The Effect of Modulation Complexity Score (MCS) on the IMRT Treatment Planning Delivery Accuracy

Omar N Jubbier¹, Siham S Abdullah², Haydar H Alabedi³, Nabaa M Alazawy⁴ and Mustafa J Al-Musawi⁵

¹,²Physiology and Medical Physics Department, Al-Nahrain College of Medicine, Baghdad, Iraq
³Surgery Department, College of Medicine, Baghdad University, Baghdad, Iraq
⁴Medical Physics Department, College of Science, Al-Karkh University of Science, Baghdad, Iraq
⁵Ministry of health and environment/medical city, Baghdad Center for radiotherapy and nuclear medicine, Baghdad, Iraq

E-mail: nabaaalazawy@gmail.com

Abstract. Intensity modulated radiation therapy (IMRT) is an effective treatment planning technique for various types of tumors such as head and neck (H&N) or pelvis. A complexity algorithm was invented to predict the deliverability and the accuracy for IMRT plans called the Modulation Complexity Score ranging from 0 to 1. The %GP is a metric depends on %DD/DTA to find the variation between the calculated dose from TPS and the measured dose from the phantom during the QA. This study is trying to assess the correlation between the MCS and planning verification outcome. Thirty-four patients treated with step and shoot IMRT technique for anatomical sites: H&N and pelvis. The planning process performed using Monaco 5.1 TPS then exported to Elekta Synergy linear accelerator. The phantom is used for the QA procedure is Octavius 4D-1500 with Verisoft 7.1 software analysis to evaluate the gamma passing rate for commonly used criteria 3%/3 mm at a 5% threshold. The MCS calculated using MATLAB 2019a. It results that the H&N plans are significantly more complex than the pelvis once with p-value 0.0192. The analysis shows a weak correlation between the MCS and MU for both treated sites. The complex H&N plans give a good value for %GP. Also, simpler pelvis plans obtain better global %GP results. Thus, modulation Complexity score can give a simple indication for pretreatment verifications of the IMRT plans for H&N and pelvis sites.

Keywords: MCS, %GP, Global, MU, Octavius 4D-1500

1. Introduction

Radiation therapy attempts mostly to destroy tumor cells using ionizing radiation such as a photon or electron beams while protecting underlying healthy tissue [1, 2]. Intensity-modulated radiation therapy (IMRT) treatment planning technique uses standardized intensities of the beam to increase the dose to the tumor and to reduce the probability of normal tissue injury [3]. Each IMRT beam consists of multiple segments with variable beam intensities measured by monitor units (MU). Intensity modulation is the combined fluency of the segments of an IMRT beam [4, 5].

Monitor units are the units that measure the output of a linear accelerator (Linac). Linacs are calibrated to give 1cGy at a source axis distance (SAD) distance of 100 cm, for a field size of 10 × 10
cm, and at the depth corresponding to Dmax, and this calibration dose is defined as one monitor unit (MU) [6, 7]. Step and Shoot (SS) IMRT technique is also called "stop and shoot" or "segmental", is an multileaf collimator (MLC) based IMRT delivery method with fixed beams. The gantry does not move during irradiation. The desired intensity pattern is obtained by the fractional weighted summation of the intensity pattern from all subfields [8].

Complexity has been defined as the frequency and amplitude of variations in the intensity distribution of a beam [9, 10]. Two contributions to sophistication heterogeneity in the shape and variance of the segments in their area are central to the modulation difficulty effect. The Modulation complexity score MCS is the score that measure the complexity of the plan. In MCS the range of 0 to 1 is calculated, and the smaller the value of the MCS, the greater the uncertainty, as compared to any other difficulty indices. MCS= 1 is without modulation while 0 stands for modulation and the average MCS value decreases always with increasing complexity [11].

The gamma index (γ) is one of the most commonly used metrics for the verification of complex radiotherapy deliveries such as IMRT and volumetric modulated arc radiotherapy (VMAT) [12]. It is only used to check the dose distribution that is consisted with the dose distribution obtained from the phantom detector (measured dose) during a quality assurance (QA) procedure [8]. It is mainly used two parameters as dose difference measured in % (ΔD) and distance to agreement measured in mm (DTA). As proposed by low (1998) [8,13], Mc Niven et al [9] invented the MCS algorithm for IMRT. They try to evaluate the utility of a new complexity metric, the MCS in treatment planning, and QA to evaluate the relationship of the metric with deliverability. The MCS was calculated for each beam and the overall treatment plan. They conclude that the MCS allows for a quantitative assessment of plan complexity, on a fixed scale, that can be applied to all treatment sites and can provide more information related to dose delivery than simple beam parameters. Another study for Mc Garry et al aimed to compare different methods of sensitivity in detecting differences in IMRT complexity plans after upgrades, change in planning parameters, and patient geometry. It is also correlated to complexity. They found that when the minimum field size of 1 to 4 cm was increased, the MCS metric detected a reduced complexity. Thus, they conclude that the deliverability of treatment seemed to be more related to MCS [14].

This study aimed to establish if there is a correlation between plan complexity with global gamma analysis passing rate and monitor units for IMRT plans using the Octavius 4D system.

2. Materials and Methods

This is a cross-sectional study conducted for 6 months (from November 2019 to April 2020) in the Baghdad center of radiotherapy and nuclear medicine at Baghdad medical city, Baghdad, Iraq. The study was approved by the Institute Review Board (IRB) of the College of Medicine at Al-Nahrain University as a research requirement of a Master of Science degree in medical physics. Thirty-four patients were selected and divided into two groups according to the tumor site. Twenty-two patients with head and neck and 12 patients had pelvis cancerous tumors. They prepared to Step and Shoot IMRT (SS-IMRT) treatment planning technique using MONACO 5.1 treatment planning system (TPS). Patients will be treated with an X-ray photon beam of 6 MV or 10 MV energy using ELEKTA’s Synergy linear accelerator. All treatment planning data will be applied to the OCTAVIUS 4D-1500 detector-phantom. OCTAVIUS 4D-1500 device (PTW, Freiburg, Germany) is a detector and cylindrical phantom combination. This system is composed of cylindrical OCTAVIUS 4D phantom and 2D-1500 ionization chambers array. It is fitted with an engine that can rotate with the portal of the LINAC by reading the inclinometer's output. The γ-index calculations are done by using the “verisoft 7.1” program which is the OCTAVIUS 4D-1500 software to make QA and evaluate IMRT plans. The gamma passing criterion used for evaluation of absorbed dose distribution (ΔD/DTA) is 3%/3mm at the threshold of 5%. The resulted data for MLC and radiation beams from OCTAVIUS QA recorded in MATLAB 2019a and writing programming to obtain the MCS for each beam and plan.
2.1. Statistical Analysis
The Statistical Packs of Social Sciences – version 24 (SPSS-24) was used for analyzing the data. Simple percentage, norm, standard deviation measurements were given as data. Using the student test for the difference between 2 independent measures or a Paired test for a difference of paired observations (or 2 dependent ways), the significance of the difference of different means (quantitative data) was checked. Distribution scattering curve for interaction. When the p-value is equal to or less than 0.05 the statistical significance was labeled.

3. Results
To assess the ability to predict the IMRT treatment planning delivery accuracy to the patient through linac, the MCS was used. All resulted data divided into two parts according to the treatment site. The first one is for the head and neck and the second for the pelvis

3.1. MCS and Treatment Site
Table 1 shows MCS findings for both pages. The MCS for H&N and Pelvis ventures show a significant difference when the H&N program values are smaller than the pelvic. H&N plans are therefore more complicated than pelvis plans.

| Treatment site | H & N       | Pelvis     |
|----------------|-------------|------------|
| MCS            | 0.499 ± 0.116 | 0.643 ± 0.174 |
| p-value        | 0.0192*     |            |

* T-Test statistical analysis. The Results are Significant at 0.05 level

3.2. The Modulation Complexity Score (MCS) and the Total Number of Monitor Units (MU)
The results of the modulation complexity score (MCS) with the total number of monitor units (MU) are listed in Table 2. It appears that the number of MU is higher in H&N plans than pelvis with a small difference.

| Treatment site | MCS         | Total MU            |
|----------------|-------------|---------------------|
| H & N          | 0.499 ± 0.116 | 599.130±280.782    |
| Pelvis         | 0.643 ± 0.174 | 539.891±105.149    |
| All cases      | 0.5483±0.150  | 578.819±231.994     |

To find the relationship between the values of MCS and MU, a regression plot model is used in Figure 1. The head and neck (H&N) plan MCS barely were increasing as the MU increased. So, it is a weak positive linear relationship. The R² is equal to 5x10⁻⁴, this indication of limited or no correlation between MCS and MU for H&N. While the MCS for the pelvis plans tends to decrease as monitor units (MU) increases making the IMRT plans more complex and the relationship is weakly negative linear as shown in Figure 2. The R² value is 0.0362 indicate that there is a weak correlation between MCS and MU for pelvis plans.
3.3. The MCS and Percentage of Global Gamma Passing Rate

Table 3 illustrates the results of the modulation complexity score (MCS) with the percentage of the global gamma passing rate (%GP) for both treatment sites (H&N and pelvis).

| Treatment site | MCS        | Global %GP       |
|----------------|------------|------------------|
| H & N          | 0.499 ± 0.116 | 94.969±6.874    |
| Pelvis         | 0.643 ± 0.174 | 97.491 ± 1.715  |
| All cases      | 0.5483±0.150 | 95.834±5.662    |
For showing more detail about how the MCS effects the Percentage of global Gamma Passing Rate (%GP), a Figure 3 plotted for H&N and Figure 4 for pelvis plans to explain the relationship between them as goes on. It shows that the global %GP decreases as the MCS value increase for the H&N plan with a strong negative linear relationship. The $R^2$ value is 0.0572 shows that there is a weak correlation between the global %GP and the MCS. This led to the fact the simple H&N plans reduce the quality of radiation delivery and dose distribution. The global %GP increases as the MCS increases for pelvis plans. The relationship is direct, weak, positive, linear with limited or no correlation at the $R^2$ value of 0.0077. This means that a qualified treatment delivery results could be obtained when increasing the value of MCS.

![Figure 3](image3.png)

**Figure 3.** Relationship between the MCS and the percentage of global gamma passing rate (%GP) for the H&N IMRT plans.

![Figure 4](image4.png)

**Figure 4.** Relationship between the MCS and the percentage of global gamma passing rate (%GP) for the pelvis IMRT plans.
4. Discussion
The concept of the MCS deals with the ability to deliver the plan basing on changes in leaf positions and aperture areas leaf positions and aperture areas. The complexity of the plan ranged from 1 for a simple plan to zero for a very complex plan [11], [15-17]. Generally, the high complexity cases occur when we increase the demands on MLCs thus, increase the probability of the diametric failure of the plan during the QA. The plan of low or no complexity is considered as a deliverable for the patient. The more complex of the beam means the measured dose from the detector phantom is different or shifted from the calculated ones in TPS [18, 19].

4.1. MCS and Treatment Site
The significant results give a difference between the MCS of H&N and pelvis plans. The H&N plans are more complex than pelvis because H&N uses a small field size and a precise PTV unlike the pelvis cases used a large field size and a bigger irradiated volume. The results of this study agreed with park et al 2018 [20] when they found that the mean value of pelvis (primary prostate) plans (0.81 ± 0.14) is a higher than the head and neck ones (0.30 ± 0.05) when they use a Trilogy linear accelerator from Varian. Elin Svensson [21] analyzes the MCS for 204 H&N VS. 31 prostate plans and found out that the prostate is a little bit higher than H&N (0.272 ± 0.074 and 0.21 ± 0.07 respectively).

4.2. The MCS and MU
The results appear that the MU is higher in H&N plans than pelvis with limited or no correlation between MCS and MU for H&N and pelvis plans. This may be because of that the complex plan requires a larger number of monitor units (MU) due to an increase in amplitude and number of valleys in intensity patterns [18], [21]. McNiven et al. [9] found that there was no correlation between MCS and the number of MU and low for pelvis cases which is in agreement with our results. So, to increase the MCS value we need to decrease the MU for pelvis plans to assess a good and homogenous dose distribution.

4.3. The MCS and Percentage of Global Gamma Passing Rate
The pelvis cases show a higher value of percentage of global gamma passing rate (global %GP) than the H&N. The increasing of MCS value decreases the %GP for the H&N plans, so it needs a complex plan for passing the QA tests. While it is a direct relationship with pelvis plans. McNiven et al [9] studied the MCS correlation with %GP as same as of our criteria 3%/3 mm and found out that the H&N, often identified as high in complexity, has low scores. For rectum plans (pelvis), which are much simpler in terms of complexity consisting of a large aperture, delivering most of the dose with a few smaller. This indicated that increasing in the uncertainty of measurements decreases the %GP and lowers the correlation between MCS and %GP which is probably due to the high dose gradient of the field edge with small field size and low modulation [22], [23] (10). Park et al 2018[20] test the correlation between the MCS and the global %GP for H&N and prostate with two types of linacs (True Beam STx and Trilogy) from Varian, each on with two types of phantom software (MapCHECK2 and Arc CHECK). They found a high correlation between MCS and global %GP using 3%/3 mm. These results agree with our findings when they declared that H&N plans had the lowest gamma passing rate with True Beam STx with both MapCHECK2 and Arc CHECK. While with Trilogy, the prostate boost plan shows the lowest %GP with both MapCHECK2 and Arc CHECK (Assessment of the modulation degrees of intensity-modulated radiation therapy plans).

5. Conclusion
This study shows that the modulation complexity score (MCS) is a good metric and predictor for the complexity of the intensity-modulated radiotherapy (IMRT) treatment planning technique and detecting the errors related to the dose delivery. It is incorporate to many parameters that affect the plan quality and deliverability into a score. It can be used in quality assurance QA to planning tests for
the pre-treatment of the head and neck and pelvis cases. The correlation between the MCS with the number of monitor units (MUs) and the global %GP rate is important as it is considered as a simple beam parameter to assess complexity and gives an indication for the plan's deliverability.

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References
[1] Chetty I J, Curran B, Cygler J E, DeMarco J J, Ezzell G, Faddegon B A, Kawrakow I, Keall P J, Liu H, Ma C M C, Rogers D W O, Seuntjens J, Sheikh-Bagheri D and Siebers J V 2007 Medical Physics
[2] Chan E M 2016 MSc Thesis
[3] Sandilos P, Angelopoulos A, Baras P, Dardoufas K, Karaiskos P, Kipouros P, Kosicki M, Rosiak J M, Sakelliou L, Seuntjens J and Vlahos L 2004 International Journal of Radiation Oncology Biology Physics vol. 59 no. 5 pp. 1540–1547
[4] Chen S, Kong V, Craig T, Chung P and T Rosewall 2018 Journal of Medical Imaging and Radiation Sciences vol. 49 no. 4 pp. 420–427
[5] Xia P, A G, S C, V GMM and S J 2018 Springer Publishing Company
[6] Beyzadeoglu M, Ozyigit G, Ebruli C 2010 Basic radiation oncology
[7] Khan F M, Gibbons J P and Sperduto P W 2016 Khan’s physics of radiation therapy, 4th ed., vol. 45 no. 2 Lippincott Williams & Wilkins
[8] Ezzell G A, Galvin J M, Low D, Palta J R, Rosen I, Sharpe M B, Xia P, Xiao Y, Xing L and Cedric X Y 2003 Medical physics vol. 30 no. 8 pp. 2089–2115
[9] McNiven A L, Sharpe M B and Purdie T G 2010 Medical Physics vol. 37 no. 2 pp. 505–515
[10] Mohan R, Arnfield M, Tong S, Wu Q and Siebers J 2000 Medical physics vol. 27 no. 6 pp. 1226–1237
[11] Masi L, Doro R, Favuzza V, Cipressi S and Livi L 2013 Medical physics vol. 40 no. 7 p. 71718
[12] Hussien M, Clark C H, Nisbet A 2017 Physica Medica vol. 36 pp. 1–11
[13] Hussien M 2015 PhD Thesis
[14] McGarry C K, Chinneck C D, O’Toole M M, O’Sullivan J M, Prise K M and Hounsell A R 2011 Medical Physics vol. 38 no. 4 pp. 2027–2034
[15] Agnew C E, Irvine D M and McGarry C K 2014 Journal of Applied Clinical Medical Physics vol. 15 no. 6 pp. 204–216
[16] Rajasekaran D, Jeevanandam P, Sukumar P, Ranganathan A and Johnjothi S 2014 vol. 20 no. 1. Wielkopolskie Centrum Onkologii
[17] Xu Z, Wang I Z, Kumaraswamy L K and Podgorsak M B 2016 Radiology and Oncology
[18] Mohan R, Arnfield M, Tong S, Wu Q and Siebers J 2000 Medical Physics
[19] Vu H T 2008 Health Physics
[20] Park S Y, Kim J I, Chun M, Ahn H and Park J M 2018 Radiation Oncology vol. 13 no. 1 pp. 1–8
[21] Svensson E, Bäck A and Hauer A K 2011 no. June
[22] Jin H, Keeling V P, Johnson D A and Ahmad S 2014 Journal of Applied Clinical Medical Physics
[23] Keeling V P, Ahmad S and Jin H 2013 Journal of Applied Clinical Medical Physics