Med. J. Cairo Univ., Vol. 90, No. 8, December: 2731-2737, 2022
www.medicaljournalofcairouniversity.net

Clinical Validation of the COMPASS System for Two Matched Elekta Versa HD Linear Accelerators in Neuroblastoma

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Abstract

Background: Quality Assurance (QA) in radiotherapy is an important studying issue in order to test the performance of medical Linac machine and verify the delivering accuracy of patient treatment plan.

Aim of Study: Clinical validation of using compass system in VMAT QA for abdomen site pediatric patients.

Material and Methods: Ten VMAT neuroblastoma plans were created using Monaco TPS.

CT images, RT Structures, RT Plans, and RT doses for all cases were exported to COMPASS system through DICOM network then COMPASS computations were performed using collapsed cone algorism for all patients with a calculation grid resolution of 2mm from the imported DICOM RT plans. Finally, a comparison was performed based on dose difference and all VMAT plans were measured at two matched linear accelerators.

Results: The mean dose of PTV and D99% for the ten cases were measured.

The comparison between the Monaco dose calculation, compass computed dose and compass reconstructed dose showed a good agreement within maximum deviation 4% for the PTVs and critical organs in point doses and volume doses.

Conclusions: Compass system is a reliable effective system to perform 3D dose verification of VMAT plans for neuroblastoma patients. So Compass QA system can be used as an effective tool before VMAT treatment. The variations of dose between TPS and Compass were due to mode of calculation (Compass algorism uses dose to water for calculation while Monte-Carlo algorism uses dose to medium).

Key Words: *QA – VMAT – TPS – COMPASS – PTV.*

Introduction

THE main purpose of radiation therapy is to deliver a therapeutic dose of radiation to kill tumor cells while limiting the side effects caused by delivering the dose to surrounding tissues and vital organs or organs at risk (OAR) **[1,2,3]**. So, high precision treatment planning is required to deliver prescribed dose to tumor target. There are various techniques to deliver complexity of these treatment planning techniques such as three dimensional conformal radiotherapy (3DCRT) or intensity modulated radiation therapy (IMRT) and volumetric modulated radiation therapy (VMAT). The complexity of VMAT technique required pre-patient specific QA tool. That's why patient specific QA measurements are recommended by both American Association of Physicists in Medicine (AAPM) Task Group (TG) 119 and TG 218 to make sure that the treatments are provided as planned **[4,5]**. Both VMAT and IMRT are frequent treatment modalities with highly conformal dose distributions **[6-8]**.

Compass system is an effective device for 3D patient verification **[9-13]**.

The aim of the present work is to validate Compass QA device as a 3D pretreatment QA system using Monaco TPS at two matched linear accelerator.

Material and Methods

Material:

Linear accelerators:

This work was carried out at children cancer hospital (CCH) which has two matched linear accelerators: Elekta Versa HD (Elekta, Stockholm, Sweden). Linear accelerator includes agility head with 160-leaf (5mm wide) at isocentre with dynamic leaf guide, multileaf collimators (MLCs) with a leaf speed of 3.5cm/s and flattening filter-free (FFF) photon beam delivery. Beams include all of the available photon energies (6, 10, 6 FFF

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and 10 FFF MV), as well as the six electron energies commissioned for clinical use (4, 6, 8, 10, 12 and 15 MeV) and the maximum field size is 40 x 40cm^2.

Treatment planning system:

Planning was performed at Monaco treatment 5.11.02 (Elekta CMS, Maryland Heights, MO, USA) with Monte Carlo, Pencil beam, Collapsed Cone algorithms to deliver highly accurate 3D, IMRT, VMAT & SRS plans. Monaco allows users to quickly access important plan information including beam or structure spread sheets, prescription and IMRT constraints. It offers the XVMC Monte Carlo dose engine for electron and photon as a continuous arc calculation for a single beam rather than dose approximations that occurs with many discrete gantry angle positions (control point). All plans were calculated by Monte Carlo algorithm.

MatriXX:

MatriXX^{Evolution} is an ionization chamber based array detector from IBA consist of 1020 ion chambers with volume 0.08cm^3 that covers an active area of 24.4 x 24.4cm^2. The distance between ion chambers is 7.619mm **[14]**.

COMPASS:

COMPASS is 3D dosimetry QA system (8-12), which consists of 3D anatomy-based dose verification software. It works in conjunction with MatriXX^{Evolution} (serial number 25731) (IBA Dosimetry, Schwarzenbruck, Germany) and with gantry angle sensor. The measurement was obtained with Compass software. Patient specific QA was measured (reconstructed) and computations were obtained with the IBA MatriXX^{Evolution} system. It uses Collapsed Cone algorithms in calculation of dose and measures actual treatment beam angles using the gantry mounted MatriXX detector (SSD =76.2cm) array for patient QA.

Methods:

Calibration of MatriXX:

The project at the Children's Cancer Hospital (CCH) 57357 at 2019.

The absolute calibration (cGy/MU) was measured by using field size geometry calibration step with an open field size of 10 x 10cm^2 for 6MV with 200 MU delivered

Validation of MatriXX:

To prepare the installation of COMPASS system, we need some information and data for the COMPASS beam modeling. For beam model commissioning, depth dose curves on the central axis, profiles and output factor were needed. All the measurements should be provided at the same SSD and all the data should be provided for different field size 2cm x 2cm, 3cm x 3cm, 5cm x 5cm, 10cm x 10cm, 15cm x 15cm, 20cm x 20cm, 30cm x 30cm and 40cm x 40cm.

All commissioning data had been sent to IBA company to send own machine and other linac parameters that had been measured to improve the quality of initial beam model.

Flattering filter position (distance from the bottom of the flattering filter to the source in cm. X Jaws position (distance from the bottom of the flattering filter to the source in cm), X Jaws transmission, Y Jaws position (distance from the bottom of the flattering filter to the source in cm, MLC position (distance from the bottom of the flattering filter to the source in cm), Transmission of MLC Tonge, Groove [cm], Leaf Tip [cm] and Collimator calibration offset [cm] (also known as leaf gap) were measured.

Before using of Compass system, we made a CT scan of MatriXX with multicube phantom and then import the MatriXX at TPS with open field size 20cm x 20cm at SSD89 with gantry angle 0 degree for 6 MV energy where MU 238 and dose 200cGy then applied these steps at linac for calibration of MatriXX to measure the dose.

To validate the Compass for clinical use, two plans (One Head & Neck case and one Prostate case) were measured with compass system and exported to IBA Company to create a model for each machine to be used in the present work. These plans (consist of the complete of CT data, RT Plan, RT Structure Set and RT Dose Dicom files) should be complied with the DICOM standard.

For clinical validation, ten cases of neuroblastoma were studied at two matched linear accelerators Elekta versa HD to compare TPS, Compass Computed (CC) and Compass Reconstructed (CR) Doses.

Results

Abdominal Cases [Neuroblastoma (NB)]:

Ten cases of neuroblastoma were treated with VMAT technique according to the protocol used with dose range 2160-4500cGy taking into consideration tumor stage and patient age, while fractional dose is 180cGy. The results show the differences in PTV mean dose, D99 and D2 between TPS, CC and CR (Table 1).

From Table (1), it was found that the range of dose differences for CC were 0.4-2.2, 0.1-3.8 and 0.2-2% for PTV mean, PTV D99 and PTV D2, respectively. While those for CR were 0.3-3.3, 0.8-4.1 and 0.3-4.7% for PTV mean, PTVD99 and PTVD2, respectively.

The average difference CC vs. TPS were 1.28, 1.93 and 1.15 for PTV mean, PTVD99 and PTVD2, respectively. While those of CR vs. TPS were 1.65, 2.04 and 1.97 for PTV mean, PTVD99 and PTVD2, respectively.

Table (1): Differences of PTV mean dose, D99 and D2 for TPS, Compass Computed and Reconstructed Dose.

patient number	PTV mean (cGY)			PTV D99 (cGY)			PTV D2 (cGY)		
P1	Ref Tps	2218		Ref Tps	1841.8		Ref Tps	2317.7	
	Differences	Cc	37.7(1.7%)	Differences	Cc	18.1(1%)	Differences	Cc	32.8(1.4%)
		Cr	27(1.2%)		Cr	-24.5(-1.3%)		Cr	25.7(1.1%)
P2	Ref Tps	2253.8		Ref Tps	2103.8		Ref Tps	2344.5	
	Differences	Cc	16.7(0.7%)	Differences	Cc	-36.5(-1.7%)	Differences	Cc	12.4(0.5%)
		Cr	17.6(0.8%)		Cr	-42.2(-2%)		Cr	25.1(1.1%)
P3	Ref Tps	2224		Ref Tps	2109.4		Ref Tps	2287.2	
	Differences	Cc	-8.1(-0.4%)	Differences	Cc	-71(-3.4%)	Differences	Cc	5.8(0.3%)
		Cr	54.2(2.4%)		Cr	21.1(1%)		Cr	75(3.3%)
P4	Ref Tps	2206.1		Ref Tps	2049.4		Ref Tps	2274.5	
	Differences	Cc	12.7(0.6%)	Differences	Cc	-77.8(-3.8%)	Differences	Cc	23.5(1%)
		Cr	73.8(3.3%)		Cr	-35.4(-1.7%)		Cr	106.5(4.7%)
P5	Ref Tps	3727.2		Ref Tps	3418.3		Ref Tps	3879.9	
	Differences	Cc	53.9(1.4%)	Differences	Cc	-102.4(-3%)	Differences	Cc	59.3(1.5%)
		Cr	24.2(0.6%)		Cr	-14(-.4%)		Cr	35.5(0.9%)
P6	Ref Tps	4542.6		Ref Tps	4249.5		Ref Tps	4732.3	
	Differences	Cc	97.2(2.1%)	Differences	Cc	97.7(2.3%)	Differences	Cc	94.3(2%)
		Cr	62.2(1.4%)		Cr	80.3(-1.9%)		Cr	44.4(0.9%)
P7	Ref Tps	2212.1		Ref Tps	2154.6		Ref Tps	2258.3	
	Differences	Cc	15.1(0.7%)	Differences	Cc	-5.6(-0.3%)	Differences	Cc	11.6(0.5%)
		Cr	42.4(1.9%)		Cr	31.3(1.5%)		Cr	47(2.1%)
P8	Ref Tps	3695.4		Ref Tps	3057.8		Ref Tps	3886.4	
	Differences	Cc	63.8(1.7%)	Differences	Cc	-48.2(-1.6%)	Differences	Cc	66.8(1.7%)
		Cr	-76.4(-2%)		Cr	-151.7(-5%)		Cr	-72.4(-1.9%)
P9	Ref Tps	2132.5		Ref Tps	2070.7		Ref Tps	2192.9	
	Differences	Cc	38.1(1.8%)	Differences	Cc	38.7(1.9%)	Differences	Cc	17.6(.8%)
		Cr	60.7(2.8%)		Cr	76.5(3.7%)		Cr	40(1.8%)
P10	Ref Tps	3708.6		Ref Tps	3229.9		Ref Tps	3891.1	
	Differences	Cc	62.9(1.7%)	Differences	Cc	8.7(0.3%)	Differences	Cc	69.4(1.8%)
		Cr	2.5(0.1%)		Cr	-61(-1.9%)		Cr	4(0.1%)
Average Differences Cc dose %		1.28			1.93			1.15	
Average Differences Cr dose %		1.65			2.04			1.79	

All differences didn't exceed 2% except for CR PTVD99 and PTVD2 (>2.1%).

These differences indicate good agreement between TPS and dose calculated (CC) and measured (CR) with Compass system.

According to the study of Pimthong et al., [3] the percent disparity between the COMPASS measured and Eclipse TPS calculated dose was less than 3%, which is consistent with our findings.

Table (2) shows the differences in dose of different critical organs for neuroblastoma cases (Rt. Kidney mean, Lt. Kidney mean, Liver mean, Spinalcord mean and Spinal cord D1) for TPS, CC and CR.

Table (2): Differences of mean dose and D1% of different critical organs for TPS, CC and CR.

Critical organs	Average differences Cc dose%	Average differences Cr dose%
Right kidney mean (cGY)	1.2	3.8
Left kidne mean (cGY)	1.1	6.7
Live mean (cGY)	0.9	5.1
Spinal cord mean (cGY)	1	4.3
Spinal cord D1 (cGY)	1.2	3.2

From Table (2), it was observed that the average difference of CC for critical organs was 1.2, 1. 1, 0.9, 1 and 1.2 for Rt. Kidneymean, Lt. Kidney mean, Liver mean, Spinal cord mean and Spinal cord D1, respectively.

While that of CR was 3.8, 6.7, 5.1, 4.3 and 3.2 for Rt. Kidney mean, Lt. Kidney mean, Liver mean, Spinal cord mean and Spinal cord D1, respectively.

It was noticed that the mean differences between TPS and CC were less than 2% for RT kidney and Lt. Kidney due to different algorithms in dose calculation between Monaco and collapsed cone at Compass. While the mean differences dose exceed 3% for Rt. Kidney and Lt. Kidney between TPS and CR. These differences may be due to high dose gradient at which both kidneys overlapped with the target.

For Liver and Spinal Cord, the mean differences doses between TPS and CC were less than 1%. While, D1% of spinal cord exceeds 1%.

The mean dose differences and D 1 % between TPS with CR exceeded 3%. Spinal cord D1 is kept in range less than 4% that is accepted due to cord small volume. The standard deviation dose difference and D1% between TPS and CC was less than 1% for liver and spinal cord. On the other hand, the standard deviation dose difference and D 1 % between TPS and CR exceeded 6% for liver and spinal cord.

The differences in standard deviation dose and D1 were high. Because the dosage disparities at critical organs were significant, so Compass beam model should be upgraded to improve low dose to enable this modelling and provide a higher score. Compass beam model should be enhanced for dosage determination in the low dose zone and the low dose components of the energy spectrum [14].

Example of DVH of a NB case patient number 7 Fig. (1). Illustrates an example of DVH/static plot of Volume [%] Vs. Dose [% of 7747cGy] PTV for NB case.

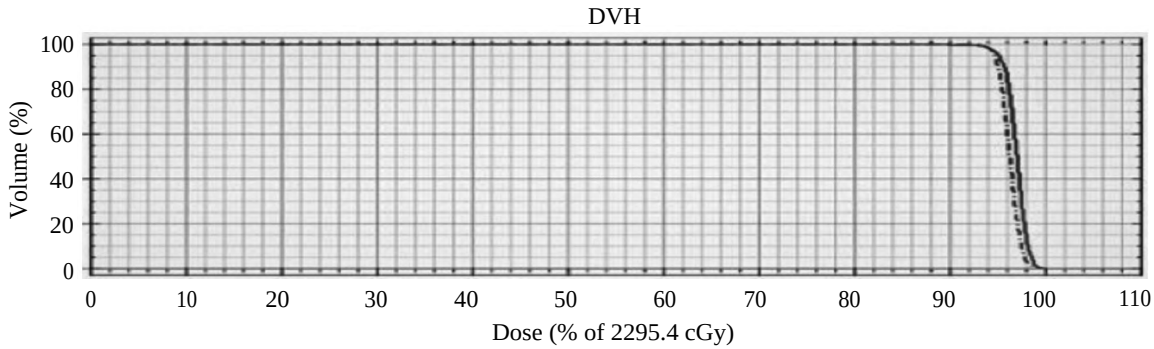

Fig. (1): Example of DVH of PTV for neuroblastoma case (dashed line refers to TPS dose and solid line refers to CC/CR).

Discussion

The DVH showed that there is no significant difference in dose between TPS dose and CC/CR. As the work of Subramani Vikraman et al., [16] showed that Compass can be used as a sensitive and meaningful quality assurance tool which is consistent with the findings of this study in small deviation dose of PTV between TPS and CC/CR. This finding is in good agreement with the finding of Vikraman et al., [15]. That show small deviation dose of PTV between TPS and CC/CR.

Fig. (3) illustrates an example of DVH plot for different critical organs for a NB case which were represented in set of different colors in Fig. (2).

	ROI
	Patient
	Kidney rt
	Kidney lt
	SPINAL CORD
	LIVER
	GTV RESIDUAL
	LUNG RT
	LUNG LT
	ctv
	ptv

Fig. (2): Set of colors represents different critical organs for a NB case number 7.

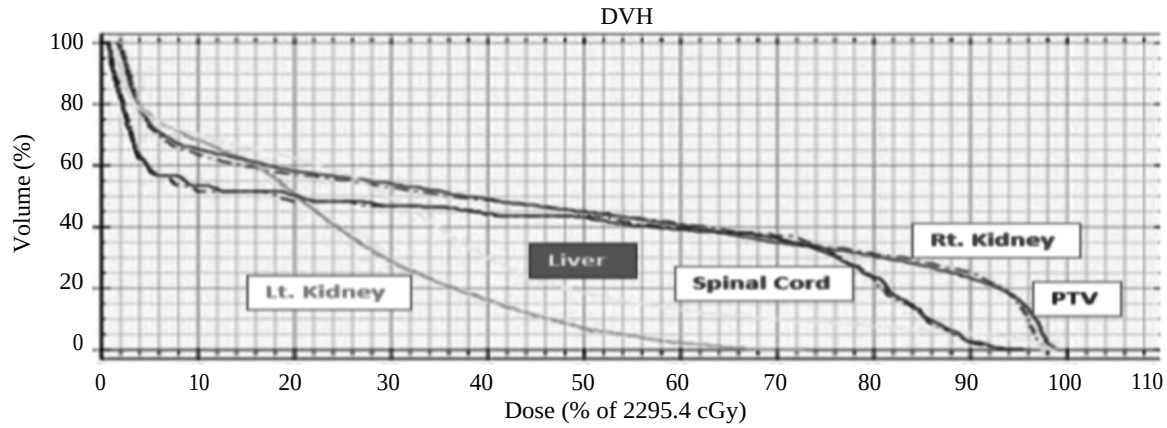

Fig. (3): Example of DVH plot of critical organs for NB case (dashed line refers to TPS dose and solid line refers to CC/CR).

The figure shows a small deviation in dose calculated at TPS and Compass system because the different in dose calculation between Monaco and collapsed cone algorithms. So, Compass system is an effective device for evaluated critical organ in plan.

Matching between two linac:

Table (3) shows the difference % in PTV mean for six cases at two linac for neuroblastoma.

Table (3): Difference of reconstructed mean dose for PTV % measured at two machine for six cases (head and neck, neuroblastoma and prostate).

Patient number	NB mean Diff%
P1	0.3
P2	0.3
P3	0.4
P4	0.6
P5	0.8
P6	0.1

The results showed that the diff % didn't exceed 1% between the two machines, so we can treat any case at two matched Linacs. This clinical experiment lead to the use of Compass as a tool for check matching procedure among many different linear accelerators that would help in clinical use in different scenarios.

Compass system is an effective tool for patient specific QA tool for VMAT plans, it give 3D dose reconstruction on patient CT. COMPASS calculate the plan by a collapsed cone algorithm dose (computed dose) to make a second check of dose calculation by the TPS. The variations of dose between TPS and Compass are due to mode of calculation, Compass algorithm uses dose to water for calculation while that of Monte-Carlo uses dose to medium **[15-18]**.

By comparing compass dosage computation with Monte Carlo-calculated dose distributions for five prostate patients, Boggula and his collagues reported that MatriXX-dose calculation showed a great agreement with Monaco while, Zamo and his collagues compared point dose from TPS and COMPASS for 10 real VMAT plans for prostate and head and neck. They found that the mean differences were below 1% for the target. On the other hand, swamy's team measured 10 head and neck (H&N) and pelvis VMAT plans using COMPASS system along with MatriXX Evolution the average dose difference between Eclipse treatment

planning system (TPS) calculated and COMPASS measured (homogenous medium) in normalization region, inner region, penumbra region and buildup region was less than ±2% which is consistent with the findings of this study **[10,14,16]**.

Conclusion:

Prior to treatment, patient-specific quality assurance (QA) should be carried out to ensure that cancer patients receiving radiation therapy employing cutting-edge methods such as IMRT and VMAT receive correct and safe care. In this research, we assessed the fundamental accuracy and calibration of reconstructed dose distributions and computed dose of the system COMPASS with a MatriXX detector. The precision and spotting ability of the COMPASS system's delivery doses were verified showing effectiveness for clinical work.

The variation in dose between the TPS and Compass system in CR and CC in different cases measured in our study is very low so, the Compass system is valid in clinical use. The result showed that there was no significant difference between reconstructed dose measured at two machines. Compass act as a tool to check the similarity between two matched linear accelerators.

Compass system is useful to use in our routine because it doesn't gave only 3D dose distribution in PTV but also give information about dose received for different critical organs.

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التحقق من تطبيق جهاز Compass للتأكد من وصول الجرعة بواسطة تقنية العلاج الاشعاعى الحجمى متغير الشدة فى حالات الأورام الارومية العصبية

مقدمة : الهدف من العلاج الاشعاعى توصيل الجرعة المطلوبة للأنسجة المصابة بالورم وتجنب الأنسجة السليمة وهذا ما يحققه التقنية الحديثة فى العلاج الاشعاعى وهى العلاج الحجمى متغير الشدة حيث أن العلاج الحجمى متغيرالشدة يوفر توزيع متجانس ومحدد من الجرعة على الورم وتحمى باقى الأعضاء من الاشعاع ونستطيع تحقيق هذا بواسطة تقنيات مختلفة مثل العلاج الشعاعى متغير الشدة بتكوين اقواس من الاشعاع بواسطة تغير زوايا موجهة الاشعاع وسرعة موجهة الاشعاع وتغير معدل الاشعاع و multi-leaf collimator (MLCs).

\الهدف : التحقق من وصول الجرعة إلى مكان الورم قبل تطبيقه على المريض.

\الطريقة : قياس الجرعة الاشعاعية فى عشر حالات باستخدام مصفوفة ثنائية الابعاد ليوضح توزيع الجرعة الاشعاعية قبل تلقى المريض العلاج الاشعاعى ومقارنتها بالخطة العلاجية على جهاز التخطيط

\النتائج : جهاز الكو مبس يعطى كفاءة عالية فى قياس الجرعات الاشعاعية بمقارنتها بالخطة العلاجية.

\الخلاصة : الكومبس له فاعليه كجهاز للتأ كد من الجرعة الاشعاعية والتحقق من خطة العلاج الاشعاعى والاختلافات البسيطة فى الجرعة الاشعاعية نتيجة لاختلاف طريقة حساب الجرعة بين جهاز تخطيط العلاج الاشعاعى والكومبس.