Toward automation of initial chart check for photon/electron EBRT: the clinical implementation of new AAPM task group reports and automation techniques

Huijun Xu | Baoshe Zhang | Mariana Guerrero | Sung-Woo Lee | Narottam Lamichhane | Shifeng Chen | Byongyong Yi

Abstract

Purpose: The recently published AAPM TG-275 and the public review version of TG-315 list new recommendations for comprehensive and minimum physics initial chart checks, respectively. This article addresses the potential development and benefit of initial chart check automation when these recommendations are implemented for clinical photon/electron EBRT.

Methods: Eight board-certified physicists with 2–20 years of clinical experience performed initial chart checks using checklists from TG-275 and TG-315. Manual check times were estimated for three types of plans (IMRT/VMAT, 3D, and 2D) and for prostate, whole pelvis, lung, breast, head and neck, and brain cancers. An expert development team of three physicists re-evaluated the automation feasibility of TG-275 checklist based on their experience of developing and implementing the in-house and the commercial automation tools in our institution. Three levels of initial chart check automation were simulated: (1) Auto_UMMS_tool (which consists of in-house program and commercially available software); (2) Auto_TG275 (with full and partial automation as indicated in TG-275); and (3) Auto_UMMS_exp (with full and partial automation as determined by our experts' re-evaluation).

Results: With no automation of initial chart checks, the ranges of manual check times were 29–56 min (full TG-315 list) and 102–163 min (full TG-275 list), which varied significantly with physicists but varied little at different tumor sites. The 69 of 71 checks which were considered as "not fully automated" in TG-275 were re-evaluated with more automation feasibility. Compared to no automation, the higher levels of automation yielded a great reduction in both manual check times (by 44%–98%) and potentially residual detectable errors (by 15–85%).

Conclusion: The initial chart check automation greatly improves the practicality and efficiency of implementing the new TG recommendations. Revisiting the TG reports with new technology/practice updates may help develop and utilize more automation clinically.
1 | INTRODUCTION

Initial chart check, a key component of medical physicists’ clinical responsibilities, has been one of the most effective ways of ensuring compliance with the prescription. Because of little available guidance on plan and chart review offered by American Association of Physicists in Medicine (AAPM) Task Group (TG) Report 40 and the American College of Radiology (ACR)/American Society for Radiation Oncology, two AAPM TG reports (275 and 315) provide recommendations for clinical practice in terms of chart review in departments of radiation oncology.

TG-275, “Strategies for Effective Physics Plan and Chart Review in Radiation Therapy,” was published in January 2020. This report is based on a survey of AAPM’s membership and included 103 multiple-choice items answered by 1,526 respondents from community hospitals, academic affiliates, and others. The goal of TG-275 is to establish a baseline for the physics plan and chart review and thereby enhance the safety and quality of care for patients. This TG considers external-beam radiotherapy (EBRT) with photons, electrons, and proton radiotherapy. A risk-informed approach considering failure mode and effects analysis (FMEA) was taken to develop the recommendations. For photon/electron EBRT initial plan/chart review checks, 151 check items were proposed under the categories of patient assessment, simulation, and treatment planning. TG-275 was revised in response to the comments from the full AAPM membership. The authors of this report emphasized that checklists were included only as examples, not as definitive lists for any one clinic.

TG-315 has been released to the public as a draft of “Plan and Chart Review in External-Beam Radiotherapy and Brachytherapy” before its publication. Unlike TG-275, the goal of TG-315 is to provide essential checklist items according to the minimum practice standards for EBRT and brachytherapy. Supported by the ACR, TG-315 excludes some TG-275 recommendations that were deemed beyond the clinical training and responsibility of a medical physicist. In its public review version, the TG-315 draft proposes a checklist with 44 items for EBRT. These items are categorized into 36 recommended items and 8 optional items. The optional items can be added to the checklist depending on specific practices at each institution. TG-315 also recommends that each institution establishes its local standard format for treatment prescription.

Current initial chart checks still rely heavily on human inspection and evaluation of various aspects of treatment plans. However, many studies have called for the improvement of pretreatment physics review performance by introducing initial chart check automation. For example, to quantify the potential effectiveness of different quality control measures, some studies have used departmental incident learning systems, which involve reporting any near-misses and incidents that occur in the practice of radiation oncology. A study conducted at the University of Washington Medical Center (Seattle, WA) documented 522 potentially severe or critical near-miss events within an institution-wide incident learning system over 3 years. The majority of errors that were not detected could have been identified if automation of specific physics checks had been in place.

Concerning the increasing reliance on initial chart check automation, TG-275 provides an estimation of the types of checks that might be automated in the future, based on a review of prior publications up to 2016 and other considerations. The feasibility of automation as indicated in TG-275, however, may be increasing with the rapid development of techniques in locally developed programs, vendor solutions, and recent acceleration of machine learning efforts. Some items previously deemed impossible for automation may become feasible through the development of new and easy-to-implement machine learning techniques. One example is a study by Luk et al. who, using a Bayesian network-based radiotherapy plan verification model, suggested a 4-year training dataset to optimize the performance of the network, and yearly updates were considered sufficient to capture the evolution of clinical practice and maintain fidelity. Other recently published papers describe and quantify time savings and error reduction using different analyses. A review of these new techniques and publications is instructive in looking at the future of initial chart check automation.

To date, no quantitative analyses on the time needed for such chart checks have been provided that take into account the TG-275 and TG-315 recommendations. The level of automation that will be required to implement these recommendations in clinical practice without being burdensome is unclear. Here, we explore the future development of initial chart check automation for photon/electron external beam radiation therapy with practical and efficient implementation of the new TG reports. We also estimate, using quantitative analysis, the benefits of time saved and errors avoided by introducing automation consistent with the new TG reports.

2 | METHODS

2.A | Evaluation of manual initial chart check time for different scenarios

An in-house study was conducted to evaluate manual initial chart check time for the full checklists of TG-315 and TG-275. The TG-315 full checklist refers to the entire list of Table 4 in the public review version of the TG-315 draft. For the minimum acceptable safety standards, particularly for the technical component, the initial treatment plan EBRT checklist in TG-315 contains 44 items for physicists. The TG-275 full checklist refers to all items listed in its Table S1A. This full list includes more than 150 check items under the categories of patient assessment, simulation, and treatment planning for...
photon/electron EBRT initial plan/chart review checks. Eight ABR-certified medical physicists in our department with differing clinical experience (2-20 years) were invited to participate in a study based on their clinical experience. Manual initial chart check times were evaluated for six different tumor sites (prostate, whole pelvis, lung, breast, head and neck, and brain cancers) based on each physicist’s experience. Three types of plans — intensity-modulated radiation therapy (IMRT)/volumetric-modulated arc therapy (VMAT), 3D, and simple calculation — were evaluated (depending on their applicability in each cancer site).

Two derived checklists were created for TG-315 and TG-275 to eliminate some uncommon check items for different scenarios. In this article, "TG-315 recommended checklist" refers only to the 36 recommended items in Table 4 of TG-315. For TG-275, a priority checklist was created based on the highest risk priority number (RPN) of the corresponding failure modes (FM) and use frequency. Ninety-five items with RPN > 100 and use > 60% were included in the priority checklist.

Therefore, four checklists were involved in our data analysis: (1) the TG-315 recommended checklist; (2) the TG-315 full checklist; (3) the TG-275 priority checklist; and (4) the TG-275 full checklist. Our physicists’ experience in the Department of Radiation Oncology at University of Maryland Medical System (UMMS) sites was based on using Varian ARIA as the radiation oncology information system (OIS), Raysearch RayStation as the treatment planning system (TPS), and Varian C-series and TrueBeam linac machines for EBRT treatment delivery.

2.B | Re-evaluation of automation feasibility of TG-275 checklists

Our expert development team including three physicists re-evaluated the TG-275 automation feasibility. This expert team has been developing automation tools for various EBRT procedures in our institution during the past 7 years. Our in-house automation tool for initial chart check includes the sophisticated scripts that can access electronic documents, treatment plan DICOM files, and record and verify (R&V) system. Table 1 shows the functions that were available at the time of publication for this in-house tool, which includes many items in the TG-275 checklist. Besides, a commercial tool — Mobius3D (Varian; Palo Alto, CA) has been used in our initial chart check procedures for years. Our experience with our in-house and commercial tools helps classify the feasibility of automating TG-275 items. Note, to be consistent with TG-275, full automation refers to “can potentially be fully automated” and partial automation refers to “can potentially automate whether particular information is present (e.g., a document exists) but not whether the information in it is correct.”

2.C | Automation level simulation for initial chart check

In this work, three levels of chart check automation, that is, Auto_UMMS_tool, Auto_TG275, and Auto_UMMS_exp, were simulated for the four checklists. Auto_UMMS_tool refers to the automation level that automates some checklist items by using our in-house tool (Table 1) and Mobius3D. Auto_TG275 refers to the automation level that automates some checklist items fully or partially as indicated in TG-275 Table S1. A.ii4. Auto_UMMS_exp refers to the automation level that allows fully or partially automated checklist items as re-evaluated by our expert development team.

Our UMMS tool is composed of the in-house automation tool and Mobius3D, and both use DICOM files for CT image, RT structures, RT plan, and RT dose as input data. The in-house tool was designed to automatically review the items in Table 1. It compares all plan parameters in a DICOM RT-Plan file from the OIS to those in its counterpart DICOM RT-Plan file from the TPS. A comparison PDF report can be generated as a patient EMR (electronic medical record) document. In the report, the hospital name, patient name, ID, plan Name/Label, and approval status in TPS and ARIA OIS are listed. Any difference in monitor units (MUs), multileaf collimator (MLC) shape, energy, collimator angle, gantry angle, gantry rotation, couch angle, source–skin distance jaw position, isocenter, segment weights, wedge, bolus, patient position, or applicator can be highlighted if that difference exceeds the predefined tolerance. For the majority of plan parameters, the predefined tolerance is zero. Non-zero predefined tolerance for some plan parameters is mainly due to rounding errors while importing/exporting plans between different systems. More information, including plan name, beam name, radiation type, tolerance table, isocenter coordinate, and treatment machine name, is also compared. The commercial software Mobius3D, powered by its own Mobius Calculation module with a GPU-accelerated collapsed-cone dose algorithm, recomputes the 3D dose distribution on the planning CT from TPS and then compares the dose distribution from its engine against the dose distribution from TPS on the same planning CT. In the Mobius QA reports, the mean dose and D95 are presented for all the target structures. The 3D global gamma and the point dose at the dose specification point for each beam are calculated in Mobius and compared against TPS. Mobius also provide other information such as beam deliverability.

The potential for automation of chart check items was mentioned in TG-275 Table S1. A.ii5. Some check items are regarded as potentially fully automated, including physician intent/prescription vs treatment plan, optimization or calculation parameter checks (target and organ at risk objectives, algorithms, dose grid size, etc.), and data transfer from the TPS to a third-party OIS. For some items, automation may be possible only to determine whether a specific document or item is present, not whether the information in that item is correct (e.g., most patient assessment and simulation checks). The remaining items require manual inspection. Most of them are related to free-typing or handwriting documents, such as consult note, physics consult, patient consent documents.

2.D | Benefit evaluation

Benefit evaluation for different automation levels was performed based on two aspects: (1) manual check time saving and (2) avoidance of errors as a result of automation.
**TABLE 1** Five categories of automated initial chart check items covered by our current in-house tool (=Auto_UMMS_Tool excluding the commercial tool) that has been used clinically for years. The corresponding TG-275 checklist items of patient assessment (PA), simulation (Sim), and treatment planning (TP) in Table S1.A.ii are also listed.

| UMMS tool check items | Corresponding TG-275 items in Table S1.A.ii |
|------------------------|---------------------------------------------|
| **Prescription**        |                                             |
| Prescription consistency with our institutional practice guidelines | PA-Q1-1, PA-Q1-9, Sim-Q1-2, TP-Q2a-10 |
| Prescription template name, creation date, approval status and physician attestation | PA-Q1-2, TP-Q6-5 |
| Pregnancy/waiver check, previous treatment history, chemotherapy, cardiac devices check | PA-Q1-5, PA-Q1-6, PA-Q1-7, PA-Q1-8 |
| Diagnosis code and description check. Consistency between treatment site and diagnosis code. Check diagnosis documents | PA-Q1-3, PA-Q1-5, TP-Q2a-1, TP-Q2a-2 |
| Check additional documents (such as patient survey/consent) | PA-Q1-11, PA-Q1-13 |
| **Plan compliance. For example, no high-energy plan for patients with cardiac device** |
| Prescription approval | PA-Q1-2 |
| Total dose = fraction dose \( \times \) fraction number | TP-Q2a-3,6,7,8 |
| Image technique | TP-Q8-5,8 |
| Fractionation, such as, BID | TP-Q2a-13 |
| Setup comments | Sim-Q1-1,9 |
| Bolus (thickness, type, use frequency) | TP-Q2a-5 |
| **Image and contour** |                                             |
| Check simulation order document | Sim-Q1-1, Sim-Q1-12 |
| Check simulation summary document | Sim-Q1-3, Sim-Q1-4, Sim-Q1-5, Sim-Q1-8, Sim-Q1-9 |
| Check CT DICOM files | Sim-Q1-10, Sim-Q1-12, Sim-Q1-13, Sim-Q1-14, Sim-Q2-1 |
| Check CT series description | Sim-Q1-14, Sim-Q2-2 |
| CT protocol | Sim-Q1-10 |
| CT density table | TP-Q4a-7 |
| CT contrast | Sim-Q1-14 |
| Max HU | TP-Q1a-6 |
| CT modification | Sim-Qa-11,12 |
| BB position consistent with user origin and localization point | Sim-Q1-6, Sim-Q1-7 |
| Density override | TP-Q1a-7, TP-Q4a-6 |
| CT thickness for different planning techniques | Sim-Q1-18 |
| Contours | TP-Q1a-1,2,3,4,7 |
| Check high-Z materials in CT and max HU outside/inside External | TP-Q1a-6 |
| Structure approval | TP-Q1a-8 |
| Check treatment couch insertion and other structures | TP-Q1a-9 |
| **Beam and plan** |                                             |
| Patient treatment position | Sim-Q1-15 |
| Beam naming | TP-Q6-4 |
| Plan deliverability, such as max/min MU for different techniques, max/min spot weight | TP-Q6-1,2 |
| Electron block | Sim-Q1-3,4, TP-Q6-8,13, TP-Q7a-15 |
| **Total body irradiation (TBI) parameters (TBI insert, dose rate, etc.)** | PA-Q1-6 |
| Special requirements for stereotactic radiosurgery (SRS), stereotactic body radiation therapy (SBRT) | TP-Q4a-3,4 |
| Dose calculation algorithms/engines | Sim-Q1-6 |
| Mono-isocenter check | Sim-Q1-6,7, TP-Q6-18 |

(Continues)
For time-saving estimation, a weighting score was assigned to each check item to scale the reduced manual check time corresponding to each of the three automation levels: “Full” = 0, “Partial” = 0.5, and “No” = 1. For a check item with automation level between any two of them, the weighting score was averaged. For example, if a check item was determined as “Full/Partial,” the automatic weighting score for the manual check time was \((0 + 0.5)/2 = 0.25\).

For the avoidance of errors as a result of automation, results from Gopan et al.\(^7\) Table 3 were used for an estimation. Gopan et. al provided the percentage of potentially detectable errors for each step in the radiation therapy process, including patient assessment, simulation, and treatment planning. Here, we defined “the residual detectable errors” as the detectable errors that require human intervention due to the limited automation. We expected that introducing more automation can catch more detectable errors automatically, yielding fewer residual detectable errors. To approximately estimate the relationship between residual detectable errors and chart check automation, we assumed that the number of residual detectable errors for the manual check is proportional to the number of the checklist items that cannot be automated.

| UMMS tool check items | Corresponding TG-275 items in Table S1.A.ii |
|-----------------------|---------------------------------------------|
| Beam isocenter relative to the target center | TP-Q6-17 |
| Dose grid relative to external | TP-Q4a-5 |
| Setup beams consistent with image techniques in the prescription | TP-Q6-14 |
| For SRS, cone and multileaf collimator (MLC) plan choice based on target size | TP-Q2a-12, TP-Q6-1.3 |
| For SRS, gap between jaw and MLC leaf | TP-Q7a-13,14,15,16 |
| For SRS, check MRI image and image registration between MRI and CT | TP-Q10-1.2 |
| Dose grid size for different plans | TP-Q4a-5 |
| Check motion management techniques | Sim-Q2-3 |
| Check optimization parameters and settings | TP-Q1a-5, TP-Q4a-1, TP-Q4a-2,3,4 |
| Check isocenter shifts for multiple iso-center plans | TP-Q3a-1, TP-Q3a-2 |
| **Plan quality** | |
| Target coverage (CTV and planning target volume [PTV]) | TP-Q5-1,2,3,4,5,6,7 |
| Contour expansion from CTV to PTV | TP-Q1q-4 |
| Max dose point | TP-Q5-5 |
| Plan quality index (such as, DVH, conformity index, gradient index, homogeneity index, etc.) | PA-Q1-10, TP-Q5-3 |
| Dose distribution for dose greater than 110% of total prescription dose | TP-Q5-5, TP-Q5-7 |
| **ARIA** | |
| Plan setup in ARIA | TP-Q7a-1.6 to TP-Q7a-24,27 |
| Fractionation consistent with prescription | TP-Q7a-2,3,4,5 |
| Plan scheduling | TP-Q10-15 |
| Dose limits (session/daily/total) consistent with prescription | TP-Q7a-25,26 |
| Course openness | TP-Q7a-28 |
| Image (kV and cone-beam Ct) approval | TP-Q8-2 to TP-Q8-8 |
| Course name consistent with prescription template name | TP-Q6-5 |
| Treatment journal entries | TP-Q7a-21 |
| Delta couch. SRS requires delta couch. Other plans (photon/electron) require delta couch cleared | TP-Q6-18 |
| Reference dose points | TP-Q7a-3,4,5,10 |
| Tolerance tables for different plans, such as SRS. | TP-Q6-14, TP-Q7a-20 |
| Check peer review task in ARIA carepath | PA-Q1-12 |
| Check billing approval in ARIA carepath | PA-Q1-14 |
| Check setup note in ARIA | Sim-Q1-9 |
| Compare DICOM files (CT, RT-Structure, RT-Plan) from TPS and ARIA | Sim-Q1-16, all items in TP-Q7a |
| Beam arrangement vs standard plan templates | TP-Q6-1 |
The maximum, the median, and the minimum average manual inspection time values for six tumor sites estimated by eight physicists with differing clinical experience to manually finish TG-315 and TG-275 checklists. No specific relationship was found between time and experience, but manual check time can vary significantly among physicists.

| Average manual check time over six tumor sites (min) | IMRT/VMAT | 3D | Simple calc |
|------------------------------------------------------|-----------|----|-------------|
| TG-315 full list                                      |           |    |             |
| Max                                                   | 66.5      | 55.5| 50.5        |
| Median                                                | 50.3      | 44.6| 19.1        |
| Min                                                   | 8.8       | 9.2 | 9.9         |
| TG-275 full list                                      |           |    |             |
| Max                                                   | 185.5     | 133.0| 95.0        |
| Median                                                | 72.8      | 71.8| 37.1        |
| Min                                                   | 36.5      | 34.6| 16.0        |
| TG-315 recommended list                               |           |    |             |
| Max                                                   | 51.9      | 47.7| 36.9        |
| Median                                                | 42.2      | 37.6| 17.0        |
| Min                                                   | 6.1       | 6.6 | 7.8         |
| TG-275 priority list (UF > 60%)                        |           |    |             |
| Max                                                   | 144.6     | 91.1| 62.6        |
| Median                                                | 48.1      | 47.1| 21.0        |
| Min                                                   | 23.0      | 22.5| 3.5         |

3 | RESULTS

Manual initial chart check time that was averaged over six tumor sites varied among different physicists’ responses in this study. Table 2 shows that the maximum, the median, and the minimum manual check time values scattered across a large range. Such differences were not correlated with the physicists’ experience; instead, differences grew as planning techniques became more complex. Note that some check items were considered to be manually impractical (e.g., MLC control points) and were excluded when our physicists estimate their check time for this study, so the actual time to finish the corresponding checklist took even longer. Different tumor sites have little impact on manual check time for each physicist: the manual check time difference for different tumor sites ranged from –3% to 4% of their average value. These time data were normalized to the average value to eliminate physician-specific difference.

The automation feasibility of chart check items mentioned in TG-275 Table S1.A.ii4 was a result of the survey from the AAPM members. Here, our expert development team re-evaluated the automation feasibility based on our experience of developing and implementing our in-house automation tool and the commercial product across our institution. Among the 71 items that were deemed not fully automated in the TG-275 report, the automation feasibility of 69 checks was re-evaluated differently. Table 3 lists some of our results versus TG-275: 35 items as “Full”, 17 as “Full/Partial”, 6 as “Partial”, 2 as “No”. The additional feasibility option “Full/Partial” means that automation can be partially implemented but full automation can be realized with certain conditions. For example, our institution is still using a scanned patient consent form. If an electronically fillable or online patient consent form is used, all the essential information could be retrieved by our in-house tool. However, using an electronically fillable or online patient consent form requires our current clinical procedure and policy to be altered, which may take a long process. Therefore, the feasibility for “patient consent” in Table 3 was re-evaluated as “Full/Partial” given the fact that we can only verify if the consent document exists and accessing the content of the document may be possible in the future.

The automation feasibility of each chart check item relies on the availability to retrieve the medical information as well as the availability of high-level automation software, either in-house or commercial. Below we present several examples that illustrate the differences between the results of our re-evaluation and the TG-275 survey results.

One example is about the “Prescription (with respect to standard of care or institutional clinical guidelines)”. TG-275 deemed its automation as “No” while our team considered it “Full.” Our institution uses a set of Microsoft Word templates for the prescription documentation in the Varian ARIA-based EMR system. The use of these electronic documents (as opposed to the scanned paper documents with handwriting in some other clinics) allows our scripts to access the content of a specific document and compare its items with the treatment plan and the ARIA databases. Our automation tool first queries and retrieves each patient’s prescription information based on the ARIA patient ID, treatment site, and document template name. Then, the tool parses all the prescription information as shown in [Fig. 1(a)] (The readers are referred to a recently published paper[35] for more details.). Meanwhile, our institution has produced a series of clinical practice guidelines for prescribing, simulation, contouring, planning, and evaluation of EBRT for each stage of various diseases. As the standard of our clinical practice, these guidelines are periodically updated by our radiation oncology teams based on their clinical experience and the latest literature publishing. Our automation tool compares an individual prescription against our corresponding practice guideline by using an xml template for the essential information, therefore the item “Prescription (with respect to standard of care or institutional clinical guidelines)” of TG-275 is already automated in our institution, which explains why our team unanimously thought it should be considered “Full.” The access to the contents of such electronic documents and our practice guidelines allows us to propose different automation feasibility of many items in Table 3 like “Prescription (respect to standard of care or institutional clinical guidelines),” “Utilization of immobilization and ancillary devices” [Fig. 1(b)], “Special Considerations for radiotherapy,” and “Utilization of other treatment modalities.” “Request for in vivo dosimetry,” and “Parameters and setup for specialized devices.” Another example is about “Insurance approval.” Our automation tool queries the Varian ARIA SQL database to check if the care path task “Billing Approval” is completed by the billing office [Fig. 1(c)] and verify if the scanned insurance card document exists. Our automation tool can also analyze the treatment plan details by accessing...
Table 3: An example of our expert team’s re-evaluation vs TG-275 survey results on the automatic feasibility of EBRT initial chart check items in TG275. The automation feasibility was categorized as “Full,” “Full/Partial,” “Partial,” or “No.” The re-evaluation was based on the existing automation tools Auto_UUMMS_Tool (that is already being used clinically) plus those scripts and programs that are under development by our expert development team.

| Photon categories | Photon physics check | TG-275 | UUMMS experts’ re-evaluation |
|-------------------|----------------------|--------|-----------------------------|
| Patient assessment| Prescription (with respect to standard of care or institutional clinical guidelines) | No     | Full                        |
|                   | Diagnosis definition, including imaging and outside records | No     | Full/Partial                |
|                   | Pathology report     | No     | Partial                     |
|                   | Medical chart to confirm laterality, site, etc. | No     | Full/Partial                |
|                   | Special considerations for radiotherapy (e.g., pacemakers, ICDs, pumps, etc.) | Partial | Full                        |
|                   | Previous radiotherapy treatments | Partial | Full/Partial                |
|                   | Utilization of other treatment modalities (i.e., chemotherapy, surgery) | No     | Full/Partial                |
|                   | Patient consent      | Partial | Full/Partial                |
|                   | Peer review of treatment decision (e.g., tumor board, peer-to-peer evaluation, etc.) | Partial | Full                        |
|                   | Consult note         | Partial | Full/Partial                |
|                   | Insurance approval   | Partial | Full                        |
| Simulation        | Physician directive for imaging technique, setup and immobilization (may include contrast, scanning orientation, immobilization device, etc.) | Partial | Full                        |
|                   | Description of target location on physician planning directive (e.g., RUL Lung, H&N, L1-L4) | Partial | Full                        |
|                   | Utilization of immobilization and ancillary devices | No     | Full                        |
|                   | Construction of immobilization and ancillary devices | No     | No                          |
|                   | Written or photographic documentation of patient positioning, immobilization, and ancillary devices | Partial | Full                        |
|                   | Isocenter placement  | No     | Full/Partial                |
|                   | Isocenter consistency between patient marking and setup instructions | Partial | Full                        |
|                   | Patient setup and positioning | Partial | Partial |                     |
|                   | Setup note           | No     | Full/Partial                |
|                   | CT scanner technique (e.g., kV, filter, etc.) | No     | Full                        |
|                   | CT scan artifacts    | No     | Partial                     |
|                   | CT scanning range (i.e., superior–inferior range includes entire target and organs at risk [OARs]) | No     | Full/Partial                |
|                   | CT scan field of view and clipping of anatomy | No     | Full/Partial                |
|                   | Use of contrast and corresponding effects on HU number | No     | Partial                     |
|                   | 4D CT parameters and data set | No     | Full                        |
|                   | Breath-hold parameters and dataset | No     | Partial                     |
|                   | Gating parameters    | No     | Partial                     |
| Treatment planning contouring checks: items reviewed during contour checks: | Target(s) | Partial | Full                        |
|                   | OARs                 | Partial | Full/Partial                |
|                   | Body/external contour (if required/applicable) | Partial | Full/Partial                |
|                   | High-Z material, contrast, artifacts | No     | Full/Partial                |
| Treatment planning prescription checks (physician intent/Rx vs treatment plan): Items reviewed for prescription checks: | Additional shielding | No | No |
|                   | Prescription vs consult note | No | Full |
|                   | Dose distribution    | No | Full |
|                   | Prior radiation      | Partial | Full                        |
|                   | Plan sum (e.g., original plus boost plans) | No | Full |

(Continues)
the planning system DICOM files, such as isocenter positioning with respect to the target, the CT image properties, and the plan quality, which also yield more advanced automation feasibility compared to the TG-275 survey results.

As more automation is introduced, manual time can be reduced significantly. Data in Fig. 2 indicate that as higher level automation is introduced, manual check times can be greatly shortened. Using the Auto_UMMS-tool, Auto_TG275, and Auto_UMMS_exp automation levels for the full TG-275 checklist, residual manual check times with no automation were reduced by about 30%, 67%, and 91%, respectively, for IMRT/VMAT; by 22%, 63%, and 91%, respectively, for 3D; and by 22%, 64%, and 91%, respectively, for 2D simple. Time reduction in percentage for different checklists was quite similar. For the TG-275 priority checklist using the Auto_UMMS-tool, Auto_TG275, and Auto_UMMS_exp automation levels, manual check times were reduced by 34%, 70%, and 95%, respectively, for IMRT/VMAT; by 22%, 66%, and 94%, respectively, for 3D; and by 22%, 69%, and 94%, respectively, for 2D simple. For the TG-315 checklists, up to 50%, 81%, and 98% of the time can be saved from pure manual check by using the Auto_UMMS-tool, Auto_TG275, and Auto_UMMS_exp automation levels, respectively. If the Auto_UMMS_exp automation level is achieved, the residual manual check time is shortened to <10 min for the TG-275 checklists and <1 min for the TG-315 checklists.

Auto_TG275 can help reduce time by 3%, 7%, and 35% for the patient assessment, simulation, and treatment planning steps, respectively. Auto_UMMS_Exp can help to achieve 6%, 18%, and 46% in corresponding reductions.

Table 4 details the reductions in the potentially residual detectable events in different radiation workflow steps for automation levels Auto_TG275 and Auto_UMMS_Exp. Data from Gopan et al.7 were used to estimate this benefit.

4 | DISCUSSION

Since the physics check is one of the most effective checks for radiation treatment,7 it is essential to stay up to date on the latest recommendations from new guidelines. For TG-315 and TG-275, which

| Table 3 (Continued) | Photon physics check | UMMS experts’ re-evaluation |
|--------------------|----------------------|-----------------------------|
| **Photon categories** | **Photon physics check** | **TG-275** | **UMMS experts’ re-evaluation** |
| Standard operating procedures of practice followed or correctly used | Setup note | Partial | Full |
| | Field aperture | No | Full |
| | Setup shifts | No | Full |
| | Treatment plan warnings/errors | Partial | Full/partial |
| Data transfer from TPS to a third-party OIS (e.g., Eclipse to MOSAIQ, Pinnacle to ARIA, etc.) | Couch parameters | Partial | Full |
| | Setup note | Partial | Full |
| | Imaging sequence | Partial | Full |
| Setup for image guidance for treatment planning | Matching instructions (e.g., 2D/2D, 3D, etc.) | No | Full |
| | Imaging technique | No | Full |
| | DRR image quality | No | Full |
| | Matching structures | Partial | Full |
| During a patient’s treatment course, verify that the original plan and corresponding dosimetry (i.e., DVH, target coverage, OAR sparing, etc.) still meet the treatment intent by using the original plan on a new simulation CT set | Old/new CT registration | No | Full |
| | Isocenter placement | No | Full |
| | Deformed or new contours | No | Full |
| Other checks during the initial plan check process | Registration/fusion of image sets (CT, PET, MRI, etc.) | No | Full/partial |
| | Image set chosen for treatment planning | No | Full |
| | Physician-designed apertures | No | Full/partial |
| | Physics consult (e.g., evaluation of dose to pacemaker, previous treatment, etc.) | No | Full |
| | Parameters and setup for specialized devices (e.g., ExacTrac, VisionRT, RPM, etc.) | No | Full |
| | Request for in vivo dosimetry | Partial | Full |
| | Motion management instructions | Partial | Full/partial |
| | Instruction for replanning | No | Full |
| | Scheduling of tasks (e.g., weekly chart checks, MD image review, etc.) | No | Full |
Fig. 1. (a) A snapshot of part of a prescription document for a pelvis patient in our institution, (b) a snapshot of part of the Simulation Summary document in our institution, and (c) a snapshot of part of the Varian ARIA’s Care Path with billing approval.
Fig. 2. Residual manual check time (averaged for all physicists) for different automation levels when using the (a) TG-275 full checklist; (b) TG-275 priority checklist; (c) TG-315 full checklist; or (d) TG-315 recommended checklist.
led to discussions about standardizing initial chart checks and the potential inclusion of automation, a careful review is needed to determine the potential for future clinical workflow improvement. This article explores the development of initial chart check automation and assesses the potential benefits as part of implementing the new guideline in routine clinical practice. Although our automation experience is institution-specific, our method can be adapted to other institutions and our work will provide an instructional reference to those who are interested in realizing their automation potential in the initial chart check procedure.

While TG-275 provides an overview of published studies on automatic checking (Section 2. D.) and suggestions for software vendors (Section 5. E.), it also addresses its limitations (Section 6). For example, TG-275 states that “It is the hope of this Task Group that this report and the data in it will be revisited as technologies and practices evolve” and “the impact of these recommendations has not been carefully studied, since this is beyond the scope of the charges of the Task Group.” The new results presented in our work show additional automation beyond TG-275. We intended to offer a quantitative reference not only for physicists but also for developers who are interested in revisiting TG-275 with the new updates of technologies or practices. The updates may vary with different institutions, but we believe such variation will be less and less significant with more prevalence of automation tools.

The results suggest a strong need for the development of automated initial chart checks for the sake of efficiency and efficacy. Introducing a high level of initial chart check automation may be the best solution to significantly ease the human workload and reduce human error. This is particularly important as our treatment techniques become more complex within the framework of precision radiotherapy. We believe that by introducing automation tools into initial chart checks for different levels of errors, from simple to sophisticated can be rapidly detected without human manual inspection. Regardless of the automation level used, we believe that human vigilance is always needed, particularly when it comes to the prevention of a medical event.

Check items in TG-275 that were considered beyond the clinical training and responsibility of a medical physicist as in TG-315 could be re-examined when we are equipped with automated tools. According to the International Organization for Medical Physics’ Policy Statement No. 1, it is physicist’s obligation to supervise QA programs and optimization of therapeutic procedures. This does not exclude cross-check of the work done by radiation oncologists, dosimetrist, therapists, or other radiation oncology team members. Once an automation tool is clinically implemented, each user must fully understand its limitations and outputs. Lack of such understanding might lead to adverse consequences in patient care.

In assessing the status of automation tool development, it seems likely that lower dimensional problems, such as treatment parameter comparison, can be easily handled by scripts/programs. Higher dimensional problems in physician order error, including disease staging and treatment modality decision, may be taken care of by machine learning, such as a k-means clustering algorithm, random forest methods, or Bayesian networks as proposed by Kalet et al. and further developed by Luk et al. As Kalet et al. pointed out, machine learning still faces many challenges and must be quality assured before introduction into the clinic. The breakthrough of automation tools or machine learning beyond low-level checks will take some time.

A limitation of this report is in quantitative analysis; our study data from physicists may be biased by their familiarity with current checklists and hardware/software, as well as by unfamiliarity with the new checklists. After becoming accustomed to the new checklists, physicists may spend less time on TG-315 or TG-275 items. However, we believe our results can provide insight into the process of evolving current initial chart check procedures to be consistent with the latest national guideline. While TG-315 is very similar to the current checklist in many clinics, it may add extra safety to also include most of the recommended items in TG-275. As pointed out in TG-275, items suggested in the report may be applied after considering each institution's workload. More automation tools will boost initial chart check efficiency, and then, it becomes practically feasible to include more check items suggested by TG-275.

### Table 4

| Workflow step       | % of potentially detectable events originating at this step | % of residual detectable event due to Auto_TG275 level of initial chart check | % of residual detectable event due to Auto_UMMS_Exp level of initial chart check |
|---------------------|-------------------------------------------------------------|-------------------------------------------------------------------------------|--------------------------------------------------------------------------------|
| Patient assessment  | 7.7                                                         | 4.6                                                                          | 1.5                                                                            |
| Simulation          | 28.2                                                        | 21.1                                                                         | 9.6                                                                            |
| Treatment planning  | 49.2                                                        | 13.7                                                                         | 3.4                                                                            |

5 | Conclusion

Without automated initial chart checks, the implementation of new guidelines, particularly TG-275, involves significant human work. Automated initial chart checks can significantly reduce manual check time and detect more potential errors. With the evolution of automation techniques, it is foreseeable that more automated checks will be available to further improve practicality and efficiency in the clinical implementation of the new TG recommendations. Revisiting the TG reports with new technology and practice updates may help develop and utilize more potential automation for clinical use.

Acknowledgement

We confirm that all coauthors contributed this work and agreed with the submission of this manuscript to JACMP.
DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

REFERENCES

1. Ford EC, Terezakis S, Souranis A, Harris K, Gay H, Mutic S. Quality control quantification (QCQ): a tool to measure the value of quality control checks in radiation oncology. Int J Radiat Oncol Biol Phys. 2012;84:e263–269.
2. Kutcher GJ, Coia L, Gillin M, et al. Comprehensive QA for radiation oncology: report of AAPM Radiation Therapy Committee Task Group 40. Med Phys. 1994;21:581–618.
3. ASTRO/ACR Practice Parameter - Radiation Oncology - American Society for Radiation Oncology (ASTRO) - American Society for Radiation Oncology (ASTRO). ASTRO. Accessed August 15, 2019. https://www.astro.org/Patient-Care-and-Research/Clinical-Practice-Statements/Practice-Parameter-on-Radiation-Oncology.
4. Ford E, Connolly L, Dong L, et al. Strategies for effective physics plan and chart review in radiation therapy: report of AAPM task group 275. Med Phys. Published online January 22, 2020. https://doi.org/10.1002/mp.14030.
5. AAPM Committee Tree - Task Group No. 315 - MPPG #11 - Plan and Chart Review in External Beam Radiotherapy and Brachytherapy (TG315). Accessed January 14, 2020. https://aapm.org/org/structure?committee_code=TG315.
6. Cunningham J, Coffey M, Knöös T, Holmberg O. Radiation Oncology: report of AAPM Radiation Therapy Committee Task Group 315. Accessed January 14, 2020. https://aapm.org/org/structure?committee_code=TG315.
7. Furhang EE, Dolan J, Sillanpaa JK, Harrison LB. Automating the initial physics chart-checking process. J Appl Clin Med Phys. 2009;10:129–135.
8. Azmandian F, Kaeli D, Dy JG, et al. Towards the development of an error checker for radiotherapy treatment plans: a preliminary study. Phys Med Biol. 2007;52:651–6524.
9. Covington EL, Chen X, Young KC, et al. Improving treatment plan evaluation with automation. J Appl Clin Med Phys. 2016;17(6):16–31.
10. Dewhurst JM, Lowe M, Hardy MJ, Boylan CJ, Whitehurst P, Row-bottom CG. AutoLock: a semiautomated system for radiotherapy treatment plan quality control. J Appl Clin Med Phys. 2015;16:5396.
11. Furhang EE, Dolan J, Sillanpaa JK, Harrison LB. Automating the initial physics chart-checking process. J Appl Clin Med Phys. 2009;10:129–135.
12. Halabi T, Lu H-M. Automating checks of plan check automation. J Appl Clin Med Phys. 2014;15:4889.
13. Olsen LA, Robinson CG, He GR, et al. Automated radiation therapy treatment plan workflow using a commercial application programming interface. Pract Radiat Oncol. 2014;4:358–367.
14. Siochi RA, Pennington EC, Waldron TJ, Bayouth JE. Radiation therapy plan checks in a paperless clinic. J Appl Clin Med Phys. 2009;10:43–62.
15. Xia J, Mart C, Bayouth J. A computer aided treatment event recognition system in radiation therapy. Med Phys. 2014;41:011173.
16. Yang D, Moore KL. Automated radiotherapy treatment plan integrity verification. Med Phys. 2012;39:1542–1551.
17. Yang D, Wu YU, Brane RS, et al. Technical Note: electronic chart checks in a paperless radiation therapy clinic. Med Phys. 2012;39:4726–4732.
18. Mans A, Wendling M, McDermott LN, et al. Catching errors with in vivo EPID dosimetry. Med Phys. 2010;37(6):2638–2644.
19. Bojeckho C, Phillips M, Kalet A, Ford EC. A quantification of the effectiveness of EPID dosimetry and software-based plan verification systems in detecting incidents in radiotherapy. Med Phys. 2015;42:5363–5369.
20. Holdsworth C, Kükük J, Molodowitch C, et al. Computerized system for safety verification of external beam radiation therapy planning. Int J Radiat Oncol Biol Phys. 2017;98:691–698.
21. Lack D, Liang J, Benedetti L, Knill C, Yan D. Early detection of potential errors during patient treatment planning. J Appl Clin Med Phys. 2018;19:724–732.
22. Hadley SW, Kessler ML, Lotzenberg DW, et al. SafetyNet: streamlining and automating QA in radiotherapy. J Appl Clin Med Phys. 2016;17:387–395.
23. Kalet AM, Gennari JH, Ford EC, Phillips MH. Bayesian network models for error detection in radiation therapy plans. Phys Med Biol. 2015;60:2735–2749.
24. Tseng H-H, Luo Y, Ten Haken RK, El Naqa I. The role of machine learning in knowledge-based response-adapted radiotherapy. Front Oncol. 2018;8:266.
25. Guidi G, Maffei N, Meduri B, et al. A machine learning tool for re-planning and adaptive RT: a multicenter cohort investigation. Physica Med. 2016;32(12):1659–1666.
26. Fan J, Wang J, Chen Z, Hu C, Zhang Z, Hu W. Automatic treatment planning based on three-dimensional dose distribution predicted from deep learning technique. Med Phys. 2019;46:370–381.
27. Valdes G, Scheuermann R, Hung CY, Olszanski A, Bellerive M, Solberg TD. A mathematical framework for virtual IMRT QA using machine learning. Med Phys. 2016;43:4323.
28. Valdes G, Chan MF, Lim SB, Scheuermann R, Deasy JO, Solberg TD. IMRT QA using machine learning: a multi-institutional validation. J Appl Clin Med Phys. 2017;18:279–284.
29. Carlson JNK, Park JM, Park S-Y, Park JI, Choi Y, Ye S-I. A machine learning approach to the accurate prediction of multi-leaf collimator positional errors. Phys Med Biol. 2016;61:2514–2531.
30. Cruz JA, Wishart DS. Applications of machine learning in cancer prediction and prognosis. Cancer Inform. 2007;2:59–77.
31. Luk SMH, Meyer J, Young LA, et al. Characterization of a Bayesian network-based radiotherapy plan verification model. Med Phys. 2019;46:2006–2014.
32. Liu S, Bush KK, Bertini J, et al. Optimizing efficiency and safety in external beam radiotherapy using automated plan check (APC) tool and six sigma methodology. J Appl Clin Med Phys. 2019;20:56–64.
33. Sarkar V, Paxton A, Kunz J, et al. A systematic evaluation of the error detection abilities of a new diode transmission detector. J Appl Clin Med Phys. 2019;20:122–132.
34. Kisling K, Johnson JL, Simonds H, et al. A risk assessment of automated treatment planning and recommendations for clinical deployment. Med Phys. 2019;46:2567–2574.
35. Zhang B, Chen S, Nichols E, D’Souza W, Prado K, Yi B. A practical cyberattack contingency plan for radiation oncology. J Appl Clin Med Phys. 2020;21:181–186.
36. IOMP Policy Statements No.1 – International Organization for Medical Physics. Accessed September 4, 2020. https://www.iomp.org/iomp-policy-statements-no-1/.
37. McIntosh C, Svistoun I, Purdie TG. Groupwise conditional random forests for automatic shape classification and contour quality assessment in radiotherapy planning. IEEE Trans Med Imaging. 2013;32:1043–1057.
38. Bayesian network models for error detection in radiotherapy plans - IOPscience. Accessed September 20, 2019. https://iopscience.iop.org/article/10.1088/0031-9155/60/7/2735.
39. Kalet AM, Luk SMH, Phillips MH. Radiation therapy quality assurance tasks and tools: The many roles of machine learning. Med Phys. 2020;47(5):e168–e177. https://doi.org/10.1002/mp.13445
40. Pillai M, Adapa K, Das SK, et al. Using artificial intelligence to improve the quality and safety of radiation therapy. J Am College Radiol. 2019;16:1267–1272.