White Paper

Technical Brief Series

Dose Efficient Dual Energy Subtraction Radiography – Theory of Operations

Dual energy digital radiography is an imaging technique that takes advantage of the differential, energy-dependent absorption properties of bone and soft tissue structures in human anatomy. By capturing two radiographic images of a patient in rapid succession, one at a relatively lower energy X-ray exposure and a second at a relatively higher energy, it is possible to mathematically derive a soft tissue-only image with bone structures removed, and a corresponding bone-only image [1] (Figure 1).

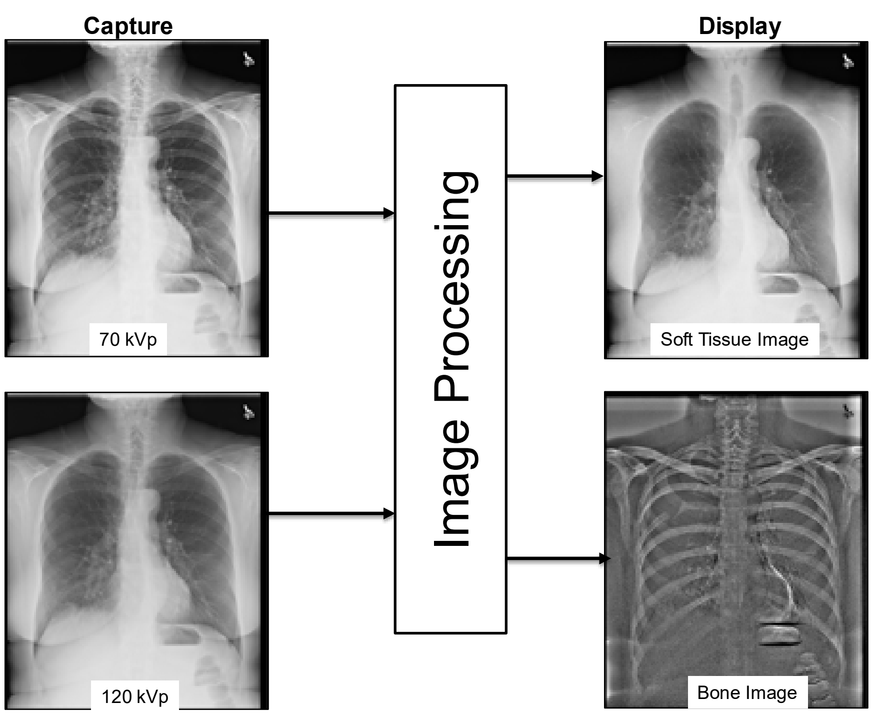

Figure 1: High and low energy images captured of a patient in rapid succession (on left) are transformed using image processing to create a soft tissue-only image and a corresponding bone-only image (on right)

Numerous studies have been reported in the scientific literature regarding the diagnostic benefits of dual energy imaging, in particular for chest radiography. For example, the detection sensitivity for abnormalities in the lung is improved because features that are often difficult to visualize in standard chest radiographs become more conspicuous when overlying rib structures are subtracted [2,3]. Dual energy imaging additionally enables a degree of quantification for certain material properties which can help to improve specificity. For example, calcified lung nodules appear more pronounced in bone-only images, which is usually indicative that the lesion is benign. Other published scientific papers have reported that dual energy soft-tissue images provide overall increased sensitivity for the detection of infectious consolidations, interstitial lung changes, and aortic or tracheal calcification. Dual energy further allows for the assessment of bone abnormalities that can simulate disease, such as a bone islands, costochondral osteophytes, or healing rib fractures, each of which may mimic a solitary pulmonary nodule.

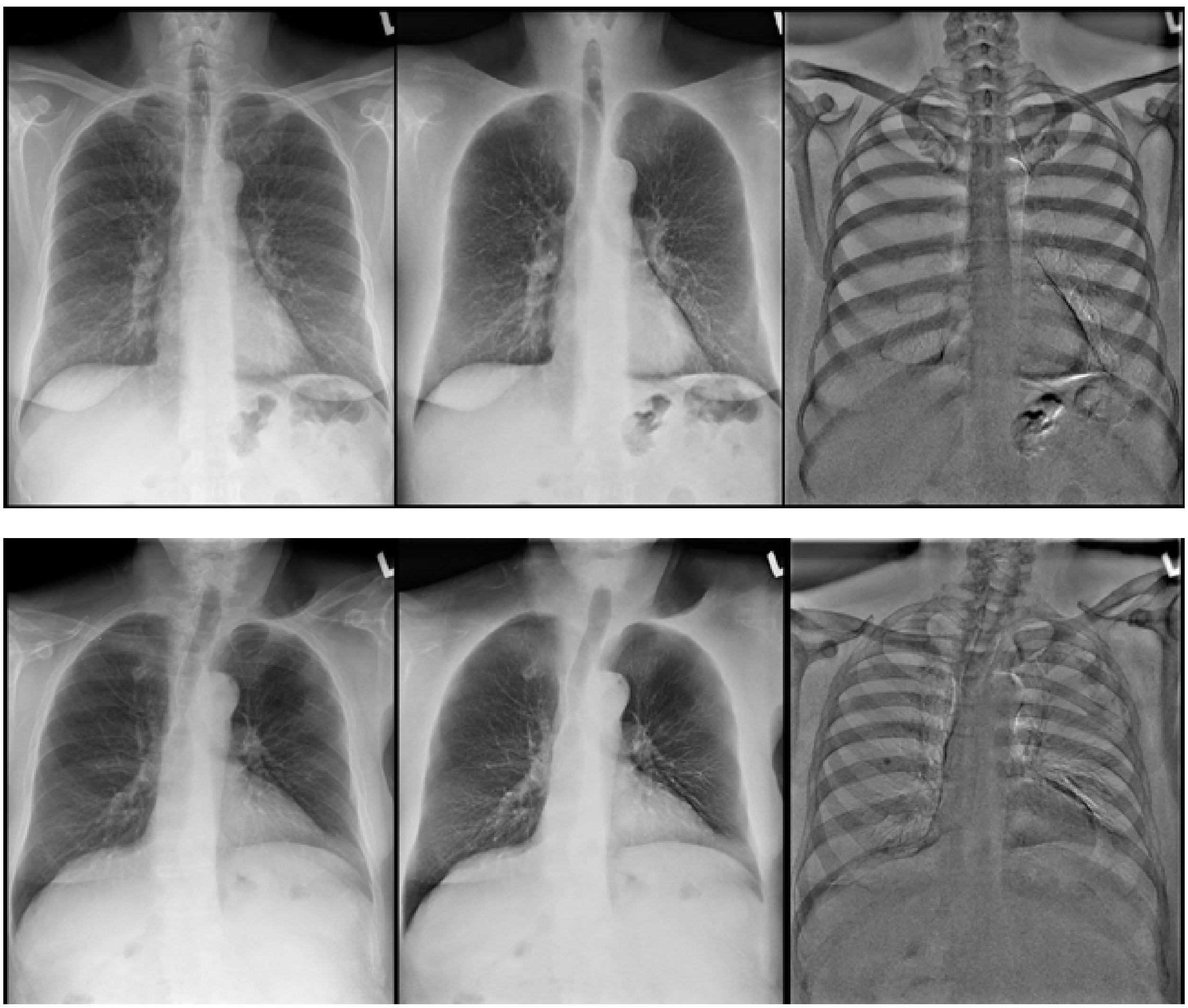

Figure 2: Two sets of image examples comparing between standard radiography (on left), and the soft tissue (in middle) and bone (on right) images from dual energy subtraction.

There are two important limitations with dual energy imaging that have historically limited its widespread adoption: 1) concerns about increased radiation dose because two exposures are required and 2) artifacts resulting from patient-motion induced misregistration (due to heartbeat and breathing) between the capture of the high and low energy image pair. Carestream's dual energy implementation addresses both of these limitations.

Exposure Dose Efficiency

The key to achieve optimal dose efficiency is to maximize the separation of the energy spectrums between the high and low energy image captures. Dose efficiency is a measure of the image quality, which is defined here as signal difference to noise ratio (SDNR), realized given the radiation dose that is delivered, i.e., for a given dose to the patient, greater dose efficiency translates to better the image quality. Currently, all (except Carestream) commercially available digital radiography systems that offer dual energy employ a fixed filtration approach. This means that the X-ray beam filtration remains constant for the exam, and that only the kilovoltage setting (kV) is changed between the high energy and low energy exposures. The Carestream dual energy technology utilizes an approach whereby different materials (filters) are placed in the X-ray beam paths respectively for the high and low energy exposures to optimally (differentially) shape the X-ray spectrums [4]. The net result is that the Carestream dual energy method delivers excellent image quality at the equivalent patient exposure as a standard (single exposure) PA or AP chest radiograph. Figure 3 illustrates the increased separation achieved for the high and low energy spectrums for the dual energy image pair when employing the differential filtration approach versus the fixed filtration approach. Figure 3 also shows that the soft tissue image quality, measured in terms of the signal difference to noise ratio (SDNR), is approximately doubled for the same exposure to the patient.

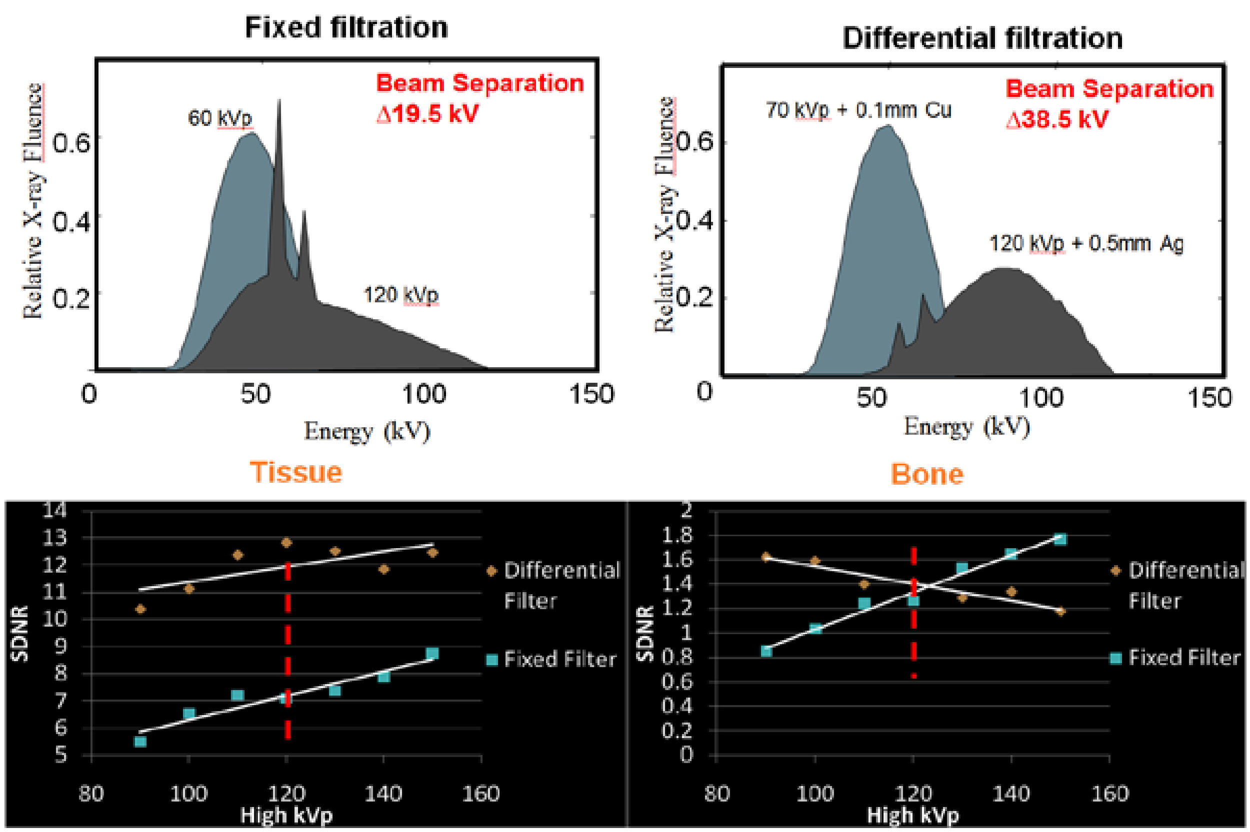

Figure 3: Comparison of dual energy imaging with fixed and differential filtration in term of beam energy separation (top) and the signal difference to noise ratio for soft tissue (bottom left) and bone (bottom right) at the same patient exposure.

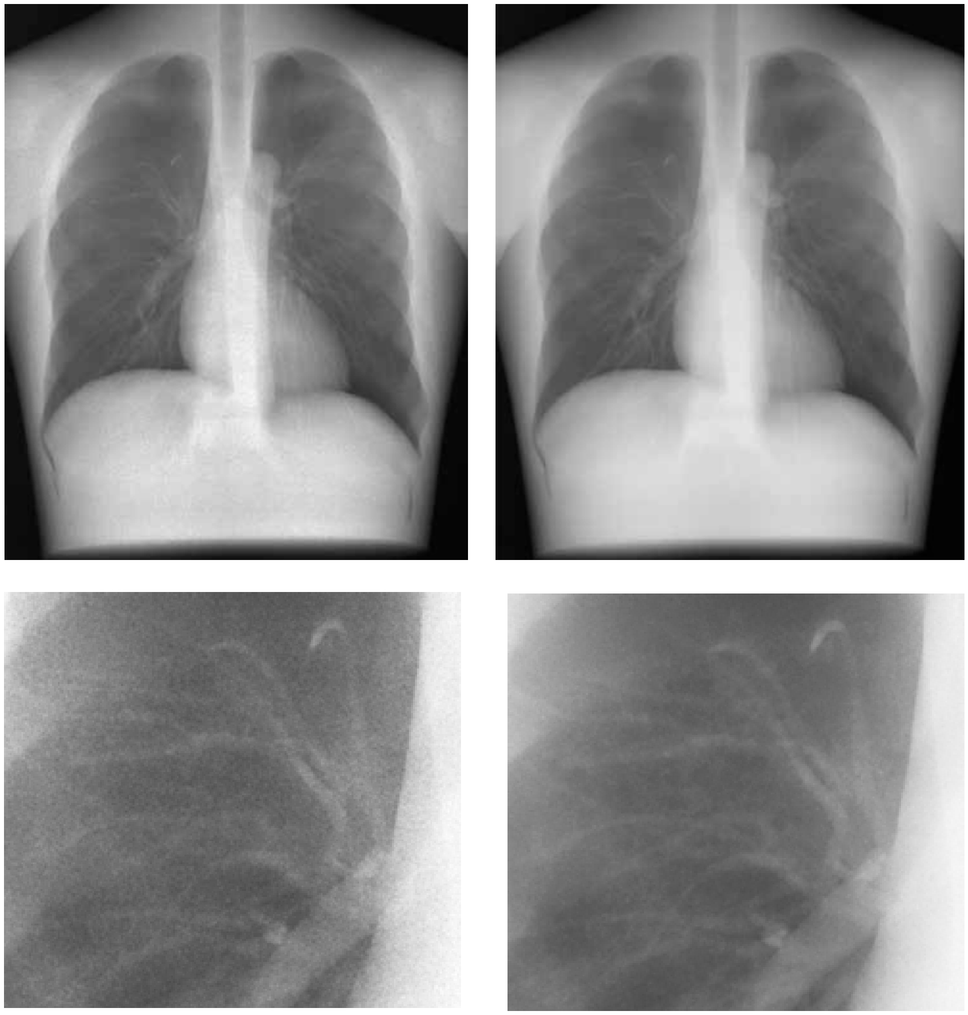

Figure 4: Comparison of soft tissue images captured of anthropomorphic chest phantom. Images were captured at the same exposure level using a fixed filtration approach (on left) and a differential filtration method (on right).

Figure 4 shows a comparison of soft tissue images of an anthropologic phantom captured at the same dose level using the fixed filtration method (on left) versus using the differential filtration method (on right). By inspection, the appearance of noise is visually less for the image captured using the differential filtration approach, consistent with the quantitative analysis illustrated in Figure 3.

Patient Motion Compensation

The time interval between the successive captures of the high and low energy image pair is rapid (about ¼ of a second). Although the time interval is short, residual misregistration caused by heartbeat and involuntary respiration occurring between the capture of high and low energy images may be introduced. To alleviate this concern, Carestream developed a motion compensation algorithm. This algorithm analyzes the relative motion inside localized regions between the high and low energy images, then corrects the motion in the high energy image by warp transform so the anatomical features in the high and low energy images are registered before the energy subtraction processing. Figure 5 shows a comparison of the soft tissue and bone images, with and without the motion compensation applied. Clinical studies were conducted that indicate the algorithm is effective in reducing patient respiration-induced motion artifacts.

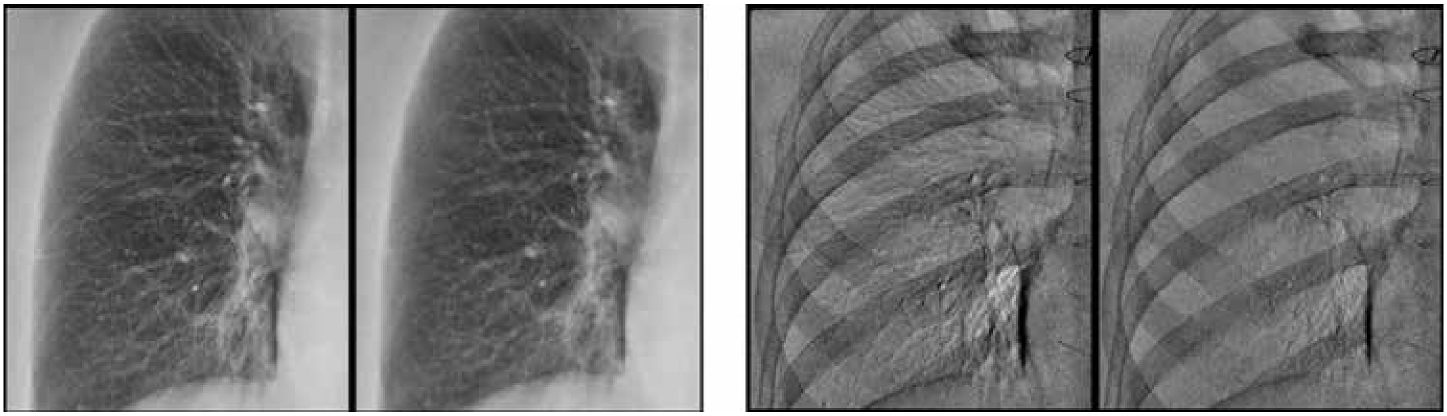

Figure 5: Soft tissue and bone images without (on left) and with (on right) patient motion correction applied. Note the appearance of residual rib edges in the uncorrected soft tissue image, and the appearance of vascular (soft tissue) structures in the uncorrected bone-only image.

Summary

The Carestream dual energy subtraction method utilizes differential filtration which enables high quality dual energy images to be captured at the same patient exposure level as a standard PA or AP digital chest radiograph. Further, the Carestream patient motion compensation software has been demonstrated in clinical studies to be effective in reducing patient respiration-induced motion artifacts.

References

1. "Development and characterization of a dual-energy subtraction imaging system for chest radiography based on CsI:Tl amorphous silicon flat-panel technology, " John M. Sabol; Gopal B. Avinash; Francois Nicolas; Bernhard E. H. Claus; Jianguo Zhao; James T. Dobbins III, Proceedings Medical Imaging 2001: Physics of Medical Imaging, vol 4320.

2. "Dual-energy subtraction chest radiography: what to look for beyond calcified nodules," Kuhlman JE1, Collins J, Brooks GN, Yandow DR, Broderick LS, Radiographics, 2006, 26(1).

3. "Dual-energy chest radiography with a flat-panel digital detector: revealing calcified chest abnormalities," Fischbach F, Freund T, Röttgen R, Engert U, Felix R, Ricke J, American Journal of Roentgenology, 2003, 181(6).

4. "Optimization of image acquisition techniques for dual-energy imaging of the chest," Shkumat NA, Siewerdsen JH, Dhanantwari AC, Williams DB, Richard S, Paul NS, Yorkston J, Van Metter R, Med Phys. 2007, 34(10).