Developing Dual Energy CT Applications for Pediatric Imaging

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Disclosures:

Nothing to disclose

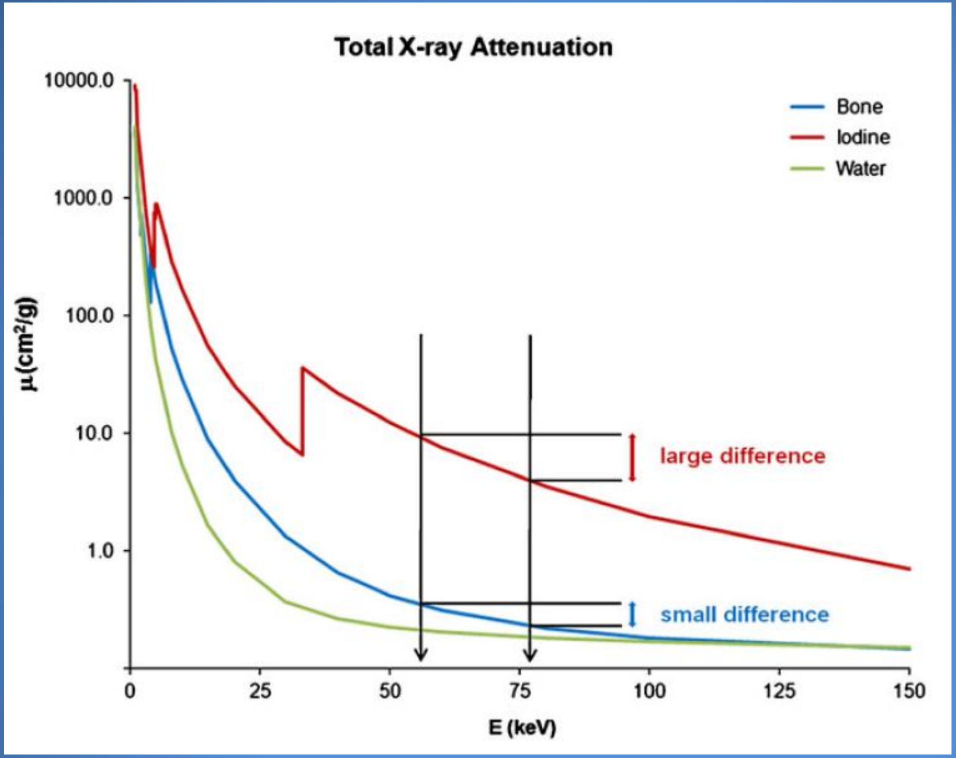
Background

- Dual Energy CT (DECT) technology is available on scanners from several vendors and offers significant advantages over classic single energy CT technology in multiple clinical applications.
- This technology utilizes photon spectra generated by two different tube voltages to identify and distinguish different materials in the body such as iodine, uric acid and calcium.

Background

- Many studies have detailed DECT applications in adults and several have evaluated the relative radiation dose performance of DECT in adult imaging.
- Little has been published on DECT imaging in the pediatric population and the relative dose performance of DECT imaging in the pediatric population is not well described.

DECT Basics – Total X-ray Absorption

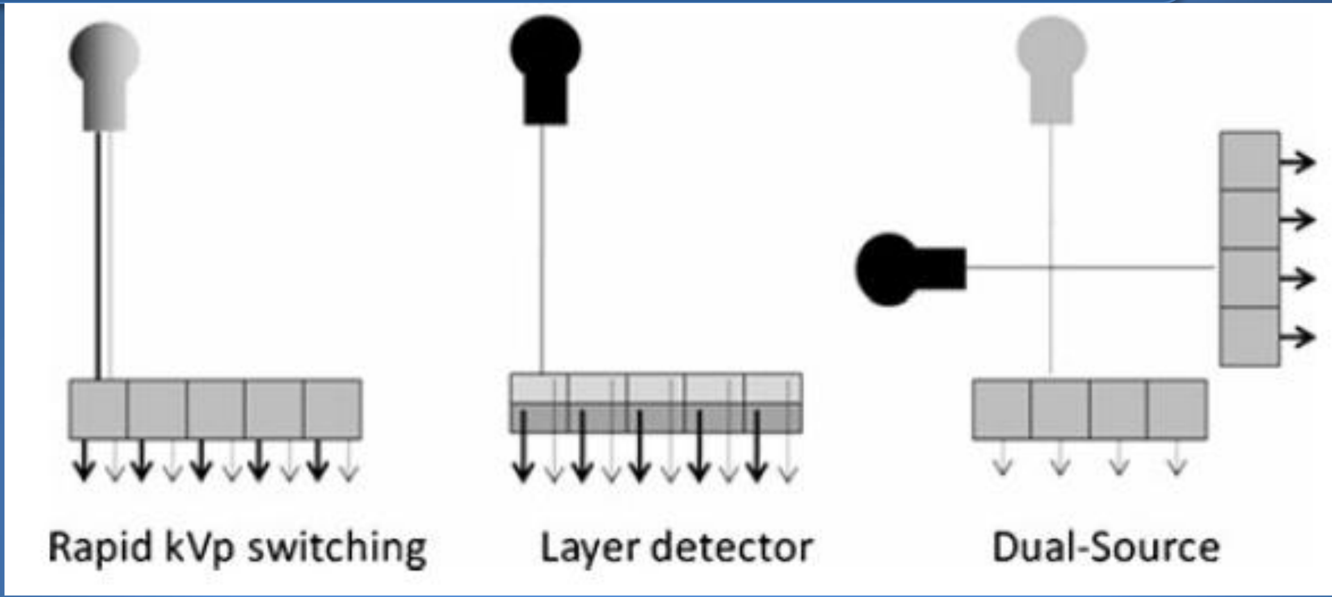


J Fornaro et al.
Insights Imaging (2011)2:149-159

Materials can be distinguished more easily when large differences in atomic numbers are present.

Differences in attenuation curves are magnified at two different energy levels, allowing differentiation on the basis of two CT numbers.

DECT Basics – Hardware



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Rapid voltage switching

X-ray tube voltage modulates rapidly to different kVp.

Dual-layer detector

Superimposed energy sensitive layers detect different energy levels.

Dual source dual energy

Two X-ray tube with corresponding detectors operate at different kVp with an angular off-set. Dual-energy data are acquired simultaneously.

DECT Applications

Current clinical applications can be divided in to two groups:

Differentiation of materials

- Bone removal (differentiation of calcium and iodine)
- Urinary stone analysis (differentiation of uric-acid containing stones, vs. other stone types)

Identification of contrast material

- Reconstruction of virtual non-contrast images from Iodine-enhanced image by subtraction of quantified iodine

Dose Neutrality?

Manufacturers suggest…

- DE scans can be performed "**dose neutral***"

*(*only in adult?)*

> *A question should be answered by pediatric facilities based on their current SE scan protocols, especially, comparing with already optimized SE protocols.*

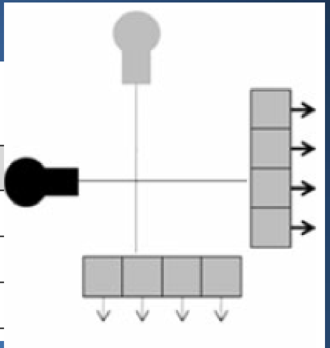
Phantom studies to investigate "dose neutrality"

- Understand the relative dose differences.
- Develop DE scan protocols based on our optimized SE protocols

Dose Neutrality? – Our study

Table 1 ATOM Phantom Anatomical References

Description	Height	Weight	Thorax Dimensions
Pediatric 1 year	75 cm (11.6")	10 kg (26.8 lb)	12 x 14 cm (1.9 x 2.1")
Pediatric 5 years	110 cm (17.1")	19 kg (51 lb)	14 x 17 cm (2.1 x 2.6")
Pediatric 10 years	140 cm (21.7")	32 kg (85.7 lb)	17 x 20 cm (2.6 x 3.1")



DE scans with matching reference $CTDI_{vol}$ of SE

- Head
- Chest
- Abdomen

Ref. $CTDI_{vol}$= Noise Index

Scan Modulations

- mAs and kV (chest, abdomen “0”, head: semi) for SE
- mAs for DE

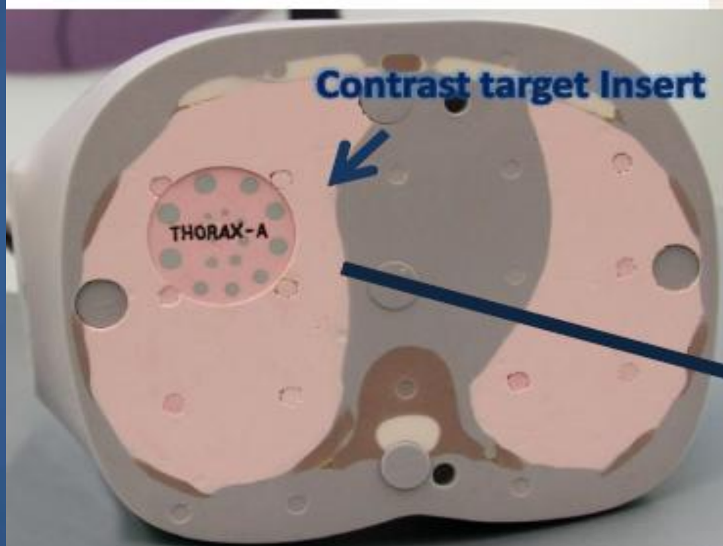
Eff. $CTDI_{vol}$= Avg. CTDI

Second DE scans with adjusted Ref $CTDI_{vol}$

- Scaled to ratio of Effective $CTDI_{Vol}$ of DE and SE scans

The Phantoms

Phantom and insert



- Inserts with 1-6 mm contrast targets
- Simulating blood in brain, nodule in chest, and iodine in abdominal regions
- For visual assessments & quantitative analysis

Studies of CTDI and CNR…

Effective CTDI* of SE and DE were compared for

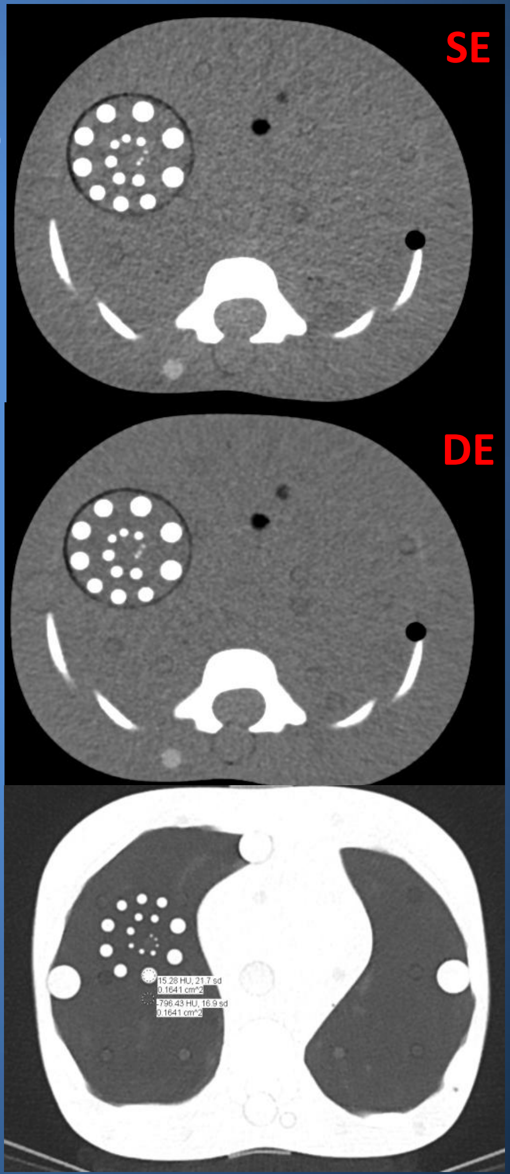
- Relative dose differences
- In each anatomical region
- In each phantom size group

* vender use 32cm phantom to report trunk region for all sizes, and 16cm for head region.

CNR Estimated for

- All phantom sizes and regions
- Ten 3mm slices with the contrast insert in each region

Two radiologists provided visual assessments



SE, DE Compared

Table 2 Single and Dual Energy Scan Reference $CTDI_{vol}$

	Single Energy	Dual Energy
Head	**Care Dose "on" CarekV Semi @120kVp**	**CareDose "on" kVp: 140Sn, 80**
	Ref $CTDI_{vol}$ mGy	Ref $CTDI_{vol}$ mGy
1y	38.25	38.22
5y	38.25	38.22
10y	38.25	38.22
Chest	**CareDose "on" CarekV dial on "0"**	**CareDose "on" kVp: 140Sn, 80**
	Ref $CTDI_{vol}$ mGy	Ref $CTDI_{vol}$ mGy
1y	2.99	3.02
1y	2.99	2.48 (2^{nd} scan)
5y	2.99	3.02
5y	2.99	2.72(2^{nd} scan)
10y	2.99	3.02
Abdomen	**CareDose "on" CarekV dial on "0"**	**CareDose "on" kVp: 140Sn, 80**
	Ref $CTDI_{vol}$ mGy	Ref $CTDI_{vol}$ mGy
1y	3.75	3.74
5y	3.75	3.74
10y	3.75	3.74

Dose Neutral?

Table 3 Single and Dual Energy Effective $CTDI_{vol}$ and Relative Dose Neutrality
(DE Eff $CTDI_{vol}$ +/- 10% of SE Eff $CTDI_{vol}$)

	Single Energy		**Dual Energy**		**Relative Dose Neutrality**
Head	**Care Dose "on" CarekV Semi @120kVp**		**CareDose "on" kVp: 140Sn, 80**		DE Eff $CTDI_{vol}$ as % of SE Eff $CTDI_{vol}$
	Ref $CTDI_{vol}$ mGy	Eff $CTDI_{vol}$ mGy	Ref $CTDI_{vol}$ mGy	Eff $CTDI_{vol}$ mGy	
1y	38.25	20.91	38.22	20.31	97%
5y	38.25	23.71	38.22	21.77	92%
10y	38.25	26.01	38.22	24.33	94%
Chest	**CareDose "on" CarekV dial on "0"**		**CareDose "on" kVp: 140Sn, 80**		DE Eff $CTDI_{vol}$ as % of SE Eff $CTDI_{vol}$
	Ref $CTDI_{vol}$ mGy	Eff $CTDI_{vol}$ mGy	Ref $CTDI_{vol}$ mGy	Eff $CTDI_{vol}$ mGy	
1y	2.99	0.65	3.02	0.78	120%
1y	2.99	0.65	2.48 (2^{nd} scan)	0.72	108%
5y	2.99	0.83	3.02	0.92	111%
5y	2.99	0.83	2.72 (2^{nd} scan)	0.86	104%
10y	2.99	0.96	3.02	1.01	105%
Abdomen	**CareDose "on" CarekV dial on "0"**		**CareDose "on" kVp: 140Sn, 80**		DE Eff $CTDI_{vol}$ as % of SE Eff $CTDI_{vol}$
	Ref $CTDI_{vol}$ mGy	Eff $CTDI_{vol}$ mGy	Ref $CTDI_{vol}$ mGy	Eff $CTDI_{vol}$ mGy	
1y	3.75	0.83	3.74	0.81	99%
5y	3.75	1.11	3.74	1.05	95%
10y	3.75	1.17	3.74	1.13	101%

Neutral

Neutral

Neutral

How about CNR?

- On CNR analysis of image quality, in head and abdominal regions, there is no statistically significant changes in CNR of dual energy scans when compare with the images of single energy scans for all three phantoms sizes

  (p-value: 0.06, 0.06, 0.16 , for 1y, 5y, 10y).

- CNR in images processed with DE specific Q40 soft tissue algorithm were slightly better than standard I41f algorithm in abdominal images, judging by the slightly higher p-values in each phantom group.

How about CNR?

- In **chest** region, although DE Eff $CTDI_{Vol}$ are higher in 1-year-old and 5-year-old phantoms (120%, 111% that of SE Eff $CTDI_{Vol}$), there is no significant difference in CNR in DE and SE images in all phantom groups (p-value: 0.11, 0.49, 0.46 for 1y, 5y, 10y).

- Further "forced" reduction of Eff $CTDI_{Vol}$ by reducing Ref $CTDI_{Vol}$ (in 1y and 5y) in chest produced DE images that have statistically significant lower CNR for the 1-year-old phantom (p-value 0.007); but no significant CNR reduction was observed in the 5-year-old phantom (p-value:0.31).

Practice Recommendation

CT Dual Energy Potential Applications Based on Dose Information

Study Description	Age specification
Stones	1 year and older
Stone and obstruction for virtual non-contrast	All ages
CT cystography, Urography for virtual non-contrast	All ages
Abdominal tumors with suspicion of calcifications for virtual non-contrast	1 yrs and older; and for younger if not seen on US
Remnant catheter in a vessel for virtual non-contrast	All ages
Diagnosis of arterial calcinosis for virtual non-contrast	All ages
Head CTA	All ages
Spine with metel implants	All ages

SAMS #1: Dual Energy CT is based on the concept that...

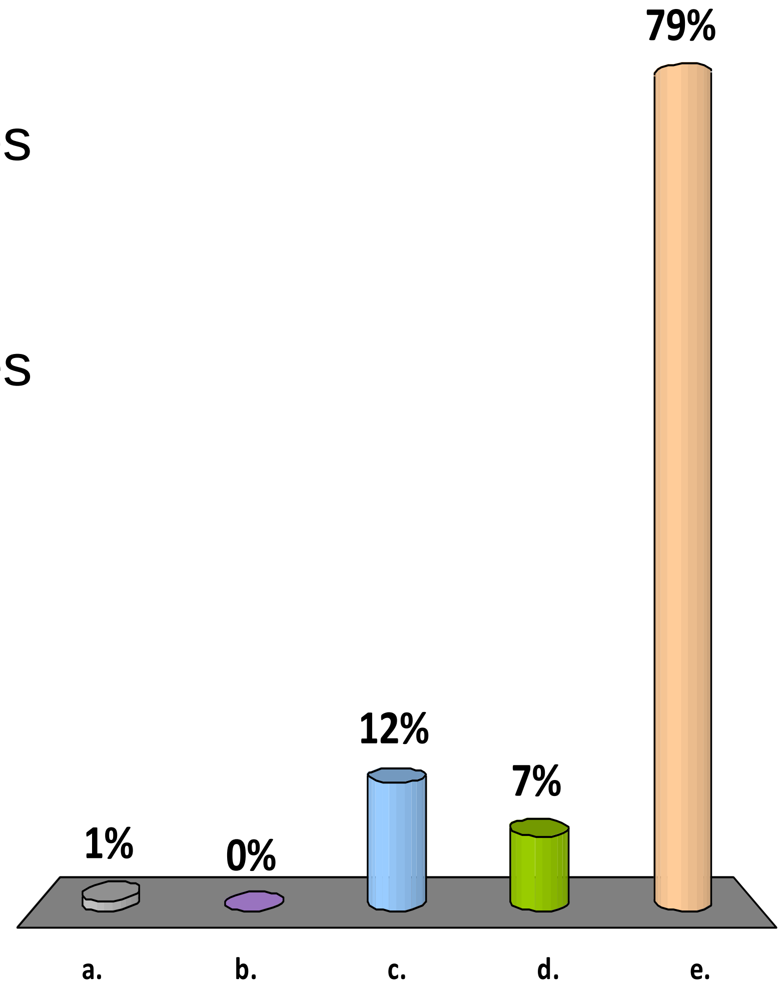
a. Materials can be distinguished more easily when large differences in atomic numbers are present.

b. Materials can be distinguished more easily when large differences in neutron numbers are present.

c. Differences in attenuation curves are magnified at two different energy levels, allowing differentiation on the basis of two CT numbers.

d. a) & b)

e. a) & c)

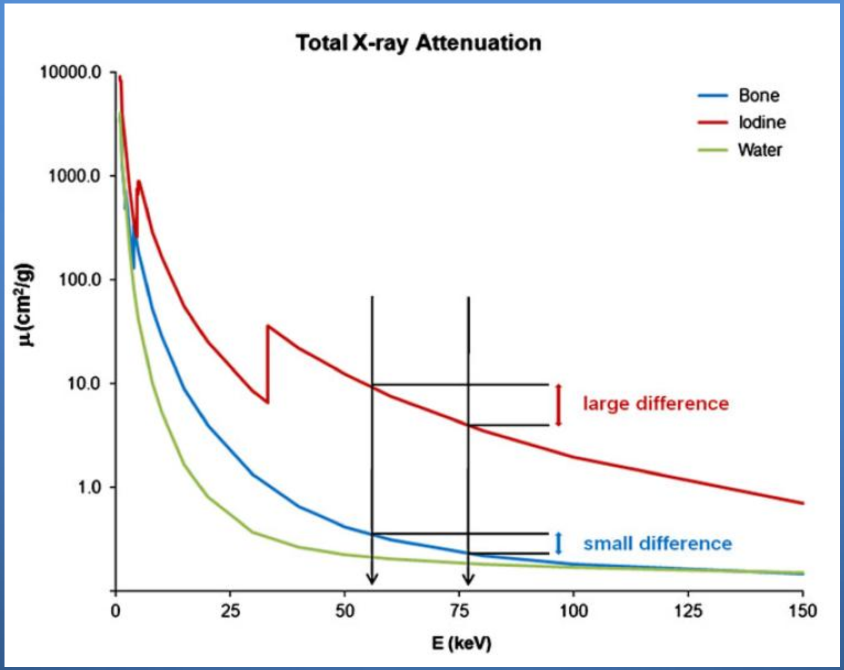


Answer to SAM QUESTION 1

Correct Answer, e).

Materials can be distinguished more easily when large differences in atomic numbers are present.

Differences in attenuation curves are magnified at two different energy levels, allowing differentiation on the basis of two CT numbers.



Ref: J Fornaro et al. Dual- and multi-energy CT: approach to functional imaging Insights Imaging (2011)2:149-159

SAMS #2: Current applications can be divided in to two groups:

22%	a.	Bone removal and Stone identification
10%	b.	Contrast removal and Bone removal
4%	c.	Metal artifact reduction and bone removal
54%	d.	Differentiation of materials and identification of contrast material
9%	e.	Stone identification and metal artifact reduction

Answer to SAM QUESTION 2

Correct Answer: d)

Current applications can be divided in to two groups:

Differentiation of materials

Bone removal (differentiation of calcium and iodine)

Urinary stone analysis (differentiation of uric-acid containing stones, vs. other stone types)

Identification of contrast material

Reconstruction of virtual none-contrast images from Iodine-enhanced image by subtraction of quantified iodine

Ref: J Fornaro et al. Dual- and multi-energy CT: approach to functional imaging Insights Imaging (2011)2:149-159

DECT Applications at CHOP

GU Imaging:

- CT Urolithiasis > 1 year old
- Contrast Renal CT for stone and obstruction Virtual Non-contrast (VNC)
- CT Cystography and Urography (VNC)

Oncological Imaging:

- > 1 year old Abdominal tumor with suspicion of calcifications (VNC)

Vascular Imaging:

- Catheter remnant in vessel (VNC)
- Arterial Calcinosis (VNC)

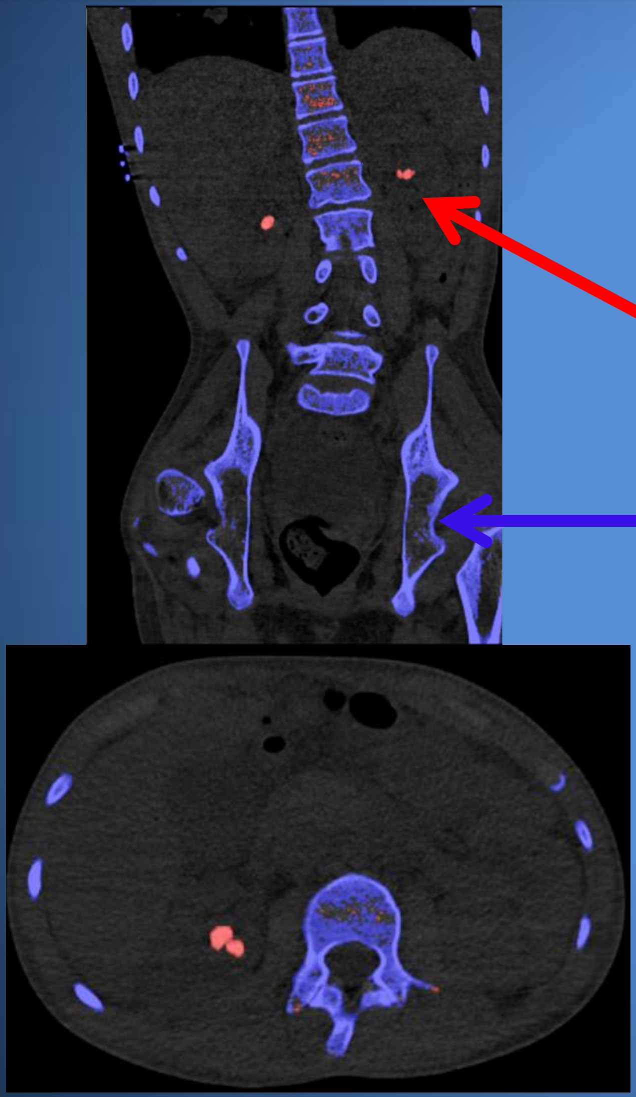
MSK Imaging:

- CT extremity with hardware

Neuro Imaging:

- CT spine with hardware
- CTA of head – bone subtraction
- Diagnosis or post-intervention assessment for bleeding vs. enhancement (VNC)

Clinical Cases



Renal Stone Composition

Color coded red indicating a lower dual energy ratio seen with uric acid based renal calculi.

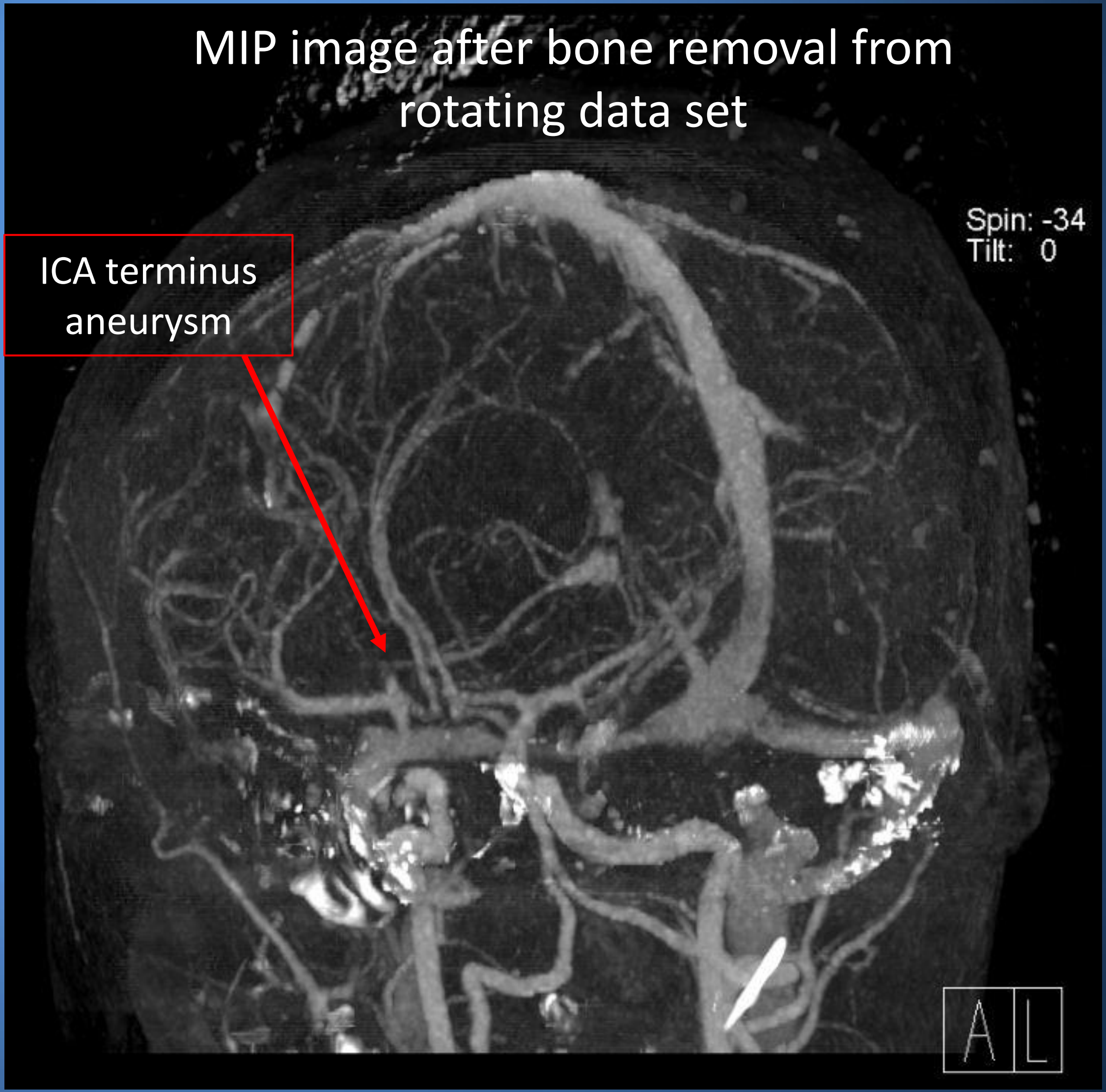
Color coded with blue indicating a larger dual energy ratio seen with calcium

(Adolescent male with Lesch-Nyhan syndrome and uric acid renal calculi.)

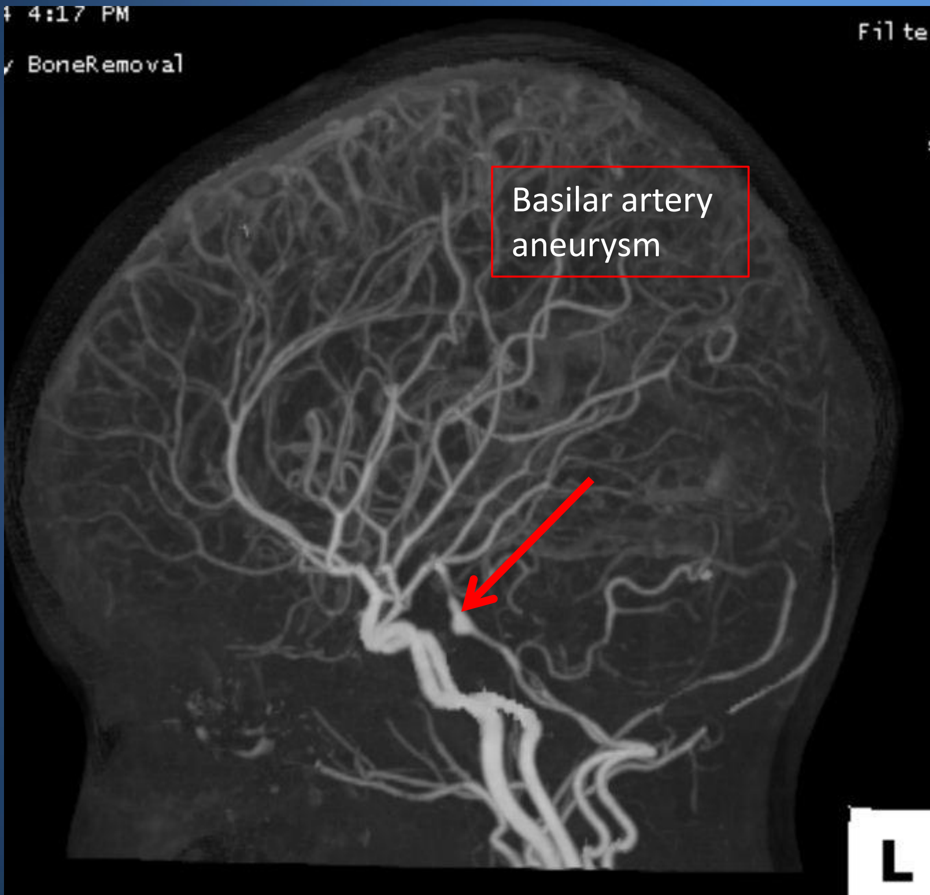
Clinical Cases - CTA with Bone Removal

Axial bone removal image

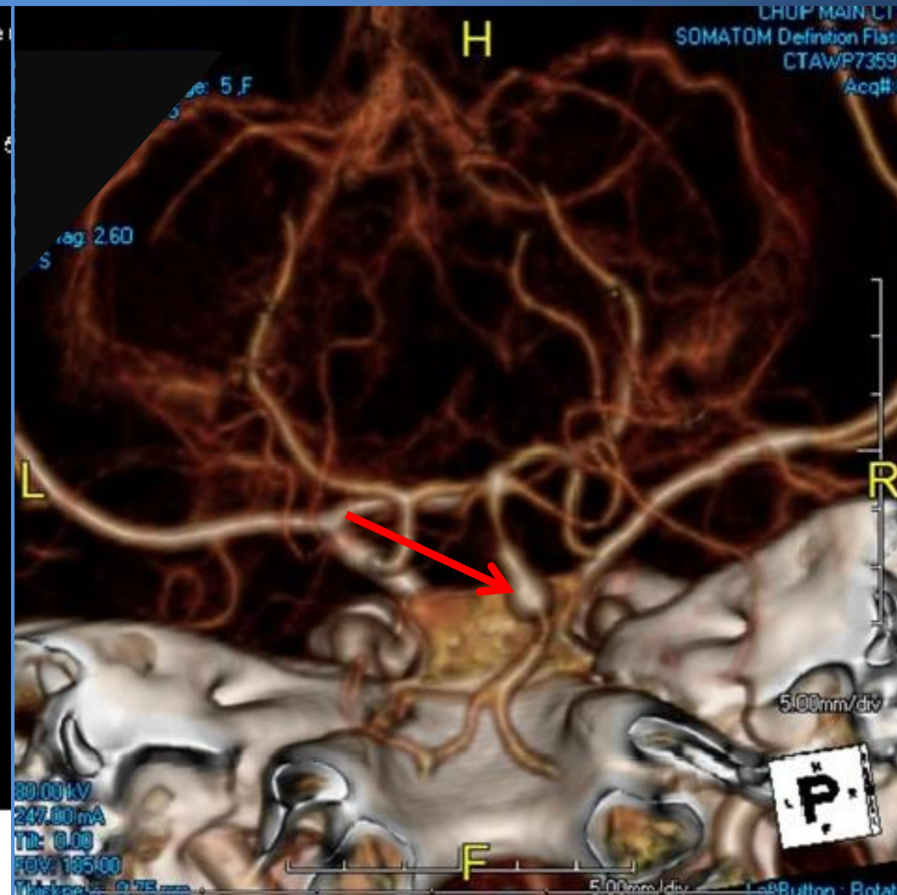
MIP image after bone removal from rotating data set



Clinical Cases – Bone Removal

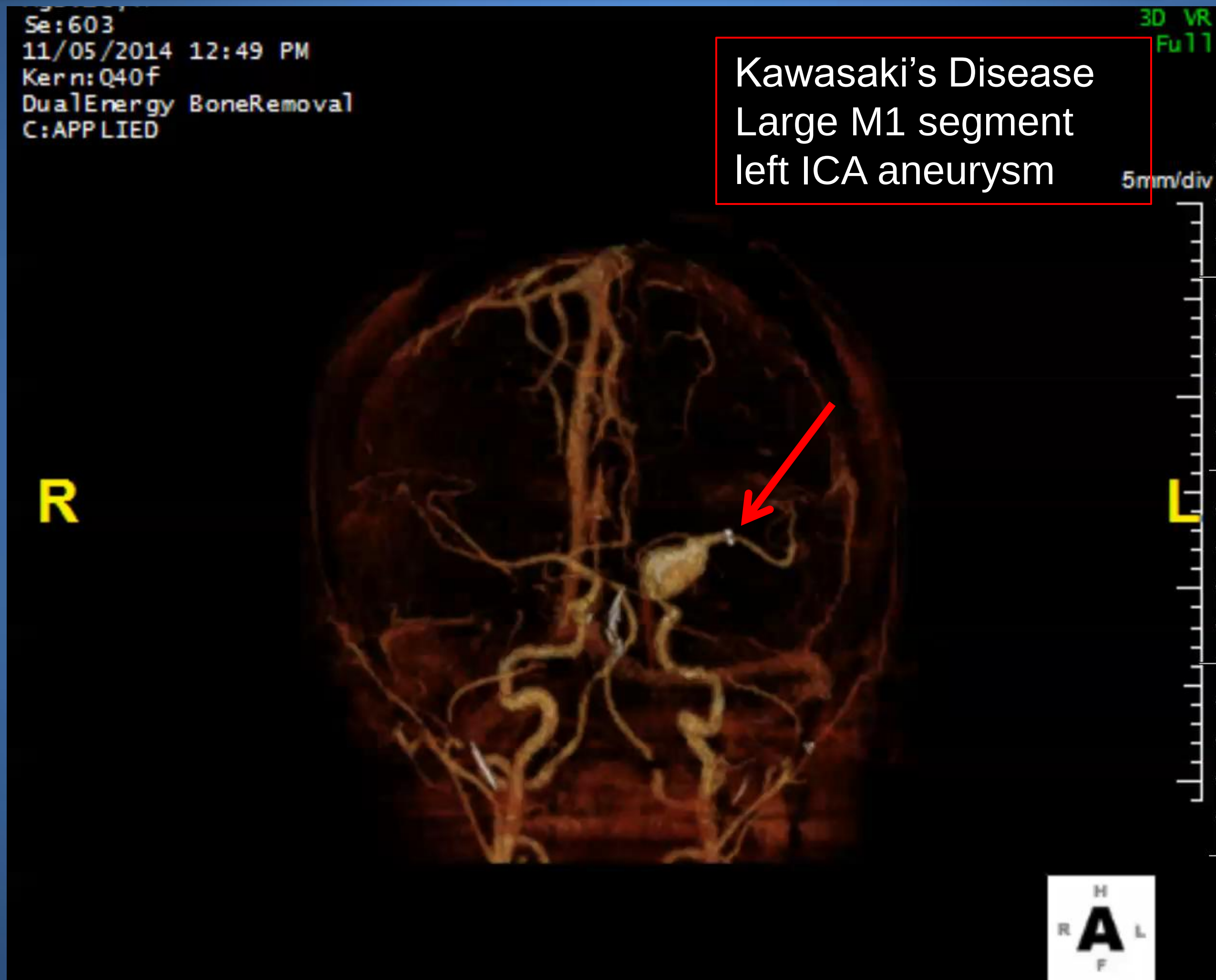


MIP image after bone removal from rotating data set generated by CT tech at the scanner



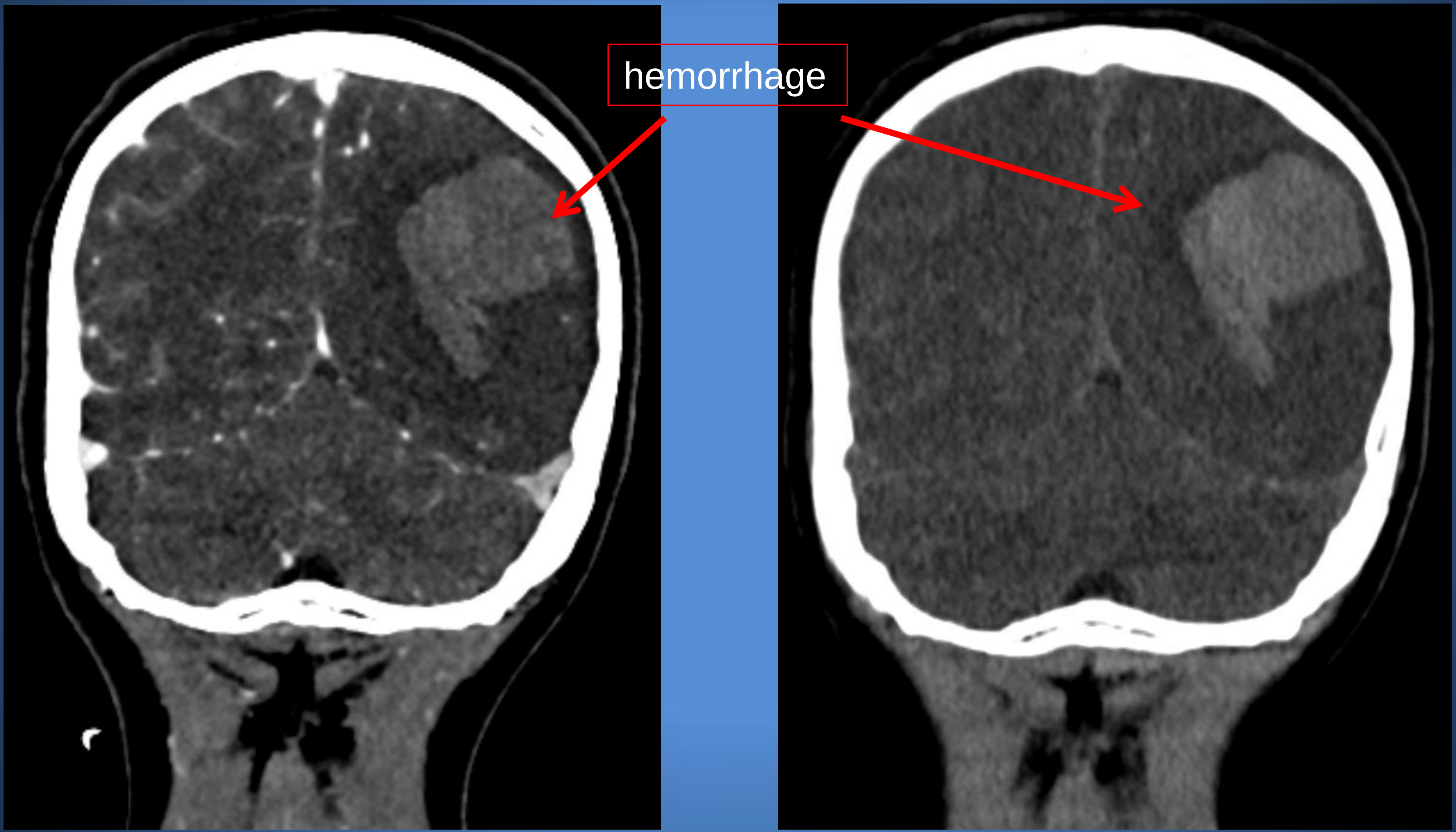
Volume rendering generated in 3D lab

Clinical Cases – Bone Removal



Iodine map image from rotating data set generated at the scanner

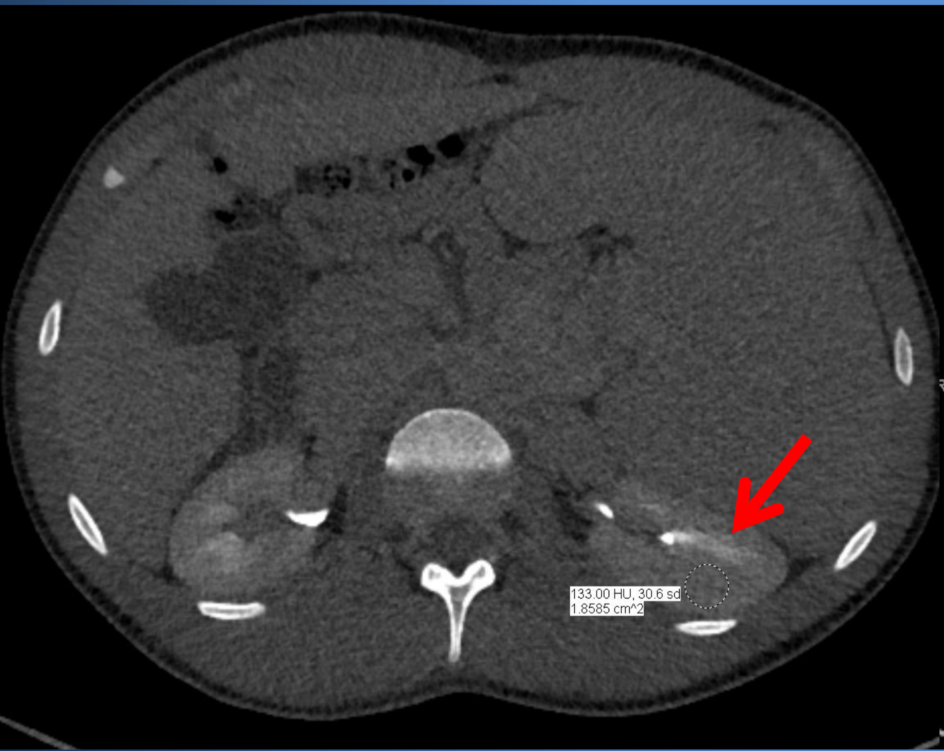
Clinical Cases - Virtual Non Contrast



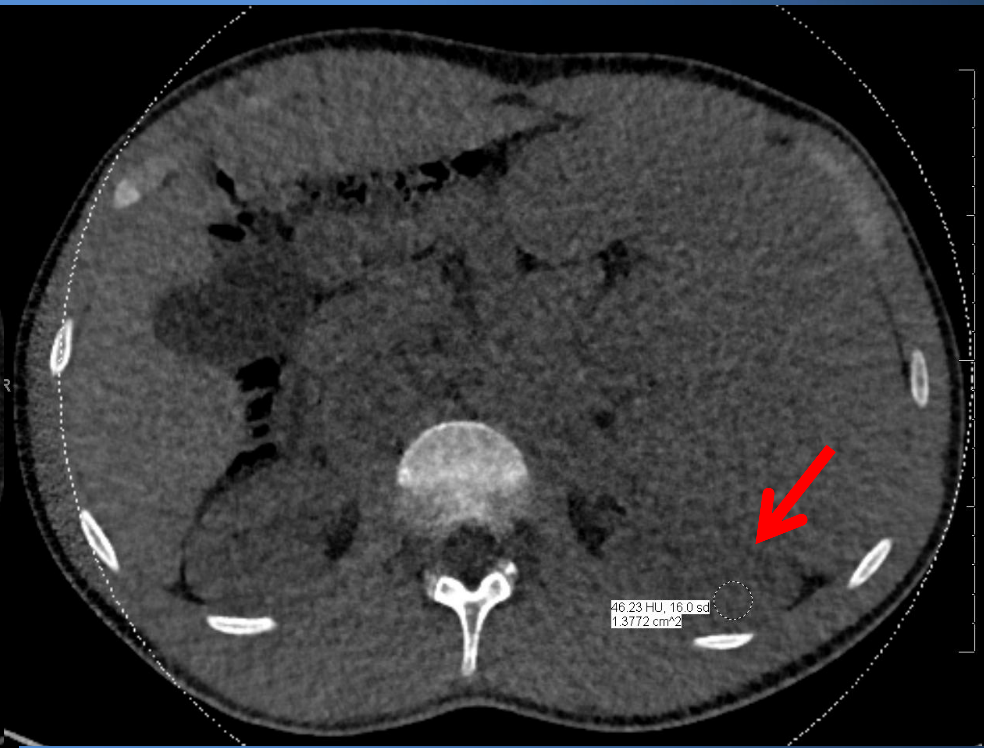
Large parenchymal hemorrhage secondary to an AVM. Virtual non-contrast confirms the presence of hemorrhage, excluding an enhancing mass.

Clinical Cases - Virtual Non Contrast

Contrast DECT scan



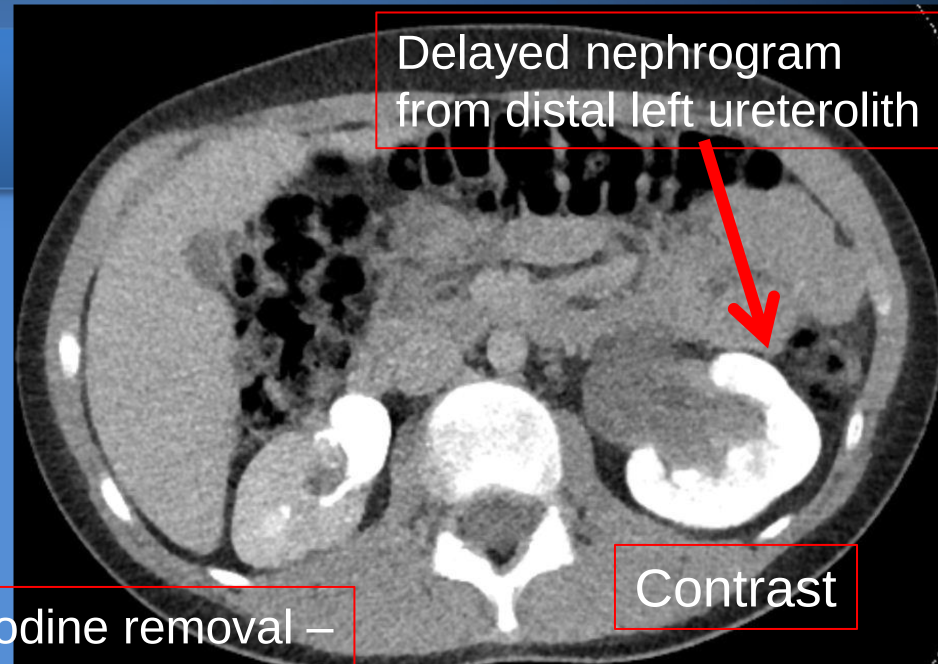
VNC

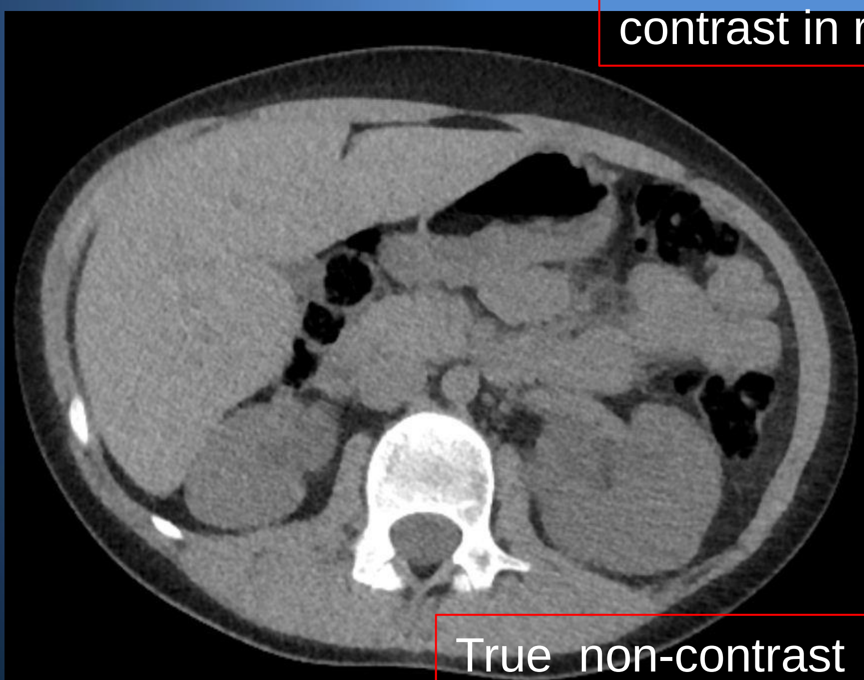


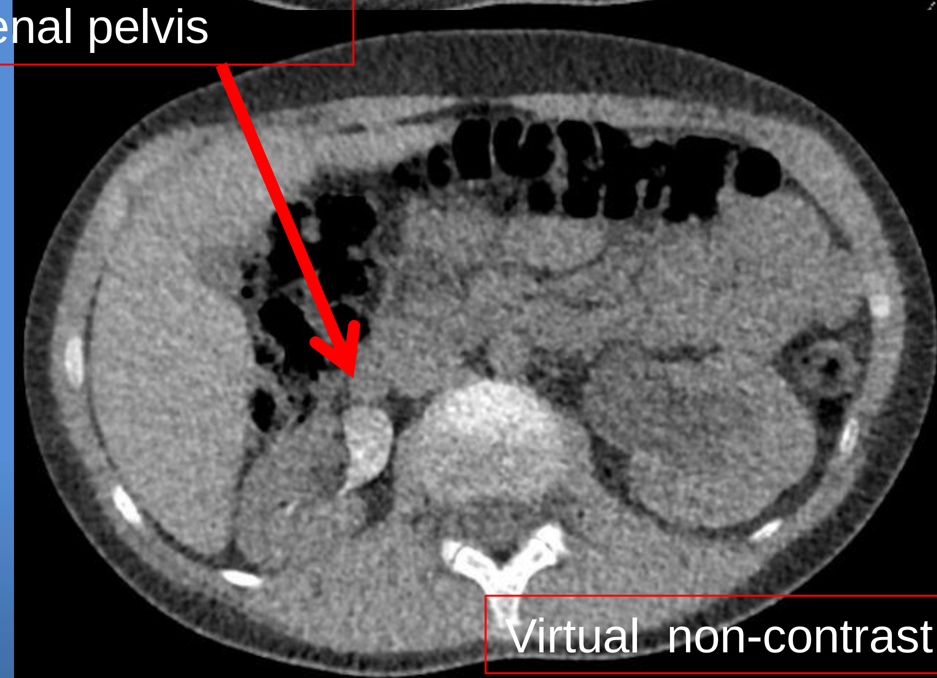
VNC generated from a single phase, contrast enhanced sequence.
Note the difference in HU in the left kidney.

Clinical Cases –

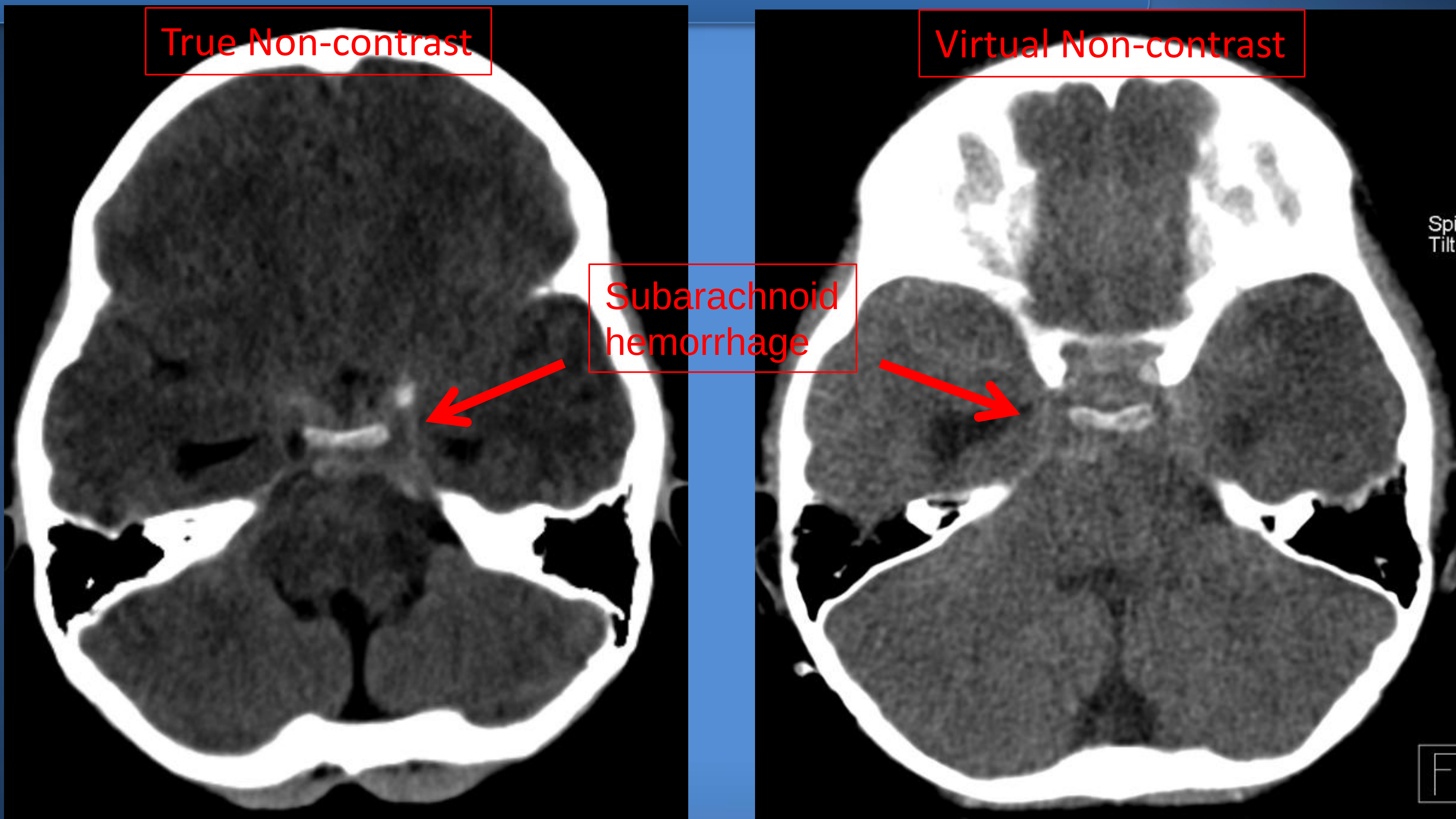
Virtual Non-Contrast
Incomplete removal of contrast







Clinical Cases – Virtual Non Contrast

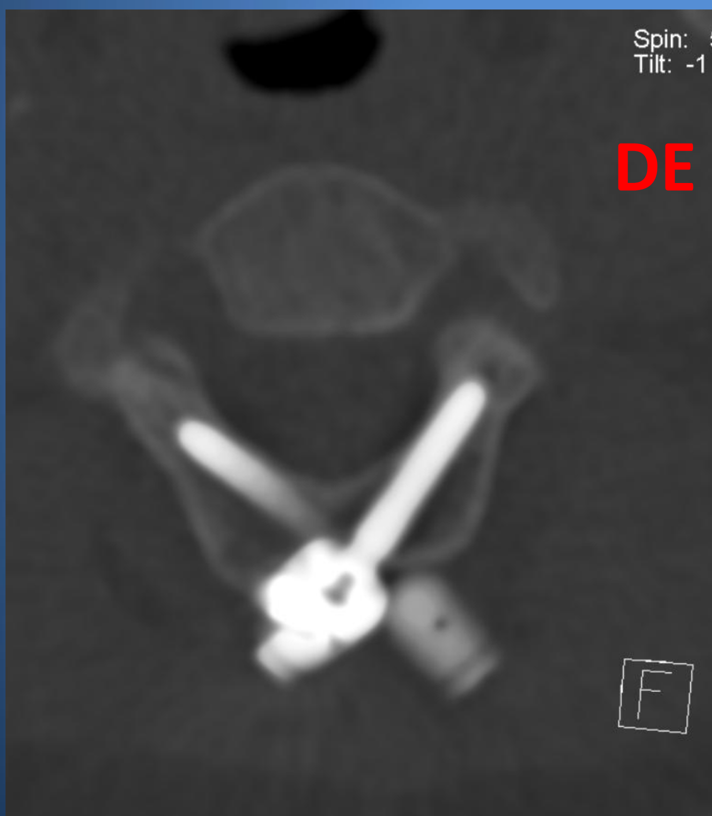


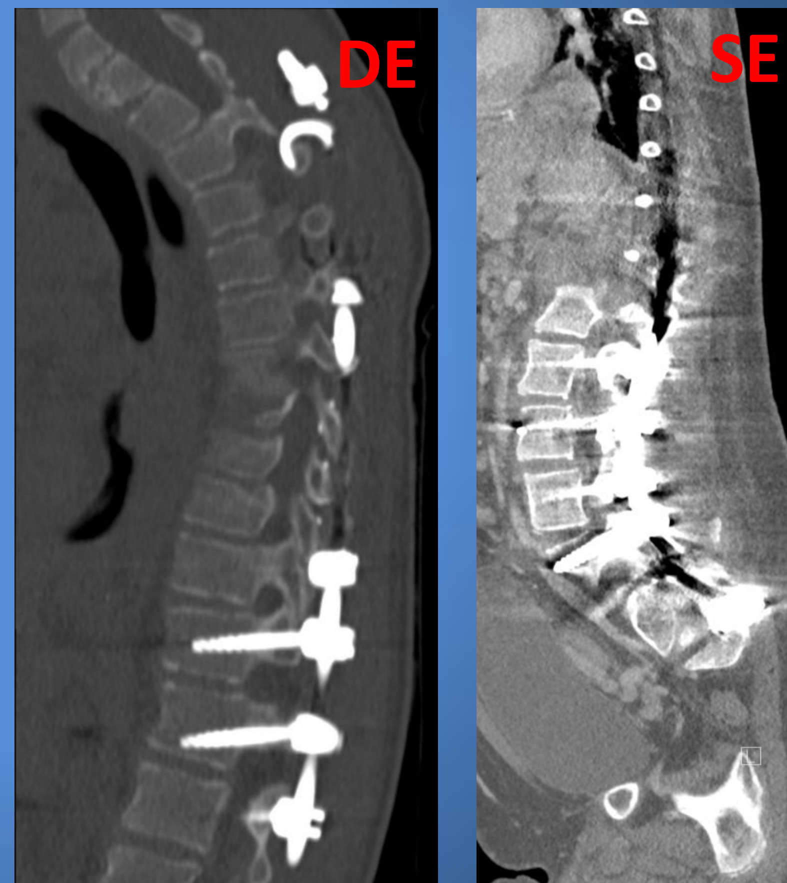
Subarachnoid hemorrhage in the prepontine cystern from a basilar aneurysm is subtle and difficult to appreciate on the VNC image.

Clinical Cases

Metallic Artifact Reduction

Posterior cervical fusion





Scoliosis with posterior spinal fusion

Summary

The pediatric phantom study

- Doses are “neutral” in head and abdominal studies; and are also “neutral” in chest studies for patients larger than a typical one year old.

- A lower mAs “floor” exists, when both tube currents reach nominally 10mAs per rotation, thus could result a limitation on “dose neutrality” when converting SE protocols to DE protocols for very small patients, or from most aggressively dose-reduced SE protocols.

Summary

The pediatric phantom study

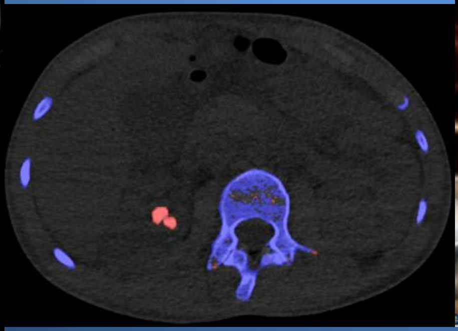
- Has helped us better understand the dose consequences of converting our single energy protocols to dual energy protocols.
- Has provided clear clinical guidelines as we begin to implement clinical dual energy protocols in pediatric imaging.

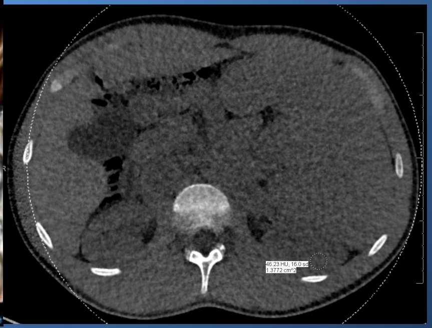
We predict a wide range of the dual energy applications in pediatric imaging that are well justified in dose and offer great potential in diagnostic imaging and image quality improvement.

Summary

CHOP has developed routine clinical applications in

- metallic artifact reduction
- renal stone evaluation
- bone removal in head/neck CTA, and
- virtual non-contrast in the evaluation of abdominal tumors with suspicion of calcifications





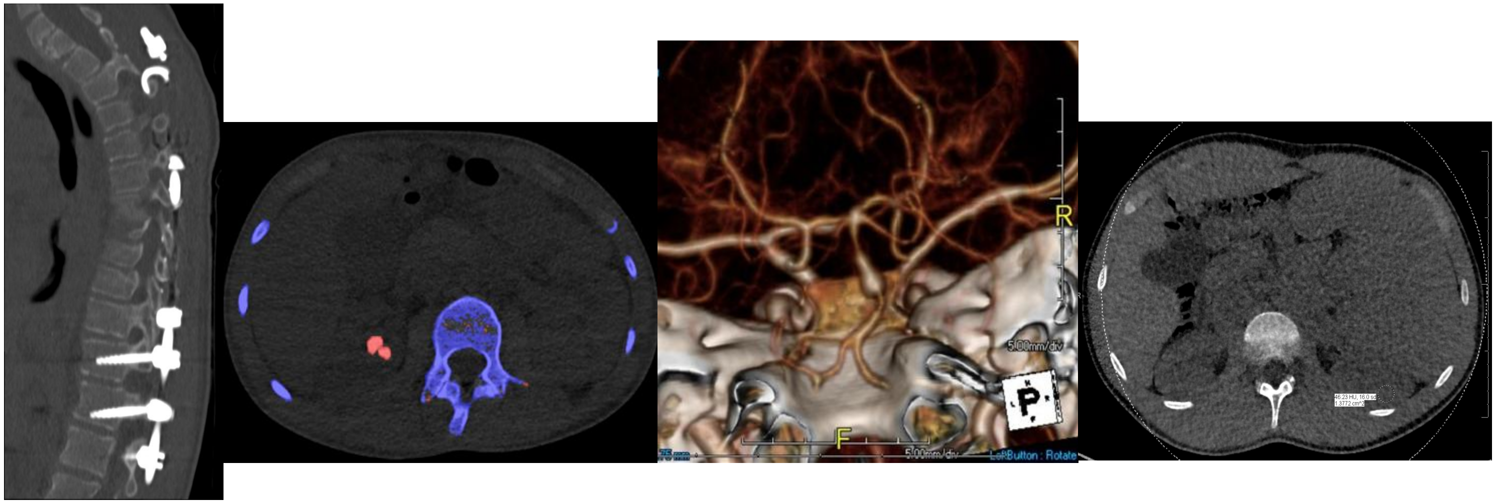
Summary

Armed with improved understanding, we

- have continued to develop more clinical applications to take full advantage of dual energy technology in the CT imaging of our pediatric population.

- believe DECT offers unique advantages in clinical CT imaging and are well justified in doses

SAMS #3: Identify the following various dual energy applications, from left to right:



8% a. Metal artifact removal, Liver VNC, Head/Neck CTA bone removal, Abd CTA

6% b. Bone removal, Stone Evaluation, Liver VNC, Head/Neck CTA

3% c. Abd CTA Metal artifact removal,, Head/Neck CTA bone removal, Liver VNC

81% d. Metal artifact removal, Stone Evaluation, Head/Neck CTA bone removal, VNC in abdomen

2% e. None of above

Answer to SAM QUESTION 3

Correct Answer: d)

(Ref: McCullough W, Vossough A, Darge K, Zhu X, Servaes, S; Implementation of Dual-Energy CT in Pediatric Imaging, Society for Pediatric Radiology Annual Meeting, April 27 – May 1, 2015, Bellevue, Washington.)

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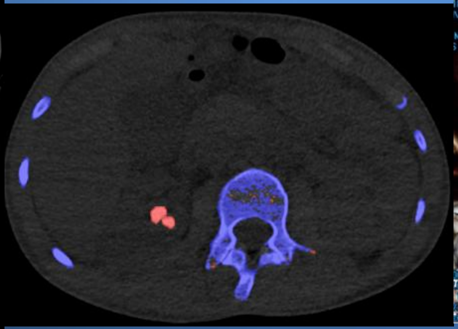
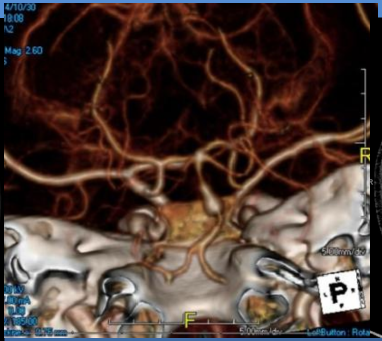
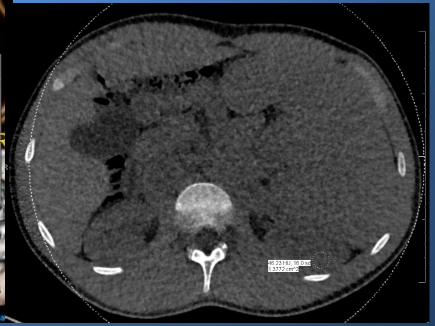

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