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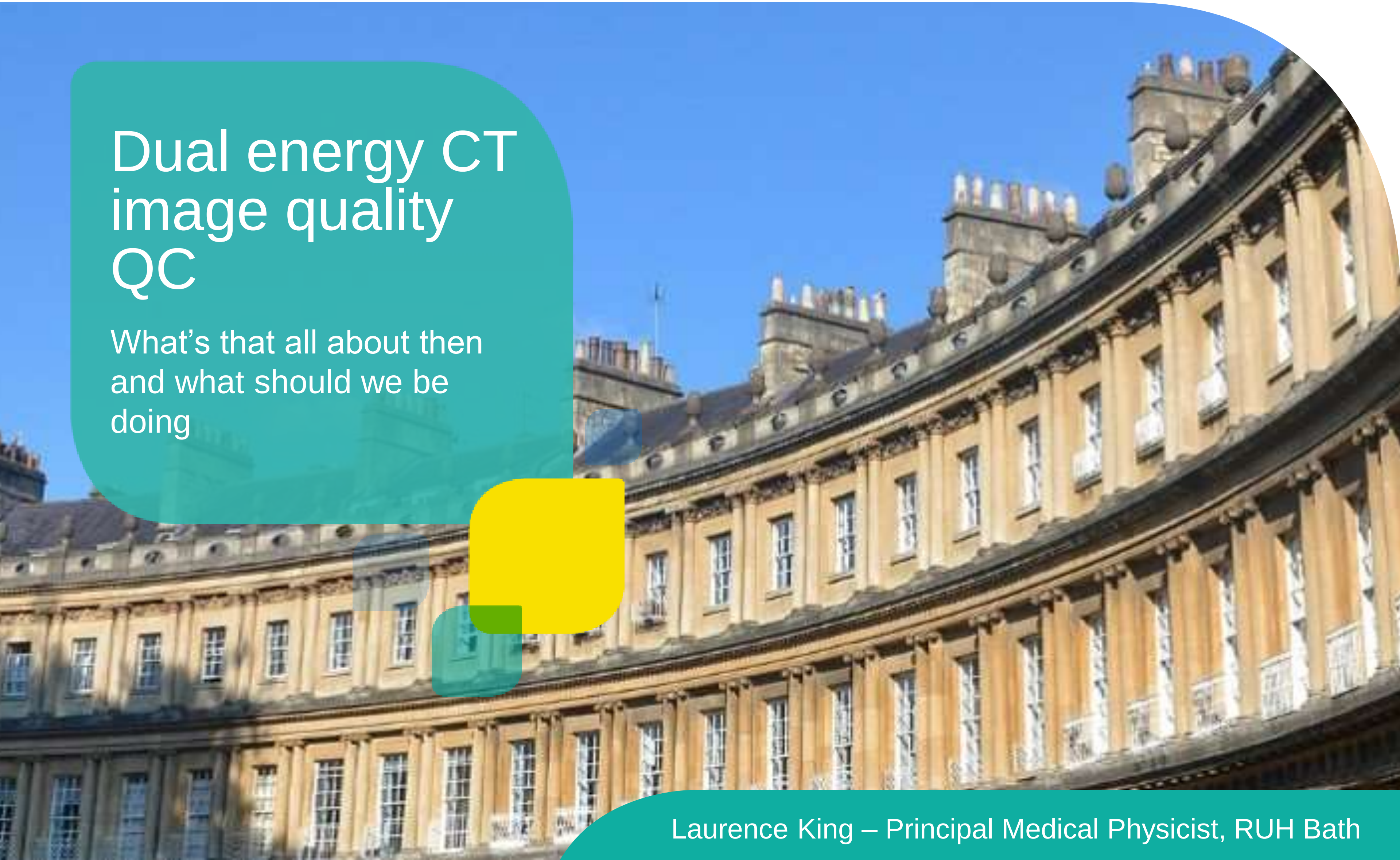


Dual energy CT image quality QC

What's that all about then and what should we be doing

Laurence King – Principal Medical Physicist, RUH Bath

Story behind this talk

- I joined the RUH in July 2020
- Three diagnostic Siemens CT scanners on site, all dual energy capable
  - A second Siemens Drive installed in June 2021

Scanner model	Dual spiral scan	TwinBeam split filter	Dual Source DE
Siemens Edge (2017)	✓	✓	
Siemens Edge+ (2019)	✓	✓	
Siemens Drive (2018, 2021)			✓

N.B.: in this talk, Dual Energy CT / Multi-Energy CT / Spectral CT are synonymous

Story behind this talk

- Performing routine CT QA towards end of 2020, and looking ahead to new install:
  - No local Dual Energy CT QA procedure

we use DECT for a small to moderate amount of scans as a routine, and it would seem sensible to have some QA – use case likely to get more, rather than less

Hi gang, we have spectral CT and I think we should do some QC of this functionality. What do you use it for?

initial attempts at DECT IVU weren't successful and the programme is paused for now.

We are starting to use it in CT imaging of the Pelvis for the possible fractures and hope that this will be used for most scans.

DECT can also be used to reduce metallic artefact so may also be used to image prosthesis. This is in the pipeline but won't be a huge volume scanned.

The three (current) Siemens DE acquisition methods

- Dual Spiral
  - Scan patient helically at 80 kV
  - Return to start position and repeat the scan at 140 kV
  - Siemens use non-rigid image registration to combine the two series.
- TwinBeam split filter
  - Scan using the tube at a single energy
  - X-ray beam is split in z-direction by Tin / Gold spectral filters
    - This halves the effective width of the detector (scan speed is reduced)
- Dual Source
  - Only available on scanners with two tubes!
  - One tube at 80 kV, second at 140 kV with Tin spectral filter
    - Second detector has limited field of view, 30 – 35 cm depending on model.

Does the physical implementation matter?

- Advantageous to acquire high and low energy signal simultaneously
  - Absolute geometric *and* temporal coincidence is the ideal

- Advantageous to have good energy separation between high and low kV spectra
  - Best satisfied by separate X-ray tubes with spectral filtration

- However, the magic happens in the image processing and reconstruction
  - And there is a lot of it.
    - Image co-registration, DE-tailored iterative reconstruction, frequency band decomposition to de-noise and improve spatial resolution.

- **High levels of image processing perhaps diminishes the importance of the method of data acquisition.**

What data do we get from DE CT that we can test?

- Many datasets available – what is most relevant?
  - Iodine maps
  - Virtual no-contrast (VNC) images with iodine subtracted
  - Other material decomposition with specific applications
    - Calcium removal
    - Renal stone characterisation
    - Gout characterisation etc.
  - Electron density and effective Z maps (rho/Z)
    - Useful for radiotherapy applications
  - CT numbers reconstructed at virtual monoenergetic X-ray energies (monoE+)
    - from 40 to 200 keV (manufacturer-dependent)
    - enhanced contrast at low monoE / improved metal artefacts at high monoE

What is out there in terms of QC guidance?

- AAPM report of task group 291 – principles and applications of MECT (July 2020)
  - Section 6.C describes the need for a quality control programme
    - "*it is the responsibility of the user to ensure quantification accuracy and reproducibility*"
  - The report gives no specific guidance.
- Paper published in Medical Physics (April 2018) describes the development of a Dual Energy CT QC program for fast kV-switching CT scanner
  - JL Nute *et al*, Med Phys. 2018 Apr; 45(4): 1444–1458.
  - https://dx.doi.org/10.1002%2Fmp.12812
  - Prototype QC phantom with 16 inserts including multiple iodine and calcium
- Similar paper published in Journal of Applied Clinical Medical Physics (Sep 2021)
  - Green, Solomon, Ruchala & Samei, J Appl Clin Med Phy. 2021; 22: 249–260
  - https://doi.org/10.1002/acm2.13396
  - Phantom based on standard ACR phantom, with four iodine and one calcium inserts

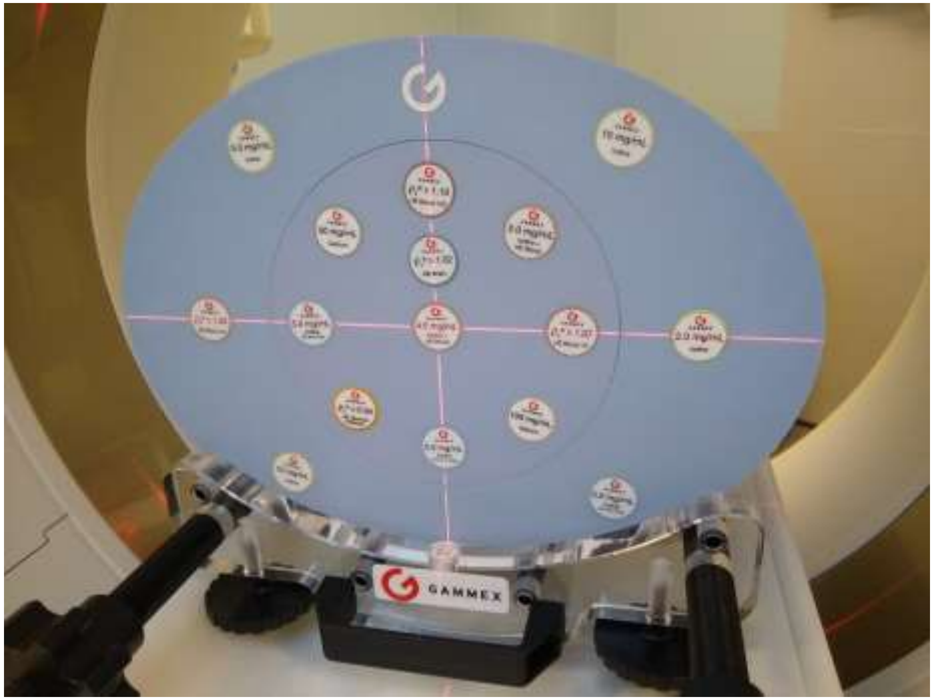
Published papers – what did they do?

- JL Nute *et al*, Med Phys. 2018 Apr; 45(4): 1444–1458.
  - Assessed iodine quantification error in mg/mL for Iodine inserts
  - MonoE+ HU stability and noise for all inserts
  - QA results were most stable over time for 70 keV monoE+ images

- Green, Solomon, Ruchala & Samei, J Appl Clin Med Phy. 2021; 22: 249–260
  - Iodine concentration in mg/ml assessed for all inserts
  - VNC HU and noise assessed for all inserts
  - MonoE+ HU assessed at 70 keV against NIST-derived nominal values
  - Calcium quantification assessed in mg/ml for all inserts

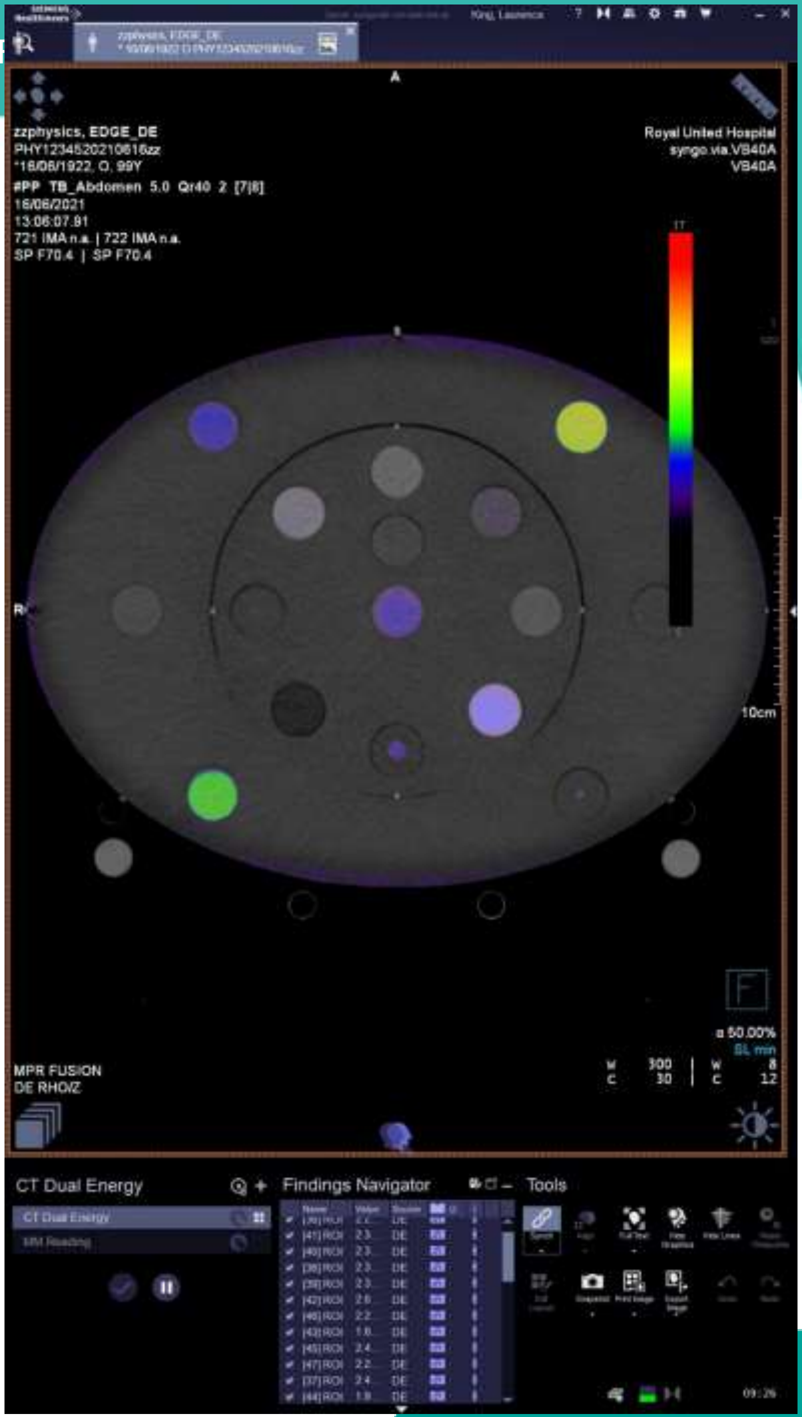
What did I do?

- Borrowed a phantom for evaluation (Gammex MECT phantom from XIEL imaging)
  - This is the phantom derived from the prototype described by Nute *et al*
- Scanned it based on a default Siemens DE abdomen protocol
  - Three × scan doses on Drive
  - TwinBeam and dual spiral on Edge+
  - High and Low kV images sent to SyngoVia for processing later.
  - Performed MonoE+ and other image analysis using SyngoVia Client
- Not enough time to do full a scanner characterisation!
  - Just trying to work out what would suffice for routine QA…



SyngoVia client

- Send just the high and low kV images from scanner
- Under different application profiles, can generate MonoE+ images, rho/Z, Iodine maps and so on, away from the scanner.
- Place ROIs and export results as .png images and text data (can be imported to Excel)
- Same recons <u>can</u> be done at the scanner, but I had limited time at the scanner to set this up.



Results – monoE accuracy

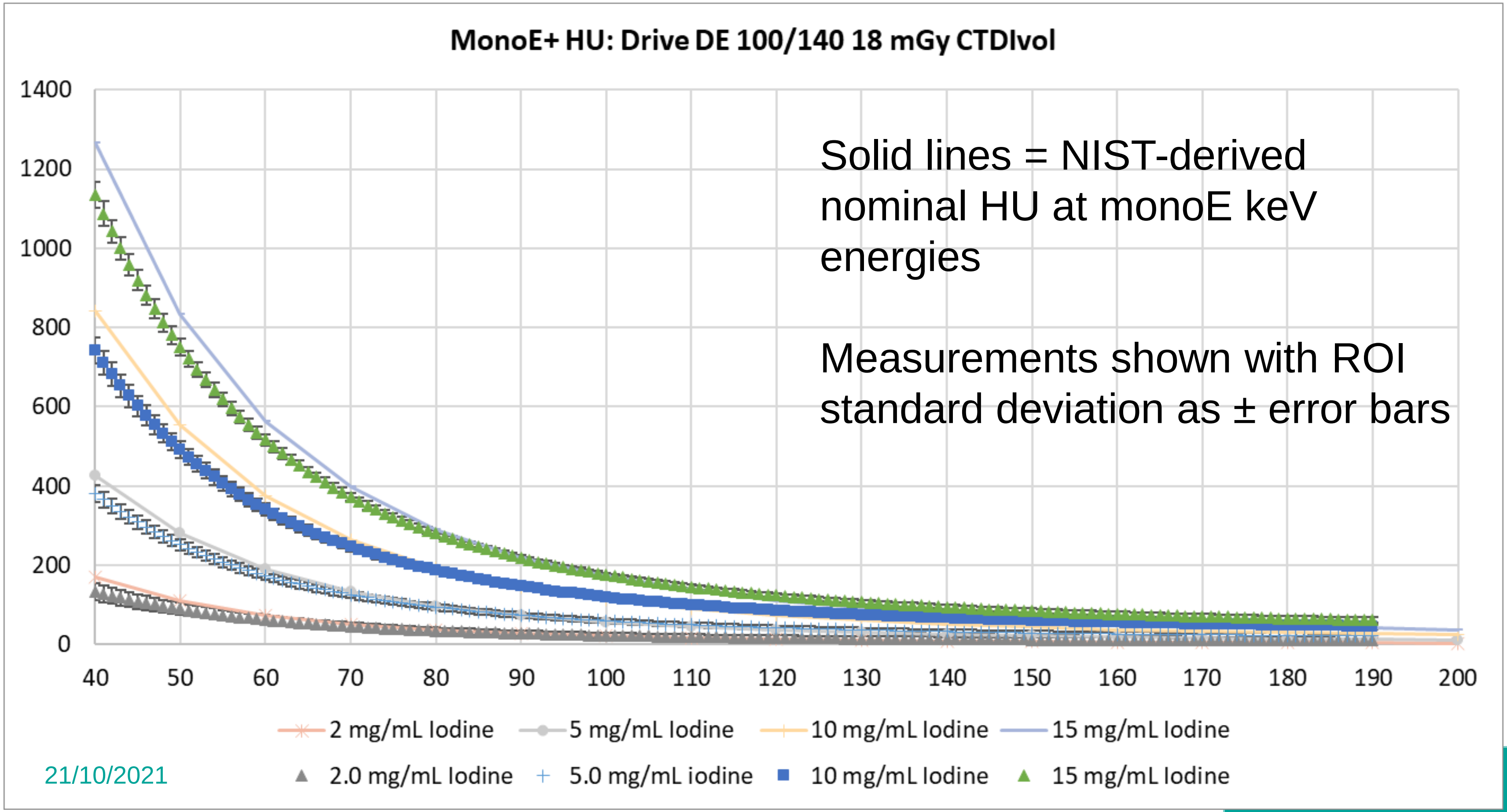
- Results – MonoE HU accuracy vs NIST-derived HU for all keV values
  - Nominal MonoE HU values are provided in the MECT phantom user manual
  - Results displayed for a limited number of inserts for brevity & legibility!
    - 2.0 mg/mL Iodine
    - 5.0 mg/mL Iodine
    - 10 mg/mL Iodine
    - 15 mg/mL Iodine
    - 50 mg/mL Calcium
    - 100 mg/mL Calcium
    - HE Brain

Solid lines = NIST-derived nominal HU at monoE keV energies

Measurements shown with ROI standard deviation as ± error bars

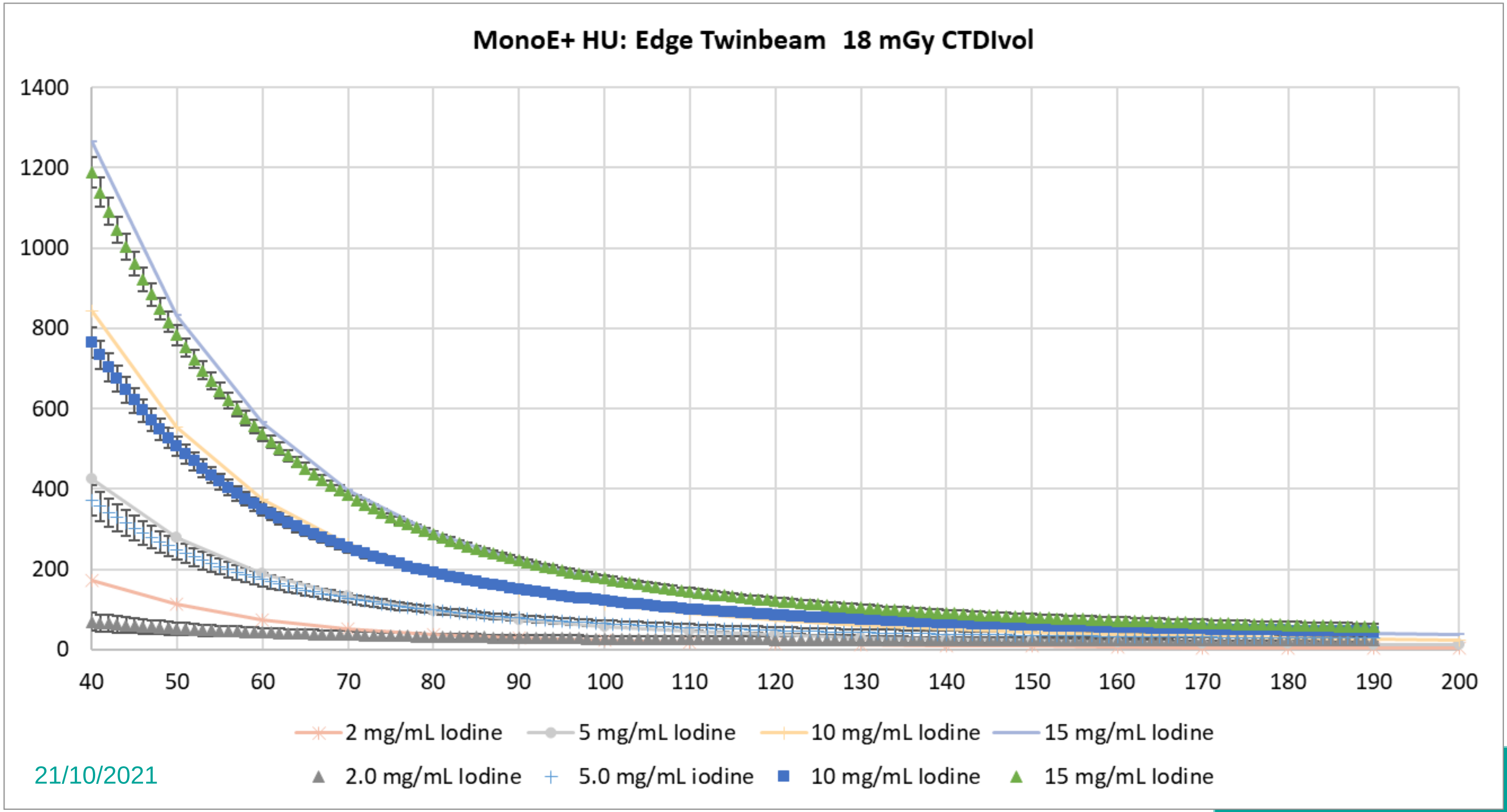
MonoE HU accuracy vs NIST-derived HU

- Nominal MonoE HU values provided in phantom user manual
- DRIVE DUAL SOURCE 100/140Sn 18 mGy acquisition: IODINE INSERTS



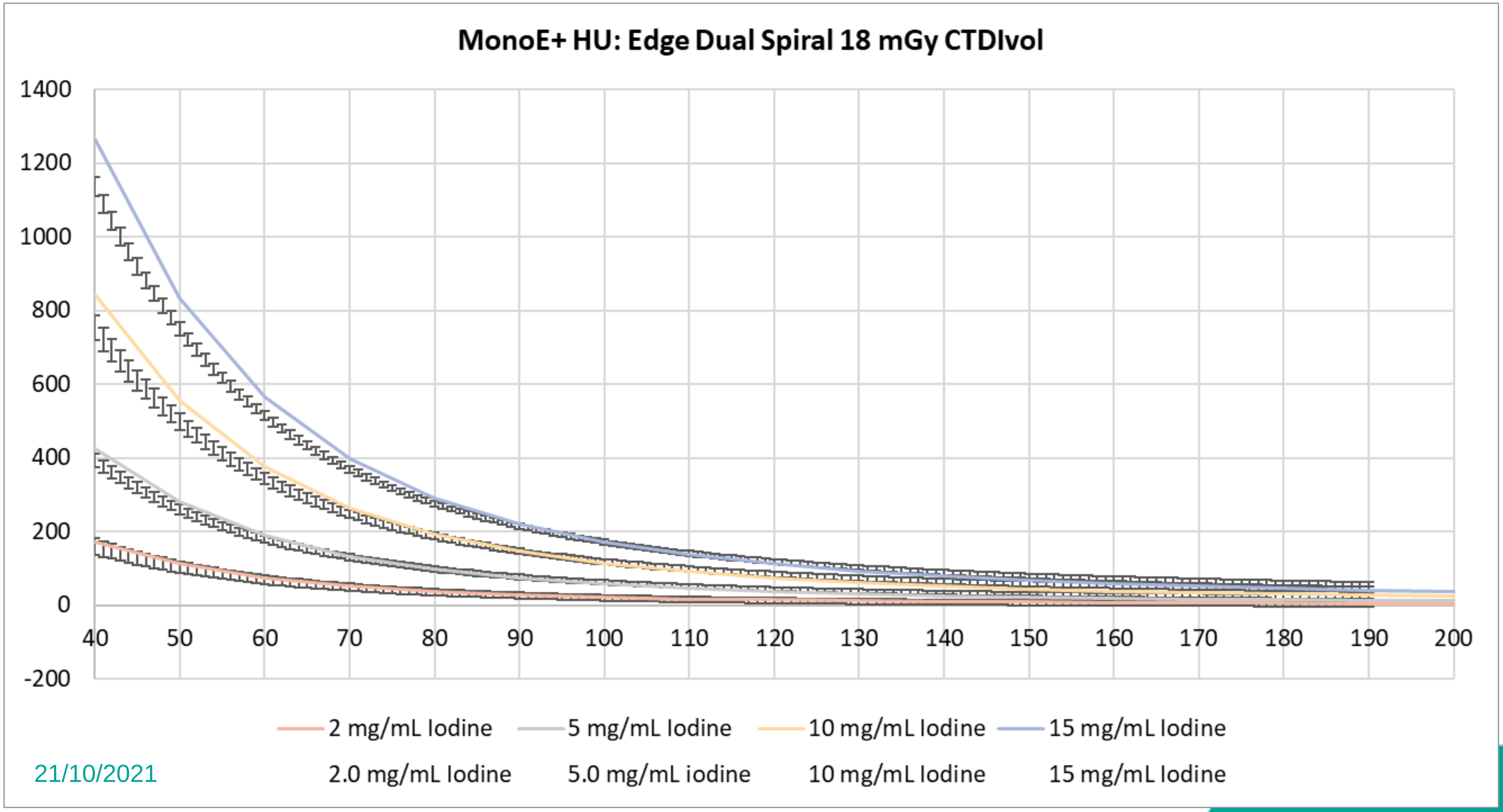
MonoE HU accuracy vs NIST-derived HU

- Nominal MonoE HU values provided in phantom user manual
- EDGE+ TWINBEAM 18 mGy acquisition: IODINE INSERTS



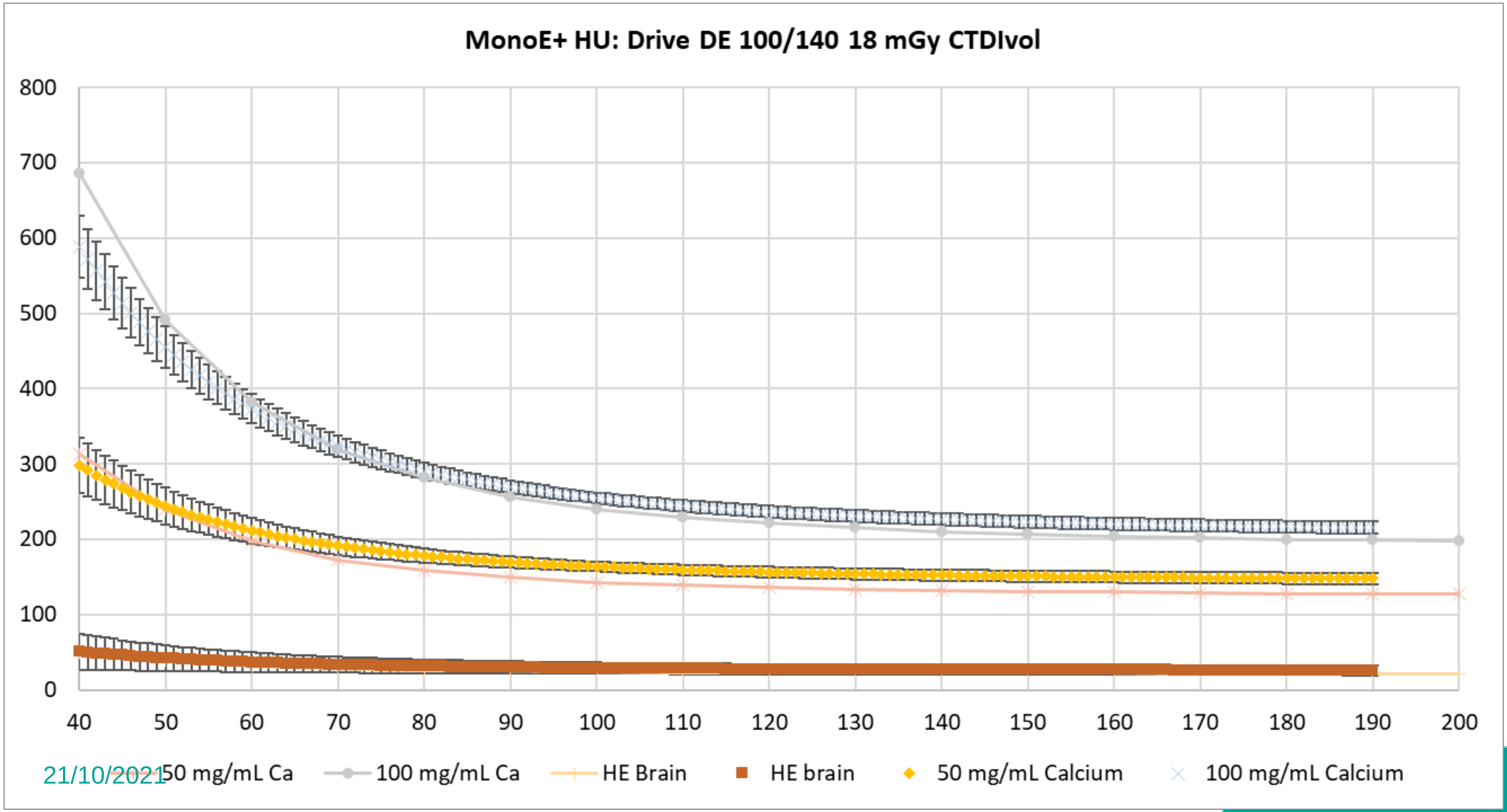
MonoE HU accuracy vs NIST-derived HU

- Nominal MonoE HU values provided in phantom user manual
- EDGE+ DUAL SPIRAL 18 mGy acquisition: IODINE INSERTS



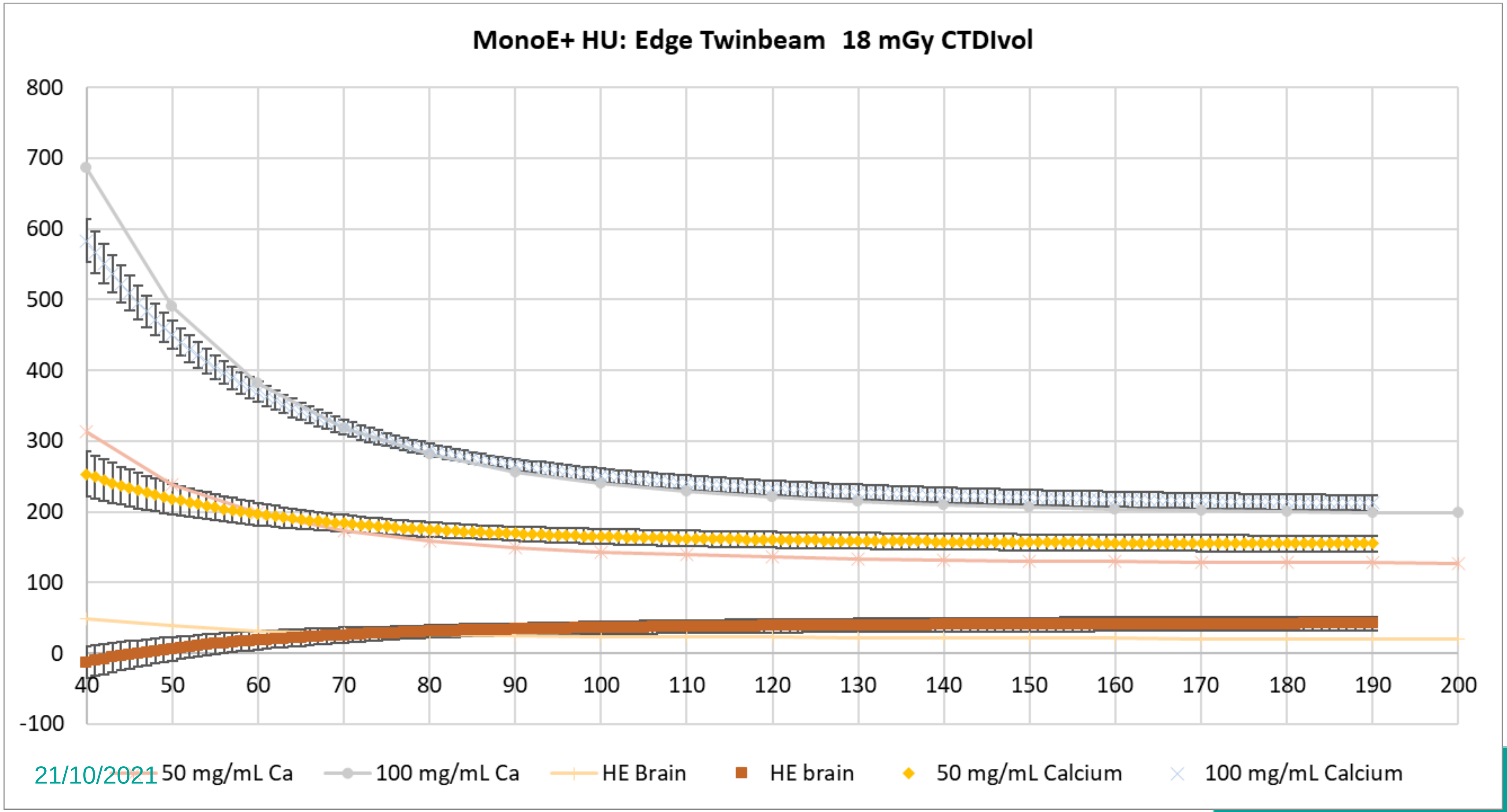
MonoE HU accuracy vs NIST-derived HU

- Nominal MonoE HU values provided in phantom user manual
- DRIVE DUAL SOURCE 100/140Sn 18 mGy acquisition: Ca AND TISSUE INSERTS



MonoE HU accuracy vs NIST-derived HU

- Nominal MonoE HU values provided in phantom user manual
- EDGE+ TWINBEAM 18 mGy acquisition: Ca AND TISSUE INSERTS



MonoE HU accuracy vs NIST-derived HU

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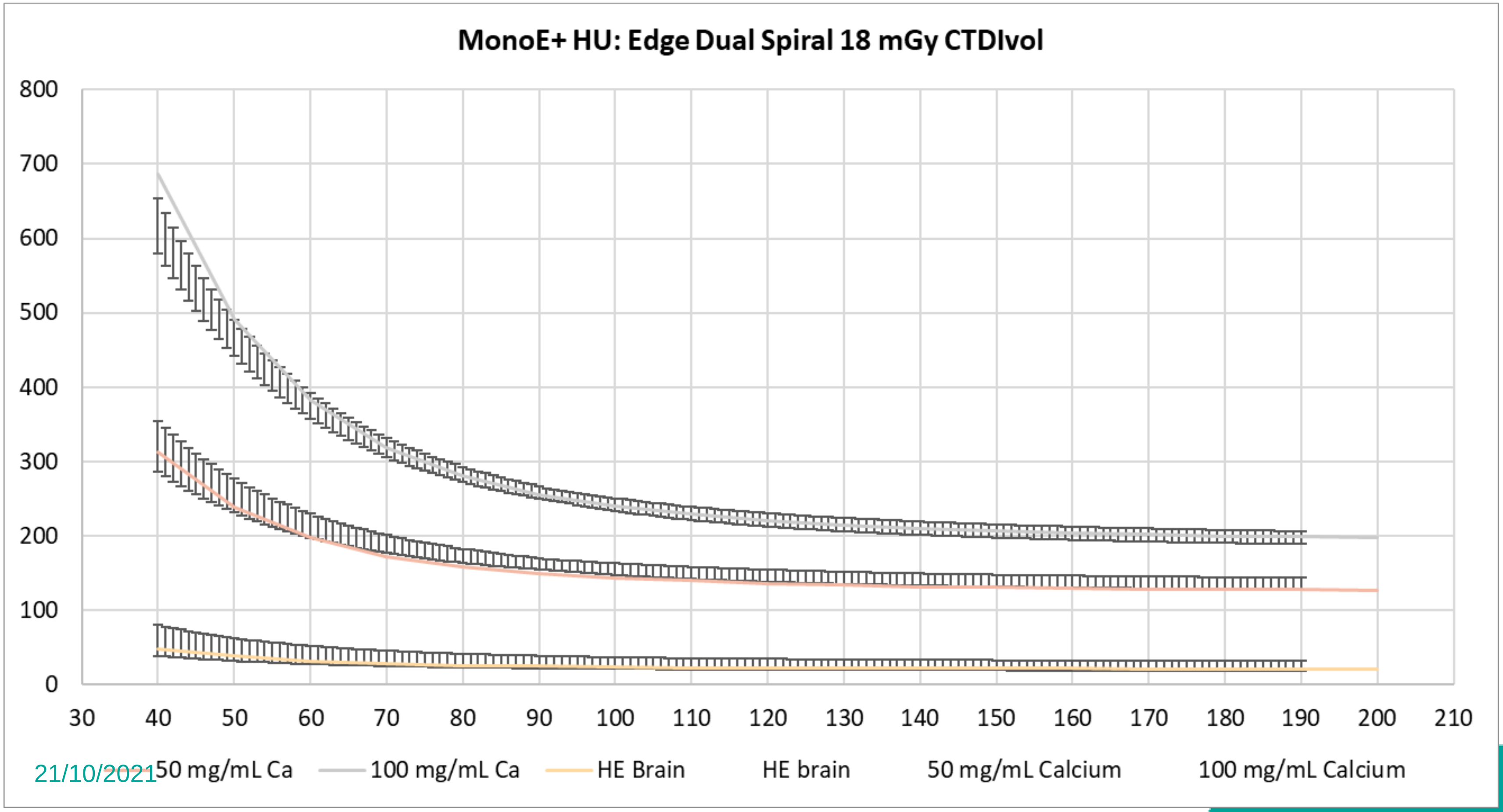
- EDGE+ DUAL SPIRAL 18 mGy acquisition: Ca AND TISSUE INSERTS



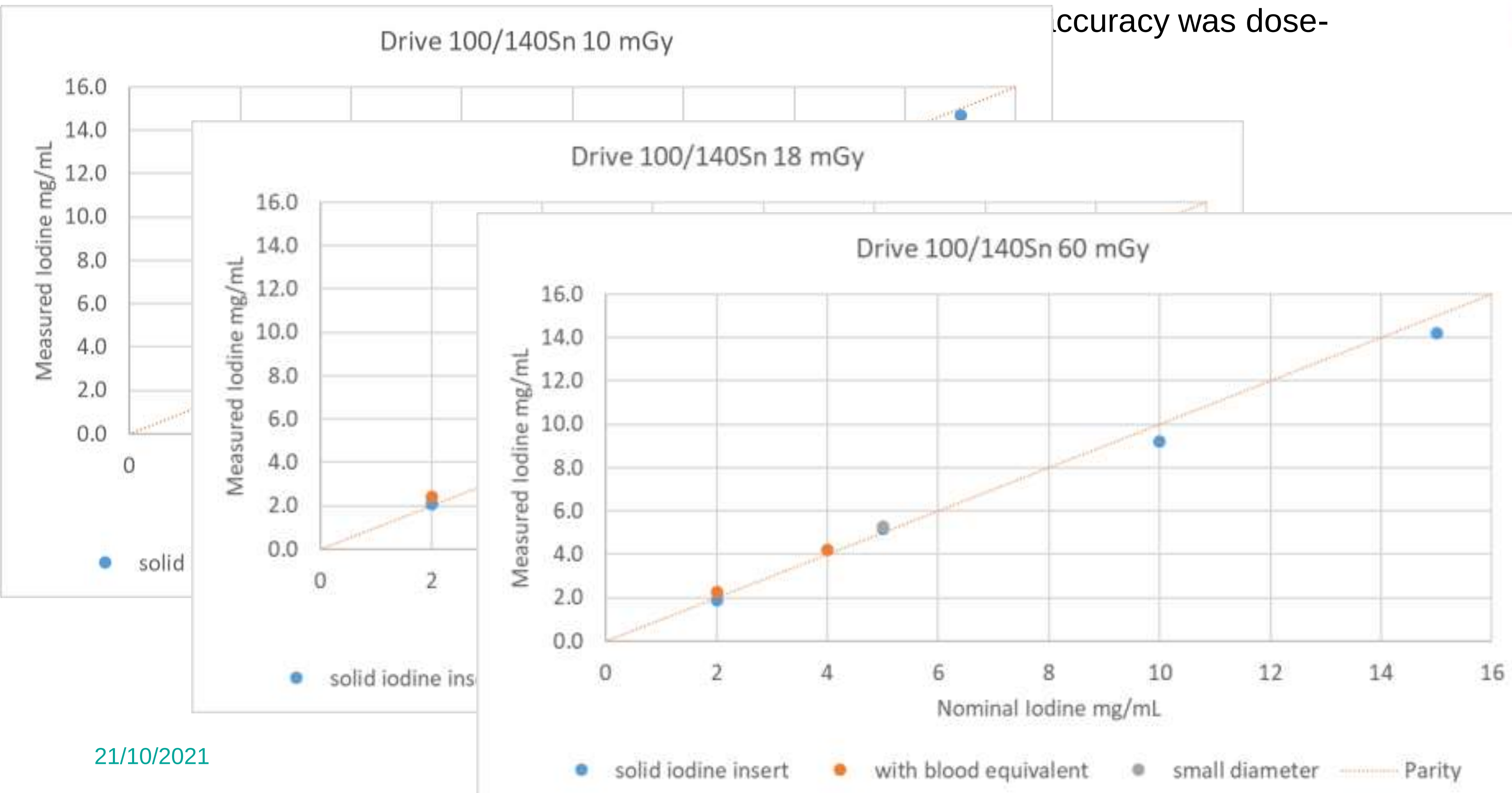
Results – Iodine quantification accuracy

- Results – Iodine quantification accuracy
  - Results presented for:
    - 2.0 mg/mL Iodine
    - 2.0 mg/mL Iodine + blood mixture
    - 4.0 mg/mL Iodine + blood mixture
    - 5.0 mg/mL Iodine
    - 5.0 mg/mL Iodine (small diameter insert)
    - 10 mg/mL Iodine
    - 15 mg/mL Iodine
  - First slide: 3× doses on Drive Dual Source scanner
  - Published work showed that GE fast kV-switching Iodine accuracy was dose-dependent.

Results – Iodine quantification vs nominal insert values

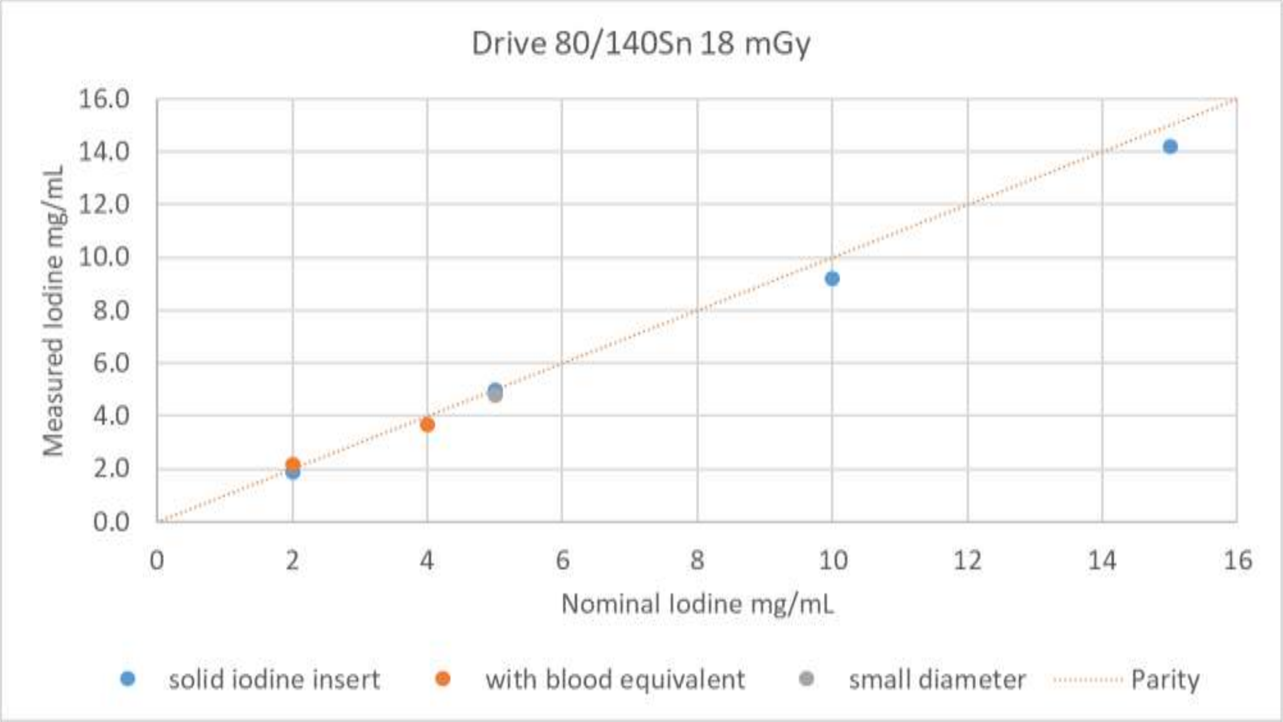
- DRIVE dual source 100/140Sn at 3× dose levels: HU accuracy of Iodine

ccuracy was dose-



Results – Iodine quantification vs nominal insert values

- DRIVE dual source 80/140Sn at 18 mGy CTDIvol
  - Not significantly different to 100/140Sn data.



Results – Iodine quantification vs nominal insert values

- EDGE TWINBEAM 120 kV 18 mGy CTDIvol
  - Lower iodine quantification accuracy at low concentration? More measurements would be useful.

Results – Iodine quantification vs nominal insert values

- EDGE DUAL SPIRAL
  - No Iodine quantification available!
  - I may not have picked up the correct protocol at the scanner…
  - From Syngo Via documentation:

Liver VNC scan requirements

If you perform a Dual Spiral or TwinSpiral Dual Energy scan for an evaluation with Liver VNC, the scan must meet the following requirements:

- The scan is performed with the scan protocol DE_Abdomen_LiverVNC_late or a scan protocol derived from it.

  - I picked up the DE_Abdomen protocol, not the specific LiverVNC protocol!

Other results I haven’t shown -

- VNC HU and noise
  - Useful to check these for constancy alongside measured image noise and HU in conventional (non-DE) scan modes.
  - Measured noise was similar across all techniques –
    - All acquisitions at 18 mGy CTDIvol
    - Lots of denoising processing going in during reconstruction

- Effective rho and Z
  - Are these useful aside from radiotherapy applications?
  - These scanners are not used in this way.
  - I have not analysed further.

End impressions

- I was able to obtain following measurements fairly straightforwardly:

- **MonoE HU measurements** against nominal for a range of materials
  - Error was larger at low keV < 70 keV
  - Greatest errors with TwinBeam acquisition mode.

- **Iodine quantification versus nominal values**
  - All modes gave lower than nominal for high concentrations (10 and 15 mg/mL)
  - TwinBeam mode also underestimated low concentration (2 mg/mL)

- I would recommend adopting these for routine quality constancy tests – if an appropriate phantom is available locally!

More considerations

- Discussion
  - Analysis was time consuming in this first instance!
  - Will be simpler when a dedicated QA protocol is saved on the scanner with the correct recons which are then exported and analysed – this would be consistent with existing routine physics CT QA workflow
- Action limits?
  - What is the required matching between scanners and techniques?
  - Some action limits suggested in Med Phys. 2018 Apr; 45(4): 1444–1458
- I haven't yet attempted Calcium quantification – important to do so if your centre uses this feature clinically

Phantoms

- The borrowed Gammex MECT phantom has many details for comprehensive system characterisation
  - Perhaps more than needed for routine QC: do we already have something local that we can use?
- The Catphan has a range of insert materials and densities but none containing iodine or calcium.
  - Cannot assess quantification for these materials.
- We also have the Mercury IV phantom which contains bone equivalent (50% $CaCO_3$), 10 mg/ml Iodine, polystyrene, air and solid water materials.
  - **My next step** will be to evaluate this phantom for routine Dual Energy CT QA
  - I have requested exact insert composition to derive nominal monoE HU values from NIST data.

Other guidelines / publications in progress

- An IPEM DR-SIG working party has recently been formed to update IPEM 32 iii guidance
  - DECT / MECT will be included in the new edition.

- IEC working group proposal for new standard covering performance of spectral CT
  - BIR and IPEM have representatives for this work

Discussion please!

- Are you carrying out QA *routinely* for:
  - DE iodine / calcium quantification?
  - Any other measures of DE image quality?
- What phantom or tools do you use?
- Are there other guidelines or publications that I’ve missed?
- Contact me: Laurence.king@nhs.net

Thanks to

- Thomas Jupp at Surrey County Hospital in Guildford for useful discussions via Teams
- CT Superintendent Rachel Ferrington at Bath
- Godfrey Hounsfield for starting all this in the first place

Other potential Physics issues

- Not yet addressed adequately (in my opinion) for Spectral CT -

- Patient dosimetry –
  - E.g. Siemens tin (Dual source) and gold/tin (Twinbeam) spectral filters produce different spectra to conventional CT. Are current conversion factors and dose calculators satisfactory?
  - Same for fast kV-switching scanners.

- Dose modulation –
  - Limited choice of kV with some techniques and limited in-scan tube current modulation on fast-kV switching techniques. How do we best assess this?