Improving stroke patient care through CT parameter optimization.

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CT and Stroke Diagnosis

Why are suspected stroke patients given a Brain CT?

Brain scans determine:

- The region of the brain affected
- The severity of the stroke
- Whether the stroke is ischaemic or haemorrhagic.

What are some indications of stroke?

- Loss of normal gray-white matter differentiation.

Relative to normal tissue:

- Ischaemic brain parenchyma is hypoattenuating.

Why is accurate diagnosis critical?

- Dictating appropriate treatment.
  - e.g., patients with large infarcts as they are less likely to benefit from thrombolysis

Why is low contrast detectability (LCD) important in stroke diagnosis?

- LCD describes the ability to distinguish between regions on a CT image that have similar x-ray attenuation characteristics.

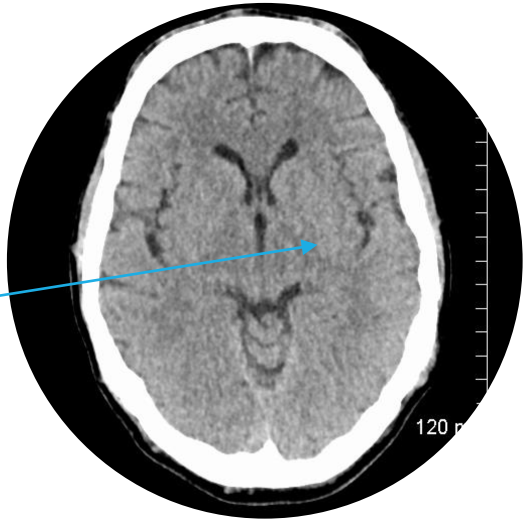
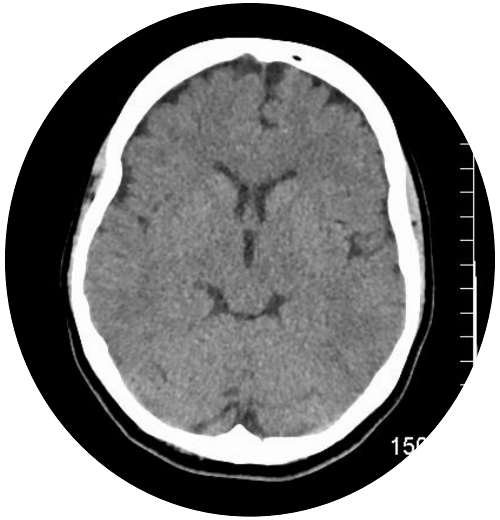
Purpose

- **Radiologists at the Mater have been concerned with inconsistencies in Brain CT image quality.**
- **Medical Physics was tasked with investigating the differences in protocols in feeder hospitals.**
- **Brain CTs are the most common CT examination in the UK and Rep. of Ireland.[1]**
  - ➢ Is there a significant variation?
  - ➢ Given the ubiquity of Brain CT, should image quality be standardised?

Purpose

- **Even to the untrained eye, differences in image quality can be seen…**

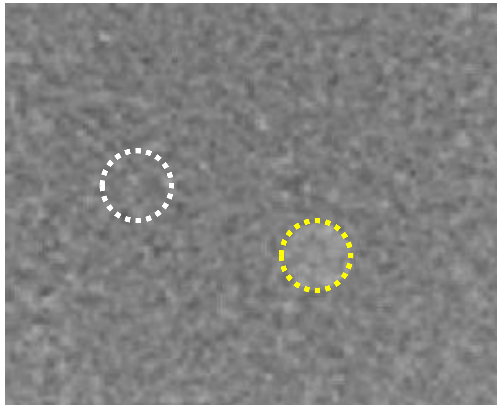
Better grey-white matter differentiation

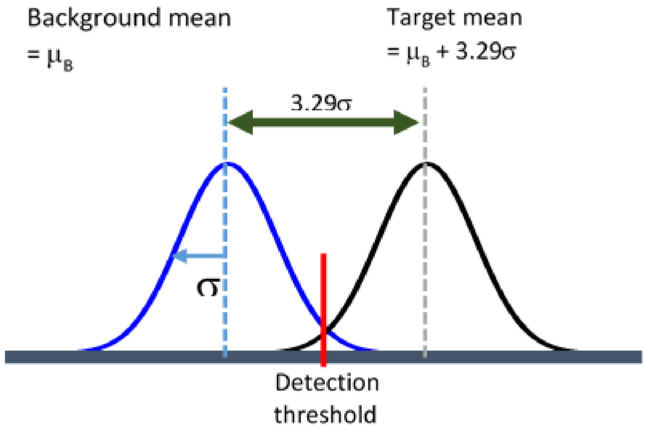



- **We aimed to:**
  - ➢ Develop an objective method of measuring LCD in CT scans.
  - ➢ Identify which combination of CT acquisition parameters maximises the ability to detect these small changes in attenuation.
  - ➢ Investigate the variation in imaging protocols for suspected acute stroke at different institutions in the regional hospital network.

Background Theory

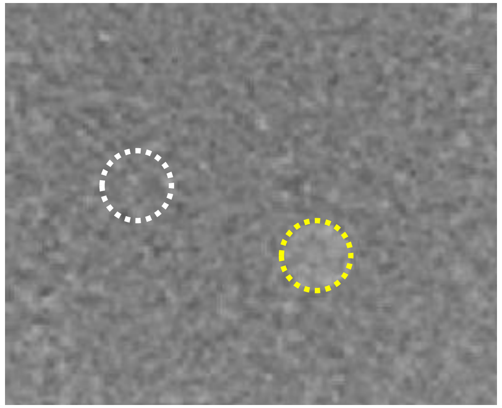
- First proposed by Chao et. al.[2] and later described by Hseih.[3]
- Take a uniform image with an attenuator approximately equivalent to a typical patient. Suppose there were a small low contrast target in the attenuator.
- Take an ROI in the image identical to that low contrast object. The pixel values would have a Gaussian distribution, with a mean pixel value μ_T and a standard deviation σ_T.
- Similarly, taking an ROI of the same size of the background, the pixel values would also follow a Gaussian distribution, with mean pixel value μ_B and a standard deviation σ_B.

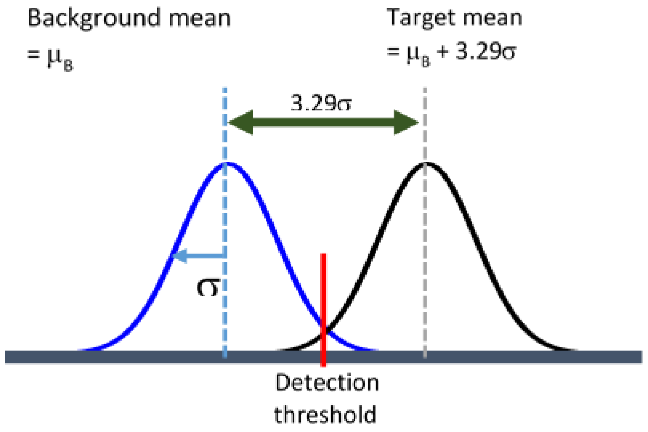




Background Theory

- Both distributions are similar in shape, just separated by the difference in their respective mean pixel values.
- Statistically, if two Gaussians distributions are separated by 3.29σ, the distributions can be distinguished at a 95% level of confidence.
- This implies that we do not actually need a physical target in the phantom.
- Calculating the parameters of the Gaussian distribution of the background pixel values i.e., the mean and standard deviation is enough to generate a "virtual" target in the background.



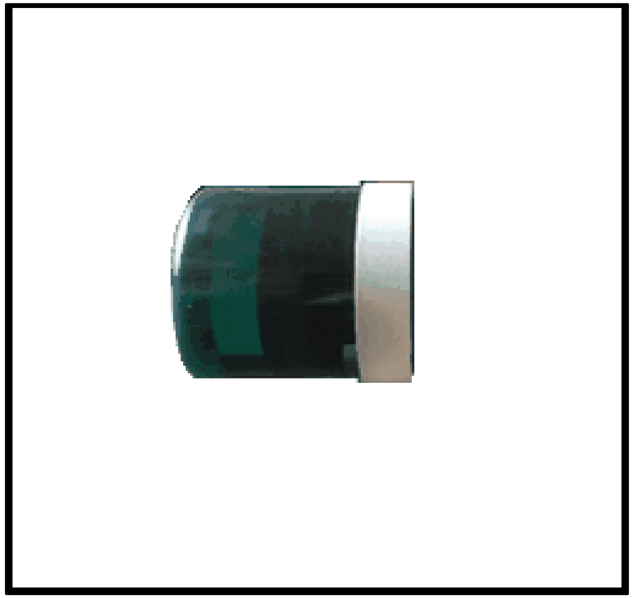


Experimental Set-up

- Uniformity module (CTP486) of the CATPHAN® 600 CT phantom was used to acquire uniform images.
- A bespoke, 3D printed calcium-like (ZP151® composite) annulus, 7 mm thick was placed around the CATPHAN® to simulate beam hardening due to the skull.
- The CATPHAN® was set-up at the head of the patient bed as per routine quality assurance tests.
- Radiographers were asked to use the same protocol as for a suspected stroke patient.

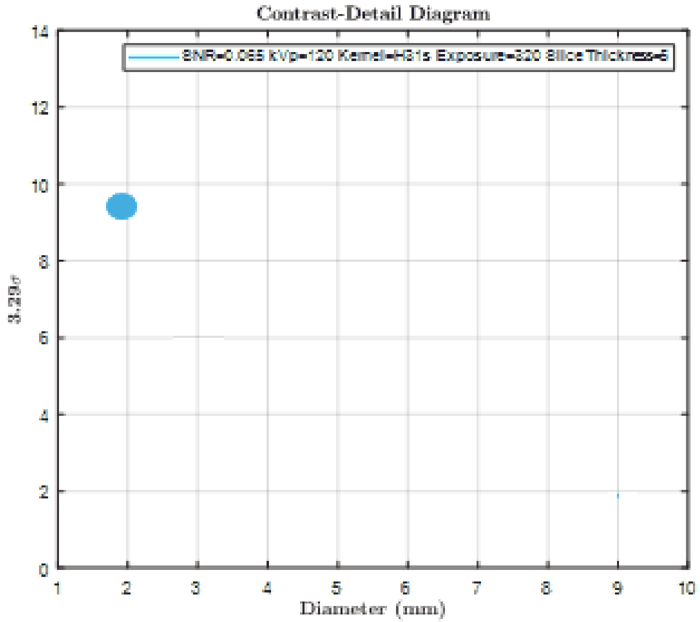
Algorithm used

- A MATLAB™ program was developed to calculate the minimum signal difference in Hounsfield Units (HU) required to distinguish an object from the background.
- Five slices from the uniformity section of the CATPHAN were analysed.
- A central square ROI, approx. 100 x 100 pixels was selected for analysis.
- The sub-region is divided up into a number of “blocks”, each of area $(np)^2$, where n is an integer and p is the pixel size.
- The mean pixel value of each block (μ_{BLOCK}) is calculated. According to the Central Limit Theorem, provided that at least 30 values of μ_{BLOCK} are obtained, the distribution of μ_{BLOCK} values will be Gaussian.

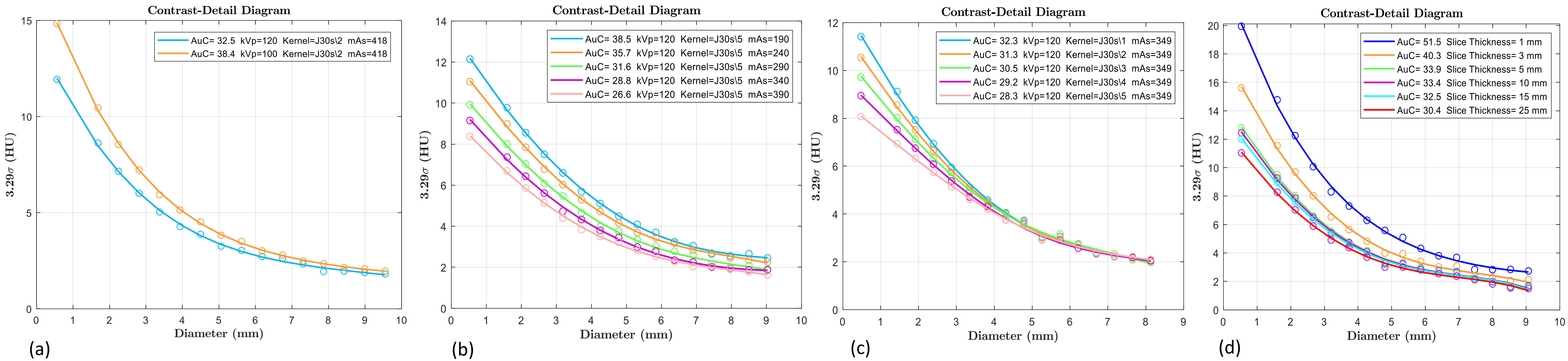


Algorithm used

- The standard deviation of this distribution, $\sigma_{\mu_{BLOCK}}$ is used to calculate signal difference. The area of the block, $(np)^2$, is converted into a disc of equal area. This process is repeated for increasing n.
- Minimum contrast necessary for conspicuity is defined as the signal difference and is equal to $3.29\sigma_{\mu_{BLOCK}}$.
- Five contrast-detail curves are averaged to give statistical contrast as a function of equivalent disc diameter in the form of a contrast-detail curve.



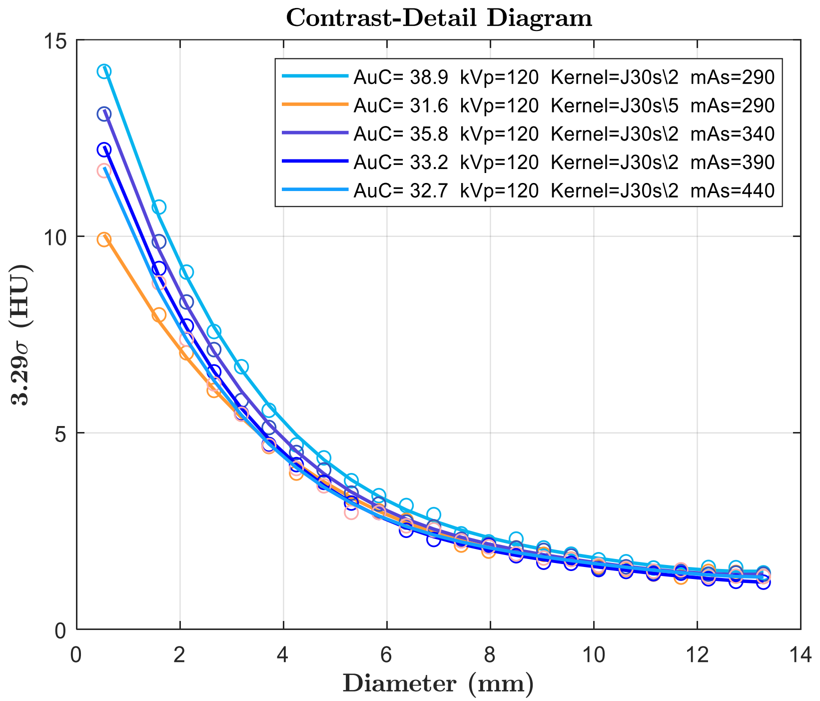
Results

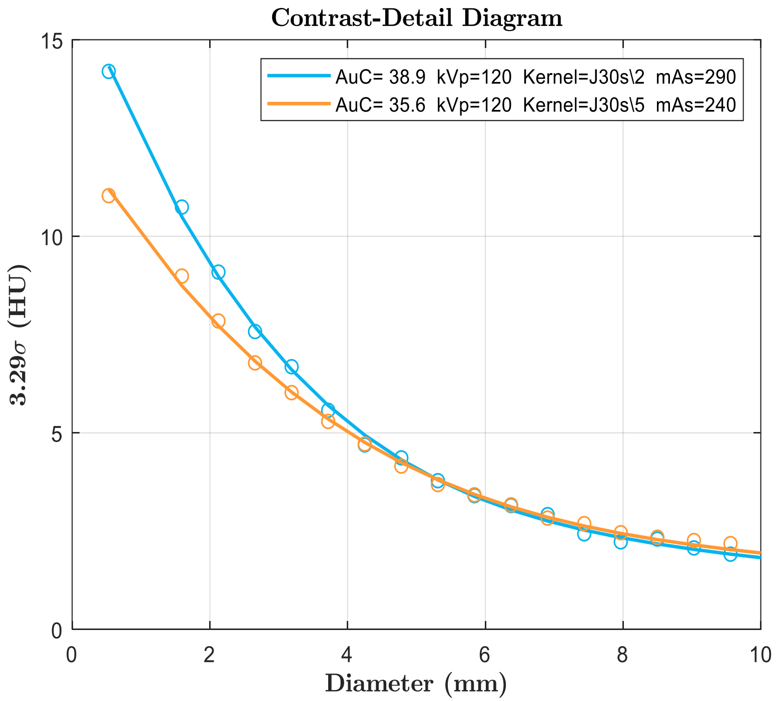


(a) A lower AuC for 120 kV indicates better LCD for higher kV when all other parameters are kept constant. (b) Increasing LCD for higher mAs. (c) Higher levels of iterative reconstruction give better LCD, in particular, for small target objects. (d) Improved LCD for thicker slices.

Data taken from a Siemens Somatom Definition AS+ scanner.

Results



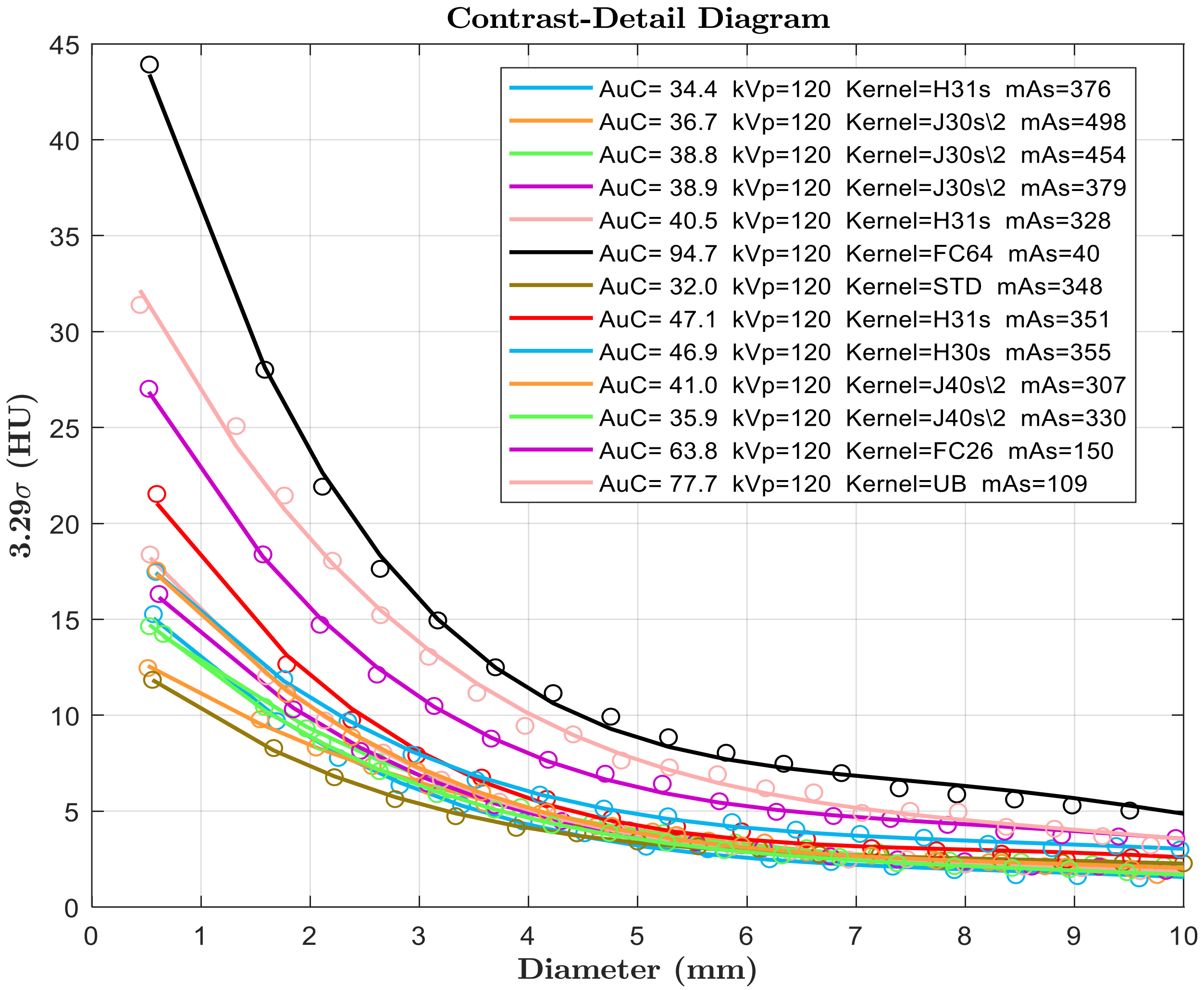


(a) mAs would have to be increased by $\approx$ 175 mAs to achieve same AuC as using maximum SAFIRE.

(b) Lower AuC can be achieved with reduced dose if SAFIRE level is increased.

Data taken from a Siemens Somatom Definition AS+ scanner.

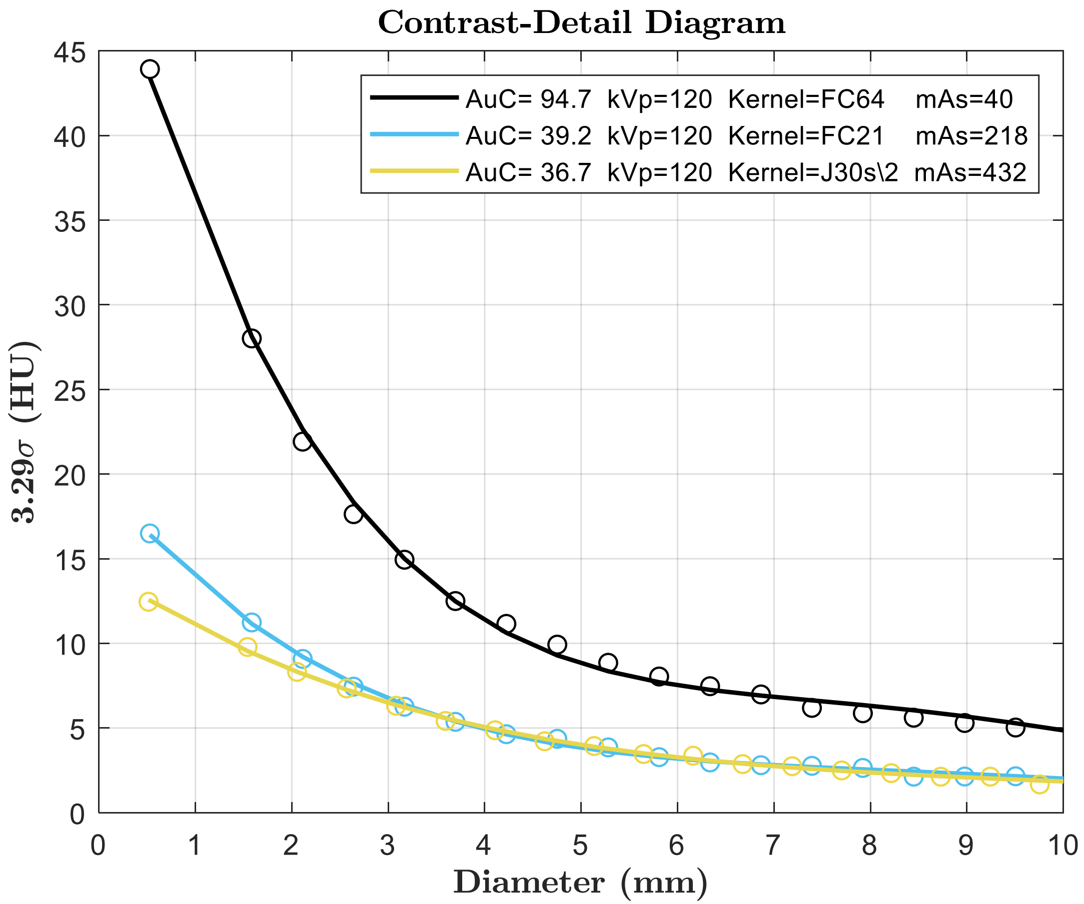
Results

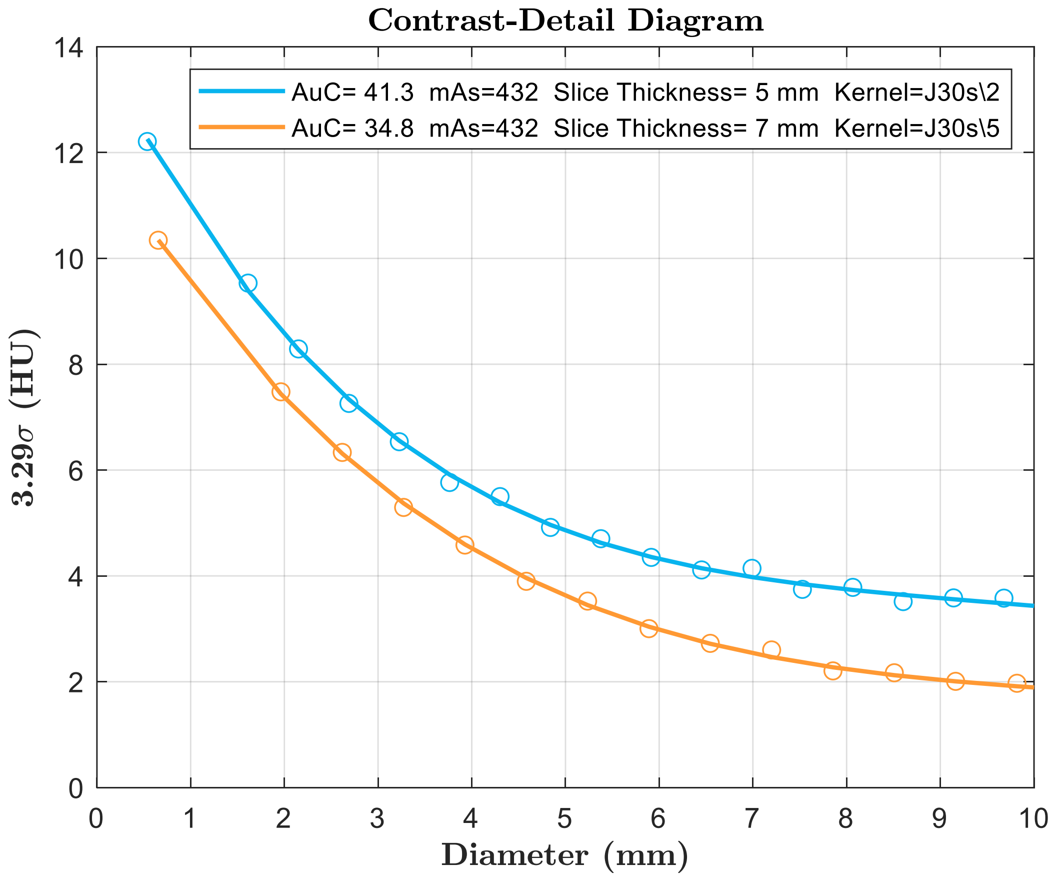


Hospital	*Brand*	*Machine*	*kV*	*Avg. mAs*	*Kernel*	*Slice Thickness*	*AuC*	*CTDI*	*FoM*
Hosp. 1 (1)	Siemens	Sensation 16	120	375	H31s	5 mm	34.4	78.3	304.3
Hosp. 1 (2)	Siemens	Somatom Definition AS+	120	461	J30s/2	5 mm	36.7	77.2	322.2
Hosp. 1 (3)	Siemens	Somatom Definition AS+	120	432	J30s/2	5 mm	38.8	65.6	314.0
Hosp. 2 (1)	Siemens	Somatom Definition	120	383	J30s/2	5 mm	38.9	61.0	304.0
Hosp. 2 (2)	Siemens	Biograph 16	120	328	H31s	4 mm	40.5	58.8	310.7
Hosp. 3	Toshiba	Acquillon	120	40	FC64	5 mm	94.7	9.9	297.9
Hosp. 4	GE	Optima CT660	120	348	"Standard"	5 mm	32.1	51.5	230.1
Hosp. 5 (1)	Siemens	Sensation 16	120	351	H31s	5 mm	46.7	54.7	345.1
Hosp. 5 (2)	Siemens	Sensation 16	120	355	H30s	5 mm	46.9	54.9	347.4
Hosp. 6 (1)	Siemens	Somatom Definition AS+	120	307	J40s/2	5 mm	41.0	47.3	282.2
Hosp. 6 (2)	Toshiba	Acquillon	120	150	FC26	3 mm	63.8	40.1	403.9
Hosp. 6 (3)	Siemens	Somatom Definition AS+	120	330	J40s/2	5 mm	35.9	47.6	247.6
Hosp. 7	Philips	Ingenuity	120	109	UB	2 mm	78.3	14.7	300.0

Contrast-detail curves of stroke CT protocols from 13 scanners across 7 hospitals.

Results


Contrast-Detail Diagram
AuC= 94.7 kVp=120 Kernel=FC64 mAs=40
AuC= 39.2 kVp=120 Kernel=FC21 mAs=218
AuC= 36.7 kVp=120 Kernel=J30s\2 mAs=432
3.29σ (HU)
Diameter (mm)


Contrast-Detail Diagram
AuC= 41.3 mAs=432 Slice Thickness= 5 mm Kernel=J30s\2
AuC= 34.8 mAs=432 Slice Thickness= 7 mm Kernel=J30s\5
3.29σ (HU)
Diameter (mm)

Parameter Optimization

- In a study in 2019, Nakamura et. al., showed the potential for improving low contrast detectability by reducing the kV, while simultaneously increasing mAs to compensate for a reduced dose to the detector.[4]

kV = 120	kV = 100	kV = 100
mAs = 500	mAs = 850	mAs = 750
$CTDI_{vol}$ = 83.5 mGy	$CTDI_{vol}$ = 86.9 mGy	$CTDI_{vol}$ = 64.8 mGy
CNR = 1.77	CNR = 2.06	CNR = 2.15
		+ Iterative Reconstruction

- We attempted to replicate these results using our objective technique.

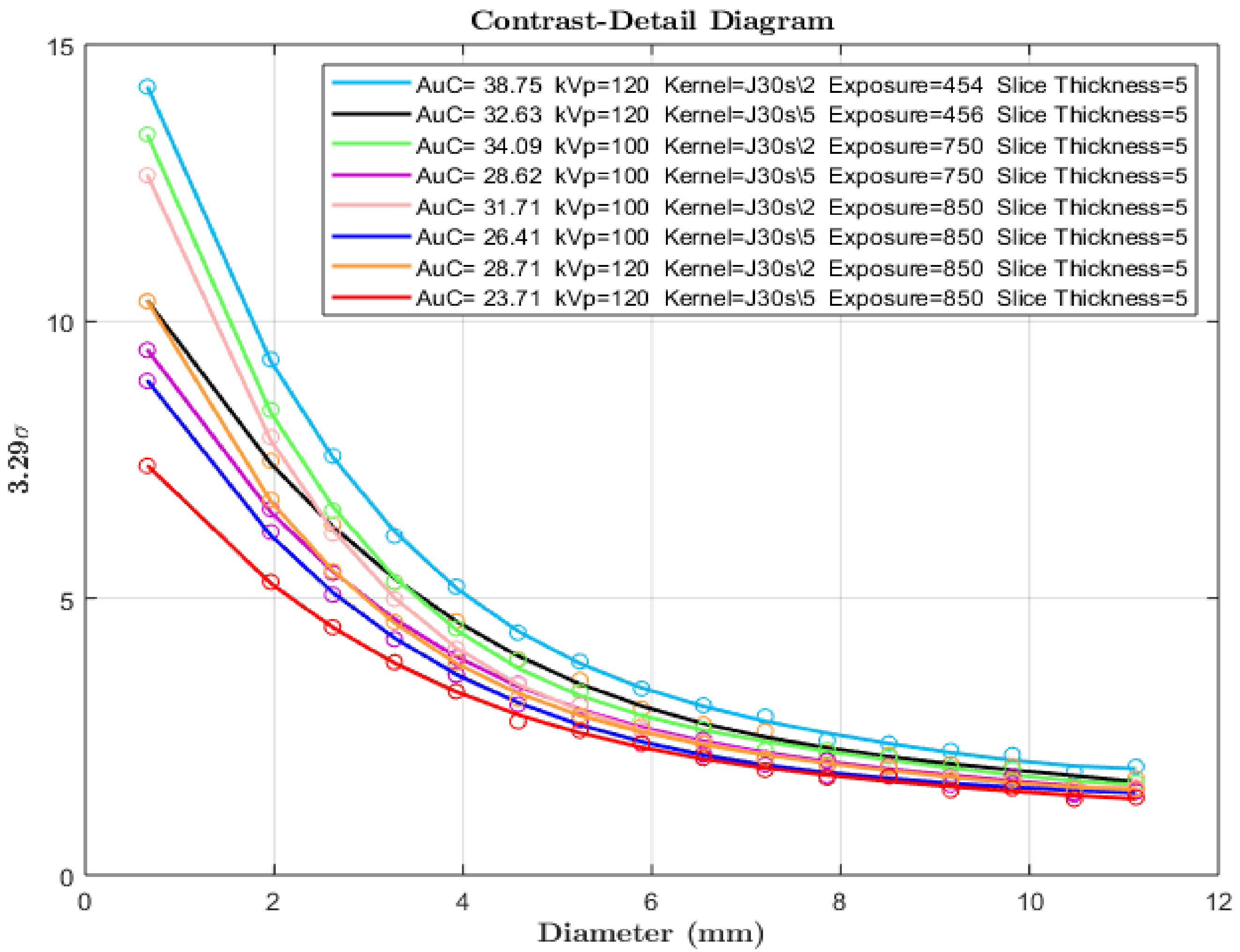
Parameter Optimization

- 4 acquisitions taken at our hospital:

kV = 120 mAs = 456* J30s/2	kV = 120 mAs = 850 J30s/2	kV = 100 mAs = 750 J30s/2	kV = 100 mAs = 850 J30s/2
kV = 120 mAs = 456* J30s/5	kV = 120 mAs = 850 J30s/5	kV = 100 mAs = 750 J30s/5	kV = 100 mAs = 850 J30s/5

* mAs selected by Siemens CARE Dose for the set-up shown earlier.

Parameter Optimization



kV	Kernel	mAs	Slice Thickness	AuC	CTDI	FOM
120	'J30s\5'	850	5 mm	23.7	121.4	261.2
100	'J30s\5'	850	5 mm	26.4	73.4	226.3
100	'J30s\5'	750	5 mm	28.6	65.0	230.8
120	'J30s\2'	850	5 mm	28.7	121.4	316.3
100	'J30s\2'	850	5 mm	31.7	73.4	271.7
100	'J30s\2'	750	5 mm	34.0	65.0	274.3
120	'J30s\5'	456	5 mm	32.6	65.6	264.4
120	'J30s\2'	454	5 mm	38.8	65.6	313.9

$$FoM = AuC * \sqrt{CTDI}$$

Parameter Optimization

- For the same dose, the 100 kV, 750 mAs protocol with stronger levels of IR, gives a better LCD than the current protocol.
- If we allow ourselves to increase the dose, the lowest (and therefore, best) FoM is obtained for the 100 kV, 850 mAs, SAFIRE 5 protocol.
- A higher FoM for the 120 kV, 850 mAs protocol shows that eventually there is diminishing returns in increasing the dose to improve image quality.

kV	Kernel	mAs	Slice Thickness	AuC	CTDI	FOM
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120	'J30s\2'	454	5 mm	38.8	65.6	313.9

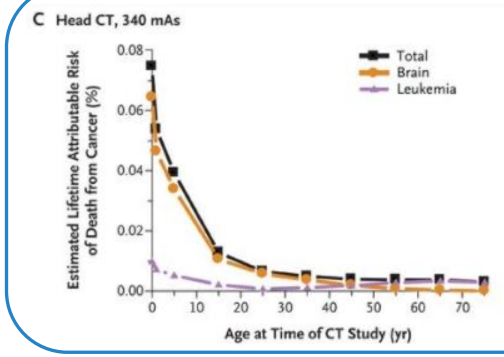
Clinical trial has been delayed due to COVID-19.
100 kV, J30s\5, with a ref. mAs that keeps the same $CTDI_{vol}$ as before.

Image Quality vs. Radiation Dose

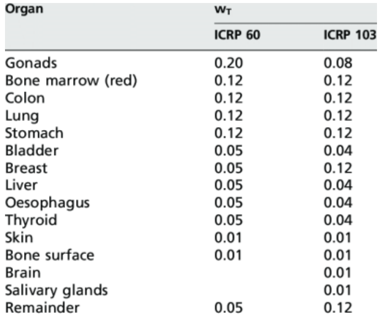
- **Traditionally, discussion of image quality has focused on reducing dose while maintaining LCD, rather than maximising the latter.**
  - ➢ **We believe this is a philosophy worth challenging.**

70% of Stroke patients experience significant degree of lasting impairment.[5]

Average age of ischaemic stroke = 74.6 years[6]

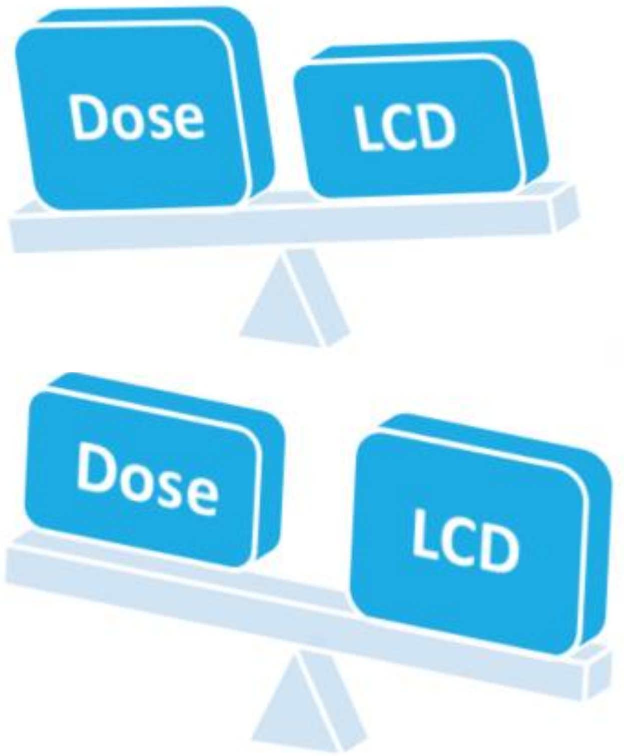


Risk of radiation-induced cancer decreases with age.[7]



Organ	w_T ICRP 60	w_T ICRP 103
Gonads	0.20	0.08
Bone marrow (red)	0.12	0.12
Colon	0.12	0.12
Lung	0.12	0.12
Stomach	0.12	0.12
Bladder	0.05	0.04
Breast	0.05	0.12
Liver	0.05	0.04
Oesophagus	0.05	0.04
Thyroid	0.05	0.04
Skin	0.01	0.01
Bone surface	0.01	0.01
Brain		0.01
Salivary glands		0.01
Remainder	0.05	0.12

Brain is relatively radioresistant.[8]

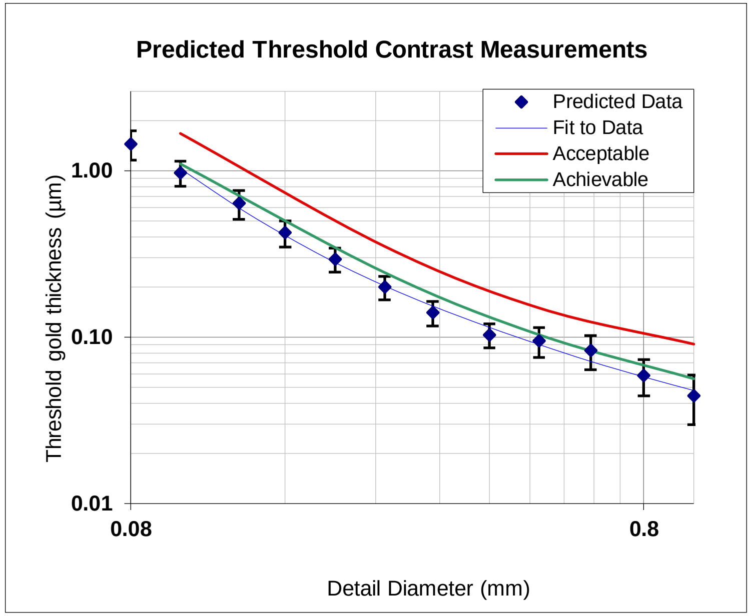


LCD vs. Dose: Which consideration should be given more weighting?

Reference LCD Curves?

- It may be worth considering a protocol-specific quality assurance test for such procedures that demand particularly high image quality standards.
- e.g., borrowing the idea of reference contrast-detail curves from our friends in mammography physics.

Pros:	Cons:
• Ensures sufficient image quality for diagnosis. • Ensures consistent image quality between hospitals.	• Consistent set-up required. • Need to liaise with Radiology to decide on "reference" curve.



	Threshold gold thickness, T		
Φ (mm)	$T_{measured}$ (µm)	T_{min} (µm)	$T_{achievable}$ (µm)
0.1	1.032	1.680	1.100
0.25	0.204	0.352	0.244

Example of reference curves already used in mammography. Acceptable and achievable standards of image quality are defined for the CDMAM by the EUREF European Guidelines.

Summary

- We have implemented an objective method of measuring low contrast detectability in brain CT.
- This objective evidence confirmed anecdotal concerns of radiologists at our hospital that the image quality in brain CT scans they have been receiving from feeder hospitals is inconsistent.
- Given that brain CTs are the most common CT examinations in the UK and Ireland[1], we want to raise awareness that significant variation can exist between centres and significantly affect stroke patient diagnosis.
- In the ethos of medical physics 3.0, we would encourage you to discuss this issue with radiologists in your hospital and take a multidisciplinary approach to optimizing CT parameters for the early detection of stroke.

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