CHAPTER 2

LITERATURE REVIEW

In the last decade, many changes happened in the field of radiotherapy due to the advancement in the imaging, introduction of new treatment techniques and the improvement in the construction of treatment machines and radiation measuring instruments. But the standards of quality control may not always accompany all these new developments. One of the major revolutionary changes in the radiation therapy was the introduction of IMRT with the help of computer controlled MLCs. There are lots of studies and publications available related to the IMRT and its quality assurance tests. A Comprehensive quality assurance for the delivery of intensity modulated radiotherapy with a multileaf collimator used in the dynamic mode was published by Thomas LoSasso et al in 2001. This work covers most of the basic tests that are mandatory to perform before starting an IMRT treatment.

Kapulsky et al. (2002) published a work about an automated phantom-film QA procedure for IMRT. To verify the calculated dose distribution delivered during IMRT, they implemented an automated plan/film validation protocol. The cubic polystyrene film phantom provided with the peacock IMRT system and the Radiation Imaging Technology (RIT) film dosimetry system were used to compare planned and delivered dose distributions. The calculated dose matrix was transferred to RIT and analyzed. The analysis included dose difference histograms, dose comparisons in low-gradient areas, and distance to
agreement in high-gradient areas, dose profiles, and isodose comparisons. Dose differences of up to 5% were observed in the high dose and low dose gradient areas between verification films and treatment plans for prostate patients. The most prominent discrepancies were detected in the high-gradient areas of dose distributions."

Murshed Hossain et al. (2002) reported his study on the output variation from a linac with intensity modulating dynamic collimator. They investigated the effect of switch rates and delay in the open/close events on the output profiles. The author interpreted these variations in terms of a simple model, which include the effect of leaf travel time during the process of opening and closing. They also included the time delay in establishing the specified pressure in the pneumatic device, which controls the opening and closing of the leaves.

Grein et al. (2002) investigated a new aSi EPID for transit dosimetry. They studied the relationship between the pixel value and exit dose for a commercially available aSi EPID. The pixel to dose mapping function was linear for distances between 116.5 cm to 150 cm from the source, radiation field sizes from 5 x 5 cm² to 20 x 20 cm² and beam energies of 6 to 18 MV. Coefficients in the mapping function were found to be dependent on beam energy and field size. Open and wedged field profiles measured with the device showed agreement to a maximum of 5% and 8%, between the EPID and ion chamber indicated a maximum deviation of 6% and 2% at 6 and 18 MV, respectively, for an attenuator thickness of 21 cm and SDD > or = 130 cm.

Vieira et al. (2002) studied about fast and accurate leaf verification for dynamic multileaf collimation using an electronic portal imaging device. They developed fast, accurate and two dimensional method for
daily leaf verification, using camera based electronic portal imaging device (EPID). This method was based on a flat field produced with a 0.5 cm wide sliding gap for each leaf pair. Deviations in gap widths were detected as deviations in gray scale value profiles derived from EPID images, and not by directly assessing leaf positions in the images. Dedicated software was developed to reduce the noise level in the low signal images produced with the narrow gaps. The accuracy of this quality assurance procedure was tested by introducing known leaf positions errors. It was shown that errors in leaf gap as small as 0.01-0.02 cm could be detected, which is certainly adequate to guarantee accurate dose delivery of DMLC treatments, even for strongly modulated beam profiles. Using this method, it was demonstrated that both short and long term reproducibility in leaf positioning were within 0.01 cm for all gantry angles, and that the effect of gravity was negligible.

Dosimetric properties of an aSi EPID for verification of dynamic IMRT was published by Greer et al. (2003). They studied the effect of build up, dose linearity, field size response, sampling of multileaf collimator leaf speeds, response to dose rate fluctuations, memory effect, and reproducibility. EPID measurements were also compared to ion chamber and film for open and wedged static fields and IMRT fields. The EPID was linear with dose and dose rate, and response to MLC speeds up to 2.5 cm/sec was found to be linear. A field size response of upto 5% relative to d-max ion-chamber measurement was found. Reproducibility was within 0.8 % (1stanadard deviation) for an IMRT delivery recorded at intervals over a period of one month. The dead time in frame acquisition resulted in errors in the EPID that increased with leaf speed and were over 20% for a 1 cm leaf gap moving at 1.0 cm/sec. The measurements were also found to depend on the input beam profile utilized for EPID flood calibration.
A convolution based calibration procedure was developed by Warkentin et al. (2003) to use an amorphous silicon flat-panel electronic imaging device (EPID) for accurate dosimetric verification of IMRT treatments. Raw EPID images were deconvolved to accurate, high-resolution 2-D distributions of primary fluence using a scatter kernel composed of two elements: a Monte Carlo generated kernel describing dose deposition in the EPID phosphor, and an empirically derived kernel describing optical photon spreading. Relative fluence profiles measured with the EPID found very good agreement with those measured with diamond detector, and shown excellent spatial resolution for IMRT verification. For dosimetric verification, the EPID measured primary fluencies were convolved with a Monte Carlo kernel describing dose deposition in a solid water phantom, and cross-calibrated with ion chamber measurements. Dose distributions measured using the EPID shown good agreement within 2.1% with those measured with film for open field sizes of up to 2 x 2 cm$^2$ and 10 x 10 cm$^2$. Predictions of the EPID phantom scattering factors (SPE) based on scatter kernels were within 1% of the SPE measured for open field sizes of up to 16 x 16 cm$^2$. Pretreatment verifications of step-and-shoot IMRT treatments using EPID shown good agreement with those performed with film, with a mean percent difference of 0.2 ± 1.0% for three IMRT treatments (24 fields).

Renner et al. (2003) developed a method for verifying the delivery of external beam radiotherapy and implemented the methodology into a system consisting of both hardware and software components. The system used grayscale images acquired on the treatment machine from the planned treatment beams. From these images, the photon fluence distribution of each beam was derived. These measured photon maps then used as input to a separate dose calculation engines to compute the delivered absolute dose
and the dose distribution in the same patient. The dose distribution generated from the measured fluence maps then compared to that of the treatment plan. Software tools, such as overlaying isodose curves generated with this method on those imported from the plan, dose difference maps, dose difference volume histograms, and three- dimensional perspective views of the dose differences, have also been developed.

The use of an aSi-based EPID for routine absolute dosimetric pre treatment verification of dynamic IMRT fields was investigated by Ann Van Esch et al. (2004). They investigated the basic dosimetric characteristics of an aSi portal imager (aS500), using an acquisition mode especially developed for portal dose (PD) integration during delivery of a- static or dynamic radiation field. Secondly, the dose calculation algorithm of a commercially available treatment planning system was modified to allow prediction of the PD image, i.e. to compare the intended fluence distribution as actually delivered by the dynamic multileaf collimator. Absolute rather than relative dose prediction was applied. The PD image prediction was compared to the corresponding acquisition for several clinical IMRT fields by means of the gamma evaluation method. Gamma evaluations of the predicted versus measured PD distribution were within the pre-defined acceptance criteria for all clinical IMRT fields, i.e. allowing a dose difference of 3% of the local field dose in combination with a distance to agreement of 3 mm.

Winkler et al. (2005) investigated the dosimetric properties of amorphous silicon EPID with respect to three photon beam qualities: 6, 10, and 25 MV. The EPID showed an excellent temporal stability on short term as well as on long term scales. The stability throughout the day was strongly influenced by warming up, which took several hours and affected EPID response by 2.5%. Ghosting effects increased the sensitivity of the
EPID. It became more pronounced with decreasing time intervals between two exposures as well as with increasing dose. Due to ghosting, changes in pixel sensitivity amounted up to 16% (locally) for the 25MV photon beam. It was observed that the response characteristics of EPID depended on dose as well as on the dose rate. Doubling the dose rate increased the EPID sensitivity by 1.5%. This behavior was successfully attributed to a dose per frame effect, i.e., a nonlinear relationship between the EPID signal and the dose which was delivered to the panel between two successive readouts. This variation was governed by two independent effects. For low doses, the EPID signal was reduced due to the changing dose rate of the linac during startup. Furthermore, the detector reading was influenced by intra-beam variations of EPID sensitivity, namely, an increase of detector response during uniform exposure. For the beam qualities which were used, the response characteristics of the EPID did not depend on energy. Differences in relative dose-response curves resulted from energy dependent temporal output characteristics of the accelerator.

Wiezorek et al. (2005) tested and compared various 2-D real time detectors for dosimetric quality assurance (QA) of intensity modulated radiotherapy (IMRT) with the vision to replace radiographic films for 2-D dosimetry. They created all IMRT treatment plans with the Konard software and final dose calculation was carried out in Konard. A Mevatron Primus linear accelerator which provides 6 MV and 15 MV high energy photon beams was used for the delivery of segmented multileaf modulated IMRT. Three different 2-D detectors, each based on a different physical (interaction) principle, were tested for the field related IMRT verification: (1) the MapCheck diode system (Sun Nuclear), (2) the IMRT QA scintillation detector (Scanditronx/ Welhofer), and the Seven29 ionization chamber array with Konard and the results obtained were compared with film measurements performed with radiographic films (EDR2, Kodak).
Additionally, measurements were performed with point detectors, such as diamond, diodes (PTW) and ionization chambers (PTW, Scanditron-ics/Welhofer) and radiochromic films (GafChromic film MD55 ISP). The results obtained with all three 2-D detector systems were in good agreement with calculations performed with the treatment planning system and with the standard dosimetric characteristics required for performing field related IMRT QA with relative dose measurements. The accuracy of the 2-D detectors was mostly 3% normalized to dose maximum for a wide dynamic range. The maximum deviations did not exceed 5% even in regions with a steep dose gradient. The main difference between the detector systems was the spatial resolution, the maximum field size, and the ability to perform absolute dosimetric measurements. They concluded that the commercial 2-D detectors have the potential to replace films as an “area detector” for field related verification of IMRT.

D-IMRT verification with a 2-D pixel ionization chamber: dosimetric and clinical results in head and neck cancer were published by Stasi et al. (2005). In this work, a PiXel –segmented ionization chamber (PXC) has been used for the verification of 19 fields used for four different head and neck cancers. The device consists of a 32x32 matrix of 1024 parallel-plate ionization chambers arranged in a square of 24x24 cm² areas. Each chamber has 0.4 cm diameter and 0.55 cm height; a distance of 0.75 cm separates the centre of adjacent chambers. The sensitive volume of each single ionization chamber is 0.07 cm³. Each of the 1024 independent chambers is read out with a custom microelectronic chip. The output factors in water obtained with the PXC at a depth of 10 cm were compared to other detectors and the maximum difference was 1.9% for field sizes down to 3x3 cm². Beam profiles for different field dimensions were measured with the PXC and two other types of ionization chambers; the maximum distance to agreement (DTA) in the 20-80 % penumbra region
of a 3x3 cm² field was 0.09cm. The leaf speed of the multileaf collimator was varied between 0.07 and 2 cm s⁻¹ and the detector response was constant to better than 0.6%. The behavior of the PXC was measured while varying the dose rate between 0.21 and 1.21 Gy min⁻¹; the mean difference was 0.05% and the maximum difference was 0.96%. Using fields obtained with an enhanced dynamic wedge and a staircase-like IMRT field, the PXC has been tested for simple modulated beams; comparison with film gave a maximum DTA of 0.12 cm. The PXC was then used to check four different IMRT plans for head and neck cancer treatment; cervical chordoma, parotid, ethmoid and skull base. In the comparison of the PXC versus film and PXC versus treatment planning system, the number of pixels with gamma (γ) parameter ≤ 1 was 97.7% and 97.6% respectively.

Viera et al. (2006) published a method for fast (1-2 min) and accurate linac quality control for dynamic multileaf collimation, using a portal imaging device. The purpose of the study was to develop an equivalent procedure for QA of IMRT with segmented (static) multileaf collimation (SMLC). The QA procedure was based on measurements performed during 3 to 8 month period at Elekta, Siemens and Varian accelerators. On each measurement day, images were acquired for a field consisting of five 3 x 22 cm (2) segments. These 10 monitor unit (MU) segments were delivered in SMLC mode, moving the leaves from left to right. Deviations of realized leaf gap widths from the prescribed width were analyzed to study the leaf positioning accuracy. To assess hysteresis in leaf positioning, the sequential delivery of the SMLC segments was also inverted. A static 20 x 20 cm (2) field was delivered with exposures between 1 and 50 MU to study the beam output and beam profile at low exposures. A comparison with an ionization chamber was made to verify the EPID dose measurements at low MU. Dedicated software was developed to improve the signal- to- noise ratio and to correct for image distortion. The observed
long term leaf gap reproducibility (1 standard deviation) was 0.1 mm for the Varian, and 0.2 mm for the Siemens and the Elekta accelerators. Down to the lowest MU, beam output measurements performed with the EPID agreed within 1+/-1% (ISD) with ionization chamber measurements. These findings led to a fast (3-4 min) procedures for accurate, daily linac quality control for SMLC.

Luice et al. (2006) studied the performance optimization of the Varian aSi500 EPID system. The general aim of this study was to optimize the acquisition parameters of aSi EPID commercially available for clinical use in radiation therapy with the view to avoid saturation of the system. Special attention was paid to selection of the parameter corresponding to the number of rows acquired between accelerator pulses (NRP) for various beam energies and dose rates. The image acquisition system (IAS2) has been studied and portal image acquisition was found to be strongly dependent on the accelerator pulse frequency. For all combinations, the image acquisition parameters were systematically changed to determine their influence on the performances of the Varian aSi500 EPID system. New parameters such as the maximum number of rows (MNR) and the number of pulses per frame (NPF) were introduced to explain portal image acquisition theory. Theoretical and experimental values of MNR and NPF were compared, and they were in good agreement. Other results showed that NPF had a major influence on detector saturation and dose per image. A rule of thumb was established to determine the optimum NRP value to be used. This practical application was illustrated by a clinical example in which the saturation of the aSi EPID was avoided by NRP optimization. Moreover, an additional study showed that image quality was relatively insensitive to these parameters.
Andenna et al. (2006) studied the comparison of dose distribution in IMRT planning using the gamma function. A software tool (DDE: Dose Distribution Evaluator), based on Low’s method was developed to evaluate the agreement between dose distribution matrices has been implemented. In particular, the proposed gamma curve, as a function of the isodose levels, gives real-time information useful for decision making about the treatment plan. The paper describes the software, and results obtained in several clinical cases (head and neck and prostate cases).

Bjorn et al. (2007) reported the spatial resolution of 2-D ionization chamber arrays for IMRT dose verification: single-detector size and sampling step width. The size of the single detector was characterized by its lateral response function, a trapezoid with 5 mm top width and 9 mm base width. Therefore, values measured with the 2-D array were regarded as sample values from the convolution product of the accelerator generated dose distribution and this lateral response function. Consequently, the dose verification e.g., by means of the gamma index, was performed by comparing the measured values of the 2-D array with the values of the convolution product of the TPS calculated dose distribution and the single-detector lateral response function. They concluded that, the spatial resolution of the 2-D array Type 10024 is appropriate for the dose verification of IMRT plans.

A survey on planar IMRT QA analysis was proposed by Benjamin et al. (2007). Results of the survey showed that a significant proportion of responding institutions (32.8%) used the single-gantry angle composite method for IMRT QA analysis instead of field by field analysis. Most institutions performed absolute dose comparison rather than relative dose comparisons, with the 3% criterion being used most often for the percentage difference analysis, and the 3mm criterion for distance to
agreement analysis. The most prevalent standard for acceptance testing was the combined 3% and 3mm criteria. The study concluded that, the survey helps in understanding how institutions perform IMRT QA analysis today. This understanding helps to move institutions toward more standardized acceptance testing. But before standards are defined, it would be useful to connect the conventional planar QA analyses to their resulting impact on the overall plan, using clinically relevant metrics.

Aleksandra et al. (2007) studied EPID dosimetry, it's configuration and use in pre-treatment IMRT verification. The purpose of this study was to calibrate the EPID and TPS and to evaluate the usefulness of that method for dose verification in IMRT technique. The first step was calibration of the aSi EPID mounted on three linear accelerators (Clinac23EXS, Varian). Afterwards, configuration of the calculation algorithm in TPS was carried out. Then dosimetric characteristics of the EPID were investigated. The EPID response depending on the beam mode, treatment time and static square field size was measured. The same measurements were repeated twice for three accelerators and analyzed. Additionally, three IMRT plans were treated for the pre-treatment dose evaluation. The calculated dose matrix was compared with the delivered one. The similarity of the calculated and measured fluency maps was evaluated by means of gamma index and score factor in Eclipse. The linearity of the EPID signal was proven. For both beam modes EPID response was proportional to treatment time and field size, within the considered field size range. The gamma evaluation indicated good correlation between predicted and acquired EPID image, although some differences in a high gradient area were found. They found the EPID-based pre-treatment IMRT verification method is a good quality assurance (QA) procedure. Quite frequent control of the method and periodic recalibration of the used device are required.
Branci et al. (2007) have developed an inter comparison between film dosimetry and diode matrix for IMRT quality assurance. Aim of this work was to compare the performances of absolute film dosimetry with a 2-D array matrix in QA procedures and to investigate the origin of possible discrepancies between the two methods. The results they presented show a very good agreement between the two detectors when used to assess the mean dose deviation between calculated and measured dose (in both cases 0.2%). When the matrix method adopted, MapCHECK™, response showed a slightly better agreement with computed dose distribution than film dosimetry (mean percentage of points satisfying the constraint $\gamma \leq 1.96\%$ versus 94%). Conclusion of their study was that, the diode matrix may effectively replace both film dosimetry and ionometric measurements in routine IMRT QA.

Delpon et al. (2007) analyzed the validation of intensity modulated radiation therapy patient plans with portal images. The goal of this study was to show the feasibility of step and shoot intensity- modulated radiation therapy pre-treatment quality control for patients using the electronic portal imaging device fitted on a linac (Elekta Oncology Systems, Crawley, UK) instead of radiographic films. They found that the EPID based IMRT QA is feasible and time consuming compared to film based QA.

Parminder et al. (2007) published a paper titled “an analysis of tolerance levels in IMRT quality assurance procedures”. The purpose of their work was to examine the relationships between two different types of IMRT QA processes in order to define, or refine, appropriate tolerances values. They examined the discrepancies between the treatment planning system TPS and results from a commercial independent monitor unit (MU) calculation program; TPS and results from a commercial diode-array
measurement system; and the independent MU calculation and the diode array measurements. Statistical tests were performed to assess significance in the IMRT QA results for different disease site and machine models. There was no evidence that the average total dose discrepancy in the monitor unit calculation depends on the disease site. Second, the discrepancies in the two IMRT QA methods were independent: there was no evidence that a better or worse monitor unit validation result is related to a better or worse diode-array measurement result. Third, there was marginal benefit in repeating the independent MU calculation with a more suitable dose point, if the initial IMRT QA failed a certain tolerance. Based on findings, the authors concluded at some acceptable tolerances based on disease site and IMRT QA method.

Rebecca et al. (2008) studied about the action levels for EPID based QA for IMRT. In this work, they evaluated three scalar parameters of agreement for 152 treatment plans (1152 treatment fields): maximum gamma ($\gamma_{\text{max}}$), average gamma ($\gamma_{\text{avg}}$), and percentage of the field area with a gamma value greater than 1.0 ($\gamma_{\%} > 1$). These data were used to set clinical action levels based on the institutional mean and standard deviations. They found that agreement between measured dose and portal dose predicted was improved by recalculating the fields at lower dose rates. They conclude that action levels are a useful tool for standardizing the evaluation of EPID based IMRT QA.

Ling et al. (2008) published a paper about the commissioning and quality assurance of rapid arc radiotherapy delivery system. Their aim was to develop rapid arc system commissioning and quality assurance (QA) procedures. First, the accuracy of DMLC position during gantry rotation was examined. Second, the ability to vary and control the dose rate and gantry speed was evaluated. Third, the combined use of variable DMLC
speed and dose rate was studied. They compared the patterns obtained with stationary gantry and in rapid arc mode, and showed that the effect of gantry rotation on leaf accuracy was minimal (< or =0.2 mm). They combined different dose-rates (111-600 MU/min), gantry speeds (5.5-4.3 degrees /s), and gantry range (Delta theta = 90-12.9 degrees) to give the same dose to seven parts of a film. When normalized to a corresponding open field (to account for flatness and symmetry), the dose of the seven portions showed good agreement, with a mean deviation of 0.7%. In assessing DMLC speed (0.46, 0.92, 1.84, and 2.76 cm/s) during rapid arc, the analysis of designed radiation pattern indicated good agreement, with a mean deviation of 0.4%.

American association of Physicists in Medicine (AAPM) TG-119 report titled IMRT commissioning: multiple institutions planning and dosimetry comparisons, was published by Ezzell et al. (2009). They produced quantitative confidence limits as baseline expectation values for IMRT commissioning. A set of test cases was developed to assess the overall accuracy of planning and delivery of IMRT treatment. Each test uses contours of targets and avoidance structures drawn with in rectangular phantom. These tests were planned, delivered, measured, and analyzed by nine facilities using a variety of IMRT planning and delivery systems. Each facility had passed the radiological physics center credentialing tests for IMRT. The agreement between the planned and measured doses was determined using ion chamber dosimetry in high and low dose regions, film dosimetry on coronal planes in the phantom with all fields delivered, and planar dosimetry for each field measured perpendicular to the central axis. The planar dose distributions were assessed using gamma criteria of 3%/3 mm. The mean values and standard deviations were used to develop confidence limits for the test results using the concept confidence limit=mean+1.96.
Jin et al. (2011) published a paper titled statistical analysis of IMRT dosimetry quality assurance measurements for local delivery guideline. The purpose was to establish institutional guideline for IMRT delivery through the statistical evaluation of dosimetry quality assurance measurements and derive local confidence limits. They analyzed the QA results of 206 patients with head and neck cancer, prostate cancer, liver cancer and brain tumors treated using LINAC based IMRT technique. The mean value and standard deviations were used to develop the local confidence and tolerance limits. The mean values and standard deviations on ion-chamber dosimetry differences between calculated and measured doses were -1.6+/−1.2% for H and N cancer, -0.4+/−1.2% for prostate and abdominal cancer, and -0.6+/−1.5% for brain tumor. Most of the measured doses (92.2%) agreed with the calculated dose within a tolerance limit of +/-3% recommended in the literature. The percentage of points passed the gamma criteria, averaged over all treatment sites was 97.3+/−3.7%. The confidence limit obtained was comparable to the AAPM task group (TG) - 119 and ESTRO guidelines.

Availability of new detectors with improved characteristics, better treatment calculation algorithms, modern treatment delivery machines and modes of delivery, made possible to improve on the conventional QA standards. New developments in the detectors such as aSi1000 based portal dosimetry, 2-D array detectors, 3-D dosimetric methods etc. made the patient specific QA now easy and thus reduces the workload. It has also made possible to adopt a flexible, user-defined QA pass fail criteria, although clear guidelines on their selection and their implications are not addressed satisfactorily.
Literature review indicating that the development of portal dosimetry, 2-D arrays and 3-D dosimetric methods for IMRT verification is currently a dynamic field of research. A robust IMRT QA program will require devices with high resolution that are easy to use. The QA protocols and acceptance criteria need to be optimized by considering all influencing factors and through statistical analysis of QA results.

In summary, there is potential to optimize and “modernize” IMRT verification procedures by using electronic detector systems like portal dosimetry, 2-D arrays and DVH based 3-D dosimetric methods.