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Comparison of emergency cranial CT interpretation between radiology residents and neuroradiologists: transverse versus three-dimensional images

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PURPOSE
Three-dimensional (3D) reformatted images provide a more inclusive representation of abnormalities than transverse images in cranial computed tomography (CT). The purpose of this study was to assess the value of 3D reformations for radiology residents in the interpretation of emergency cranial CTs.

MATERIALS AND METHODS
In total, 218 consecutive patients who underwent emergency cranial CT scans with 3D reformation were included in this retrospective study. Four blinded readers (three radiology residents and a neuroradiologist) interpreted the transverse and 3D images in two separate sessions. Each reader assessed 1) abnormal finding(s) and the confidence score(s) (5-point scale) for transverse and 3D images, 2) added value score of 3D images (5-point scale), and 3) interpretation time for both transverse and 3D images. We analyzed discordance between each radiology resident and the neuroradiologist on a lesion-by-lesion basis.

RESULTS
In total, 509 lesions were detected in 218 patients. Discordance rates between the three residents and the neuroradiologist were 11.4%–20.2% (mean, 15.0%) and 8.8%–16.9% (mean, 12.1%) in the interpretation of transverse and 3D images, respectively. Confidence scores were higher for 3D images than for transverse images for all readers. The added value scores for the 3D images were relatively higher for the inexperienced residents. Interpretation times for 3D images were significantly higher than for transverse images for all readers.

CONCLUSION
The 3D reformations assist radiology residents in the interpretation of emergency cranial CT examinations.

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Unenhanced cranial computed tomography (CT) is the primary imaging modality for the emergency evaluation of patients with acute neurological deficits because of its wide availability, speed, costeffectiveness, and ability to assess less stable patients (1). Although some institutions may have 24-hour CT interpretation by an experienced neuroradiologist, many hospitals provide overnight coverage for CT studies by an on-call radiology resident. The final interpretation is then provided by attending neuroradiologists, usually the next day. Thus, accurate initial interpretation of cranial CT scans by the resident is critical for proper patient management.

A few studies have investigated discordance between radiology residents and neuroradiologists in the interpretation of unenhanced cranial CT scans and they reported discordance rates in the range of 2.1%–8.3% (2–4). This discordance rate may be influenced by several factors, such as the resident's level of training, prevalence and type of disease, and imaging technique (e.g., resolution, display, image plane).

A few studies have assessed the added value of three-dimensional (3D) reformations versus transverse plane views in the evaluation of cranial CT examinations (5, 6). To our knowledge, however, no reported study has evaluated the effect of 3D reformatted images on radiology residents' performance.

The aim of this study was to assess the value of 3D reformations to radiology residents in the interpretation of unenhanced emergency cranial CT scans.

Materials and methods

Study design and population

In this retrospective study, we assessed 219 consecutive adult patients who visited the emergency room and underwent unenhanced cranial CT examination with 3D reformations from May 2012 to July 2012. The indications for CT included trauma (n=160, 73.1%), cerebrovascular accident (n=29, 13.2%), severe headache (n=14, 6.4%), reduced level of consciousness (n=12, 5.5%), and seizure (n=4, 1.8%). One patient was excluded because of nondiagnostic image quality. Thus, our study population consisted of 218 patients (138 males, 80 females; mean age, 56.7±18.2 years; range, 18–91 years).

Our Institutional Review Board approved this study and waived the requirement for informed consent.

CT imaging technique

All CT scans were obtained on a 256-slice multi-detector row CT scanner (Brilliance iCT, Philips Healthcare, Cleveland, Ohio, USA) from the base of the skull through the vertex. The following scanning parameters were used: 120 kVp; 350 mAs; 16×0.625 mm collimation; pitch, 2.0; table speed, 20.3 mm/s; gantry speed, 0.4 s per rotation; matrix, 512×512; and field of view, 240 mm.

Reconstruction was performed using a commercially available console system (Extended Brilliance Workspace, Philips Healthcare) devoted to rapid reconstruction. The axial source data were reconstructed with 0.8-mm-thick sections at 0.4-mm intervals in the transverse plane. The axial source data were then reformatted in transverse (with slight craniocaudal angle), sagittal, and coronal planes with 5-mm-thick sections at 5-mm intervals. The mean numbers of reconstructed images for the transverse, sagittal, and coronal planes were 27.2, 28.5, and 32.8, respectively. The scan generator required ~90 s to reconstruct all transverse, sagittal, and coronal images. All acquired images were transferred to a picture archiving and communication system (PACS, Pi-ViewStar, Infinitt, Seoul, Republic of Korea) as a separate series of scans.

Image analysis

All CT scans were reviewed on a PACS workstation (XW6000, Hewlett-Packard, Palo Alto, California, USA) and flat-panel monochrome 3-megapixel monitors (IF 2103A, WIDE, Seoul, Republic of Korea) with a diagonal display size of 21 inches (53.3 cm). Each reviewer could change the window or level settings of the scans and could use cross-reference line functionality for combined transverse, sagittal, and coronal images.

Four radiologists served as independent readers: first, second, and third-year radiology residents with two, four, and six months of training in cranial CT interpretation (H.L., Y.J.K., and A.H., respectively) and a board-certified staff neuroradiologist with 18 years experience in cranial CT interpretation (D.Y.Y.). Each CT reader reviewed 218 examinations independently in two reading sessions: 1) transverse image set, 2) combined three-dimensional (3D) (transverse, sagittal, and coronal) image set. To minimize recall bias, reading sessions were separated by eight weeks (transverse image set was reviewed first). Using a random-number table, the images of each set were presented in random order to each reader. The patient's name and hospital record number were removed from the images. The readers were blinded to the original CT report, results of the other imaging set, results of the other readers, and all clinical information; they were aware of only the patient's age and gender.

Before interpreting the images, overall image quality was evaluated subjectively by two readers (D.Y.Y. and E.S.K., a board-certified neuroradiologist with four years experience in cranial CT interpretation) by consensus. All three planes were reviewed, and image quality was assessed subjectively on a five-point scale (1, nondiagnostic; 2, poor; 3, satisfactory; 4, good; 5, excellent).

Scans were initially categorized as "normal" or "abnormal". If the scans were thought to be abnormal, readers recorded all abnormalities detected on CT scans and their locations. A confidence score for each abnormality was obtained with a five-point scale: 1, definitely absent; 2, probably absent; 3, equivocal; 4, probably present; or 5, definitely present. In assessing the 3D images, readers judged whether the 3D images provide added value to the transverse images for the identification of each abnormality with a five-point scale: 1, abnormality definitely less well seen on 3D images; 2, abnormality somewhat less well seen on 3D images; 3, no difference in abnormality visualization; 4, abnormality somewhat better seen on 3D images; or 5, abnormality definitely better seen on 3D images. If no lesion was seen, no added value score was recorded. Finally, readers were asked to record total interpretation time (including the time required to load images) needed for each evaluation.

To avoid interpretation error by the reading neuroradiologist, the images were reviewed again with both transverse and 3D images by another neuroradiologist (E.S.K.) after completion of the independent randomized readings. In cases of disagreement, a third neuroradiologist (H.C.K., a board-certified neuroradiologist with 14 years of experience in cranial CT interpretation) reviewed the images, and the consensus interpretation of the three neuroradiologists was used as the gold standard.

The attending neuroradiologist (E.S.K.) reviewed all reported disagreement between image sets and discordance between readers on a lesion-by-lesion basis. The interpretations were also categorized as either "concordant" (if the CT interpretations between the resident and the neuroradiologist matched) or "discordant". Discordant lesions were further divided into false-negatives (findings missed by the resident compared with the neuroradiologists' reading), false-positives (findings reported by the resident that were not reported by the neuroradiologist), and misinterpretations (although recognized as abnormal, diagnosis of the resident was not the same as that of the neuroradiologist).

The next step was to determine whether the discordance was clinically significant. A significant abnormality was defined as any CT finding that could result in a change in the clinical status of the patient or a change in management if diagnosed incorrectly. Table 1 lists the CT findings that were considered significant and insignificant.

Statistical analysis

We determined discordance rates between interpretations by residents and consensus interpretations by neuroradiologists on the basis of both the transverse images alone and the 3D images. The effect of the level of residency training on discordance rates was assessed using the chi-square test. Differences in confidence and added value scores were determined using the paired Student's t test and one-way analysis of variance, respectively. Interpretation time differences between image sets were assessed using the paired Student's t test.

All statistical analyses were performed with the Statistical Package for the Social Sciences (SPSS) software (version 19.0 for Windows; SPSS Inc., Chicago, Illinois, USA). A P value of < 0.05 was considered to indicate a statistically significant difference.

Results

Image quality

For most (211, 96.3%) of the 219 cases, the overall subjective image quality

Table 1. Abnormalities on emergency cranial CT scans as interpreted by a neuroradiologist based on three-dimensional images (n=509)

	n (%)
Significant abnormalities	
Subdural hematoma	88 (17.3)
Subarachnoid hemorrhage	69 (13.6)
Skull fracture	59 (11.6)
Cerebral contusion	39 (7.7)
Parenchymal hematoma	36 (7.1)
Epidural hematoma	25 (4.9)
Infarction (other than lacunar infarction)	22 (4.3)
Herniation or midline shift	14 (2.8)
Intraventricular hemorrhage	12 (2.4)
Hydrocephalus	6 (1.2)
Diffuse axonal injury	3 (0.6)
Pneumocephalus	2 (0.4)
Any mass lesion (other than intracranial hematoma)	1 (0.2)
Total	376 (73.9)
Insignificant abnormalities	
Microvascular disease	63 (12.4)
Facial bone fracture	24 (4.7)
Cerebral atrophy	21 (4.1)
Previous craniotomy/benign bone lesion	10 (2.0)
Nonphysiologic calcification	4 (0.8)
Other abnormality	11 (2.2)
Total	133 (26.1)

Table 2. Discordance between neuroradiologist and radiology residents in interpretation of cranial CT scans based on a lesion-by-lesion basis for transverse and three-dimensional images

	Transverse images	Three-dimensional images
Neuroradiologist and resident (first year)	99 (20.2)[a]	86 (16.9)[b]
Significant abnormality	64 (13.0)	55 (10.8)
Insignificant abnormality	35 (7.1)	31 (6.1)
Neuroradiologist and resident (second year)	56 (11.4)	45 (8.8)
Significant abnormality	39 (7.9)	32 (6.3)
Insignificant abnormality	17 (3.5)	13 (2.6)
Neuroradiologist and resident (third year)	66 (13.4)	54 (10.6)
Significant abnormality	50 (10.2)	40 (7.9)
Insignificant abnormality	16 (3.3)	14 (2.8)

[a]Significantly higher than second year and third year residents ($P = 0.0003$, Chi-square test).
[b]Significantly higher than second year and third year residents ($P = 0.0002$, Chi-square test).
Data are the number of lesions (%).

was graded as excellent (score 5); images in only seven patients (3.2%) were of good (score 4, n=3) or satisfactory (score 3, n=4) quality. Only one case (0.5%) was graded as nondiagnostic image quality (score 1), and was excluded.

Abnormalities detected on CT

Among the 218 cranial CT scans, 29 (13.3%) were considered normal, based on the 3D CT interpretation of neuroradiologists; the remaining 189 (86.7%) were abnormal. In total, 509 lesions in 189 abnormal CT scans were detected by the neuroradiologists' interpretation; 376 were significant abnormalities and 133 were insignificant according to the predetermined criteria. The most common abnormalities were subdural hematoma (n=88), subarachnoid hemorrhage (n=69), and skull fracture (n=59; Table 1).

Overall, the disagreement rate between transverse and 3D images was 4.7% for neuroradiologists on a lesion-by lesion basis. Neuroradiologists missed 21 significant abnormalities on transverse images: 14 skull fractures, three cerebral contusions, two subarachnoid hemorrhages, one parenchymal hematoma, and one hydrocephalus. In contrast, they overdiagnosed three insignificant abnormalities (three facial bone fractures) on transverse images.

Discordance between residents and neuroradiologists

The discordance rate between the three residents and neuroradiologists was 11.4%–20.2% (mean, 15.0%) in interpretation of transverse images. When combined 3D images were assessed, the discordance rate decreased in all residents to 8.8%–16.9% (mean, 12.1%). If only the discordances in interpretations of significant abnormalities were evaluated, the discordance rates between the three residents and neuroradiologists was 7.9%–13.0% (mean, 10.4%) and 6.3%–10.8% (mean, 8.3%) in the interpretation of transverse and 3D images, respectively (Table 2). The level of residency training affected discordance rates significantly with both transverse ($P = 0.0003$) and 3D images ($P = 0.0002$); the first year resident had higher rates of discordance than the second year and third year residents.

With respect to the discordant lesions, further subdivisions into significant or insignificant abnormalities and false-negative, false-positive, or misinterpreted results are shown in Table 3. The most common discrepant misin-

Table 3. Discordance between a neuroradiologist and radiology residents for transverse and three-dimensional images

	Discordance							
	Transverse images				Three-dimensional images			
	Number (reported by NR)	R1 vs. NR	R2 vs. NR	R3 vs. NR	Number (reported by NR)	R1 vs. NR	R2 vs. NR	R3 vs. NR
Significant abnormalities								
Subdural hematoma	88	8	4	4	88	6	1	4
Subarachnoid hemorrhage	67	11	2	1	69	11	2	2
Skull fracture	45	4	5	3	59	3	3	2
Cerebral contusion	36	15	14	12	39	12	13	14
Parenchymal hematoma	35	5	5	5	36	3	2	4
Infarction (other than lacunar infarction)	22	7	2	3	22	7	4	3
Epidural hematoma	25	7	3	12	25	5	2	4
Herniation or midline shift	14	2	2	2	14	2	2	2
Intraventricular hemorrhage	12	2	1	1	12	3	2	2
Hydrocephalus	5	1	0	2	6	1	0	1
Diffuse axonal injury	3	2	1	2	3	2	1	2
Pneumocephalus	2	0	0	1	2	0	0	0
Any mass lesion	1	0	0	1	1	0	0	0
Total	355	64	39	50	376	55	32	40
Insignificant abnormalities								
Microvascular disease	63	12	1	1	63	10	1	0
Facial bone fracture	27	11	7	9	24	9	5	9
Cerebral atrophy	21	5	3	1	21	5	3	0
Previous craniotomy/benign bone lesion	10	2	2	2	10	2	0	2
Nonphysiologic calcification	4	1	0	2	4	1	0	2
Other abnormality	11	4	4	1	11	4	4	1
Total	136	35	17	16	133	31	13	14
	Discordance type							
	Transverse images				Three-dimensional images			
	FN	FP	MIS	Total	FN	FP	MIS	Total
NR and R1	85	1	13	99	70	1	15	86
NR and R2	41	3	12	56	34	1	10	45
NR and R3	42	5	19	66	31	4	19	54

NR, neuroradiologist; R1, first year resident; R2, second year resident; R3, third year resident; FN, false negative (findings missed by the resident as compared with the neuroradiologist's reading); FP, false-positive (findings reported by the resident that were not reported by the neuroradiologist); MIS, misinterpretation (although recognized as abnormal, diagnosis of the resident was not the same as that of the neuroradiologist).
Data are given as the number of lesions.

terpretations were cerebral contusions. Representative cases are demonstrated in Figs. 1–3.

Confidence and added value scores

In patients with abnormalities, all readers' confidence scores for individual lesions on 3D images (mean confidence score, 4.79) were greater than those on transverse images (mean confidence score, 4.70), although these differences did not reach statistical significance for the residents. In contrast, in patients without abnormalities, confidence scores for the diagnosis of a normal cranial CT were identical between the transverse and 3D images (Table 4).

The added value scores of 3D images compared with transverse images were 3.48–4.06 (mean, 3.75) for the residents and 3.39 for the neuroradiologist (Table 4). There were significant differences in the added value scores of 3D images among the four readers.

Differences in interpretation time

There was a significant difference in interpretation time between the two image sets for each reader. The inter-

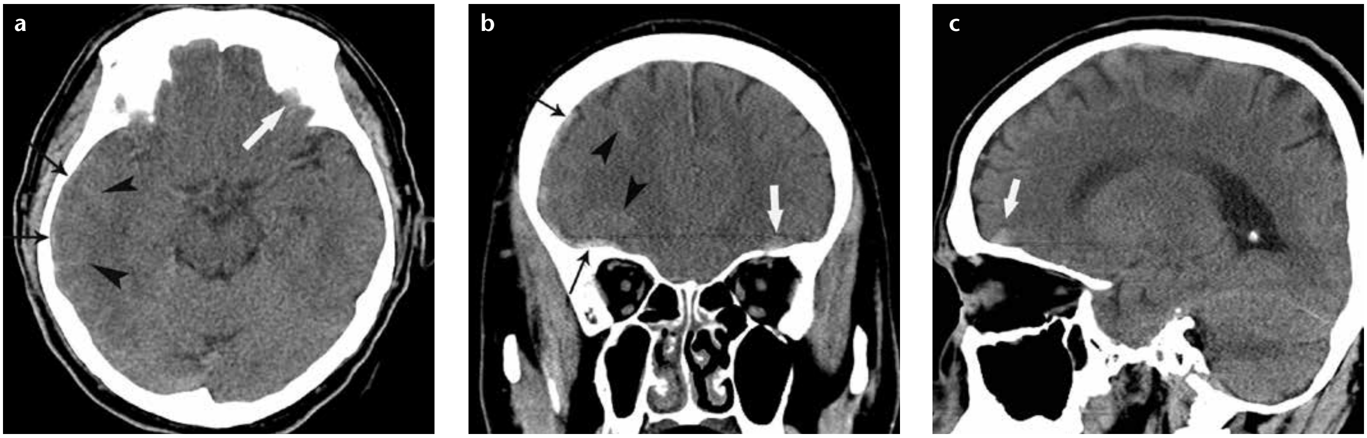

Figure 1. a–c. A 48-year-old male with head trauma. Unenhanced transverse CT image **(a)** shows a small right subdural hematoma *(black arrows)* that was identified only by the neuroradiologist (missed by all three radiology residents), and a questionable contusion in the left inferior frontal lobe *(white arrow)* that was missed by all four readers. Coronal **(b)** and sagittal **(c)** reformatted images show a small right subdural hematoma (**b**, *black arrows*) and a small left inferior frontal lobe contusion (**b, c,** *white arrows*), which were identified by all four readers. Additionally, there is a right temporoparietal subarachnoid hemorrhage (**a, b,** *arrowheads*), which was identified by all four readers.

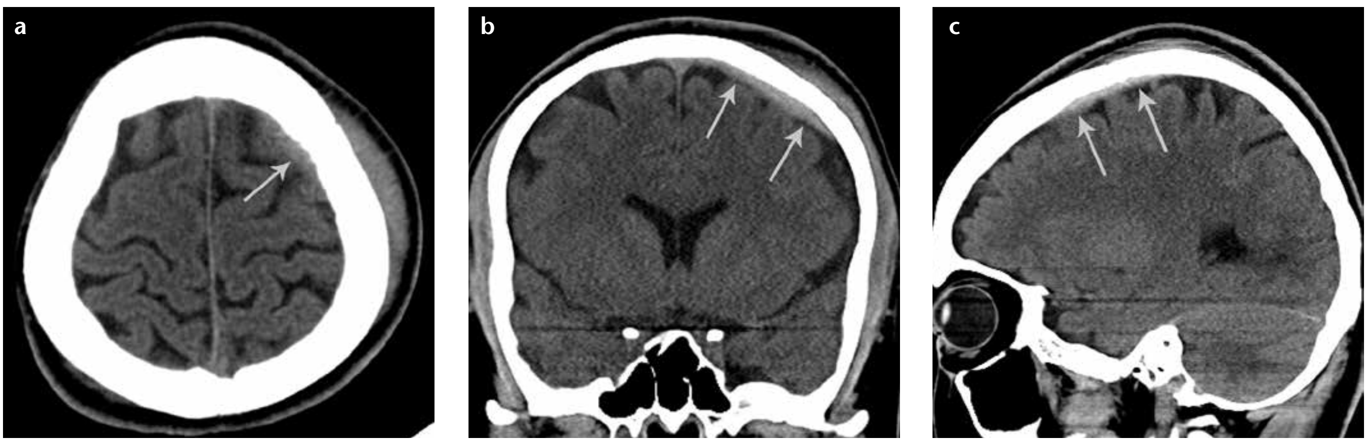

Figure 2. a–c. A 28-year-old female with head trauma. Unenhanced transverse CT image **(a)** shows a thin left epidural hematoma *(arrow)* that was correctly diagnosed by the neuroradiologist and a radiology resident (missed by two residents). On coronal **(b)** and sagittal **(c)** reformatted images, all four readers identified a left epidural hematoma *(arrows)*.

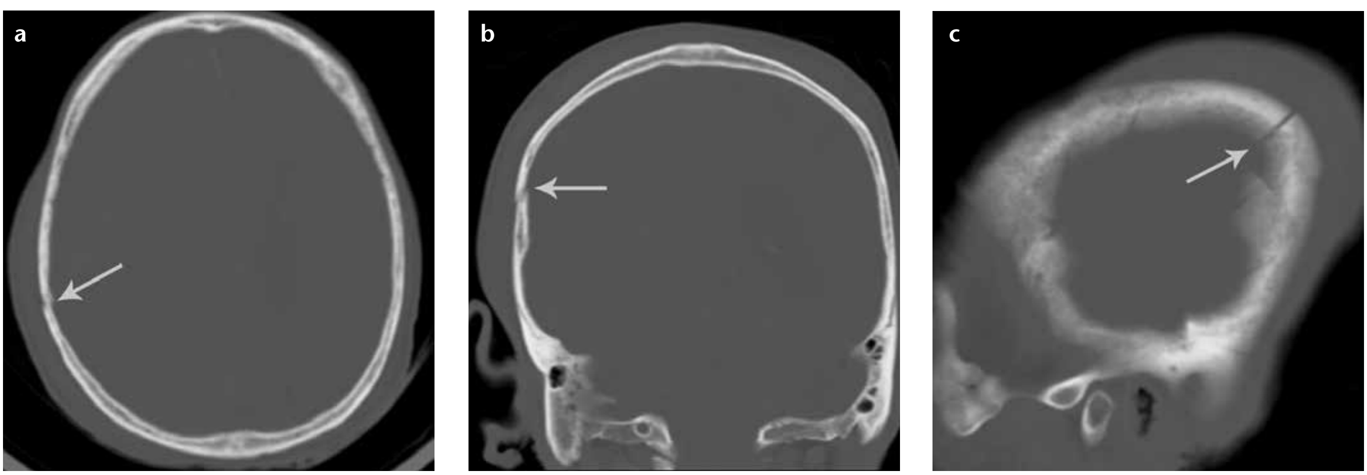

Figure 3. a–c. An 82-year-old male with head trauma. Unenhanced transverse CT image with a bone window setting **(a)** shows a fracture line *(arrow)* in the right parietal region. The neuroradiologist and a radiology resident identified a fracture in the transverse plane (missed by two residents). Coronal **(b)** and sagittal **(c)** reformatted images clearly show a linear fracture *(arrows)* through the right parietal bone, which was identified by all four readers.

pretation time for combined 3D images was 1.01–1.52 min longer than that required for transverse images alone (Table 4).

Discussion

In the present study, we examined the discordance rates between radiology residents' and neuroradiologist's interpretations of both transverse and 3D images of emergency cranial CT scans. The results showed that the mean percentage of significant discordance was 15.0% on a lesion-by-lesion basis for transverse images.

Several previous studies have documented discordance rates between neuroradiologists and other readers (e.g., radiology residents, 2.1%–8.3%; radiology fellows, 2.6%; general radiologists, 1.3%–5.8%; and emergency physicians, 7.2%–28.3%) in interpretation of cranial CT (2–4, 7–12). Interestingly, the reported discordance rates for emergency physicians (7–9) were higher than those reported for radiology trainees (2–4, 10).

The design and methodology of these studies vary considerably in several ways, making direct comparisons between the published reports and the present study difficult. First, the various rates of discordance may be due, in part, to the varying prevalence of CT abnormalities. Several studies have reported that the proportion of abnormal studies influences concordance, because the discordant rate for abnormal studies is higher than for normal studies (3, 13). The proportion of abnormal scans in our series (86.7%) was markedly higher than the 35%–42% rate of positive findings described in previous studies (2–4). Second, the methodology for calculating the discordance rate differed between previous studies and ours. In previous studies, patients were categorized as discordant if there was a single discordance between the radiology resident and neuroradiologist, even if other parts of the study were correctly interpreted by the resident. We used the lesion as the unit of data analysis in this study, because lesion-by-lesion analysis is a more reliable method than patient-by-patient analysis in comparisons of CT interpretations. Third, the reviewers in our study were blinded to patient clinical information. In the routine clinical setting, however, the radiologists would not be blinded to patient clinical data but would be aware of the results obtained from any other diagnostic examinations (e.g., plain radiographs). The lack of this information may have disadvantaged our study subjects, resulting in a poorer performance. Finally, the definitions of significant (or major) and insignificant (or minor) discordance in the published literature are variable. These factors can lead to differences in discordant rates among studies, even with similar reader performance.

Usually, brain CT images are acquired and viewed in the transverse plane. However, traditionally displayed transverse CT images may not be ideally suited for the evaluation of small lesions in the posterior fossa, middle cranial fossa, inferior frontal lobes, or vertex area due to beam-hardening artifacts and partial volume effects from adjacent osseous structures (14). The limitations of transverse images for evaluating these areas are of concern, because these are precisely the locations that are at higher risk for injury in head trauma (15). In such cases, 3D reformatted images provide a more inclusive representation of abnormalities as well as help to display the surrounding structures more clearly by allowing the integration of information in multiple viewing planes. With technological advances in multi-detector row CT, it is now possible to provide improved image quality of 3D reformations with isotropic voxels and high *z*-axis resolution (16). Two recent studies have shown the value of 3D reformations in the interpretation of cranial CT studies. Wei et al. (5) demonstrated that coronal reformation improved the detection of traumatic intracranial hemorrhage over transverse images in 15 (14.4%) of 104 hemorrhages. Similarly, Zacharia and Nguyen (6) investigated the advantages of coronal and sagittal reformations obtained with CT in patients with acute head trauma. They reported that coronal and sagittal reformations confirmed subtle findings, which were undetected initially on transverse images in 10 (18.2%) of 55 cases with acute traumatic intracranial abnormalities. Our results also showed that the discordance rates between radiology residents and neuroradiologists were consistently lower for combined 3D images than for transverse images alone.

In this series, ~70% of the discordances were related to false-negative (resident miss) findings rather than to false-positive (resident overdiagnosis) findings or misinterpretation of identified abnormalities. This result is consistent with prior studies showing false-negative detection errors occur more often than false-positive detection errors. This finding, in part, may be due to the limited scope of the cranial abnormalities in patients referred from the emergency department.An additional advantage of the 3D images is that the additional imaging planes increase specificity by enabling more confident evaluation of questionable findings detected on transverse images. In our patients, the confidence scores of the four readers on 3D images were higher than those on transverse images alone. Previous studies have also shown the efficacy of combined multiplanar reformations in improving reader confidence for the diagnosis or exclusion of specific conditions (17–19).

In our study, abnormalities were somewhat or definitely better seen on 3D images versus transverse images (score 4 or 5) in most lesions. Additionally, the less experience the reader had with cranial CT, the higher the added value score was: the first-year resident benefitted most from the 3D images (Table 4). Based on these results, we suggest that 3D images may be more helpful to less-experienced than experienced readers in interpreting cranial CT studies. This may be because 3D images appear to be more descriptive and provide a more intuitive perspective on the orientation of normal or pathological structures, particularly to readers with less imaging experience.

The main drawback of 3D reformations is the increased number of images necessary to review and the increase in interpretation time for the readers. Our results showed that all readers took significantly longer to read 3D images than transverse images; the time difference, however, was only 1.0–1.5 min. This may be attributed to more rapid comprehension of the

Table 4. Comparison of confidence scores for the detection of cranial CT abnormality, interpretation time required for cranial CT, and added value scores of three-dimensional images between readers

	Confidence score[a]		
	Transverse images	Three-dimensional images	P
Normal scan			
Resident (first year)	1.00±0.00	1.00±0.00	1.000
Resident (second year)	1.11±0.33	1.11±0.33	1.000
Resident (third year)	1.00±0.00	1.00±0.00	1.000
Neuroradiologist	1.10±0.31	1.10±0.30	0.965
Abnormal scan			
Resident (first year)	4.55±0.56	4.71±0.55	0.092
Resident (second year)	4.74±0.53	4.76±0.50	0.327
Resident (third year)	4.68±0.52	4.72±0.47	0.246
Neuroradiologist	4.81±0.44	4.96±0.19	< 0.001
	Added value score[b,c]		
Resident (first year)	4.06±0.82		
Resident (second year)	3.71±0.89		
Resident (third year)	3.48±0.68		
Neuroradiologist	3.39±0.67		
	Interpretation time (min)		
	Transverse images	Three-dimensional images	P
Resident (first year)	8.12±3.34	9.52±3.66	0.003
Resident (second year)	4.73±1.92	5.74±2.42	0.002
Resident (third year)	4.99±1.59	6.51±1.99	< 0.001
Neuroradiologist	4.68±1.16	5.96±1.52	< 0.001

[a]Confidence score: 1, definitely absent; 2, probably absent; 3, equivocal; 4, probably present; 5, definitely present.
[b]Ability score: 1, abnormality definitely less well seen on reformatted images; 2, abnormality somewhat less well seen on reformatted images; 3, no difference in abnormality visualization; 4, abnormality somewhat better seen on reformatted images; 5, abnormality definitely better seen on reformatted images.
[c]Statistically significant difference between four readers (one-way analysis of variance, $P < 0.001$).
Data are given as the mean±standard deviation.

3D configuration using the multiplanar reformations. Additionally, the radiologists were able to scroll quickly through 3D images at a workstation and concentrate on abnormalities, using cross-reference lines, on 3D images after detecting abnormal areas on transverse images.

Because 3D reformations can be simply and rapidly constructed from CT data acquisitions and provide significant benefit for interpretation of these studies, they are now routinely used in cranial CT examinations at our institution. Fortunately, our 256 multidetector row CT and upgraded software allow automatic reformations in any preselected plane to be performed within 2 min at the end of the examination. In our clinical practice, the 3D images are sent directly to the PACS and appear as a separate series for interpretation.There were several potential limitations to the present study. First, our primary outcome was discordant interpretations between radiology residents and a neuroradiologist, not accuracy. Thus, it is possible that the interpretation of the neuroradiologists was incorrect in cases in which discordance arose. Second, because this study included a limited number of CT readers arbitrarily selected from a single institution, the findings of this study may be institution-dependent and not generalizable. Furthermore, the study examined only patients from the emergency department. Future prospective studies are needed to replicate our results and address the advantages of 3D reformations in cranial CT interpretation.

In conclusion, the use of 3D reformations can improve diagnostic performance and reader confidence in radiology residents in the evaluation of emergency cranial CT.

Conflict of interest disclosure

The authors declared no conflicts of interest.

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