RESEARCH ARTICLE

Efficiency and reporting confidence analysis of sequential dual-energy subtraction for thoracic x-ray examinations

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ABSTRACT

Rationale and objectives: We aimed to report and compare accuracy, reproducibility, and reporting confidence between thoracic dual-energy subtraction (DES) and routine posterior–anterior chest radiography (PA-CR) techniques.

Materials (patients) and methods: We obtained DES (D1–D4) images from 96 patients using DES and a high-resolution dynamic flat-panel detector in combination. We compared the DES images of these patients with their PA-CR images. The maximum time interval between performing DES and PA-CR was nine weeks. Two radiologists evaluated abnormal findings on DES and PA-CR images using a three-point scale, and reporting confidence was scored using a four-point scale. The intra- and interobserver agreement values of the scores were analyzed. Further, the radiation exposure doses during PA-CR and DES acquisitions were calculated.

Results: The intra- and interobserver agreement values of PA-CR and DES images were good. The reporting confidence scores for DES were generally higher than those for PA-CR. Between bone-subtracted (D3) and soft-tissue-subtracted (D4) images, the former was more successful and useful in the evaluation of bone structures, whereas the latter was better in the evaluation of consolidation and/or solitary nodules.

Conclusions: DES has the potential to improve the accuracy, reproducibility, and reporting confidence of thoracic radiography. It also has the potential to provide a better diagnosis of chest pathologies using relatively low dose radiation.

Keywords: Direct digital radiography, thorax, chest radiography, dose, computed tomography, dual-energy subtraction
INTRODUCTION
Routine posterior–anterior chest radiography (PA-CR) remains the mainstay for the diagnosis of many thoracic abnormalities.\(^1\) Accurate and efficient evaluation of radiographs is crucial for avoiding unnecessary chest computed tomography (CT) examinations.\(^2-^4\) Generally, CT is preferred as a secondary imaging technique for accurate Table 1. Intra-observer agreement results between DSR and PA-CR findings for chest roentgenogram findings (parameters) scores.

| Groups      | Parameters                                | Kappa value | SD    | P-value  |
|-------------|-------------------------------------------|-------------|-------|----------|
| DSR scores  | Diaphragm integrity                        | 1.000       | 0.000 | <0.001   |
|             | Pleural effusion                           | 1.000       | 0.000 | <0.001   |
|             | Atelectasis                                | 1.000       | 0.000 | <0.001   |
|             | Heart borders                              | 0.869       | 0.064 | <0.001   |
|             | Hilar abnormality                          | 1.000       | 0.000 | <0.001   |
|             | Morphology of costae                       | 0.795       | 0.200 | <0.001   |
|             | Vertebræ                                  | 0.976       | 0.024 | <0.001   |
|             | Clavicle                                   | 1.000       | 0.000 | <0.001   |
|             | Trachea                                    | 1.000       | 0.000 | <0.001   |
|             | Bronchovascular abnormality                | 0.928       | 0.072 | <0.001   |
|             | Aortic morphology                          | 1.000       | 0.000 | <0.001   |
|             | Fissures                                   | 0.826       | 0.075 | <0.001   |
|             | Kerley lines                               | 1.000       | 0.000 | <0.001   |
|             | Consolidation                              | 0.883       | 0.115 | <0.001   |
|             | Presence of air bronchogram                | 1.000       | 0.000 | <0.001   |
|             | Solitary nodule                            | 0.846       | 0.106 | <0.001   |
|             | Lung regions behind the heart              | 1.000       | 0.000 | <0.001   |
|             | Fibrotic lung shrinkage                    | 0.852       | 0.083 | <0.001   |
| PA-CR scores| Diaphragm integrity                        | 1.000       | 0.000 | <0.001   |
|             | Pleural effusion                           | 1.000       | 0.000 | <0.001   |
|             | Atelectasis                                | 1.000       | 0.000 | <0.001   |
|             | Heart borders                              | 0.833       | 0.072 | <0.001   |
|             | Hilar abnormality                          | 1.000       | 0.000 | <0.001   |
|             | Morphology of costae                       | 1.000       | 0.000 | <0.001   |
|             | Vertebræ                                  | 0.973       | 0.027 | <0.001   |
|             | Clavicle                                   | 1.000       | 0.000 | <0.001   |
|             | Trachea                                    | 1.000       | 0.000 | <0.001   |
|             | Bronchovascular abnormality                | 0.928       | 0.072 | <0.001   |
|             | Aortic morphology                          | 1.000       | 0.000 | <0.001   |
|             | Fissures                                   | 0.826       | 0.075 | <0.001   |
|             | Kerley lines                               | 1.000       | 0.000 | <0.001   |
|             | Consolidation                              | 0.883       | 0.115 | <0.001   |
|             | Presence of air bronchogram                | 1.000       | 0.000 | <0.001   |
|             | Solitary nodule                            | 0.904       | 0.095 | <0.001   |
|             | Lung regions behind the heart              | 1.000       | 0.000 | <0.001   |
|             | Fibrotic lung shrinkage                    | 0.897       | 0.071 | <0.001   |
characterization of lesions previously detected using CR. However, the use of CT increases the radiation exposure and financial burden on the healthcare system.\textsuperscript{3} The radiation exposure increases due to the widespread use of multidetector CT devices for CT.\textsuperscript{3–5}

The purpose of dual-energy subtraction (DES) acquisitions is to highlight the tissue of interest with

Table 2. Intra-observer agreement results between DSR and PA–CR findings for reporting confidence scores.

| Groups | Parameters                        | Kappa values | SD  | P-values       |
|--------|-----------------------------------|--------------|-----|----------------|
| DSR    | Diaphragm integrity               | 0.930        | 0.000 | <0.001         |
|        | Pleural effusion                  | 1.000        | 0.000 | <0.001         |
|        | Atelectasis                       | 1.000        | 0.000 | <0.001         |
|        | Heart borders                     | 1.000        | 0.000 | <0.001         |
|        | Hilar abnormality                 | 1.000        | 0.000 | <0.001         |
|        | Morphology of costae              | 1.000        | 0.000 | <0.001         |
|        | Vertebrae                         | 0.977        | 0.023 | <0.001         |
|        | Clavicle                          | 1.000        | 0.000 | <0.001         |
|        | Trachea                           | 1.000        | 0.000 | <0.001         |
|        | Bronchovascular abnormality       | 1.000        | 0.000 | <0.001         |
|        | Aortic morphology                 | 1.000        | 0.000 | <0.001         |
|        | Fissures                          | 0.795        | 0.200 | <0.001         |
|        | Kerley lines                      | 1.000        | 0.000 | <0.001         |
|        | Consolidation                     | 1.000        | 0.000 | <0.001         |
|        | Presence of air bronchogram       | 1.000        | 0.000 | <0.001         |
|        | Solitary nodule                   | 1.000        | 0.000 | <0.001         |
|        | Lung regions behind the heart     | 1.000        | 0.000 | <0.001         |
|        | Fibrotic lung shrinkage           | 1.000        | 0.000 | <0.001         |
| PA–CR  | Diaphragm integrity               | 0.758        | 0.134 | <0.001         |
|        | Pleural effusion                  | 1.000        | 0.000 | <0.001         |
|        | Atelectasis                       | 1.000        | 0.000 | <0.001         |
|        | Heart borders                     | 1.000        | 0.000 | <0.001         |
|        | Hilar abnormality                 | 0.742        | 0.175 | <0.001         |
|        | Morphology of costae              | 1.000        | 0.000 | <0.001         |
|        | Vertebrae                         | 0.963        | 0.036 | <0.001         |
|        | Clavicle                          | 1.000        | 0.000 | <0.001         |
|        | Trachea                           | 1.000        | 0.000 | <0.001         |
|        | Bronchovascular abnormality       | 0.642        | 0.146 | <0.001         |
|        | Aortic morphology                 | 1.000        | 0.000 | <0.001         |
|        | Fissures                          | 0.905        | 0.094 | <0.001         |
|        | Kerley lines                      | 1.000        | 0.000 | <0.001         |
|        | Consolidation                     | 1.000        | 0.000 | <0.001         |
|        | Presence of air bronchogram       | 1.000        | 0.000 | <0.001         |
|        | Solitary nodule                   | 1.000        | 0.000 | <0.001         |
|        | Lung regions behind the heart     | 1.000        | 0.000 | <0.001         |
|        | Fibrotic lung shrinkage           | 1.000        | 0.000 | <0.001         |
radiological images obtained using different energy levels and image-processing techniques. Using DES to highlight the tissue of interest, radiologists can achieve tissue-specific examination by the detection of energy levels at which the K-edge peak sensitivity is specific to that tissue. Unlike PA–CR, DES may be used to obtain soft-tissue–subtracted images wherein bone structures remain in the background or bone-subtracted images wherein bone structures do not have soft tissue superimposed on them. This property of DES is useful for evaluating obscured lesions in lung parenchyma, particularly for nodule detection. Similarly, by eliminating superimposed soft tissues from images, DES may allow for better evaluation of bone lesions. However, DES is not widely used in routine practice. Therefore, we aimed to determine the efficiency and reliability of raw and subtracted images obtained with high-resolution DES for the detection of thoracic lesions and to determine the reporting confidence for this technique.

**MATERIAL AND METHODS**

We obtained approval from the local ethics committee for the present retrospective study. We identified all patients (n = 1945) who underwent CR within a one-year period using the picture and archiving communicating (PACS) system of our hospital. Among these, 144 patients underwent CR with PA–CR and DES during this period. We obtained the clinical and laboratory data of these patients from PACS. We excluded the following patients: those with poor-quality images and those who underwent chemotherapy, antibiotherapy, thoracic intervention, or medication for cardiovascular diseases. Consequently, we included 96 patients (50 male and 45 female; mean age: 52.5 ± 14.5 years) in the study. DES and PA–CR were performed in the same radiology center and with the patient in the same position. DES and PA–CR exams were randomly performed. DES was performed using a 4343R flat-panel detector (FPD).

**Table 3. Intra-observer agreement results of chest roentgenogram findings scores in each DSR subgroup (D1-D4) images.**

| Parameters                      | K values | SD | P-values | K values | SD | P-values | K values | SD | P-values | K values | SD | P-values |
|---------------------------------|----------|----|----------|----------|----|----------|----------|----|----------|----------|----|----------|
| Diaphragm integrity             | 1.000    | 0.000 | <0.001   | 1.000    | 0.000 | <0.001   | 1.000    | 0.000 | <0.001   | 1.000    | 0.000 | <0.001   |
| Pleural effusion                | 0.871    | 0.073 | <0.001   | 0.969    | 0.031 | <0.001   | 0.969    | 0.031 | <0.001   | 0.968    | 0.032 | <0.001   |
| Atelectasis                     | 0.855    | 0.063 | <0.001   | 0.950    | 0.057 | <0.001   | 0.982    | 0.058 | <0.001   | 0.955    | 0.063 | <0.001   |
| Atelectasis                     | 0.871    | 0.073 | <0.001   | 0.969    | 0.031 | <0.001   | 0.969    | 0.031 | <0.001   | 0.968    | 0.032 | <0.001   |
| Heart borders                   | 0.855    | 0.063 | <0.001   | 0.950    | 0.057 | <0.001   | 0.982    | 0.058 | <0.001   | 0.955    | 0.063 | <0.001   |
| Hilar abnormality               | 1.000    | 0.000 | <0.001   | 1.000    | 0.000 | <0.001   | 1.000    | 0.000 | <0.001   | 1.000    | 0.000 | <0.001   |
| Morphology of costae            | 0.878    | 0.048 | <0.001   | 0.950    | 0.057 | <0.001   | 0.982    | 0.058 | <0.001   | 0.955    | 0.063 | <0.001   |
| Clavicle                        | 1.000    | 0.000 | <0.001   | 1.000    | 0.000 | <0.001   | 1.000    | 0.000 | <0.001   | 1.000    | 0.000 | <0.001   |
| Trachea                         | 1.000    | 0.000 | <0.001   | 1.000    | 0.000 | <0.001   | 1.000    | 0.000 | <0.001   | 1.000    | 0.000 | <0.001   |
| Bronchovascular abnormality     | 1.000    | 0.000 | <0.001   | 1.000    | 0.000 | <0.001   | 1.000    | 0.000 | <0.001   | 1.000    | 0.000 | <0.001   |
| Aortic morphology               | 0.806    | 0.064 | <0.001   | 0.833    | 0.060 | <0.001   | 0.855    | 0.057 | <0.001   | 0.833    | 0.060 | <0.001   |
| Fissures                        | 0.817    | 0.079 | <0.001   | 0.786    | 0.084 | <0.001   | 0.850    | 0.073 | <0.001   | 0.850    | 0.073 | <0.001   |
| Kerley lines                    | 1.000    | 0.000 | <0.001   | 1.000    | 0.000 | <0.001   | 1.000    | 0.000 | <0.001   | 1.000    | 0.000 | <0.001   |
| Consolidation                   | 0.884    | 0.115 | <0.001   | 0.884    | 0.115 | <0.001   | 0.884    | 0.115 | <0.001   | 0.884    | 0.115 | <0.001   |
| Presence of air bronchogram     | 1.000    | 0.000 | <0.001   | 1.000    | 0.000 | <0.001   | 1.000    | 0.000 | <0.001   | 1.000    | 0.000 | <0.001   |
| Solitary nodule                 | 0.846    | 0.106 | <0.001   | 0.846    | 0.106 | <0.001   | 0.784    | 0.120 | <0.001   | 0.784    | 0.120 | <0.001   |
| Lung regions behind the heart   | 1.000    | 0.000 | <0.001   | 1.000    | 0.000 | <0.001   | 1.000    | 0.000 | <0.001   | 1.000    | 0.000 | <0.001   |
| Fibrotic lung shrinkage         | 0.852    | 0.083 | <0.001   | 0.852    | 0.083 | <0.001   | 0.855    | 0.082 | <0.001   | 0.852    | 0.083 | <0.001   |
We obtained DES images using two consequent
Palo Alto, California, USA).
FPD (4343R, Paxscan, Varian Medical Systems,
Ontario, Canada) and 14-bit A/D converter and was
maximum output power of 32 – 100 kVp
produce X-ray at a maximum peak voltage of 150 kVp
and used a high-frequency generator that could
irradiate with the precision of 1 ms. PA-CR images
were obtained using a generator that had a
maximum output power of 32 – 100 kVp (CPI,
Ontario, Canada) and 14-bit A/D converter and was
42.7 × 42.7 cm in diameter (pixel pitch: 139
× 139 µm, pixel matrix: 9.2 million, DQE: 70%) large
FPD (4343R, Paxscan, Varian Medical Systems,
Palo Alto, California, USA).

We obtained DES images using two consequent
exposures at peak voltages of 120 (mAs: 0.2 – 1) and
65 (mAs: 1 – 4) kVp at 100-ms intervals. As a result of
these exposures, we obtained two radiographs at two
different energy levels, including high (D1) and low
(D2) peak voltage. We subtracted these images from
each other using the methods described previously6–9
to obtain bone- and soft-tissue-subtracted (D3 and
D4, respectively) images. Therefore, we obtained four
images (D1 – D4) in total using DES.

We performed measurements of the radiation
exposure dose for PA-CR and DES in a sample group
containing 25 individuals. We obtained these
measurements using the Accu-pro 9096 dose-
measuring device (Radcal, California, USA) during the
examinations. Further, we obtained PA-CR dose
results via a single shot during exposure. DES results
were the cumulative summation of two exposures
depending on the dual energy used. We added the
measured doses under automatic exposure control for
the DES and PA-CR systems in the DICOM files of the
patients. Subsequently, we recorded the results of
these measurements.

Table 4. Intra-observer agreement results of reporting confidence scores in each DSR subgroup (D1–D4)
images.

| Parameters | GROUPS | D1 | | | D2 | | | D3 | | | D4 |
|-----------|--------|---|---|---|---|---|---|---|---|---|---|
| Diaphragm integrity | | K values | SD | P-values | K values | SD | P-values | K values | SD | P-values | K values | SD | P-values |
| Pleural effusion | | 1.000 | 0.000 | <0.001 | 1.000 | 0.000 | <0.001 | 1.000 | 0.000 | <0.001 | 1.000 | 0.000 | <0.001 |
| Atelectasis | | 0.918 | 0.082 | <0.001 | 0.928 | 0.071 | <0.001 | 0.967 | 0.033 | <0.001 | 1.000 | 0.000 | <0.001 |
| Heart borders | | 1.000 | 0.000 | <0.001 | 1.000 | 0.000 | <0.001 | 1.000 | 0.000 | <0.001 | 1.000 | 0.000 | <0.001 |
| Hilar abnormality | | 1.000 | 0.000 | <0.001 | 1.000 | 0.000 | <0.001 | 1.000 | 0.000 | <0.001 | 1.000 | 0.000 | <0.001 |
| Morphology of costae | | 1.000 | 0.000 | <0.001 | 1.000 | 0.000 | <0.001 | 1.000 | 0.000 | <0.001 | 1.000 | 0.000 | <0.001 |
| Vertebral | | 0.904 | 0.038 | <0.001 | 0.916 | 0.036 | <0.001 | 0.916 | 0.036 | <0.001 | 0.921 | 0.034 | <0.001 |
| Clavicle | | 1.000 | 0.000 | <0.001 | 1.000 | 0.000 | <0.001 | 1.000 | 0.000 | <0.001 | 1.000 | 0.000 | <0.001 |
| Trachea | | 0.853 | 0.145 | <0.001 | 0.853 | 0.144 | <0.001 | 0.928 | 0.050 | <0.001 | 1.000 | 0.000 | <0.001 |
| Bronchovascular abnormality | | 1.000 | 0.000 | <0.001 | 1.000 | 0.000 | <0.001 | 1.000 | 0.000 | <0.001 | 1.000 | 0.000 | <0.001 |
| Aortic morphology | | 0.492 | 0.306 | <0.001 | 0.492 | 0.306 | <0.001 | 1.000 | 0.000 | <0.001 | 1.000 | 0.000 | <0.001 |
| Fissures | | 0.880 | 0.066 | <0.001 | 0.808 | 0.089 | <0.001 | 0.835 | 0.064 | <0.001 | 0.884 | 0.115 | <0.001 |
| Kerley lines | | 1.000 | 0.000 | <0.001 | 1.000 | 0.000 | <0.001 | 1.000 | 0.000 | <0.001 | 1.000 | 0.000 | <0.001 |
| Consolidation | | 1.000 | 0.000 | <0.001 | 1.000 | 0.000 | <0.001 | 1.000 | 0.000 | <0.001 | 1.000 | 0.000 | <0.001 |
| Presence of air bronchogram | | 1.000 | 0.000 | <0.001 | 1.000 | 0.000 | <0.001 | 1.000 | 0.000 | <0.001 | 1.000 | 0.000 | <0.001 |
| Solitary nodule | | 0.866 | 0.093 | <0.001 | 0.848 | 0.106 | <0.001 | 0.656 | 0.184 | <0.001 | 0.796 | 0.199 | <0.001 |
| Lung regions behind the heart | | 1.000 | 0.000 | <0.001 | 1.000 | 0.000 | <0.001 | 1.000 | 0.000 | <0.001 | 1.000 | 0.000 | <0.001 |
| Fibrotic lung shrinkage | | 0.800 | 0.097 | <0.001 | 0.759 | 0.115 | <0.001 | 0.830 | 0.095 | <0.001 | 0.796 | 0.199 | <0.001 |

(Toshiba, Tokyo, Japan), which had a MTF value of
40% at a frequency of 2 lp/mm; A/D converter with
14-bit (pixel pitch: 143 × 143 µm, pixel matrix: 9.2
million, DQE: 70%); and DDR-line device (Istanbul,
Turkey) with an energy of 50 kW, which could

Table 5. Inter-observer agreement results between DSR and PA-CR findings for chest roentgenogram parameters scores.

| Groups   | Parameters                | Kappa values | SD  | P-values |
|----------|---------------------------|--------------|-----|----------|
| DSR      | Diaphragm integrity      | -0.016       | 0.012 | 0.857    |
|          | Pleural effusion          | 0.716        | 0.101 | <0.001   |
|          | Atelectasis               | 0.795        | 0.080 | <0.001   |
|          | Heart borders             | 0.182        | 0.118 | 0.051    |
|          | Hilar abnormality         | 0.206        | 0.124 | 0.001    |
|          | Morphology of costae      | 0.420        | 0.210 | <0.001   |
|          | Vertebræ                  | 0.478        | 0.074 | <0.001   |
|          | Clavicle                  | 1.000        | 0.000 | <0.001   |
|          | Trachea                   | -0.011       | 0.007 | 0.918    |
|          | Bronchovascular abnormality| 0.468       | 0.111 | <0.001   |
|          | Aortic morphology         | 0.826        | 0.063 | <0.001   |
|          | Fissures                  | 0.432        | 0.119 | <0.001   |
|          | Kerley lines              | 1.000        | 0.000 | <0.001   |
|          | Consolidation             | 0.556        | 0.229 | <0.001   |
|          | Presence of air bronchogram| 0.558       | 0.225 | <0.001   |
|          | Solitary nodule           | 0.471        | 0.181 | <0.001   |
|          | Lung regions behind the heart| 1.000    | 0.000 | <0.001   |
|          | Fibrotic lung shrinkage   | 0.498        | 0.125 | <0.001   |

| PA-CR    | Diaphragm integrity      | 0.312        | 0.253 | 0.002    |
|          | Pleural effusion          | 0.583        | 0.118 | <0.001   |
|          | Atelectasis               | *            | *     | *        |
|          | Heart borders             | *            | *     | *        |
|          | Hilar abnormality         | *            | *     | *        |
|          | Morphology of costae      | 0.484        | 0.216 | <0.001   |
|          | Vertebræ                  | 0.512        | 0.079 | <0.001   |
|          | Clavicle                  | 1.000        | 0.000 | <0.001   |
|          | Trachea                   | *            | *     | *        |
|          | Bronchovascular abnormality| 0.429       | 0.107 | <0.001   |
|          | Aortic morphology         | 0.826        | 0.063 | <0.001   |
|          | Fissures                  | *            | *     | *        |
|          | Kerley lines              | 1.000        | 0.000 | <0.001   |
|          | Consolidation             | 0.368        | 0.202 | <0.001   |
|          | Presence of air bronchogram| 0.558       | 0.225 | <0.001   |
|          | Solitary nodule           | 0.579        | 0.189 | <0.001   |
|          | Lung regions behind the heart| 0.662    | 0.316 | <0.001   |
|          | Fibrotic lung shrinkage   | 0.401        | 0.136 | <0.001   |

*: Statistical analyses cannot be performed due to small case numbers.
Table 6. Inter-observer agreement results between DSR and PA-CR findings for reporting confidence scores.

| Groups    | Parameters                          | Kappa values | SD    | P-values      |
|-----------|-------------------------------------|--------------|-------|---------------|
|           |                                     |              |       |               |
| DSR       | Diaphragm integrity                 | *            | *     | *             |
|           | Pleural effusion                     | 1.000        | 0.000 | <0.001        |
|           | Atelectasis                          | -0.011       | 0.007 | 0.918         |
|           | Heart borders                        | *            | *     | *             |
|           | Hilar abnormality                    | 1.000        | 0.000 | <0.001        |
|           | Morphology of costae                 | 1.000        | 0.000 | <0.001        |
|           | Vertebrae                            | 0.150        | 0.046 | <0.001        |
|           | Clavicle                             | 1.000        | 0.000 | <0.001        |
|           | Trachea                              | 0.489        | 0.311 | <0.001        |
|           | Bronchovascular abnormality          | 1.000        | 0.000 | <0.001        |
|           | Aortic morphology                    | *            | *     | *             |
|           | Fissures                             | 1.000        | 0.000 | <0.001        |
|           | Kerley lines                         | 1.000        | 0.000 | <0.001        |
|           | Consolidation                        | 1.000        | 0.000 | <0.001        |
|           | Presence of air bronchogram          | -0.011       | 0.007 | 0.918         |
|           | Solitary nodule                      | 1.000        | 0.000 | <0.001        |
|           | Lung regions behind the heart        | -0.014       | 0.010 | 0.883         |
|           | Fibrotic lung shrinkage              | 1.000        | 0.000 | <0.001        |
| PA-CR     | Diaphragm integrity                 | *            | *     | *             |
|           | Pleural effusion                     | 1.000        | 0.000 | <0.001        |
|           | Atelectasis                          | *            | *     | *             |
|           | Heart borders                        | 0.167        | 0.132 | 0.042         |
|           | Hilar abnormality                    | *            | *     | *             |
|           | Morphology of costae                 | *            | *     | *             |
|           | Vertebrae                            | 0.236        | 0.060 | <0.001        |
|           | Clavicle                             | 1.000        | 0.000 | <0.001        |
|           | Trachea                              | 0.029        | 0.022 | 0.066         |
|           | Bronchovascular abnormality          | -0.021       | 0.021 | 0.003         |
|           | Aortic morphology                    | 1.000        | 0.000 | <0.001        |
|           | Fissures                             | 0.426        | 0.208 | <0.001        |
|           | Kerley lines                         | 1.000        | 0.000 | <0.001        |
|           | Consolidation                        | 1.000        | 0.000 | <0.001        |
|           | Presence of air bronchogram          | 1.000        | 0.000 | <0.001        |
|           | Solitary nodule                      | 1.000        | 0.000 | <0.001        |
|           | Lung regions behind the heart        | *            | *     | *             |
|           | Fibrotic lung shrinkage              | 1.000        | 0.000 | <0.001        |

*: Statistical analyses cannot be performed due to small case numbers.
The images of the patients obtained using both techniques were evaluated using the PACS system using the following parameters:

**Investigated parameters on chest radiographs:**
1. Morphology of thoracic bones, trachea, and fissures
2. Integrity of the diaphragm and heart borders
3. Presence of fibrotic lung shrinkage, nodule, atelectasis, pleural effusion, cardiomegaly, Kerley lines, consolidation, and/or air bronchogram
4. Hilar, aortic, or bronchovascular abnormality

Each finding was recorded in the Excel data and scored according to the following system:

**Scoring schema of chest radiograph findings:**
- Score 0: There are no pathological findings or anatomical integrity is normal
- Score 1: There is a suspicious pathological finding or the anatomy of the tissue of interest cannot be clearly evaluated
- Score 2: There is a definite pathological finding or the anatomical integrity is impaired

We scored the reporting confidence of the radiologists regarding the assessment of the mentioned findings as follows.

**Reporting confidence scoring scale:**
- Score 0: Ineffective/doubtful radiological assessment; the radiologist has low reporting confidence
- Score 1: Moderate reporting confidence
- Score 2: Good reporting confidence
- Score 3: Absolute radiological assessment; the radiologist has high reporting confidence

We compared the four images obtained using DES (image obtained using a high kVp (D1), that obtained using a low kVp (D2), subtracted images obtained by subtracting D1 from D2 (D3), and subtracted images obtained by subtracting D2 from D1 (D4)) and the

| GROUPS | Diaphragm integrity | Pleural effusion | Atelectasis | Heart borders | Hilar abnormality | Morphology of costae | Vertebral abnormality | Clavicle | Trachea | Bronchovascular abnormality | Aortic morphology | Fissures | Kerley lines | Consolidation | Presence of air bronchogram | Solitary nodule | Lung regions behind the heart | Fibrotic lung shrinkage |
|--------|---------------------|------------------|-------------|---------------|-------------------|---------------------|----------------------|----------|--------|---------------------------|-------------------|----------|-------------|--------------|-----------------------------|----------------|-----------------------------|----------------------|
| D1     | 0.314 0.251 0.001   | 0.524 0.126 0.001 | 0.754 0.088 0.001 | 0.186 0.115 0.040 | 0.205 0.124 0.001 | 0.657 0.225 0.001   | 0.391 0.073 0.001   | 1.000 0.000 0.001 | -0.011 0.008 0.917 | 0.471 0.127 0.001   | 0.627 0.090 0.001   | 0.411 0.129 0.001 | 1.000 0.000 0.001 | 0.657 0.225 0.001   | 0.470 0.181 0.001   | 1.000 0.000 0.001 | 0.524 0.125 0.001   |
| D2     | 0.314 0.251 0.001   | 0.524 0.126 0.001 | 0.754 0.088 0.001 | 0.186 0.020 0.040 | 0.205 0.124 0.001 | 0.657 0.225 0.001   | 0.380 0.075 0.001   | 1.000 0.000 0.001 | 0.011 0.008 0.917   | 0.471 0.127 0.001   | 0.627 0.090 0.001   | 0.411 0.129 0.001 | 1.000 0.000 0.001 | 0.657 0.225 0.001   | 0.470 0.181 0.001   | 1.000 0.000 0.001 | 0.524 0.125 0.001   |
| D3     | 0.314 0.251 0.001   | 0.524 0.126 0.001 | 0.754 0.088 0.001 | 0.186 0.115 0.040 | 0.205 0.124 0.001 | 0.657 0.225 0.001   | 0.404 0.078 0.001   | 1.000 0.000 0.001 | 0.211 0.008 0.917   | 0.471 0.127 0.001   | 0.627 0.090 0.001   | 0.411 0.129 0.001 | 1.000 0.000 0.001 | 0.657 0.225 0.001   | 0.578 0.190 0.001   | 1.000 0.000 0.001 | 0.524 0.125 0.001   |
| D4     | 0.314 0.251 0.001   | 0.524 0.126 0.001 | 0.754 0.088 0.001 | 0.186 0.115 0.040 | 0.205 0.124 0.001 | 0.657 0.225 0.001   | 0.404 0.078 0.001   | 1.000 0.000 0.001 | 0.211 0.008 0.917   | 0.471 0.127 0.001   | 0.627 0.090 0.001   | 0.411 0.129 0.001 | 1.000 0.000 0.001 | 0.657 0.225 0.001   | 0.578 0.190 0.001   | 1.000 0.000 0.001 | 0.524 0.125 0.001   |
results of conventional radiography in terms of the mentioned variables. Scoring was performed by two radiologists with four and three years of experience in determining interobserver reliability. In addition, the first radiologist performed scoring again three weeks later to evaluate intraobserver reliability. The duration of assessment of radiography was not limited, and all images were evaluated within the same PACS system using the same computer and screen.

Clinical and laboratory tests as well as thoracic CT and/or surgical–pathological (if results were available) examination were used as gold standard methods for determining the accuracy of PA-CR and DES.

**Statistical analysis**

SPSS version 15.0 (SPSS Inc., Chicago, IL, USA) and R program were used for all statistical analyses. A module called ‘nparLD’ was used for analyzing the LD_F1 design on R program. Shapiro–Wilk test was used to determine whether the age of the study patients were normally distributed. Cohen’s kappa (κ) coefficient was used for evaluating inter- and intra-observer reliability. Differences between DES and PA-CR or between the four images obtained with DES (subgroup DES images: high/low kV and subtracted images) were assessed by performing ANOVA using the LD_F1 design. This was performed to assess pathological findings, abnormalities on chest radiographs, and reporting confidence scores. The relative treatment effect was evaluated for the variables in which a significant difference was obtained for pairwise comparison. Radiation dose measurements performed for DES and PA-CR were assessed using the MATLAB platform and ANOVA methods. A p value of <0.05 was considered statistically significant.

Table 8. Inter–observer agreement results of reporting confidence scores in each DSR subgroup (D1–D4) images.

| Parameters            | Groups D1 | Groups D2 | Groups D3 | Groups D4 |
|-----------------------|-----------|-----------|-----------|-----------|
| Diaphragm integrity  | *         | *         | *         | *         |
| Pleural effusion      | 1.000 0.000 <0.001 | 1.000 0.000 <0.001 | *         | *         |
| Atelectasis           | 0.225 0.202 0.011 | *         | *         | *         | *         | *         | *         | *         |
| Heart borders         | 1.000 0.000 <0.001 | 1.000 0.000 <0.001 | *         | *         | 1.000 0.000 <0.001 |
| Hilar abnormality     | −0.018 0.014 0.831 | −0.018 0.014 0.831 | *         | *         | *         | *         | *         | *         |
| Morphology of costae  | *         | *         | *         | *         | *         | *         | *         | *         | *         |
| Vertebral             | 0.214 0.077 0.001 | 0.133 0.061 0.012 | 0.070 0.082 0.304 | 0.091 0.052 0.073 |
| Clavicle              | 1.000 0.000 <0.001 | 1.000 0.000 <0.001 | 1.000 0.000 <0.001 | 1.000 0.000 <0.001 |
| Trachea               | *         | *         | *         | *         | *         | *         | *         | *         | *         |
| Bronchovascular       | *         | *         | *         | *         | *         | *         | *         | *         | *         |
| Aortic morphology     | −0.015 0.010 0.882 | −0.015 0.010 0.882 | *         | *         | *         | *         | *         | *         | *         |
| Fissures              | *         | *         | *         | *         | *         | *         | *         | *         | *         |
| Kerley lines          | *         | *         | *         | *         | *         | *         | *         | *         | *         | *         |
| Consolidation         | *         | *         | *         | *         | *         | *         | *         | *         | *         | *         | −0.011 0.008 0.917 |
| Presence of air       | 0.000 0.000 <0.001 | 1.000 0.000 <0.001 | *         | *         | 1.000 0.000 <0.001 |
| Bronchogram           | −0.009 0.010 0.175 | 0.003 0.002 0.707 | 0.048 0.079 0.560 | *         | *         | *         | *         | *         | *         | *         | 0.030 0.052 0.693 |
| Solitary nodule       | *         | *         | *         | *         | *         | *         | *         | *         | *         | *         | *         | *         | −0.020 0.010 0.805 |
| Lung regions behind   | *         | *         | *         | *         | *         | *         | *         | *         | *         | *         | *         | *         | *         |
| the heart             | *         | *         | *         | *         | *         | *         | *         | *         | *         | *         | *         | *         | *         |

*: Statistical analyses cannot be performed due to small case numbers.
Table 9. Statistical differences between DSR and PA-CR results for each chest roentgenogram findings and reporting confidence scores (ANOVA test results).

| Parameters                      | F-values | P-values |
|---------------------------------|----------|----------|
| Chest roentgenogram findings    |          |          |
| Diaphragm integrity             | NA       | NA       |
| Pleural effusion                | 1.000    | 0.317    |
| Atelectasis                     | 1.000    | 0.317    |
| Heart borders                   | NA       | NA       |
| Hilar abnormality               | 1.000    | 0.317    |
| Morphology of costae            | 1.000    | 0.317    |
| Vertebrae                       | 1.048    | 0.306    |
| Clavicle                        | NA       | NA       |
| Trachea                         | NA       | NA       |
| Bronchovascular abnormality     | NA       | NA       |
| Aortic morphology               | NA       | NA       |
| Fissures                        | NA       | NA       |
| Kerley lines                    | NA       | NA       |
| Consolidation                   | NA       | NA       |
| Presence of air bronchogram     | NA       | NA       |
| Solitary nodule                 | 2.021    | 0.155    |
| Lung regions behind the heart   | 1.000    | 0.317    |
| Fibrotic lung shrinkage         | 1.000    | 0.317    |
| Reporting confidence            |          |          |
| Diaphragm integrity             | 472.297  | <0.001   |
| Pleural effusion                | NA       | NA       |
| Atelectasis                     | NA       | NA       |
| Heart borders                   | 5.300    | 0.021    |
| Hilar abnormality               | 2062.790 | <0.001   |
| Morphology of costae            | 11.047   | <0.001   |
| Vertebrae                       | 13.901   | <0.001   |
| Clavicle                        | NA       | NA       |
| Trachea                         | 3973.634 | <0.001   |
| Bronchovascular abnormality     | 817.000  | <0.001   |
| Aortic morphology               | 1.000    | 0.317    |
| Fissures                        | 1.180    | 0.277    |
| Kerley lines                    | NA       | NA       |
| Consolidation                   | NA       | NA       |
| Presence of air bronchogram     | NA       | NA       |
| Solitary nodule                 | NA       | NA       |
| Lung regions behind the heart   | 1.000    | 0.317    |
| Fibrotic lung shrinkage         | 1.000    | 0.317    |

NA: Statistical analysis is not possible.
RESULTS

We found no significant differences in terms of age and sex among the patients included in the present study ($p > 0.05$). The intra-observer agreement values for chest radiograph findings and reporting confidence scores were generally excellent for DES, PA-CR, and subgroup DES (D1–D4: raw and subtracted versions) images (Tables 1–4). On the other hand, the inter-observer agreement values for chest radiograph findings and reporting confidence scores were generally good for these images (Tables 5–8). When we compared DES and PA-CR in terms of reporting confidence, we found a significant difference in terms of certain parameters such as diaphragm integrity, heart border definition, and hilar/costal/vertebral abnormalities.

Table 10. Relative effects of the variables that were found statistically significant in the accordance with groups of DSR and PA-CR technique in reporting confidence results.

| Parameters                  | DSR Relative effects | PA-CR Relative effects |
|-----------------------------|----------------------|------------------------|
| Reporting confidences       |                      |                        |
| Diaphragm integrity        | 0.709                | 0.290                  |
| Heart borders               | 0.513                | 0.487                  |
| Hilar abnormality           | 0.740                | 0.260                  |
| Morphology of costae        | 0.526                | 0.473                  |
| Vertebrae                   | 0.467                | 0.533                  |
| Trachea                     | 0.742                | 0.258                  |
| Bronchovascular abnormality | 0.724                | 0.276                  |

Diagram 1. Graphics of the reporting confidence scores for DES and PA-CR.
The reporting confidence scores for these parameters were higher in DES than in PA-CR (Tables 9 – 10, Diagram 1).

Additional findings that could not be determined using PA-CR were detected using DES in 10 patients (Figure 1). These additional findings included the following: pleural effusion (n = 2, 2%), indefinite diaphragm/heart/aortic borders (n = 5, 5%), atelectasis (n = 2, 2%), sclerotic costal lesion (n = 1, 1%), solitary nodules (n = 2, 2%), and fibrotic lung shrinkage (n = 2, 2%).

When we compared DES subgroup (D1 – D4) images in terms of reporting confidence scores and relative treatment effect values, we found significant differences in terms of the following parameters: diaphragm integrity; pleural effusion; atelectasis; hilar abnormality; costal, vertebral, tracheal, and fissures morphology; bronchovascular abnormality; consolidation; air bronchograms; solitary nodules; and fibrotic lung shrinkage (Table 11). For instance, the reporting confidence scores for D3 images in the evaluation of hilar abnormality and presence of air bronchograms were lower than those in the assessment of bone structure (Diagram 2, Figure 2). However, the reporting confidence scores for D4 images in the evaluation of consolidation and solitary

![Image](99x625 to 483x744)

**Figure 1.** PA radiograph (left), soft-tissue-subtracted DES (middle), coronal reformatted CT (right) images of a 72-year-old male demonstrates multiple focal consolidations and ground-glass opacifications, particularly in the right lung. These images clearly show that soft-tissue-subtracted DES images are more sensitive than conventional X-ray images. Remarkably, ground-glass opacification in the right upper lobe is present on soft-tissue-subtracted DES (arrow, middle) and CT (right) images but not on conventional X-ray image (left).

Table 11. Relative effects of the variables that found statistically significant in accordance with the groups of D1, D2, D3 and D4 in the results of reporting confidence of the first observer for each group.

| Parameters                        | D1 Relative effects | D2 Relative effects | D3 Relative effects | D4 Relative effects |
|-----------------------------------|---------------------|---------------------|---------------------|---------------------|
| Reporting confidences             | Diaphragm integrity | 0.516               | 0.521               | 0.477               | 0.487               |
|                                   | Pleural effusion    | 0.512               | 0.512               | 0.465               | 0.512               |
|                                   | Atelectasis         | 0.512               | 0.512               | 0.465               | 0.512               |
|                                   | Hilar abnormality   | 0.625               | 0.625               | 0.130               | 0.620               |
|                                   | Morphology of costae| 0.376               | 0.376               | 0.875               | 0.372               |
|                                   | Vertebralia         | 0.434               | 0.432               | 0.706               | 0.428               |
|                                   | Trachea             | 0.509               | 0.502               | 0.143               | 0.847               |
|                                   | Bronchovascular abnormality | 0.617           | 0.619               | 0.133               | 0.631               |
|                                   | Fissures            | 0.472               | 0.483               | 0.213               | 0.831               |
|                                   | Consolidation       | 0.390               | 0.390               | 0.364               | 0.856               |
|                                   | Presence of air bronchogram | 0.625           | 0.625               | 0.130               | 0.620               |
|                                   | Solitary nodule     | 0.385               | 0.398               | 0.379               | 0.838               |
|                                   | Fibrotic lung shrinkage | 0.506           | 0.506               | 0.150               | 0.838               |
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Diagram 2. Graphics of the reporting confidence scores for DES subgroup images.

nODULES were higher than for the other images (Table 11, Diagram 2).
There was a significant difference in terms of the radiation exposure dose between DES and PA-CR (Table 12). The mean radiation exposure dose was 107 ± 39.12 μSv for DES and 219 ± 44.18 μSv for PA-CR (p < 0.05). According to the mean values of the two datasets, DES used 48% radiation dose according to the PA-CR system.

DISCUSSION
Chest roentgenography is the main imaging technique in thoracic radiology. Accurate and efficient use of imaging techniques such as CR decreases the need for CT as a secondary imaging technique, thus preventing additional radiation exposure. The primary difficulty in assessing chest radiographs is the superimposition of several structures due to the projection of three-dimensional volumetric structures as a two-dimensional image. For instance, the superimposition of bone structures can obscure the lesions in the lung parenchyma. We obtained two raw images using DES (D1 and D2) and two subtracted images (D3 and D4); this facilitates better evaluation by reducing superimposition. The data obtained in this study support this hypothesis.

DES used in the present study is a relatively new technique. It uses a full-field digital FPD with high quantum efficiency and frame rate, functions based on double shot (DS), and causes lower radiation exposure than single-shot systems. Low-energy images are obtained with a low peak voltage (60 – 90 kVp) and high-energy images with a high peak voltage (120 – 150 kVp) in DS-DES. Another advantage of DS-DES is a high DQE value. A higher DQE value allows better identification of an object against a noisy background. The devices with higher DQE values provide better visualization of inadequate-quality images with less radiation exposure. The exposure radiation dose for...
DS–DES using a new-generation FPD system is 35%–50% less than that for PA-CR, consistent with our results.\textsuperscript{4,7–14}

Data composed of four images can be obtained after each DS–DES acquisition.\textsuperscript{5} These images are as follows: raw image (D1) obtained with a high peak voltage, raw image (D2) obtained with a low peak voltage, bone-subtracted image (D3), and soft-tissue-subtracted image (D4).\textsuperscript{5–10,14} To obtain subtracted images, the data from the raw image with the desired contrast are mathematically multiplied by two or three, and the other raw image is obtained from that enhanced image.\textsuperscript{1,3}

Swensen et al.\textsuperscript{15} compared DES and PA-CR in a study on 50 patients with lung cancer. They found that mediastinal structures or pathological findings could be better demonstrated with DES. Tagashiara et al.\textsuperscript{16} also reported that DES could detect more nodules than PA-CR. Observer error, superimpositions of the surrounding tissues/bones, lesion characteristics (size, conspicuity, and location), and technical defects are the main causes of undetected lung cancer.\textsuperscript{17}

DS–DES may help reduce diagnostic errors and interpretation/reporting time.\textsuperscript{17} To the best of our knowledge, there are few published reports focusing on the DS–DES used in the present study.

We found high-degree similarity between inter- and intra-observer agreement values for DES and PA-CR images. Our results show that DES is a reliable method for thoracic evaluation.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{image}
\caption{PA X-ray (upper line) and coronal CT (lower line) images of a 61-year-old male showing emphysematous areas (predominantly located in the lower lobes) and left hilar mass. Soft-tissue-subtracted DES images (D4, upper right) is more useful than conventional PA radiograph (upper left) for the evaluation of these pathological changes. Emphysematous areas were not reported in the conventional PA radiograph report.}
\end{figure}
In general, reporting confidence scores for DES were higher than those for PA-CR. These results show that DES facilitates the evaluation of chest radiographs. DES can also prevent misdiagnosis caused by less-experienced radiologists.

In addition, the joint assessment of all DES subgroup images provides a more efficient analysis of several abnormalities compared with the assessment of PA-CR images. Our results are supported by those of Tagashira et al.,\textsuperscript{16} For instance, in our study, atelectasis or solitary nodules could be seen on the DES images of two patients but not on the PA-CR images of the same patients.

To the best of our knowledge, our study is the first to compare DES subgroup images. D3 images emphasizing bone structures were usually more efficient in assessing bone pathologies than other images. For instance, costal disorder could be detected only using DES images (particularly the D3 images) in one patient. Similarly, D4 images were more effective in the detection of solitary nodules, fibrotic lung shrinkage, and consolidation. Previous reports show that DES is superior to other techniques in the evaluation of solitary nodules.\textsuperscript{5,16} Austin et al.,\textsuperscript{18} demonstrated that 81% of undetectable lung cancers occurred in the region that obscures solitary nodules.

Table 12. For dose comparison between DES and conventional CR devices. We have used the ANOVA test (variance analysis). The boxplot on this table shows us mean values are different for different X-ray techniques. Y-axis is for DES dose usage, the x-axis is for CR dose usage, boxplots are for the X-ray studies dose outputs correlated between CR and DES. CR dose results have been taken via a single shot during the exposure. DES results are the cumulative summation of two exposures depending on the dual energy. Depending on the means of two datasets DES system uses %48 percent radiation dose compared to the conventional CR system (mean doses for DES and CR are 218.85 and 106.72, respectively).
(particularly in the upper lobes of the lungs). Uemura et al., 19 and Ricke et al., 20 indicated that the detectability of solitary nodules is higher in DES images than in PA–CR images in patients with a history of solitary nodules. This is most likely due to the elimination of bones in soft-tissue-subtracted (D4) images. This study also showed that DES could reduce the need to use CT for follow-up analysis of solitary nodules. Because there are no studies that demonstrate this claim in the literature, further studies are needed to test the validity of our suggestion.

Each subgroup image should be evaluated separately for more accurate assessment of DES images. Bone structures should be re-evaluated using bone-subtracted (D3) images after these assessments. The re-evaluation of soft tissues and lungs using soft-tissue-subtracted (D4) images could also increase reporting impact and confidence. However, DES is not the ideal technique. For instance, DES may not be useful in the detection of some small nodules obscured by soft tissues. Because DES relies on projection; it has some limitations related to superimposition similar to PA–CR. 21,22 In addition, subtracted images are highly susceptible to motion effects. 5,23 Thus, motion artifacts could be seen, particularly at the contours of the diaphragm and heart, on these images. Low-dose CT may be useful for overcoming this limitation. 22 The major limitation of our study is that the number of patients who had abnormal findings was small. Therefore, the assessment of some parameters and more detailed statistical analyses could not be performed sufficiently for all chest radiograph findings. The second limitation is that the findings obtained on DES and PA–CR could not be compared with gold standard methods (such as CT) in all patients. In addition, the low-level experience of the radiologists in performing DES is a limitation. Furthermore, the scoring methods used are subjective and may be influenced by interpersonal differences in interpretation. As observed by Manji et al., 23 the preliminary nature of our study as well as limited time and resources limited the numbers of readers and patients. Lastly, the interval between DES and PA–CR is another limitation. Further comprehensive studies are needed to overcome these limitations.

CONCLUSION

DES is a technique that allows more accurate and comfortable evaluation of soft tissues and bone structures. DES can increase the visibility of parenchymal and bone abnormalities obscured in the background by eliminating structural noise. It can decrease the need for chest CT examination, which prevents further radiation exposure. The inter- and intra-observer reliability values of DES are generally good. Further, DES may decrease the radiation exposure dose.

ACKNOWLEDGEMENTS

The authors would like to thank Deniz Delibas, MD, for her excellent contributions.

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