Web-based system for Quality Assurance of Radiation Oncology equipment and procedures

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DEDICATION

To my family for all their love, support and motivation which made all of this possible for me.

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ABSTRACT

In a radiation therapy department, several periodic (daily, monthly, quarterly, yearly, etc.) and on-request quality control tests are performed as part of the quality assurance program. The lack of a commercial solution to unify all these tests in one single system was the motivation for this project. The goal of this thesis work was to develop a web-based quality assurance software tool for the radiation oncology division of the Jewish General Hospital that would be easily expendable and manageable. The tool that was created allows easy access to the tests through a simple web interface yet allowing advanced management of user rights, processing of complex numerical data, warning users through email alerts and reports, scheduling tests, keeping trends of the test results and providing safe storage for the collected data.

Our system is based on Drupal, an open source web content management system. Several customizations were done to the basic Drupal system to adapt it to our needs: several scripts and specialized modules were used to enter and analyse collected data (text and images) as well as exchange data with the radiotherapy electronic medical record database.

In this thesis work we have selected and implemented in our system a limited collection of quality control tests (9) that are representative of all types of tests that are performed in a radiotherapy clinic, as a full implementation would be beyond

the time frame of this project. They are the bases for a future complete implementation and can be used as a model for other similar tests. The implemented tests are now being introduced in the clinic simplifying data entry, access, and analysis.

ABRÉGÉ

Dans un département de radiothérapie plusieurs tests de contrôle de qualité sont exécutés de façon périodique (journalière, mensuelle, trimestrielle, annuelle, etc.) où sur demande dans le cadre du programme d'assurance qualité. L'absence d'une solution commerciale pour unifier tous ces tests dans un seul système informatique est la motivation de ce projet. L'objectif de ce travail de thèse était de développer un outil logiciel web d'assurance qualité pour la division de radio-oncologie de l'Hôpital général juif qui serait facilement extensible et facile à gérer. L'outil qui a été créé permet un accès facile à des tests via une interface web simple tout en permettant une gestion avancée des droits des utilisateurs, du traitement des données numériques complexes, permet l'envoie d'alertes e-mail et de rapports, la planification temporelle des tests, l'analyse des tendances des résultats et le stockage des données recueillies.

Notre système est basé sur un logiciel libre de gestion de contenu, Drupal. Plusieurs adaptations ont été apportées au système Drupal de base pour l'adapter à nos besoins: plusieurs scripts et modules spécialisés ont été programmés et utilisés pour saisir et analyser les données recueillies (texte et images) ainsi que l'échange de données avec la base de données de dossiers médicaux électroniques de radiothérapie.

Dans ce travail de thèse, nous avons sélectionné et implémenté dans notre système une collection limitée de tests de contrôle de qualité (9) qui sont représentatifs de tous les types de tests qui sont effectués dans une clinique de radiothérapie puisque la mise en œuvre complète de tous les tests est au-delà du délai de cette projet. Les tests implémentés peuvent facilement être utilisés comme modèles pour les autres tests. Les tests présentement implémentés sont en cours d'introduction dans la clinique et simplifie la saisie, l'accès et l'analyse aux données.

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Introduction

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1.1 Quality

As described by Pawlicki et al. [1], the very first movements towards quality started in the early years of the 20th century. In those days, quality was not the main attention of industries. On the other hand, their major focus was on how to fill the markets with as much of their products as possible or “mass production”. It was during the same period that a modern approach that considered quality as a statistical phenomenon was developed at Bell Telephone laboratories in the United States. Also, the concept of t-test was introduced first time by William Sealy Gosset, a chemist working for the Guniess brewry (Dublin, Irland). He applied t-test

statistics to monitor the quality of industrial process in the Guiness breweries [42]. Later in 1954, Japanese industries modified this concept of quality and promoted new quality management tools that evolved their products in such a way that defeated American products in both price and quality by the late 1970's. It was then that quality with the definition that is used nowadays was introduced in the U.S. industry to induce a new spirit of competitiveness with Japanese products in global markets.

Quality is a subjective term and there are several interpretations and definitions for it. According to Peter Drucker [2] "Quality in a product or a service is not what the supplier puts in. It is what the customer gets out and is willing to pay for". Phillip B. Crosby [3] defines quality as "conformance to requirements". A more integral definition of quality is given by the American Society of Quality (ASQ) [4]: "Characteristics of a product or service that bear on its ability to satisfy stated or implied needs; or a product/ service free of deficiencies".

1.2 Quality Assurance/ Quality Control / Quality Audit

Quality Assurance (QA) and Quality Control (QC) are very similar concepts as they both refer to actions that assure the quality of a service or product. The ASQ [4] defines these terms as below:

"Quality Assurance is all those planned or systematic actions necessary to provide adequate confidence that a product or service will satisfy given requirements for quality".

"Quality Control is the operational techniques and activities used to fulfill requirements of quality".

Thus, QA and QC both involve preventing systematic errors and making sure that the quality is satisfactory and is what it should be.

ASQ [4] defines quality audit as "a systematic and independent examination and evaluation to determine whether quality activities and results comply with planned arrangements and whether their arrangements are implemented effectively".

Hence, the role of a quality audit is evaluation of needs to improve or correct actions and is performed by personnel not directly responsible for the QA/QC.

1.3 Radiation Therapy

Radiation therapy (RT) is the application of high doses of ionizing radiation with the aim of destroying cancer cells while minimizing damage to normal tissues. Common modalities of RT that deliver radiation depending on the type and location of cancer include [5]:

- External Beam Radiation Therapy (EBRT): This is the most common type of radiation therapy. High doses of radiation are used to destroy cancer cells and shrink the tumor. A large machine directs radiation at the tumor tissue and to some tissue around it [7]. Various radiation types include [5], [7]:
    - Photon therapy
    - Electron therapy
    - Proton therapy

– Brachytherapy: In this treatment method, a high radiation dose is delivered locally to the tumor using a sealed radioactive source such as ^{137}Cs or ^{192}Ir placed internally at a short distance to the tumor [5]. The source that is also called implant comes in different sizes and shapes and can be temporary or permanent [5], [7].

1.3.1 Radiation Therapy Process

Achieving the aforementioned goal of RT needs a number of complex interrelated tasks. After the disease is diagnosed and initial consultations are done to acquire as much information as possible about patient's health and tumour, the radiation therapy team (including radiation oncologist, physicist, radiation therapist, etc.) start the planning and therapy phases [6], [7], [8].

The first step in the treatment planning process is patient positioning and immobilization to establish a patient coordinate system. Radiography, Computed Tomography (CT scan), Magnetic Resonance Imaging (MRI), Positron Emission Tomography (PET) or Ultrasound (US) images are acquired and input into the planning system. In the next step the anatomy is defined and organ contours are determined on set of images [6], [7], [8]. In reports 50 and 62 of the International Commission on Radiation Units and Measurements (ICRU), these contours are defined as following [9]:

- Gross Treatment Volume (GTV): Gross palpable or visible extent and location of the malignant growth, which consists of primary tumor and

metastasis. If the tumor is removed before radiotherapy, then no GTV can be defined.

- Clinical Treatment Volume (CTV): Tissue volume that contains GTV and subclinical microscopic disease, which has to be eliminated.
- Planning Treatment Volume (PTV): Geometrical concept that takes into account the effect of all possible geometrical uncertainties, in order to ensure that the prescribed dose is delivered to the CTV. It is used for dose planning and reporting.
- Organs At Risk (OAR): Normal tissues whose radiation sensitivity may significantly influence the treatment planning or prescribed dose.

Next, a treatment plan consisting of a combination of radiation beams or source arrangements around the 3D virtual volume of the patient (from the imaging modalities) is developed using a Treatment Planning System (TPS) that includes dose calculation algorithms to virtually plan the patient according to the doctor's prescription. The best plan is determined through the use of several analysis and optimization tools such as conformity and uniformity indices and a Dose Volume Histogram (DVH). Finally, the quantities that define the delivered dose on the specific treatment units (Monitor Units (MU) for EBRT or source dwell time for Brachytherapy) are calculated. In EBRT, 1 MU is calibrated to correspond to a given dose (cGy) under a given geometry; this is referred to as the dose calibration of the treatment unit. For Brachytherapy the current activity of the source is taken

into account to calculate the dwell time corresponding to the desired dose. After all aspects of the plan are reviewed and approved by the radiation oncologist, plan data are transferred to the treatment machine to start the therapy phase [6], [7], [8].

1.4 Quality in RT

Radiation therapy is a high-risk procedure that requires continuous attention to its quality to minimize the risk of possible errors and prevent catastrophic accidents [10]. To comply with high standard recommendations regarding the accuracy of the dose to be delivered to the patient is challenging when considering the multistep process of radiation therapy and the uncertainties in each step. Furthermore, the increasing complexity of the treatment modalities and processes should not be neglected [8], [11]. Considering these aspects and remembering that patient is the main beneficiary of a high-quality treatment service, we realize the importance of managing the quality of each step to assure optimal patient care during the full therapy procedure [8], [11], [12].

In Report TG-46 [8] of the American Association of Physicists in Medicine (AAPM) quality in radiation oncology is defined as “the totality of features or characteristics of the radiation oncology service that bear on its ability to satisfy the stated or implied goal of effective patient care”

TG-46 also defines quality assurance in radiation therapy as “all those planned or systematic actions necessary to provide adequate confidence that the radiation oncology service will satisfy the given requirements for quality care”.

From these definitions, we understand that the ultimate goal of quality assurance in RT is to ensure that the patient receives an accurate and error-free treatment during the entire treatment process.

1.4.1 QA in RT

A QA program in radiation therapy needs to be comprehensive in the sense that it should cover the quality of: (1) administrative aspects (such as taking patient data, making appointments, follow-up, technique optimization); (2) physical aspects (products and equipment used) and; (3) clinical aspects (diagnosis, planning and treatment) of patient care. Moreover, results of the QC tests and their frequency should be recorded. That information being recorded in time allows trend analysis of the results as well as studying current status of quality assurance performance of the RT department [5], [8]. Likewise, resources are another important aspect of a successful comprehensive QA program. Three types of resources are needed to ensure a QA procedure is handled successfully [8]:

- Personnel: Radiation oncology physicist and dosimetrist
- Tools: QC test tools and equipment
- Time: Assigned time for QA performance, results review and educational programs

1.4.2 General quality standards in RT

Several parameters are studied in order to evaluate the quality of a radiation oncology equipment or process [8], [13], [14]:

1. Functionality: This criterion evaluates if a system is working or not. Safety features of equipment are an example of this category.
2. Reproducibility: The results of a test are compared against previous results acquired when the equipment was commissioned. An example is the physical characteristics of the treatment beam.
3. Accuracy: Evaluation of the accuracy of a measurement tells us how much the measured value is deviated from the defined value of a specific parameter. For example, the accuracy of the dose delivered to the patient compared to the calculated dose value.
4. Characterisation and documentation (commissioning): This parameter is measured in order to characterise the performance of a tool or equipment before it can be used clinically; such is measurement of the ion collection efficiency or charge leakage of an ion chamber.
5. Linearity of response: This criterion checks if a specific variable changes linearly with the change of a dependent parameter. An example is the test of timer linearity of a Brachytherapy unit.
6. Data transfer and validation: Evaluation of this parameter confirms that the data transmission processes that include both human and machine involvement have been performed properly and are error-free.

1.4.3 Tolerance/Action level

In order to measure and evaluate the aforementioned parameters, we need to have Tolerance and Action levels. The Canadian Association of Provincial Cancer Agencies (CAPCA) defines these terms as the following in its reports [13]:

- Tolerance Level: If the difference between the measured and expected value is at or below the stated tolerance level for a parameter then no further action is required for that parameter.
- Action Level: If the difference between the measured value and its expected or defined value exceeds the action level (often twice the tolerance level) then an action is required immediately.

Thus, any measurement that exceeds the action level requires immediate action that includes not using the machine (or stopping the treatment process) and investigating the problem until it is solved. Measurements that fall between tolerance and action levels are acceptable until the next daily measurement [12].

1.4.4 Physical QA

Physical QA is the evaluation of the dosimetry, mechanical and imaging characteristics of the radiation therapy equipment. Even small discrepancies in any of these characteristics can result into a geometrical (such as a beam modifier eg. collimator or jaw) and dosimetric (like dose calculations) inaccuracy in the dose delivered to the patient. Gradual wear of the RT equipment and sudden malfunctions - that might be the result of a failure in the performance of their

components - could cause serious deviations in the physical parameters from the values established during the commissioning of the device. To avoid such performance deficiencies, two essential QA procedures on the RT machines and devices are recommended [8], [14]:

i. Periodic/Scheduled QA: This QA program is scheduled on daily, weekly, monthly and annual periods to ensure the accuracy of the performance parameters of the equipment.

ii. Unscheduled QA: This is a preventive and maintenance QA program and is performed following the breakdown/repair of equipment.

As mentioned in the AAPM TG-46 report [8], daily tests are done on parameters that have a major impact on patient dose, patient positioning and safety features. Monthly tests include those with lower probability of changing or affecting the above features. Weekly tests are rarely recommended and annual tests normally consist of a full calibration of the equipment [8], [15].

As mentioned above, physical QA includes the QA of dosimetry, radiation therapy and imaging equipment. The Quality Assurance aspect of each group of equipment is described in more details in the following sections.

1.4.4.1 Dosimetry equipment

The QA of dosimetry equipment is a very important component of the physical aspect of any quality assurance program in RT as such equipment plays a vital role in the determination of absorbed dose. The purpose of this QA is to evaluate the

operational characteristics of a dosimetry instrument to ensure that the treatment unit continues to maintain calibration over its time. Thus, apart from the commissioning of the device that is done at time of purchase, periodic recalibration or constancy checks are performed. Below is a list of measurement and dosimetry devices [8], [13], [14], [16]:

1. Devices for reference dosimetry: Ionization chambers and electrometers
2. Devices for relative dosimetry: Ionization chambers, diodes, TLD and film
3. Basic measurement devices: thermometer, barometer, ruler, etc.
4. Automated beam scanning devices: water tank scanners and software
5. QA devices: Ionization chamber, diode array and their software
6. Phantoms

1.4.4.2 Radiation Therapy equipment

Three parameters are tested in a QA program for these equipment [14]:

- Dosimetry (output, beam profile, energy constancy, …)
- Mechanical (light/radiation field coincidence, isocentre, jaws, MLC, …)
- Safety (door interlock, audiovisual monitors, …)

A sample of radiation therapy equipment and some typical QA tests are reviewed in this section [8], [13], [14], [16]:

1. Cobalt therapy units: Co-60 units are not commonly used these days. The main components of a teletherapy unit are: radioactive source such as Co-60; source housing; gantry and stand; patient support; and machine console. The

radioactive source is a gamma ray source used in EBRT [18]. A complete list of periodically performed quality control tests that are part of the QA program for this equipment can be found in AAPM TG-46 [8] and CAPCA [17] reports.

2. Medical Linear Accelerators (linacs) and Multileaf Collimators: linacs accelerate electrons to kinetic energies from 4 to 25 MeV. Some linacs provide x-rays only in the low megavoltage range (4 MV to 10 MV) while others provide both x-rays and electrons at various megavoltage energies. A typical modern high-energy linac will provide two or three photon energies in the range 4 to 10 MeV and on in the range 12 to 25 MeV as well as several electron energies in the range 4 to 22 MeV [18]. Linacs are currently the most commonly used treatment modalities in radiation therapy. In recent years, linacs have become more complex integrated machines with the advent of technologies such as EPID (Electronic Portal Imaging Device), OBI (On-Board Imaging), 4D management, VMAT (Volumetric-Modulated Arc Therapy), etc. This naturally increases the number of quality control tests for these machines. Quality assurance guidelines for linacs are described in AAPM TG-46 [8], AAPM TG-142 [19] and the newly-created Canadian Partnership for Quality Radiotherapy (CPQR) reports [20]. In addition, every manufacturer has recommended guidelines and test procedures that should be followed to ensure proper performance of the machine.

A relatively recent technological addition to linacs is the Multileaf Collimator (MLC), a computer-controlled device that consists of several pairs of narrow, closely joined tungsten leaves. MLCs are used as beam modifiers to shape irregular fields. A quality assurance program must include MLC control tests to ensure safe mechanical operation (motion of leaves, interlocks for the leaves, etc.), dosimetric compliance (transmission of the leaves, leakage between the leaves, etc.), and proper software (data transfer between the TPS and the MLC, etc.) aspects [18]. Details and procedures to execute the performance tests of the MLC are described in AAPM TG-142 [19], CPQR [20], and AAPM No.72 [21]. Moreover, Galvin [22] has provided a comparative quality control guideline between MLCc manufactured by Elekta (Stockholm, Sweden) and Varian (Palo Alto, CA).

3. Kilovoltage X-ray radiotherapy machines: Kilovoltage (40-300 kV) x-ray beams are used in radiation therapy for treatment of skin lesions (superficial x-ray: 40-100 kV) and shallow tumours (orthovoltage x-ray: 100-300 kV). They are generally less complex treatment machines and this leads to a simpler quality assurance program in comparison to a linac. The QA program of kilovoltage machines mainly involves the evaluation of dosimetry parameters like output checks and beam profiles. Nevertheless, a few tests are also performed for the purpose of quality control of mechanical and safety features of the unit. CPQR [23] covers QA details of kilovoltage unit

and dosimetry. Moreover, QA procedures are available through the AAPM TG-61 [24] report.

4. Stereotactic Radiosurgery (SRS): This is a complex technique that delivers a very-high prescribed dose of ionizing radiation to stereotactically localized benign or malignant lesions in the brain and for the treatment of vascular malformations or other functional conditions. Several techniques are used to deliver SRS treeatments [18], [24]:
    - Linac-based which uses a linac with tight mechanical and electrical tolerances such as a remotely controlled motorized table and a micro MLC. A rigid frame is used in this technique to fix the patients head for the purpose of precise beam delivery.
    - Gamma knife (Elekta, Stockholm, Sweden) that consists of a helmet containing 201 Co-60 sources and a collimator that directs the beams to a focal point.
    - Cyber knife (Accuray, Sunnyvale, CA) that is a miniature linac on a robotic arm and allows frameless radiosurgery. It uses and on-line imaging system for finding the exact position of the target by tracking the patient's position continuously.

The quality assurance for radiosurgery comprises: 1. The basic quality assurance protocol dealing with the accuracy of the target localization, dose delivery, etc.; 2. The treatment QA protocol covering the calibration and

preparation of equipment before each SRS treatment delivery, and 3. Patient specific QA which will be described in more detail in section 1.4.5. Also, details on SRS quality assurance protocols and procedures are available through CAPCA [24] reports on SRS and AAPM report No.54 [25]. A separate report published by the AAPM (as Task Group 135) covers the recommendations on quality control and dosimetric verification for Cyberknife [26].

5. Brachytherapy remote afterloader: Brachytherapy is the placement of encapsulated radioactive sources at a short distance from the target volume (i.e. tumour). The sources are either low dose rate (LDR, 0.4-2 Gy/h) or high dose rate (HDR, >12 Gy/h). In order to reduce or even eliminate the radiation exposure to the staff, remote afterloading equipment is operated remotely from a central room. Brachytherapy plays an important role in the treatment of many cancers such as GYN, prostate, breast, head and neck and etc. Quality assurance tests for remote afterloaders should anticipate possible failures of the system. A standard QA procedure for a remote afterloader includes testing the accuracy of the source selection as well as the spatial positioning and control of treatment duration. Moreover, safety features should be included [27], [28]. Details are provided in a CPQR report on the QA of brachytherapy remote afterloaders [28] and the AAPM TG- 56 [27].

1.4.4.3 Imaging equipment

The main purpose of physical QA for imaging equipment used in RT is to test: 1) image quality characteristics such as contrast, resolution, and SNR and 2) output and dose control 3) mechanical and geometrical accuracy.

Imaging equipment reviewed in this section includes on-board imagers and simulators. There are also diagnostic imagers like MRI and PET and details on their quality control can be found in various AAPM Task Groups [40], [41].

1. Conventional simulators and CT simulators: A simulator consists of a diagnostic x-ray tube mounted on a machine that mimics all the mechanical features of a megavoltage machine. It is used to simulate the patient's position, shape and anatomy relative to the RT machine and isocentre [18], [30]. A CT simulator uses a helical CT to [18], [31]: 1) Acquire a CT image, 2) Transfer the image to the RT planning software, and 3) Marking patient's reference point to transfer the coordinates of the tumour isocentre to the surface of the patient.

   From the above functionality of simulators we understand that they should be subject to the same mechanical/geometric and safety checks as Linacs as well as image quality tests [8], [14]. QA checks for conventional simulators are tabulated in CAPCA quality report for conventional simulators [30]. Moreover, CAPCA report on CT-simulators [31] covers the QA checks for CT simulators.

2. On-Board Imagers: This is one of the modalities of Image Guided Radiotherapy (IGRT) that is used during treatment to monitor and adjust radiotherapy delivery. A kV X-ray source is used in on-board imagers [32]. Yoo et al. [33] provide a quality assurance program for On-Board Imagers (OBI).
3. Electronic Portal Imaging Devices: This is another modality of IGRT and is an effective way to verify the geometric treatment accuracy in order to reduce setup errors in external beam RT. Instructions to perform quality control tests for EPID are provided in CAPCA [34] and AAPM-TG 58 [29] reports.

1.4.5 Clinical QA

Clinical QA includes the quality checks for the radiation therapy treatment planning and consists of quality control of general and patient specific/new patient treatment planning process and Treatment Planning Systems (TPS). These quality control procedures are usually tailored to the complexity and functionality of treatment planning procedures and systems in different clinics.

1. Patient specific/new patient QA: Due to the complex procedure, high dose delivery and precision in techniques such as conformal 3D (IMRT, Rapid-Arc, ...) and SRS a patient specific dosimetry and treatment delivery quality control system is designed to validate the feasibility and accuracy of dose delivery prior to the first treatment fraction. Performing patient specific QA

is of high importance and neglecting these checks could result in non-reversible issues ranging from minor performance to patient death [35]. New patient QA is a peer review among the radiation therapy team and consists of the following components [8]:

I. New patient planning conference: Medical history, diagnostic findings, tumour staging, and treatment strategy

II. Chart/film review: Patient ID, initial physical and clinical information, treatment planning, clinical assessment during treatment, treatment summary and follow-up

III. Film review: Assessment of radiation field position and target volume

2. Treatment Planning System: A TPS comprises the hardware and software to input patient and simulation data, define target volumes and organs at risk and perform dose calculations and optimization and finally output the results of calculations. Quality control of a TPS has two components: 1) Quality checks for the dose calculation algorithms in use to assure that the correct algorithm is used and clinically accurate dosimetry predictions are generated, and 2) quality test of the software and hardware system to prevent any malfunctions of the system [36]. Also, quality control checks provided by TPS vendors must be performed to ensure the functionality of the system.

More details on RT clinical QA is available through CPQR report on Treatment Planning Systems [36] and AAPM reports on different RT techniques like IMRT (Intensity Modulated Radiation Therapy)[37] and SRS [25], [26]. However, as mentioned at the beginning of this section, patient specific QA is inspired from various particular guidelines but each clinic customizes its program based on its specific needs and policies.

1.4.6 Quality Audits in RT

A fundamental step in any QA program are the audits that should be performed by independent external organizations (national or international) at a frequency stated in the policies and procedures manual. The main purpose of quality audits is to ensure that components of the quality assurance program in a radiation therapy department are performed appropriately. The feedback from the process is used to improve the quality generally. In other words, it is a detailed and careful review of the RT department's QA program and includes checks of dosimetry systems, safety tests (electrical, mechanical, etc.), tests of TPSs, and a review of clinical dosimetry records [8], [18], [38].

1.4.7 QA guidelines in RT

Many national and international bodies have developed various guidelines and protocols on the QA of radiation therapy equipment and procedures. AAPM, CAPCA and CPQR provide comprehensive guidelines on the QA of equipment and treatment planning in the United States and Canada respectively. CPQR has taken

the responsibility of CAPCA and publishes updated versions of documents previously provided by CAPCA. QA of new RT technologies are mostly covered by CAPCA and CPQR. In Europe, the European Society for Therapeutic Radiology and Oncology (ESTRO) [11] and at the international level, the International Atomic Energy Agency (IAEA)/ World Health Organization (WHO) provide guidelines on the quality assurance/quality audit of radiation therapy [39]. Other organizations like the American Society for Therapeutic Radiology and Oncology (ASTRO, Fairfax, VA), the Radiation Therapy Oncology Group (RTOG, Philadelphia, PA) and the Quality Assurance Review Center (QARC, Lincoln, RI) perform studies at the national level in order to help the evaluation and upgrade of the radiation therapy services quality and quality control.

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CHAPTER 2

Current practices and innovations in radiation therapy QA

Contents

2.1 Commercial QA systems

As mentioned in the previous chapter, there are several quality control checks that need to be performed either periodically or case-based in a radiation therapy centre. Thus, the use of an information system (IS) that would record, log, schedule and to some extent manage and regroup all quality control tests would greatly simplify and quicken the QA process in radiation therapy and could be truly efficient from several aspects. Below is a list of some commercially available QA systems:

- Argus (Varian, Palo Alto, CA)
- Atlas (Sun Nuclear Corp., Melbourne, FL)
- eQA (Modus, London, ON)
- PIPSpro (Standard Imaging, Middleton, WI)
- QualiMagiQ (Qualiformed, La Roche Sur Yon, France)
- OmniPro Advance (IBA, Louvain-la-Neuve, Belgium)

- MLC Soft EPID (PTW, Freiburg, Germany)
- Leafline MLC QA (Civco, Kalona, Iowa)

Quality Assurance systems can be classified in two categories based on their functionalities (D. Létourneau, personal communication, Jun 27, 2012):

I. Generic and basic analysis (*Argus* and *Atlas*)

II. Task-specific and full analysis (*eQA, PIPSpro*, …)

Group I, generally consists of tests such as checklists, security checks, etc. Whereas group II refers to more specific equipment tests such as specific beam modifier measurements (MLC, wedges, jaws), machine positioning tolerances, image analysis tests, etc.

Fig. 1 gives an overview of the number of tests versus the system used for QA data analysis.

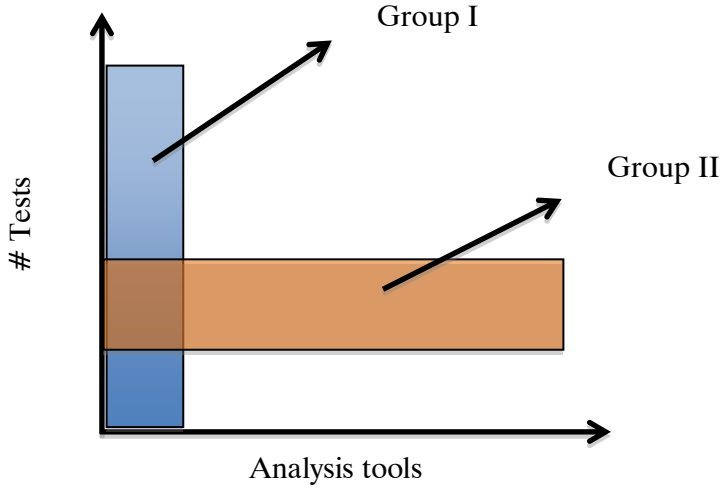

Fig. 1: Overview of QA analysis tools (Courtesy of Daniel Létourneau).

There were some recent attempts of developing QA analysis tools that would include both generic and task specific tests. Such attempts include commercial

products such as the new version of ATLAS QA from Sun Nuclear and a collaborative academic QA system called AQUA, developed at the University of Toronto [1].

2.2 Ideal QA system

The ideal radiation therapy quality assurance system would include the following features:

1. Automated analysis of the data
2. Accurate, precise and sensitive
3. Fast and user friendly
4. Powerful in report generation and keeping trends
5. Centralized and searchable database
6. Compatible with the departmental electronic medical record systems
7. Accessible to all desktop computers and mobile devices

2.3 Rational and objectives for the thesis

The motivation for this project is to develop a software QA tool for our radiation therapy department at the Montreal Jewish General Hospital (JGH). This tool should ease the storage and retrieval of QA data and should allow trend keeping and report generation. It should include scheduling, managing and supervising workflows through the use of email alerts and electronic calendars. Such a system should use a centralized database and ideally be web-based to allow wide access to QA data, analysis and reports (desktop computer, smart phone, tablets,

etc.). This tool should replace Excel files (Microsoft, Redmond, WA), paper forms and records as well as some highly specific QA software tools. Moreover, the tool should permit data transfer from the Electronic Medical Record (EMR) and Treatment Planning System (TPS) of our radiation oncology department. This transfer would minimize the manual data entry and possibility of errors on the QA tool side.

An EMR is a computer-based medical record system used by health care professionals and comprises a database containing patients' information such as demographic, medical and drug history, and diagnostic information. It also contains scheduling information and is often integrated with other software that manages other clinical activities [2], [3]. At the JGH, we use the *ARIA EMR* system (ARIA V. 10, Varian, Palo Alto, CA). *ARIA* is a comprehensive oncology information system provided by *Varian Medical Systems*. ARIA combines radiation, medical and surgical oncology information and allows the radiation oncology team to oversee all aspects of oncology care of their patient from initial diagnosis through post-treatment follow-ups [4].

As defined by AAPM- TG 53 report [5], A Radiotherapy TPS is a "computerized program that helps the treatment planner and physician define the target volume, determine beam directions and shapes, calculate the associated dose distribution, and evaluate that dose distribution". At the JGH we use the Eclipse TPS (Eclipse V.10, Varian, Palo Alto, CA).

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CHAPTER 3

Concepts in Content Management and Drupal overview

Contents

3.1 Content and Content Management

Definition of content can vary depending on the context in which it is in use. For example, content of a printed material such as books, user guides, and business documents is text and graphics. For digital publications such as web sites and e-books, content is any type or unit of digital information. It includes text, graphics, video, sounds, etc. In other words, it could be anything that is likely to be managed in electronic format [1], [2].

Content Management is effective management of the aforementioned electronic content in such a way that it would be stored as organized and consolidated pieces of content. This is achievable by combining rules, process and/or workflows. This organized content can be used several times in different digital publications [1], [2].

3.1.1 A brief history of Content Management

Before we take a closer look at Content Management and Content Management Systems as they work today, we will briefly review the history of how the content of a website was managed before the creation of Content Management Systems.

In the 1990s, web pages consisted only of simple text files (like *index.html, news.html,* and so on) that linked to each other through the Hypertext Markup Language (*HTML*) and could also contain media. Known as websites, these files were bundled into folders on servers on the Internet and were viewable by anyone through a web browser [3]. Figure 2 is a structure diagram of such a website.

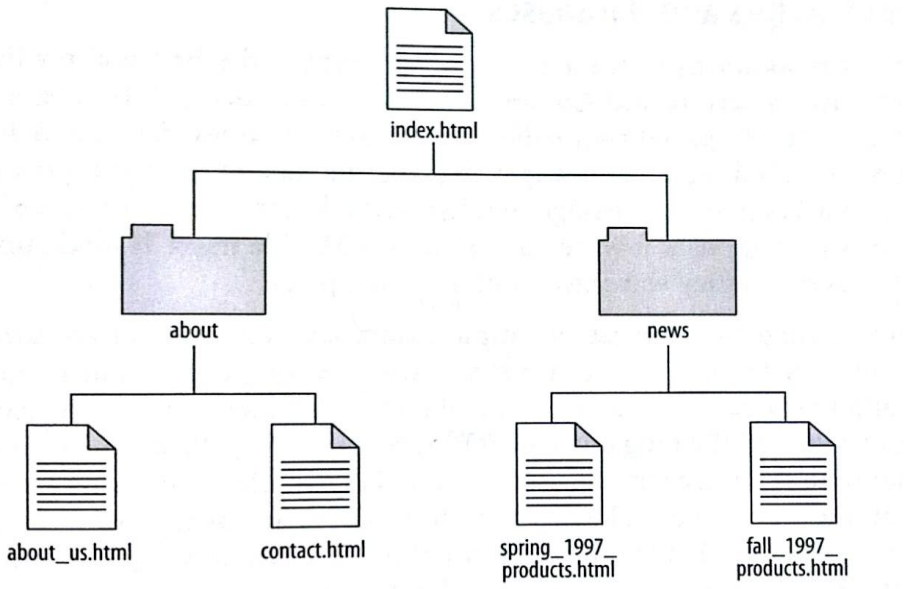

Fig. 2: Website structure in the 1990s [3].

This system works relatively well however, adding content to the website is a tedious task as it requires lots of manual operations.

To facilitate content management, two changes were introduced to web servers [3]:

1. The use of scripts and *Common Gateway Interface* (CGI) to simplify updating the content of the web page. Special tags were added to HTML files to tell the web server to catch the content of another file – *that stored all the updates* - and include it in the current web page as if it were part of the HTML file.
2. The use of databases to store pieces of similar content. Thus, instead of storing each content as a separate HTML file, it was tracked down and retrieved from the database and sent back to the website to be displayed.

Figure 3 shows the structure of a database-driven website.

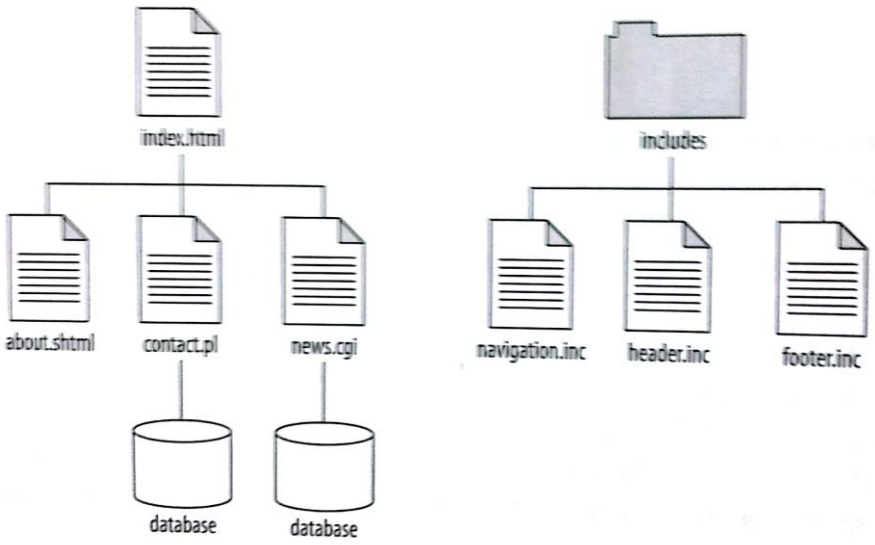

Fig. 3: Structure of a database-driven website [3].

Although all these changes solved some problems, challenges like managing contents of large sites and dealing with dynamic contents still remained unsolved.

It was at this stage that Content Management Systems emerged and provided the necessary tools and mechanisms to enable web servers to manage dynamically complex content.

3.1.2 CMS

In simple words, a Content Management System or CMS is a system used to manage the content of a web site. More technically, CMS can be defined as the following [2]:

"A CMS is a tool that enables a variety of technical (centralised) and non technical (de-centralised) staff to create, edit, manage and finally publish a variety of content in a number of formats such as text, graphics, video, documents, etc., whilst being constrained by a centralised set of rules, process and workflows that ensure coherent, validated electronic content".

A CMS consists of two major elements [4]:

1. *Content Management Application* (CMA): This element allows the content manager or author of the web site to create, modify and remove the contents of a website without having any knowledge of HTML.
2. *Content Delivery Application* (CDA): This element works as the compiler of the created information through CMA, to update the website.

3.1.3 Types of CMS

Although features of different CMS systems vary, they are common in features such as web-based publishing, format management, revision control, indexing, search and retrieval [4]. They provide tools for organizations that might produce one or some of the following contents [1], [4]:

- Technical documentation (parts catalogues, user's manuals)
- Reference materials (encyclopaedia, dictionary)
- Testing and training materials (e-learning programs, testing booklets)
- Marketing and educational materials (brochures, promotional flyers, one-to-one marketing)

Based on the different features and capabilities of a CMS and considering the type of content an organization might publish, five major types of CMS's are defined that are categorized in table 1 next page [1], [2].

Type of CMS	Purpose
Web Content Management (WCM)	Managing and delivering content to websites
Digital Asset Management (DAM)	Managing graphics and multimedia and their corresponding metadata, no text
Document Management (DM)	Managing whole document rather than the actual content itself
Enterprise Content Management (ECM)	Managing all aspects of content within an organization (i.e., emails, business documents, etc.) and is scalable for use throughout the entire enterprise
Component Content Management (CCM) or XML Content Management (XML CM)	Managing content at the component level and storing it only one time as a single source for maximum content reuse and delivery to multiple medial channels (i.e., print, PDF, etc.)

Table 1: Major categories of Content Management Systems [1], [2].

3.1.4 Benefits of using a CMS

A major benefit when using a CMS to manage (store and interact) with large amounts of data is having a better integration and organization of the content. The CMS offers an easy solution to track and adapt changes to the structure of the data

while maintaining a consistent and optimized database. The benefits provided by a CMS to any organization are [1]:

- Centralized and shared content: Content is concentrated and integrated into a powerful repository that facilitates content sharing among co-workers. This prevents creation of duplicate content in different formats.
- Accurate content: Content is stored one time but any changes made to is tracked by the CMS to make sure that all appropriate links and instances are updated and remain consistent. Hence, individually updated versions of one document would not exist anymore.
- Secure content: User permissions are assigned, so only authorized people can access certain contents and security threats no more exist.
- Shorter editorial cycles: Automated alerts can be assigned to users' daily tasks and due dates. This could help save the time to editorial tasks and monitoring of responsibilities.
- Quick creation of new publications: Creation of new publication can happen within a few minutes as previously written contents can be searched, retrieved and reused.
- Timely delivery of publications: As the single-source content is updated once and repurposed for multiple media channels periodically, separate files are not needed for print, web, and Protable Document Format

(PDF) versions of the content. Thus time to update and publish content is saved.

- Lower translation costs: A CMS has full Unicode (Unicode.org) support that allows "chunks" of updated content to be translated instead of the entire document and thus is less confusing and costly.

3.2 Drupal overview

Drupal [5] is an open source CMS used by hundreds of thousands of organizations to build customized websites to their precise needs. To maintain a Drupal website, no manual change of source code is required; maintenance can be done through online forms [3], [5]. As Drupal is open source it is free to download and use. It is distributed under the terms of GNU General Public License (GPL)[5].

3.2.1 Drupal's history

Dries Buytaert (a student at university of Antwerp, Belgium) started to develop Drupal in 1999. Initially, Drupal was a *"Message Board"* system that was shared on the university Local Area Network (LAN) with the purpose of communication and information exchange among his colleagues. After he graduated he moved this *"Message Board"* to a live website on the Internet [5].

It was around 2001 that Buytaert realized the growing interests for his online *"Message Board"* and decided to distribute his software to the community as an open source distribution for people to experiment on their own and add new features to it. It was at this point that his local *"Message Board"* became **"Drupal".**

Since that day, many additional modules have been developed for Drupal to extend its capabilities. The interest for Drupal is constantly growing with an active community of over 650,000 users and 10,000 developers in 228 countries [5].

3.2.2 Features of Drupal

As a CMS, Drupal provides a number of features that eases the creation and management of websites. These features have highly increased the popularity of Drupal in such a way that not only small businesses but also several global corporations use Drupal widely as their publishing platform.

Below are some examples of large companies that use Drupal [3], [5]:

- The Economist, Popular Science (*News publishing*)
- AOL Corporate (*Intranet/ Corporate Websites*)
- Harvard University, MIT University, McGill University (*Education*)
- MTV UK, Sony Music (*Art, Music, Multimedia*)
- Team Sugar (*Community Portal Sites*)
- Drupal SN (*Social Networking Sites*)

All these sites need very powerful publishing and rich community features. These features are provided by Drupal and include [3], [5]:

- Flexible module system: Drupal provides a pre-defined configuration of site features and functions for variety of purposes and site types which eliminate the need to custom programming and start from scratch every time a new site is built. Modules are plug-ins that can modify and add

features to a Drupal site. There is almost an existing module for any functional requirement; or they can be combined with each other to fit the need exactly. Moreover, Drupal's API (Application Programming Interface) allows users to write their own modules and customize every piece of Drupal as they desire.

- Extensible content creation: To create and manage contents in Drupal, users do not need to know HTML or any other programming languages. Countless types of content including pages, blogs, events, videos, and so on can be defined dynamically. They can be customized easily with a variety of out-of-the-box and add-on field types. Figure 4 shows a snapshot of these customizable content types.

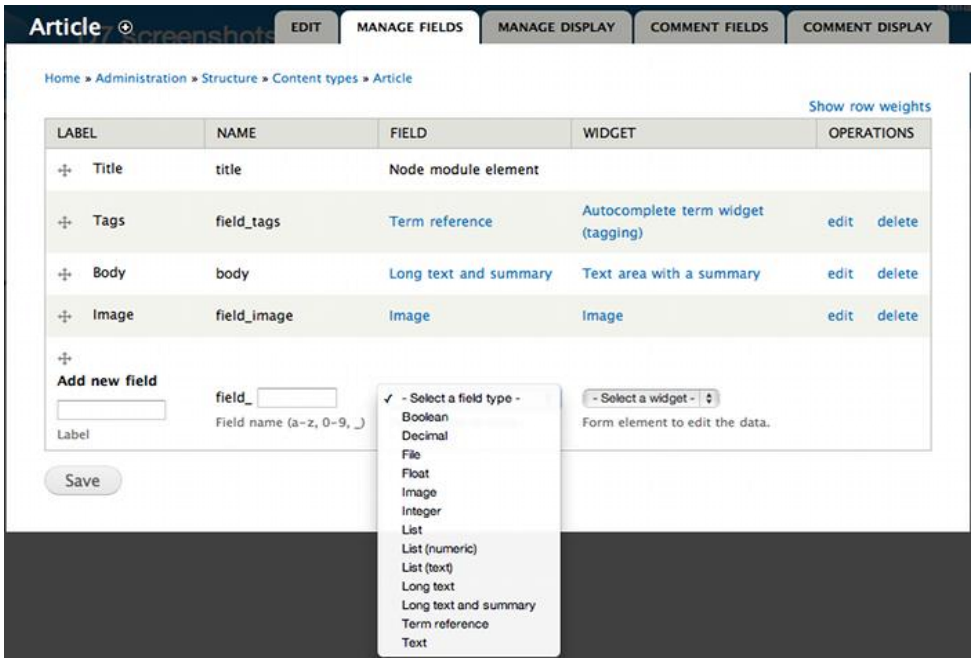

Fig. 4: Drupal's customizable content types [5].

- Customizable design and display: Drupal's output is fully customizable and allows designers to change its look to fit their needs. Users can either use Drupal's default themes or they can design their own themes. Moreover, they can customize themes using contents such as blocks, menus, etc. Besides, views plugins can also be useful tools for designers to display contents of their website the way that satisfies them most and also allows them to better customize the themes.
- Innate search engine optimization: Drupal has straightforward tools for creating, organizing, and re-using content on a website. Taxonomy, menus, human-readable URLs, Drupal's core search, custom lists, and flagging are some of the features that empower categorizing and searching contents in Drupal. Figure 5 shows this feature of Drupal.

Fig. 5: Powered search results by Drupal [5].

- Social publishing and collaboration tools: Drupal supports social publishing by built-in tools such as group blogging, comments, forums and customized profiles. It also adds other features including ratings and user groups that can help set up an organization or a group within Drupal. This feature is shown in figure 6.

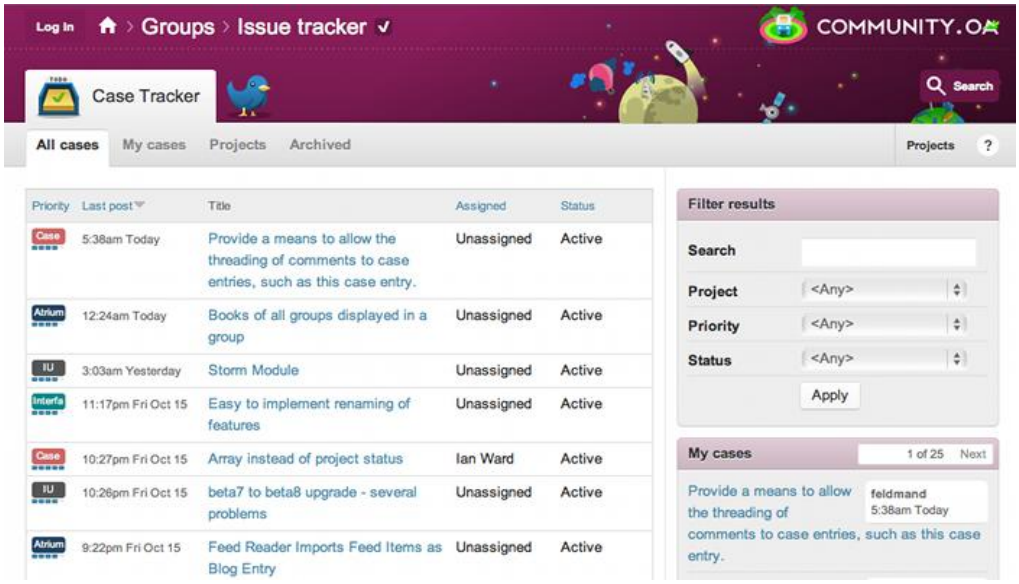

Fig. 6: A Drupal collaborative tool for team projects [5].

- Role-based access permissions: Drupal offers a comprehensive user administrative interface to easily create and manage users and groups. One or more roles are assigned to users and the permissions allow a user with custom roles to view and create only what is permitted by the administrator. A snapshot of this interface is shown in figure 7. Moreover, Drupal can use LDAP (Lightweight Directory Access Protocol) for user's login information and rights. LDAP is an Internet

protocol that email and other programs use to look up user and group information from a server.

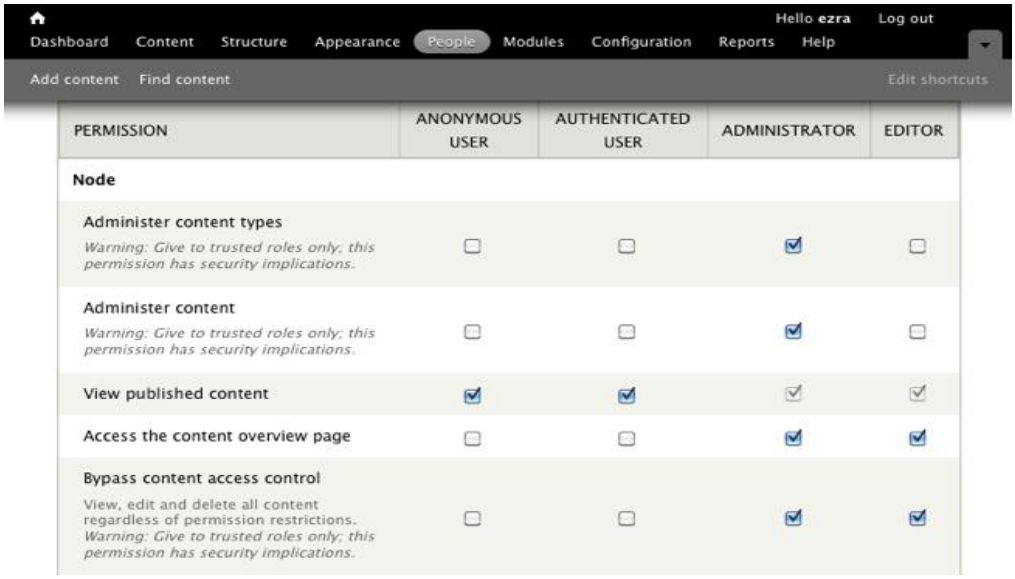

Fig. 7: User permission interface in Drupal [5].

- Easy connection: With Drupal it is easy to connect a website to other sites and social networking services across the web. Different and services allow the Drupal site designers to share data between the Drupal site and non-Drupal sites. Figure 8 shows this feature.

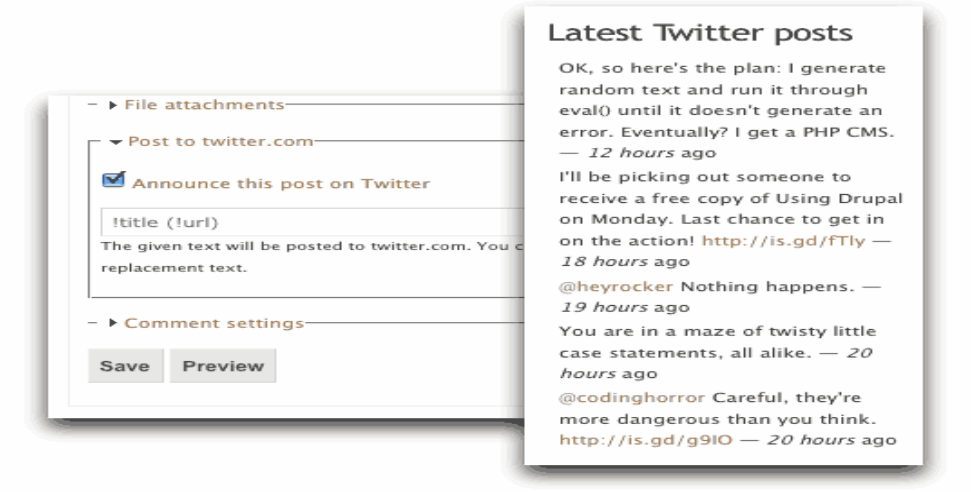

Fig. 8: Twitter module on Drupal [5].

3.2.3 Drupal's architecture

Building any internal/external website in Drupal is a matter of combining together various "*Building Blocks*". Figure 9 shows Drupal's layers between other layers of a website.

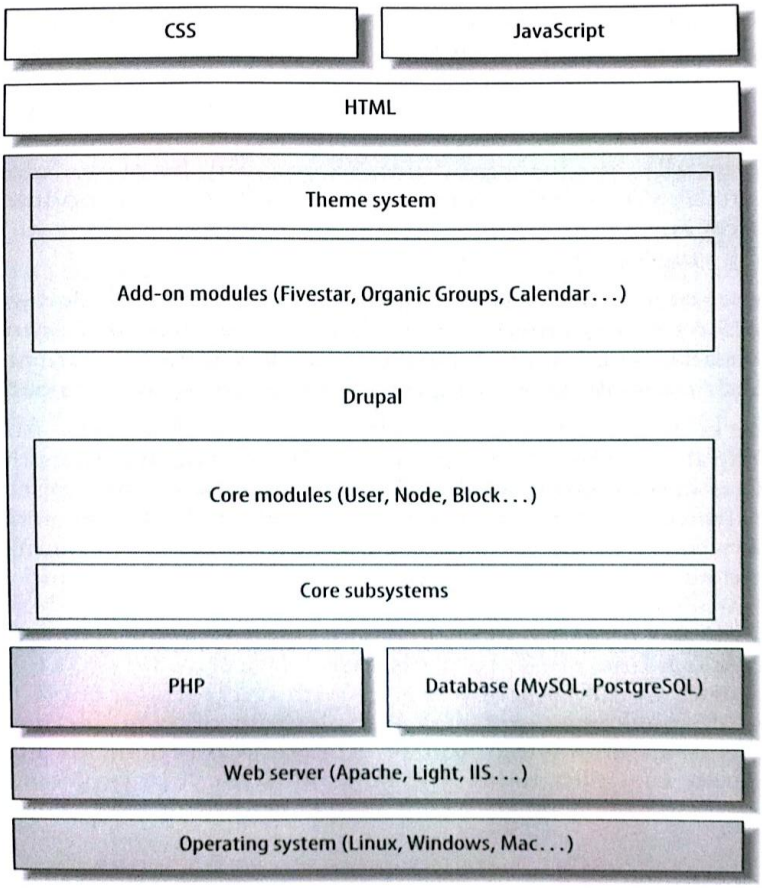

Fig. 9: Drupal's stack between other layers of a website [3].

Almost every aspect of Drupal's behaviour and functionality is built using a combination of Core and Add-on *Modules*. They are files containing PHP (Hypertext Processor) codes and a set of functionalities that Drupal knows how to use. Modules add fundamental to complex features to Drupal and generate the contents of any given page [3], [5].

Users are one of the building blocks in the Core modules that are defined and assigned roles by the site administrator. As described previously, each role can be given permissions to do different actions on the website [3].

One of the most important Drupal's building blocks is *Nodes* or *Contents*. Each node stores a specific kind of content or "content type". However, they all hold common properties [3]:

- Author
- Creation date
- Title
- Body content

Nodes can contain specific fields that could be of different types including text, integer, date-time, computed and so on.

Theming is Drupal's presentation layer and can rearrange and override CSS (Cascading Style Sheets), JavaScript, images and HTML (Hypertext Markup Language). Drupal's theme system provides special formatting of the site and controls the layout, colors, fonts, and other specifications of page contents. Page content is usually presented as XHTML (Extensible Hypertext Markup Language) through theme system [3], [5].

Core subsystems are the lowest layer of Drupal's architecture that provide additional functionalities such as user session handling, security filtering and rely upon supplement functionality of modules [3].

In the bottom layer of figure 9, the backend keeps the Internet connection alive and includes operating system, web server, database, and PHP. The *operating system* handles low-level tasks like network connections, files, and file permissions.

Web server makes the computer accessible over the Internet and uploads the correct content of any web page. When it comes to content storage, Drupal framework can be used with several *database* servers such as MySQL (mysql.com), Oracle (Oracle, Redwood Shores, CA), and many others [3], [5]. Finally, we get to the *PHP* that is a widely used open source general purposed scripting language well suited for web development [3], [5], [6].

3.3 Software packages

The main software package used in this work is Drupal V.6. All contents and web pages of the web-based QA management system for RT are created through Drupal along with PHP programming to customize our needs. We use MySQL as our database server to store Drupal's data. All the information such as patient data, images, contouring, clinical people's tasks, etc. is retrieved from the clinical ARIA database which uses Sybase (SAP, sap.com). To access the ARIA database and fetch required information for our tests we use SQL (Structured Query Language) (Oracle, Redwood Shore, CA) scripts.

Each QC test form is made out of a *"Drupal form"*. A form consists of a collection of fields (pop menus, checkboxes, textboxes, radio buttons, etc.), organized in a logical manner to follow the flow of the specific QC test. Those forms

are defined and created using the concept of nodes explained previously. These forms may contain different content and come as different formats. They can be a simple checklist, more complicated forms which involve text and measurement result entry, forms with simple or complex calculations, and finally forms that contain an image or other file formats. Some data are entered in the configuration of the Drupal site such as: the definition of the various measurements tools (ionization chambers, electrometers, linacs, imaging devices, etc.) using the taxonomy of Drupal (similar to a dictionary). These data are used as the reference data for QC tests. Our configuration of Drupal includes:

- Scheduling a QC test or a specific task that must be performed by a specific person or group responsible for that task and sending them email alerts. These email alerts could work as reminders or warning about tasks that have not been executed or have been delayed. Also, emails in form of reports (summary/trends/results/alerts/etc.) can be generated and circulated among people responsible for a given task.
- Generating a PDF version of the forms created for each test
- Graphics module to show plots and graphical presentation (trends) of the QC data
- Spreadsheet module that simulate Excel files for some data storage purposes
- Possibility of uploading different file formats such as image files and present them in QC forms

- Utilising hospital centralized LDAP user information as a login tool for the users to login to the system
- Automatic system log off when the system is not used for a certain period of time (this period can be defined in the system settings). This increases the security of the system to make sure that different users can not create or finish a test form in other users' login.
- Showing first and last name of the logged-in user automatically as the creator of the test form. This reduces manual data entry and increases system security.
- Connecting Drupal test forms to external scripts such as Python (Python Software Foundation) scripts to show test results executed in Python.
- Data search, retrieval and report generation of fulfilled test forms

For image-based QC tests (such as tests mentioned in TG-142) we took the decision to use the linac's OBI for the image acquisition. Specifically for beam port tests we use the Varian portal imager aS1000 (Varian, Palo Alto, CA). This panel has an active imaging area of 30 x 40 cm^2 and a pixel matrix of dimensions 1024 x 768 which consists of an amorphous silicon detector yielding a contrast resolution of 0.2% for a 6MV beam. Images are saved and normalized to a calibration factors that we have to consider when analysing the images. This calibration factor can be accessed in the DICOM (NEMA, Rosslyn, VA) file header, DICOM being the

default format in which the images are saved (Digital Imaging and Communication in Medicine). First, a SQL query is executed through a python scripts initiated by the Drupal form. This script queries the Unique Identifier number (UID) for the specific patient/test phantom images from the ARIA database. This UID is then used in another python script to retrieve (through a DICOM query) the specific desired image from the ARIA image DICOM server using the pynetdicom (pynetdicome V. 0.8.0, MIT license, https://pypi.python.org) python modules. This image is then analyzed by a third python script using Matplotlib, a powerful imaging module in python [7]. The results of this analysis, (values or graphs/images) can be injected into the corresponding Drupal form of that test. Figure 10 depicts a schematic of this flow.

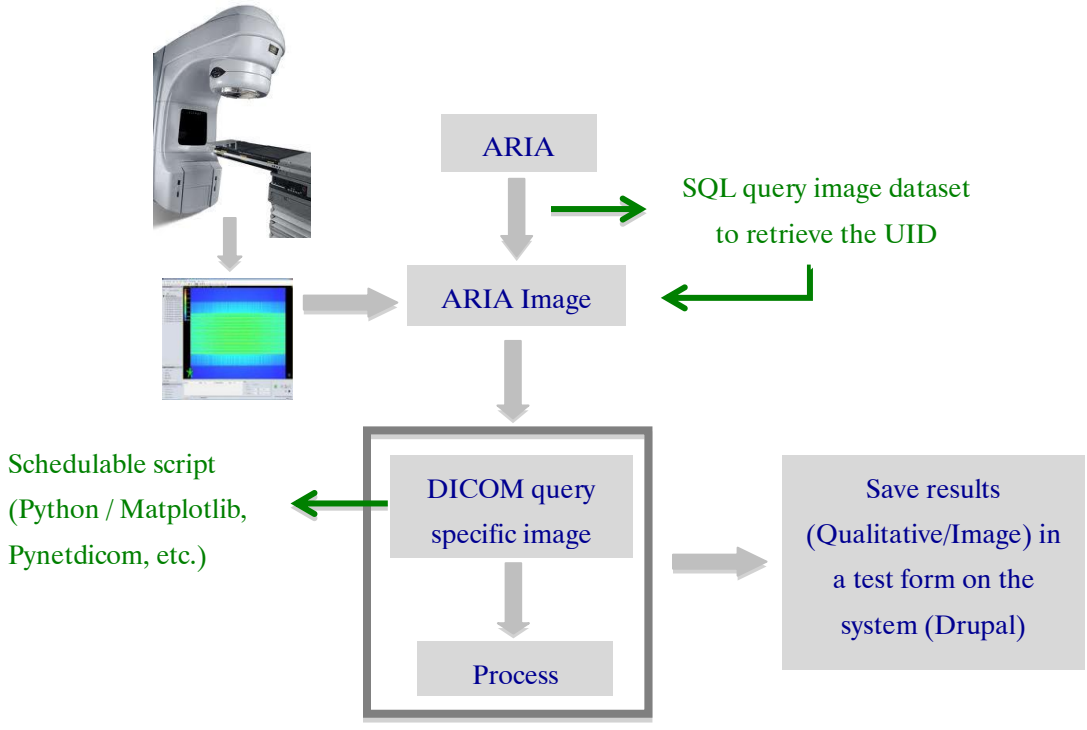

Fig. 10: Flowchart to perform image-based QC tests.

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CHAPTER 4

Results and Discussion

Contents

4.1 Introduction

Following the discussions in the precedent chapters, a software QA tool has been developed using Drupal with customized PHP scripts as well as a collection of python scripts and modules. A large number of QC tests are performed (daily, monthly, yearly, etc.) in the division of radiation oncology at the Jewish General Hospital. In the interest of time and to keep the scope of this project reasonable, we have chosen a handful of these tests (9) to be implemented within our Drupal QA system. The selection has taken into consideration the relevance of these tests and their role as a model for further development. For example, we have chosen two image-based tests to demonstrate the feasibility of all the tests that would use images acquired by the portal imager to characterize the MLC and the Jaws.

The system is hosted on a virtual linux server running Ubuntu (Ubuntu V.10, Canonical Ltd, ubuntu.com) in the IT department of the hospital, and is properly backed up as other clinical application/data hospital wide. It is accessible through a

main login webpage using any browser capable device (desktop, tablet and smart phones) on the hospital intranet. Every hospital user has a centralized user account at the IT department within the hospital LDAP server. The user rights or permissions are managed within the Drupal systems through the roles settings of Drupal. The role of a user is either: administrator, dosimetrist, physicist, engineer, or technologist. This role defines the user access to the different test modules of the system. After the user has logged into the system, a series of tests based on user role are available for him/her to choose. Therefore, not all tests are accessible to all roles. Users can choose the QC tests they want to perform. The user will first initiate the test by clicking on it then he/she will fill in the required information. Once complete the user saves the form, follows the steps required to validate the data entry, and then finalizes the form, i.e. sealing the results which corresponds to an electronic signature. Figure 11 shows a snapshot of the login page and figure 12 is the QC tests selection available to a physicist user after logging into the system.

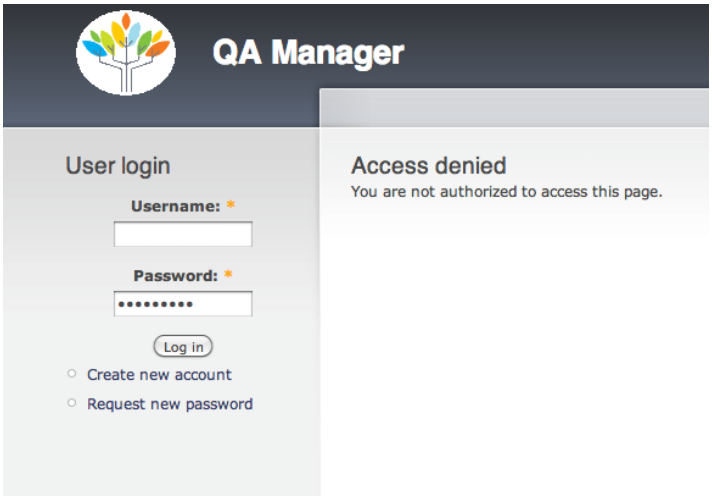


Fig. 11: User login page with username and password text boxes.

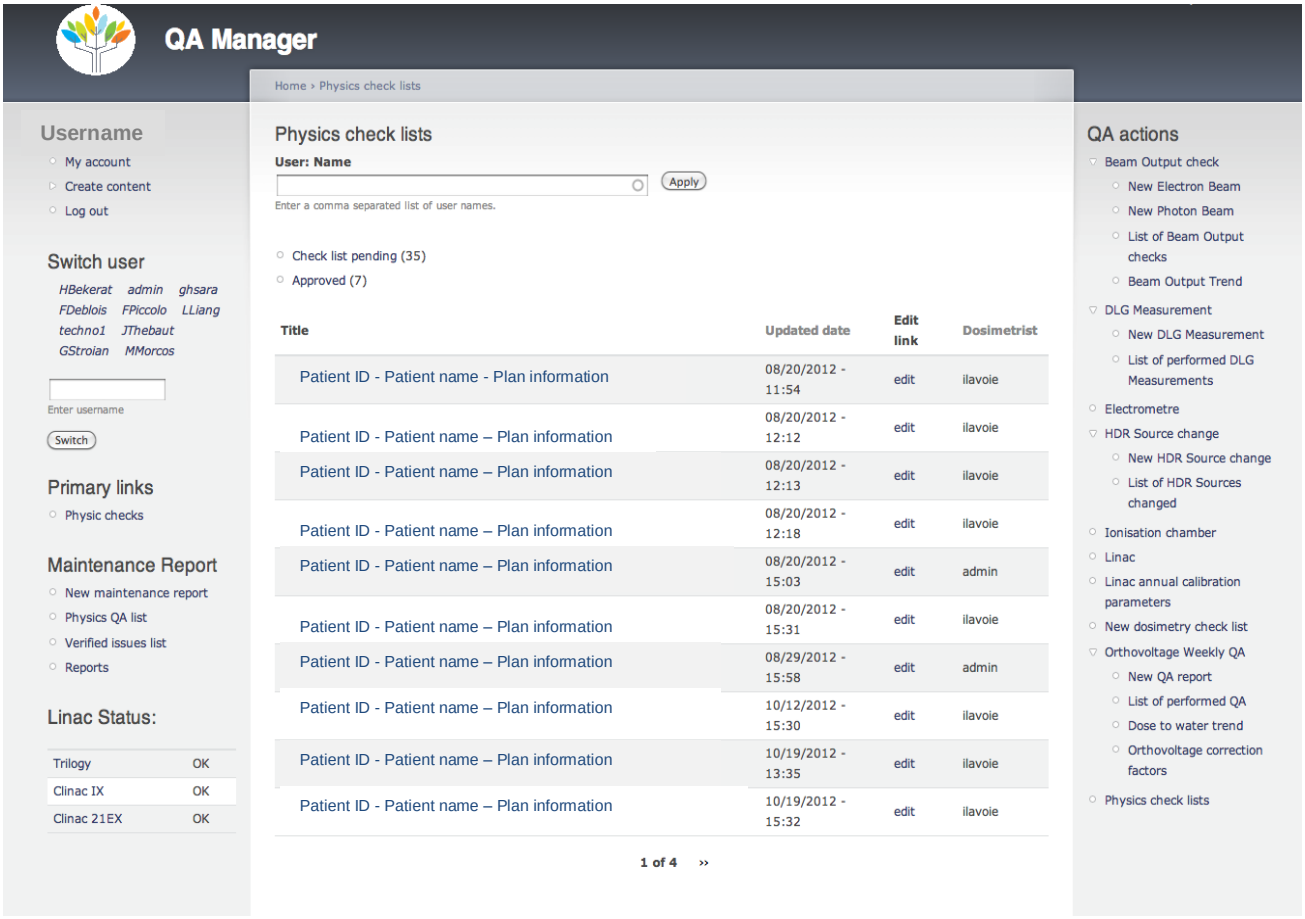


Fig. 12: System page after a physicist logs in. It shows the available tests for this role on the right bar (QA actions) and user account information on the upper left bar (Username). A linac status menu is also available at the lower left bar to view linacs' latest status. The status indicates if the linac is in operational clinical mode.

4.2 Implemented QC tests

Table 2 in next two pages lists the implemented QC tests and their corresponding properties.

Tests	Frequency							Group				Class		Form type			
	On Demand	Daily	Weekly	Monthly	Quarterly	Biannually	Annually	Physicist	Dosimetrist	Technologist	Engineer	Patient	Machine	Checklist	Calculation	Image	Text
(1) Plan QA Dosi / Physics	✓							✓	✓			✓		✓			
(2) Maintenance Worksheet	✓							✓		✓	✓		✓	✓	✓		✓
(3) HDR source change	✓							✓					✓		✓	✓	
(4) Photon / Electron Output for linacs				✓				✓					✓		✓		
(5) DLG measurement				✓				✓					✓		✓		

Table 2: Implemented QC tests with their corresponding properties.

Tests	Frequency							Group				Class		Form type			
	On Demand	Daily	Weekly	Monthly	Quarterly	Biannually	Annually	Physicist	Dosimetrist	Technologist	Engineer	Patient	Machine	Checklist	Calculation	Image	Text
(6) Ortho Weekly QA			✓					✓					✓		✓		
(7) Morning QA for all machines		✓								✓			✓	✓			
(8) Image-based test: MLC acceleration					✓			✓					✓	✓	✓	✓	✓
(9) Image-based test: Asymmetric collimator jaws					✓			✓					✓	✓	✓	✓	✓

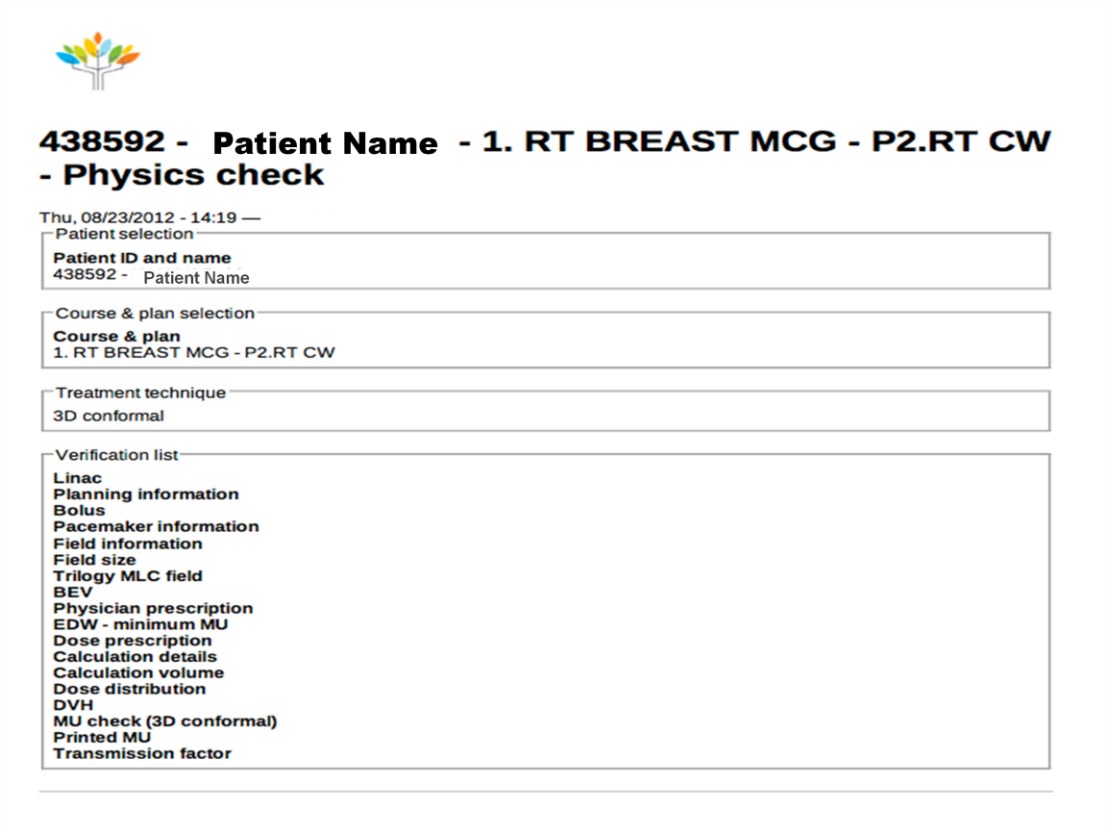
Table 2 Continued: Implemented QC tests with their corresponding properties.

As shown in Table 2, we have classified the tests by their frequency, user groups, class (machine/patient), and Drupal form types.

The following pages describe the results of the implemented tests. It should be noted that the data content in the reports presented in this section are tests data and do not necessarily represent real measured clinical data. Each of them was extensively tested but not all of them are in clinical use at the time this thesis is being written.

(1) **Plan QA Dosi / Physics:** This test is meant to be a written electronic recorded verification of the key items that the different groups (dosimetrists and physicists) verify before releasing a treatment plan to the treatment unit. It basically consists of an extensive check list of treatment plan dosimetric and physical properties. It is naturally based on a checklist form and is generated every time a new treatment plan is being approved within the Eclipse treatment planning system. Treatment course and plan information are retrieved by querying ARIA by filtering only the patient names/IDs that have an approved plan at the time of the query therefore saving searching time for the specific patients and minimizing data entry error as all the required demographic and plan information for this patient will be transferred directly from Aria. This checklist runs in two steps. First the dosimetrist initiates the dosimetry checklist by filtering for the proper patient and completes the dosimetry checklist. Next, a physics checklist tests follows that dosimetry check and is generated and

completed by physicist. Figure 13 shows the PDF report generated by our system for the Physics part of that checklist. Note that we find all demographic information as well as planning details and the list of checked items.



438592 - Patient Name - 1. RT BREAST MCG - P2.RT CW - Physics check

Thu, 08/23/2012 - 14:19 —

Patient selection

Patient ID and name
438592 - Patient Name

Course & plan selection

Course & plan
1. RT BREAST MCG - P2.RT CW

Treatment technique

3D conformal

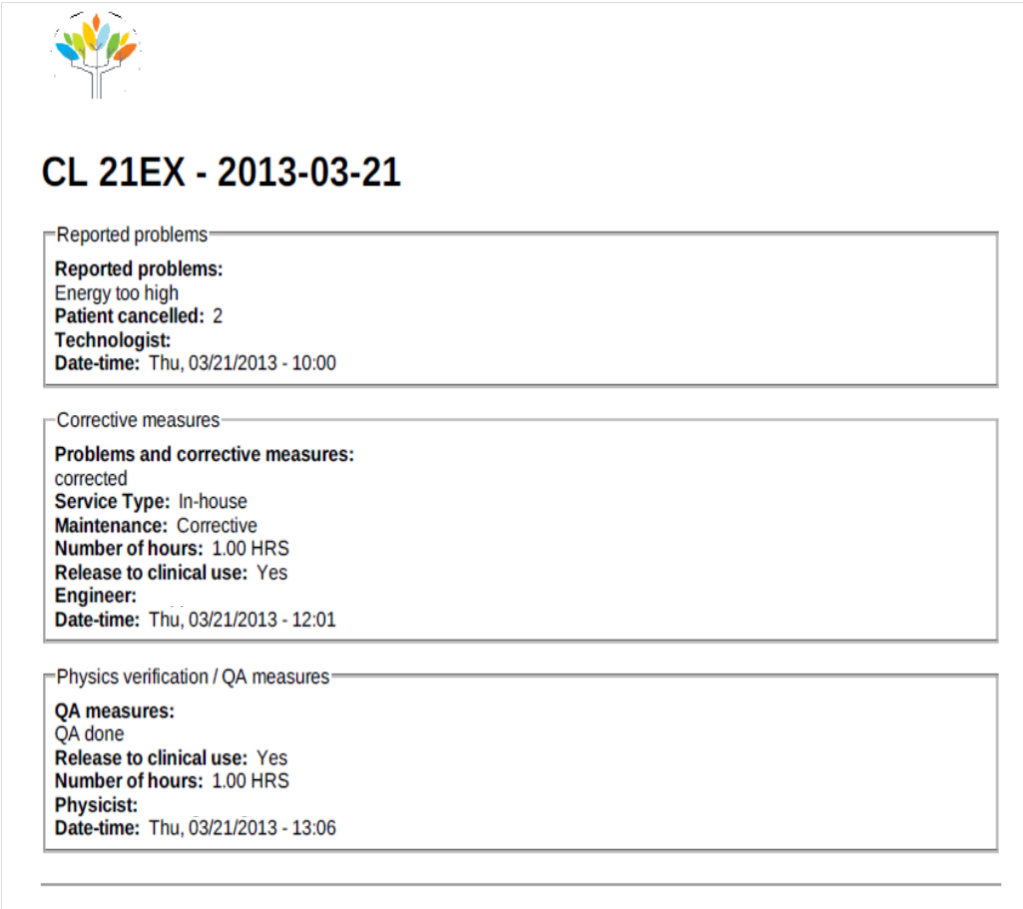
Verification list

Linac
Planning information
Bolus
Pacemaker information
Field information
Field size
Trilogy MLC field
BEV
Physician prescription
EDW - minimum MU
Dose prescription
Calculation details
Calculation volume
Dose distribution
DVH
MU check (3D conformal)
Printed MU
Transmission factor

Figure 13: Plan QA Physics verification report. It contains patient demographics and plan specific information as well as checked items.

(2) **Maintenance worksheet:** This form is meant to replace our current machine maintenance intervention paperwork. The paper form is not optimal since it requires many levels of signatures and follow-ups hence very likely to cause unwanted delays and communication problems. The Drupal implementation of that form can be used sequentially by (1) the technologist who reports the problem; (2) the engineer who fixes the problem and finally (3) by the physicist

who performs relevant QC tests required to release the specific machine clinically. Once the problem is reported by the technologist, a form is initiated on which the problem is described and the form is saved. The engineering team receives an email with a link to the reported problem page in the system. After fixing the equipment, the engineering team fill-in and save its section of the form describing the details of corrective actions. At this moment an email is sent to the physicist of the day who is responsible to continue the process. The physicist of the day is determined by a simple SQL query to the Aria database that looks at the schedule and returns the physicist of the day. The form is then ready for this physicist to complete when the relevant machine verifications are performed and machine is ready for clinical use. Figure 14 shows the report summary of the problem and actions taken.



CL 21EX - 2013-03-21

Reported problems

Reported problems:
Energy too high
Patient cancelled: 2
Technologist:
Date-time: Thu, 03/21/2013 - 10:00

Corrective measures

Problems and corrective measures:
corrected
Service Type: In-house
Maintenance: Corrective
Number of hours: 1.00 HRS
Release to clinical use: Yes
Engineer:
Date-time: Thu, 03/21/2013 - 12:01

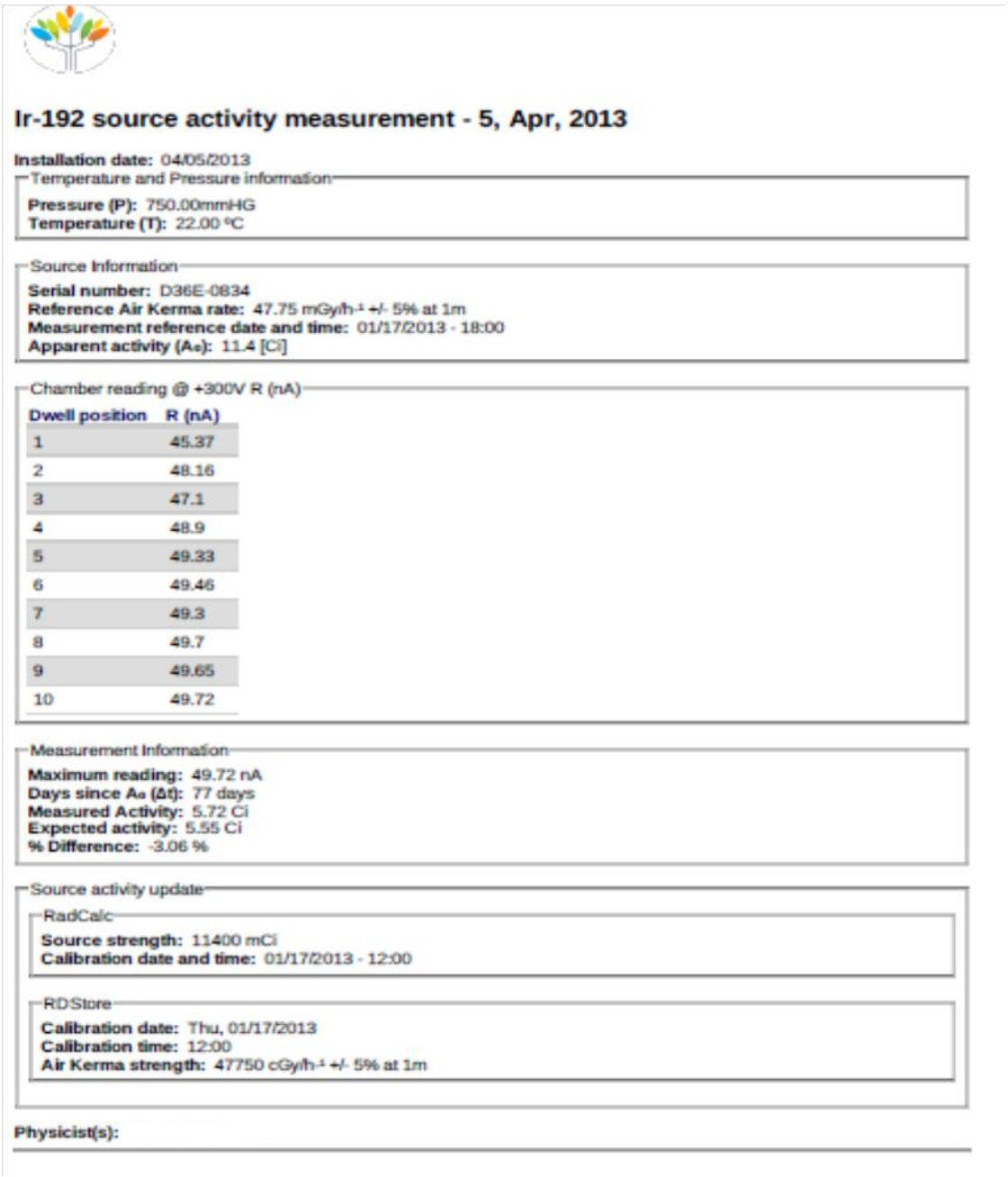
Physics verification / QA measures

QA measures:
QA done
Release to clinical use: Yes
Number of hours: 1.00 HRS
Physicist:
Date-time: Thu, 03/21/2013 - 13:06

Figure 14: Maintenance sheet report. It contains detailed information of the problem as well as corrective and verification actions.

These results (processed and signed report forms) can be sorted and searched by maintenance type or equipment which simplifies greatly tracking stability of various piece of equipment with time. Moreover, a special report was developed to comply with the Canadian Nuclear Safety Commission (CNSC) expectations. The CNSC inspects the treatment machine intervention documentation during their inspections; this report is tailored made for that. This report saves an important amount of time in comparison to assembling it manually from paper documents.

(3) **HDR source change:** This test replaces an excel sheet and is to be filled out during our HDR source change. The physicist who supervises the source change enters the new source data (serial number, apparent activity, etc.) from the "*Certificate for Sealed Sources*" provided by the manufacturer and performs all mandatory measurements: new source strength / activity and position verification measurements and logs all the information into the system. Using the Drupal form minimizes manual intervention and data manipulation. The Drupal form is generated every time our HDR source needs to be replaced. A sample image of the sealed source certificate is uploaded in the system to guide the users through the proper sequence of data entry. Calculation information for different values such as measured and expected activity, as well as relevant electrometer and chamber information are available through a hyperlink accessible at the top of the HDR source change form. Pressure, temperature and dosimetric readings for several dwell positions are performed and recorded in the Drupal form. Measured source activity is calculated (from source strength values) and compared to the expected activity (calculated from source data entered from source data sheet). By the time the physicist is satisfied with the results, he/she moves to the next step of the form that consists of completing activity updates (updated automatically from previously calculated values) and completes the process. A summary report of all the measurements and calculations is generated at the end of the process that is shown in figure 15.



Ir-192 source activity measurement - 5, Apr, 2013

Installation date: 04/05/2013

Temperature and Pressure information

Pressure (P): 750.00mmHG
Temperature (T): 22.00 °C

Source Information

Serial number: D36E-0834
Reference Air Kerma rate: 47.75 mGy/h⁻¹ +/- 5% at 1m
Measurement reference date and time: 01/17/2013 - 18:00
Apparent activity (A_e): 11.4 [Ci]

Chamber reading @ +300V R (nA)

Dwell position	R (nA)
1	45.37
2	48.16
3	47.1
4	48.9
5	49.33
6	49.46
7	49.3
8	49.7
9	49.65
10	49.72

Measurement Information

Maximum reading: 49.72 nA
Days since A_e (Δt): 77 days
Measured Activity: 5.72 Ci
Expected activity: 5.55 Ci
% Difference: -3.06 %

Source activity update

RadCalc

Source strength: 11400 mCi
Calibration date and time: 01/17/2013 - 12:00

RDStore

Calibration date: Thu, 01/17/2013
Calibration time: 12:00
Air Kerma strength: 47750 cGy/h⁻¹ +/- 5% at 1m

Physicist(s):

Figure 15: HDR source change report. Details of source information, measurements and activity updates are comprised in this report.

(4) **Photon / Electron Output for linacs:** This form replaces an Excel sheet that is used to enter QC test data for photon or electron beam output tests. This test is

recommended by TG-142 to verify the photon and electron beam output consistency and is performed by physicists on a monthly basis at the JGH. A verification of the outputs is also performed by technologists every morning during the warm-up of the linacs with a BeamChecker (QA Beamchecker Plus, Standard Imaging, Middleton, WI). The BeamChecker data is not yet integrated in our system. For our Drupal output test, the ion chamber readings are measured, corrected for temperature and pressure and recorded for each beam energy for both electron and photon beams. The output is then calculated from TG-51 data which is available within our Drupal system: Percent Depth Dose (PDD) for photon beams and Transfer Coefficient (TC) for electron beams. Finally these numbers are compared to the yearly calibration data to ensure that the test passes and linac output are consistent for both electron and photon beams. In Drupal, this form is initiated by selection of the linac type and preconfigured ion chambers and electrometers corresponding to the selected linac. Also, setup information is available on the initial page of the form to ensure that physicists follow correct setup while performing the test. In the next step, all the calibration data retrieved from TG-51 QC results performed annually are imported for each linac depending on the beam type (photon or electron) and energy selected. Calibration data is available in a form that was created to keep the annual calibration data that will be used in other QC tests. These data include factors such as PDD (photon beams) and TC (electron

beams). After ion chamber readings are performed and output calculations are executed in the Drupal form, the physicist reviews all these data and decides to either finalize the measurements or repeat them depending on how satisfactory the results are. Figures 16 and 17 show the results for both photon and electron output tests generated by the system.

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Photon Beam Output - Clinac IX - 5, Apr, 2013

Fri, 04/05/2013 - 10:28 —
Physicist(s):

Linac, electrometer, and ion chamber

Linac: Clinac IX
Ion chamber: Main IC - NE 2571 / SN 3569
Reader (Voltage=+300V): Electrometer Keithley 35040 / SN 99782

Temperature and Pressure information

Pressure (P): 757.9mmHG
Temperature (T): 21.5 °C
PT,P: 1.001

Measurement results:

Nominal Energy	6 MV	18 MV	6 MV SRS
Phantom material	Solid Water	Solid Water	Solid Water
SSD	100 cm	100 cm	100 cm
Field size	10 x 10 cm²	10 x 10 cm²	10 x 10 cm²
Dose rate	600 MU/min	600 MU/min	600 MU/min
Depth of measurement	10 cm	10 cm	10 cm
Readings / 100 MU			
Reading #1	14.536	17.626	
Reading #2	14.535	17.628	
Reading #3			
Reading #4			
Reading #5			
Reading / 500 MU	72.62	88.10	
Equivalent Reading / 100 MU	14.524	17.62	
Average Reading / 100 MU	14.532	17.625	
Standard deviation / 100 MU	0.007	0.004	
Corrected Average / 100 MU	14.547	17.643	
PDD(10,10x10,100,energy) measured on 27-Oct-2012	66.3	79.1	
Transfer coefficient (cGy/nC) measured on 03-Nov-2012	4.584	4.5	
Output (cGy/100MU)	100.6	100.4	

Mechanical Counter Reading (Battery OK): OK

Figure 16: Photon beam output check report reprinting measurements, calculations and calibration data.

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Electron Beam Output - Clinac 21EX - 5, Apr, 2013

Fri, 04/05/2013 - 09:57 — admin
Physicist(s):

Linac and Ion chamber information

Linac: Clinac 21EX
Ion chamber: Main IC - PTW 30011 / SN 61
Reader (Voltage=+300V): Electrometer Keithley 35040 / SN 92156

Temperature and Pressure information

Pressure (P): 753.7mmHG
Temperature (T): 23.9 °C
$P_{T,P}$: 1.015

Measurement results:

Nominal Energy	6 MeV	9 MeV	12MeV	16 MeV	20 MeV
Phantom material	Solid Water	Solid Water	Solid Water	Solid Water	Solid Water
Cone size	100 cm	100 cm	100 cm	100 cm	100 cm
Dose rate	600 MU/min	600 MU/min	600 MU/min	600 MU/min	600 MU/min
Collimator setting	20 x 20 cm²	20 x 20 cm²	14 x 14 cm²	14 x 14 cm²	14 x 14 cm²
Depth of measurement	1.3 cm	2 cm	3 cm	3 cm	3 cm
Readings / 100 MU					
Reading #1	22.780	23.01	23.3	23.66	24.51
Reading #2	22.780	23.03	23.29	23.65	24.53
Reading #3					
Reading #4					
Reading #5					
Reading / 500 MU	113.760	115.040	116.530	118.33	122.68
Equivalent Reading / 100 MU	22.752	23.008	23.306	23.666	24.536
Average Reading / 100 MU	22.771	23.016	23.299	23.659	24.525
Standard deviation / 100 MU	0.016	0.012	0.008	0.008	0.014
Corrected Average / 100 MU	23.113	23.361	23.648	24.014	24.893
Transfer coefficient (cGy/nC) measured on 15-Dec-2012	5.053	5.003	4.929	4.852	4.803
Output (cGy/100MU)	116.8	116.9	116.6	114.7	119.6

Mechanical Counter Reading (Battery OK): OK

Figure 17: Electron beam output check report representing measurements, calculations and calibration data.

A trend of the output for both photon and electron beams is available for all linacs and can be accessed through a search tool by filtering the linac type, its corresponding ion chamber and test date. A screen shot of this trend for 6 MV photon beams of the Varian linac IX, measured by Main IC is shown in figure 18.

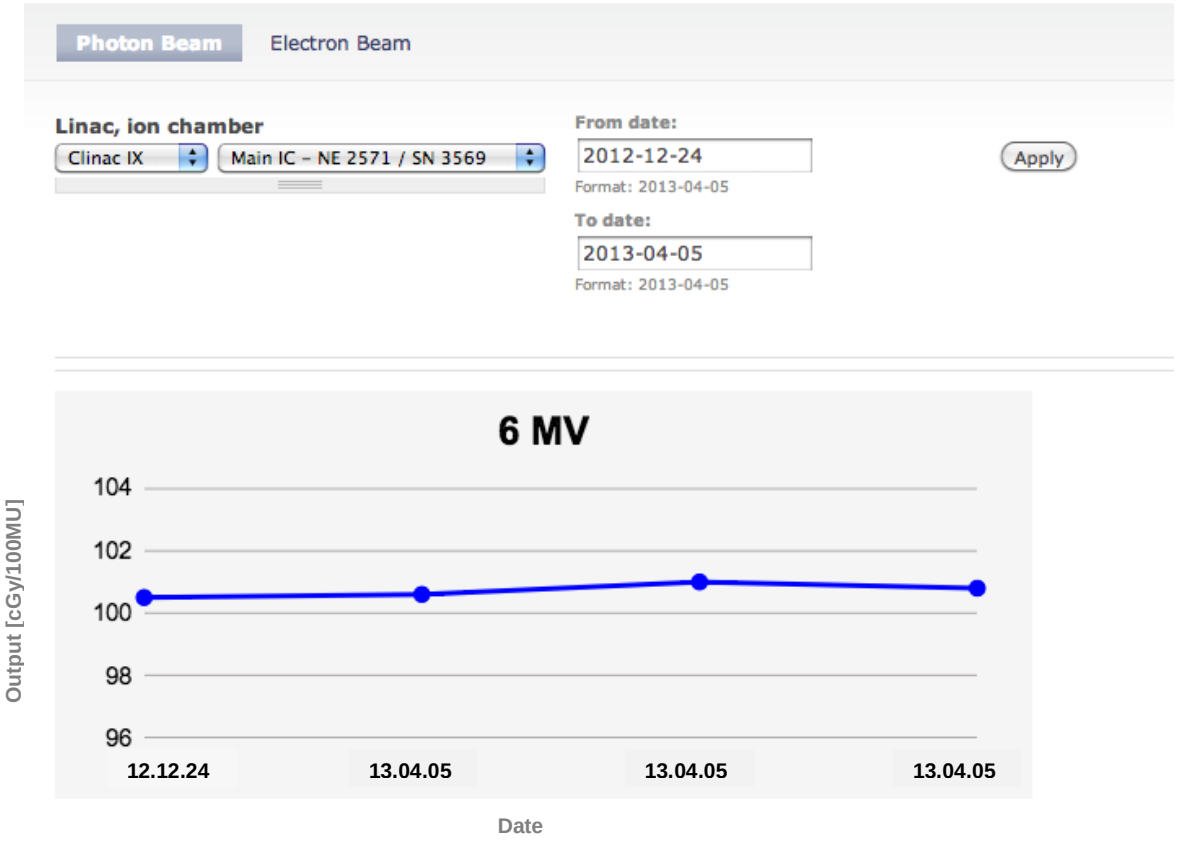

Figure 18: Beam output trend filtered for linac type, ion chamber and date.

(5) **DLG Measurement:** The Dosimetric Leaf Gap (DLG) measurement is one of linac monthly tests to verify the stability of the MLC leaf gap that is a critical factor in the delivery of intensity modulated radiotherapy beams i.e. IMRT or VMAT plans. The Drupal form for this test replaces an Excel sheet to log and

calculate the test results. Ion chamber readings for several nominal leaf gap values ranging from 2 mm to 20 mm are entered in the form and the leaf gap value for which there is no transmission (null reading) is calculated. This value is calculated by extrapolation of the measurements data. The Drupal form is initiated by choosing linac type and corresponding ion chamber and electrometer. In the next step, ion chamber readings for all nominal gaps are measured, entered and saved in the form. However, no leaf gap value is calculated and presented until the last measurement i.e. the measurement of 20 mm gap is executed. This is to avoid any misleading that could happen during analysis if this value was calculated and shown after each nominal gap measurement. Finally, the physicist saves and finalizes the test when he/she is satisfied with the test results. Figure 19 is an example of the DLG measurement test report generated by our system.

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DLG Measurement - Clinac 21EX - 11, Feb, 2013

Mon, 02/11/2013 - 14:30 —
Physicist(s):

Linac: Clinac 21EX
Ion chamber: Main IC - PTW 30011 / SN 61

Bank A	Bank B
0.19921	0.18867
0.19904	0.18825
0.19849	0.18855

Nominal gap (mm)	2	4	6	10	14	16	20
Readings (nc/100MU) at 300 MU/min							
Reading#1	0.5475	0.7487	0.947	1.3442	1.7454	1.9474	2.345
Reading#2	0.5476	0.7488	0.9463	1.3445	1.7442	1.9464	2.345
Reading#3	0.5475	0.7484	0.9468	1.3448	1.7471	1.95	2.343
Rg	0.5475	0.7486	0.9467	1.3445	1.7456	1.9479	1.7456
RT= (Bank A+Bank B)/2	0.1938	0.1938	0.1938	0.1938	0.1938	0.1938	0.1938
RgT= RT [1-(g (mm)/120 (mm)]	0.1906	0.1873	0.1841	0.1777	0.1712	0.168	0.1615
R'g= Rg - RT	0.3569	0.5613	0.7626	1.1668	1.5744	1.7799	2.1828

Leaf Gap: 1.52mm

Figure 19: DLG Measurement test report.

(6) **Orthovoltage Weekly QA:** This test consists of an output (dose to water D_w (in cGy) ⁄100 MU at the reference point) check for all beam qualities of the orthovoltage machine. This test is performed on weekly basis. The Drupal form replaces the Excel sheet used for this test. In the Drupal form for this test, the ion chamber readings for each beam quality are entered one by one. Readings are then corrected taking into consideration the ion chamber polarity (P_{pol}), the ion recombination (P_{ion}), the temperature and pressure ($P_{t,p}$), etc. These correction factors are retrieved from the annual measurements data that are

saved in a separate Drupal form. Physicists see values of these correction factors in a table format on the Drupal form of this test. In the next step, dose to water the output is calculated using the annual TG-61 calibration coefficients (N_k) for each energy. These calculated outputs are compared to the annual measurements and a percentage difference value is calculated. These differences must lie within the accepted range of action level (3%). Finally, physicist can terminate the test and view the report table that consists of the readings, correction factors and calculations. At this time, a summary of the performed QC test including outputs and difference values is generated and sent automatically to the physicist who supervises the QC of the orthovoltage machine for a quick review of the test result. For the purpose of ensuring that the test is performed on weekly basis, a schedule that checks the creation of this QC test report runs every Friday evening. If the QC test is not performed, the physicist who supervises the QC of this unit receives an email alert/warning. Furthermore, a trend of the dose to water can be generated by filtering test date and beam quality. In figure 20 and 21 a sample of the test report and dose to water trend for all beam qualities are shown consecutively.

Orthovoltage Xstrahl/Gulmay 200 D3225 Weekly QA - 03 - 27 - 2013

Temperature and Pressure information

Pressure (P): 749.4mmHG
Temperature (T): 21 °C
$P_{T,P}$: 1.011

Beam Quality	120 kVp (4.91 mm of Al)	180 kVp (0.53 mm of Cu)	120 kVp (4.91 mm of Al)	180 kVp (0.53 mm of Cu)
Filter number	5	7	4	6
Dose rate [MU/min]	92	133	535	759
Phantom material	None - In air	None - In air	None - In air	None - In air
SSD	50 cm	50 cm	20 cm	20 cm
Applicator	SQUARE 10 x 10 cm²	SQUARE 10 x 10 cm²	CIRCULAR 5 cm	CIRCULAR 5 cm
Exposure time	100 MU	100 MU	100 MU	100 MU
Depth of measurement	At Cone End	At Cone End	At Cone End	At Cone End
Readings / 100 MU				
Reading #1	16.306	15.986	17.851	17.932
Reading #2	16.307	15.987	17.853	17.910
Reading #3	16.318	15.976	17.853	17.918
Reading #4				
Reading #5				
Average reading Mraw	16.31	15.983	17.852	17.92
Corrections				
Ppol	0.999	1.001	0.999	1.001
Pion	1.002	1.001	1.002	1.001
Pelec	1	1	1	1
Cssd	1.017	1.017	1.044	1.044
Corrected reading (M=Mraw x Ppol x Pion x Pelec x $P_{T,P}$ x Cssd)	16.786	16.466	18.861	18.952
Calibration coefficient Nk (cGy/nC) measured on 25-Jul-2012	4.282	4.22	4.312	4.217
Water Kerma based backscatter factor Bw for water phantom	1.366	1.394	1.233	1.232
Stem correction factor Pstem	1	1	1	1
Ratio of average mass energy absorption coefficient, water to air, free in air [(μen/ρ)w,air]air	1.029	1.052	1.029	1.052
Dose to water (Dw = M x Nk x Bw x Pstem x [(μen/ρ)w,air]air) cGy/100 MU	101	101.9	103.2	103.6
Dw (cGy/100 MU) in table measured on Jun-2012	101.1	101.3	103	103.1
Percent Error %	0.1	-0.59	-0.19	-0.48

Physicist(s):

Figure 20: Orthovoltage weekly QA report presenting measurements, calculations and calibration data.

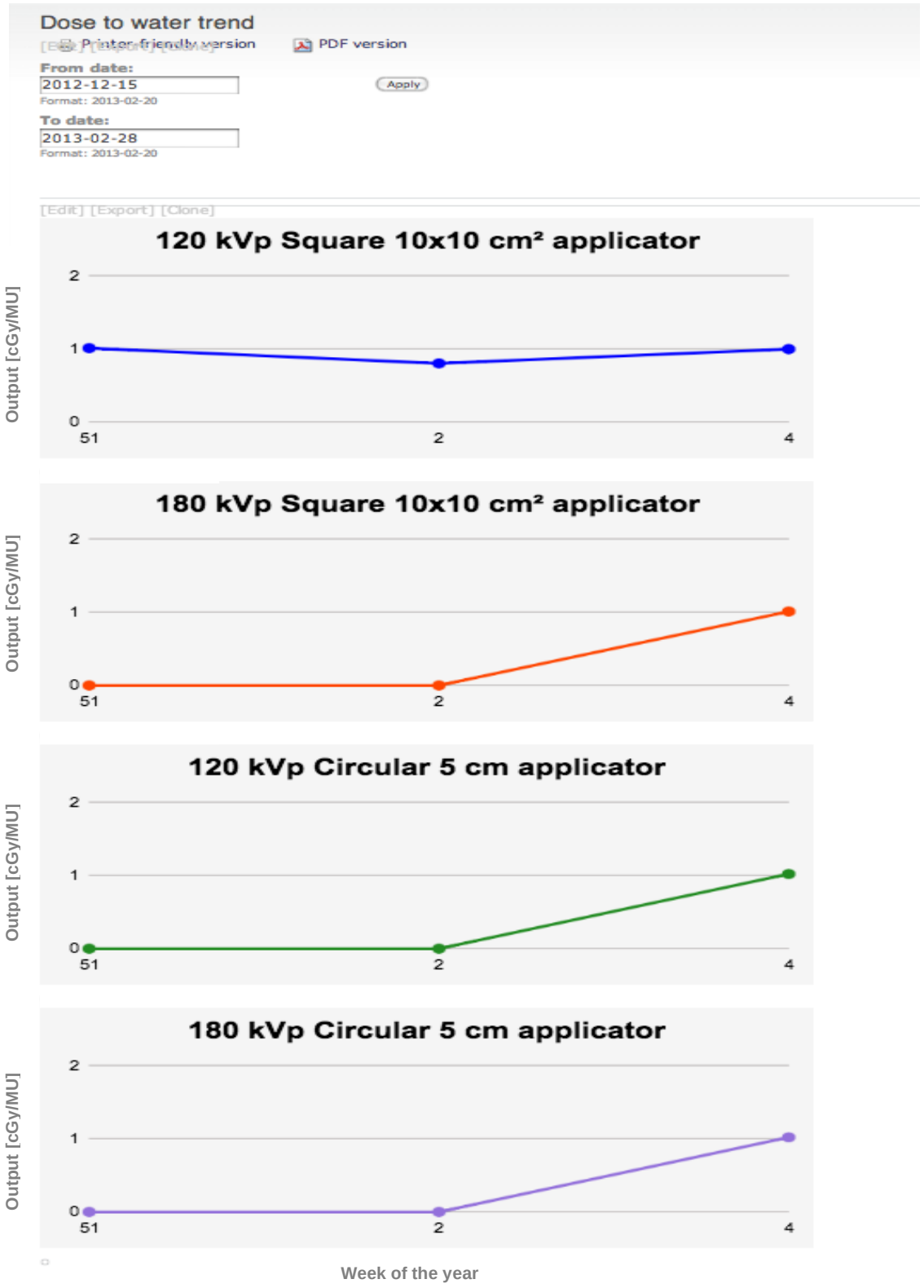

Figure 21: Beam output trend by date for each orthovoltage beam quality.

(7) **Morning QA:** This test consists of an exhaustive checklist that is filled out every morning by the technologist who performs the warm-up of specific equipment and ensures that all important aspects of that equipment are as working properly. Drupal checklists are created for linacs, Acuity Simulator (Varian, Palo Alto, CA), Brachytherapy HDR afterloader unit (Microselectron V3, Elekta, Stockholm, Sweden), LightSpeed RT 16 CT-Simulator (GE Healthcare, Little Chalfont, United Kingdom) and orthovoltage unit (XStrahl Ltd., Camberley, United Kingdom). All procedures and safety instructions for each machine can be accessed through the links available on their corresponding Drupal test forms. Another feature of this module is the email alerts that are sent to the chief technologist in case of an incomplete or non-performed morning QC test of any equipment at a specific time of the day. This time is configurable in the system. However, this email is not generated during weekends.

In the following section, we discuss the results of the two image-based QC tests that we have implemented in our system (MLC acceleration and asymmetric jaws tests).

(8) **MLC acceleration test:** This is a quarterly QC test that verifies that the acceleration of a linac's MLC leafs is consistent in time. For each linac, a pre-defined QA treatment plan that consists of a complex MLC sequence is

delivered and an image is recorded on the portal imager. Figure 22 is a sample of the recorded image on the portal imager.

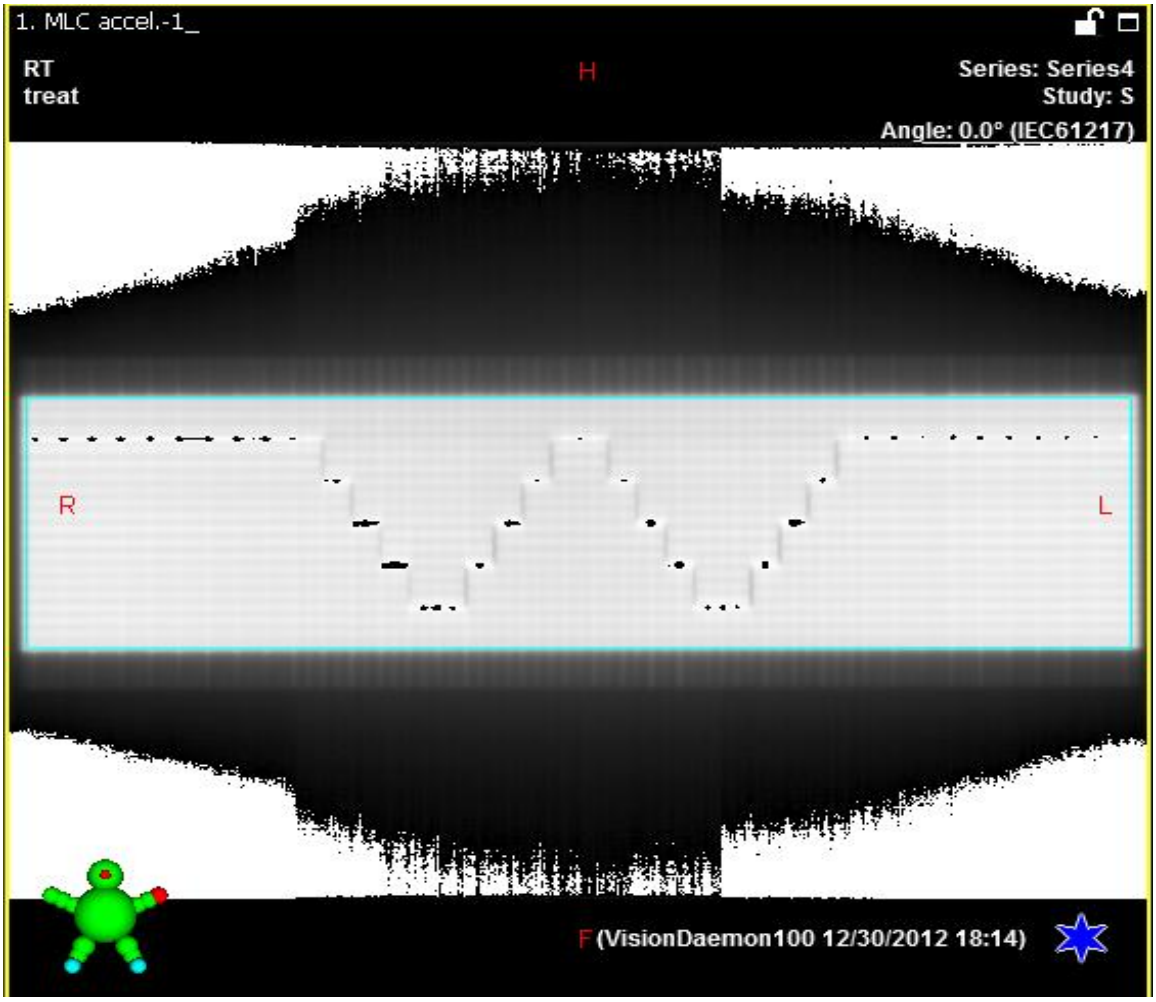

Figure 22: MLC acceleration test image acquired on the portal imager of a linac.

To analyse the performance of the MLC, the acquired image in figure 22 is retrieved through the process described in section 3.2.4. The image is then analysed by calculating and comparing dose delivered to two different regions of the image. These Regions of Interests (ROI) are defined and the mean pixel

values as well as standard deviations of the pixel values are calculated. Finally, the difference between mean pixel values of the two ROI's are calculated. A test with difference value less than or equal to 3% is considered as passed. An example of the results of the test is shown in figure 23.

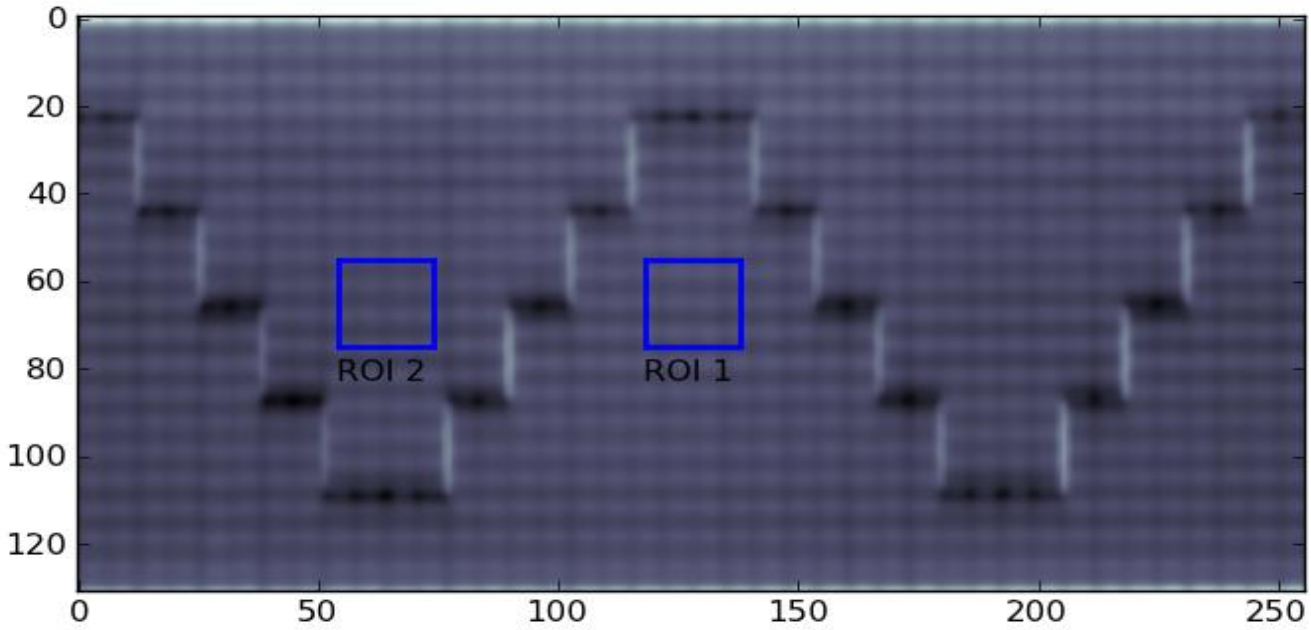

Figure 23: MLC acceleration test results by python script. The acquired image on the imager with defined ROI's (top figure). ROI analysis results (bottom figure).

The same MLC pattern test is performed using Gafchromic film (EBT2, Ashland, Wayne, NJ) but as described, our system allows automatic analysis of the pattern by recording it on the portal imager.

(9) **Collimator Asymmetric Jaws test:** This is a quarterly QC test to verify the linac asymmetric junction of the jaws. Four asymmetric fields of 5 x 5 cm^2 are delivered sequentially, each being a quadrant of a 10 x 10 cm^2 area. The composite irradiation of these four fields would ideally yield a flat 10 x 10 cm^2 field. In reality we observe a cross at their junction that we want to characterize. We want to perform our test with the portal imager of the linac to simplify the analysis of the results as we directly obtain a digital image in the form of a DICOM file in the clinical database. We validated our technique with our current clinical practice, i.e. using Gafchromic film (EBT2, Ashland, Wayne, NJ) where the four irradiations are recorded on one piece of film. The irradiated film is scanned and analysed using the Film QA Pro (Film QA Pro 2013, Ashland, Wayne, NJ) software with an Epson scanner (10000XL, Suwa, Nagona, Japan). From Film QA Pro we obtain a calibrated image that is proportional to dose using the clinical calibration curves of the EBT2 film. For the portal imager acquisition, we repeat three times the irradiation of four quadrants to get better statistics on the image by taking a simple average of them. As the portal imager doesn't move between the irradiation of the four quadrants, the images are inherently aligned and the average of the four images could potentially also average errors from small motion of the whole carriage. Figure 24 shows the four quadrant images acquired on the portal imager.

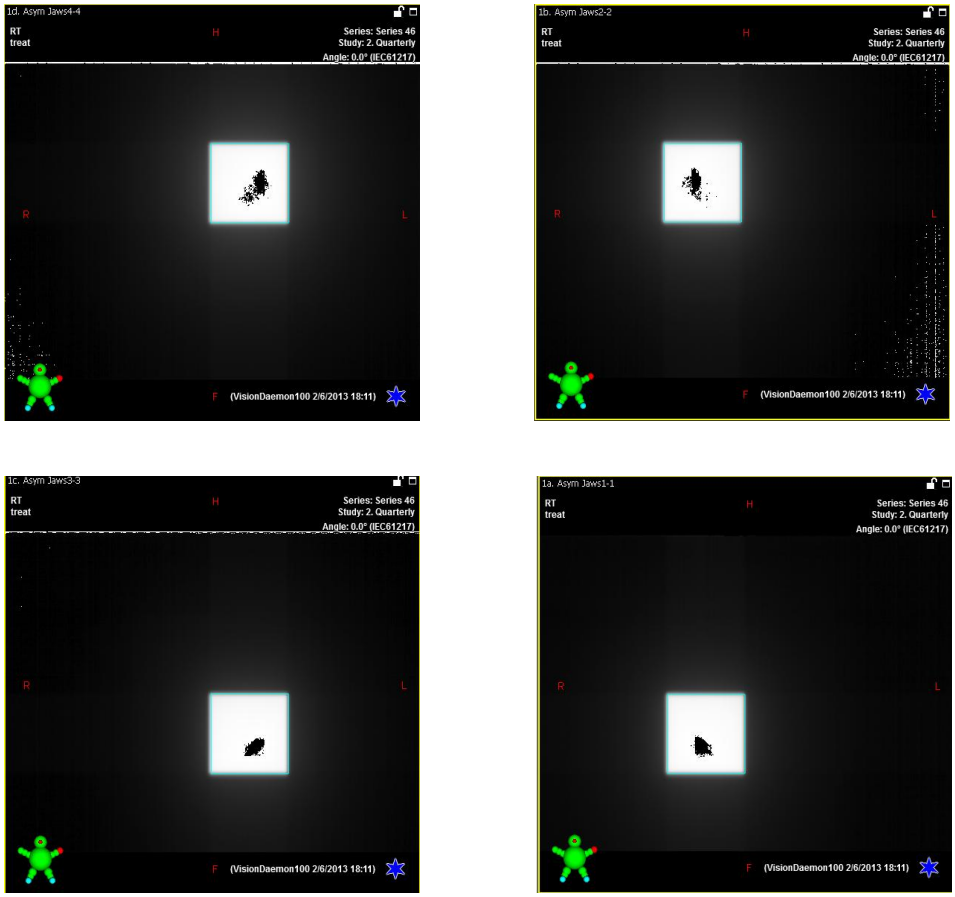

Figure 24: Four asymmetric fields of 5 x 5 cm^2.

Dark regions on the fields are artefacts caused by the display settings limitations (image width and level). The image data is good.

The 12 DICOM images are retrieved by the process described in section 3.2.4 to be used as the inputs of a python script that analyses the junctions. Images are first averaged and merged to reconstruct the final image (similar to the image acquired on the film). As explained above radiographic film was also irradiated simultaneously to compare the results with the results of the portal images.

Figures 25 and 26 show the reconstructed image from the 12 portal images and the image acquired with a film.

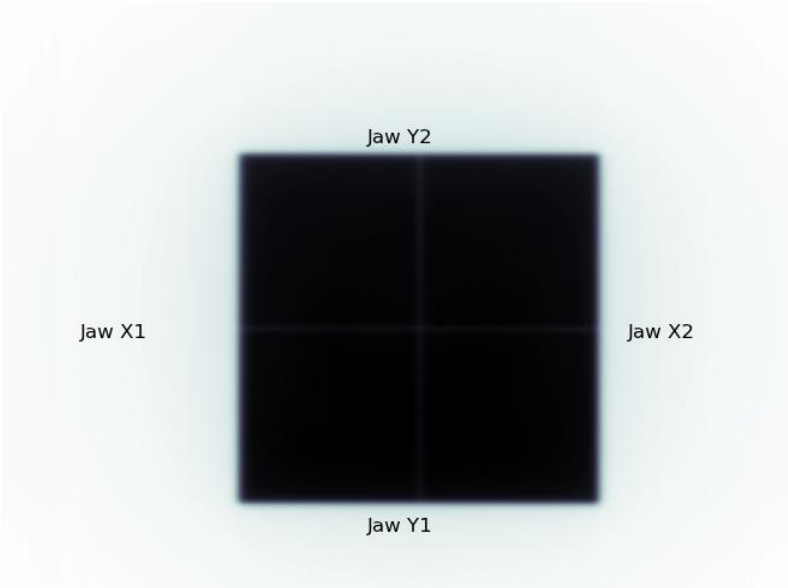

Figure 25: Reconstructed image of the image acquired on the portal imager.

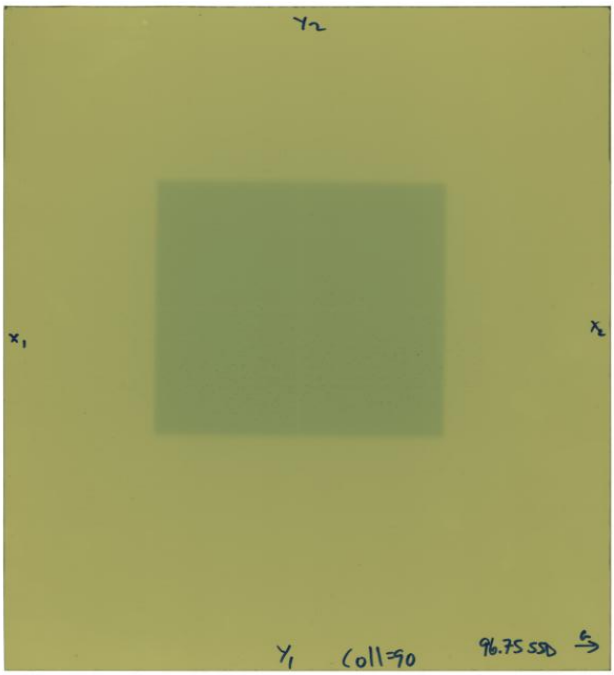

Figure 26: Image acquired on the film (scaling is different on both images).

We investigated and compared two different features of these two images:

1) Measurement of the irradiated flat fields on each image shows that both of these fields represent a 10 x 10 cm^2

2) In both images, as expected, we observe a cross at the jaw junctions resulting from four asymmetric field irradiations.

To characterize the junctions, we first look at the dose profiles (on the film or on the portal images) at the jaw junctions i.e. X1, X2, Y1, Y2. Figures 27 and 28 show these dose profiles for one pixel line in Calibrated Units (CU) (for the portal images) and in dose percentage (for the film). Both set of curves are proportional to dose and can be normalized for means of inter-comparison.

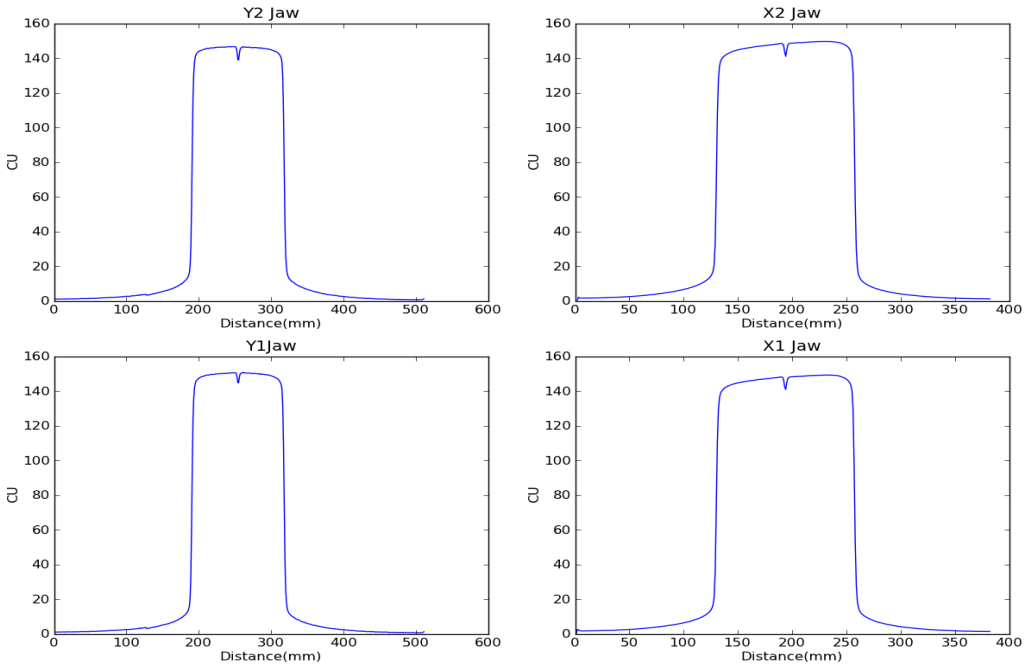

Figure 27: Jaw junctions' dose profiles in CU from the portal images analysis; Y2 (upper left); Y1 (lower left); X2 (upper right); X2 (lower right).

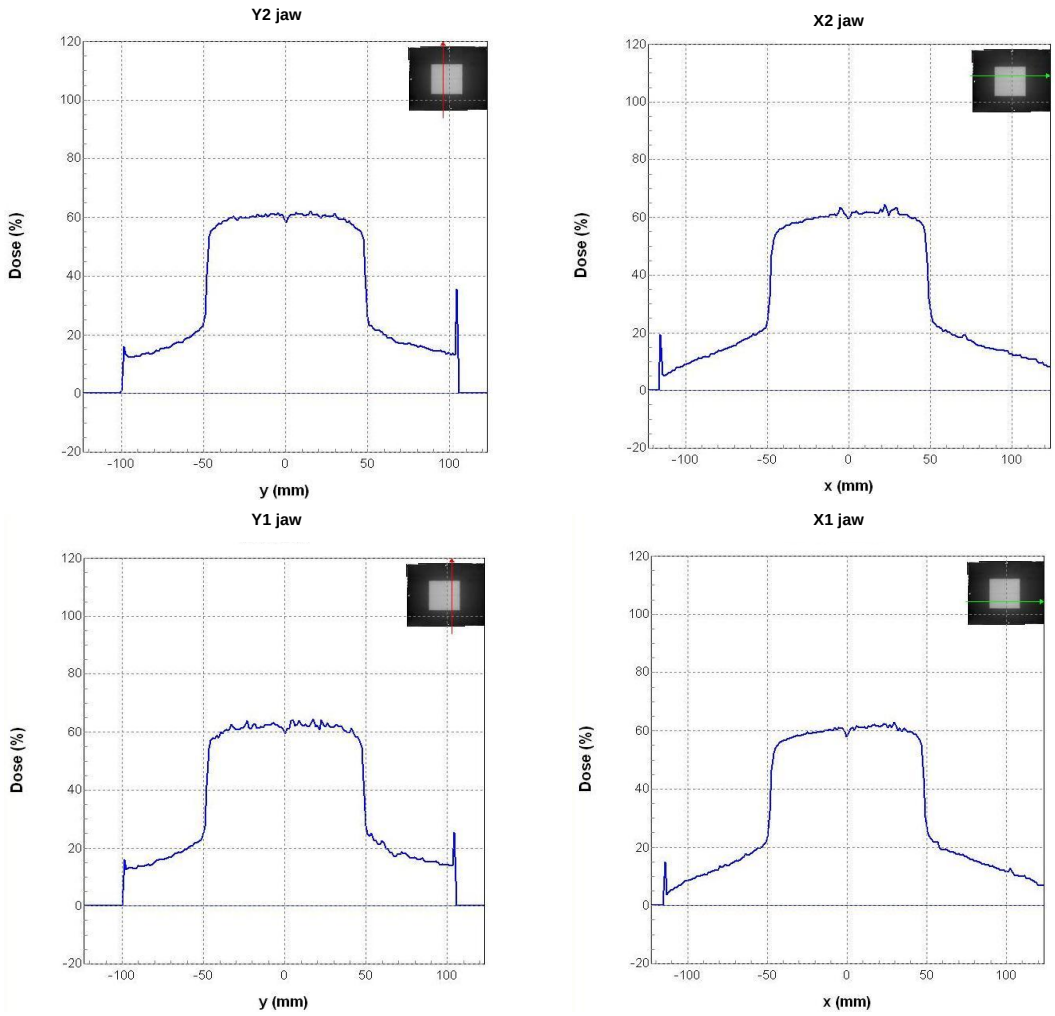

Figure 28: Jaw junctions' dose profile in dose percentage from the film analysis; Y2 (upper left); Y1 (lower left); X2 (upper right); X2 (lower right).

The profiles of the portal images are smoother than the film profiles. This results from the characteristics of the aS1000 portal imager that reduces noise to improve image quality. For the full analysis and comparison we are interested in obtaining a numerical quantification of the junctions. To get better statistics and

a more reliable analysis we have decided to use an average of many profiles over an ROI across the junction as shown in figure 29. Two parameters are reported:

1. Dose difference between minimum / maximum dose value at jaw junctions in the dose profile and the adjunct dose values. We would like to make sure that this value is not exceeding 5%.
2. Full width at half maximum (FWHM) for the four junctions.

For this analysis, we decided to choose four regions of interest (ROI) that include jaw junctions on the reconstructed image as shown in figure 29.

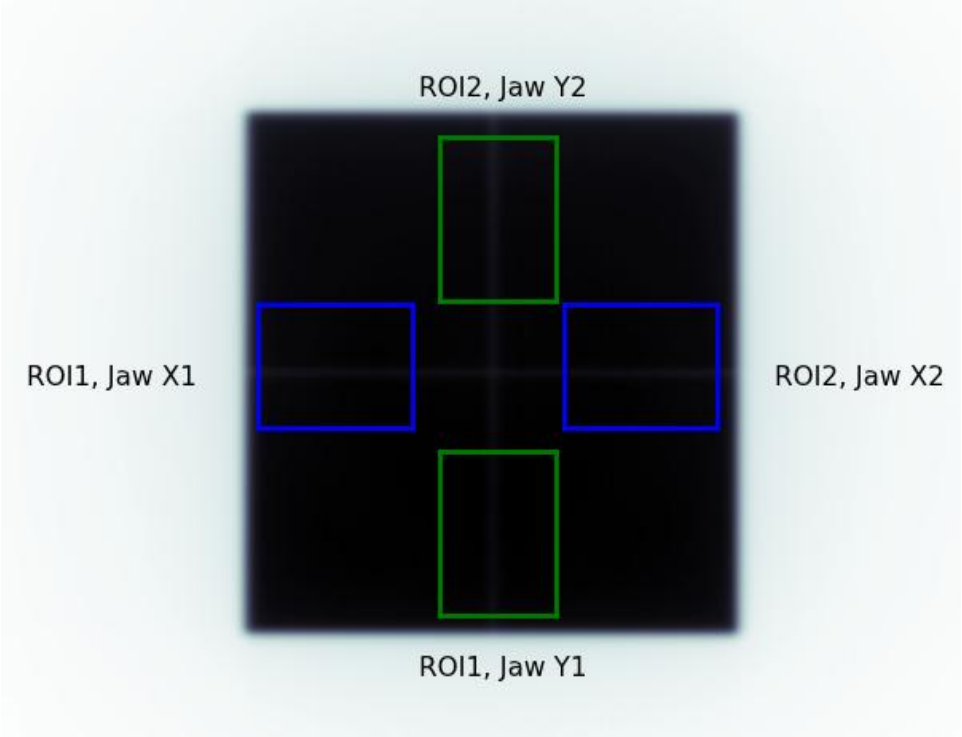

Figure 29: ROI's at four jaw junctions on the portal image.

Each green ROI is “collapsed” on the vertical direction to obtain one average dose profile and each blue ROI is “collapsed” or averaged on the horizontal direction. These averaged one dimensional arrays of pixels are shown in figure 30.

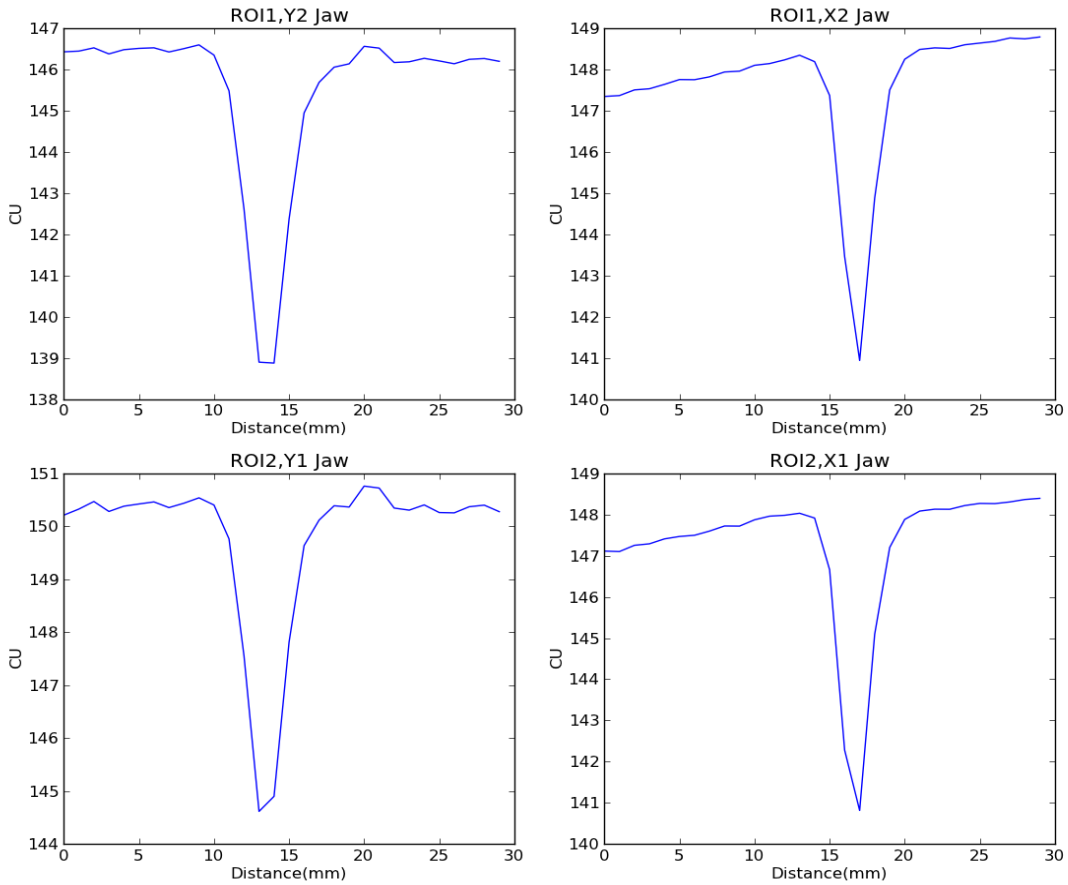

Figure 30: Dose profiles in CU for the ROI’s at the four jaw junctions; ROI1, Y2(upper left); ROI2, Y2(lower left); ROI1, X1(upper right); ROI2, X1(lower right).

The results of our analysis script are shown in figure 31.

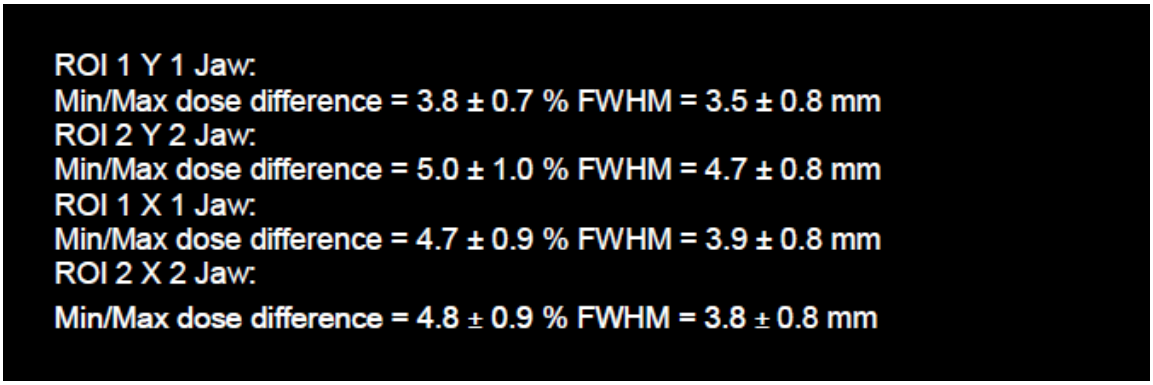

Figure 31: Dose profile analysis. Min/max dose difference and FWHM.

Finally, the same analysis was performed on the film and the comparison between the two methods is presented in tables 3 and 4. Values in the tables are calibrated and scaled values.

Jaw	Min/Max dose difference	
	Portal image (%)	Film (%)
Y1	3.8±0.7	3.6±1.5
Y2	5.0±1.0	4.8±1.9
X1	4.7±0.9	4.9±1.6
X2	4.8±0.9	4.9±1.6

Table 3: Comparison of min/max dose difference between the film image and the portal image.

Jaw	FWHM	
	Portal image (± 0.8 mm)	Film (± 0.2 mm)
Y1	3.5	3.5
Y2	4.7	4.6
X1	3.9	3.8
X2	3.8	3.8

Table 4: Comparison of FWHM analysis between the film and the portal image. The third column represents the percentage difference between the value obtained with the portal imager and the film.

In table 3, the uncertainties for the max/min dose differences are calculated based on the standard deviation of a flat area of the image (0.2 in CU for the portal image and for the 0.4 in dose percentage for the film). We can see that the max/min difference values for the portal and the film images are equal within their respective errors.

In table 4, the uncertainty for the FWHM values is ± 0.78 mm (equal to the portal imager pixel pitch (distance between two pixels)) for the portal images and ± 0.17 mm for the film. We can see that the FWHM values for the portal and the film images are equal within their respective errors.

CHAPTER 5

Conclusions and Future Work

5.1 Conclusions

We have successfully implemented a web-based quality control system for the division of radiation oncology at the Jewish General Hospital. Our system is based on the popular open source Content Management System Drupal. We have extended the capabilities of Drupal by using some custom PHP and Python scripts as well as some specialized Drupal modules. The various quality control tests are implemented as Drupal forms containing several fields to select or fill up. The system manages user login through the hospital's LDAP server. Group rights are defined through specific modules in the Drupal system. Our system can directly query our Electronic Medical Record database for patient and plan information as well as our image database through DICOM queries for image-based tests.

This tool favourably replaces many Excel sheets and paper forms as it provides an easy access to users and managers. It optimizes QA data entry and minimizes the possibility of errors and provides easier storage and retrieval of these data within our radiation oncology division. Based on a centralized database, it is accessible to

users on desktop computers, smart phones, tablets, etc. and considerably facilitates trend keeping and report generation (PDF/ graphical trends/summary/etc). Functions such as scheduling and email alerts, allow more efficient management and supervision of the workflows within our department. Moreover, data transfer from the EMR and TPS of our department offers a fast and reliable way to enter important data to the system. Using hospital LDAP as a login tool and the possibility of electronic signature of the logged-in user saves time for paper signature and improves security of the system.

Image-based QC tests (MLC acceleration and Asymmetric Jaws tests) executed on the portal imager replace the film acquisition and manipulation hence greatly simplifying the workflow for these tests. This approach also allows “automatic” analysis from daily or weekly image acquisition performed by technologists as part of a morning QA for example.

5.2 Future Work

Extending our tool to support all other QC tests that are performed as part of our QA program is a priority. We have established a broad range of capabilities with the already implemented tests and their specifications should be sufficient to cover all other tests.

Additional work on scheduling tests, e-calendars, email alerts/reports and automatic updating of the equipment’s clinical status would be greatly profitable, principally in making these options more organized globally within the tool.

Image-based tests performed on the portal imager are numerous and advanced image analysis tools are available to us through specialised python modules. The possibility of automatic analysis of any image acquisition is certainly to be explored as they could be incorporated in the morning QC tests performed routinely by technologists. Results of these tests could be trended and reported automatically.

Future extension could include direct communication with some measurement tool such as electrometers and specialized devices (Beamchecker, Profiler II (Sun Nuclear Corp., Melbourne, FL), Matrix (IBA, Louvain-la-Neuve, Belgium), etc.). The recent install of a TrueBeam linac (Varian, Palo Alto, CA) in our clinic opens the door to complex, extensive and automatic tests as this new linac can fully be controlled with external scripts (codes in XML (W3C Document License, w3.org)). One can imagine coding an automatic sequence of QC tests to perform on this linac, fully controlling all parameters of the delivery and saving their results directly in our QA tool.

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