Quality Assurance of Radiotherapy in Cancer Treatment: Toward Improvement of Patient Safety and Quality of Care

Satoshi Ishikura

Outreach Radiation Oncology and Physics, Clinical Trials and Practice Support Division, Center for Cancer Control and Information Services, National Cancer Center, Chuo-ku, Tokyo, Japan

Received August 29, 2008; accepted September 18, 2008

The process of radiotherapy (RT) is complex and involves understanding of the principles of medical physics, radiobiology, radiation safety, dosimetry, radiation treatment planning, simulation and interaction of radiation with other treatment modalities. Each step in the integrated process of RT needs quality control and quality assurance (QA) to prevent errors and to give high confidence that patients will receive the prescribed treatment correctly. Recent advances in RT, including intensity-modulated and image-guided RT, focus on the need for a systematic RTQA program that balances patient safety and quality with available resources. It is necessary to develop more formal error mitigation and process analysis methods, such as failure mode and effect analysis, to focus available QA resources optimally on process components. External audit programs are also effective. The International Atomic Energy Agency has operated both an on-site and off-site postal dosimetry audit to improve practice and to assure the dose from RT equipment. Several countries have adopted a similar approach for national clinical auditing. In addition, clinical trial QA has a significant role in enhancing the quality of care. The Advanced Technology Consortium has pioneered the development of an infrastructure and QA method for advanced technology clinical trials, including credentialing and individual case review. These activities have an impact not only on the treatment received by patients enrolled in clinical trials, but also on the quality of treatment administered to all patients treated in each institution, and have been adopted globally; by the USA, Europe and Japan also.

Key words: radiation therapy – quality assurance – radiation dosimetry – clinical audit – clinical trials

INTRODUCTION

Radiotherapy (RT) is one of the major options in cancer treatment. As a multimodality treatment combined with surgery and/or chemotherapy, it plays an important role in curing cancers. RT is also a very effective treatment option for palliation and symptom control in advanced or recurrent cancers. In Japan, only a quarter of patients receive RT (1,2), but 52% of patients should receive RT at least once during their treatment of cancer according to the best available evidence (3).

The process of RT is complex and involves understanding of the principles of medical physics, radiobiology, radiation safety, dosimetry, RT planning, simulation and interaction of RT with other treatment modalities. The professional team for RT includes radiation oncologists, medical physicists, radiation technologists and radiation nurses. These professionals work through an integrated process to plan and deliver RT to cancer patients. The sequential process is shown in Fig. 1 and each step needs quality control (QC) and quality assurance (QA) to prevent errors and to give high confidence that patients will receive the prescribed treatment correctly (4).
The current paradigm of quality management (QM) in RT focuses on measuring the functional performance of RT equipment by measurable parameters with tolerances set at strict but achievable values. Guidelines for these have been provided by: the American Association of Physicists in Medicine (AAPM) in various documents, such as Task Group (TG) 40, 43, 53, 56, 59, 60 and 64 (5–11); the American College of Radiology and the American College of Medical Physics in reports on RTQA; the European Society for Therapeutic Radiology and Oncology (ESTRO) in a report on RTQA (12); the International Electrotechnical Commission publications on functional performance of RT equipment; and the International Organization for Standardization (ISO). The Japanese Society for Therapeutic Radiology and Oncology has also published guidelines in accordance with these for domestic RT institutions. Most of these reports recommend that every parameter that can be checked should be checked. This approach does not provide guidelines for optimally distributing resources for QA and QM activities to maximize the quality of patient care. This is a major problem, because almost no facility has the personnel to cover everything. The difficulty of this situation worsens as new advanced technologies, such as intensity-modulated radiation therapy (IMRT) and image-guided radiation therapy (IGRT) are introduced into the clinic. As new technologies are introduced, the number and sophistication of possible activities, tests and measurements required to maintain quality also increase. Therefore, there is a keen need to develop a systematic RTQA program that balances patient safety and quality with available resources and also prescriptiveness with flexibility (13).

**PROBLEMS WITH CURRENT RTQA PROGRAMS**

The goal of an RTQA program is to deliver the best and safest RT to each patient to achieve cure or palliation. The quality of RT has been defined as the totality of features or characteristics of the RT service that bear on its ability to satisfy the stated or implied goal of effective patient care. The integrated nature of QA in RT makes it impossible to consider QA as limited to simply checking machine output or calibrating brachytherapy sources. QA activities cover a very broad range of areas in which the actions of radiation oncologists, radiation technologists, dosimetrists, accelerator engineers and medical physicists are important. With the increasing complexity of the equipment and processes required to deliver modern RT, the activities required to maintain and enhance quality are consuming ever more resources, and we need to re-examine the amount and distribution of resources committed to QA. In particular, we need to link QA activities to the expected benefit to the patient. In addition to re-examining current practice, the rapid introduction of new advanced technologies poses other challenges. The current process of developing consensus recommendations for prescriptive QA activities remains valid for many of the devices and software systems used in modern RT; however, for some technologies, QA guidance is incomplete or out of date. The formulation of QA guidance lags far behind the penetration of IMRT and IGRT into the community, leaving physicists and radiation oncologists without a clear strategy to maintain the quality and safety of treatment. In addition to leaving practitioners and patients at greater risk of catastrophic delivery errors, data from phantom testing have suggested that the quality of IMRT delivery has been much poorer than that expected (14). In such situations, physicists will be best served by guidance on how to approach the development of a QM system. Even before the availability of advanced technologies such as IMRT and IGRT, it was clear that the treatment preparation and the delivery equipment had such a wide range of possible configurations that both commissioning and routine QA activities could do no more than sample the performance of the equipment under selected conditions. There is a need to re-examine objectively those selected conditions and confirm that they are the most critical for modern RT (15,16).

**NEW PARADIGM FOR RTQA**

To solve these problems, it is important to evaluate more formal error mitigation and process analysis methods of industrial engineering, such as aircraft accident analysis (17), to focus available QA resources more optimally on process components that have a significant likelihood of compromising patient safety or treatment outcomes.

The new possible approach is based on designing a framework for QM activities with the maximal impact being achieved when resource allocation reflects both the probability of an event and the severity should it occur; this requires quantitative knowledge of both probability and severity. To understand the new approach, new concepts, failure mode and effect analysis (FMEA) need to be
understood (18,19). This is a systematic method for documenting potential failure modes, determining effects, identifying causes of failures, values are assigned in three categories: \( O \), the probability that a specific cause will result in a failure mode; \( S \), the severity of the effects resulting from a specific failure mode should it go undetected throughout treatment; and \( D \), the probability that the failure mode resulting from the specific cause will go undetected. Convention uses numbers between 1 and 10. The product of these three indices forms the risk probability number (RPN = \( O \times S \times D \)). When designing a QM program based on the RPN values, resources should be allocated to failure modes with higher RPN values. TG 100 of the AAPM is now working to develop a consistent set of values for \( O, S \) and \( D \), and a consistent set of terminology for describing the potential causes of failure and potential effects of failure. TG 100 also suggests that this approach could be a useful framework for the objective analysis of myriad emerging technologies. Adoption of a standard approach to QM would have clear advantages in developing new recommendations efficiently.

On the other hand, the WHO World Alliance for Patient Safety has taken an initiative to address high-risk areas in the RT process of care, complementary to the International Atomic Energy Agency (IAEA)-developed safety measures and other previously developed standards, to address non-equipment, non-system faults associated with RT delivery. An expert group facilitated by the WHO World Alliance for Patient Safety is in the process of developing a guide to identify high-risk practices in RT and to suggest specifically targeted interventions to improve patient safety. A literature review showed that, in the last three decades (1976–2007), >1700 patients were affected and ~2% of patients were reported to have died due to radiation overdose toxicity in middle- and high-income countries in the USA, Latin America, Europe and Asia. Most incidents (~98%) were reported to have occurred in the planning stage during the introduction of new systems and/or equipment. Of all incidents without any known adverse events to patients, 7% were related to the planning stage; 39% were related to information transfer and 19% to the treatment delivery stage. The remaining 35% of incidents occurred in the categories of prescription, simulation, patient positioning or in a combination of multiple stages (personal communication). The report will be published in the near future and will be useful to develop process-oriented RTQA programs.

**EXTERNAL PEER REVIEW AUDIT**

External audit programs for RTQA can serve to improve patient safety and quality of care. The international basic safety standards (20) require radiation centers to establish comprehensive QA programs for medical exposure, including external auditing for RT. Both regulatory authorities and professional societies have responded, producing similar end products. The Council Directive of the European Community 97/43/European Atomic Energy Community strengthened the need for clinical auditing in Europe. The regulatory authority of Finland (21,22) is pursuing a program to implement the European Union directive in all areas of radiation medicine. Norway’s Radiation Protection Authority (23) has reported that ‘Clinical audit/review involves mutual learning wherein colleagues evaluate completed work from the perspective of good clinical practice. This is essentially different from an authority’s regulatory inspection where practice/activities are evaluated against laws and regulations.’ The ESTRO has initiated a process to define comprehensive auditing (24). In all cases, the auditing team is composed of professionals; physician, medical physicist and radiation technologist. The IAEA also introduced its QA Team for Radiation Oncology (QUATRO) (25). The objective of QUATRO auditing is to review and evaluate the quality of the practice of RT at a cancer center to define how best to improve the practice. A guideline document (26) has defined how to conduct the audit. The IAEA has organized several workshops to train QUATRO auditors, and 17 missions were completed as of November 2006 in Europe and Asia. Individual RT centers received recommendations on quality improvement. In eastern European countries, most audited centers operate at a level requiring only minor improvements, except for the general shortage of well-qualified radiation technologists. Two centers were identified as operating at an internationally accepted level (27). Some countries, such as the Czech Republic (28), have adapted the QUATRO approach for national clinical auditing. In Asia, existing structural inadequacies were addressed.

In addition to an on-site audit, an off-site audit, such as a postal dosimetry audit program, is necessary to assure the dose from RT equipment. For more than three decades, the IAEA has operated a postal thermoluminescent dosimetry (TLD) dose-auditing program (29) for more than 1600 RT institutions in 120 countries. A global and steady improvement in the performance of dosimetry audits has been occurring so that ~95% of the participating institutions are within the 5% acceptance limit for beam calibration. Several countries have adopted the IAEA’s method to establish their own national auditing networks (30–32). In Japan, a similar postal dosimetry audit program using a glass dosimeter was started on November 2007 (33,34). Further development is being considered to check not only the reference condition, i.e. beam calibration, but also non-reference conditions, such as irregularly shaped and wedged beams.

**CLINICAL TRIAL QA**

In the USA, RTQA programs have been developed mainly through clinical trial QA. The Radiological Physics Center (RPC) has been funded by the National Cancer Institute (NCI) continually since 1968 to provide quality auditing of
dosimetry practices at institutions participating in NCI cooperative clinical trials. The primary responsibility of the RPC is to assure the NCI and the cooperative clinical trial groups that all participating institutions have the equipment, personnel and procedures necessary to administer radiation doses that are clinically comparable and consistent. The monitoring tools used include on-site dosimetry reviews; remote auditing tools, including TLD and anthropomorphic phantoms; and reviews of both benchmark and actual protocol patient treatments. As of 2007, the RPC monitors nearly 1500 RT institutions. Discrepancies detected by the RPC are investigated to help the institution resolve them. The RPC overall RTQA program has an impact not only on the treatment received by patients enrolled in clinical trials, but also on the quality of treatment administered to all patients treated at the institution.

The NCI-sponsored Advanced Technology QA Consortium (ATC), which consists of the Image-Guided Therapy QA Center (ITC), Radiation Therapy Oncology Group (RTOG), RPC, QA Review Center (QARC) and Resource Center for Emerging Technologies, has pioneered the development of an infrastructure and QA method for advanced technology clinical trials that requires volumetric digital data submission of a protocol patient’s treatment plan and verification data. In particular, the ITC has nearly 15 years’ experience in facilitating the QA review for RTOG advanced technology clinical trials. This QA process includes: (i) a data integrity review for completeness of protocol-required elements, the format of data, and possible data corruption, and recalculation of dose–volume histograms, (ii) a review of compliance with target volume and organ-at-risk contours by study chairs and (iii) a review of dose prescription and dose heterogeneity compliance by the RTOG Headquarters Dosimetry Group.

They also require institutions to obtain credentials before participating in clinical trials. The concepts pioneered by the ITC and RTOG include: (i) a facility questionnaire that documents the institution’s technical capabilities and identifies the critical treatment team individuals and (ii) a series of tests that are protocol modality-specific, including an electronic data submission test and a dry-run test, to demonstrate understanding of the protocol planning and data submission requirements. New modalities such as IMRT and Stereotactic Body Radiation Therapy (SBRT) require additional credential tests. The RPC developed a postal anthropomorphic phantom (Fig. 2) that contains dosimeters to test the delivery capabilities of the institutions’ IMRT systems (35) and a localization credential test has been implemented for SBRT protocols to test the reproducibility of the patient setup (36). The primary goal of credentials is to reduce the deviation rate for data submitted to clinical trials. Cooperative groups have experienced deviation rates that sometimes amount to as much as 17% of the cases submitted, according to a study conducted by the RPC (37). An elevated number of deviations reduce the quality of the study, and increased rates of major deviations may limit accrual to the trial. Credentialing evaluations result in feedback to the institution, to explain the results of the procedure and to give suggestions to improve those results in the future. Three protocols for which credentialing was required from all participants had rates of deviation between 0 and 4%, whereas two protocols that had limited credential requirements had rates of deviation of the order of 7–17% (37,38).

These activities have also been adopted in Europe and Japan. As early as in 1982, the European Organization for Research and Treatment of Cancer RT Group (EORTC) established RTQA programs. In the course of 25 years, QA procedures have become a vast and important part of the activities of the group. The radiation dosimetry QA program demonstrated the disappearance of large deviations of photon and electron beam calibrations after two successive audits (39). This methodology has now become a standard procedure in RT routine practice in Europe. In Japan, following the results of a phase III trial that revealed poor protocol compliance (40%), the Japan Clinical Oncology Group (JCOG) started clinical trial RTQA programs in 2002 (40,41). The QA scores of the first trial (JCOG 0202) that required on-going RTQA have been reported recently and showed good protocol compliance (42). The JCOG is also collaborating with the ATC and EORTC to establish a global standard in advanced technology clinical trial QA. A phase II SBRT trial for stage I non-small cell lung cancer (JCOG 0403) is supported by the ATC (43) and individual case reviews are being performed using a web-based remote review tool (Fig. 3).

**CONCLUSIONS**

Recent advances in RT focus on the need for a systematic RTQA program that balances patient safety and quality with
available resources. It is necessary to develop more formal error mitigation and process analysis methods such as FMEA to focus available QA resources more optimally on process components to avoid catastrophic delivery errors. External audit programs for RTQA are also effective. Both postal dosimetry audit and clinical trial RTQA, especially for advanced technologies, in collaboration with global networks, will serve to enhance patient safety and quality of care.

Conflict of interest statement
None declared.

References
Quality assurance of radiotherapy


40. Ishikura S, Teshima T, Ikeda H, Hayakawa K, Hiraoka M, Atagi S, et al. Initial experience of quality assurance in radiotherapy within the...
