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Five years' experience with a customized electronic checklist for radiation therapy planning quality assurance in a multicampus institution

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Abstract

Introduction—An electronic checklist has been designed with the intention of reducing errors while minimizing user effort in completing the checklist. We analyze the clinical use and evolution of the checklist over the past 5 years and review data in an incident learning system (ILS) to investigate whether it has contributed to an improvement in patient safety.

Methods and materials—The checklist is written as a standalone HTML application using VBScript. User selection of pertinent demographic details limits the display of checklist items only to those necessary for the particular clinical scenario. Ten common clinical scenarios were used to illustrate the difference between the maximum possible number of checklist items available in the code versus the number displayed to the user at any one time. An ILS database of errors and near misses was reviewed to evaluate whether the checklist influenced the occurrence of reported events.

Results—Over 5 years, the number of checklist items available in the code nearly doubled, whereas the number displayed to the user at any one time stayed constant. Events reported in our ILS related to the beam energy used with pacemakers, projection of anatomy on digitally reconstructed radiographs, orthogonality of setup fields, and field extension beyond match lines, did not recur after the items were added to the checklist. Other events related to bolus documentation and breakpoints continued to be reported.

Conclusion—Our checklist is adaptable to the introduction of new technologies, transitions between planning systems, and to errors and near misses recorded in the ILS. The electronic format allows us to restrict user display to a small, relevant, subset of possible checklist items, limiting the planner effort needed to review and complete the checklist.

Introduction

Radiation oncology is a highly technical field of medicine characterized by the rapid adoption of intricate hardware control systems and mathematically complex software served by a multidisciplinary team of physicians, physicists, engineers, therapists, dosimetrists, and

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support staff. As such, quality control systems are essential for the safe and effective treatment of radiation therapy patients. Other highly complex fields, such as aviation¹ and manufacturing,² and other medical fields such as surgery³ and critical care,⁴ have successfully adopted checklists as a quality control tool in their processes. It has been estimated that 63.6% of New York State Department of Health medical linear accelerator (LINAC) reportable events were due to a “failure to follow policy and procedures.”⁵ Properly configured checklists⁶ could potentially improve compliance with policy and procedures by highlighting “mission critical” steps in the treatment planning process, thus reducing the incidence of errors that reach the patient.

Checklists were first used in the Department of Medical Physics at Memorial Sloan Kettering Cancer Center on paper in 2010. We shifted to an electronic version, called SmartChecklist, in November 2011 based primarily on the complaint that many of the items on the paper checklist were not applicable to a given treatment plan, which was leading to checklist fatigue. We specifically designed SmartChecklist to dynamically display only the relevant checklist items for the case at hand, protecting the user from having to filter through details and questions unrelated to a particular treatment. Over time, SmartChecklist has been frequently updated to keep pace with the evolution of technology in our practice and to respond to errors and near-misses in the clinic. Our experience with SmartChecklist, including aspects of its design and function, its relationship with the occurrence of errors and near-misses, as well as areas identified as still in need of improvement, represent a valuable guide for stakeholders interested in implementing similar programs in their own clinics. Our experience also represents a practical instance of the theoretical concepts introduced in the recent Medical Physics Practice Guideline 4a focusing on the development, implementation, use, and maintenance of safety checklists.⁶

Methods and materials

Description of SmartChecklist

SmartChecklist is used by external beam radiation therapy treatment planners upon completion of the planning process to ensure that all critical planning steps have been completed. The checklist is designed to work as a timeout between the completion of the planning process and the start of the physics plan check. The treatment planner fills out SmartChecklist and prints the form. SmartChecklist disables the print function until all of the reviewable items have been checked off and the identity of the planner has been entered. The planner then submits the form to a senior physicist who is designated as the plan checker. The physicist is not permitted to perform the plan check until he or she has received the SmartChecklist from the planner. At the time of data collection, our institution consisted of 24 medical LINACs, of varying ages, models, and capabilities, spread over 6 campuses. More than 65 physicists and dosimetrists in the institution are involved with external beam radiation therapy planning and plan checking.

The electronic checklist is written as a standalone HTML application using VBScript (Microsoft, Redmond, WA) for the logic. This allows the application to be easily run on any PC from a shared network location and to be easily modified or enhanced. As seen in Fig 1A–B, SmartChecklist has 3 main parts: demographics, to be entered by the planner; the

checklist items to be reviewed by the planner; and a list of necessary supporting documentation. The specific subset of demographic options is dynamic and the display at any given time depends on the choice of treatment category, treatment machine, and beam energy and modality. The checklist items that are displayed for user review depend on the particular combination of demographic options selected. The user clicks the box next to each reviewable item to add a checkmark. An illustration of the dynamic nature of the demographics and reviewable items can be observed by comparing the prostate and breast examples in Fig 1A and B, respectively. Note that the respiratory monitoring options became available in the demographics when a machine capable of using them was selected. Because deep inspiration breath hold was selected in Fig 1B, several reviewable items related to deep inspiration breath hold were displayed.

SmartChecklist is coded to reject clinically disallowed or technically unavailable combinations of demographic information and does not allow the user to proceed until correcting the items. Examples of such rejections include pacemaker combined with 15 MV x-rays (Fig 1C), flattening filter free beams with electronic portal imaging device dosimetry (Fig 1D), and total body irradiation treatments at the wrong energy (Fig 1E). Subsequent modifications to the demographic selections will automatically “uncheck” any affected reviewable items, ensuring that they are rereviewed.

SmartChecklist evolves with clinical practice. Thirty-three versions of SmartChecklist were clinically released, 16 for our in-house treatment planning system between November 16, 2011, and August 7, 2014, and 17 for Eclipse (Varian Medical Systems, Palo Alto, CA) between August 7, 2014, and September 1, 2016. Major milestones in the checklist development are indicated in Fig 2. There are 4 main mechanisms by which the checklist is modified. The first is that the departmental quality assurance committee, after performing root cause analysis of an event entered into our patient safety and risk management incident learning system (RISQ) (RL Solutions, Toronto, Canada), may suggest an addition or modification to the checklist to help prevent the event from happening again. Second, if difficult-to-remember details can be stored in the checklist and inferred by the demographics, they are added to the checklist, which reduces the demand on the human’s memory. For example, SmartChecklist keeps track of which couch is associated with which LINAC, which is important from the perspective of accounting for couch attenuation. Third, checklist items may be added to help ease a transition in our clinical practice. For example, the transition of select organ-at-risk segmentation responsibilities from the physicians to physics resulted in a checklist item reminding planners to ensure certain anatomical structures were delineated on the scan. Finally, LINAC replacements, or changes in the tools and ancillary systems associated with a particular LINAC, are reflected as updates to SmartChecklist. Checklist items may be removed if they are rendered null by changes in clinical practice or if they were serving as temporary memory aids during a clinical transition. In all cases, the decision to add or remove items from the checklist is made through consultation between the head physicist for treatment planning and the checklist development team.

Measurement of SmartChecklist performance

Each of the clinically released versions of SmartChecklist used at Memorial Sloan Kettering Cancer Center between November 16, 2011, and September 1, 2016, were reviewed to study the evolution of the checklist with clinical practice. For each version, the total possible number of demographic items, the total possible number of reviewable items, and the actual number of reviewable items displayed for 10 common clinical scenarios were recorded and plotted in Fig 2. The 10 most common clinical scenarios are characterized in Table 1. The number of demographic and reviewable items typically displayed for the user will be much less than the total possible number because only a subset is applicable for a given treatment technique and LINAC.

A review of RISQ events related to the planning process that were discovered downstream of the use of the checklist (ie, by the plan checker, treating therapists, or during weekly or end of treatment chart checks) between January 1, 2012, and September 15, 2016, was performed. Six specific changes made to the checklist in response to RISQ events were identified, and a count was made of how many reports of each of those events were recorded before and after the corresponding checklist modifications.

Results

As the checklist code became more complex over time, there was a corresponding increase in the number of possible demographic items that the user has to review and select. This allowed for greater specificity in the number of reviewable checklist items displayed to the user for a given clinical scenario. The number of items displayed to the user for 10 typical clinical scenarios (Table 1) has remained relatively flat, or even slightly decreased, over 5 years despite a greater than 2-fold increase in possible reviewable items built into the checklist (Fig 2).

The results of a review of our RISQ database are displayed in Table 2. The first 4 rows demonstrate instances in which changes to the user interface or the addition of reviewable checklist items has coincided with an absence of subsequent similar RISQ events. The bottom 2 rows demonstrate instances in which the event has recurred in RISQ after the checklist modifications were made.

Discussion

SmartChecklist has become an integral part of the culture in the external beam treatment planning section at Memorial Sloan Kettering Cancer Center. The tool is valued by planners, plan checkers, and supervisory personnel. Maintaining consistency in the planning process between personnel within a large institution⁷ and among campuses of a geographically disparate institution⁸ is difficult. SmartChecklist is a tool, among others, that we use to try to increase plan consistency and compliance with procedures. That 33 versions of the checklist were released over an approximate 5-year period speaks to the reality that external beam treatment planning clinics face rapid technological and procedural changes. Having this tool to help users verify that they have completed all essential steps in the planning process helps make that pace of change manageable. The frequent modifications of the checklist also

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speak to our departmental commitment to keeping SmartChecklist as relevant and helpful as possible.

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During this period, a major change in our department that highlights the flexibility of SmartChecklist was a shift from our in-house treatment planning system⁹ to Eclipse. Because SmartChecklist's primary focus is on the planning process rather than particular vendor-specific steps, the number of possible checklist items only grew from 48 to 50 (Fig 2). The greatest growth in the checklist occurred either when users requested that the checklist be expanded to include other clinical processes (eg, total body irradiation, information about patient-specific quality assurance) or when we added new technologies into the clinic (eg, flattening filter free beams).

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Several modifications to SmartChecklist were made in response to RISQ events in our department. Frequently, these changes were implemented soon after the first occurrence of the event, so the number of occurrences was very low, rendering statistical evaluation impractical. We cannot conclude that SmartChecklist was responsible for preventing the events from recurring; however, taken together, the illustrative examples of pacemaker policy compliance, digitally reconstructed radiograph anatomy projection, setup field clearance, and head and neck planning demonstrate the potential advantages of the virtuous cycle of identifying events, recording events, updating our safety procedures and checklist in response to events, and then monitoring for future events.

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Our design choices about SmartChecklist have been primarily motivated by an attempt to prevent checklist fatigue. An increase in demographic items has been necessary to achieve the relatively constant amount of reviewable items seen over time. The user feedback that we received indicated that a larger list of demographics was acceptable if it enabled us to keep the list of reviewable items applicable only to the case at hand. Appropriate selection of demographic options is essential for the appropriate list items to be visible to the user for a particular clinical scenario. Some modifications to SmartChecklist, such as instructions about how to communicate bolus to the therapists and the use of breakpoints in the record and verify system, have continued to have events reported despite their presence on the checklist. This could be, at least partly, attributed to users neglecting to select these options in the demographics. This issue was also observed for pacemaker events. As illustrated in Fig 3A, early versions of the checklist placed the pacemaker checkbox among other demographic information. By not checking the box, it was unclear whether the user truly verified the absence of a pacemaker or if he or she simply skipped over this particular check. We hypothesized that this feature weakened SmartChecklist's ability to remind users about our important clinical policy regarding treatment beam energy in the presence of pacemakers; therefore, current versions now have implemented a hard stop, which forces the user to answer a yes/no question for pacemaker to be able to complete and print the form (Fig 3B). Hard stops are also used for other demographic combinations that are not technically feasible or clinically allowed, some of which are shown in Fig 1.

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Changing every demographic option into a hard stop that demands a response would double the total number of demographic boxes and, in our judgment, increase checklist fatigue and decrease compliance; therefore, hard stops have been reserved for only the most critical of

the checklist items. A more fundamental reason why these events are still occurring is that safety interventions such as checklists are relatively low on the hierarchy of effectiveness.¹⁰ A checklist is really just a memory tool, reminding the user of the proper policy and procedures, not a forcing function to ensure that those policy and procedures are followed. For this reason, we are currently in a transition away from this user-demographics entry-based style and are codeveloping an automated plan checking script, originally developed at the University of Michigan. This script interacts directly with the patient study in Eclipse and can automatically populate key demographic and plan-specific information through Eclipse's applications programming interface.^{11,12} This transition is observed in Fig 2, where, since the implementation of this applications programming interface script, the number of possible electronic checklist items has decreased from its maximum of 78 to the range of 59 to 62.

Conclusion

Checklists play an important role in the planning process at Memorial Sloan Kettering Cancer Center and are valued by the members of the team. SmartChecklist is adaptable to the introduction of new technologies, transitions between planning systems, and to errors and near-misses recorded in the incident learning system. The electronic format allows us to restrict user display to a small, relevant subset of possible checklist items, limiting the planner effort needed to review and complete the checklist. Although increased sophistication in the scripting abilities of commercial treatment planning software is now allowing us to transition to a more automated program, SmartChecklist has served our department well for the past half-decade and will continue to have a role for the foreseeable future.

Acknowledgments

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Eclipse Smart Planning Checklist

Patient Name: _____ Patient MRN: _____ Plan Site: _____

Instructions:

- One form for each step/phase submitted, including cone-downs
- Re-do if plan/calc is changed due to plan check, 2nd check, etc.
- Dr. and J. planners must fill out separate forms
- Fill out all demographic info carefully - this guides the checklist item display

Treatment Category: ☒ Initial Plan ☐ CD Plan ☐ Re-Plan ☐ Calc ☐ Standing TBI

Treatment Machine: [241] Modality: [15X/ dualE]

Fractionation: ☐ Single ☒ Multiple

Pacemaker/Defib: ☐ Yes ☒ No *Verify in both HIS and Prescription

Planning Technique: ☐ EDW ☒ IMRT / FIF

Beam Modifiers: ☐ Bolus ☐ Blocks

IGRT/Motion Monitoring: ☒ 2D OBI ☒ 3D OBI

Respiratory Monitoring: ☐ Gating ☒ DBH

Plan Specific: ☐ Prev Treatment ☐ Re-eval Dose ☐ Couch Kicks ☐ Iso-Shift

Site: ☐ Breast tangents ☐ PAB ☐ H&N w/ LAN ☐ Prostate

Patient Specific QA: ☐ Paraspinal ☐ Lung SBRT ☐ IRB 13-174 ☐ IRB 14-225

Immobilization Type: ☐ Film ☐ Mapcheck ☐ EPID

Review each item:

- Prescription First: Confirm All Elements of Rx agree with plan/calc before proceeding
- Isocenter: Confirm DICOM Offset b/w Sim Docs and Eclipse, and original Sim marked iso = (0,0,0)
- Transmission Factors: Considered if necessary and if so, are for correct energy
- Ana: Verify that all dose tracking reference points equal their respective Rx doses
- Imaging QA: If patient has fiducials, add markers for marker match and use OBI PRO SEEDS for DRR's

Planner: _____ Covering Planner: _____

Necessary additional supporting documentation:

3D OBI Pre-Treatment QA and Shift Record

a

b

c

d

e

Figure 1.
a–e. Examples of SmartChecklist, filled out for prostate (a) and breast tangents (b) plans. The checklist is coded to not allow invalid states such as (c) pacemaker with 15 MV x-rays, (d) electronic portal imaging device patient specific QA measurements with 6 MV flattening filter free x-rays, and (e) total body irradiation (TBI) with 6 MV x-rays.

Figure 2.

The total possible number of demographic (triangles) and reviewable (diamonds) items are plotted as a function of the release date of each checklist version. Ten typical clinical scenarios, detailed in Table 1, are used to create a plot of the median number of reviewable items typically seen at any 1 time (squares). The whiskers represent the maximum and minimum values over those 10 scenarios. Major milestones in the checklist development are seen as jumps in the number of possible reviewable items plot: (i) added TBI checks (May 17, 2013), (ii) transitioned to checklist for Eclipse treatment planning system (August 7, 2014), (iii) added patient-specific quality assurance and flattening filter free beam information (April 16, 2015], and (iv) introduction of the University of Michigan/Memorial Sloan Kettering Cancer Center automated plan checker software script (May 20, 2016).

Treatment Category: ☒ Initial Plan ☐ CD Plan ☐ Re-Plan ☐ Calc ☐ Standing TBI

Treatment Machine: 443 **Modality:** 6X

Fractionation: ☐ Single ☐ Multiple

Planning Technique: ☐ EDW ☐ IMRT / FIF

Beam Modifiers: ☐ Bolus

IGRT/Motion Monitoring: ☐ 2D OBI ☐ 3D OBI ☐ AlignRT

Respiratory Monitoring: ☐ Gating ☐ DIBH

Patient/Plan Specific: ☐ Pacemaker/Defib ☐ Prev Treatment ☐ Re-eval Dose ☐ Iso-Shift ☐ Couch Kicks

Site: ☐ Breast tangents ☐ PAB ☐ H&N w/ LAN ☐ GI ☐ Paraspinal

☐ Lung SBRT ☐ Prostate

Patient Specific QA: ☐ Film ☐ Mapcheck ☐ EPID

Immobilization Type: ---

a

Treatment Category: ☒ Initial Plan ☐ CD Plan ☐ Re-Plan ☐ Calc ☐ Standing TBI

Treatment Machine: 443 **Modality:** 6X

Fractionation: ☐ Single ☐ Multiple

Pacemaker/Defib: ☐ Yes ☐ No *Verify in both HIS and Prescription

Planning Technique: ☐ EDW ☐ IMRT / FIF

Beam Modifiers:

IGRT/Motion Monitoring:

Respiratory Monitoring:

Plan Specific:

Site: ☐ Prostate

Patient Specific QA:

Immobilization Type:

b

Figure 3.

(A) Originally, pacemaker was a choice mixed in with other demographic options. (B) In response to risk management incident learning system events, pacemaker was promoted to its own line and changed to a yes/no question. Failure to answer the question prompts an error message, and the user is prevented from printing the checklist until it is answered.

Table 1

Details for the 10 representative clinical scenarios used to produce the plot of the median (maximum/minimum) number of reviewable items seen in Fig 2

Scenario	Site	Treatment category	LINAC type	Energy	Fractionation	Pacemaker	Planning technique	IGRT/motion monitoring	Previous treatment	PSQA	Immobilization	Other
1	SBRT lung	Initial plan	TrueBeam	6 MV [FFF]	Multiple	No	VMAT	2D kV orthogonal, kV CBCT	No	No	Lung Board	NA
2	Head and neck	Cone-down	TrueBeam	6 MV	Multiple	No	VMAT	2D kV orthogonal, kV CBCT	No	No	Orfit Board	NA
3	Pelvis	Replan	2100-EX	15 MV	Multiple	No	EDW	2D kV orthogonal	No	No	Prostate Board	NA
4	Whole brain to C2	Manual MU calculation	6-EX	6 MV	Multiple	Yes	NA	NA	Yes	No	Orfit Board	NA
5	Prostate	Initial plan	TrueBeam	15 MV	Multiple	No	VMAT	2D kV orthogonal, kV CBCT	No	No	Prostate Board	NA
6	SBRT paraspinal	Initial plan	TrueBeam with HD-mlc	6 MV (FFF)	Single	No	VMAT	2D kV orthogonal, kV CBCT, ExacTrac	Yes	Mapcheck	CDR Board	NA
7	TBI	Standing TBI	TrueBeam	15 MV	Multiple	No	NA	NA	No	No	NA	NA
8	Breast tangents	Initial plan	Trilogy	6 MV	Multiple	No	IMRT	DIBH	No	No	CIVCO® Breast Board	NA
9	Brain	Initial plan	Trilogy	6 MV	Multiple	No	IMRT	2D kV orthogonal	No	No	CDR Board	Couch kicks
10	Multilesion cranial SRS	Initial plan	TrueBeam with HD-mlc	6 MV	Single	No	VMAT	2D kV orthogonal, kV CBCT, AlignRT	Yes	EPID	CDR Board	Couch kicks, isocenter shift

CBCT, cone beam computed tomography; 2D, 2-dimensional; DIBH, deep inspiration breath hold; EDW, enhanced dynamic wedge; EPID, electronic portal imaging device; FFF, flattening filter free; HD-mlc, high-definition multileaf collimator; IGRT, image guided radiation therapy; LINAC, linear accelerator; NA, not available; PSQA, patient-specific quality assurance; SBRT, stereotactic body radiation therapy; SRS, stereotactic radiosurgery; TBI, total body irradiation; VMAT, volumetric modulated arc therapy.

Table 2

Summary of the number of errors and near misses reported in RISQ for 6 clinical policies and the corresponding modifications made to the checklist in response

Clinical policy violated	Corresponding checklist modification		Number of violations recorded in RISQ relative to date of checklist modification	
	Date	Description	Before	After
IMRT fields should match, not overlap with, the anteroposterior LAN field in a head and neck radiation therapy plan.	2/2013	“H&N w/LAN” was added as an anatomical site to the checklist and when chosen, the message “Verify match b/w IMRT and LAN” is displayed.	2	0
Kilovoltage planar x-ray setup field angles should be chosen that do not collide with the patient and immobilization device	12/2014	When kV orthogonal radiographs are chosen in the “IGRT/motion monitoring” section, the message “Confirm OBI ortho pairs are ordered correctly and gantry/imager clearance at machine” is displayed.	4	0
A contour of the scar should be projected on the DRR for breast boost fields.	4/2015	“Breast” was added as an anatomical site to the checklist and when chosen, the message “Confirm that Scar/lumpectomy contours are visible on DRR for tangents. (Nipple/scar for boost)” is displayed.	2	0
X-ray energy should be restricted to 6 MV if the patient has a pacemaker.	12/2015	User interface was modified such that the “pacemaker/defib” option went from a simple checkbox to a “hard stop” (ie, a yes/no question where you cannot proceed unless you choose one or the other) (Fig 3).	2	0
Physics communicates to therapists that a bolus was used in the plan by manually setting a flag in the R&V system.	4/2012	When bolus is chosen in the “Beam Modifiers” section, the message “Indicate bolus in field setup notes and compensator mount in RT Chart” is displayed.	0	9
A breakpoint should be entered into the R&V system to coincide with a prescribed re-evaluation dose.	10/2013	“Re-eval dose” was added as a “patient/plan specific” item to the checklist and when chosen, the message “Rx has re-eval dose: Enter breakpoint into Aria” is displayed.	1	3

Note that for the bolus flag, the change was initially made to the checklist as a memory aid, rather than in response to a RISQ event. b/w, between; DRR, digitally reconstructed radiograph; H&N, head and neck; IMRT, intensity modulated radiation therapy; LAN, lower anterior neck;

R&V, record and verify; RISQ, record and verify. Other abbreviation as in Table 1.