Quantification of Radiation Therapy Plan Complexity

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ABSTRACT

Some degree of complexity in radiation therapy planning is required to deliver sufficient dose to cancerous cells and minimal dose to healthy cells elsewhere in the body. However, disagreement between the planned dose and delivered dose increases as a plan gets more complicated. The goal of this project was to develop metrics to quantify radiation therapy plan complexity. A computer application was created to score overall plan complexity on a 5-level scale, and indicate which attributes of the plan contributed most strongly to its score. When the complexity scores of 318 treatment plans were compared to quality assurance tests conducted on the ArcCHECK detector, the application was found to predict a plan's performance with nearly 80% accuracy. The application can be used to accurately predict treatment plan complexity before conducting quality assurance tests.

INTRODUCTION

External Beam Radiation

A linear accelerator (LINAC) is a device that can produce high energy x-ray beams. X-ray beams can be contoured to the shape of a treatment site using a multi-leaf collimator (MLC). The MLC contains two banks of independently moving tungsten leaves. The MLC leaves are controlled by computer to create apertures of varying shape.

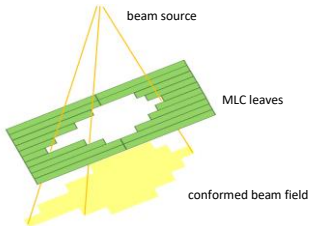


Fig.1: Diagram of MLC leaves conforming beam shape.

Volumetric modulated arc therapy (VMAT) is a dynamic method of delivering the beam. The MLC leaves move throughout irradiation to produce varying aperture shapes. As this occurs, the LINAC rotates in an arc around the patient. This approach ensures that a higher dose of radiation builds up at the treatment site. The arc is divided into a sequence of segments.

METRICS OF BEAM COMPLEXITY

To quantify plan complexity, numerous metrics were developed.

Field Size

Collimators contain two pairs of jaws that close over sections of the MLC leaves that do not contain an aperture, as seen in *Figure 2.* The field size is defined as the area exposed by the MLC jaws.

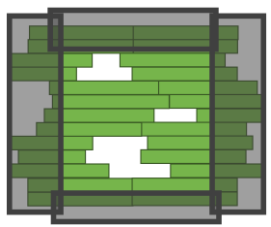


Figure 2: Three apertures formed by leaves within the MLC jaws.

Ratio of Field Size to Aperture Area

For a static rectangular opening, the edges of the jaws can align with the edges of the MLC leaves. As aperture shape and location vary, the jaws must open wider to accommodate, increasing the ratio.

Ratio of Field Size to Average Leaf Pair Opening (ALPO)

Average leaf pair opening (ALPO) refers to the mean distance between a pair of MLC leaves.

Percentage of Leaf Pair Openings Less than 10mm Wide

As stated, this metric records the percent of leaf pair openings less than 10mm.

Number of Leaf Banks Exceeding a 15cm Separation

This metric counts the number of times the most extended and most retracted leaves within a leaf bank exceed a 15cm separation.

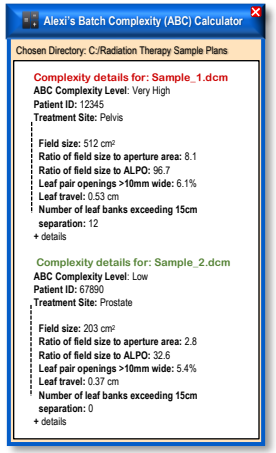
Leaf Travel

This metric calculates the mean distance travelled by an MLC leaf between consecutive segments *p* and *p-1*. The following formula is used where *x* is leaf position in cm and *l* denotes the leaf number.

$$Leaf\ Travel = \frac{1}{number\ of\ leaves}\sum_{l=1}^{m}\frac{1}{number\ of\ segments}\sum_{p=2}^{n}|x_{l,p}-x_{l,p-1}|$$

DEVELOPMENT OF A COMPUTER APPLICATION

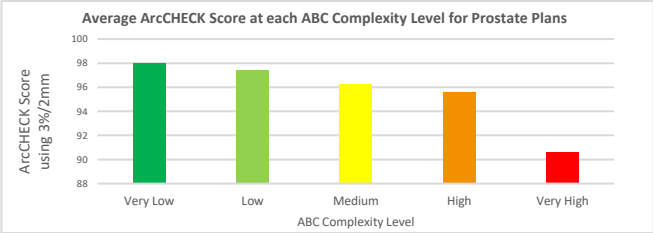
The computer application is titled "Alexi's Batch Complexity Calculator" or "ABC Calculator" for short. It calculates the metric values for each plan and gives the plan an overall complexity level. The levels are based on a 5-tier system ranging from "Very Low" complexity to "Very High" complexity. The calculator also indicates which metrics contributed most to plan complexity.



RESULTS

After a treatment plan is made, its deliverability is tested using a quality assurance device called ArcCHECK. A plan's performance during ArcCHECK QA can be compared to its complexity level given by the ABC Calculator. As a plan becomes more complex, one would expect the accuracy of its delivery to decrease. *Figure 4* compares the ABC complexity level with the average ArcCHECK score for 98 prostate plans. The ArcCHECK score is taken with a criterion of 3%/2mm using 2D mode.

Figure 4 shows that the ABC Calculator is reliable in determining treatment plan complexity.



Although the calculator is designed as a level system, pass and fail criteria must be defined to calculate accuracy. Plans scoring less than 95% during ArcCHECK QA are defined as "failing" treatment plans. Thus, labelling a failing plan as "Medium" to "High" complexity by the ABC Calculator is defined as a true positive. Using these definitions, different measures of accuracy can be calculated as summarized in the table below.

Table 1: Predictions of plan complexity by the ABC Calculator

Treatment Site	Total Plans	Accuracy	Precision	Sensitivity	Specificity
Anus	53	84%	36%	80%	85%
Pelvis (bilateral)	167	80%	35%	74%	77%
Prostate	98	70%	35%	68%	70%

DISCUSSION

It was found that leaf travel contributed most to increased plan complexity for all treatment sites. For example, pelvis plans were two times more likely to score below 95% on the ArcCHECK QA when leaf travel exceeded 0.5 cm. A large number of leaf banks exceeding a 15cm separation also strongly correlated with poor ArcCHECK QA performance. Numerous factors can affect the score a treatment plan receives during ArcCHECK QA, including variance in detector setup and changes in LINAC performance from day-to-day. Minimizing these effects may show that the ABC Calculator has better accuracy than the values reported. Although it is an estimate, the ABC Calculator is clearly reputable in determining plan complexity and may be a useful tool during the radiation therapy planning process.

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