Real-time Verification of VMAT Delivery by an Automated Beam Monitoring System

M Farrokhkish, M Islam , R Heaton , B Norrlinger , D Jaffray

Princess Margaret Cancer Centre, University Health Network, Toronto, ON

Princess Margaret Cancer Centre UHN

TECHNA Institute for the Advancement of Technology for Health

UNIVERSITY OF TORONTO

---------------Introduction and Objectives---------------

- Daily Adaptive Radiotherapy (ART) with Volumetric Modulated Arc Radiotherapy (VMAT) technique would require a new genre of Quality Assurance (QA) devices which are capable of monitoring & validating the treatment beams in real-time.
- The Integral Quality Monitor (IQM) system (iRT, Koblenz, Germany) is designed to be an independent intra-fraction beam verification system that measures spatially sensitive "dose-area" product of each beam segment, and compares to reference signals in real time.
- IQM system utilizes a large area ionization chamber that spans the entire radiation field when mounted to the Linear Accelerator (LINAC) collimator head. The hardware components include an onboard dual channel electrometer, Tri-axis MEMs accelerometer, and a Bluetooth transceiver module, powered by a rechargeable battery.
- The following investigations were done to evaluate IQM system's beam monitoring performance:

1) Assess the accuracy and reproducibility of LINAC beam delivery, and those of beam monitoring performance by the IQM system to define a segment wise tolerance band.

2) Evaluate IQM signal calculation accuracy (segment wise, and cumulative), and measurement reproducibility, by utilizing the pre-defined tolerance band.

3) Evaluate IQM systems error detectability

----------------------------Method----------------------------

- In this work 32 Head & Neck VMAT test fields (with 110 segments each) were calculated by IQM CALC application, then delivered by a TrueBeam LINAC (Varian Medical Systems, Palo Alto, CA) for 15 fractions over a course of 50 days.
- Assessment of LINAC's beam delivery reproducibility, and accuracy of the delivered MU, and start/ end segment gantry angle for each segment was done by direct comparison of Trajectory Log Files (TLF) with corresponding planned parameters. Similarly, gantry angles determined by IQM accelerometer were compared to those from TLF. The maximum observed deviations from above were used to specify a tolerance band (While ignoring other sources of uncertainties such as MLC positioning) around each calculated segment signal $S_C(n)$, defined by **equation 1**. A measured segment signal $S_m(n)$ is considered as "pass" if it is within $S_C(n) \pm \partial S_C(n)$. The pass criteria below was used to determine the segment % pass rate

$$S_C(n) - \partial S_C(n) \le S_m(n) \le S_C(n) + \partial S_C(n)$$

- **IQM segment based calculation accuracy** was assessed by evaluating the % pass rate for all delivered fields. **The cumulative calculation accuracy** was measured by directly evaluating the deviation in measured cumulative signal from calculation.

$$\partial s_C(n) = \pm s_C(n)\sqrt{\left(\frac{\partial G}{\Delta G}\right)^2 + \left(\frac{\partial MU}{\Delta MU}\right)^2 + \left(\frac{\partial G'}{\Delta G}\right)^2} \quad \text{Equation 1}$$

$s_C(n)$= Calculated signal for segment n; ΔG = segment gantry span (3 degrees) ∂G =Linac rotational gantry accuracy; $\partial G'$= IQM gantry angle accuracy; ΔMU = planned segment MU; ∂MU = Linac MU delivery accuracy

- **IQM segment based signal reproducibility** was evaluated by calculating the %STDEV for all measured signals across 15 fractions**. The cumulative signal reproducibility** was assessed by calculating overall deviation in measured cumulative signals from calculated signal.
- IQM system's error detectability was tested by introducing the following systematic errors into 5 randomly chosen test plans : ±3 and 5 % change in total MU (simulating machine output change); ±1 and 2 mm change in MLC bank position (simulating calibration error); and energy mix-up from 6MV to 6FFF,10MV, and 10FFF. The differences in measured and calculated cumulative signals were then quantified.

---------------------------- Results ----------------------------

- A total of 52800 segments were delivered and measured. TLF analysis revealed the accuracies in LINAC's VMAT segment boundary detection and MU delivery were within 0.3 degrees and 0.2 MU respectively. **Fig. 1a and 1b** shows these variation from test field #7. The deviations were found to be highly reproducible, reflecting on stability of the LINAC & limitations in LINAC's control system. The IQM accelerometer rotational accuracy was found to be within 0.4 degrees.
- IQM Segment based tolerance band were defined using the system uncertainties. The total segment % pass rates were calculated for every delivered field as shown in **Fig. 2a**. On average, 96.2% of the total measured segments were within $S_C(n) \pm \partial s_C(n)$. The cumulative calculated signals agreed to measured values to within ± 2%.
- The IQM segment wise measured signal variations is mainly a function of signal size and accelerometer accuracy. **Fig. 2b** shows the %STDEV distribution of 15 repeated measurements. The mean %STDEV was calculated to be 4.60%. The cumulative measured signal was reproducible to within ± 1% throughout the measurement period.

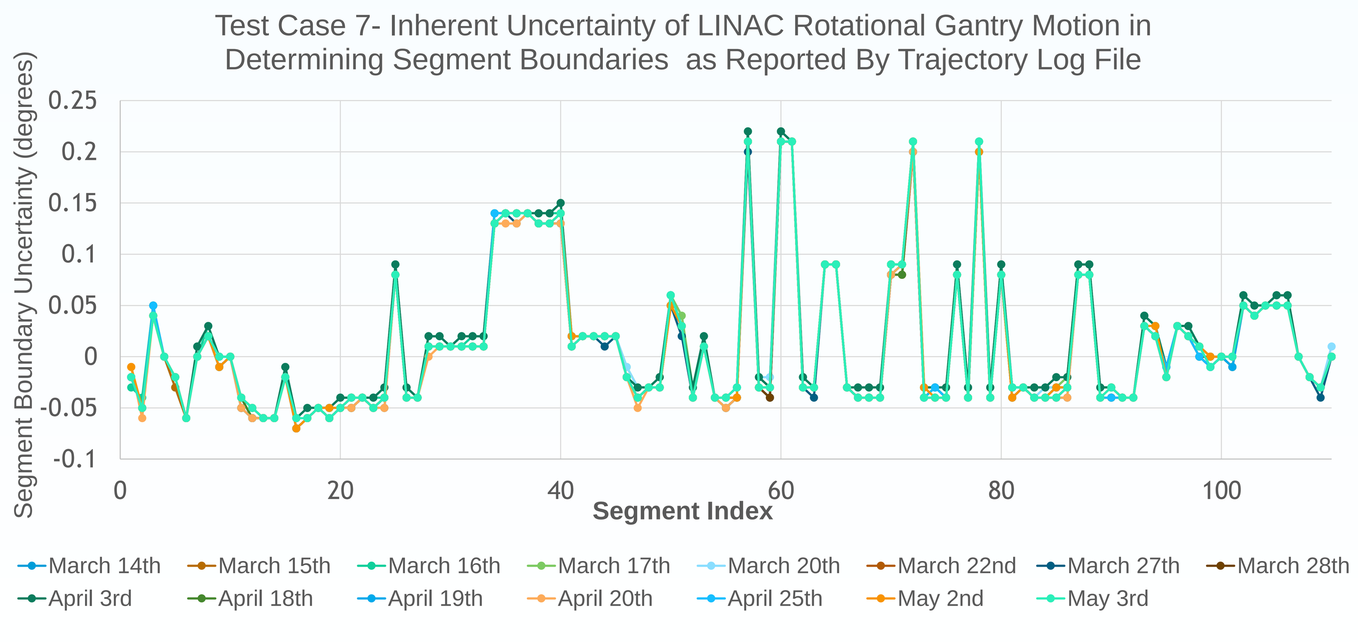

Fig 1a. Uncertainty in VMAT segment boundary determination can be as high as 0.3 degrees. This is in agreement with Varian TrueBeam LINAC specification. An uncertainty in this magnitude can account for 10% of IQM signal for a 3 degree segment span. The uncertainty pattern is unique for every field, and is reproducible over 50 days. The pattern is also dependent on direction of gantry rotation.

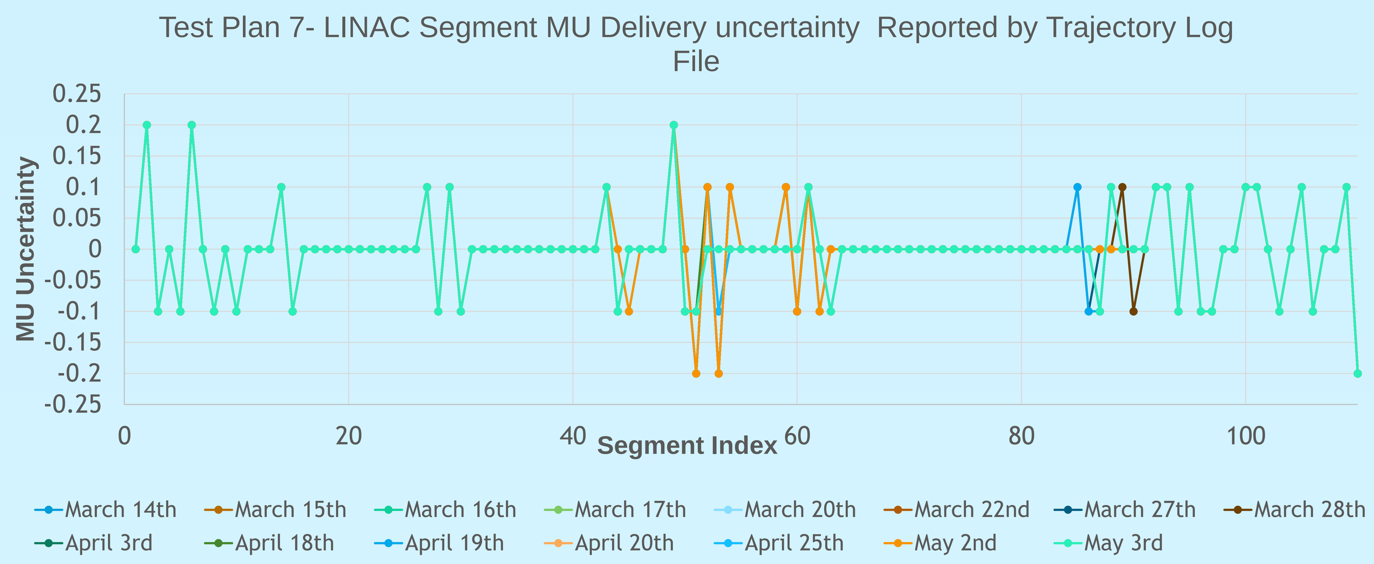

Fig 1b. Uncertainty in VMAT segment MU is due to both fractional MU rounding and delivery uncertainty. The planned MU for some segments were blow 1 MU, and this uncertainty can cause up to 10% variation for those low MU segments. The MU variation was also found toe be reproducible through out the measurement period

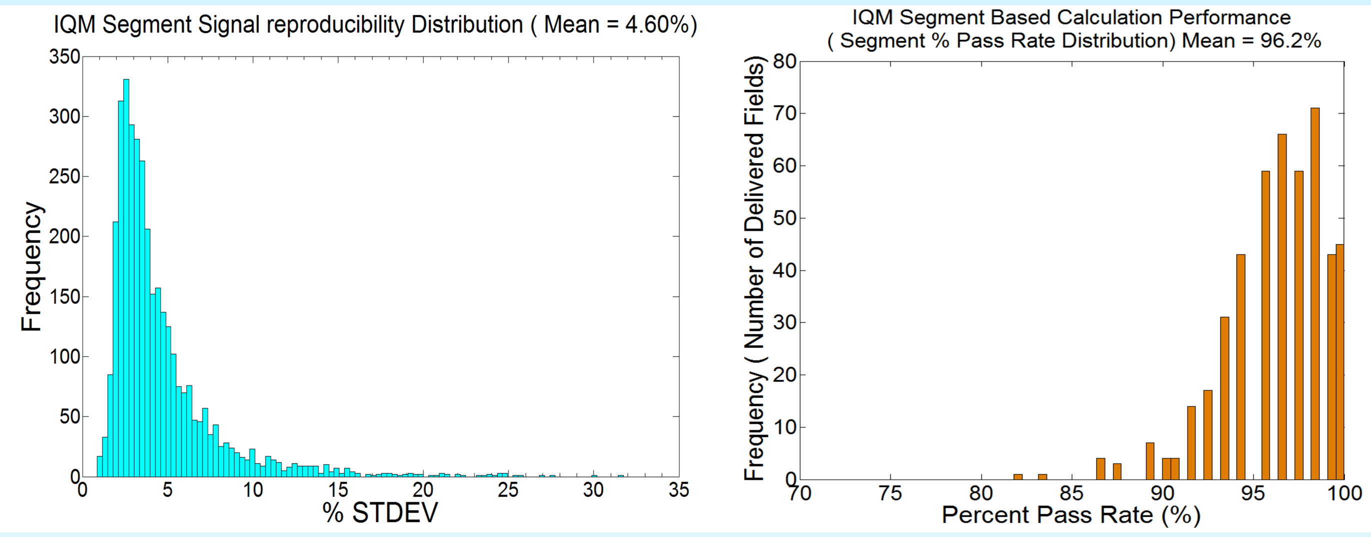

Fig 2a (RIGHT): Major system uncertainties were recognized, and IQM calculation model was evaluated by taking system uncertainties into consideration. Overall 96.2 % of the delivered segments were within the Calculation tolerance. Fig 2b(LEFT): The reproducibility in IQM segment measurement depends mostly on segment size and IQM accelerometer accuracy. The measured segments were reproducible within 5% of mean value

- Various types of errors were introduced to 5 test plans. Although the signal deviations due to errors may not be fully identifiable in a segment due to the presence of tolerance band, but they are fully detectable in the cumulative signal due to 2% accuracy of IQM calc. **Fig. 3** presents the change in measured cumulative signal WRT reference calculation.

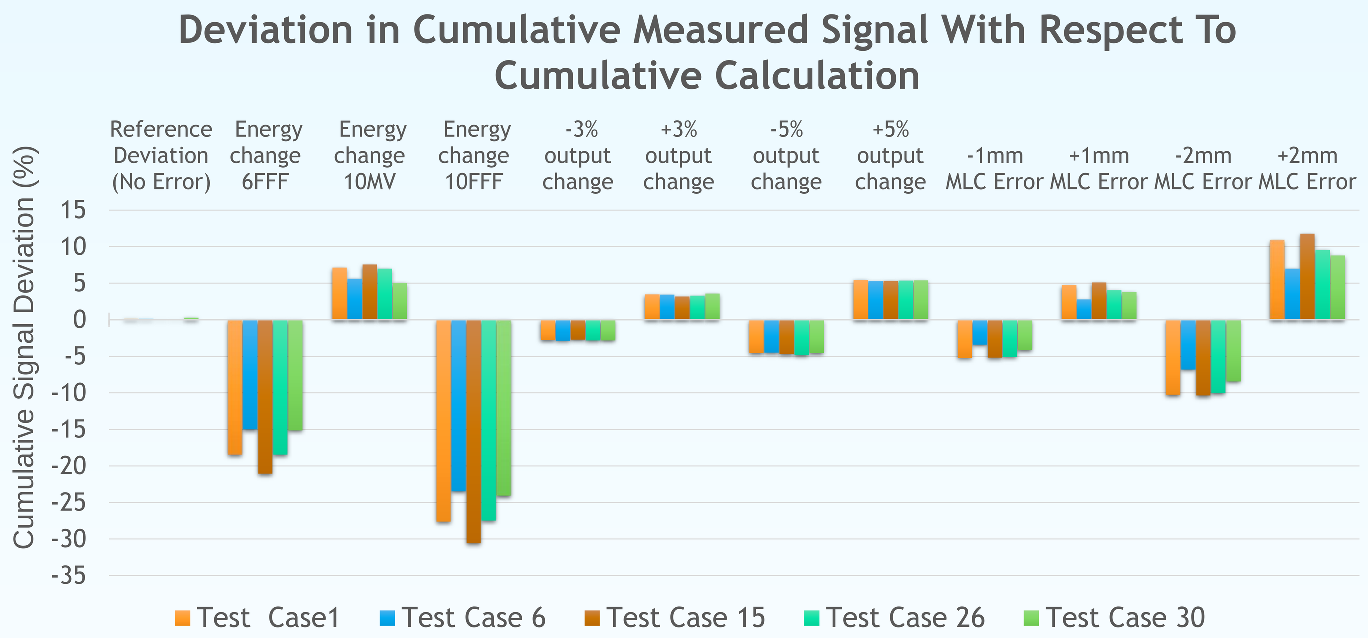

Fig 3: A 1mm error in MLC bank calibration caused approximately 5% change in cumulative signal. A change in machine output varied the measured cumulative signal by approximately the same proportion. The system showed a high degree of beam energy discrimination for Head & Neck VMAT fields.

---------------------------Conclusion---------------------------

- The variations in segment wise beam delivery by the LINAC, and monitoring by IQM, should be considered when performing calculation-measurement analysis.
- Calculation model performance found to be satisfactory for Head & Neck VMAT beam monitoring
- IQM dynamic signal reproducibility per segment was within 5% of the mean value.
- IQM is capable of detecting 1mm error in MLC bank position, change in machine output by >3%, and any mix-up of beam energy.