Enhanced Interpretation of Chest Radiographs: Application of Rib-Contrast Suppression Processing in Conjunction with Low-Energy X-rays Imaging

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Purpose

Chest X-ray radiograph (CXR) is the most commonly performed exam for screening and diagnosis of lung diseases. At nominal exposure conditions, anatomical clutter from the rib structures on CXR is the most significant source of noise affecting conspicuity.[1] As a result conventional imaging protocols used for adult patients PA-view CXRs range from 110 to 130 kVp, so as to mitigate the contrast from anatomical clutters from the rib structures. However, published work [2] indicated that with poly-energetic X-rays, the kVp at maximum contrast-to-noise dose efficiency (CNR^2/dose) for thoracic soft-tissue features ranges from 60 to 80 and around 50 for bones (Figure 1). This tradeoff in anatomical noise and soft-tissue CNR, can be mitigated by rib contrast suppression (RCS) processing software. Doi et. al. have demonstrated that the performance of radiologists in the detection of subtle nodules can be improved with RCS [3].

The purpose of this presentation is to investigate the use of lower kVp imaging technique in combination with RCS processing in order to achieve optimal CNR at fixed effective patient dose for both soft tissue features (e.g. lesion conspicuity) and rib structures.
Fig. 1: For chest exams with poly-energetic x-rays the optimal energy is around 80 kVp when a CsI detector is used.

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Methods and Materials

Rib Contrast Suppression Processing

Our suppression technique includes 1) lung segmentation, 2) initial rib detection based on pixel classification, 3) rib labeling to identify individual ribs, 4) rib modeling to further refine rib detection, 5) rib edge detection based on already-refined rib detection, and 6) rib suppression. The initial rib detection requires training on a set of chest images with manually identified ribs as the truth using a set of derivative and other features extracted from each individual pixel. Rib modeling is based on the initial detections. The rib edge detection uses gradient features and the information extracted from the modeled ribs.

We collected over 400 posterior-anterior (PA) or anterior-posterior (AP) chest images acquired from DR and CR systems. The detected ribs from step 5 before suppression were evaluated against the hand-draw truth. The rib suppressed images were evaluated subjectively.

Phantom Imaging and Calculation of Lesion Conspicuity

Lesion conspicuity of 10mm lung nodules was computed via the observer detectability index ($d'$), which accounts for lesion contrast and background anatomical clutter (Figure 2). The calculations were performed based phantom images captured under the following conditions:

- Kyoto chest phantom (Figure 3), PA-view, w/ and w/o two additional 2.5 cm PMMA slabs to simulate 'normal' and 'large' sized adult patients.
- 60, 80, 100, and 120 kVp with 2.7 aluminum equivalent filtration.
- Additional 0.0, 0.1, and 0.2 mm Cu plus 1.0 mm Al filtration.
- Aluminum interspacer/aluminum cover grid, 12:1, 40lp/cm, 180cm focal distance.
- mAs variable to achieve the same patient effective dose.

The simulated `normal' and `large' sized adult patients have an estimated body height of 178 cm, body weight of 73 kg and 93 kg, respectively. Patient effective dose was computed using a Monte-Carlo software [4] which can factor in patient size and age, beam quality (kVp, mAs, filtration), organ dose and effective dose (mSv). The mAs at each kVp and filtration settings for acquiring the phantom images were adjusted such that the effective dose was kept at the same level as that of 400 speed screen/film systems at 120kVp with 3.7 mm aluminum equivalent filtration (0.045 mSv and 0.108 mSv for `normal' and `large' sized patients, respectively).
Cascaded systems analysis was used to model the overall system performance at different kVp and mAs [5, 6]. Experimentally measured MTF and NPS data from a CsI flat-panel detector (Carestream Health, DRX1-C) was used to validate the cascaded systems analysis.

Background anatomical variations (NPS_B) from the rib structure were measured as stochastic noise using the $K/f^{2.5}$ noise power model. A total of 80 ROIs of 128 x 128 pixels were randomly selected from each image within the lung region and at each kVp and filtration setting (Figure 4). The magnitude of the anatomical noise was extracted as a fitting parameter, K, to the noise power measurements.

All phantom images were processed with and without RCS for the calculation of $d'$. Figure 5 shows some image examples.
Fig. 2: The observer detectability index (d') accounts for lesion contrast and background anatomical clutter.

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Fig. 3: The Kyoto chest phantom used in experiments to simulate 'normal' sized patients. Additional 2.5cm PMMA slabs, one in the front and one in the back, were attached to the phantom to simulate 'large' sized patients.

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\[ NPS_B(f) \approx \frac{K}{f^{2.5}} \]

where \( K \) quantifies the magnitude of anatomical noise and is determined empirically from radiographs.

**Fig. 4:** ROI selection for anatomical noise calculation.

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**Fig. 5:** Phantom images processed without (top row) and with (bottom row) RCS. The phantom images (‘normal’ sized patient) were captured at different kVp without additional Cu filtration.

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Results

Performance of Rib Contrast Suppression Processing

Our results from over 400 images demonstrated the robustness of both rib detection and suppression. Similar performances were obtained for images acquired from different detector types, different view positions (AP vs. PA) or different image processing (processed vs. unprocessed). The rib detection yields a sensitivity of 78%-85% on four different databases when compared against the hand-drawn ribs. Ultimately, rib suppression yields one rib visible per image on average with a slightly lower performance on AP images.

Anatomical Noise and Lesion Conspicuity

Figure 6 shows that the magnitude of anatomical noise in the phantom images simulating `normal' sized patient, as reflected by the K parameter, decreases dramatically as kVp increases, but only decreases slightly as additional Cu filtration increases. The K parameter is dramatically reduced when RCS is applied, which demonstrates the effectiveness of RCS in reducing the anatomical clutters from the rib structures.

Figure 7 shows the calculated d’ values for the `normal' sized patients. When RCS is not available, the optimal imaging technique (at the maximum d’ value of 1.86) is 120 kVp without any filtration, which is consistent to the daily practice for chest imaging. When RCS is applied, the detectability index for 120 kVp imaging technique increases to 2.42 and increases furthermore to 2.64 at 80 kVp with RCS. Similar results are found with `large' sized patients (Figure 8).

Results also show how entrance skin exposure (ESE) drop much faster than d’ as Cu filtration is added, indicating that the patient ESE and d’ tradeoff can be improved at 80 kVp with 0.1 mm Cu.

Figure 9 and Figure 10 show two ROI regions in the chest phantom image processed with and without RCS.
Fig. 6: For `normal' sized patients, the K factor from background anatomical variations at different kVp and filtration, which is greatly reduced when RCS is applied.

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Fig. 7: For `normal' sized patient the calculated d' values (left) and the measured entrance skin exposure (right) at different kVp and filtration.

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**Fig. 8:** For `large` sized patient the calculated d’ values at different kVp and filtration.

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**Fig. 9:** Examples of one ROI region in the chest phantom image processed with and without RCS.

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**Fig. 10:** Examples of another ROI region in the chest phantom image processed with and without RCS.

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Conclusion

The RCS algorithm works robustly on a rather large dataset including images collected from different detector types and different regions. The algorithm performs at a similar level for PA and AP chest images.

Low kVp with RCS can be used to maximize the diagnostic quality of CXR while maintaining the same patient effective dose.

- Anatomical contrast increases as kVp is lowered.
- RCS dramatically reduces anatomical clutters (NPS$_B$) introduced by rib structures.
- CXR can be optimized at lower kVp with RCS, which can be patient size dependent.
- For normal-sized patients under fixed effective dose, 10 mm lesion conspicuity ($d'$) increases from 1.86 (120 kVp, no RCS) to 2.42 (120 kVp, RCS), and 2.64 (80 kVp, RCS).
- Cu filtration helps reduce ESE, but with slight IQ penalty.

It should be noted that the performance improvement with lower kVp imaging technique depends on the performance of the RCS processing. The better the rib structures can be suppressed, the more benefit can be realized. In addition, a CsI detector was modeled in the experiment. If a GOS detector is used in practice, the conclusion can be slightly different; the optimal imaging technique may be higher than 80 kVp due to the lower DQE of the GoS detector at lower kV.
References


Personal Information

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