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Physics Contribution

Quantitative Approach to Failure Mode and Effect Analysis for Linear Accelerator Quality Assurance

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Summary

This work presents a novel approach to performing a failure mode and effects analysis for linear accelerator quality assurance based on TG-142. The goal is to determine appropriate clinic-specific testing frequencies, so as to better focus physicist time and effort. Rather than a conventional, time-consuming, qualitative, committee-based approach, a quantitative approach based on quality assurance records and error modeling in the treatment planning system is proposed.

Purpose: To determine clinic-specific linear accelerator quality assurance (QA) TG-142 test frequencies, to maximize physicist time efficiency and patient treatment quality.

Methods and Materials: A novel quantitative approach to failure mode and effect analysis is proposed. Nine linear accelerator-years of QA records provided data on failure occurrence rates. The severity of test failure was modeled by introducing corresponding errors into head and neck intensity modulated radiation therapy treatment plans. The relative risk of daily linear accelerator QA was calculated as a function of frequency of test performance.

Results: Although the failure severity was greatest for daily imaging QA (imaging vs treatment isocenter and imaging positioning/repositioning), the failure occurrence rate was greatest for output and laser testing. The composite ranking results suggest that performing output and lasers tests daily, imaging versus treatment isocenter and imaging positioning/repositioning tests weekly, and optical distance indicator and jaws versus light field tests biweekly would be acceptable for non-stereotactic radiosurgery/stereotactic body radiation therapy linear accelerators.

Conclusions: Failure mode and effect analysis is a useful tool to determine the relative importance of QA tests from TG-142. Because there are practical time limitations on how many QA tests can be performed, this analysis highlights which tests are the most important and suggests the frequency of testing based on each test's risk priority number.

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Introduction

In conventional use, an FMEA (failure mode and effect analysis) study is done for a specific process (ie, initial chart check, lung stereotactic body radiation therapy delivery) to determine potential errors that could occur and their relative importance. The risk from each error is relative to its severity, its frequency of occurrence, and the probability of detecting the error. A diverse group of qualified radiation oncology personnel (therapists, dosimetrists, physicists, oncologists, nurses, administrators) meet to: (*1*) develop a process tree describing the workflow; (*2*) brainstorm all possible failures; (*3*) qualitatively rank the failures according to each person's experience; (*4*) determine the relative importance of each failure; and (*5*) determine methods to prevent the failure from occurring and/or mitigate damage if it does occur. The use of FMEA analysis in radiation oncology first appeared in the literature in 2008 with the work of the American Association of Physicists in Medicine (AAPM) Task Group 100 (1, 2) describing how the FMEA process could be applied to a radiation oncology department. Another article quickly followed, describing the outcome of a full FMEA analysis in a particular radiation oncology department (3). Since that time several publications have examined the application of FMEA analysis to proton therapy (4), intraoperative radiation therapy (5, 6), brachytherapy (7-9), stereotactic radiosurgery (10), stereotactic body radiation therapy (11-13), and to general radiation oncology (14, 15).

In radiation oncology the linear accelerators undergo daily, weekly, monthly, and annual quality assurance (QA) following the recommendations of the AAPM Task Group 142 report (16). In general, clinics adhere to the default testing frequencies. There is significant debate amongst physicists as to whether these frequencies are appropriate and that perhaps physics effort may be better spent on other clinical tasks (17). The TG-142 report recommends that individual clinics perform an FMEA analysis of their unique practice to determine appropriate testing frequencies. However, this requires significant dedicated time from a radiation oncology team. The results are qualitative, dependent on the experience and personalities within the committee. Additionally, human errors constitute the vast majority of significant failures in the published FMEA literature, giving little guidance into the subtleties of linear accelerator testing frequencies.

In this work we have approached FMEA in a different fashion. First, we focused solely on the QA tests and their clinical impact. Second, we used a quantitative approach to determine values for: (*1*) the severity, S, of impact on our patients' radiation therapy if the test fails and is not caught; (*2*) the failure occurrence rate, O; and (*3*) the probability of detecting the error, D, without performing the TG-142 tests. For this initial work we concentrated on the TG-142 recommended daily linear accelerator mechanical, imaging, and output QA tests (Table 1, column 1). This method could also be applied to monthly and annual QA tests.

Table 1 Modeling TG-142 errors in the treatment planning system

TG-142 daily QA test (tolerance level)	Modeled error
1. Output constancy (3%)	3% dose variation to all structures
2. Laser localization (1.5 mm)	Translational shift of 1.5 mm along all 3 axes
3. Distance indicator (ODI) @ iso (2 mm)	Anterior or posterior shift of 2.0 mm
4. Jaws vs light field (daily 2 mm)	Increase or decrease of 2.0 mm in all jaws
5. MV/kV: imaging and treatment isocenter coincidence (2 mm)	Translational shift of 2.0 mm along all 3 axes
6. MV/kV/CBCT: positioning/repositioning (2 mm) (reference 18)	Translational shift of 2.0 mm along all 3 axes

Abbreviations: CBCT = cone-beam CT; kV = kilovoltage; MV = megavoltage; ODI = optical distance indicator; QA = quality assurance.

Methods and Materials

Our goal was to determine the S, O, and D, as described above, for each daily TG-142 QA test. We will describe each method in detail below. In essence, S was determined via modeling the error associated with each QA test in our treatment planning system. O was determined by reviewing QA records. Detectability (D) was approached in a theoretical manner as described below. Table 2 summarizes our ranking system based on that of TG-100 (2, 19). Some specific considerations will be discussed in detail below.

Severity

The patient population under treatment will affect the outcome of a TG-142 FMEA. The impact of setup error on radiation treatment with larger planning margins (2-dimensional and 3-dimensional treatment plans) will be less than those with smaller margins (intensity modulated radiation therapy/volumetric arc therapy and stereotactic radiosurgery/stereotactic body radiation therapy treatment plans). In this work we have focused on head and neck intensity modulated radiation therapy patients. Given the large target volumes, small planning margins, and proximity of critical structures such as the spinal cord, we expect plans for these patients will provide a good representation of the severity of the errors under study. Ten patients treated within a 4-month period were randomly selected for this study. These included diagnoses of pyriform sinus (1 patient), retromolar area (1), larynx/base of tongue (1), anterior tongue (1), parotid gland (1), tonsil (2),