SUMMARY OF GUIDELINES FOR ROUTINE QA OF IMAGING SYSTEMS

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Joint ICTP-IAEA Workshop on Radiation Protection in Image-Guided Radiotherapy (IGRT)
Trieste, Italy, 7-11 October 2024

Disclosures

- Nothing to disclose
- Any reference to commercial products does not imply endorsement

Outline

- Introduction
- Quality Assurance of X-Ray Based Systems installed on C-arm linacs
  - Planar Imaging (MV and kV)
  - Volumetric Imaging (kV CBCT)
- Summary and Conclusions

Other systems will be discussed in this afternoon's session

Outline

- Introduction
- Quality Assurance of X-Ray Based Systems installed on C-arm linacs
  - Planar Imaging (MV and kV)
  - Volumetric Imaging (kV CBCT)
- Summary and Conclusions

Introduction

- IGRT QA:
  - Includes assessment of the geometric accuracy of the imaging and treatment of the patient, hence improving safety of treatment deliveries
  - Helps in predicting image degradation issues, hence reduces repeat imaging

Introduction

- IGRT QA:
  - Includes measurement of imaging dose, hence provides necessary info to the staff to select appropriate imaging technique
  - Should be integrated into the overall radiation delivery system QA, including motion management devices and registration software

Importance of IGRT QA

Practical Radiation Oncology (2013)

practical radiation oncology
pro

Assuring Safety and Quality in Image Guided Delivery Of Radiation Therapy

David A. Jaffray, Ph.D.[a], Katja M. Langen, Ph.D.[b], Gikas Mageras, Ph.D.[c], Laura A. Dawson, M.D. [d], Di Yan, D.Sc.[e], Robert Adams, Ed.D. [f], Arno J. Mundt, M.D.[g], Benedick Fraass, Ph.D.[h]

IGRT is a powerful advance in radiation oncology practice that can increase the fidelity, quality and safety of the intervention. However, if this increase is to be achieved, IGRT needs to be deployed in a robust and safe fashion.

Failure to do so can result in a very complex treatment being ‘precisely wrong.’

Outline

- Introduction
- Quality Assurance of X-Ray Based Systems installed on C-arm linacs
  - Planar Imaging (MV and kV)
  - Volumetric Imaging (kV CBCT)
- Summary and Conclusions

Task Group 142 report: Quality assurance of medical accelerators[a)]

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(Received 24 February 2009; published 17 August 2009)

Received: 9 February 2021 | Revised: 16 March 2021 | Accepted: 28 April 2021
DOI: 10.1002/mp.14992
AAPM SCIENTIFIC REPORT
MEDICAL PHYSICS

AAPM Task Group 198 Report: An implementation guide for TG 142 quality assurance of medical accelerators

Joseph Hanley[1] | Sean Dresser[2] | William Simon[3] | Ryan Flynn[4] | Eric E. Klein[5] | Daniel Letourneau[6] | Chihray Liu[7] | Fang-Fang Yin[8] |

Received: 7 April 2021 | Revised: 19 May 2021 | Accepted: 4 June 2021
DOI: 10.1002/acm2.13346
RADIATION ONCOLOGY PHYSICS
JOURNAL OF APPLIED CLINICAL MEDICAL PHYSICS

AAPM MEDICAL PHYSICS PRACTICE GUIDELINE 2.b.: Commissioning and quality assurance of X-ray-based image-guided radiotherapy systems

Steven P. McCullough[1] | Hassaan Alkhatib[2] | Kyle J. Antes[3] | Sarah Castillo[4] | Jonas D. Fontenot[5] | Andrew R Jensen[6] | Jason Matney[7] | Arthur J. Olch[8,9]

Received: 28 June 2017 | Revised: 23 January 2018 | Accepted: 29 January 2018
DOI: 10.1002/acm2.12302
COMP REPORTS AND DOCUMENTS
WILEY

COMP report: CPQR technical quality control guidelines for accelerator-integrated cone-beam systems for verification imaging

Jean-Pierre Bissonnette[1,2]

Quality assurance for image-guided radiation therapy utilizing CT-based technologies: A report of the AAPM TG-179

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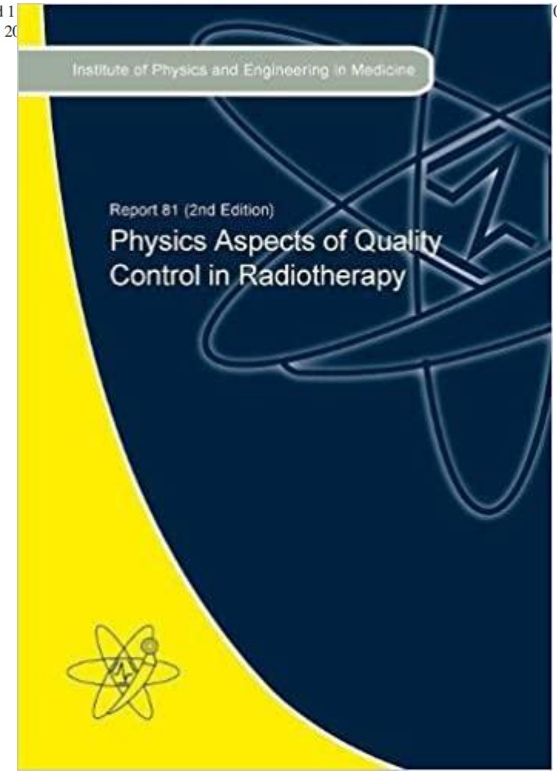
(Received 1 … 012; published 2…



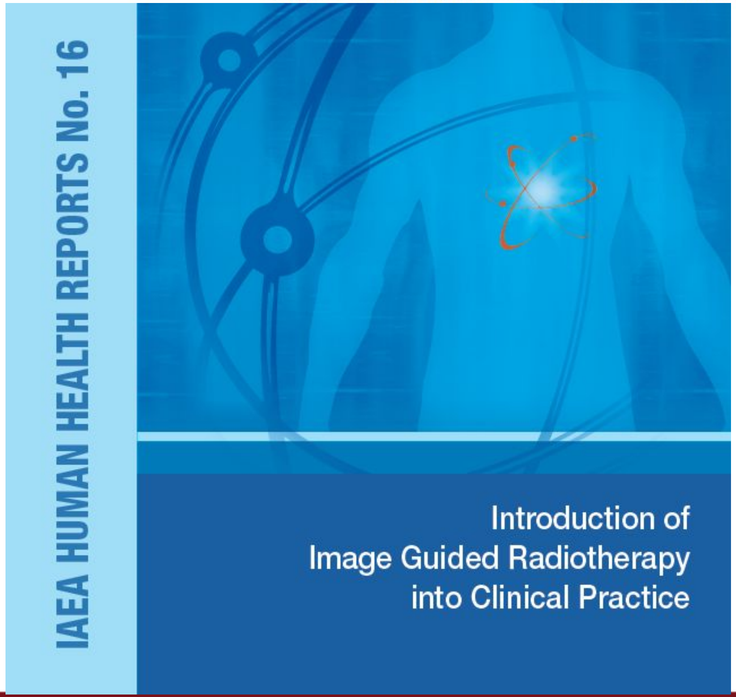
Quality control in cone-beam computed tomography (CBCT)

EFOMP-ESTRO-IAEA protocol

Quality assurance of cone-beam CT for radiotherapy

NEDERLANDSE COMMISSIE VOOR STRALINGSDOSIMETRIE

Report 32 of the Netherlands Commission on Radiation Dosimetry



Relevant Reports on IGRT QA

- Often similar guidelines for routine quality assurance for:
  – Electronic portal imaging devices (EPID)
  – Planar kilovoltage imagers
  – Kilovoltage CBCT

- Other reports provide guidelines for specialized treatment delivery units (Tomotherapy/Radixact, CyberKnife, …), as well as surface and MR-guidance, …

Planar Imaging QA

Planar Imaging QA

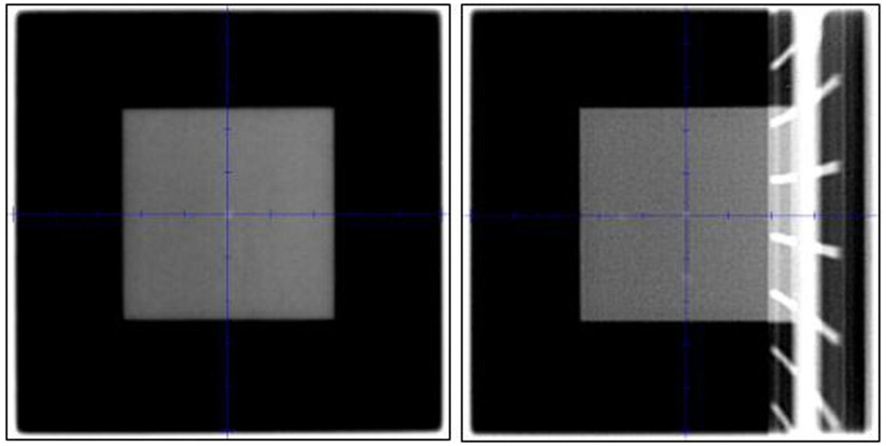
Monthly				
Planar MV imaging (EPID)				
Imaging and treatment coordinate coincidence	≤2 mm / ≤1 mm	Phantom containing radiopaque markers.	15–20 min	QMP or Designee
Scaling	≤2 mm / ≤1 mm	Object of known dimensions	5 min	QMP or Designee
Spatial resolution	≥ Baseline	Manufacturer supplied test phantom	5–10 min	QMP or Designee
Contrast	≥ Baseline	Manufacturer supplied test phantom	5–10 min	QMP or Designee
Uniformity and noise	≥ Baseline	Manufacturer supplied test phantom	5–10 min	QMP or Designee
Planar kV imaging				
Imaging and treatment coordinate coincidence	≤2 mm / ≤1 mm	Phantom containing radiopaque markers.	15–20 min	QMP or Designee
Scaling	≤2 mm / ≤1 mm	Object of known dimensions	5 min	QMP or Designee
Spatial resolution	≥ Baseline	Manufacturer supplied test phantom	5–10 min	QMP or Designee
Contrast	≥ Baseline	Manufacturer supplied test phantom	5–10 min	QMP or Designee
Uniformity and noise	≥ Baseline	Manufacturer supplied test phantom	5–10 min	QMP or Designee

"Baseline" Tolerances

Imaging/Treatment Coordinate Coincidence

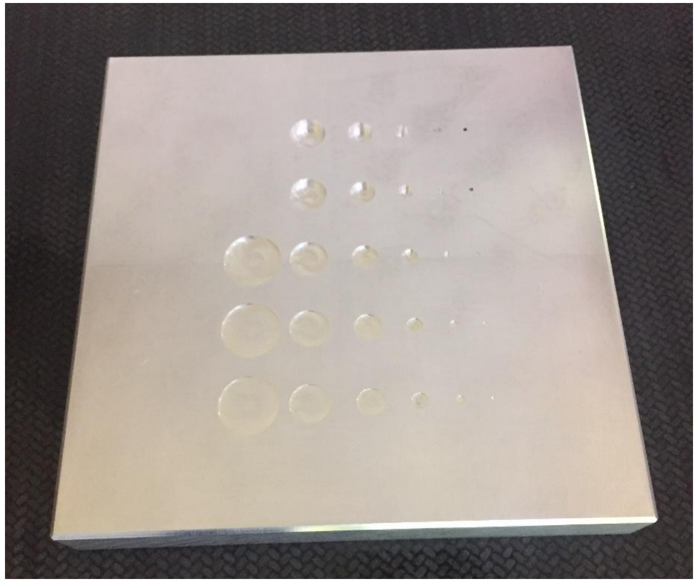
- Using a cube phantom containing radiopaque markers, image in 4 cardinal angles, and record the deviation between crosshairs and markers

- Or, perform a CBCT first, applying corresponding table shifts, and then acquire an orthogonal pair of kV and MV images and determine residual shifts (more common)



- Tolerance: ≤2mm (≤1mm day of SRS)

Image Quality-MV

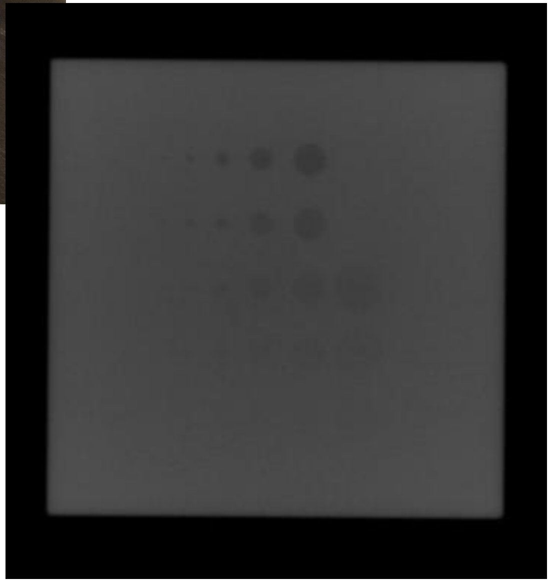


<u>Low contrast evaluation</u>

Las Vegas phantom: 28 circular holes with different diameters and depths

Number of visible holes compared with those during acceptance (i.e. Tolerance: ≥baseline)

Image Quality-MV



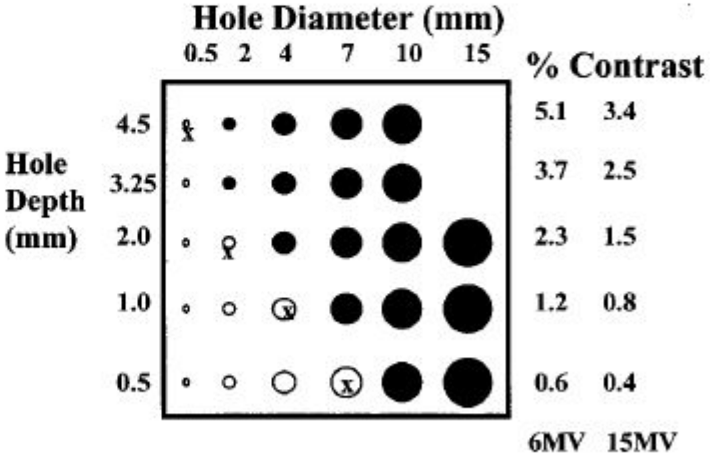
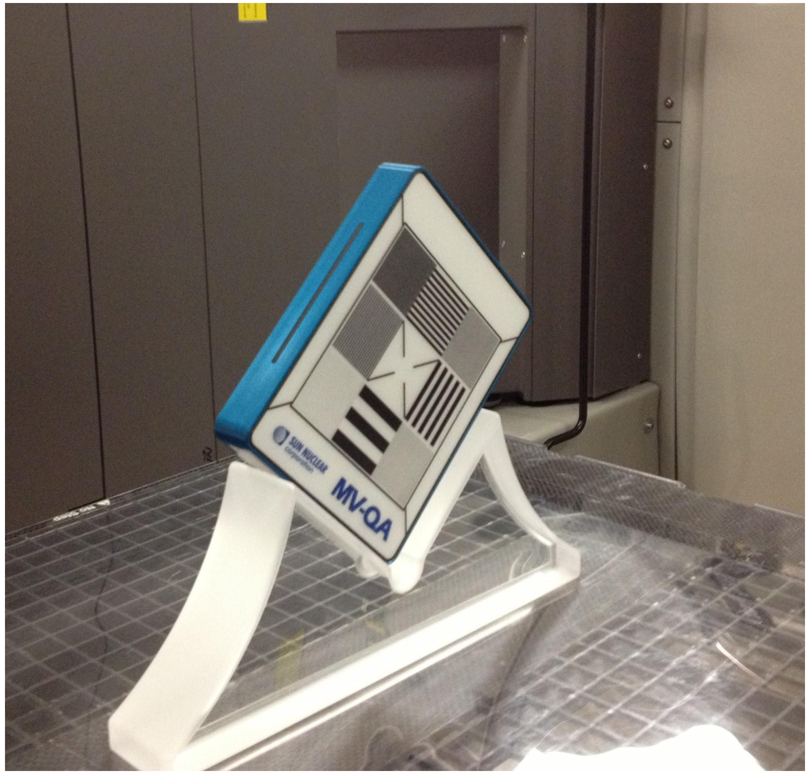
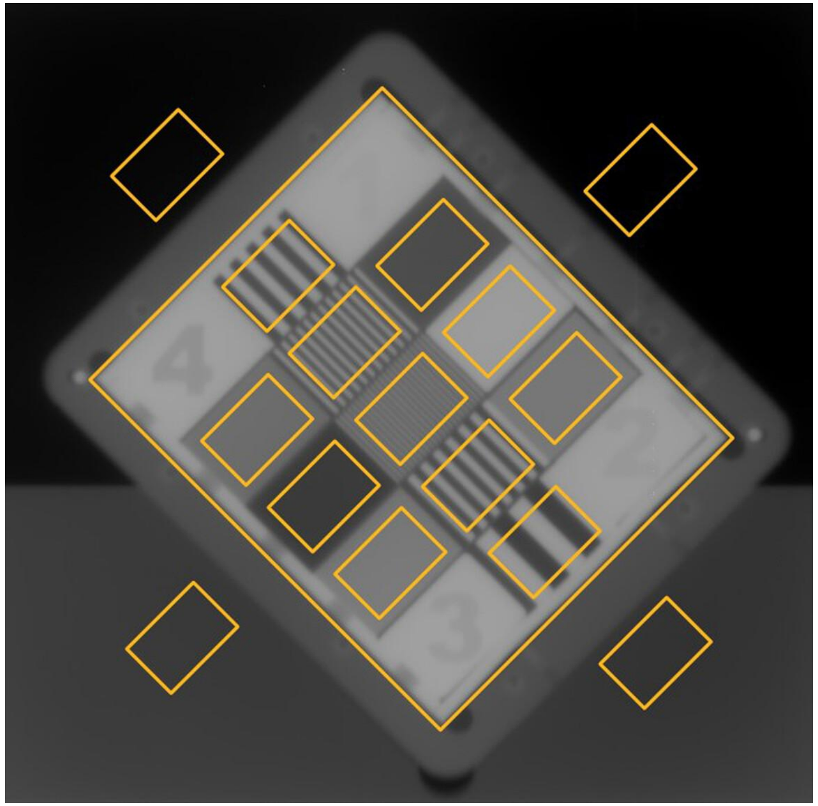


FIG. 10. Aluminum Las Vegas phantom for EPID image contrast and spatial resolution.

Visibility of circles per AAPM TG-58

Image Quality-MV





High contrast evaluation

Number of lp/mm compared with those during acceptance (i.e. Tolerance: ≥baseline)

Image Quality-kV

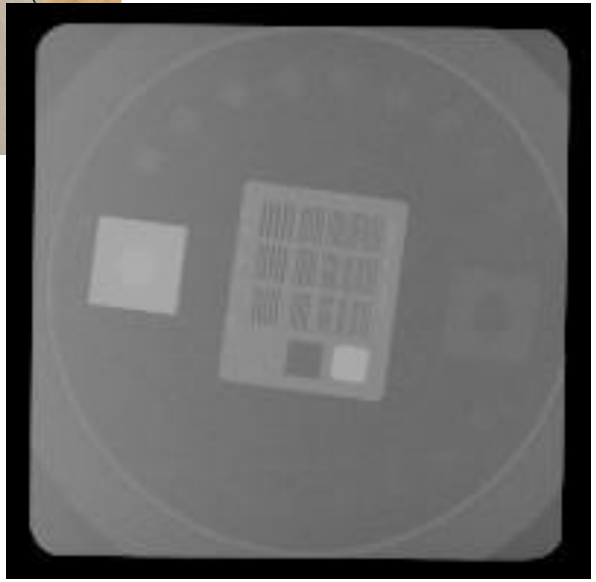
Phantom designed for fluoroscopy

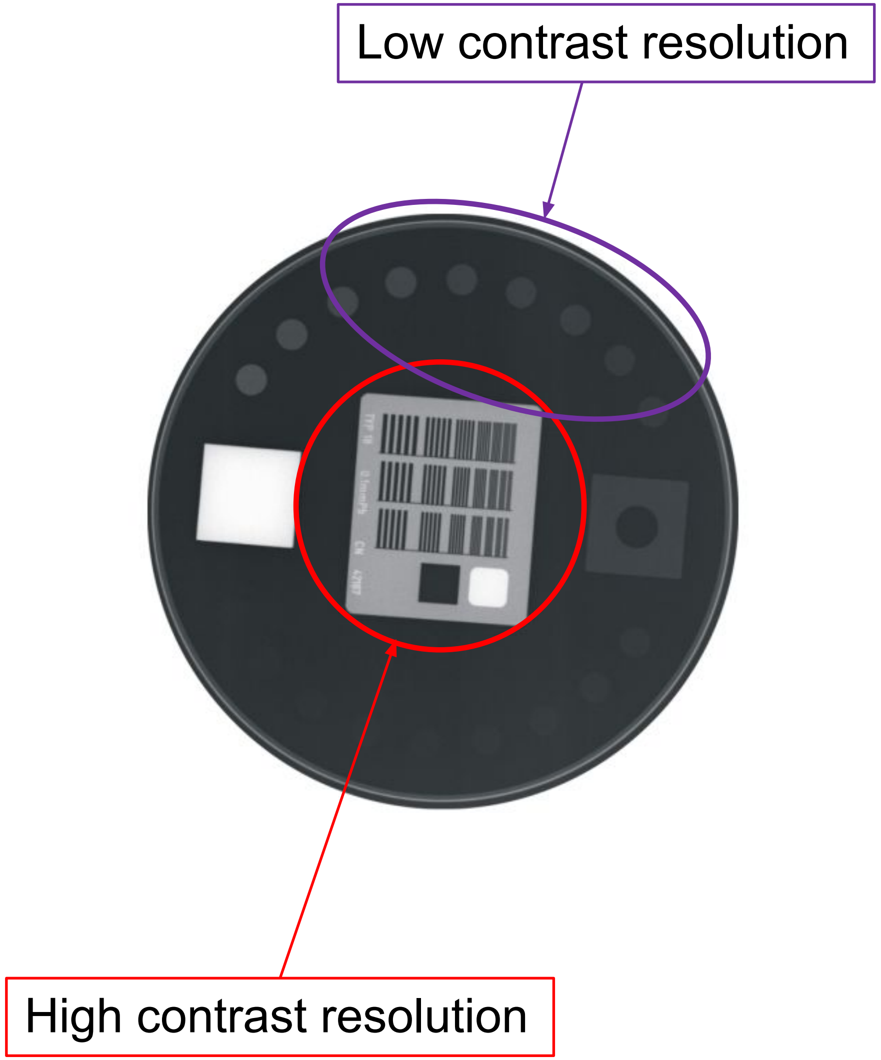
High contrast resolution between 0.5 to 5.0 lp/mm
Low contrast resolution (18 details, 8 mm diameter)

Use the same techniques as those used during commissioning

Tolerance: ≥baseline

Image Quality-kV





Volumetric Imaging QA

CBCT QA-Comparison of Recommendations

Quality assurance for image-guided radiation therapy utilizing CT-based technologies: A report of the AAPM TG-179

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(Received 11 August 2011; revised 19 January 2012; accepted for publication 10 February 2012; published 20 March 2012)

Quality control in cone-beam computed tomography (CBCT)

EFOMP-ESTRO-IAEA protocol

EFOMP European Federation of Organisations for Medical Physics

ESTRO

IAEA International Atomic Energy Agency

EFOMP

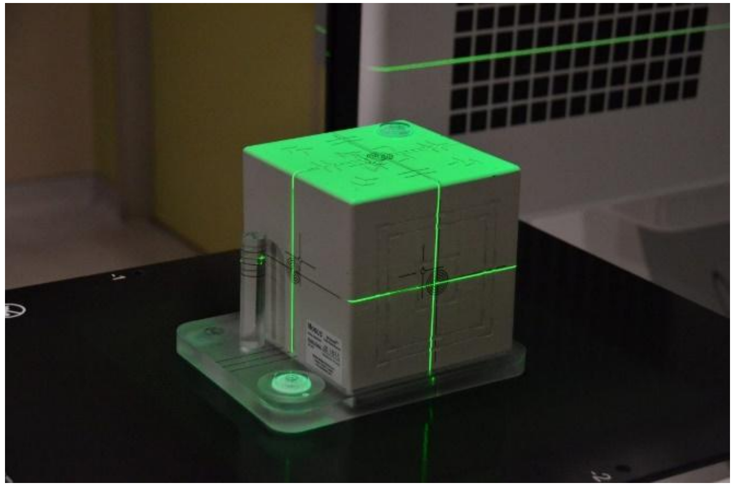
2nd edition, May 2019

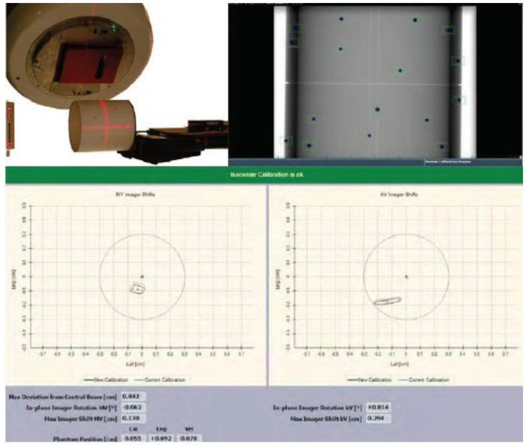
CBCT QA-Comparison of Recommendations

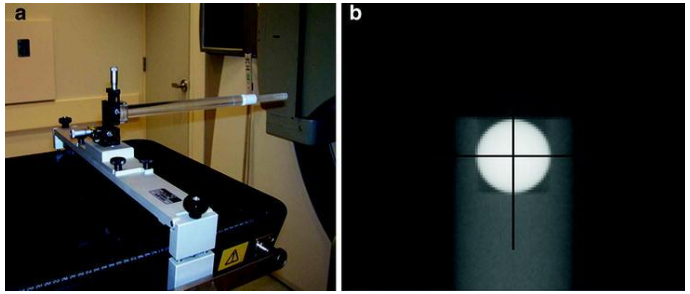
AAPM TG-179 (2012)	EFOPM-ESTRO-IAEA Protocol (2019)	
Geometric accuracy	Geometrical precision	Geometry
Scale and distance accuracy		
Low contrast resolution	Low contrast resolution	Image Quality
Spatial resolution	Spatial resolution	
Uniformity and noise	Uniformity	
	Noise	
Accuracy of CT numbers	Voxel density values	
Image dose	Patient dosimetry	Dose
Image registration		Other QA Tasks
Accuracy of remote-controlled couch		

Coincidence of Axes

- Laser/image/treatment isocenter coincidence AND phantom localization and repositioning with couch shift

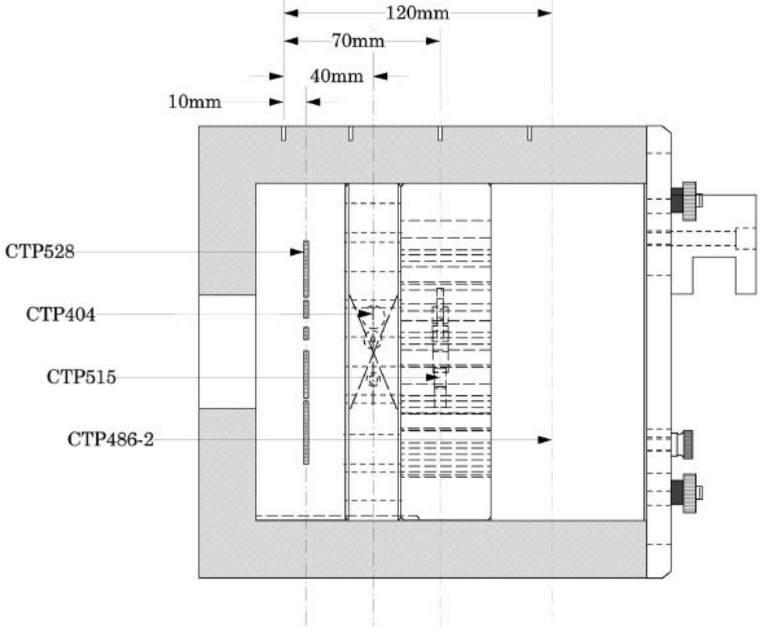


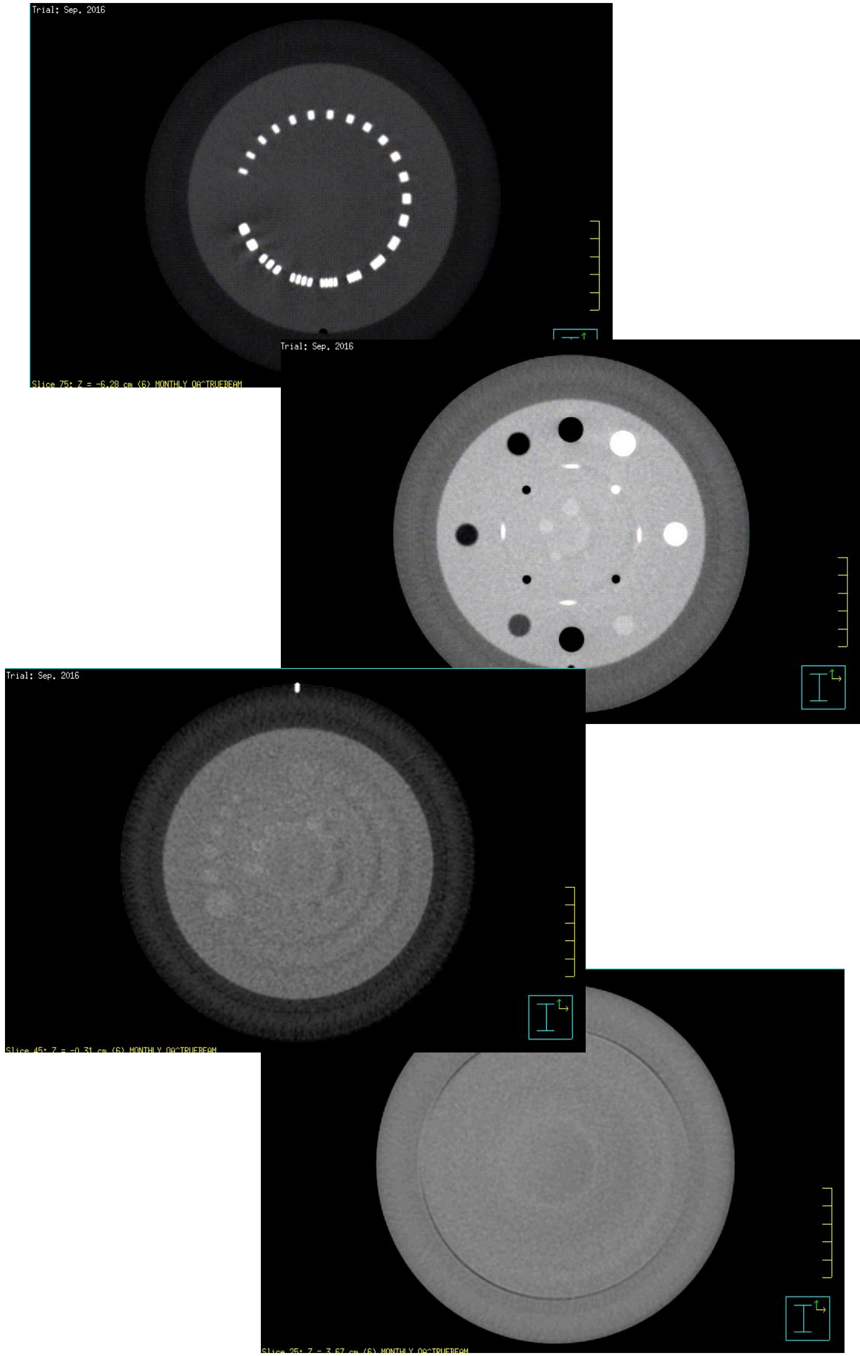




Recommended frequency: Daily & Monthly

CBCT Imaging QA



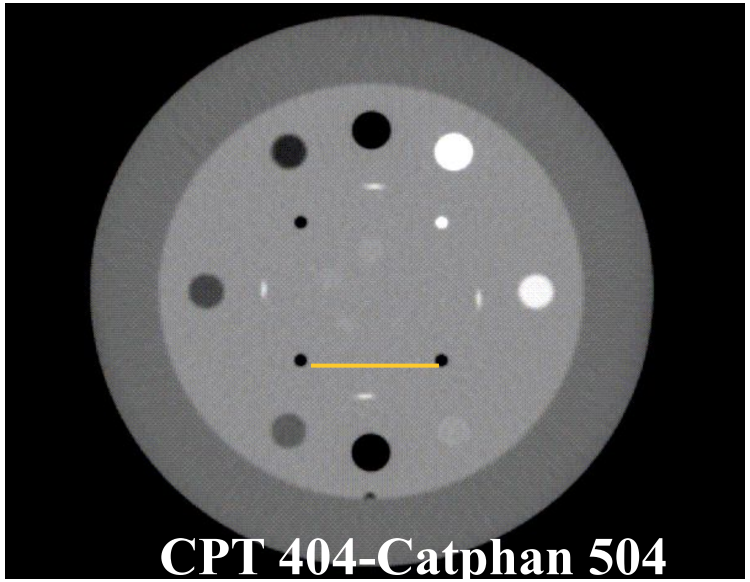


Catphan 504 pictured, other models slightly different

Geometrical Accuracy/Precision

- The ability to reproduce accurate spatial relationship of the internal structures to match that of imaged ones

Scaling/linearity and distance accuracy

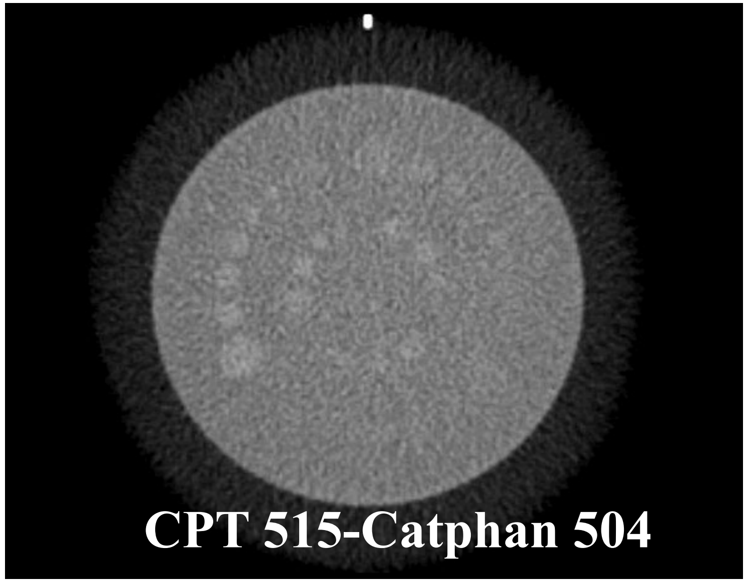


Recommended frequency: Monthly

Low Contrast Resolution

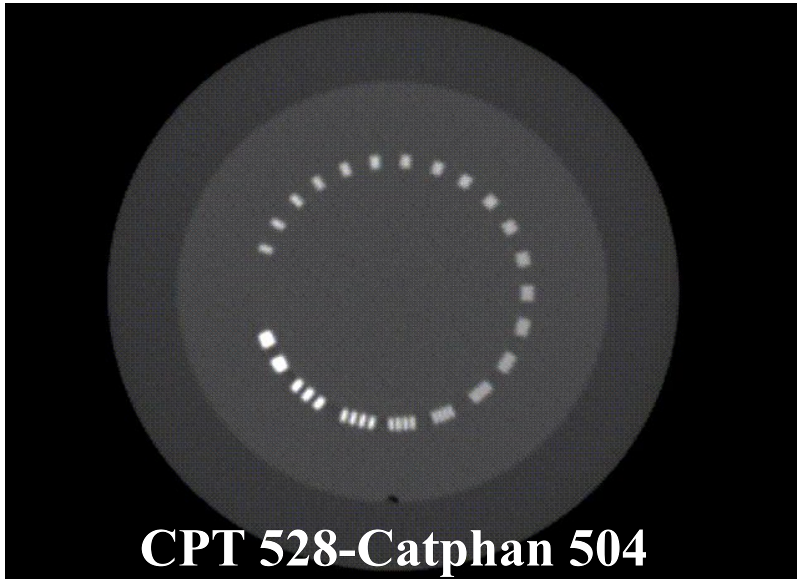
- The ability to detect subtle differences in gray scale values
  - It is important in IGRT to visualize soft tissue variations

Recommended frequency: Monthly



High Contrast Resolution

- Refers to the smallest object that can be resolved in a volumetric dataset resulting from a computed tomography acquisition
  - It is expressed in terms of lp/cm or lp/mm, also called spatial resolution

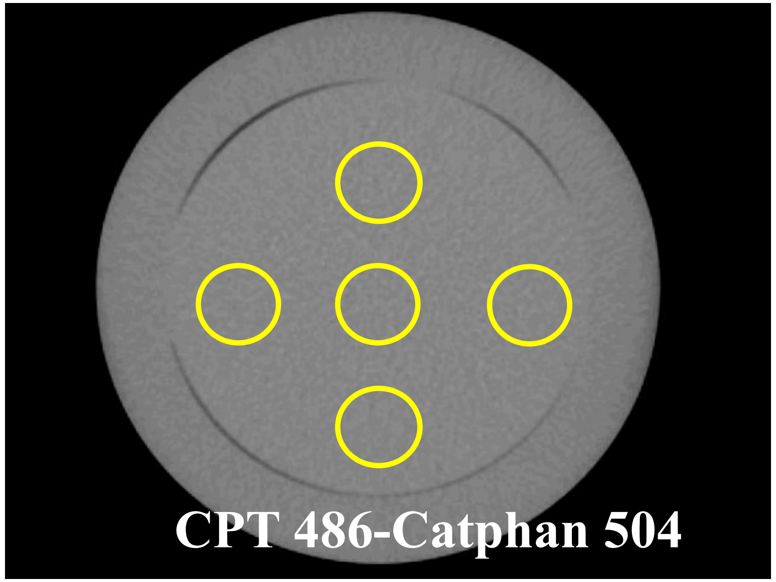


Recommended frequency: Monthly

Uniformity and Noise

- Uniformity is a measure of the CBCT scanner's ability to produce an image of a homogeneous object with mean pixel values that do not depend on the position of the pixel
- Noise refers to the fluctuations in pixel values in the image that can mask lesions or structures of interest

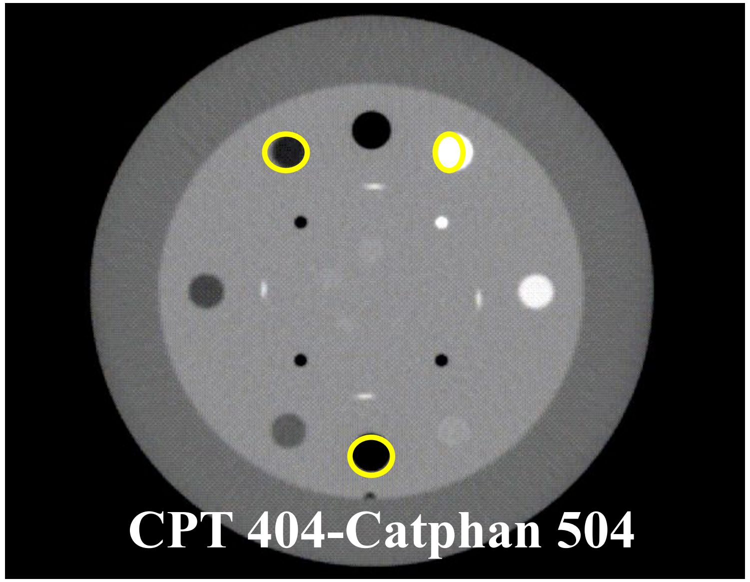
Recommended frequency: Monthly



Accuracy of CT Numbers/Voxel Density Values

- Accuracy of CT numbers is important when CBCT scans are used for dose calculation/adaptive RT
- Scatter radiation, beam hardening, high density materials affect the CT number (Hounsfield units)

Recommended frequency: Monthly



Evaluating and Quantifying Image Quality QA

- Geometric QA tasks have specific tolerance values, e.g. MV/kV beam isocenter coincidence
- Image quality tasks have no tolerance values and are often compared to "baseline" ones

Establishing Baselines

- "It is recommended that the image quality tests be performed during system acceptance to obtain a system performance baseline…"

  AAPM TG-179

- "The baseline value … refers to the IGRT system manufacturer's minimum performance standard… if unavailable … value measured at commissioning"

  AAPM MPPG 2.a.

Establishing Baselines

- Baselines established after analysis of imager performance for a certain time period
  - May need to be established per imager, even if they are of the same model
  - May need to be re-established after imager calibration

Received: 29 May 2020 | Revised: 14 September 2020 | Accepted: 15 September 2020

DOI: 10.1002/acm2.13062

MEDICAL IMAGING

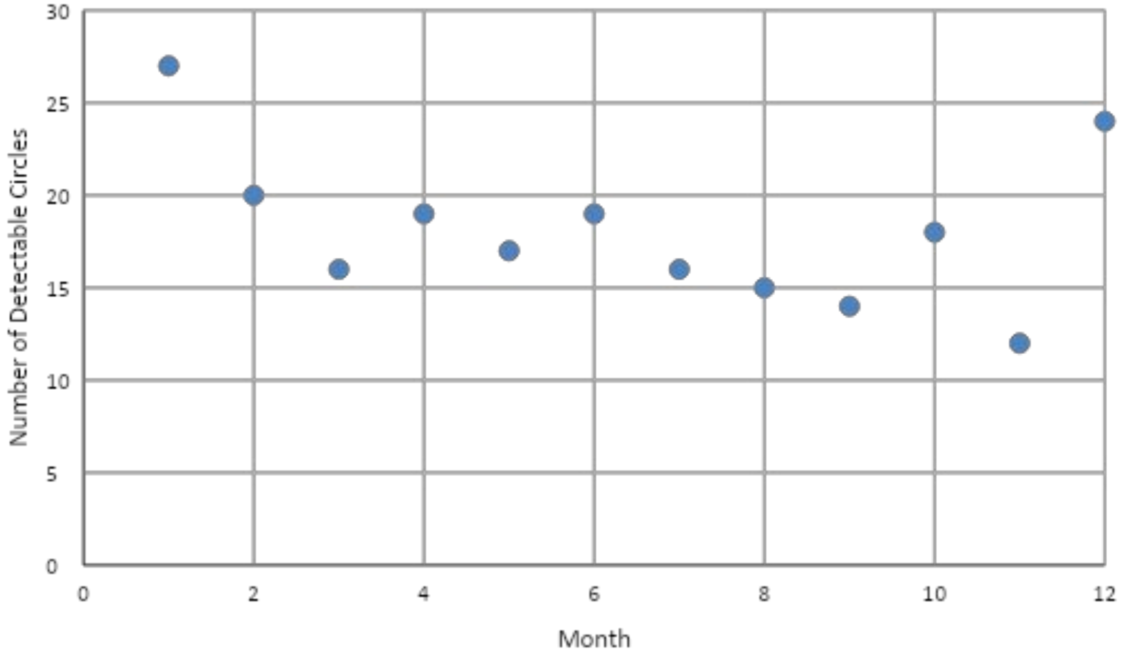
WILEY

CBCT image quality QA: Establishing a quantitative program

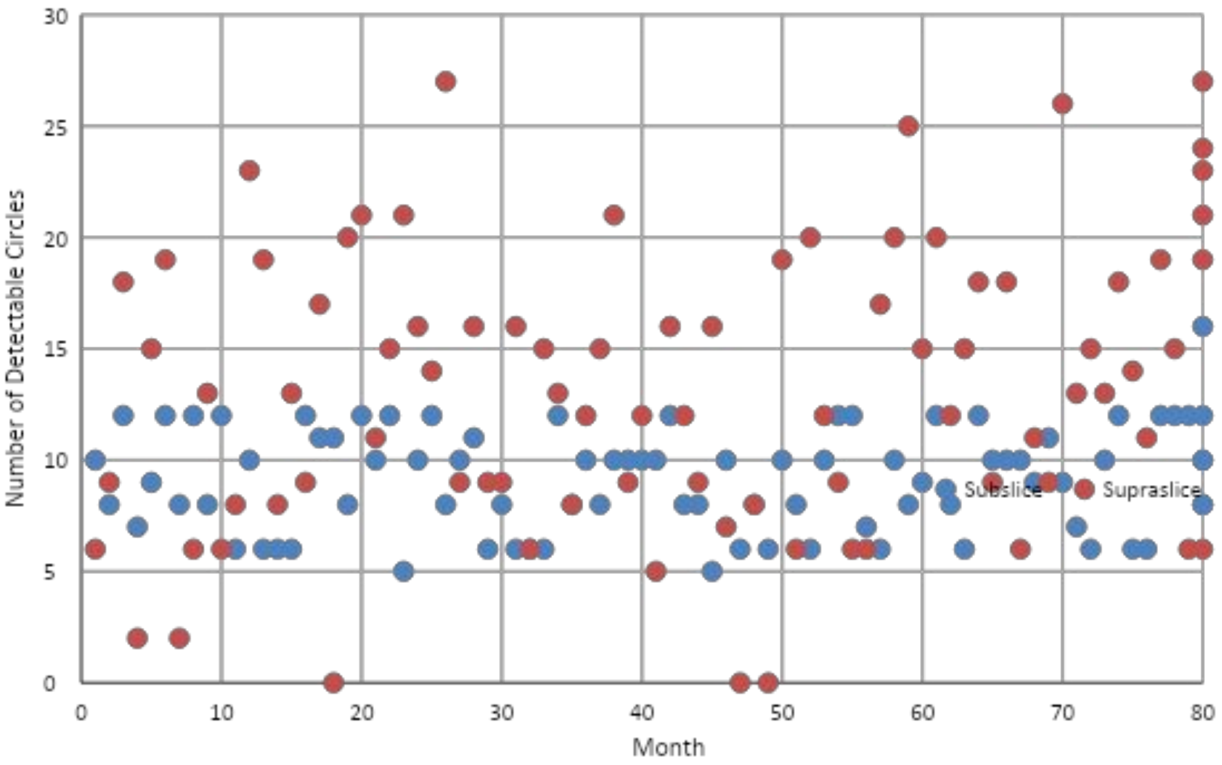
Sameer Taneja | David L. Barbee | Anthony J. Rea | Martha Malin

Establishing Baselines

Contrast evaluated using RIT for one year-Varian Edge/Catphan 604

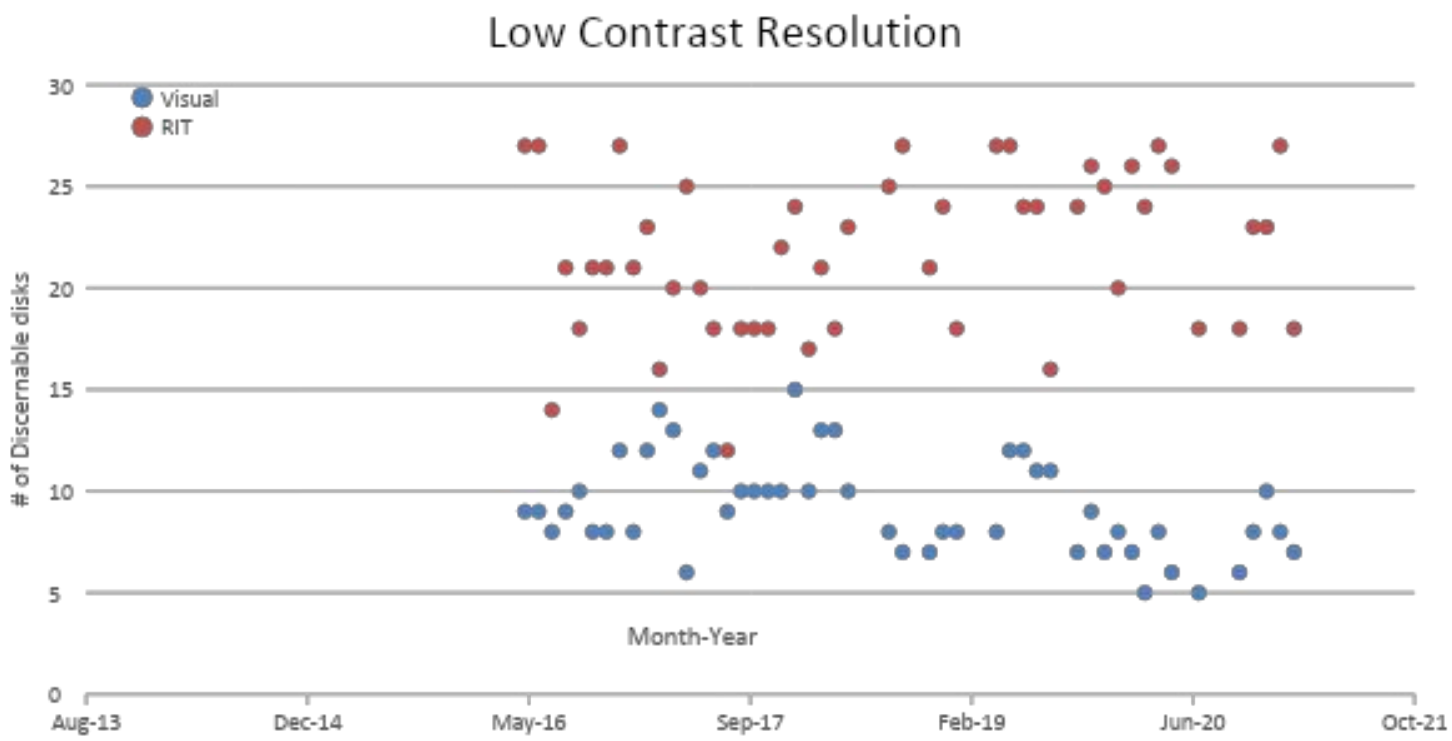


Contrast evaluated using RIT over 85 months-Varian TrueBeam/Catphan 504

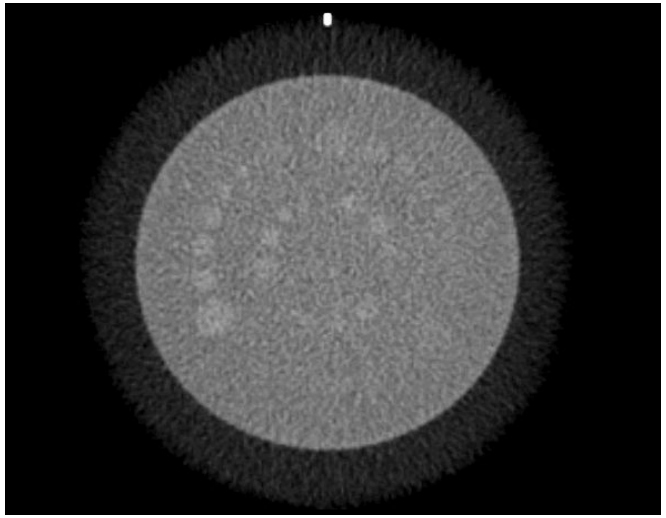


It may be challenging to establish baselines for certain image quality metrics

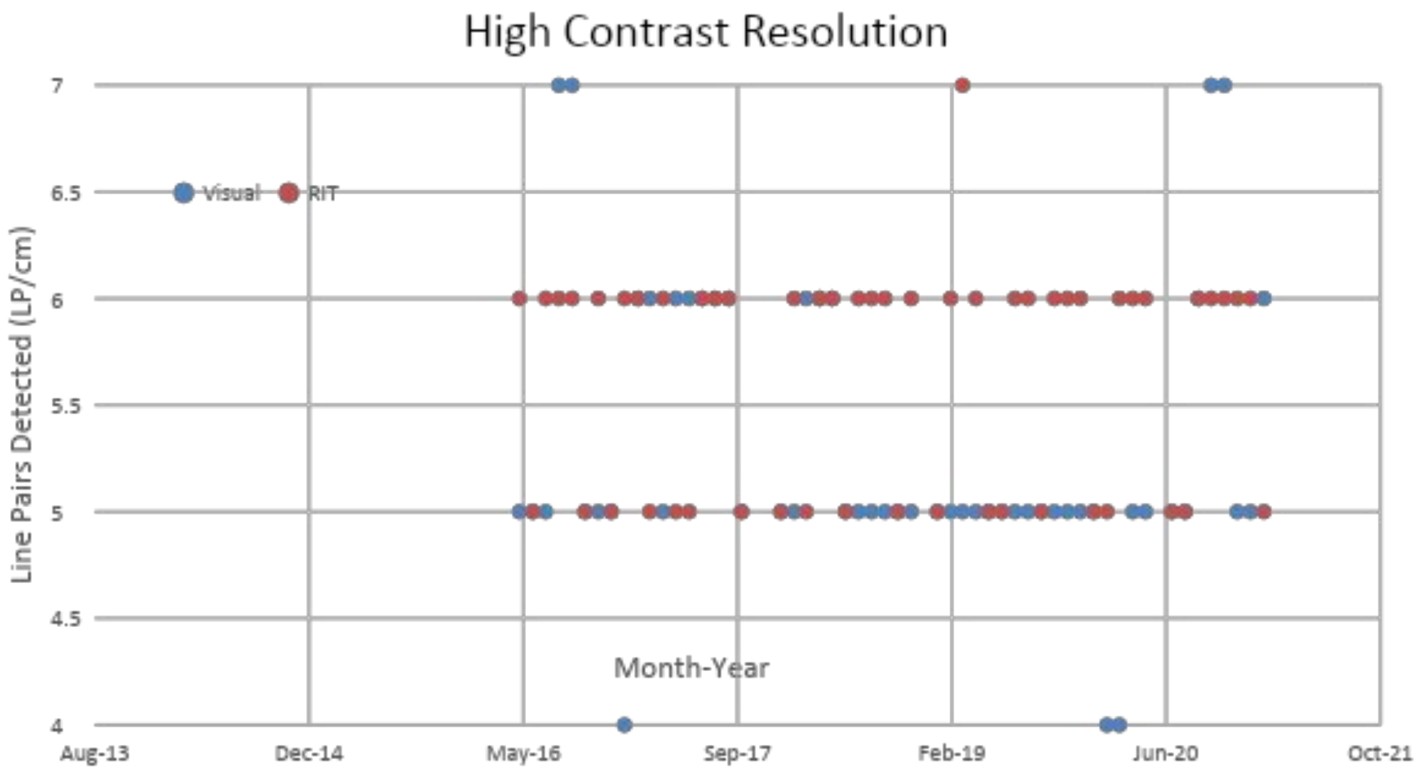
Visual vs. Software-Based Analysis



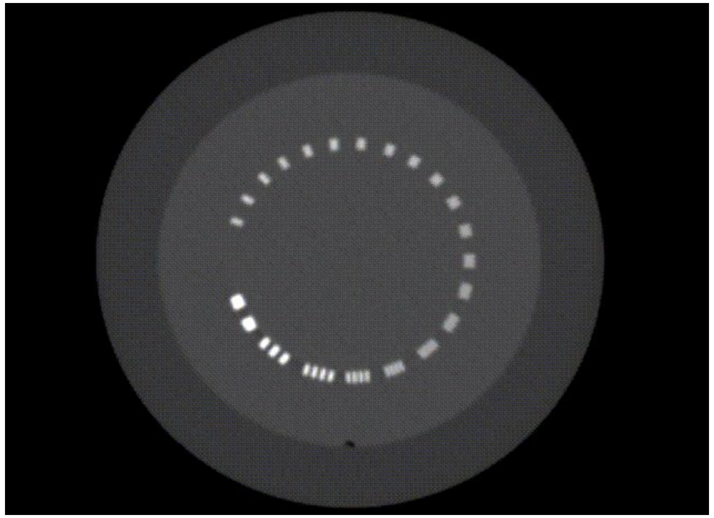
Statistically significant differences observed for low contrast resolution



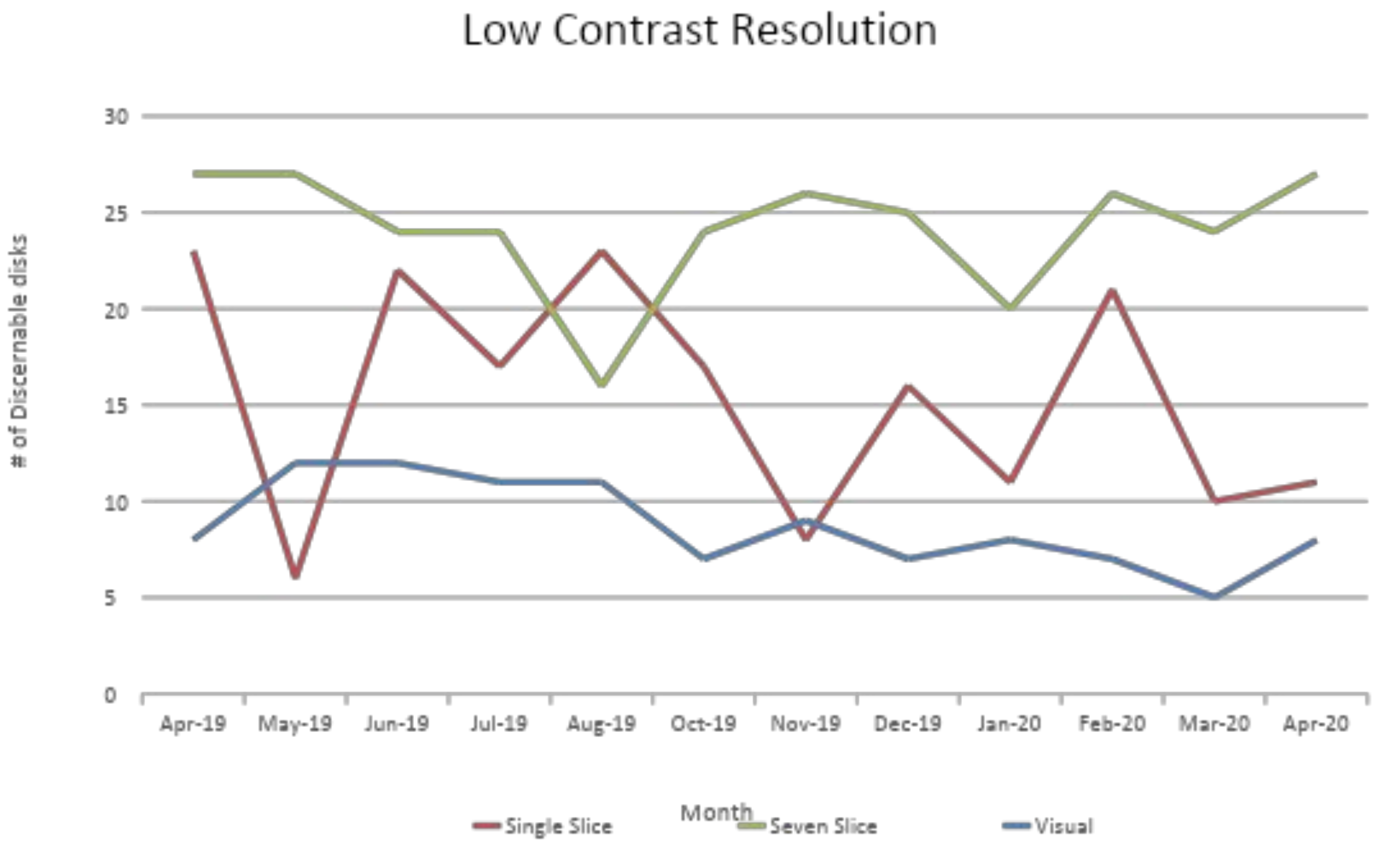
Visual vs. Software-Based Analysis



Statistically significant differences not observed for high contrast resolution



Factors Affecting Software-Based Analysis



-Slice selection (middle of module vs. periphery)

-Single vs. multi slice analysis (frame averaging may improve results)

It is important to perform the analysis consistently!

Is Software-Based Analysis Always Superior to Visual One?

- Software-based analysis is superior to visual ones for certain image quality analysis tests

- It may not provide significantly different results for other tests

BUT

- Will save time, streamline the process, and remove user variability

Becerra-Espinosa et al., *J App Clin Med Phys* 2024; 25: e-14190

Does Software-Based Analysis Detect All Potential Issues?

- Study of automated QA using Catphan/Image Owl Total QA

- Out of 23 CBCT image quality issue, 18 were discovered by therapists or physicians while using CBCT to set up the patient
  - Automated CBCT QA may not predict all human observable image quality issues with the exception of uniformity

Technical Note: Assessing the performance of monthly CBCT image quality QA

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(Received 14 January 2019; revised 11 March 2019; accepted for publication 2 April 2019; published 24 April 2019)

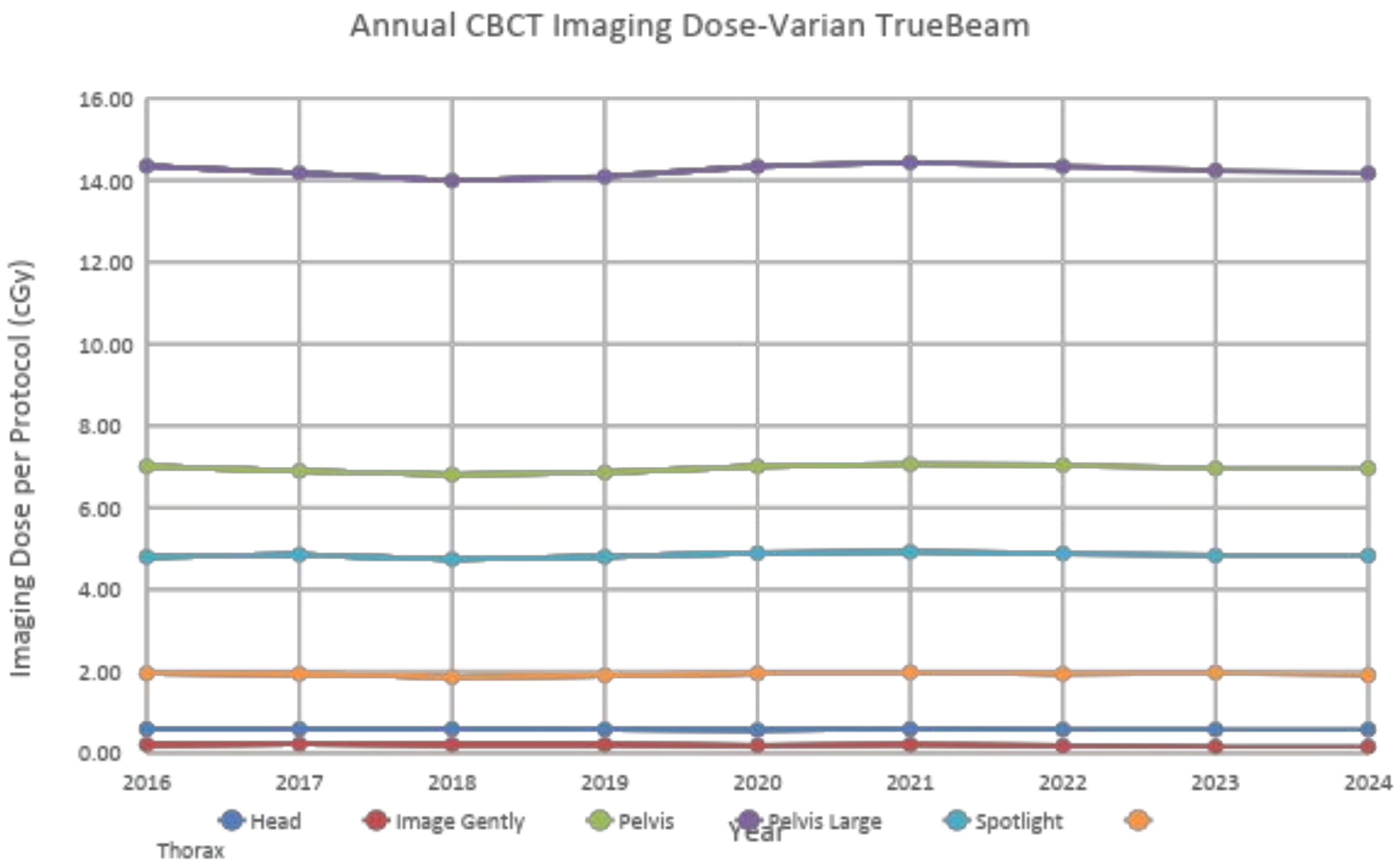
Image Dose

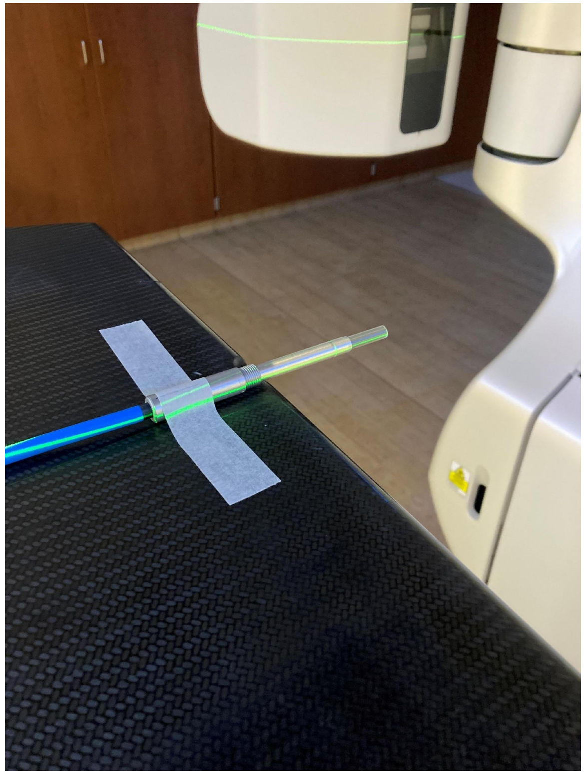
- AAPM reports recommend measuring the CBCT dose on an annual basis and compare that to the baseline values measured at commissioning
- None explicitly specify "how" to measure the dose (in phantom or in air)
- Many have employed the CTDI concept to assess dose from CBCT systems
  - Suffers from inaccuracies due to finite phantom and detector length, half-beam scanning, etc.

Image Dose

- Other methods to determine the dose from CBCT scans:
  - IAEA Report No. 5 methodology
  - AAPM TG-111 report methodology
  - Use a Farmer-type chamber commonly available in RT departments and make an in-air measurement (requires calibration factor for kV beam energies)
  - In either case, this is a measure (index) of scanner output AND not a measure of patient dose

Image Dose





Imaging dose trend over a nine-year period for one Linac,
Dose measured using an ion chamber placed at the isocenter

Outline

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Summary and Conclusions

- IGRT QA is an integral part of routine quality assurance of treatment delivery systems
- There are established guidelines for IGRT QA but this is an <u>evolving field</u> so there will be additional tasks as new imaging modalities are employed
  - There are no established tolerance values for certain image quality indicators, they are compared to “baseline” values


Questions?