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RESEARCH ARTICLE

VALIDATION OF COMPASS FOR PRE-TREATMENT PATIENT-SPECIFIC QUALITY ASSURANCE

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Abstract

Aim: Purpose of study is to validate COMPASS 3D patient specific quality-assurance software with Monaco treatment planning system (TPS) for routine quality assurance.

Materials & methods: Purpose is to test the MLC modelling in COMPASS software, using Elekta Express QA package contains eight QA fields as follows (i) 10x10 (ii) 20x20 (iii) 3ABUT (iv) DMLC1 (v) HIMRT (vi) HDMLC(vii) 7SegA (viii) Four L were measured with COMPASS and compared with Monaco TPS. For clinical validation of COMPASS, VMAT plans were created for downloadable contoured structure set of AAPM TG119 cases for energy 6MV using Monaco (5.11) TPS for Versa-HD linear-accelerator and verified by COMPASS (calculated and measured).

Results: For express QA check, all beams showed gamma pass-rate above 95% except for FourL field. FourL field Monaco versus COMPASS reconstructed gamma pass-rate was 98.4% but Monaco versus COMPASS computed gamma pass rate was 93.4%. COMPASS computed and measured, TG119 test cases showed good agreement with Monaco TPS, except some higher variation in low dose region.

Conclusion: COMPASS measured (reconstructed) and computed results are in good agreement with Monaco TPS, therefore can be used for routine patient-specific quality-assurance. Special consideration has to be taken for superficially located targets.

Introduction:-

Traditional method of patient specific quality assurance for IMRT/VMAT (intensity modulated radiotherapy/ volumetric modulated arc therapy) was 2D fluence (planned versus measured) comparison using gamma index[1,2]. Gamma index method for comparing planned and measured dose distribution is a very widely used method for plan comparison but gamma index results are influenced by the method of measurement and evaluation[3,4]. In year 2010 Jon J. Kruse et al.[5] found that a fraction of pixels passing the gamma analysis was found to be a poor predictor of dosimetric accuracy. Further in year 2011 Nelms et al., Zhen et. al. [6,7] also observed that the most common acceptance criteria (3%/ 3mm) and published actions levels have insufficient, or unproven, predictive power for per-patient IMRT QA. Therefore, need of alternative three dimensional quality assurance method aroused so that planned and measured dose distribution can be compared in terms of dose volume parameters which is more

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clinically understandable (or relevant). We have procured the COMPASS (IBA Dosimetry, Schwarzenbruck, Germany) system for 3D treatment verification and patient dose analysis. COMPASS software uses collapsed cone convolution dose calculation algorithm [8,9] developed in collaboration with ray search laboratories which requires full beam data modelling like treatment planning system (TPS). COMPASS reconstruct dose form measured fluence by scaling the response from predicted fluence based on TPS calculated dose distribution[9]. Also, COMPASS can calculate dose independently therefore TPS calculation can be verified by independent secondary dose calculation software. Therefore, aim of the present study is to validate the COMPASS 3D dosimetry system, so that it can be used for day to day IMRT/VMAT patient specific quality assurance.

Materials And Methods:-

For present study all the measurements were carried out using Elekta Versa HD linear accelerator (Elekta, Stockholm, Sweden) with 6MV X-rays. Treatment planning and dose calculations were done using Monaco 5.11 (Elekta, Stockholm, Sweden) treatment planning system (TPS).

COMPASS 3D dosimetry system is a combination of two part (i) is software which can be used as secondary dose calculation tool for TPS and (ii) 2D detector array (I'matriXX with gantry angle sensor) for anatomy based 3D dose measurement [10].

Beam data requirement for COMPASS commissioning

Depth dose curve required from 2cm x 2cm to 40cm x 40cm and profile from 2cm x 2cm to 40cm x 40cm at 1.5cm, 5.0c, 10.0cm, and 20.0cm depth. MLC (multi-leaf collimator) transmission, Output and output factor information is also required for COMPASS commissioning. Recently we have commissioned the Versa HD linear accelerator (LINAC) along with Monaco treatment panning system (TPS) and collected all radiation field analyser (RFA) data. Data required for COMPASS commissioning is subset of data required in Monaco commissioning; therefore we need not to take any extra measurement for COMPASS commissioning. Data acquired for Monaco commissioning was used for COMPASS beam data modelling.

Compass workflow

COMPASS system can analyse dose distribution in terms of dose volume histogram (DVH) and TPS calculated dose can be compared. Once COMPASS beam modelling is done, patients DICOM information (RT plan, RT structures, RT dose) has to be imported in COMPASS for secondary dose calculation and measurement. COMPASS calculate dose using its beam model and for dose reconstruction COMPASS predict the detector response, the difference between measured and COMPASS predicted detector response is applied to 3D dose measurement of COMPASS. The flow diagram of COMPASS work flow is shown in Figure-1.

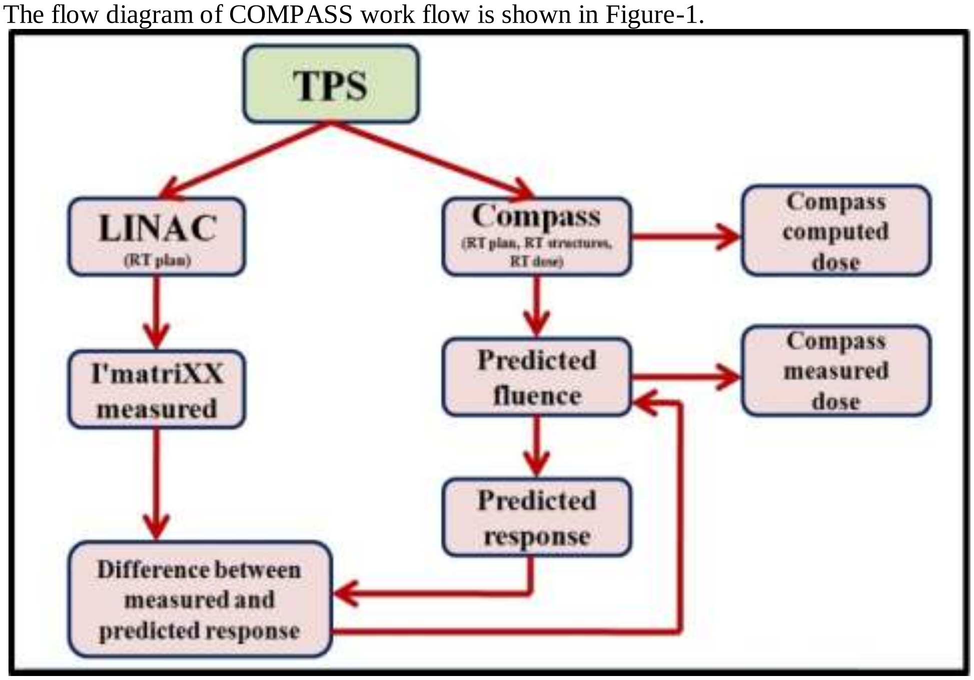

Figure1:- Showing the flow diagram of COMPASS work flow.

Compass measurement setup

COMPASS is a 3D patient specific quality assurance device. COMPASS is software which uses I'matriXX^{Evolution} detector with gantry mount and a gantry angle sensor for 3D dose measurement. Figure-2 shows the COMPASS measurement set up on Versa HD LINAC (I'matriXX detector with 2.0cm build up plates). Gantry mount assembly (I'matriXX^{Evolution} with 2.0cm build up plates) is calibrated for 100.0cm SSD. Alignment srews can be adjusted to match the detector cross wires to the LINAC cross wires [10]. After setting up the detector, I'matriXX^{Evolution} is connected to COMPASS software via Ethernet cable at console.

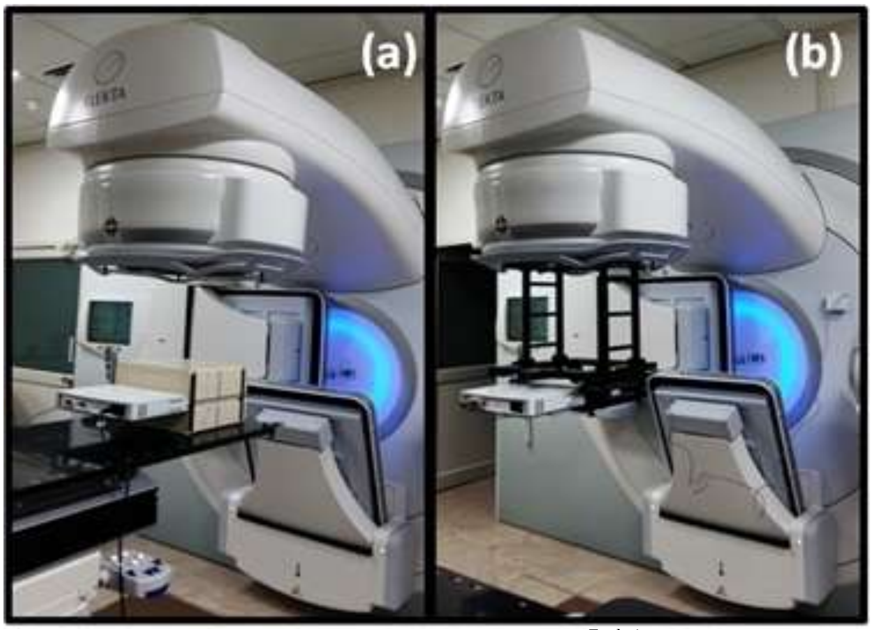

Figure2:- Measurement setup for (a) 2D planar dose using I'matriXX^{Evolution}and (b) 3D dose using COMPASS.

Validation of COMPASS using MLC Express QA beams

The delivery accuracy of IMRT/VMAT plan is based on performance of VERSA HD Agility MLC. To test the accuracy of MLC modelled parameters in Monaco TPS, the vendor provides a set of predesigned fields called as Express QA (quality assurance) package[11]. In case of any fine adjustment is required in LINAC specific MLC model parameters that can be tuned in Monaco 5.11 treatment planning system to exactly match with the exit fluence from the LINAC head. Synder et al. (2016) tested the Agility MLC modelling accuracy in Monaco TPS using Elekta provided Exp-QA beam package, and concluded that Exp-QA beams are very useful in checking the leaf tip and MLC transmission modelling [12]. Similarly, as we are going to use COMPASS software for secondary calculation device for Monaco therefore Elekta express QA beams were measured with COMPASS system to check the MLC modelling in COMPASS software. Express QA package contains eight QA fields as follows (i) 10x10- MLC+Jaw 10x10cm field to check absolute dose calibration (ii) 20x20- MLC+Jaw 20x20cm field to check absolute dose to check field flatness, symmetry, QA detector response (iii) 3ABUT- is a 6x24 abutted segments used to check the MLC major offset (iv) DMLC1- to check MLC leaves major and minor offset (v) 7SegA- 7 segments of 2x24cm beam a typical picket fence beam (vi) FourL- 4 L MLC segments, jaw 20x20 to check MLC offset, leaf groove, MLC transmission (vii) HIMRT- A 33 segment head and neck IMRT beam (viii) HDMLC- A 33 segment head and neck DMLC IMRT beam.

To check the MLC modelling in COMPASS all the Express QA beams were calculated in Multicube-lite phantom (IBA, Schwarzenbruck, Germany, Multicube phantom with I'matriXX at 11.0cm depth) using Monaco 5.11 TPS, statistical uncertainty was set as 0.5% per control point. Then calculated RT plan RT structure set and RT dose were exported to COMPASS in DICOM format to compare the Monaco TPS doses with COMPASS. All express QA beam were measured with COMPASS along with I'matriXX detector attached with a gantry holder calibrated for 100.0 cm SSD. After calculation and measurement with COMPASS, measured and COMPASS computed distribution were exported via DICOM and imported in My QA software for 2D comparison (to compare the profiles, computed and measured by COMPASS with Monaco calculated Profile of fields) using gamma index criteria of 3% dose difference and 3mm distance to agreement, threshold was set as 20%. 2%/2mm criteria results were also noted. A central plane of multicube phantom (at detector level) was selected for 2D Gamma analysis. COMPASS measured and computed results of express QA beams were also compared with baseline 2D express QA measurements done for Monaco TPS commissioning using I'matriXX detector array. For 2D measurement setup, phantom was kept at couch and source to surface distance was kept at 89.0cm, I'matriXX was at 11.0cm depth. After dose calculation coronal fluence dose plane was exported to My QA software (IBA).

Validation of COMPASS using AAPM TG-119 test suite

To validate the COMPASS software results in clinical environment the downloadable phantom with contoured structure set was downloaded from AAPM (American association of physicist in medicine) website provided with the TG-119 (task group-119) report and above structure sets were used as the patient for all plans created in the study [13-16]. TG-119 mock cases represents clinically relevant structures and shapes i.e. multitarget, prostate, head and neck and C-shape target. The treatment plans were optimised using Monaco TPS. All the treatment plans were calculated for dose to medium in Monaco TPS using Monte Carlo dose calculation algorithm. Treatment plans were generated for 6MV energy beams having maximum dose rate of 600MU/min. For VMAT plan single arc was used. For all the plans prescription and dose volume constraints were kept as per TG-119 guidelines. After planning all the plans were exported to COMPASS for independent calculation and 3D dose measurement. Monaco versus COMPASS computed and COMPASS reconstructed doses were also compared using dose volume histogram (DVH) and also compared in terms of 2D profile comparison. For 2D comparison, plans were exported to My-QA software for 2D planar (at central plane) analysis using gamma-index (3%/3mm criteria, 20% threshold).

Results:-

Validation with MLC Express QA

The results of 2D gamma analysis of express QA beam measured with I'matriXX and multicube during our Monaco TPS commissioning (baseline data with I'matriXX) are summarized in table-1. As shown in table-1, the 2D-Gamma passing rate for 3%/3mm, 20% threshold were above 95% for all the eight beams calculated by Monaco TPS and measured with I'matriXX. For 2%/2mm, 20% threshold, 10X10, 20X20, 3ABUT, HIMRT showed Gamma passing rate above 95%. Gamma passing rate for DMLC1 was 89.6%, 7SegA was 88.3% and for fourL was 90.5% for 2%/2mm, 20% threshold criteria.

The results of 2D gamma analysis of express QA beam measured and computed with COMPASS are summarized in table-2.

The Gamma pass rate for all express QA beams for Monaco versus COMPASS computed, Monaco versus COMPASS reconstructed & COMPASS computed versus COMPASS reconstructed were above 95% except for FourL field. FourL field Monaco versus COMPASS reconstructed gamma pass rate was 98.4% but Monaco versus COMPASS computed gamma pass rate was 93.4%. For 2%/2mm criteria COMPASS calculated and measured gamma analysis results with Monaco TPS are almost similar as observed for our routine 2D QA with I'matriXX. Nakaguchi et. al. (2015) studied the different MLC pattern (10.0mm, 5.0mm gap pattern and tongue & groove pattern) and IMRT fields (step and pyramid pattern) using COMPASS. Results showed MLC test pattern was within 3.0% and IMRT fields were in good agreement with TPS computed dose and measurement[17]. Godart et. al. (2011) also studied the different MLC test patterns using compass and concluded that COMPASS has capability to detect the MLC positioning error [18].

Table1:- 2D Gamma analysis of MLC express QA beams measured using I'matriXX with multicube phantom.

Exp. QA beams	2D measurement using I'matriXX with multi-cube (Monaco VS Delivered)	2D measurement using I'matriXX with multi-cube (Monaco VS Delivered)
	Gamma pass rate(3%/3mm)	Gamma pass rate (2%/2mm)
10x10	100.0%	100.0%
20x20	100.0%	99.9%
3ABUT	98.9%	97.0%
DMLC1	98.4%	89.6%
HIMRT	99.4%	98.7%
HDMLC	99.7%	98.8%

7SegA	98.8%	88.3%
Four L	97.3%	90.5%

Table2:- 2D Gamma analysis of MLC express QA beams, computed and measured using COMPASS 3D-QA system.

Exp. QA beams	2D measurement with Compass gamma pass rate(3%/3mm)			2D measurement with Compass gamma pass rate (2%/2mm)		
	Monaco VS Compass Computed	Monaco VS Compass Reconstructed	Compass Computed VS Compass Reconstructed	Monaco VS Compass Computed	Monaco VS Compass Reconstructed	Compass Computed VS Compass Reconstructed
10x10	100.0	100.0	100.0	99.9	96.5	100.0
20x20	99.3	99.8	100.0	88.6	95.4	100.0
3ABUT	100.0	99.2	100.0	93.7	93.6	99.8
DMLC1	99.3	95.5	99.9	93.8	82.2	98.1
HIMRT	98.9	99.9	99.9	94.2	99.0	96.7
HDMLC	98.5	99.8	99.3	89.3	99.0	94.0
7SegA	100.0	98.3	98.9	98.8	88.6	94.8
Four L	93.4	98.4	94.2	83.7	91.1	77.7

As shown in table1 &2, express QA beam planar dose (Profile) measurements with COMPASS and I'matriXX were above 95% except for fourL beam, using 3%/3mm criteria.

Results of 2D planar fluence (profile) comparison of Monaco calculated and COMPASS calculated and reconstructed are shown in figure-3(a&b). As can be seen in the figure-3(a&b) that the Monaco calculated and COMPASS calculated and measured profiles are almost overlapping except for 4L field measurement which showed some deviations from TPS.

Validation with AAPM TG-119

All planning dose volume constraints have been achieved as per TG119 report shown in table-3.

Monaco versus COMPASS computed percentage variations for Prostate PTV and OAR were less than 1.18%, for Multi-target variations were within 3.09% except for central target D99 which showed variation of -3.9%, similarly for Head and Neck maximum variation seen was -3.48%, which was showed by PTV D99, and last the C-Shape core D10 showed percentage variation of 7.78%. Monaco versus COMPASS reconstructed percentage variations for Prostate, Head and Neck, C-Shape PTV and central & superior target were within 3.0%. OAR and low dose region structures (less compare to PTV) showed more variation larger than 3.0%. Clemente Guiterrezet al. (2015) validated Mobius and COMPASS (3D dose verification system) using AAPM TG-119 and found larger difference for high dose regions (D99 in H&N, and D99 in superior target, D99 in inferior target volumes for Multi-target). For parotids in H&N case were also observed larger dose differences [19].

2D-Gamma pass rate for Monaco versus COMPASS computed were 98.2%, 98.1%, 96.3%, 97.3% and Monaco versus COMPASS reconstructed were 97.7%, 98.9%, 94.1%, 97.1% for prostate, multi-target, head and neck and C-Shape respectively at central plane as shown in table-4.

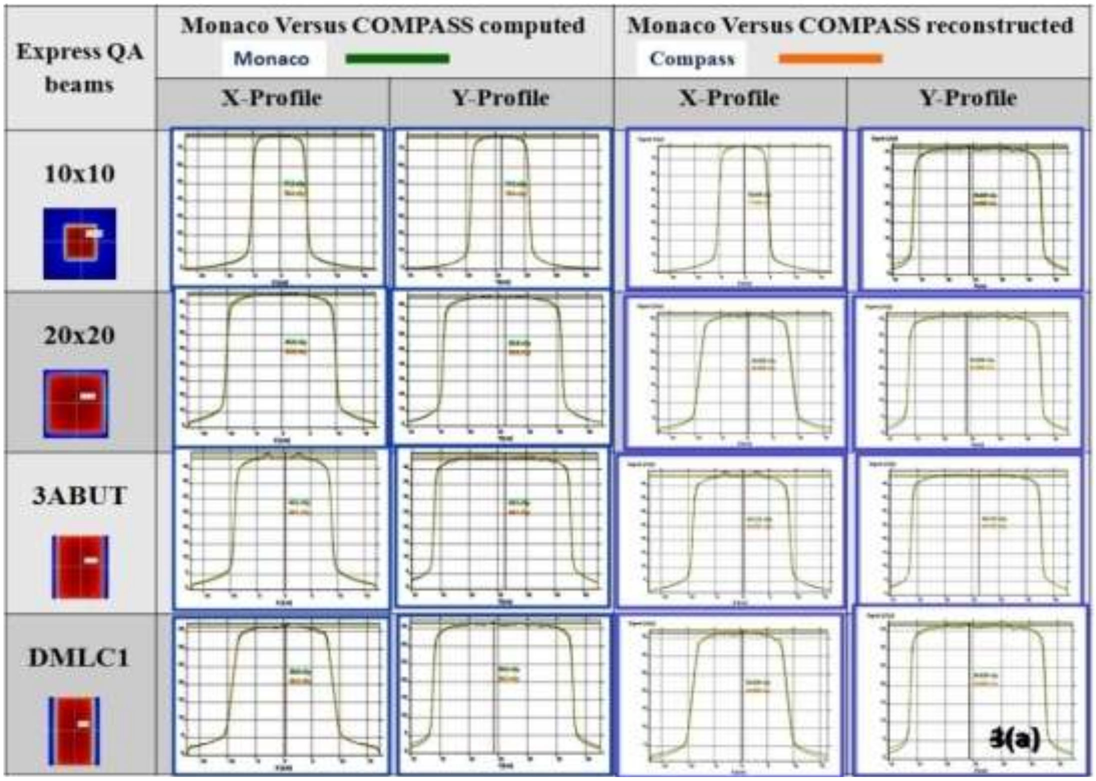

Figure-3(a):-Showing the profile comparison results of MLC express QA beams check using Compass.

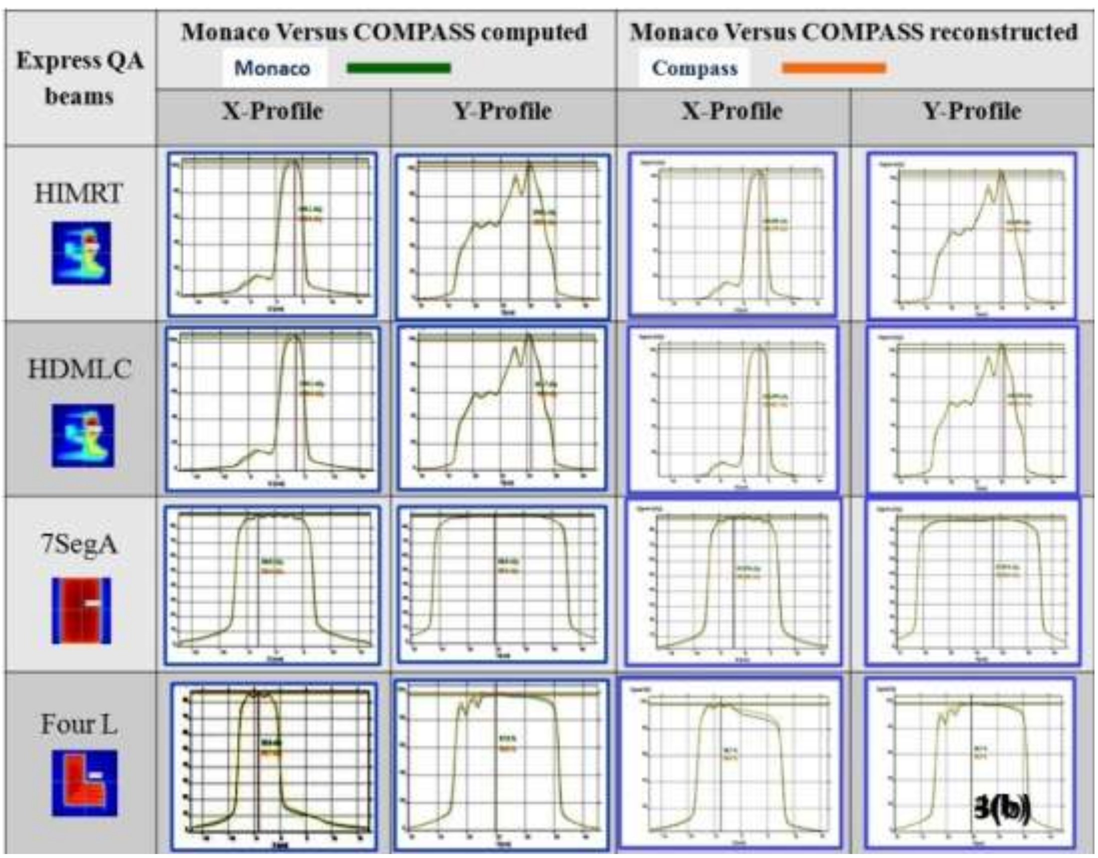

Figure3(b):-Showing the profile comparison results of MLC express QA beams check using Compass.

Table3:- Results of AAPM TG-119, planned by Monaco and compared with COMPASS computed and reconstructed.

Test Suite	Parameters	Goal	TG-119 results	Monaco Computed results	Monaco VS Compass Computed	Monaco VS Compass Reconstructed	Compass Computed VS Compass Reconstructed
		(cGy)	mean±SD (cGy)	(cGy)	% difference	% difference	% difference
Prostate	PTV D95	7560	7566±21	7575.4	-0.12	-1.27	-1.15
	PTV D5	<8300	8143±156	8125.2	1.18	2.05	0.85
	Rectum D30	<7000	6536±297	6067.2	0.81	-4.99	-5.76
	Rectum D10	<7500	7303±150	7339.2	0.42	-4.20	-4.60
	Bladder D30	<7000	4394±878	4605.5	-0.02	6.97	6.99
	Bladder D10	<7500	6269±815	6348.0	0.32	8.12	7.77
Multi Target	Central target D99	>5000	4955±162	4924.3	-3.9	1.7	5.8
	Central target D10	<5300	5455±173	5349.5	2.72	2.54	-0.18
	Superior target D99	>2500	2516±85	2723.1	1.1	1.5	0.40
	Superior target D10	<3500	3412±304	3539.3	2.71	1.71	-0.98
	Inferior target D99	>1250	1407±185	1329.8	1.2	-0.9	-2.1
	Inferior target D10	<2500	2418±272	2434.6	3.09	-8.29	-13.95
Head & Neck	PTV D90	5000	5028±58	5001.0	0.08	1.78	1.70
	PTV D99	>4650	4704±52	4612.8	-3.48	0.81	4.45
	PTV D20	<5500	5299±93	5372.2	1.86	2.42	0.55
	Cord Max.	<4000	3741±250	3616.2	1.0	-3.70	-4.70
	Rt. Parotid D50	<2000	1798±184	2089.5	0.28	0.96	0.68
	Lt. Parotid D50	<2000	1798±184	2018.5	1.91	2.05	9.95
C-Shape	PTV D95	5000	5010±17	5006.5	0.21	-0.44	-0.65
	PTV D10	<5500	5440±52	5421.9	2.01	2.68	0.66
	Core D10	<2500	2200±314	2486.9	7.78	2.44	-4.95

Table4:- 2D Gamma analysis of AAPM TG-119 test suites, computed and measured using COMPASS 3D-QA system.

Test Suite	2D Gamma analysis Monaco VS COMPASS computed	2D Gamma analysis Monaco VS COMPASS measured
	gamma pass rate(3%/3mm)	gamma pass rate (3%/3mm)
Prostate	98.2%	97.7%
Multi Target	98.1%	98.9%
Head & Neck	96.3%	94.1%

C-Shape	97.3%	97.1%

Discussion:-

The purpose of the present study was to evaluate the reliability of COMPASS 3D-QA system, so that we can use it in clinic. So far we were doing 2D-QA with I'matriXX detector array in which we are able to compare the 2D planar, planned and delivered fluence by means of Gamma index. When we have 3D measured and computed doses we can compare (planned and delivered) in terms of dose volume histogram in addition to that each and every plane can be compared instead of any single planar dose. COMPASS system has module to compare doses in any particular 2D-plane otherwise one use IBA MY QA Patient module, which is specifically made for 2D patient specific QA. We have measured express QA beam and TG-119 test suites plan with COMPASS (3D QA) and analysed by both 2D and 3D comparison method.

Elekta express QA beams are designed to check the MLC modelling accuracy in TPS, we have measured and calculated the above beams with COMPASS and compared with Monaco TPS and results showed good agreement between them, therefore as per study results COMPASS modelling is closer to our planning and delivery system and can be used for routine QA.

For clinical validation of COMPASS, AAPM TG119 structure sets were measured and computed, variations between Monaco and COMPASS calculated/measured were within acceptable tolerance except in low dose region. For setting the tolerance for clinical acceptability of plan based on anatomy based QA further investigations are required.

Prabhakar et. al. (2011) studied the target volume computation by different 3D treatment planning systems and author concluded that the different planning systems showed variation in CTV and PTV volume computation that also has to taken in consideration while comparing using dose volume histogram [20].

Even though DVH based plan comparison gives clear idea in terms of clinically understandable manner but as we know that DVH has no spatial information. All the area of normal tissue is not contoured in CT images and if there is a mismatch in that area, chances of missing will be there by comparing DVH based. DVH based plan comparison has to substantiate with other 2D or 3D comparison tools.

For validation of COMPASS; In 2010 R Boggulaet al.[21]studied the dosimetric performance of COMPASS, a 3D quality assurance system for verification of volumetric-modulated arc therapy (VMAT) treatment plans. COMPASS can correlate the delivered dose to the patient's anatomy, taking into account the tissue inhomogeneity. The results matched well between COMPASSand measurements for the ionization chamber (3%) and film (73–99% for gamma *(*3%*/*3mm*)* <1 and 98–100% for gamma *(*5%*/*5mm*)* <1) for the phantom plans. Differences in dose–volume statistics for the average dose to the PTV were within 2.5% for three treatment plans. For the structures located in the low-dose region, a maximum difference of <9% was observed. Korevaar et. al. (2011) to test the reliability of dose reconstruction with COMPASS, 24 H&N patient's film QA results were compared with COMPASS QA results and good agreement was found between film and COMPASS measurement [22]. Boggula et.al. (2011) tested the performance of COMPASS system for both offline and online measurements and concluded that I'matriXX based dose reconstruction were within 0.5% with ion chamber and mean dose to volume indices were less than 2% [23]. Vikraman et. al. (2015) evaluated the COMPASS system for stereotactic VMAT delivery and concluded that the COMPASS can be used for small field measurement also despite of its limited detector resolution[24]. COMPASS beam data requirement if from 2X2 cm^2 as per the study by Valve at. al. (2017) resulted as COMPASS should not be used for field size smaller than 3x3cm^2 [25].

Limiting factor for COMPASS measurement is, as the I'matriXX is attached with the gantry during the measurement, therefore it is not able to detect the errors related to gantry and couch rotation.

Conclusion:-

COMPASS measured (reconstructed) and computed results are in good agreement with Monaco (5.11) TPS. COMPASS software can compare the plan using dose volume parameters, which is more relevant and understandable for oncologist. COMPASS measurement is not replacing the 2D measurement on the other hand it is giving us (more insight) one more way to compare plan in terms of DVH along with 2D and 3D gamma analysis.

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