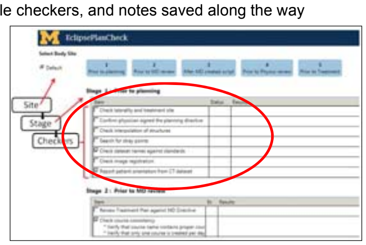
## Covington et al 2016: Scripting for EBRT

- Developed a plan checker tool with ESAPI for initial physics plan checks -- EBRT
- Plan parameters
- Plan quality

*Covington et al., 2016, JACMP.*

## Reports→Worfklow Manager

- Created a GUI where they organized checker into 5 stages during the QA process
- Multiple checkers, and notes saved along the way




## Combines Items into a Single Report

- Manual check, automated check, & reported items visualized in one interface → Checklist & checker rolled into one!
- Reports can be uploaded into treatment management system

| | | |
|---|---|---|
| Verify origin is set correctly | M | Manually Verified |
| Check consistency of RX | | Beam/Modality prescription check failed because there is a mismatch beween presription: 6X and fields: 6X 16X<br>Prescription: DOSE PER FRACTION: 2Gy; TOTAL DOSE: 50Gy; VOLUME ID: BREAST<br>Prescribe Treat: Prescribed: 100%( Relative); Dose per Fraction: 2Gy; Total dose: 50Gy<br>Primary Reference Point: Dose per fraction 2Gy; Total dose: 50Gy |
| Check dose limits in Reference Points | | Eclipse session dose limit: 2Gy; Eclipse daily dose limit: 2Gy; Eclipse total dose limit: 50Gy<br>Primary Reference Point: Dose per fraction 2Gy; Total dose: 50Gy<br>Automatic Checks passed |
| Verify beam energy and modality | | |
| Report if bolus is attached to any beams | | This plan does not have structure bolus and tray bolus is not listed under slot 4. |

## In Summary

Potential benefits of scripting for HDR brachytherapy plan QA:

- •Increase/improve plan quality & integrity
- •Better handle highly customized (complex) plans
- •Improve planning and plan check efficiency
- •Reduce variation between planners and also between checkers

Potential advancements:

- Incorporate Covington's functionality: workflow manager, checker & checklist in one!
- Identify other potential problems of the plan – what other checks can be scripted?
- Expand to more sites and applicators
- Inter-plan comparison to assess plan quality, find outliers

*Kalet et al., 2015, PMB.*
*Furhang et al., 2009, JACMP*
*Young et., 2015, PMB.*

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