Automation of DVH Constraint Checks and Physics Quality Control Review Improves Patient Safety in Radiotherapy

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Abstract

This study investigates whether patient safety can be enhanced by the implementation of an automated electronic checklist (PlanCheck) for physics quality control review (QCR) of radiotherapy photon plans. PlanCheck evaluates both technical aspects and DVH constraints. Three hundred and thirty-one consecutively approved radiotherapy plans previously reviewed with manual QCR were retrospectively checked with PlanCheck. Four hundred and thirty-three (3.4%) of the 12783 automated technical checks executed in the 331 plans yielded an error. All errors were scored using the severity rating from the American Association of Physicists in Medicine TG-100 report. Nineteen of these errors (4%) either could have affected or affected target dose (severity 5+) implicating a maximum dose difference to the target or a critical organ at risk of 0.5% to 10% and 3 errors could have resulted in stereotactic brain treatments being delivered to the wrong location (severity 10). Forty-seven breast cancer plans were retrospectively subjected to automated DVH check, 10 undocumented dose constraint violations were found. PlanCheck has been shown to reduce errors in manually reviewed radiotherapy plans and thus to enhance patient safety.

Keywords: Eclipse Scripting Application Programming Interface script, patient safety, quality control, treatment planning

INTRODUCTION

The physics quality control review (QCR) of radiotherapy treatment plans has been proven the most effective check for preventing accidents in radiation oncology. However, the increased complexity of treatment plans, time pressure, and shortage of qualified medical physicists (QMPs) have made QCR more challenging. As an aid in the QCR process, checklists are now recommended by the American Society for Radiation Oncology and in 2015 American Association of Physicists in Medicine (AAPM) published guidelines for the implementation and maintenance of checklists. However, QCR checklists constantly need to be adapted to new treatment techniques and updated with new departmental guidelines and new national laws and regulations. The difficulty of ensuring that all QMPs use the same physical paper checklists has been obvious at our institution and has been a threat to patient safety. As an alternative to paper checklists, electronic checklists have proven successful both with regard to standardization, reduction of plan rejection rates, reducing patient delays, reducing QCR time, and for enhancing patient safety. PlanCheck is a semi-automated electronic checklist containing 39 automated checks of technical radiotherapy plan aspects. As opposed to previously published electronic checklists, PlanCheck not only checks technical plan aspects but also contains automated dose-volume histograms (DVHs) constraints checks for all local dose constraints for all plans treated with photons at our institution. In this study, we assess the impact on patient safety of both the technical checks and the DVH constraint checks. PlanCheck is created with minimum effort using the Eclipse Scripting Application Programming Interface (ESAPI) (Varian Medical Systems, Inc, Palo Alto, CA). Developing a checklist as a script greatly simplifies and shortens the implementation of an automated checklist compared to stand-alone programs, thus making plan QCR automation

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more readily available for clinics with sparse programming experience and time.

**Materials and Methods**

The PlanCheck script is a C# in-house-developed electronic checklist created using ESAPI, partly based on a previous scripting project, and interacting with a local database created in MySQL (Oracle Corporation Redwood City, CA) containing all structure names and DVH constraints.

Our institution has made use of a physical manual checklist for QCR of treatment plans for many years. The purpose of PlanCheck was to automate as many of the checks in this physical checklist as technically possible. PlanCheck currently automates 39 checks [Appendix Table 1] and checks 856 dose constraints for all 224 diagnoses treated with photons at our institution. PlanCheck is executed on a plan-by-plan basis and generates a report showing both the values expected by the script (fetched from the database) and the values extracted from the plan and the DVHs through ESAPI. Checks producing no errors are showed in green and checks that are out of tolerance are showed in red. Furthermore, the checks are written in a traffic light system, where the color of the traffic light indicates the importance of the check, red traffic light indicating the highest level of importance, yellow being the intermediate importance level, and green being the lowest level of importance. In order to standardize the physics QCR procedure, the checks that are not automated are printed in the report in the form of a manual checklist.

PlanCheck is dynamic in the sense that only the checks that are relevant for the plan in question will be activated [see what checks are activated for what plans in Appendix Table 1]. Adherence to all checks activated for a specific plan ensures a complete physics QCR of that plan at our institution and is followed by a checkpoint to be signed off electronically. In order to save time in the clinical workflow, PlanCheck is not only executed by the QMP as part of the physics QCR but the automated part of the script is also executed by the treatment planner at the planning stage before reaching plan approval and physics QCR, thus avoiding unnecessary plan iterations due to errors caught late in the planning process.

This study investigates whether automated physics QCR with PlanCheck reduces the number of errors in plans previously clinically approved with manual QCR, i.e., using a paper checklist. To assess the impact on patient safety of the 39 technical checks, a retrospective study was conducted. Thus, 331 consecutively approved plans, approved for treatment with manual QCR between July 1 and August 31, 2017 (before the implementation of PlanCheck), were subjected to automated QCR with the script. All errors were automatically saved in a database and the error categories (a combination of the type of check and the type of the plan) where given a severity score using the recommendations from the AAPM TG-100 report. Errors with a possible severity score of 5 or higher (5+) were reviewed and the errors where scored and evaluated individually. The dosimetric impact of errors with severity of 5+ were assessed by subtracting the treatment approved dose distribution from the intended dose distribution in the Eclipse treatment planning system (TPS) (Varian Medical Systems, Palo Alto, CA). The largest dose difference (DD) in the target or a critical organ at risk (OAR) thus found was recorded.

The assessment of the impact of the automated DVH checks on patient safety is made difficult since these results are not saved in the database. However, our local dose constraints for breast cancer patients were revised in December 2020 while PlanCheck was not updated until January 2021. Thus, in December 2020, 47 consecutive breast cancer radiotherapy plans were approved using manual DVH checks only. This gave us the possibility to in February 2021 retrospectively investigate whether PlanCheck could catch DVH violations that were overlooked in the manual QCR in these breast cancer plans. The DVH constraint violations thus found were recorded and assessed dosimetrically. Dose constraint violations detected by PlanCheck but documented in the patient journal were excluded from the analysis.

**Results**

A total of 12783 automated technical plan checks were executed in 331 consecutively approved plans, resulting in 433 potential errors detected (3.4% of the checks resulted in an error). The distribution of the detected errors between the checks is shown in Figure 1 [Descriptions of checks in Appendix Table 1].

In Table 1, the severity distribution of the detected errors, according to the AAPM TG-100 report is shown. Eighty-four percent of the errors (362) had no impact while 11% (48 errors) were assessed to potentially cause inconvenience, either to the staff or to the patient (severity 1–3). Four plans had errors that could have led to suboptimal dose deliveries (severity 4). Of the 14 plans scored with severity 5, six plans had a wrong dose normalization method (DD 0.5%–2%), two breast cancer plans did not include the couch in the dose calculation (DD 0.5% and 2%), 5 plans had an incorrect mean dose to the target compared to the prescription dose (DD 2%–2.5%), and one plan had an

| Severity score | Number of errors |
|----------------|------------------|
| No             | 362              |
| 1              | 44               |
| 2              | 2                |
| 3              | 2                |
| 4              | 4                |
| 5              | 14               |
| 6              | 2                |
| 10             | 3                |
| Severity ≥1    | 71               |
| Sum            | 433              |

**Table 1: Overview of the distribution of severities among the technical plan errors detected by the automated checks**
showed that PlanCheck reduces the mean time spent per
made under time pressure. Furthermore, our previous study
corrective measures by dosimetrists and physicists are often
in the clinic and has a positive impact on patient safety since
In addition to the obvious enhancement in patient safety
overlooked in manual QCR.
In agreement with previously published work,7,16 our results
show that the automated electronic checklist can detect errors
overlooked in manual QCR.
In addition to the obvious enhancement in patient safety
gained by reducing errors of geographical or dosimetric
impact (severity 5+), reducing also clerical errors saves time
in the clinic and has a positive impact on patient safety since
corrective measures by dosimetrists and physicists are often
made under time pressure. Furthermore, our previous study16
showed that PlanCheck reduces the mean time spent per
plan QCR from 16:20 minutes ±8:50 to 12:00 minutes ±9:20
(P = 0.009).
PlanCheck is continuously updated to ensure that the checks
included are catching the errors seen in incidents or in clinical
practice and to ensure that the script is keeping up with the
technical advances in the clinic. Furthermore, the amount
of checks being automated is continuously increasing, thus
easing the time pressure on the physicist performing the
QCR. Some parts of the check, for example, the shape and
position of the gross tumor volume and clinical target volume
or the dose distribution outside of the target and OARs, will
be manual for still quite some time. However, due to the new
technical possibilities, the size of the planning target volume
is something that will be checked automatically in a future
version of the software. Occasionally, we have seen that errors
that could have been caught by PlanCheck have remained
uncorrected in the approved treatment plan. To deal with this
issue, we have recently implemented check points to be signed
off whenever PlanCheck should be run, either at the planning
stage or during QCR.
Since all errors were detected retrospectively some patients
in this study were treated with defective treatment plans. The
19 errors with a severity of 5+ were reviewed manually, and no
error was assessed to have impacted the clinical outcome to the
patient, however all 19 errors were reported in accordance with
national guidelines. Specifically, the three plans with severity
10 were found to not have resulted in mistreatment, although
they could have resulted in a complete geographic miss. This
study shows that PlanCheck contributes to improving patient
safety. PlanCheck is currently used routinely for all diagnoses
with photons at our institution. Since all structure
types and dose constraints are held in a database, PlanCheck
is both easy to maintain and easily implementable in other
institutions using the Eclipse TPS. Versions of PlanCheck are
currently used at Rigshospitalet (Copenhagen, Denmark) and at
Zealand University Hospital (Næstved, Denmark) and another
version is being implemented at Herlev Hospital (Herlev,
Denmark). To aid in the implementation of PlanCheck in
other institutions we have recently made PlanCheck publicly
available on GitHub along with an SQL file containing the
full constraint database.17 As one of the authors performed
the implementation at Zealand University Hospital, we have
no data of how long a full implementation of the script would
take for institutions unfamiliar with the script. However, the
documentation on GitHub not only contains information about
the content of the files and the functionality of the methods
but also on what methods need editing upon implementation
of PlanCheck in a new institution.

**Discussion**

In addition to the obvious enhancement in patient safety
gained by reducing errors of geographical or dosimetric
impact (severity 5+), reducing also clerical errors saves time
in the clinic and has a positive impact on patient safety since
corrective measures by dosimetrists and physicists are often
made under time pressure. Furthermore, our previous study16
showed that PlanCheck reduces the mean time spent per

**Conclusion**

PlanCheck reduces the number of undetected technical errors
and DVH constraint violations in treatment plans compared
with manual QCR at our institution and thus enhances patient
safety. Furthermore, PlanCheck is both easy to maintain and

![Figure 1: Histogram showing the per-check distribution of the 433 errors caught by the automated checks in PlanCheck sorted in pareto order. The dashed line showing the cumulative percentage of each error to the total amount of detected errors](image-url)
easily implementable in other institutions that are using the Eclipse TPS. It has proven its ability to catch rare errors with high potential severity for the patients, i.e., errors easily missed in a manual QCR.

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Conflicts of interest
There are no conflicts of interest.

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Appendix Table 1: A short description of the checks in PlanCheck, including information about what types of plans the checks are activated for and whether the checks are executed automatically or performed manually by the physicist

| Type of check       | Name of automated check | Description of check                                                                 | When executed?       |
|---------------------|-------------------------|--------------------------------------------------------------------------------------|----------------------|
| Automated           | Plan_name_id            | Dose constraints                                                                     | All plans            |
| Automated           | Course_diagnose         | Diagnose attached to course                                                          | All plans            |
| Automated           | Number_of_fractions     | Number of fractions                                                                  | All plans            |
| Automated           | Fraction_dose           | Dose per fraction                                                                    | All plans            |
| Automated           | Ref_point_number        | Reference point number                                                               | All plans            |
| Automated           | Scan_name               | Scan name                                                                            | All plans            |
| Automated           | Use_gated               | The plan can be used gated                                                            | All plans            |
| Automated           | Scan_date               | Scan date                                                                            | All plans            |
| Automated           | User_origin_in_body     | Is the user origin inside the body structure?                                        | All plans            |
| Automated           | Couch_type              | Has the right couch top been added?                                                  | All plans            |
| Automated           | Couch_HU_int            | Is HU of internal couch correct?                                                      | All plans            |
| Automated           | Couch_HU_ext            | Is HU of external couch correct?                                                      | All plans            |
| Automated           | Virtual_bolus           | Are virtual boluses attached to all fields?                                          | All plans            |
| Automated           | Same_isocenter          | Do all fields have the same isocenter?                                               | All plans            |
| Automated           | Treat_name              | Names of treatment fields and setup fields. Also checks whether there is an image field for partial breast irradiations | All plans            |
| Automated           | DIBH_wedge              | Wedge on DIBH field?                                                                 | Only static DIBH fields |
| Automated           | RA_collimator           | Is any collimator placed at a cardinal angle and are there any identical collimator angles? | VMAT only            |
| Automated           | Arc_x_coll              | Are the X field sizes below departmental limits?                                     | VMAT only            |
| Automated           | y_coll                  | Are Y collimators below departmental limits?                                         | VMAT only            |
| Automated           | Setup_coll              | Setup field size (CBCT and OBI)                                                      | All plans            |
| Automated           | cbct_bones              | Are the bones delineated?                                                             | Only CBCT as setup field |
| Automated           | Dose_algorithm          | Algorithm used for dose calculation                                                  | All plans            |
| Automated           | Dose_resolution         | Dose calculation resolution                                                           | All plans            |
| Automated           | Dmean_target            | Mean dose to target                                                                  | All plans            |
| Automated           | Refpoint_target         | Is physical reference point inside the target structure?                             | Only for physical reference points |
| Automated           | Total_referencepoint    | Reference point total dose limit                                                     | All plans            |
| Automated           | Daily_referencepoint    | Reference point daily dose limit                                                     | All plans            |
| Automated           | Session_referencepoint  | Reference point session dose limit                                                   | All plans            |
| Automated           | mu_gy                   | Number of MU per Gy. Fails if≥300 MU/Gy                                              | All plans            |
| Automated           | Dose_2_refpoint         | Dose to reference point                                                               | All plans            |
| Automated           | Lower_objective_oar     | Lower objective on OAR?                                                               | All plans            |
| Automated           | Dmax_in_target          | Is the maximum dose inside the target structure?                                     | All plans            |
| Automated           | mle_at_max              | Are any MLC’s at maximum extension?                                                  | All plans            |
| Automated           | Normalization           | Normalization method                                                                 | All plans            |
| Automated           | obi_angle               | OBI angles                                                                            | OBI setup fields only |
| Automated           | Normal_tissue_objective | Has a ring or normal tissue objective been used?                                     | VMAT only            |
| Automated           | Plan_norm_value         | Plan normalization value                                                              | All plans            |
| Automated           | Virtual_refpoint        | Virtual reference point used?                                                         | All plans            |
| Automated           | Treatment_time          | Treatment time                                                                       | All plans            |
| Manual              | N/A                     | Is the plan ID the same as in the patient journal?                                    | All plans            |
| Manual              | N/A                     | Correct accelerator?                                                                 | All plans            |
| Manual              | N/A                     | Placement of user origin                                                              | All plans            |
| Manual              | N/A                     | Pacemaker or ICD accounted for?                                                       | All plans            |
| Manual              | N/A                     | Metal artefacts, air gaps and contrast agents accounted for?                         | All plans            |
| Manual              | N/A                     | Is the target delineated according to the patient journal?                           | All plans            |
| Manual              | N/A                     | Is the target structure properly delineated?                                         | All plans            |
| Manual              | N/A                     | Placement of couch on CT scan                                                        | All plans            |
| Manual              | N/A                     | Accuracy of body contour                                                              | All plans            |
| Manual              | N/A                     | Target structures cropped from body structure?                                       | All plans            |

Contd...
### Appendix Table 1: Contd...

| Type of check | Name of automated check | Description of check | When executed? |
|---------------|-------------------------|----------------------|----------------|
| Manual        | N/A                     | PTV margin           | All plans      |
| Manual        | N/A                     | Should there be a bolus? | All plans      |
| Manual        | N/A                     | Correct treatment technique used? | All plans |
| Manual        | N/A                     | Isocenter position   | All plans      |
| Manual        | N/A                     | MLC movements        | VMAT only      |
| Manual        | N/A                     | Should arms be delineated and used as objectives? | VMAT only |
| Manual        | N/A                     | Number of arcs       | VMAT only      |
| Manual        | N/A                     | Matching strategy    | All plans      |
| Manual        | N/A                     | Positioning of calculation box | All plans |
| Manual        | N/A                     | Dose distribution outside target and OARs | All plans |
| Manual        | N/A                     | Does the dose overlap with previous treatments? | All plans |
| Manual        | N/A                     | The value of the maximum dose according to position | All plans |
| Manual        | N/A                     | Planning CT and PTV margins | Lung plans with DIBH |
| Manual        | N/A                     | Should DIBH be used? | Breast cancer and lung cancer |
| Manual        | N/A                     | The appearance of the DIBH curve | DIBH plans |
| Manual        | N/A                     | Placement and thickness of bolus | If bolus used |
| Manual        | N/A                     | MU of fields connecting supraclavicular fields with breast fields | Breast cancer where supraclavicular lymph nodes are treated |

DIBH: Deep inspiration breath-hold, CT: Computerized tomography, PTV: Planning target volume, VMAT: Volumetric modulated arc therapy, OAR: Organ at risk, HU: Hounsfield unit, RA: RapidArc, CBCT: Cone beam computed tomography, OBI: On-board imaging, MLC: Multileaf collimator, ICD: Implantable cardioverter defibrillator, MU: Monitor unit