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Image quality of mixed convolution kernel in thoracic computed tomography

Jakob Neubauer, MD*, Eva Maria Spira, MD, Juliane Strube, MD, Mathias Langer, MD, Christian Voss, MD, Elmar Kotter, MD, MSc

Abstract

The mixed convolution kernel alters his properties geographically according to the depicted organ structure, especially for the lung. Therefore, we compared the image quality of the mixed convolution kernel to standard soft and hard kernel reconstructions for different organ structures in thoracic computed tomography (CT) images.

Our Ethics Committee approved this prospective study. In total, 31 patients who underwent contrast-enhanced thoracic CT studies were included after informed consent. Axial reconstructions were performed with hard, soft, and mixed convolution kernel. Three independent and blinded observers rated the image quality according to the European Guidelines for Quality Criteria of Thoracic CT for 13 organ structures. The observers rated the depiction of the structures in all reconstructions on a 5-point Likert scale. Statistical analysis was performed with the Friedman Test and post hoc analysis with the Wilcoxon rank-sum test.

Compared to the soft convolution kernel, the mixed convolution kernel was rated with a higher image quality for lung parenchyma, segmental bronchi, and the border between the pleura and the thoracic wall ($P < 0.03$). Compared to the hard convolution kernel, the mixed convolution kernel was rated with a higher image quality for aorta, anterior mediastinal structures, paratracheal soft tissue, hilar lymph nodes, esophagus, pleuromediastinal border, large and medium sized pulmonary vessels and abdomen ($P < 0.004$) but a lower image quality for trachea, segmental bronchi, lung parenchyma, and skeleton ($P < 0.001$).

The mixed convolution kernel cannot fully substitute the standard CT reconstructions. Hard and soft convolution kernel reconstructions still seem to be mandatory for thoracic CT.

Abbreviations: CT = computed tomography, HU = Hounsfield units.

Keywords: computed tomography, convolution kernel, image quality, mixed convolution kernel, thoracic computed tomography

1. Introduction

Images of thoracic computed tomography (CT) are usually created using 2 different sets of algorithms (convolution kernels). These algorithms differ in the degree of edge enhancement. The high-resolution algorithms (edge preserving convolution kernel) generate images that provide a high amount of spatial information but also high amount of noise. These so-called hard reconstructed images are particularly suitable for the evaluation of structures with high endogenous contrast, such as the bone and lung tissue. Soft algorithms (edge smoothing convolution kernel), on the other hand, adapt the pixel values more strongly according to the values of surrounding structures, resulting in lower spatial information and less noise. These soft reconstructed images are particularly suitable for the evaluation of structures with low endogenous contrast, such as soft tissue, for example, the mediastinum. Thus, evaluation of thoracic CT images is performed utilizing 2 different image stacks.

However, combining both types of algorithms to create 1 image stack has been proven to be feasible and advantageous for different anatomical regions.[1–3] The purpose of this study was to evaluate the image quality of a mixed convolution kernel that alters its properties geographically according to the depicted organ structure, especially the lung. This happens by sharpening regions with air-like density in a soft kernel reconstruction. If the mixed kernel could be proven to be equivalent or better than the standard reconstructions, the standard double reconstruction could become unnecessary. Thus, we might end up with smaller quantities of data and fewer images that have to be reconstructed, observed, and stored. Therefore, we compared the image quality of the mixed convolution kernel to standard soft and hard kernel reconstructions for different organ structures in thoracic CT images.

2. Methods

2.1. Patients

Our Ethics Committee (Ethics Committee University Medical Center Freiburg) approved this prospective study (Universal Trial

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Department of Radiology, Medical Center—University of Freiburg, Faculty of Medicine, University of Freiburg, Germany.

** Correspondence: Jakob Neubauer, Department of Radiology, Medical Center–University of Freiburg, Faculty of Medicine, University of Freiburg, Germany (e-mail: jakob.neubauer@uniklinik-freiburg.de).*

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Number: U1111-1147-7379). In May 2013, 16 male (mean age: 62 years; standard deviation: 16 years) and 15 female (mean age: 58 years; standard deviation: 16 years) consecutive patients who were scheduled to undergo contrast enhanced thoracic CT for staging purposes were included in the study after written informed consent.

2.2. Image acquisition

All patients underwent standard contrast enhanced thoracic CT. CT imaging was performed with a 320 row multidetector CT (Aquilion One; Toshiba Medical Systems, Otawara, Japan). 80 mL of contrast agent (Imeron 400 MCT, Bracco, Milan, Italy) diluted to 90% with saline (0.5% NaCl, Braun, Melsungen, Germany) was administered at a rate of 2.5 mL/s followed by a 50 mL bolus of saline at a rate of 2.5 mL/s. Bolus triggering was performed at the level of the mid-thoracic aorta descendens.

The scans were performed with a tube voltage of 120 kVp and automatic tube current modulation. The rotation time was 0.5 seconds. The pitch factor was 0.813. The calibration FOV was 320 mm and the detector configuration was 80 × 0.5 mm. Axial reconstructions were performed with hard (FC35), soft (FC18), and mixed (FC18H) convolution kernel with 3 mm slice thickness and slice sparing. All reconstructions were performed with iterative reconstruction technique (Adaptive Iterative Dose Reduction 3D/ strength: default). The mixed convolution kernel images were produced by reconstructions with a soft convolution kernel and sharpening processing of regions with air-like density in the images. All images were sent to a picture archiving and communication system (IMPAX EE; Agfa, Mortsel, Belgium).

2.3. Qualitative image analysis

The mixed convolution kernel reconstructions of 1 patient's dataset were randomly chosen to be the reference images. The hard, mixed, and soft convolution kernel reconstructions of all patients were presented to 3 independent radiologists for image quality assessment. These images were rated in 3 sessions that were separated by at least 4 weeks to avoid recall bias. In each session, 1 randomly assigned reconstruction from each patient was presented to the observers. Every observer rated the reconstructions in a different order. The observers did not know the type of reconstruction algorithm of the presented images or the reference images. The observers rated the depiction of 13 organ structures in all reconstructions in comparison with the reference images on a 5-point Likert scale ranging from "–2" to "+2" with "–2" being much worse, "–1" worse, "0" equal, "1" better and "2" much better. These 13 organ structures included the thoracic aorta, anterior mediastinal structures, trachea and main bronchi, paratracheal soft tissue, hilar lymph nodes, esophagus, pleuromediastinal border, large and medium sized pulmonary vessels, segmental bronchi, lung parenchyma, border between the pleura and the thoracic wall, abdomen and skeleton according to the European Guidelines for Quality Criteria of Thoracic CT (Bongartz et al, 1999). The observers performed the ratings under standardized conditions with subdued lighting on clinical review monitors (RadiForce GS320, EIZO NANAO Corp., Hakusan, Ishikawa, Japan). The initial windowing was set to Level/ Window 500/2000 HU for all scans. The observers adjusted the windowing freely. All observers' ratings are accessible as supplemental table (see Table, Supplemental Digital Content 1, http://links.lww.com/MD/B380)

Table 1

Kappa values for inter-rater agreement for all analyzed structures.

Structure	kappa
Thoracic aorta	0.28
Anterior mediastinal structures	0.17
Trachea und main bronchi	0.35
Paratracheal tissue	0.26
Hilar lymph nodes	0.27
Esophagus	0.25
Pleuromediastinal border	0.10
Large and medium sized pulmonary vessels	0.08
Segmental bronchi	0.22
Lung parenchyma	0.38
Pleura and thoracic wall	0.05
Abdomen	0.37
Skeleton	0.45

2.4. Quantitative image analysis

Images analysis was performed with ImageJ (Version 1.51f). A radiologist measured the mean and standard deviation of CT numbers of the pulmonary trunk and the lung parenchyma of the left upper lobe with fixed circular regions of interest (1 cm radius) in all patients.

2.5. Statistical analysis

The inter-rater correlation was performed with Conger's kappa. Ratings of all observers were pooled for further analysis. Differences between the ratings and measurements for the soft, the mixed, and the hard convolution kernel reconstructions were analyzed with Friedman test and post hoc analysis with Wilcoxon rank-sum test. A P value < 0.05 was considered to account statistically significant. The family-wise error rate was controlled by Holm correction.[4] Analysis was performed with R version 3.2.4.[5,6]

3. Results

The inter-rater agreement was considerably different between the analyzed structures ranging from substantial (0.45 for skeleton) to poor (0.05 for pleura and thoracic wall) (Table 1).

Compared to the soft convolution kernel, the mixed convolution kernel was rated with a higher image quality for lung parenchyma, segmental bronchi and the border between the pleura and the thoracic wall ($P < 0.03$).

Compared to the hard convolution kernel, the mixed convolution kernel was rated with a higher image quality for aorta, anterior mediastinal structures, paratracheal soft tissue, hilar lymph nodes, esophagus, pleuromediastinal border, large and medium sized pulmonary vessels and abdomen ($P < 0.005$), but a lower image quality for trachea, segmental bronchi, lung parenchyma, and skeleton ($P < 0.001$).

These results were almost identical to those comparing the soft with the hard convolution kernel with exception of the pulmonary vessels, whose depiction was rated equally for soft and hard convolution kernel (Median ratings Table 2/ Imaging examples Figs. 1–3).

Regarding the CT number measurements of the pulmonary trunk, the mixed and soft convolution kernel performed

Table 2

Median ratings and *P*-values for all organ structures evaluated.

Structure	Median rating hard	Median rating mixed	Median rating soft	Friedman test *P*-value	Post hoc hard vs mixed *P*-value	Post hoc soft vs mixed *P*-value	Post hoc hard vs soft *P*-value
Thoracic aorta	−2	0	0	<0.001	<0.001	0.66	<0.001
Anterior mediastinal structures	−1	0	0	<0.001	<0.001	0.34	<0.001
Trachea und main bronchi	1	0	0	<0.001	<0.001	0.08	<0.001
Paratracheal tissue	−2	0	0	<0.001	<0.001	0.92	<0.001
Hilar lymph nodes	−1	0	0	<0.001	<0.001	0.61	<0.001
Esophagus	−2	0	0	<0.001	<0.001	0.61	0.049
Pleuromediastinal border	−1	0	0	<0.001	<0.001	0.34	<0.001
Large and medium sized pulmonary vessels	−2	0	0	<0.001	0.005	0.22	0.22
Segmental bronchi	2	0	−1	<0.001	<0.001	<0.001	<0.001
Lung parenchyma	2	0	−1	<0.001	<0.001	<0.001	<0.001
Pleura and thoracic wall	1	0	0	0.038	0.35	0.032	0.10
Abdomen	−2	0	0	<0.001	<0.001	0.71	<0.001
Skeleton	2	0	0	<0.001	<0.001	0.82	<0.001

similarly. Both of them showed a slightly lower mean value and a lower standard deviation compared to the hard convolution kernel.

Regarding the CT number measurements of the lung parenchyma, all convolution kernels showed different mean attenuation values. The standard deviation of the CT number measurements of the lung parenchyma, however, was higher in the mixed and the hard convolution kernel compared to the soft convolution kernel (Table 3).

4. Discussion

In our prospective study, we found the mixed convolution kernel to have properties very similar to the soft convolution kernel. Solely the lung parenchyma and a few adjacent structures were depicted in higher quality with the mixed convolution kernel compared to the soft convolution kernel. However, the mixed convolution kernel could not reach the quality for lung depiction shown by the hard convolution kernel. The mixed convolution kernel, therefore, cannot substitute the hard convolution kernel reconstruction and the standard hard and soft convolution kernel reconstructions are still necessary.

We used a semiquantitative relative visual grading technique for assessment of image quality in our study. This technique lets the observer compare and rate the depiction quality of clinically relevant anatomical structures against the same structures in a reference image. The clinically relevant anatomical structures in our case are proposed by the European Guidelines for Quality Criteria of Thoracic CT.[7,8] The idea is that good depiction of the normal anatomy will lead to reliable detection of pathological findings. The relevance of visual grading in this setting is supported by the fact that visual grading has been shown to correlate with physical image quality.[9] However, the ratings performed in visual grading are subjective and may differ between different observers, which is shown by the heterogeneous inter-rater agreement for the different anatomic structures in our study. To reduce the influence of subjectivity of the single rater, we performed a pooled analysis and analyzed the ratings of all observers together. Also, we additionally performed measurements of CT numbers, which underline the results of the qualitative image analysis.

The spatial resolution of an image is directly linked to its noise. Nonetheless, the spatial resolution as well as the noise has a great influence on the potential of images to depict different structures such that they can be satisfactorily evaluated by readers. Reconstructions that preserve the high spatial resolution do this at the cost of high image noise. If the reader evaluates structures with high endogenous contrast the high noise levels fall back

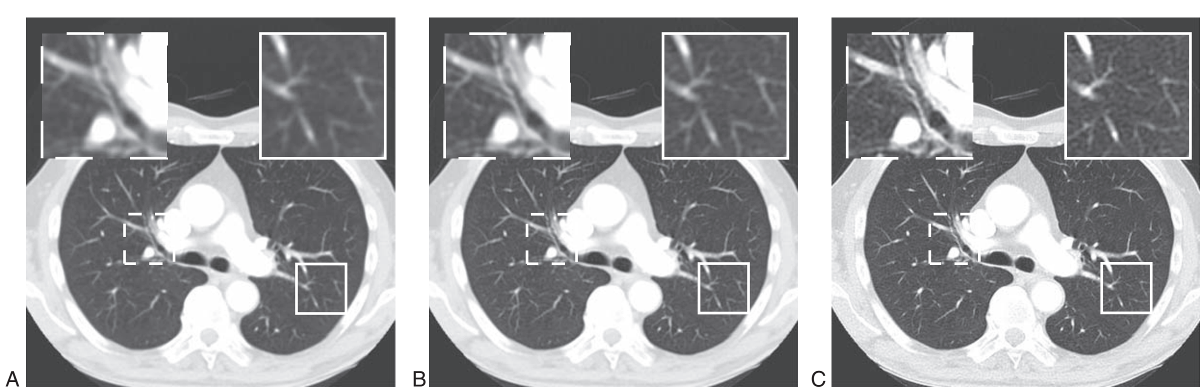

Figure 1. Depiction of lung parenchyma. Soft (A), mixed (B), and hard (C) convolution kernel reconstructions in lung window with zoom images for main bronchi (dashed line) and lung parenchyma (continuous line).

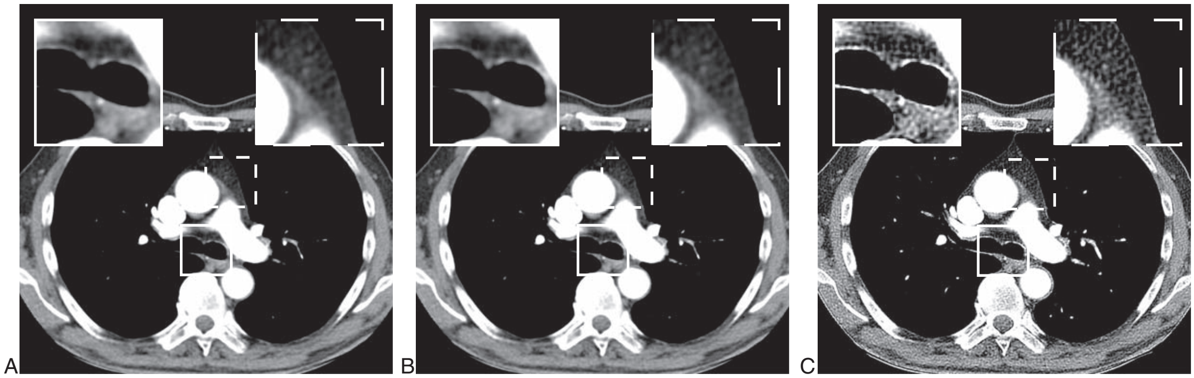

Figure 2. Depiction of soft tissue. Soft (A), mixed (B), and hard (C) convolution kernel reconstructions in soft tissue window with zoom images for paratracheal soft tissue (continuous line) and anterior mediastinal structures (dashed line).

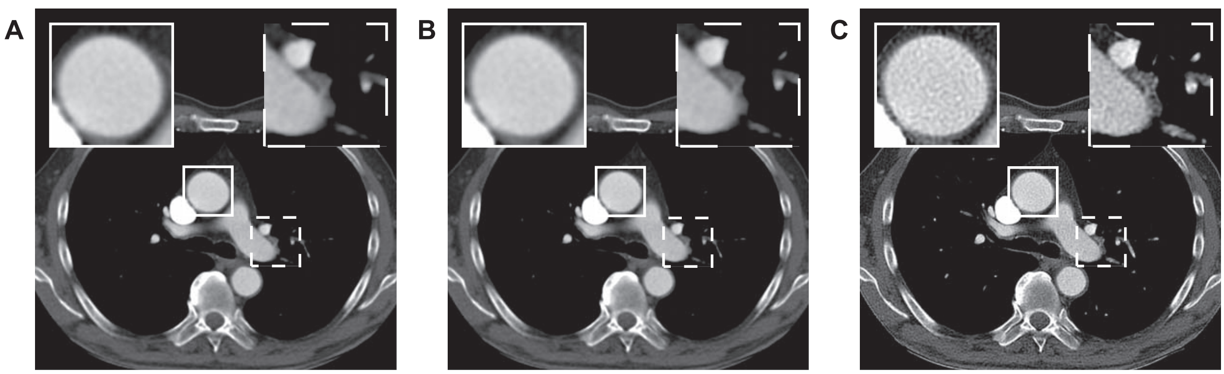

Figure 3. Depiction of vessels. Soft (A), mixed (B), and hard (C) convolution kernel reconstructions in vessel window with zoom images for aorta (continuous line) and large and medium sized pulmonary vessels (dashed line).

behind the endogenous contrast and they become negligible. If the endogenous contrast of the imaged structure is low, however, the noise hinders the reader to perceive the structures contrast in the images. To reduce the troublesome noise the images are reconstructed with a soft convolution kernel. The soft convolution kernel basically narrows the differences of proximate pixel intensities, thereby reducing noise but also the spatial resolution.

Thoracic CT images contain structures with high endogenous contrast, for example, the lung, and with low endogenous contrast, for example, the mediastinum. To enable satisfactory evaluation conditions for all imaged structures, thoracic CT images are reconstructed in a hard convolution kernel and a soft convolution kernel. Depending on their contrast, the different structures are either evaluated in the hard or the soft reconstructed images. The idea behind the mixed convolution kernel is to combine the advantages of both reconstruction algorithms in 1 image by geographically altering its "hardness" or "softness" according to the imaged organ structures. The advantages of such reconstructions will be fewer images that would have to be reconstructed, evaluated, and stored with possibly positive economic side effects.

Contrary to our results, several studies have shown combined convolution kernel CT reconstructions to have a similar image quality to soft and hard convolution kernel reconstructions.[1,2]

Table 3

Mean values, standard deviation, and *P*-values for truncus pulmonalis and lung parenchyma.

Structure	Hard	Mixed	Soft	Friedman test *P*-value	Post hoc hard vs mixed *P*-value	Post hoc soft vs mixed *P*-value	Post hoc hard vs soft *P*-value
Pulmonary trunk, mean value	302	297	297	<0.001	<0.001	0.59	<0.001
Pulmonary trunk, median standard deviation	28	12	12	<0.001	<0.001	0.2	<0.001
Lung parenchyma, mean value	–870	–859	–861	<0.001	<0.001	<0.001	<0.001
Lung parenchyma, median standard deviation	55	51	34	<0.001	0.08	<0.001	<0.001

These studies put the combined images together from previously reconstructed standard hard and soft convolution kernel reconstructions. Thus, the technique probably is more likely to result in high-quality combined convolution kernel reconstructions than the mixed convolution kernel tested in this study, where the regions of air-like density in a soft convolution kernel reconstruction are processed to appear sharper. In addition, advanced iterative reconstruction techniques have been described as raising the image quality in thoracic CT.[10] However, the iterative reconstruction technique was applied for all reconstructions in our study.

A completely different approach to alter the image properties regarding the spatial resolution and noise by filtering directly in the image space is reported by Ohkubo et al.[11] The reconstruction of several image stacks with different convolution kernels could become completely redundant if this technique were applied. However, this promising method is not yet clinical standard and will have to undergo further scientific investigation.

As for now, the mixed convolution kernel tested in this study will probably have no substantial benefit. However, the possible advantages of combined kernel reconstructions remain. Further studies should concentrate on the techniques shown in previous papers,[1,2] which resulted in an image quality equivalent to the standard hard and soft convolution kernel reconstructions.

4.1. Limitations

We included patients without known lung disease. The performance of the mixed convolution kernel in patients with lung disease could significantly differ from the results presented. This analysis was, however, not the aim of the study.

To sum up, we showed that the mixed convolution kernel could not fully substitute the standard hard and soft convolution kernel reconstructions; these reconstructions still seem to be mandatory for thoracic CT.

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