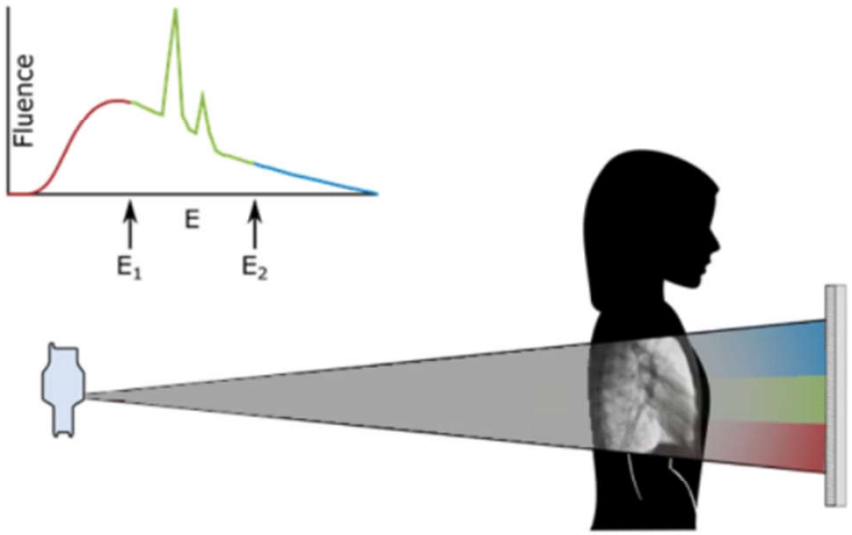
Improving Department Results with Single Exposure Dual-Energy Subtraction X-Ray: Clinical, Operational and Financial Benefits

KA Imaging
July 27, 2021

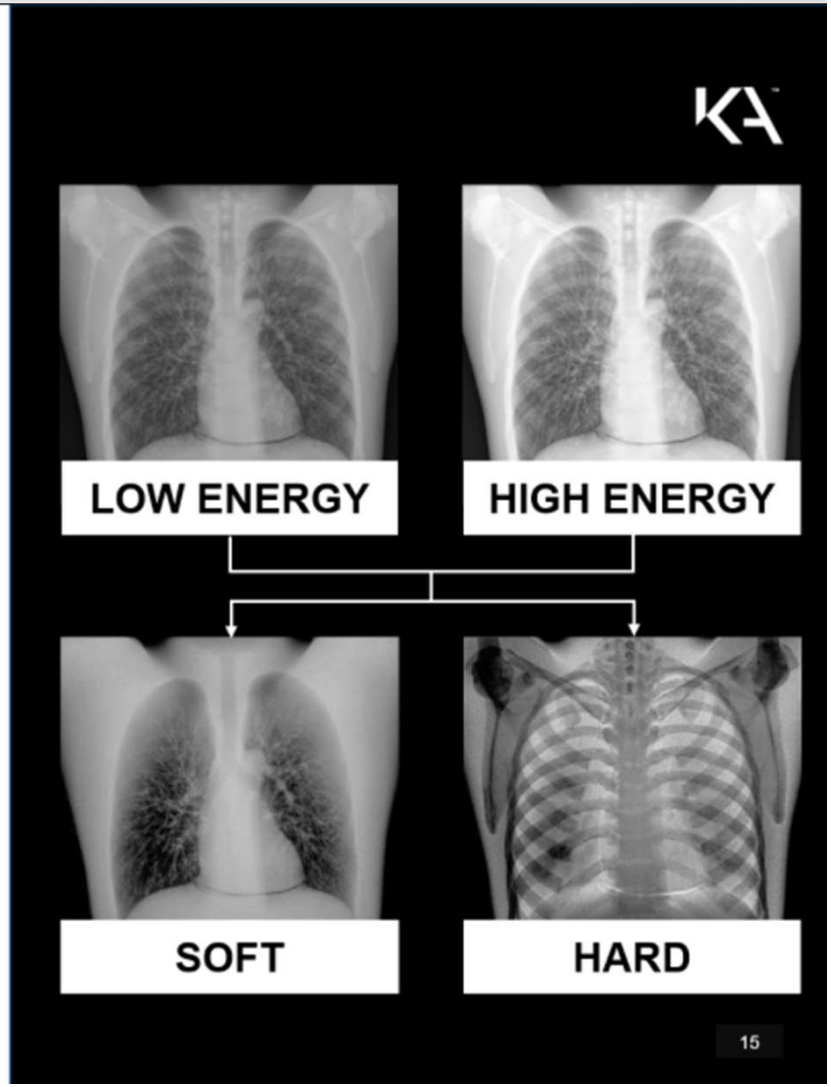
Karim S Karim PhD PEng MBA FEIC
Founder and Chief Technology Officer

Jay Potipcoe, MRT(R), BA
Applications Specialist

Dual-Energy (DE) X-Ray Subtraction (1970s)



Studies have shown that DE enables accurate diagnosis by removing bones/soft tissue from X-ray image.



Problems with Dual Energy

Access

- Higher radiation per scan → Limited use cases
- Not portable
- Cannot substitute standard chest X-ray

Quality

- DE images unreadable up to 20% of the time due to misregistration errors (motion artifact)

Cost

- Fixed system available from very few manufacturers
- Large upfront costs (acquisition, installation and maintenance)

DE solutions to date have seen slow adoption because of motion artifacts, higher radiation, change in workflow and expensive X-ray systems

Dual Energy Motion Artifact
RSNA Radiographics(2006) vol. 26 pp. 79-9

Dual-Energy Solutions:
Dual-layer Detector Technology (1990's)

X-RAY SOURCE

Conventional X-Ray source

X-RAY DETECTOR

Energy Separation performed in the detector

DOSE EFFICIENCY $\mathrm{DQE}(u, v)$

POOR

- Significant loss of photons in mid-filter

DUAL-ENERGY IMAGE QUALITY

POOR

- Tradeoff between mid-filter thickness, dose efficiency and spectral separation

Dual-Energy Solutions: Bone Suppression Software (2010's)

X-RAY SOURCE

Conventional X-Ray source

X-RAY DETECTOR

Morphology based software solution (not true dual-energy) used to perform bone and tissue separation

✓ DOSE EFFICIENCY $\mathrm{DQE}(u, v)$	✗ DUAL-ENERGY IMAGE QUALITY
GOOD	**POOR**
Same as chest X-ray	• Limited use cases (i.e. nodules) • Limited views (i.e. PA/AP only) • Cannot effectively distinguish between soft tissue and bone

Dual-Energy Solutions:
Triple-layer Detector Technology (2020's)

X-RAY SOURCE

Conventional X-Ray source

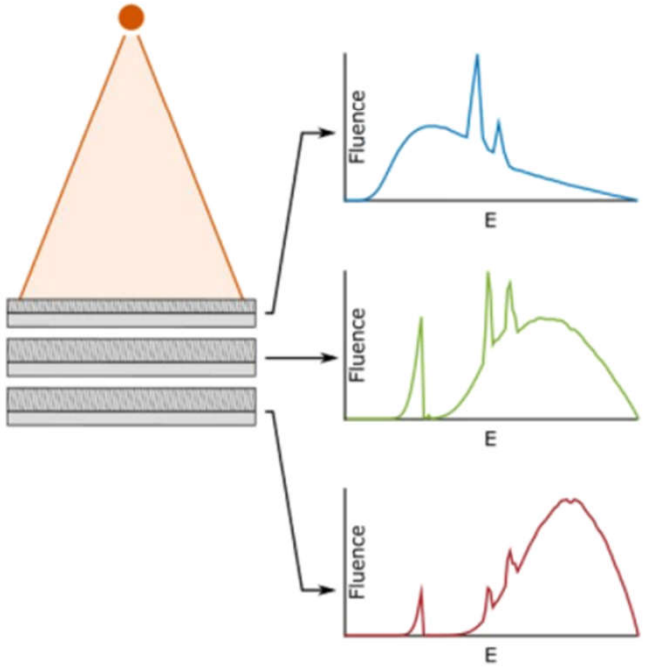
X-RAY DETECTOR

Energy Separation performed in the detector

DOSE EFFICIENCY $\mathrm{DQE}(u,v)$	DUAL-ENERGY IMAGE QUALITY
EXCELLENT	**EXCELLENT**
• Three sensor layers capture more photons • Better DQE than most chest X-rays	• Layers optimized for high spectral separation • Zero motion artifact

Single X-ray Exposure

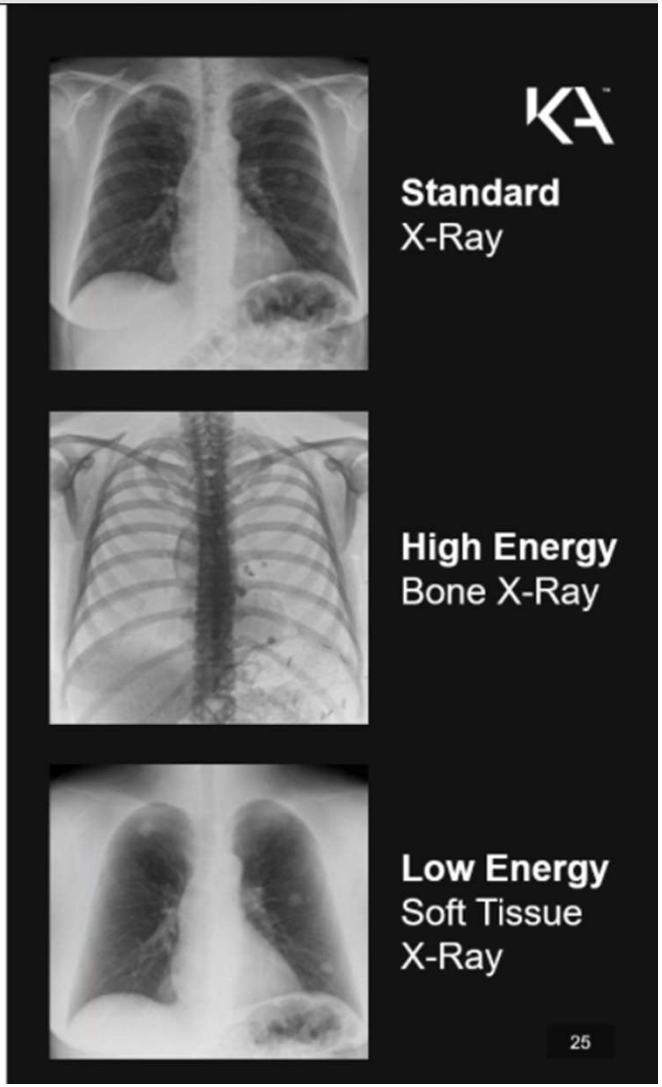
How Do Three Layers Work?



- Single 120 kVp exposure generates three distinct spectral X-ray images
- Thickness for each layer can be optimized for best spectral separation without losing X-ray dose efficiency
- X-ray signals from all three layers are added to get the best-in-class dose efficiency X-ray image
- Signals from Layer 1 and Layer 3 are subtracted to yield dual energy images
- Simultaneous acquisition of three images results in zero motion artifact

Single Exposure Dual Energy Solution

Three images from one chest X-ray exposure maintains same clinical technique and dose as digital chest X-ray



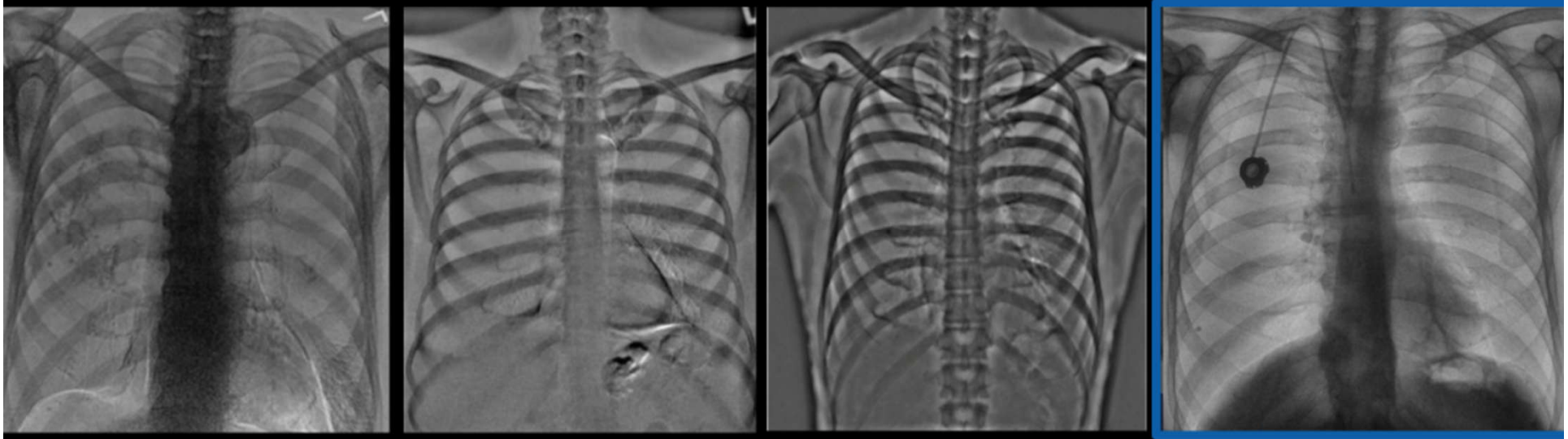
Comparison Between Different Solutions

	Single Exposure Dual-Energy	X-ray + Bone Suppression Software	Dual Exposure Dual Energy	Digital Chest X-ray
Clinical Use Cases	More than Chest X-ray	Limited to nodules	Less than Chest X-ray	Standard
Number of X-rays (Radiation)	Single	Single	Double	Single
Use of Grid	As per clinical technique	As per clinical technique	Always required	As per clinical technique
Better Sensitivity than Chest X-ray	Yes	Marginal	Yes	No
Distinguish Calcium from Soft Tissue	Yes (physics solution)	Marginal (software solution)	Yes (physics solution)	No
AP, PA, Lateral and Oblique Views	Yes	No	No	Yes
Portable and Mobile Applications	Yes	Yes	No	Yes
Motion Artifacts	Absent	Absent	Present	N/A

Motion Artifact Comparison

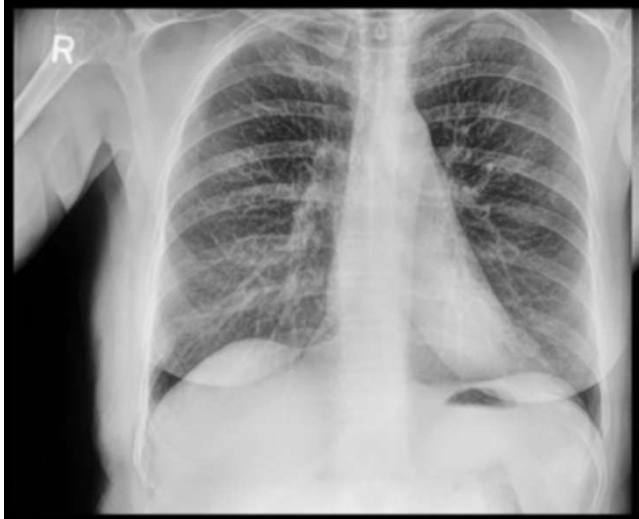
Single exposure DE produces DE images free of motion artifacts

Solution 1: Dual exposure DE	Solution 2: Dual exposure DE	Solution 3: Dual exposure DE	Solution 4: Single exposure DE

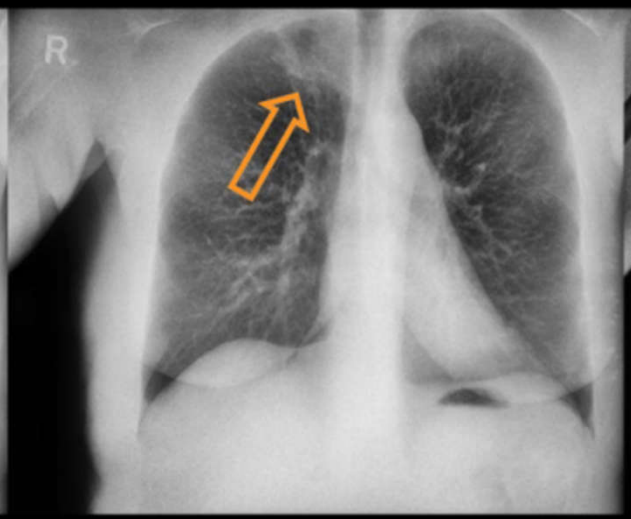


CASE A: Hidden Apical Lesion in RUL

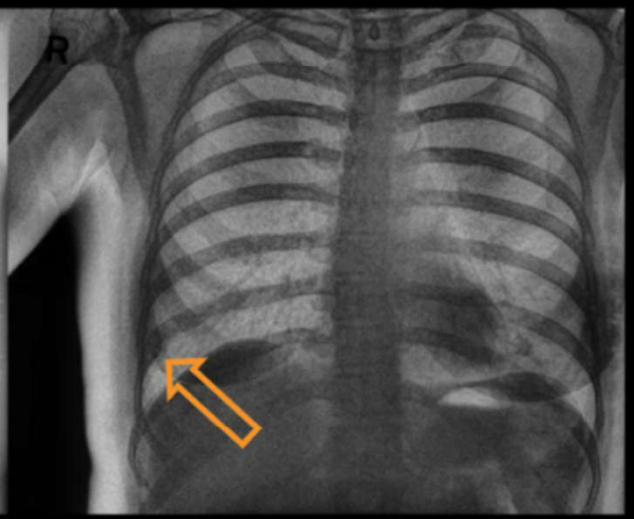
Conventional DR X-Ray



Soft Tissue Image



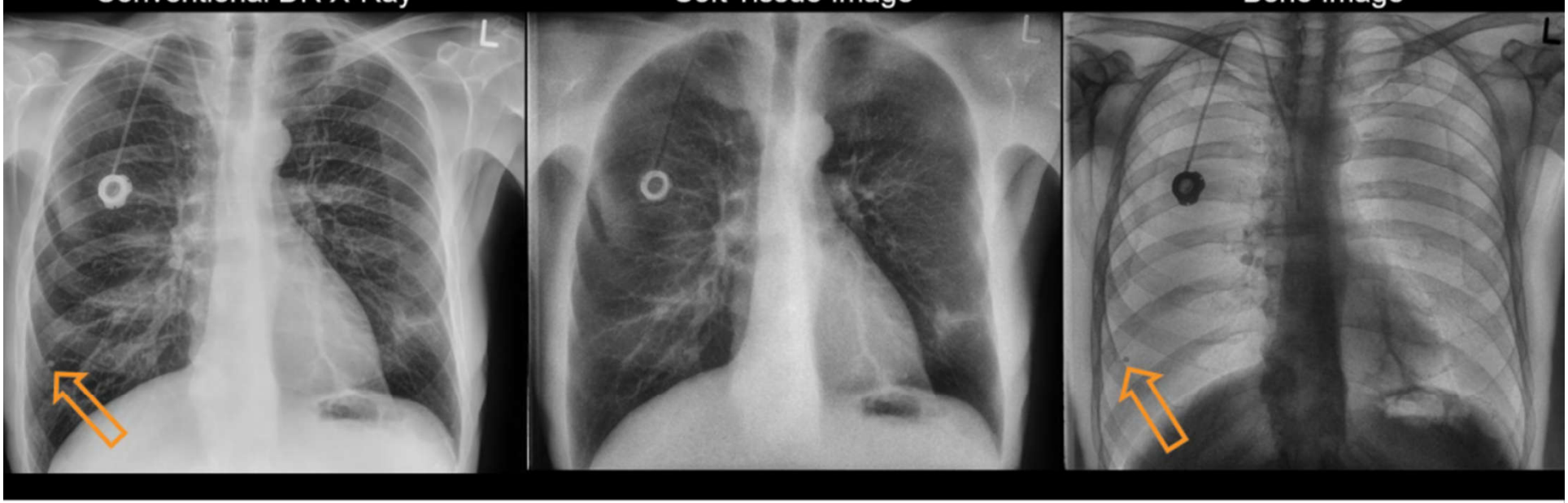
Bone Image



-This DR image was read as normal by the radiologist, but the patient actually has an apical lung lesion that was missed, due to overlapping bone. When shown the DE images, pathology was seen by the radiologist. Without DE, this would have gone unnoticed, losing valuable proactive treatment time.

-Incidentally, an older rib fracture also became visible on right side.

CASE B: Hidden Mass in RLL Obscured by Degenerative Bone Disease (PA)

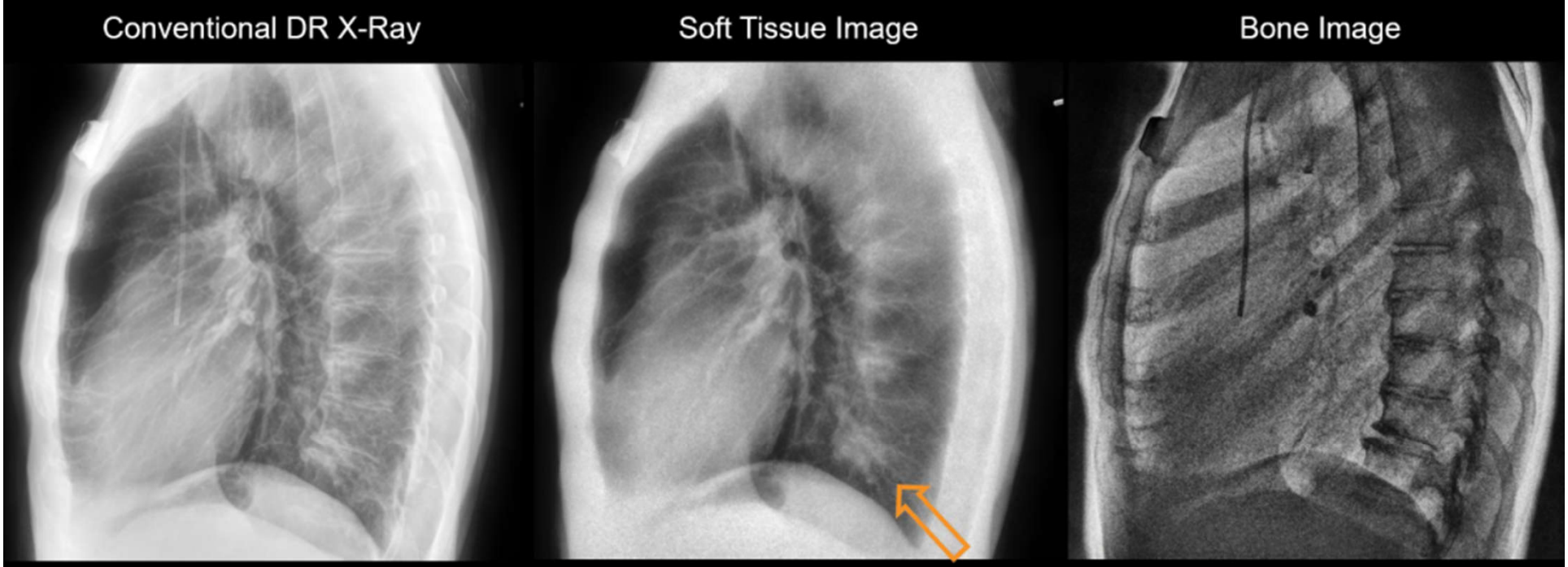


-This granuloma in the DR image can be classified as being calcified, due to its appearance in the Bone Image.

-The PortoCath line is very easy to see on the Bone Image

-There is, however, a mass behind the heart <u>not seen in this PA image</u>. Because KA Imaging's Single Exposure DE detector can perform lateral chest imaging, the mass will be seen in that view.

CASE B: Hidden Mass in RLL Obscured by Degenerative Bone Disease (Lat)



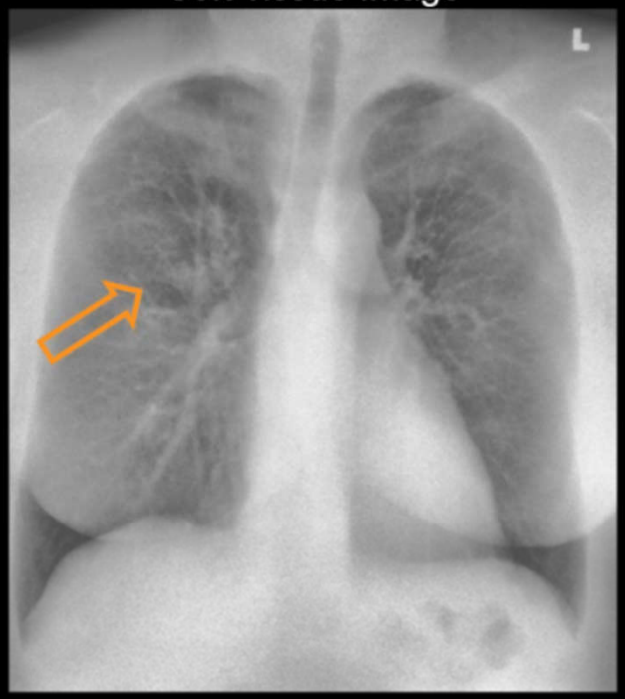
-The mass seen behind the heart is superimposed over a calcified joint in the conventional DR image. However, the Soft Tissue image clearly displays the mass to the radiologist, by removing the overlapping bone.

-The PortoCath line and sternum are also nicely differentiated in the Bone Image.

CASE C: Focal Opacity in RUL

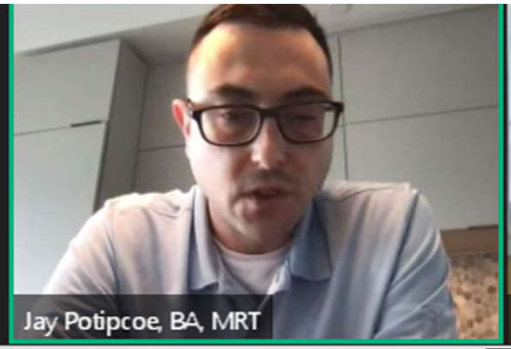
Conventional DR X-Ray

Soft Tissue Image



CT Image

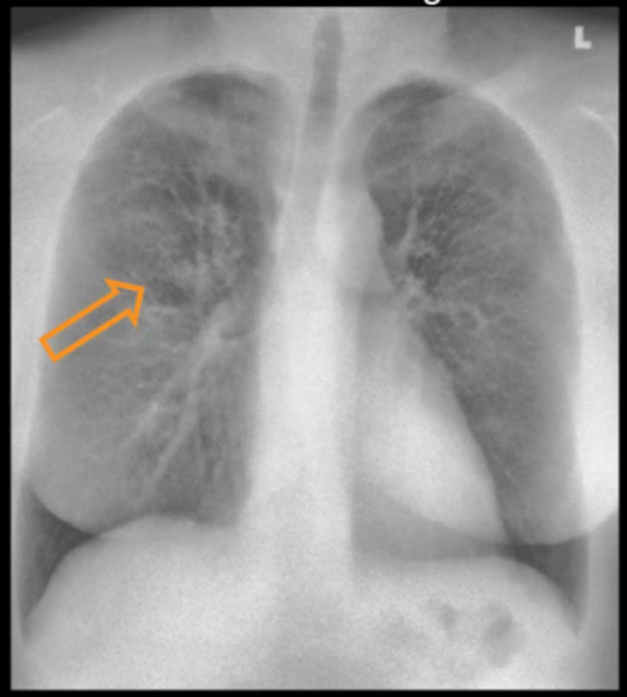
-This case involved a 51-year-old female leukemia patient. The Conventional DR X-Ray was given to the radiologist and read as normal. However, upon subsequently being shown the DE Soft Tissue image, the radiologist noticed a highlighted focal opacity indicating pneumonia (confirmed on CT). This patient would not have received prompt treatment for the pneumonia, if not for the DE image.



CASE C: Focal Opacity in RUL

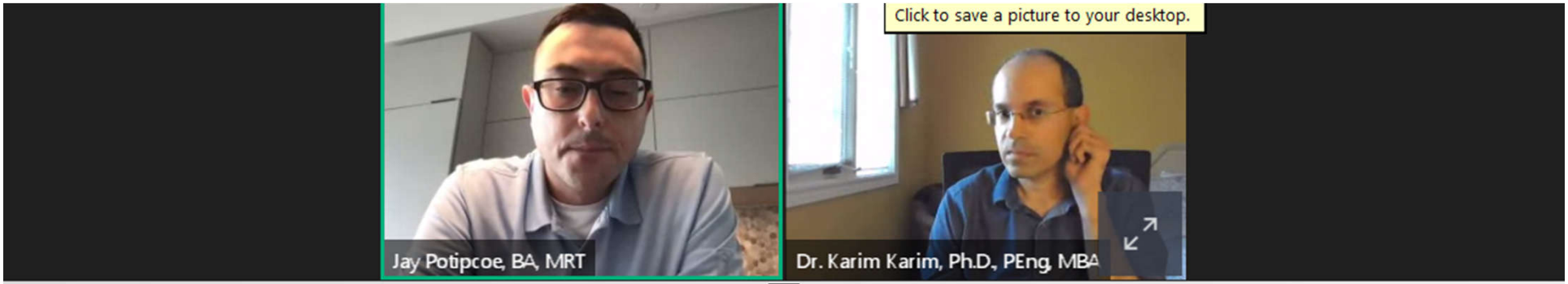
Conventional DR X-Ray

Soft Tissue Image

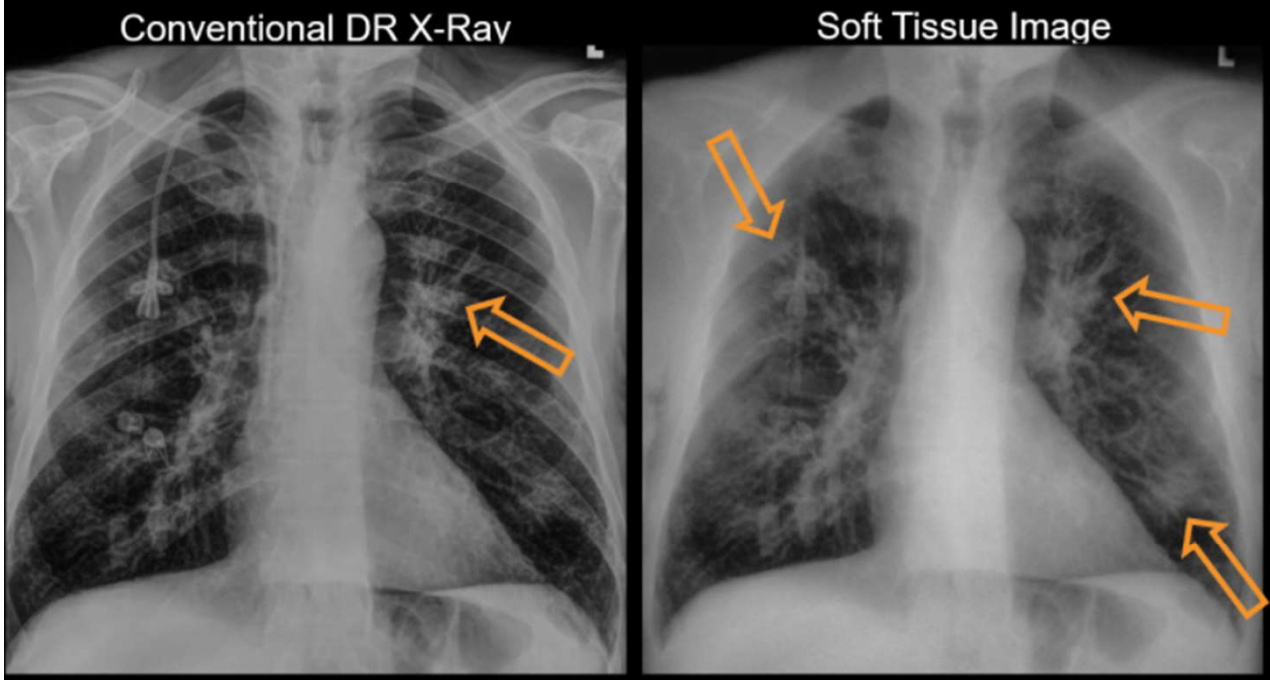


CT Image

-This case involved a 51-year-old female leukemia patient. The Conventional DR X-Ray was given to the radiologist and read as normal. However, upon subsequently being shown the DE Soft Tissue image, the radiologist noticed a highlighted focal opacity indicating pneumonia (confirmed on CT). This patient would not have received prompt treatment for the pneumonia, if not for the DE image.

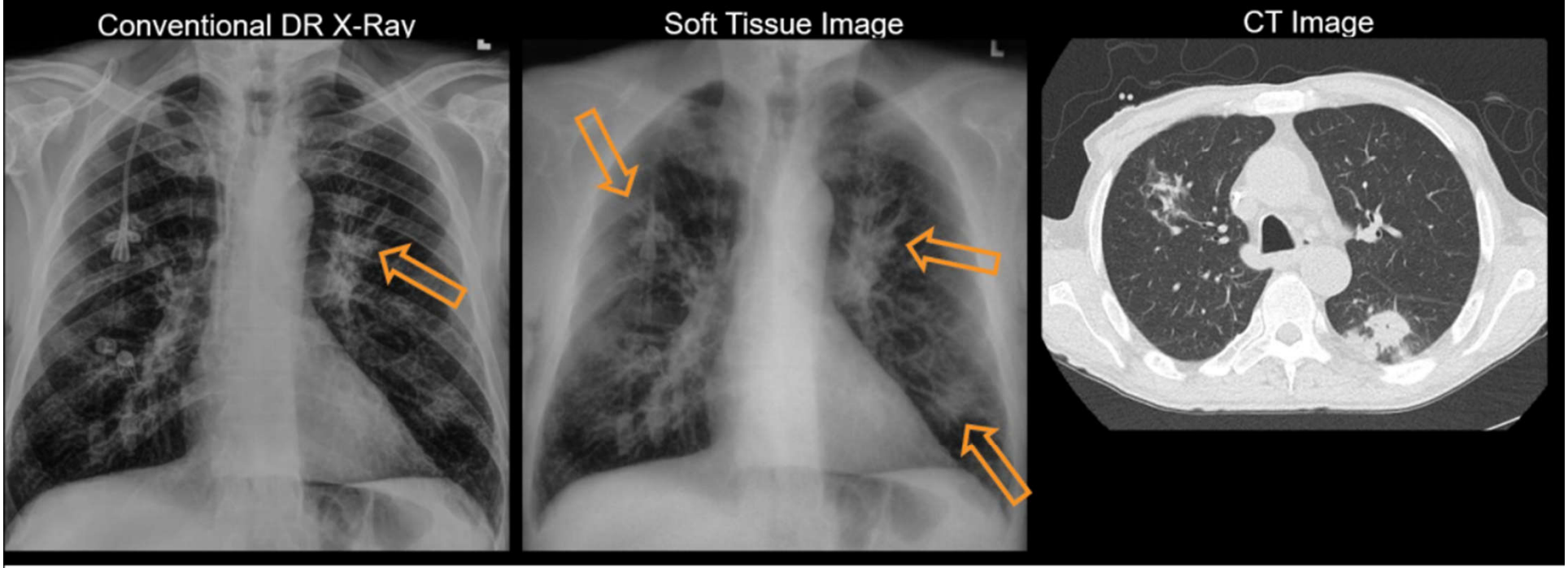


CASE D: Left Perihilar Opacity



-The Conventional DR image of this 74-year-old male with leukemia was read as showing a possible fungal pneumonia in the left hilar region. The radiologist placed confidence in diagnosis at a mere 1/5. Given the DE Soft Tissue image, the radiologist placed confidence as 5/5 for left hilar fungal pneumonia. Two other bilateral opacities were also noted in the Soft Tissue image (RUL and LLL), that were not shown in the Conventional DR image. Diagnosis was confirmed by CT.

CASE D: Left Perihilar Opacity

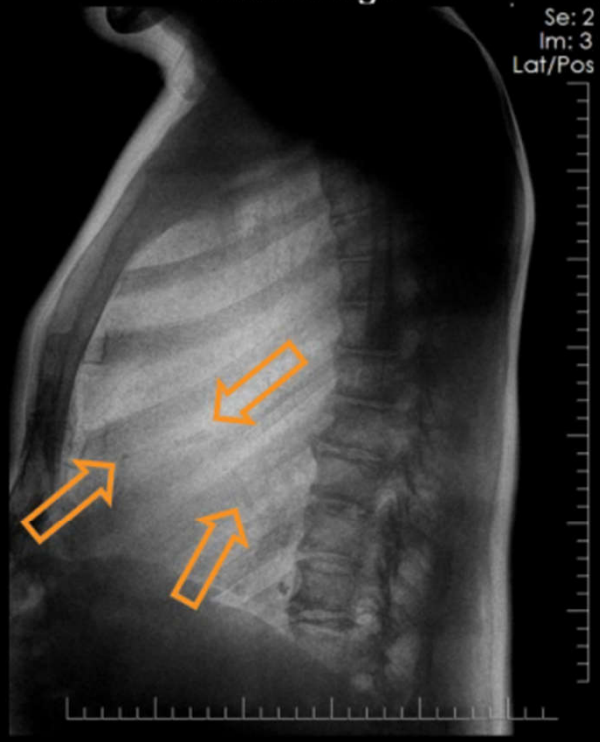


-The Conventional DR image of this 74-year-old male with leukemia was read as showing a possible fungal pneumonia in the left hilar region. The radiologist placed confidence in diagnosis at a mere 1/5. Given the DE Soft Tissue image, the radiologist placed confidence as 5/5 for left hilar fungal pneumonia. Two other bilateral opacities were also noted in the Soft Tissue image (RUL and LLL), that were not shown in the Conventional DR image. Diagnosis was confirmed by CT.

CASE E: Coronary Stents

Conventional DR X-Ray

Bone Image



-Cardiac calcifications and stents can be seen clearly using a DE Bone Image in lateral configuration

CASE F: Coronary Calcium

Conventional DR X-Ray

Soft Tissue Image

Bone Image

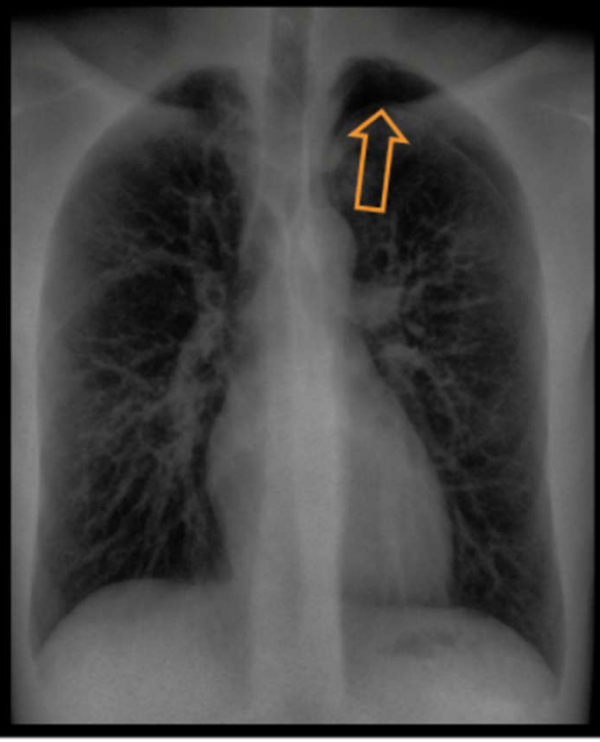
-Calcified Coronary vessels clearly seen in lateral image

-Clearly seen PortoCath line, sternum, and sternal wire ties in Bone Image

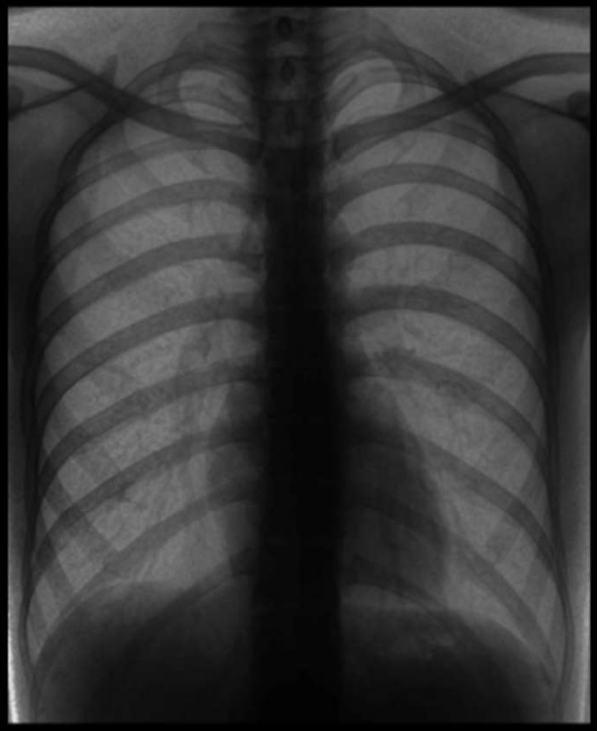
CASE G: Pneumothorax

Conventional DR X-Ray

Soft Tissue Image



Bone Image



-This 26-year-old male presented to the ER with difficulty breathing and chest pain. A single exposure dual energy X-ray detector was used to generate all 3 images, and clearly displays the left apical pneumothorax, best seen in the Soft Tissue Image.

Benefits of Dual Energy Subtraction – Pneumonia

Diagnosis: history, exam, clinical signs, **chest X-ray** → **Pneumonia Misdiagnosed in 33% of patients** → **Low sensitivity** for chest X-ray

		Sensitivity		Specificity	
		Chest X-ray	Dual Energy	Chest X-ray	Dual Energy
Interstitial disease	Lung emphysema	45%	75%	84%	83%
	Scarring	77%	96%	76%	70%
	Reticular lung changes	81%	92%	87%	87%
Infective consolidation		41%	61%	98%	97%
Lung atelectasis		22%	67%	99%	99%

Martini, Katharina, Marco Baessler, Stephan Baumueller, and Thomas Frauenfelder. "Diagnostic accuracy and added value of dual-energy subtraction radiography compared to standard conventional radiography using computed tomography as standard of reference." PloS one 12, no. 3 (2017): e0174285.

Dual energy increases sensitivity up to 50% → Early diagnosis and monitoring → **Can replace Chest X-ray in Emergency Department**

Case Study #2: Indeterminate Nodules

Solitary Pulmonary Nodules (SPN) are prevalent in **0.15%** of the general population

150 million chest X-Rays performed in the US in 2018

Lung cancer is #1 killer out of all cancers worldwide → Late-stage detection leads to high mortality rates → Small nodules are missed on chest X-rays in younger, asymptomatic patients

At 0.15% prevalence, and 150 million chest X-Rays, this indicates up to 225,000 cases of SPN could have been found → **1.66 per 1000 cases of missed SPN result in suits. At 225,000 missed cases, this implies 374 patients filed suit** → Annual payouts in US for missed nodule lawsuits total ~ $100 million. This indicates an average of $294,000 per claim

DE X-Ray has a 33% higher sensitivity for pulmonary nodules, compared to regular X-Ray → With 33% increase in detection with DE, and the 0.15% prevalence, a hospital taking an average 120 chest X-Rays/day will find 12 extra cases of SPN each year, compared to regular X-Ray → Estimating $10,000 treatment costs per patient, this allows for an extra $120,000 in hospital income annually

Earlier and Easier Detection = Better Patient Outcomes, More Downstream Revenue, and Enhanced Risk Avoidance

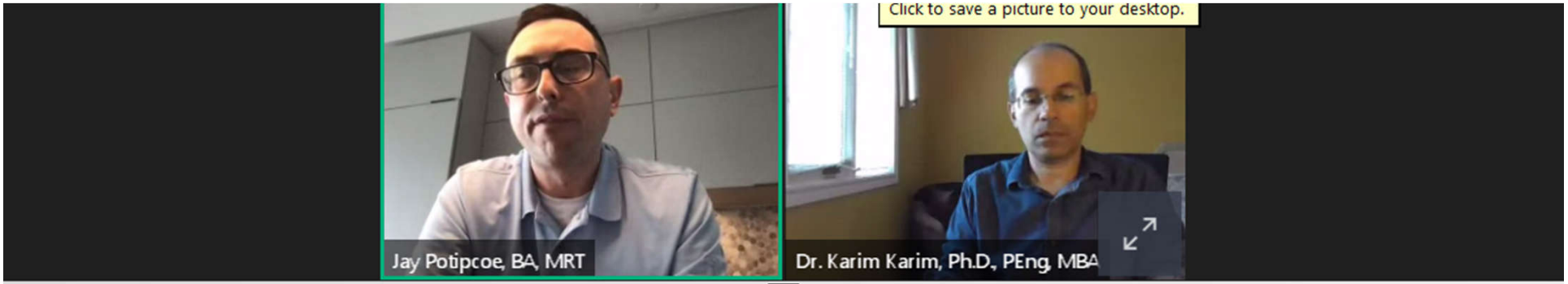
Karim S Karim, "Single Exposure, Digital Dual-Energy Subtraction X-Ray Ushers in a New Era of Diagnostic X-Ray

Benefits of Dual Energy Subtraction - Nodules

	Sensitivity (%)		Specificity		Accuracy		PPV		NPV	
	Chest X-ray	Dual Energy	Chest X-ray	Dual Energy	Chest X-ray	Dual Energy	Chest X-ray	Dual Energy	Chest X-ray	Dual Energy
Small lung nodules < 20 mm, Solid, Part-solid, Non-solid	47.6	63	72.5	72.5	56.7	66.5	75.6	80.1	44.4	53.7

Oda, Seitaro, Kazuo Awai, Kenji Suzuki, Yumi Yanaga, Yoshinori Funama, Heber MacMahon, and Yasuyuki Yamashita. "Performance of radiologists in detection of small pulmonary nodules on chest radiographs: effect of rib suppression with a massive-training artificial neural network." American Journal of Roentgenology 193, no. 5 (2009): W397-W402.

Dual energy increases sensitivity by 33% relative to X-ray → Early detection for proactively finding cases → Replacement for Chest X-ray in Outpatient Settings

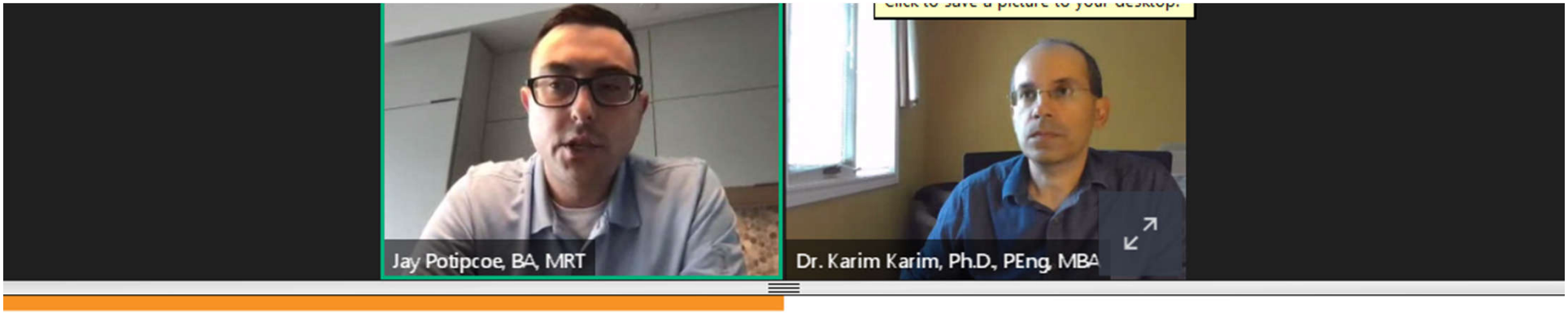


Case Study #3: Small-Volume Pneumothorax

Affects up to **35** out of every 100,000 people

Cost of treatment is ~ **$25,000**/case.
Cost goes up if case worsens, due to misdiagnosis

Over 50,000 error-induced pneumothoraces in USA annually	Can cause death quickly if not detected early	Missed often on portable chest X-ray, mistakes not reimbursed
Missed pneumothoraces can progress without diagnosis and treatment	**Missed cases can develop into life-threatening tension pneumothoraces (TPT): cardiac shift, pressure on heart, reduced flow**	Vented patients at higher risk of TPT when smaller pneumothoraces missed. TPT has mortality rate of up to 91% in ICU patients
DE X-Ray boosts detection sensitivity by 12% and specificity by 8%	Thousands of pneumothorax cases detected and treated earlier	Enhanced patient outcomes. Greater avoidance of malpractice liability
Pneumothorax-related malpractice suits have an average cost of ~ $143,250/case in the US	DE X-Ray can identify challenging small-volume pneumothoraces in up to 30% of cases where it was missed in regular X-Ray	DE X-Ray can help prevent deaths, painful surgical interventions, and money lost through malpractice suits, by improving early identification of pneumothoraces



Benefits of Dual Energy Subtraction - Pneumothorax

	Chest X-ray	Dual Energy
	# of cases found in study	# of cases found in study
Interns	6.2	8.8
Residents	9.1	11
Senior Physicians	9.5	10.9
Non-radiologists	9.2	10.6
Radiologists	9.5	10.6

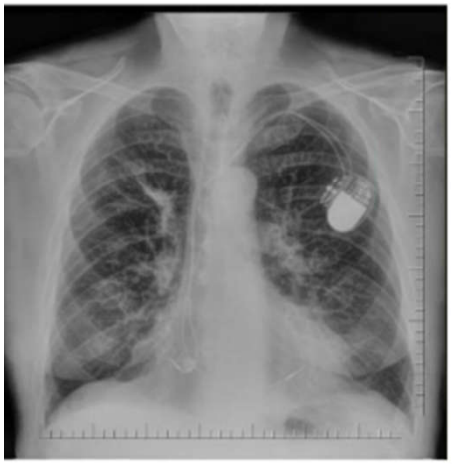
Urbaneja, Ayla, Gauthier Dodin, Gabriela Hossu, Omar Bakour, Rachid Kechidi, Pedro Gondim Teixeira, and Alain Blum. "Added value of bone subtraction in dual-energy digital radiography in the detection of pneumothorax: impact of reader expertise and medical specialty." Academic radiology 25, no. 1 (2018): 82-87.

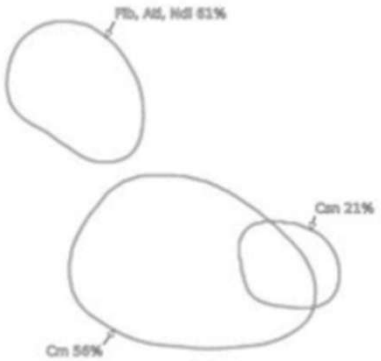
Dual energy detected up to 30% more small volume pneumothoraces → Early detection leads to cost savings and better patient outcomes → Replaces Portable X-ray in Critical Care Units

Clinical Use Cases with High Economic Impact

Use Case	Issue	Extra Cases Found Relative to Chest X-ray over 5 years	Improved by DE
Solitary Pulmonary Nodule	**Lung is #1 Killer cancer** worldwide	**60** (US data)	Increase in sensitivity **by 33%** for nodules < 20mm
Coronary Calcium	**Cardiac disease is the #1 Killer** in developed countries	**205** (US data)	Presence of calcium in DE bone image is **strongly correlated with calcium in CT**
Pneumonia	**33%** of patients misdiagnosed, CXR not sensitive	**90** (US data)	Sensitivity increases for infectious consolidation **by 50%** and atelectasis **by 3X**
Pneumothorax	**>50,000** due to errors in the USA, 20% die	**15** (US data)	**Up to 30%** more small volume pneumothoraces found even by residents and interns
Tuberculosis	**1.5 million** die annually in LMICs	**> 300** (in a high TB prevalence setting in Asia)	**Up to 30%** increase in sensitivity and **NPV** for consolidation and cavitation

AI vs. Dual Energy



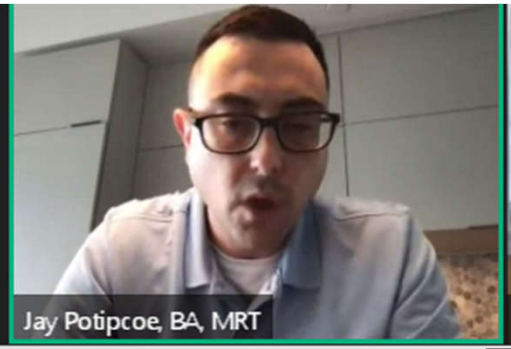


CASE REPORT			
Abnormality Score 61%			
Atl	Atelectasis	48%	right upper
Calc	Calcification	Low	-
Cm	Cardiomegaly	56%	present
Con	Consolidation	21%	left lower
Fib	Fibrosis	61%	right upper
MW	Mediastinal Widening	Low	-
Ndl	Nodule	18%	right upper
PEf	Pleural effusion	Low	-
Ppm	Pneumoperitoneum	Low	-
Ptx	Pneumothorax	Low	-

CASE REPORT			
Abnormality Score 61%			
Atl	Atelectasis	48%	right upper
Calc	Calcification	Low	-
Cm	Cardiomegaly	56%	present
Con	Consolidation	21%	left lower
Fib	Fibrosis	61%	right upper
MW	Mediastinal Widening	Low	-
Ndl	Nodule	18%	right upper
PEf	Pleural effusion	Low	-
Ppm	Pneumoperitoneum	Low	-
Ptx	Pneumothorax	Low	-

This is an example of a commercial AI chest product.

The image on the left is a DR image and the two images on the right are the outputs of the AI algorithms.



Compared with Single Exposure Dual Energy

AI missed nodules in the lower part of the image that are near the mediastinum

There is also pneumonia seen in the soft tissue image that was not identified by the AI

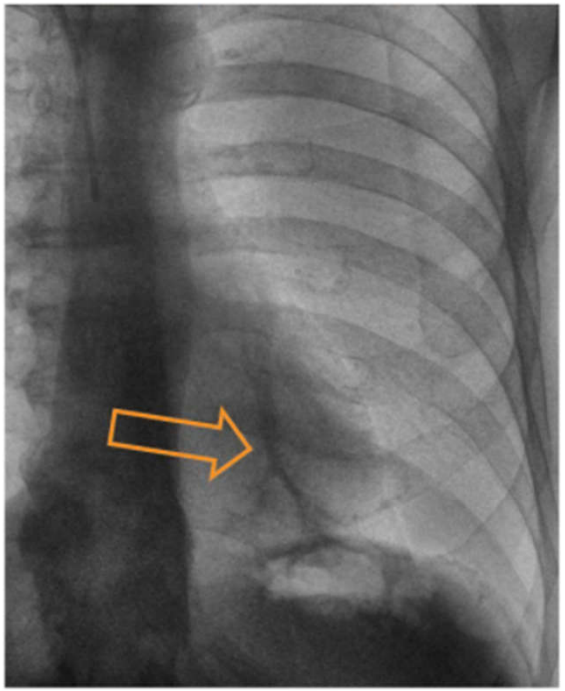
Looking to the Future: Coronary Calcium Scoring (New Use Case for X-ray)

-Data shows dual energy X-ray is adept at displaying coronary calcifications. There is exciting potential for using DE X-ray for calcium scoring[1]

-With proper processing applied to DE images, calcified coronary arteries can be visualized, and data shows these images can be used in Agatston calcium scoring

-Calcium scoring done on proper-quality DE chest X-rays was considerably accurate, as confirmed by subsequent CT calcium scoring[1]

-Using DE chest X-rays to engage in calcium scoring can expand coronary disease screening programs, keep dose low, and enhance patient care



[1] Yingnan Song, Hao Wu, Di Wen, Bo Zhu, Philipp Graner, Leslie Ciancibello, Haran Rajeswaran, Karma Salem, Mehrdad Hajmomenian, Robert C. Gilkeson and David L. Wilson, "Detection of coronary calcifications with dual energy chest X-rays: clinical evaluation," Int J Cardiovasc Imaging (2020).

Single Exposure Dual Energy Enables New Opportunities For X-ray Imaging

- More confident, accurate image interpretation
- Save time and benefit patients in Radiology, Emergency and Critical Care departments
- No additional procedure or dose – same as chest X-ray
- Leverage existing X-ray equipment and clinical techniques

www.kaimaging.com
(226) 215-9897
info@kaimaging.com

Jay Potipcoe
Applications Specialist
jpotipcoe@kaimaging.com

Karim Karim
CTO
kkarim@kaimaging.com

ICEwebinars

A COOL SERIES FOR HOT TOPICS

NGUYEN VAN CONG

Has Attended the Following Webinar

Improving Department Results with Single Exposure Dual-Energy Subtraction X-Ray: Clinical, Operational and Financial Benefits

on

7/27/2021

CERTIFICATE OF ATTENDANCE

Sponsored by KA Imaging. Presented by Dr. Karim Karim, Ph.D., PEng, MBA and Jay Potipcoe, BA, MRT. Approved for 1 ARRT Category A CE credit by AHRA (Ref. LEC11337). Approved for 1 CRA credit. Expires 7/28/2022.