Dosimetric Comparison Between Three Dimensional Conformal Radiation Therapy (3D-CRT) and Dynamic RapidArc Therapy for Different Types of Malignant Tumors

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Introduction & Literature Review

1.1. Management of the Patient with Cancer

The optimal care of patients with malignant tumors is a multidisciplinary effort that combines the classic modalities, surgery, radiation therapy, and chemotherapy. The role of the radiation oncologist is to assess all conditions relative to the patient and tumor, systematically review the need for diagnostic and staging procedures, and in consultation with other oncologists, determine the best therapeutic strategy. Radiation oncology is the clinical and scientific discipline devoted to management of patients with cancer (and other diseases) with ionizing radiation (alone or combined with other modalities), investigation of the biologic and physical basis of radiation therapy, and training of professionals in the field. The aim of radiation therapy is to deliver a precisely measured dose of irradiation to a defined tumor volume with minimal damage to surrounding healthy tissue. This results in eradication of tumor, high quality of life, and prolongation of survival at competitive cost, and allows for effective palliation or prevention of symptoms of cancer, including pain, restoring luminal patency, skeletal integrity, and organ function, with minimal morbidity [1,2].
1.2. Process of Radiation Therapy

The goal of therapy should be defined at the onset of therapeutic intervention:

- **Curative**: There is a probability of long-term survival after adequate therapy; some side effects of therapy, although undesirable, may be acceptable.

- **Palliative**: There is no hope of survival for extended periods. Symptoms producing discomfort or an impending condition that may impair comfort or self-sufficiency require treatment. No major iatrogenic conditions should be seen. Relatively high doses of irradiation (sometimes 75% to 80% of curative dose) are required to control the tumor for the survival period of the patient [3].

1.3. Basis for Prescription of Irradiation

- Evaluation of tumor extent (staging), including diagnostic studies.
- Knowledge of pathologic characteristics of the disease.
- Definition of goal of therapy (cure or palliation).
- Selection of appropriate treatment modalities (irradiation alone or combined with surgery, chemotherapy, or both).
- Determination of optimal dose of irradiation and volume to be treated, according to anatomic location, histologic type, stage, potential regional nodal involvement (and other tumor characteristics), and normal structures in the region.
- Evaluation of patient's general condition, plus periodic assessment of tolerance to treatment, tumor response, and status of normal tissues treated.
• Radiation oncologist must work closely with physicist, treatment planning, and dosimetry staffs to ensure greatest accuracy, practicality, and cost benefit in design of treatment plans.
• Ultimate responsibility for treatment decisions, technical execution of therapy, and consequences of therapy always rests with the radiation oncologist [1,4].

1.4. Radiation Treatment Planning

Different irradiation doses are required for given probabilities of tumor control, depending on tumor type and the initial number of clonogenic cells present. Varying radiation doses can be delivered to specific portions of the tumor (periphery versus central portion) or to the tumor bed in cases in which all gross tumor has been surgically removed.
• International Commission on Radiation Units and Measurements Reports Nos. 50 and 62 define the following treatment planning volumes [5,6]:
  • Gross tumor volume (GTV): All known gross disease, including abnormally enlarged regional lymph nodes. To determine GTV, appropriate computed tomography (CT) window and level settings that give the maximum dimension of what is considered potential gross disease must be used.
  • Clinical target volume (CTV): Encompasses GTV plus regions considered to harbor potential microscopic disease.
  • Planning target volume (PTV): Provides margin around CTV to allow for internal target motion, other anatomic motion during treatment (e.g., respiration), and variations in treatment setup. Does not account for treatment machine beam characteristics [7].
• Treatment portals must adequately cover all treatment volumes plus a margin to account for beam physical characteristics, such as penumbra.
• Simulation is used to accurately identify target volumes and sensitive structures, and to document configuration of portals and target volume to be irradiated.
• Treatment aids (e.g., shielding blocks, molds, masks, immobilization devices, compensators) are extremely important in treatment planning and delivery of optimal dose distribution. Repositioning and immobilization devices are critical because the only effective irradiation is that which strikes the clonogenic tumor cells [8].
• Simpler treatment techniques that yield an acceptable dose distribution are preferred over more costly and complex ones, which may have a greater margin of error in day-to-day treatment.
• Accuracy periodically is assessed with portal (localization) films or on-line (electronic portal) imaging verification devices. Portal localization errors may be systematic or may occur at random [7].

1.5. Three-Dimensional Treatment Planning
• CT simulation allows more accurate definition of target volume and anatomy of critical normal structures, three-dimensional (3-D) treatment planning to optimize dose distribution, and radiographic verification of volume treated [9].
• Advances in computer technology have augmented accurate and timely computation, display of 3-D radiation dose distributions, and dose-volume histograms that yield relevant information for evaluation of tumor extent, definition of target volume, delineation of normal tissues, virtual simulation of therapy, generation of digitally reconstructed radiographs, design of treatment portals and aids, calculation of 3-D dose distributions and dose optimization, and critical evaluation of the treatment plan [10].

• Dose-volume histograms are useful in assessing several treatment plan dose distributions and provide a complete summary of the entire 3-D dose matrix, showing the amount of target volume or critical structure receiving more than the specified dose. They do not provide spatial dose information and cannot replace other methods of dose display [11].

• 3-D treatment planning systems play an important role in treatment verification. Digitally reconstructed radiographs based on sequential CT slice data generate a simulation film that can be used in portal localization and for comparison with the treatment portal film for verifying treatment geometry [12].

• Increased sophistication in treatment planning requires parallel precision in patient repositioning and immobilization, as well as in portal verification techniques. Several real-time, on-line verification systems allow monitoring of the position of the area to be treated during radiation exposure.

• Computer-aided integration of data generated by 3-D radiation treatment planning with parameters used on the treatment machine, including gantry and couch position, may decrease localization errors and enhance the precision and efficiency of irradiation [13].
1.6. Intensity-Modulated Radiation Therapy

- Intensity-modulated radiation therapy (IMRT), a new approach to 3-D treatment planning and conformal therapy, optimizes delivery of irradiation to irregularly shaped volumes through complex forward or inverse treatment planning and dynamic delivery of irradiation that results in modulated fluence of multiple photon beam profiles.
- Inverse planning starts with an ideal dose distribution and finds, through trial and error or multiple iterations (simulated annealing), the beam characteristics (fluence profiles). It then produces the best approximation to the ideal dose defined in a 3-D array of dose voxels organized in a stack of two-dimensional arrays [12].
- Other approaches to achieve IMRT include the following:
  1. The step-and-shoot method, with a linear accelerator and multileaf collimation (MLC), uses a variety of portals at various angles; the MLC determines photon modulated fluency and portal shape.
  2. Dynamic computer-controlled IMRT is delivered when the configuration of the portals with the MLC changes at the same time that the gantry or accelerator changes positions around the patient.
  3. In helical tomotherapy, a photon fan beam continually rotates around the patient as the couch transports the patient longitudinally through a ring gantry.
  4. The robotic arm IMRT system (Cyberknife) consists of a miniaturized 6 MV photon linear accelerator mounted on a highly mobile arm and a set of ceiling-mounted x-ray cameras to provide near real time information on patient position and target exposure during treatment [14].
• The majority of IMRT systems use 6 MV x-rays, but energies of 8 to 10 MV may be more desirable in some anatomic sites to decrease skin and superficial subcutaneous tissue dose [15].

1.7. Quality Assurance
• A comprehensive quality assurance (QA) program is critical to ensure the best treatment for each patient and to establish and document all operating policies and procedures.
• QA procedures in radiation therapy vary, depending on whether standard treatment or a clinical trial is carried out, and at single or multiple institutions. In multi-institutional studies, it is important to provide all participants with clear instructions and standardized parameters in dosimetry procedures, treatment techniques, and treatment [16].

1.8. From IMRT to VMAT
1.8.1. Principles of IMRT
The concept of IMRT was not applied until 1990s. This is due to the software and hardware were not available before that time [17]. IMRT is a more advance mode of conformal radiotherapy and extension of three dimensional conformal radiation therapy (3D-CRT) with use a larger number of x-ray beam compared to 3D-CRT. Therefore, large volume of healthy tissue expose to low levels of radiation [18,19]. IMRT are able to conform the high and low doses to the target and healthy tissue respectively, by creating unununiform radiation beam intensities across the irradiation field. This can be done in two ways: step and shoot (static technique) or sliding window (dynamic technique) [14,19,20].
Intensity modulated arc therapy (IMAT) is the next step in IMRT radiation delivery whereby the gantry rotates around the patient and radiation dose is delivered continuously in an arc [14].

It is possible to summarize the advantages of IMRT in good sparing to critical structures and fairly quick planning. Whereas the disadvantages, complex QA and longer treatment time.

1.8.2. VMAT

Volumetric modulated arc therapy (VMAT) is a novel from of IMRT allows the radiation delivered to the patient in a single 360° of gantry rotation accurately and efficiently with varying in velocities and positions of the MLC, dose rate and gantry speed. This lead to VMAT is an intensity modulated dose distribution [21]. RapidArc (Varain medical system) is form of Volumetric Modulated Arc Therapy [22]. RapidArc (RA) intended to protect healthy tissue more than other technique and improve target coverage distribution, treatment time and attainment accurate dosimetric delivery to have the ideal dose distribution. VMAT has many different advantages over conventional modality 3D-CRT [20]. The fundamental feature is treatment time. VMAT treatment time was 1.3 minutes, IMRT treatment time was 8 minutes and 3D-CRT was 3 minutes [23,24]. Other studies have proved similar decline in treatment time between VMAT and 3D-CRT. Depending on decreased treatment time in the machine, patient comfort, compliance and patient throughput increased. The main disadvantages of VMAT is the increase optimization time compared to 3D-CRT.
From previous study comparing dual arc VMAT to 3D-CRT for other treatment site, VMAT attain superior normal tissue protection as compared to 3D-CRT, with similar dose delivering to the target volume for prostate cancer [25]. VMAT achieve superior dose distribution and conformity indices when compared to 3D-CRT for bladder cancer. These studies proved that VMAT is able to treating different type of malignant tumor, the degree of benefit appears to depend on the treatment site [26].
الملخص بالعربي

الهدف من الدراسة
مقارنة قياس الجرعة بين العلاج الإشعاعي الثلاثي الأبعاد والعلاج الإشعاعي باستخدام الأقواس لأنواع مختلفة من الأورام الخبيثة.

الأجهزة المستخدمة والطريقة
تم تصوير المرضى بجهاز الأشعة المقطعية ثم عمل الخطة العلاجية حتى تتم معالجتهم في جهاز المعجل الخطي. في هذه الدراسة ثلاثون حالة تم تخطيطها عن طريق تقنية العلاج الإشعاعي بالأقواس قمنا بإعادة التخطيط العلاجي لها باستخدام العلاج الإشعاعي الثلاثي الأبعاد وجمع بيانات من الرسم البياني لحجم الورم وجمع بيانات من الرسم البياني لحجم الورم وجمع بيانات من الرسم البياني لحجم الورم وجمع بيانات من الرسم البياني لحجم الورم. هذه البيانات استخدمناها في معادلات وحصمنا منها على قيم كانت أساس المقارنة في هذه الدراسة.

النتائج
حصلنا على نتائج مقبولة في كلا التقنيتين لكننا وجدنا أن العلاج الإشعاعي باستخدام الأقواس أظهر نتائج أفضل سواء في تغطية حجم الورم و في حماية الأنسجة الحساسة المجاورة.

الخلاصة
هذه الدراسة وضعت أن العلاج الإشعاعي باستخدام الأقواس أعطى نتائج أفضل من العلاج الإشعاعي الثلاثي الأبعاد، حيث أن الوقت المستغرق في جلسة العلاج كذلك كان أقل وهذا أفضل لراحة المريض.
ABSTRACT

Purpose
The aim of this thesis is to make a dosimetric comparison between two techniques that are currently used in radiotherapy, Three Dimensional Conformal Radiation Therapy (3D-CRT) and RapidArc (RA), which is a kind of Volumetric Modulated Arc Therapy (VMAT) in terms of dose calculation, conformity, homogeneity and dose coverage for selected sites of cancer treatment by:

1. **Create treatment plans for RapidArc and 3D-CRT**
All selected patients were planned and organs at risks (OARs) were contoured using RapidArc and Three Dimensional Conformal Radiation Therapy planning techniques with Eclips (Varian 10.0, Varian Medical System) treatment planning software.

2. **Metric evaluation of treatment plan**
Dosimetric plan evaluation metrics were applied to the plans created by both planning modalities. Dosimetric metrics included: mean, maximum and minimum dose to the planning target volume (PTV); dose to 95% of the planning target volume (PTV); homogeneity index (HI) and conformity index (CI) for the PTV; mean and maximum dose to organs at risks (OARs) and target coverage index (TCI).
Materials and Methods
RapidArc plans of 30 patients were identified and re-planned for (3D-CRT). All plans were evaluated on parameters including conformity index (CI), dose homogeneity index (HI) and target coverage index (TCI) of planning target volume (PTV), dose received by organs at risk (OARs) and data derived from dose volume histograms (DVHs).

Results
Treatment cancer using RapidArc, accurate and reduce the time during a session of radiotherapy more than 3D-CRT. Both modalities produced clinically acceptable plans. However, dose volume histogram statistic, CI, HI and TCI were analyzed to compare treatment plans. RapidArc showed significantly better PTV coverage, conformity, and homogeneity than 3D-CRT. Generally, RapidArc provided superior sparing of OARs and provided inferior sparing of OARs in breast site. This study indicates that RapidArc should be selected due to the plan quality, delivery efficiency and superior sparing of OARs. However, RapidArc is not superior to 3D-CRT for breast cancer.

Conclusion
RapidArc achieved better CI, HI and TCI of PTV and offered a greater degree of OAR sparing. RapidArc also improved the treatment efficiency due to the smaller number of monitor units (MUs) required and lowered the treatment time.
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