Clinical Utility of Multiplanar Reformation in Pulmonary CT Angiography

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OBJECTIVE. The purpose of this study was to determine whether the view used, multiplanar or axial, for image interpretation at pulmonary CT angiography for suspected acute pulmonary embolism alters the diagnostic confidence, accuracy, and interpretation time of cardiothoracic radiology specialists and radiology residents.

MATERIALS AND METHODS. Patients who underwent 50 consecutive pulmonary 64-MDCT angiographic examinations formed the study group (18 men, 32 women; mean age, 53 years; range, 19–93 years). Three blinded cardiothoracic faculty radiologists and three blinded radiology residents reviewed each case independently initially using only axial display mode and later using multiplanar reformation (MPR) in any x-, y-, or z-axis. The presence of pulmonary embolism in the main through subsegmental pulmonary arteries was scored on a 5-point scale; diagnostic confidence for the overall examination was scored on a 3-point scale; and interpretation time was recorded. A surrogate reference standard consisted of either faculty agreement or, in cases of disagreement, adjudication by another, senior faculty member. Statistical analysis included the Kendall coefficient (W), receiver operating characteristics curves, and a univariate repeated measures model.

RESULTS. Interobserver agreement between specialists on the diagnosis of pulmonary embolism was good for axial viewing (W = 0.72) and for MPR viewing (W = 0.79). Interobserver agreement between residents was good for axial viewing (W = 0.62) and for MPR viewing (W = 0.70). Reader confidence improved among all readers with MPR viewing, but the difference did not reach statistical significance. Interpretation time with MPR was significantly longer for two of the three specialists and significantly shorter for two of the three residents.

CONCLUSION. Use of MPR for viewing increased the reader agreement and interpretation time of cardiothoracic specialists but increased reader agreement between residents and might have decreased interpretation time. All readers had a trend toward increased confidence.

With MDCT volumetric and isotropic data on the entire thorax are acquired with thin collimation and few artifacts; therefore, images can be viewed in any plane. For primary image viewing, the use of multiplanar reformation (MPR) images of the chest, abdomen, and pelvis has been found [1–7] to increase detection of abnormalities including air trapping, bronchiectasis, emphysema, hilar lymph node enlargement, lung tumors, appendicitis, abdominal lymph node enlargement, bowel obstruction, hernia, and inflammatory bowel disease. Use of MPR viewing in conjunction with axial images also increases the rate of detection of appendicitis [8]. Use of MPR primarily [7] and with axial images [6, 8] has been found to increase reader confidence. Use of MPR viewing also has increased interobserver agreement on findings in the chest, abdomen, and pelvis [2, 6]. Some authors [9], however, found that although MPR viewing increased specificity, it did so at the cost of decreased sensitivity for nodule detection and for emphysema in particular.

The benefits of MPR were not corroborated in studies [10–14] in which no difference in disease detection was found between use of MPR images of the chest, abdomen, and pelvis instead of and use of MPR in addition to axial images. With respect to CT for suspected pulmonary embolism (PE), several studies [10–13] showed that coronal images alone are as informative as axial images alone. The purpose of this study was to determine whether multiplanar viewing of pulmonary CT angiography improved diagnostic confidence, accuracy, and interpretation time.
CT angiographic (CTA) images in unlimited planes alters reader agreement, diagnostic confidence, and interpretation time compared with axial image viewing alone among both cardiothoracic radiology faculty specialists and diagnostic radiology residents.

Materials and Methods

Patient Sample and Data Sources

Institutional review board approval with a waiver of informed consent was received for this retrospective review. The study group consisted of 50 patients (18 men, 32 women; mean age, 53 years; range, 19–93 years) who from March 7, 2006, through March 23, 2006, underwent 50 pulmonary CTA examinations with a 64-MDCT scanner. Eighteen of the patients (36%) were inpatients, 29 (58%) were emergency department patients, and three (6%) were outpatients, reflecting everyday clinical practice at our institution. The sample size of 50 was chosen to balance statistical power and resource constraints.

CT Technique

All CT examinations were performed with a 64-MDCT scanner (LightSpeed VCT, GE Healthcare). Acquisition was caudal to cranial from the lowest hemidiaphragm to the lung apices at 1.25-mm collimation, 0.625-mm reconstruction interval, 120 kVp, 500 mA, 0.6-second gantry rotation, and 1.375:1 pitch. The image field of view was lateral chest wall skin surface to opposite lateral chest wall skin surface. A dose of 125 mL iopromide 370 mg I/mL (Ultravist 370, Bayer Healthcare) was injected into an upper extremity peripheral vein at 4 mL/s. The start of image acquisition was determined with bolus tracking in a region of interest located on the main pulmonary artery with a trigger threshold of 70 HU and an additional 3-second delay. The additional delay was set to maximize opacification and avoid technical errors in triggering the scan. The acquisition time ranged from 3.5 to 6 seconds, and images were obtained in a single breath-hold.

Data Collection and Image Analysis

Identifying information was removed from all pulmonary CTA studies; only the study date was preserved. Analysis of axial images alone was performed with one of two U.S. Food and Drug Administration–approved diagnostic workstations (Advantage Windows version 4.0, GE Healthcare; IMACS, Siemens Healthcare). Readings were performed independently by three fellowship-trained thoracic radiologists (2, 3, and 6 years of postfellowship training) and three diagnostic radiology residents (one second year, one third year, and one fourth year). Readers were blinded to the other readers’ interpretations and to clinical data, including previous clinical interpretations.

For images from each pulmonary CTA examination as a whole, readers used the following 5-point scale to score their overall determination of the presence of PE: 5, definitely present; 4, probably present; 3, indeterminate; 2, probably absent; 1, definitely absent. They rated their diagnostic confidence on the following 3-point scale: 1, highly confident; 2, moderately confident; or 3, not confident. The readers used the 5-point scale to score the pulmonary arteries at different anatomic levels of each lobe: supralobar (main, right, and left), lobar, segmental, and subsegmental. Using a stopwatch, readers recorded their reading time for each examination.

Several months after the axial-only image analysis, readers used the multiplanar display of the reformat tool of one of the workstations (Advantage Windows version 4.0) to repeat their reviews of each pulmonary CTA study. They were blinded to their previous interpretations, and the studies were given different identification numbers for the second reading. With the reformat tool sagittal, coronal, and axial images and rotating maximum, minimum, and average intensity projections are simultaneously displayed on the left monitor, and a separate full-screen display that can be rotated into any imaging plane (multiplanar or omniplanar including oblique and nonorthogonal planes) is presented on the right monitor (Fig. 1). The readers were allowed to adjust images by changing the window and level, magnification, and section thickness. Curved MPR and vessel analysis were not used. The scoring system used for the axial-only image reading was used for the MPR reading.

After both reading sessions, the readers used the following 3-point scale to score their perceptions of the usefulness of MPR viewing in the evaluation of acute PE: 1, very useful; 2, moderately useful; and 3, not useful.

An absolute reference standard for the presence of PE or deep venous thrombosis, such as autopsy or catheter angiography, was not available for most of the patients. Therefore, a surrogate reference standard as to the presence or absence of PE was used for each overall examination. When all three faculty cardiothoracic radiology specialists were in agreement over the presence or absence of PE after reading the studies with both axial and MPR images, this agreement was used as the truth condition. If there was any disagreement among the three cardiothoracic specialists, the cases were reviewed independently by an additional experienced cardiothoracic radiologist (15 years of postfellowship training) who was not one of the three initial readers and who served as the adjudicator. The adjudicator did not know which of the readers disagreed. Seven cases had to be rereviewed.

Statistical Analysis

For evaluation of interobserver variability in the overall diagnosis of PE, the Kendall coefficient of concordance was determined. The Kendall coefficient ranges from 0 (no agreement) to 1 (complete agreement). Interpretation of the Kendall coefficient is similar to that of the kappa value. The Kendall coefficient is a measure of the extent of agreement between multiple readers who are rating on an ordered scale, whereas the kappa value is a measure of agreement between two readers on a nominal scale.

Diagnostic certainty in the diagnosis of PE at each anatomic pulmonary arterial level also was evaluated. Receiver operating characteristics analysis of the pulmonary CTA interpretations (overall diagnosis) by each reader was performed with the

Fig. 1—55-year-old man with chest pain. Pulmonary CT angiographic oblique reformat ted images. A, Oblique sagittal reformatted image shows filling defect (arrows) in segmental pulmonary artery of left lower lobe. B, Oblique coronal reformatted image shows filling defects (arrows) in addition to those in A in segmental pulmonary arteries of left upper and lower lobes.
TABLE 1: Area Under the Receiver Operating Characteristics Curve

<table>
<thead>
<tr>
<th>Reader</th>
<th>Axial Images</th>
<th>Multiplanar Reformations</th>
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</thead>
<tbody>
<tr>
<td>Residents</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0.91</td>
<td>0.8</td>
</tr>
<tr>
<td>2</td>
<td>0.84</td>
<td>0.76</td>
</tr>
<tr>
<td>3</td>
<td>0.58</td>
<td>0.81</td>
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<tr>
<td>Average</td>
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<td>0.79</td>
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<tr>
<td>Faculty</td>
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<tr>
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<td>0.7</td>
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<tr>
<td>2</td>
<td>0.83</td>
<td>0.86</td>
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<tr>
<td>3</td>
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<td>0.94</td>
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<tr>
<td>Average</td>
<td>0.83</td>
<td>0.88</td>
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Results

In comparison with the described surrogate reference standard, the readers rated 10% of pulmonary CTA examinations as showing the presence of PE, 68% as definitely or probably showing the absence of PE, and 22% as indeterminate. Analysis of interobserver variability among the faculty cardiothoracic radiology specialists for the overall presence of PE showed a Kendall coefficient of 0.72 for axial images only and of 0.79 for MPRs. Analysis of interobserver variability among radiology residents for the overall presence of PE showed a Kendall coefficient of 0.62 for axial images only and a Kendall coefficient of 0.70 for MPR.

Summary receiver operating characteristics curves for each reader’s performance are presented in Table 1 and Figures 2 and 3. The average diagnostic confidence scores for the faculty cardiothoracic radiology specialists were 1.537 (1 indicating very confident and 3, not confident) for axial images only and 1.54 for MPRs; the difference was not statistically significant ($F$ test, $p > 0.05$). The average diagnostic confidence for radiology residents was 1.93 for axial images only and 1.76 for MPRs, also not statistically significant.

Overall, the thoracic radiology specialists were significantly more confident in their diagnoses than were the residents ($F$ test, $p < 0.0001$) (Figs. 4 and 5). When asked to rate the usefulness of MPRs for evaluating a suspected diagnosis of acute PE, faculty readers had an average score of 2.3, and resident readers had an average score of 2.5 (1 indicating very helpful; 2, moderately helpful; and 3, not helpful) (Fig. 6).

The analysis of variance model fit with a significant interaction between image type and experience level ($p < 0.0001$). The differences in interpretation times therefore must be evaluated with both factors at the same time. The mean interpretation times are shown in Table 2. On average, the thoracic radiology specialists had a significantly greater interpretation time using MPRs than they did using axial images ($p = 0.001$). In contrast, the residents had a shorter average interpretation time using MPRs than they did using axial images ($p < 0.0001$). The average faculty and resident reading times are depicted in Figure 7. In addition, the faculty were significantly faster than the residents using axial images.
images alone \( (p = 0.01) \), whereas the residents were significantly faster than the faculty using MPRs \( (p < 0.0001) \). Kappa statistics on interobserver variability at each segmental level did not prove to be measures of true interobserver agreement because of a lack of variability among readers in making the PE diagnosis and because of the small number of cases of PE included in the study.

**Discussion**

The advent of MDCT, particularly 16- and 64-MDCT, made volumetric acquisition of images of the entire chest in a single breath-hold with isotropic resolution possible. This capability enables multiplanar (if not possible omniplanar) viewing instead of axial viewing, which has dominated radiology interpretation since the days in which CT images on film dominated the reading environment. Although coronal views have been found equivalent to axial views alone for reading pulmonary CTA images \[10–13\], the benefit of interactive multiplanar viewing of axial, sagittal, and coronal images as a foundation has not been previously studied, to our knowledge.

The readers in this study were allowed to use MPRs to evaluate the pulmonary arteries not only in a standard presentation of axial, coronal, and sagittal planes but also in any plane of their choice in addition to the three standard planes. This method simulates reading practice based on a PACS workstation with embedded reformatting software or on an independent advanced interpretation workstation. Previous studies have shown good interobserver agreement in the detection of PE in both axial and MPR views \[12, 13\]. One study of interobserver agreement based on vessel level for axial and MPR viewing showed better agreement on both axial and MPR images at the larger pulmonary arterial levels \[13\]. We found that reading images from pulmonary CTA examinations as MPRs increased overall interobserver agreement between both fellowship-trained cardiothoracic radiology specialists and diagnostically radiology residents, the Kendall coefficient increasing from 0.72 to 0.79 for the faculty and from 0.62 to 0.70 for residents. These findings are in keeping with those of Nishino et al. \[12\], who found similar interobserver agreement for axial and MPR viewing in the detection of PE.

It was not surprising that cardiothoracic radiology specialists were significantly more confident than diagnostic radiology residents in both axial and MPR readings. Although there was a trend toward improvement in confidence with the addition of MPR, the difference was not statistically significant. To the best of our knowledge, in none of the previous studies of PE detection was reader confidence evaluated.

In the examination of receiver operating characteristics curves, the accuracy represented by the area under the curve for thoracic specialists averaged 0.83 with axial images alone and 0.88 with MPRs. For residents, the average area under the curve was 0.78 with axial images and 0.88 with MPRs. Neither of these differences reached statistical significance. This finding is in agreement with those in previous studies that showed no increase in accuracy for PE detection using MPR viewing; in our study, however, MPRs were used in addition to rather than as a replacement for the axial images \[10–13\]. Although the average areas under the curve for residents did not differ significantly between

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**Fig. 4**—Graph shows cardiothoracic radiology faculty confidence. Readers were asked to rate their degree of confidence in diagnosis of pulmonary embolism using axial images alone (light gray) and axial images and multiplanar reformations (dark gray). Scale was 1, very confident; 2, moderately confident; and 3, not confident. Values are average number of cases rated in each category.

**Fig. 5**—Graph shows resident reader confidence. Readers were asked to rate their degree of confidence in diagnosis of pulmonary embolism with axial images alone (light gray) and with axial images and MPR (dark gray). Scale was 1, very confident; 2, moderately confident; and 3, not confident. Values are average number of cases rated in each category.

**Fig. 6**—Graph shows reader perception of usefulness of multiplanar reformations. For assessment of usefulness of multiplanar reformations in making or excluding diagnosis of pulmonary embolism, readers rated usefulness 1, very useful; 2, moderately useful; or 3, not useful. Values are average number of cases rated in each category for residents (light gray) and faculty (dark gray).
axial images and MPRs, it is notable that two resident readers had decreased accuracy and reading time with the addition of MPRs. This difference may have been due to several factors, including misinterpretation of reformatted images, overreliance on MPRs rather than axial images in making a diagnosis, and a false sense of confidence in MPRs, leading to shorter interpretation times. However, the data are insufficient to fully determine why these two residents were less accurate when using MPRs. Additional studies may be useful to further analyze the effect of multiplanar imaging on image review and accuracy.

The resident readers took significantly longer than faculty readers to interpret axial images, 5:21 versus 4:29 minutes, which is consistent with differences in reader experience and training. However, resident readers took significantly less time than faculty readers to interpret the MPRs, 4:06 versus 5:14 minutes. Several factors can account for this difference. When reading MPRs, faculty readers indicated they primarily read from the axial images first and used the other images to problem solve. The resident readers, however, read the entire study in more than one plane simultaneously. This difference in approach is not surprising because there may have been differences in computer literacy and familiarity with postprocessing software. Furthermore, faculty readers’ primary practice over most of their careers had been with axial images on film or axial views on a PACS workstation in the past, leading to shorter interpretation times.

The resident readers in this study began learning multiplanar imaging in residency, which was relatively recent in their reading experience. In this study, both faculty and residents perceived MPRs as being moderately useful or not useful most of the time. In the case of faculty, this perception might have been due to unfamiliarity with multiplanar viewing.

Our study had several limitations. First, the reference standard was consensus of the three cardiothoracic radiology specialists and arbitration by a fourth cardiothoracic radiologist. No independent and consistent reference standard, such as catheter pulmonary angiography, which is seldom performed clinically, was available. There also are limitations, however, to the traditional reference standards of autopsy and pulmonary angiography, and there are issues of invasiveness and limited availability of catheter angiography.

The second limitation was that only 10% of the studies had findings positive for PE. This rate of positive findings is similar to that of other published studies and is representative of our population. Low percentage of studies with positive findings might have affected the ratio of instances in which MPR was deemed very useful in making or excluding the diagnosis of PE. In addition, the number of studies labeled indeterminate was high at 22%. The effects of artifacts, including motion, streak, and poor contrast, on diagnostic quality was not specifically evaluated in our questionnaire.

Third, one can argue that the first reading session with axial images alone gave the readers additional experience in pulmonary CTA that added to their confidence and skills during the MPR reading session months later. For faculty members who had read axial images from several hundred pulmonary CTA examinations a year for several years, the 50 cases from the first axial reading session are not likely to have added significantly to their skill set and confidence. For residents who may have reviewed few pulmonary CTA cases in their residency before this study, the first interpretation of axial images alone can be seen as additional training and may have influenced their confidence at the MPR reading session months later.

In this study of 50 consecutive pulmonary CTA examinations for acute PE, MPR viewing increased reader agreement and showed a trend toward improving confidence among both cardiothoracic radiology specialists and diagnostic radiology residents. That MPR viewing reduced interpretation time for residents but not cardiothoracic radiologists over axial viewing alone likely reflects the preexisting bias of practicing specialists toward the use of axial images because of their training and time in practice in which use of axial images was the mainstay of interpretation.

Acknowledgment

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MPR in Pulmonary CT Angiography

References