Multi-Slice CT for Visualization of Pulmonary Embolism using Perfusion Weighted Color Maps

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Summary. Purpose: The purpose of our preliminary study was to evaluate the feasibility of a new technique for the perfusion weighted color display of the density of lung parenchyma derived from multi-slice CT (MSCT) data sets of clinical routine examinations for visualization of pulmonary embolism (PE). **Materials and Methods:** Imaging of patients with suspected PE was performed on a commercially available MSCT (Somatom Volume Zoom; Siemens, Forchheim, Germany) after intravenous application of 120 cc of contrast-medium using a power injector. Scan parameters were 140 kV and 100 mAs, using a thin collimation of 4×1 mm and a table speed of 7 mm (pitch: 1.75). Derived from thin collimation axial slices (slice thickness$_{eff.}$ 1.25 mm, reconstruction increment 0.8 mm), a new image processing technique was deployed. Based on these source images, an automated 3D-segmentation of the lungs was performed followed by threshold based extraction of major airways and vascular structures. The filtered volume data were color encoded and finally overlayed onto the original CT images. This color encoded display of parenchymal density distribution of the lungs was shown in axial, coronal and sagittal plane orientation. In four patients with excluded PE as well as in two patients with proven PE this new technique was performed. **Results:** In the four patients that were considered negative regarding PE on MSCT, lung densitometry showed a homogeneous distribution of color encoded densities without circumscribed decreased or increased areas, beside the usually present gravity-dependent gradient in ventro-dorsal direction. In the two patients with proven PE, low density values on perfusion weighted color maps were found distally to the occluded pulmonary arteries. **Conclusions:** Our initial experience indicates that lung densitometry with an optimized display of the density distribution within the lung parenchyma may provide additional information in patients with suspected or proven PE. However, a comparison with ventilation/perfusion scintigraphy and a larger number of patients are necessary for the full clinical evaluation of this new functional imaging methodology.

Key words: Computed tomography (CT), spiral – Computed tomography (CT), function – Embolism, pulmonary – Lung, perfusion

***Farbkodierte Darstellung des Lungenparenchyms bei vermuteter Lungenembolie mittels Mehrschicht-Spiral-CT.* Einleitung:** Ziel unserer Studie war die Erprobung einer neuen farbkodierten Darstellung des Lungenparenchyms an Patienten mit Verdacht auf Lungenembolie (LE) anhand von Mehrschicht-Spiral CT (MSCT) Datensätzen aus der klinischen Routine. **Material und Methode:** Die Untersuchungen bei klinisch vermuteter LE wurden an einem MSCT (Somatom Volume Zoom; Siemens, Forchheim) nach intravenöser Gabe von 120 ml nichtionischem Kontrastmittels über einen Power-Injektor durchgeführt. Die Acquisitionsparameter waren 140 kV und 100 mAs mit dünner Kollimation (4×1 mm) und einem Tischvorschub von 7 mm (Pitch: 1,75). Anhand dünner axialer Primärschichten (Eff. Schichtdicke: 1,25 mm, Rekonstruktionsinkrement: 0,8 mm) wurde eine neue Nachverarbeitungstechnik angewandt. Anhand der Quellschichten erfolgte eine automatisierte 3D-Segmentierung der Lungen, gefolgt von einer schwellwertbasierten Eliminierung größerer Bronchi und Gefäße. Die so gefilterten Volumendatensätze wurden farbkodiert, um eine differenzierte Visualisierung der Dichteverteilung im Lungenparenchym in axialer, coronarer und sagittaler Raumebene zu ermöglichen. Diese neue Technik wurde bei vier Patienten ohne LE sowie bei zwei Patienten mit nachgewiesener LE untersucht. **Ergebnisse:** Bei den vier Patienten ohne LE-Nachweis in der MSCT zeigte die farbkodierte Darstellung des Lungenparenchyms eine homogene Dichteverteilung ohne umschriebene dichtegeminderte oder -angehobene Bezirke, abgesehen von einem ventro-dorsalen Dichtegradienten. Bei den beiden Patienten mit LE wurden Bezirke verminderter Dichte distal der verschlossenen Pulmo-nalarterien nachgewiesen. **Schlussfolgerungen:** Über eine farbkodierte Darstellung der Dichteverteilung innerhalb des Lungenparenchyms können Zusatzinformationen bei Patienten mit vemuteter LE gewonnen werden. Die Untersuchung eines größeren Patientenkollektivs und der Vergleich mit anderen Verfahren, wie der Perfusions-/Ventilations-Szintigraphie, sind für eine abschließende klinische Beurteilung dieser Funktionsbildgebung erforderlich.

Schlüsselwörter: CT, Spiral – CT, Funktion – Lungenembolie – Lungenperfusion

Introduction

Clinical diagnosis of pulmonary embolism (PE) is often difficult or even impossible and remains a diagnostic challenge in modern medicine [1]. In the diagnostic work-up of suspected PE, computed tomography (CT) has become increasingly popular. Compared to the gold standard – pulmonary arteriography [1] – spiral CT has proven to be an efficient and sensitive imaging modality [2 – 4]. In diagnostic algorithms of suspected PE regarding cost-effectiveness, all of the best strategies include pulmonary CT angiography (CTA) [5]. Thin collimation helical CT is mandatory, especially for assessing peripheral PE [6]. One advantage of CT is the direct visualization of clot material following contrast enhancement.

Subsecond spiral CT (0.75 s) is associated with improved clarity and diminished motion artifacts on lung and especially mediastinal structures when compared with 1-second spiral CT [7]. With 0.5 s rotation time and simultaneous acquisition of four slices using multi-slice CT (MSCT), the 8-fold increase in performance may be distributed over the three cornerstones: volume, time and axial resolution [8]. Therefore, thin collimation CTA of the entire chest can be performed within a single breathhold, even in critically ill patients.

As known from pulmonary angiography, perfusion defects allow the direct assessment of the extent of PE. Therefore, post-contrast CT data sets of the lung are of high interest as well. Dynamic scanning of the entire lung is not yet possible, since detector aperture is still too small. Nevertheless, parenchymal enhancement is directly correlated to functional parameters such as lung perfusion. Thus, the goal of our study was to extract additional information related to parenchymal enhancement using a new dedicated image processing technique.

Materials and Methods

The image processing was performed on clinical data sets, acquired from MSCT chest examinations for clinical suspicion of PE. Six patients (two male, four female) with a mean age of 65 years (48 – 72 y, ±8.2 y) were examined. All were clinically stable, regarding their cardiac and respiratory status. Non-ionic contrast media (Ultravist 370, Schering, Berlin, Germany) was applied intravenously using a double power injector (CT 9000 Digital Injection System; Liebel-Flarsheim, Cincinnatti, OH). Flow parameters were 3 cc/s, with a total amount of 120 cc, followed by a saline chaser bolus (3 cc/s, 30 cc). Start delay of all examinations was 30 s in cranio-caudad direction. Imaging was performed on a commercially available MSCT (Somatom Volume Zoom; Siemens, Forchheim, Germany). Scan parameters were 140 kV and 100 mAs, using a rotation time of 0.5 sec, thin collimation of 4 × 1 mm and a table speed of 7 mm (pitch: 1.75). Therefore, the entire chest was examined within a 19.7 – 22.1 s (m = 21.0 ± 0.31) breathhold. No additional late phase scanning was required.

First, axial images were reconstructed twice. Two sets were reconstructed with a slice thickness of 5 mm, using a standard soft tissue kernel and an edge-enhanced kernel for lung window settings. Technical quality of the data sets was evaluated first. Therefore, Hounsfield Units (HU) within the main pulmonary vessels were characterized with ROI-methodology. Radiological diagnoses regarding PE were established on these axial slices on hard copies as well as on an additionally generated set of thin collimated slices (slice thickness$_{eff.}$ 1.25 mm, reconstruction increment 0.8 mm, standard soft tissue kernel) in cine mode view on a workstation (Wizard, Siemens). For the patients studied, 292 – 354 axial source images were calculated (325 ± 19.3). Complete or incomplete occlusion of pulmonary arteries as direct visualization of emboli due to filling defects were used as signs of PE.

The image processing algorithm for visualization of post-contrast parenchymal enhancement was structured into 5 steps: segmentation, vessel cutting, adaptive filtering, color-coding and overlay with the original images.

Contour definition by identifying the lung using threshold based contour finding

In a first step, a binary mask of the image was derived by identifying lung areas and non-lung areas. A threshold based contour finder was used for segmentation, as lung tissue (low HU) is generally enclosed by high HU areas (pleura, chest wall). The threshold HU value separated both HU ranges and defined the contour of the lung. A typical value for the segmentation threshold was – 300 HU.

To exclude pleural walls, 5 layers of pixels were removed at the border of segmented lung areas by applying the morphological operation of erosion five times to the binary segmentation mask, using the four connected neighbours as structuring element.

All following steps were performed on the extracted lung-areas, only.

Vessel cutting

Major vascular structures and airways were removed by HU range selection to prepare images for subsequent filtering.

A lower threshold HU_B and an upper threshold HU_V were specified, pixels below HU_B were identified as airways, pixels above HU_V as vessels. For optimal image visualization, vessel cutting had to be balanced with preserving as many lung pixels as possible. The algorithm removed all pixels below HU_B and adjusted HU_V to reach a maximum share of 28 % of removed pixels.

Adaptive filtering

The segmented dataset was reformarted by linear interpolation to obtain a dataset with isotropic voxel spacing. An adaptive sliding mean value filter was applied, using a spherical 3D kernel with a diameter of 5 mm. In most datasets, this corresponded to 7 pixels. In this process, up to 7 adjacent slices were combined. Lost pixels due to vessel cutting were replaced to a specified extent, by the average of pixel value from their 3D environment. Removed pixels did not contribute to the averaging density values.

Color coding

To facilitate visualization of parenchymal enhancement, the resulting image was mapped onto a spectral color scale.

Mapping was controlled by center and width, analogous to gray scale image mapping. As subtraction technique from native data was not possible, no baseline was defined. A heuristic approach analyzed the parenchymal histogram and determined the window parameters automatically. The algorithm used the mean value of the processed parenchymal pixels as the center value, the width range was fixed to 100 HU.

Image fusion with the original image

The resulting color-encoded parenchymal images were overlayed onto the original CT images, as these CT source images were crucial for spatial orientation in the dataset. For overlay, all non parenchymal pixels were replaced by the original pixels of the respective slice position and displayed in the usual CT gray scale presentation. In addition, manual interactive windowing of the gray and the colored parts of the image by the user was possible.

A pictorial overview of the image processing algorithm is given in Fig. **1**. These algorithms were implemented in a matlab based development environment (MatLab 5.3; The MathWorks Inc., Natick, MA) on a PC (Pentium III, 600 MHz). Finally, these color-coded images were evaluated for distribution of density values within the whole data set. Deviations from homogeneous green-yellow colors were correlated retrospectively with the source images in a second reading.

Results

Density distribution (Hounsfield Units [HU]) in the pulmonary arteries was measured using ROI methodology. Mean HU values in the pulmonary trunk were 326 ± 50.0 HU, 317 ± 56.6 HU in the left main pulmonary artery and 307 ± 55.3 HU in the right main pulmonary artery. There fore, a homogeneous distribu-

tion of contrast material was achieved in all six patients. Also the HU values of the patients with proven PE were comparable to the healthy patients in this respect.

In all six patients, mean density values on CT perfusion weighted color maps were comparable, ranging from -860 HU to -915 HU (m = -892 ± 17.3 HU).

In the four patients with normal CT scans in axial scanning, color-coded display of lung parenchyma showed quite a homogeneous appearance of density values, displayed in bright green and partly yellow colors (Fig. **2a–c**). Anatomical details, such as lung fissures, were sharply delineated and allowed anatomical orientation, even on sagittal and coronal images.

In the patients with proven central and peripheral PE, filling defects on CTA corresponded to areas of decreased densities, as arterial inflow into the lung parenchyma was impaired significantly in these lung segments. These areas were predominantly displayed in violet and dark blue colors (Fig. **3a–c**).

Discussion

Visualization of lung perfusion as an adjunct to CTA seems to be an attractive technique to improve the diagnostic accuracy of PE diagnostics. Especially, as segmental and subsegmental emboli are detected more often, when thin collimation spiral CT examinations are performed [3,6]. Basis for this methodology is a high contrast bolus within the vessel lumen. Prokop et al. [9] stressed the importance of a high volume/high flow contrast application protocol in this respect. Using high-concentrated, non-ionic contrast material followed by an additional chaser bolus, we achieved mean density values above 300 HU within
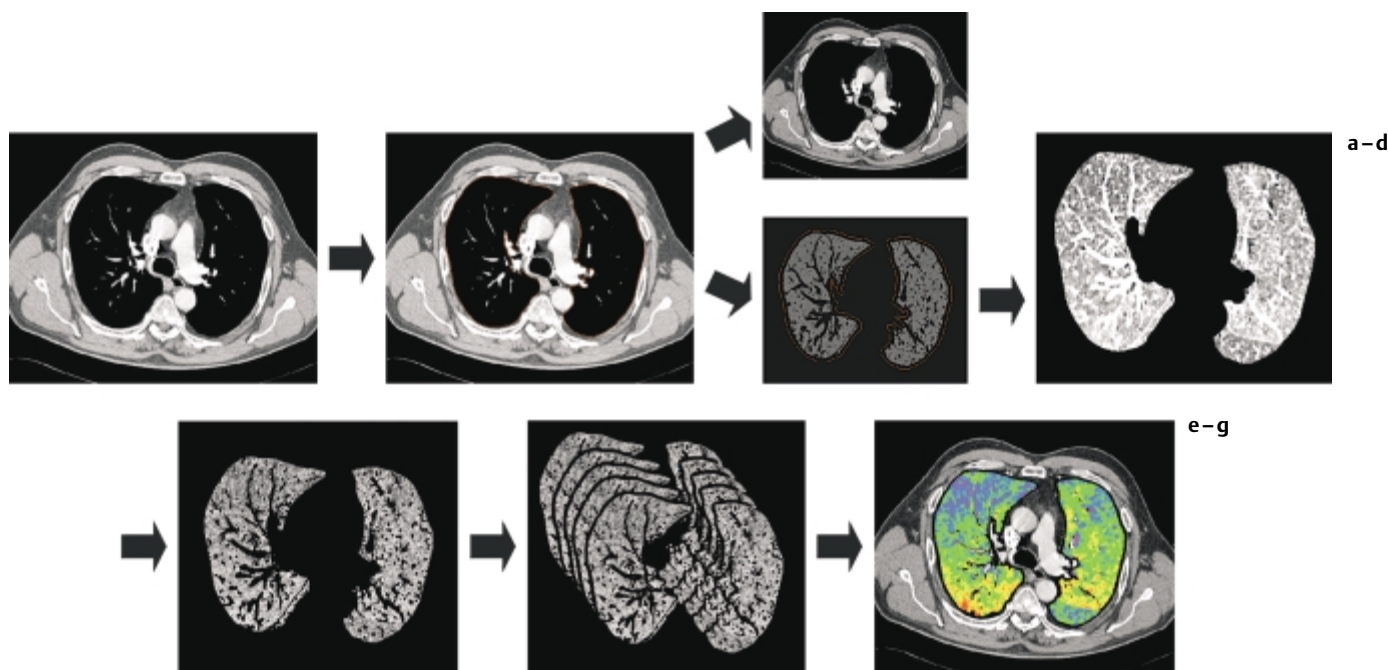
Fig. 1   Image processing algorithm: (**a**) Original image, (**b**) Contour detection, (**c**) Split-image, lung/non-lung, (**d**) Removal of pleura walls, (**e**) Removal of vessels and bronchi, (**f**) 3D adaptive filtering on image-stack, (**g**) Color-coding and overlay to original image
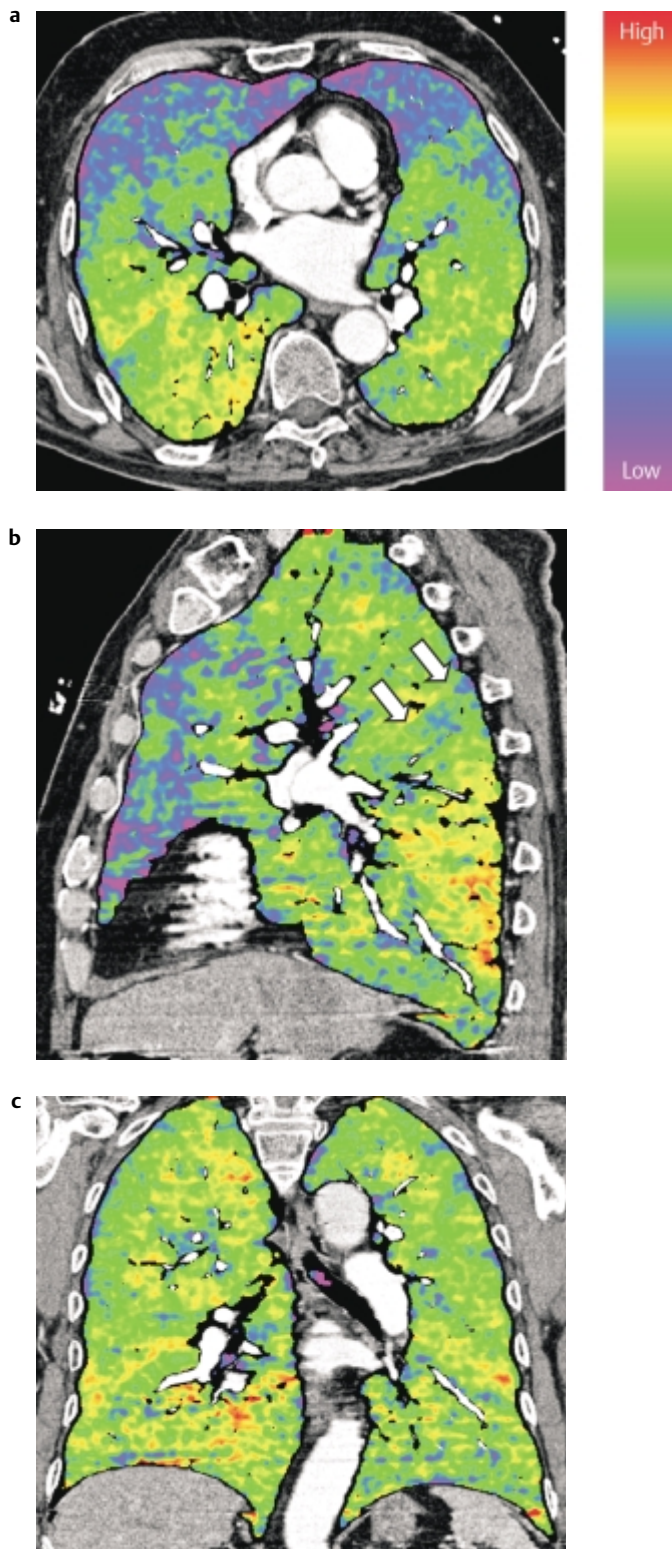
Fig. 2 (**a**) Axial image at the level of the left atrium after intravenous administration of contrast medium. Complete enhancement of all lung vessels. No perfusion deficits are detected on lung densitometry. Note the gravity dependent gradient shift in ventro-dorsal direction. (**b**) Sagittal view with homogeneous color coding of the entire lung beside the gravity dependent gradient. No local areas with increased or decreased lung density values. The major septum can be delineated (arrows). (**c**) In coronal plane, homogeneous density distribution is depicted.

the main pulmonary arteries. This guaranteed homogeneous filling of lung microcirculation in our patients.

Thin-collimation, sub-second spiral CT leads to improved spatial resolution and consequently increased analyzable subsegmental pulmonary arteries [6]. With the availability of MSCT within clinical routine, even a further increase in sensitivity and specificity can be expected. However, there are no larger patient series available for now. First initial data from dual-section CT suggest a depiction of (sub-) segmental emboli in approximately 90 % [3], although the clinical impact of these findings is discussed controversially [2, 3]. In this context, additional functional parameters would be desirable.

Wintersperger et al. [10] studied the right heart load in patients with suspected and proven PE. They concluded from their examinations in 61 patients (30 with acute PE), that cardiac measurements on spiral CT correlated well with the severity of PE and right ventricular failure. Schoepf et al. [11] performed initial lung perfusion studies for assessment of pulmonary blood flow in patients with proven PE. Using electron-beam CT (EBCT), a dynamic multisection blood flow CT study was performed on a 7.6 ccm lung volume with electrocardiographic gating. They found a statistically significant decrease of blood flow in occluded vessels (0.63 mL/min/mL vs. 2.27 mL/min/mL). However, EBCT is not generally available, and only 25 – 30 % of the entire chest was studied in these series. Also, functional scanning was performed after initial routine examinations, necessitating a second administration of contrast material with high flow rates (10 mL/s, total amount: 40 mL).

Depiction of four slices within one gantry rotation allows a maximum volume coverage of 20 mm for dynamic MSCT studies at the moment. A subtraction technique, as known from angiography, is technically not yet feasible using MSCT.

Groell et al [12] evaluated the potential of spiral CT densitometry by scanning the chest before and after IV contrast. They found significantly lower mean CT density values and decreased contrast enhancement in segments with decreased perfusion when compared to segments with normal perfusion on ventilation/perfusion scintigraphy. These perfusion deficits were measured by ROI-methodology. However, for assessment of CT densitometry, the entire examination had to be performed twice.

With MSCT, scanning of the entire chest within a single breathhold is technically feasible, even with thin collimation protocols. These protocols are necessary for generating nearly isotropic voxels with adequate delineation in z-direction. This is mandatory for displaying the acquired CT data not only in axial, but also in coronal and sagittal view directions [13].

Coulden et al. [14] studied 10 patients with chronic thromboembolic pulmonary hypertension (mean PA > 30 mm Hg) and compared perfusion abnormalities shown by scintigraphy with 3D-reconstructions of the lung obtained using MSCT. Areas of low attenuation on multiplanar reformations (MPR) showed excellent correlation with perfusion defects depicted by scintigraphy. These correlated with segmental pulmonary arterial occlusions derived from CTA of the same data set.
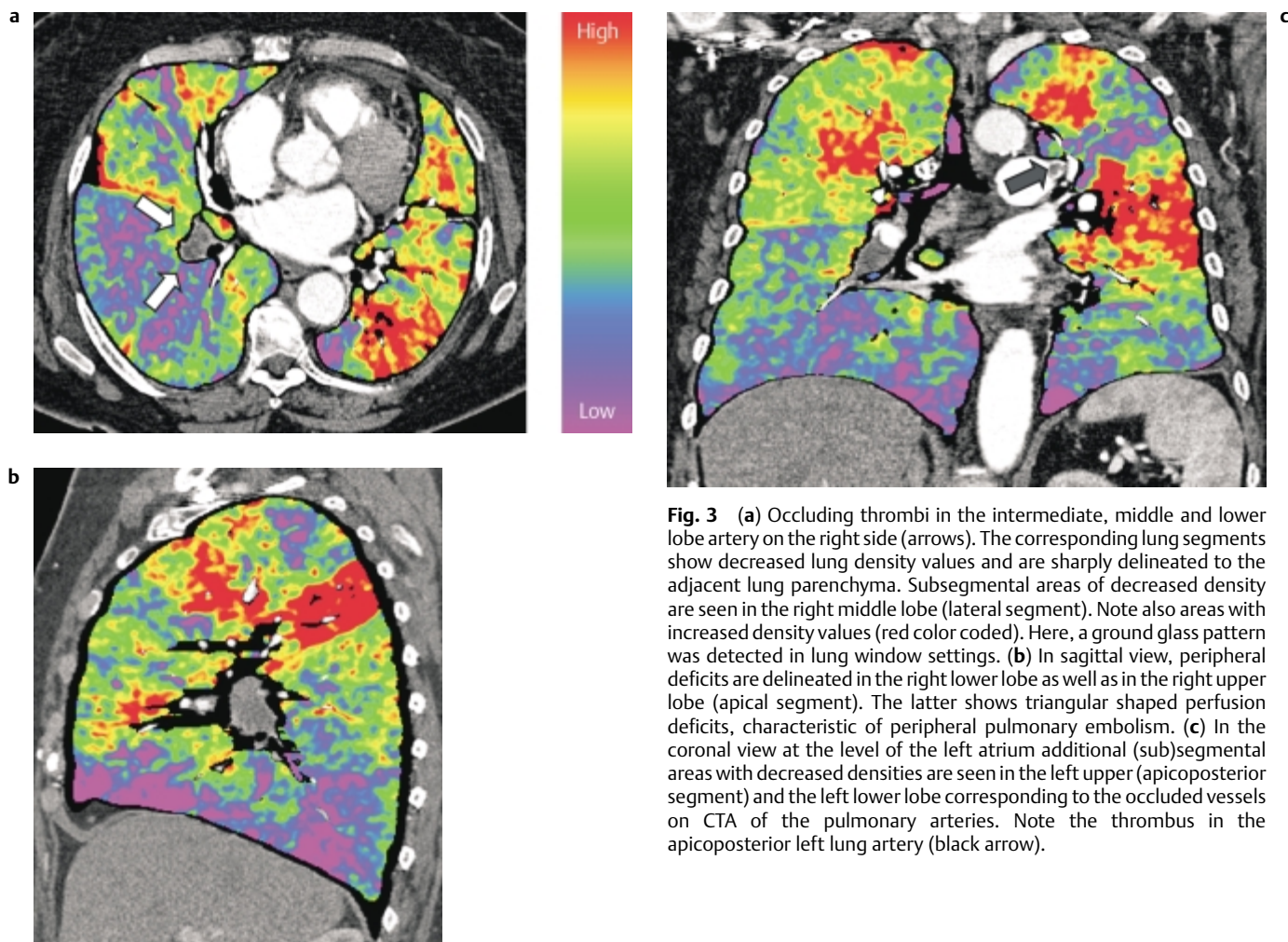
Fig. 3 (**a**) Occluding thrombi in the intermediate, middle and lower lobe artery on the right side (arrows). The corresponding lung segments show decreased lung density values and are sharply delineated to the adjacent lung parenchyma. Subsegmental areas of decreased density are seen in the right middle lobe (lateral segment). Note also areas with increased density values (red color coded). Here, a ground glass pattern was detected in lung window settings. (**b**) In sagittal view, peripheral deficits are delineated in the right lower lobe as well as in the right upper lobe (apical segment). The latter shows triangular shaped perfusion deficits, characteristic of peripheral pulmonary embolism. (**c**) In the coronal view at the level of the left atrium additional (sub)segmental areas with decreased densities are seen in the left upper (apicoposterior segment) and the left lower lobe corresponding to the occluded vessels on CTA of the pulmonary arteries. Note the thrombus in the apicoposterior left lung artery (black arrow).

In the postprocessing method presented, data sets are displayed by color-coding in axial, coronal as well as in sagittal view directions. As the parenchymal histogram and the window parameters are determined automatically, no further (subjective) windowing is needed. Information of the lung perfusion can be obtained by careful analysis of anatomic detail in all three directions. Occluded vessels led to a decrease of blood flow in the corresponding lung parenchyma, which was displayed in dark blue and violet colors. In combination with coronal and sagittal orientations, the lung segments affected were easily delineated.

This methodology will have limitations in patients with underlying emphysema due to their inappropriate re-distribution. Also interpretation of areas with increased density values remains challenging, as several conditions may lead to this finding. In the patients with proven PE, dystelectatic areas led to increasing lung densities, which therefore have to be carefully analyzed on the source images. Other additional findings, such as pleural effusion, ground glass and mosaic attenuation patterns as well as atelectases for several reasons might also have effects on the methodology presented.

Perfusion weighted color maps utilizing MSCT may serve as an additional imaging technique derived from data sets of the entire chest. However, a comparison with ventilation/perfusion scintigraphy and a larger number of patients are necessary for the full clinical evaluation of this new functional imaging methodology in daily routine.

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