Image Quality of Multisection CT of the Brain: Thickly Collimated Sequential Scanning versus Thinly Collimated Spiral Scanning with Image Combining

**BACKGROUND AND PURPOSE:** Routine CT of the brain is traditionally performed with sequential CT. We assessed whether sequential CT can be replaced with thinly collimated multisection spiral CT without loss of image quality.

**MATERIALS AND METHODS:** An observer study was conducted using data from 23 patients who were scanned with both a sequential (collimation, $4 \times 5 \text{ mm}$) and a spiral technique (collimation, $4 \times 1 \text{ mm}$; pitch, 0.875). Each sequential image was registered with 4 combined spiral CT images at 1.2 mm distance. Two neuroradiologists blindly scored 232 image pairs on 6 aspects: streak artifacts, visualization of brain tissue near skull, visualization of hypoattenuated lesions, gray/white matter differentiation, image noise, and overall image quality. A 5-point scale (range, −2 to 2) was used to score the preferences. The 23 pairs of complete scans were scored likewise. In this case, no registration was performed.

**RESULTS:** Virtually all mean scores were positive (ie, showed a preference for the spiral technique). For the comparison of image pairs, the preferences with respect to streak artifacts (mean score, 1.36), visualization of brain tissue near the skull (mean score, 0.69), and overall image quality (mean score, 0.95) were significant ($P < .001$). With respect to visualization of hypoattenuated lesions, image noise, and gray/white matter differentiation (mean scores, 0.18, 0.27, and 0.13), the preferences for spiral CT were not significant. The preferences for the spiral technique were also present at the comparison of the complete scans.

**CONCLUSION:** Thinly collimated multisection spiral CT of the brain with image combining is superior to thickly collimated sequential CT.

**Materials and Methods**

**CT Scans**

Nonenhanced brain CT scans, both sequential CT and spiral CT, were made of 24 consecutive patients. The patients’ physicians requested...
The continuous line depicts the profile of 4 combined spiral mode images with an increment of 1.2 mm (positions of each image given by asterisks on the z-axis).
techniques. Because these artifacts could possibly introduce a bias when scoring other aspects of the image quality, individual image pairs were compared first. This way, the blindness of the study was preserved for image pairs without the above-mentioned artifacts. An advantage of the comparison of a large number of image pairs is that the differences between the 2 scan techniques could be assessed more sensitively. In the second part of the observer study, complete sequential and spiral CT scans were compared to more closely mimic the normal diagnostic situation.

Two neuroradiologists independently judged the images in a blinded fashion. Patient data and scan parameters were removed from all images. The images were displayed on a digital PACS system (Agfa-Gevaert, Mortsel, Belgium) with a window center of 30 HU and a window width of 70 HU.

For the first part of the observer study, the images from all patients were divided into 3 groups. The first group contained the images from all patients from the middle region of the brain, where no clear systematic information was present that could be used to distinguish sequential from spiral images. The second and third group contained images from all patients above and below this region, respectively. To reduce the total number of images to be scored, only even image numbers were used. The sequential image and the corresponding spiral image were paired and labeled A or B at random. All image pairs within each group were presented in a random order. The order of the groups, described above, was also the order in which the observers scored the image pairs.

The observers compared each image pair on 6 aspects: streak artifacts, visualization of brain tissue near skull, visualization of hypoattenuated lesion(s), gray/white matter differentiation, image noise, and overall image quality. The aspect “visualization of brain tissue near skull” refers to the depiction of intracranial tissue or fluid up to a distance of approximately 1 cm from the skull. Other studies have already shown that the image quality may be compromised when using thickly collimated CT for imaging the skull base and posterior fossa. An adequate visualization of tissue or fluid adjacent to the calvaria is also important, for example, when the presence of small extra-axial fluid collections, cortical infarcts or hematomas, or subarachnoid hemorrhage has to be confirmed or ruled out. With respect to the “visualization of hypoattenuated lesion(s),” the observers had to judge the visualization of small lesions (ie, lesions with dimensions on the order of ≤ 1 cm), including lacunar infarcts.

For each aspect, a score on a 5-point scale had to be given: preference for image A, slight preference for image A, no preference, slight preference for image B, and preference for image B. For streak artifacts, gray/white matter differentiation, and visualization of hypoattenuated lesion(s), the observers had the additional option “not applicable.”

In the second part, complete sequential and spiral studies were compared. No image registration was performed. For each sequential image, the 4 closest spiral images with an in-between distance of 1.2 mm were averaged (Fig 1). The CT values of the spiral images were shifted as described previously (see image processing above).

The 2 scans from each patient were labeled at random A and B. The same aspects on the 5-point scale were scored as in the first part of the observer study.

Statistical Analysis
The scores on the 5-point scale were converted into preferences for the sequential or the spiral technique: −2, preference for the sequential technique; −1, slight preference for the sequential technique; 0, no preference; +1, slight preference for the spiral technique; +2, preference for the spiral technique.

For both observers and both studies the mean score for each aspect was calculated. The statistical significance (P < .05) of the difference between sequential CT and spiral CT was determined with a paired Wilcoxon signed-rank test. As multiple tests were executed, the observed P values were corrected by the Bonferroni method.

For each aspect in both studies, the interobserver agreement was calculated. For this calculation, the categories preference and slight preference were merged. The observations for which at least one observer had chosen the option not applicable were excluded. At first, the κ value was determined to measure the observer agreement. However, some κ values seemed to be exceedingly low despite an apparently good observer agreement. This was due to the distribution of data across the 3 (merged) categories. Therefore, a prevalence- and bias-adjusted κ value (PABAK) was also determined.

The guidelines from Landis and Koch for the qualification of the strength of agreement indicated with κ values were used.

Results
First Part of the Observer Study
In total, 232 image pairs were scored on 6 image quality aspects by 2 observers. In Table 2, the scores are given. For all aspects, the mean score was positive, showing a preference of the observers for the spiral technique. The preferences with respect to streak artifacts, visualization of brain tissue near skull, image noise (for observer 2), and overall image quality were statistically significant.

To detect a possible influence of the gantry tilt on the image quality, we divided the patients into 2 groups. The first group, containing 8 patients, had a mean gantry tilt of 5.9° (range, 0.0–10.5). The second group, containing 15 patients, had a mean gantry tilt of 14.6° (range, 12.0–18.0). No significant difference was present between the mean score for the overall image quality in both groups (0.58 and 0.62, respectively). For the individual aspects, the mean scores also did not differ significantly between the 2 groups.

The largest differences between the 2 scan techniques were found with respect to streak artifacts (mean score, 1.35), visualization of brain tissue near the skull (mean score, 0.68), and overall image quality (mean score, 0.61). In Fig 2, 2 images are shown of the skull base. The sequential image in Fig 2A shows streak artifacts. In this case both observers had a preference for the spiral image in Fig 2B. The CT values of the brain tissue were often slightly increased on the sequential images, especially near the skull in the region of the upper cranium, as shown in Fig 3. With regard to the visualization of brain tissue near the skull, both observers had a preference for the spiral technique (Fig 3B).

With respect to the “overall image quality,” it seemed that a particular score in this category correlated strongly with some specific aspects of image quality. Figure 4 shows an example in which both observers had a slight preference for the spiral image. The spiral image was also slightly preferred by both observers with regard to the visualization of brain tissue near the skull and image noise. No preference for the gray/white matter differentiation was present in this case.

The mean scores for the aspects visualization of hypoattenuated lesions, gray/white matter differentiation, and image
noise were relatively close to zero (0.18, 0.13, and 0.27, respectively).

**Second Part of the Observer Study**

In Table 3, the scores of both observers for the second part of the observer study are given. Again, the mean score was positive for all aspects, showing a preference for the spiral technique (except for observer 1 with respect to image noise). The preferences with respect to streak artifacts, visualization of brain tissue near skull, gray/white matter differentiation (for observer 2), image noise (for observer 2), and overall image quality were statistically significant.

**Interobserver Agreement**

In Table 4 the interobserver agreement is given for the first part of the study (columns 2–4) and the second part of the study (columns 5–7). For the judgment of the amount of agreement, the PABAK values were used, if available. In the
first part of the study, the agreement with respect to the streak artifacts and the visualization of brain tissue near the skull was almost perfect and moderate, respectively. With respect to the overall image quality, there was fair agreement. With respect to the visualization of hypoattenuated lesions and image noise, there was slight agreement. With respect to gray/white matter differentiation, there was no more agreement between the observers than could be expected based on chance.

The observer agreement in the second part of the study was (almost) perfect with respect to the streak artifacts, the visualization of brain tissue near the skull, and the overall image quality. With respect to the visualization of hypoattenuated lesions, there was slight agreement. For the remaining aspects, gray/white matter differentiation and image noise, no meaningful PABAK value could be determined (Table 4).

Discussion

Observer Study

Two observers compared in a blinded fashion the image quality of sequential CT images (with a section thickness of 4.6 mm) with the image quality of thinly collimated spiral CT images, which were combined to obtain approximately the same section thickness. With respect to nearly all aspects of the
image quality, both observers had a preference for the spiral technique. For the other aspects, no statistical significant differences between the techniques were present.

The preference for the spiral technique was most clear with regard to the absence of the streak artifacts, the better visualization of the brain tissue near the skull, and the better overall image quality. Images made with the sequential technique often showed severe partial volume artifacts in the skull base. These artifacts were caused by attenuated bone structures that are only partly present in the section that is imaged. When the collimation was reduced from 5 mm at sequential CT to 1 mm at spiral CT, these partial volume artifacts were reduced considerably. The reduction of partial volume artifacts in the skull base with reduction of section thickness was also found in earlier studies, both for thinly collimated spiral and sequential CT.

We did not find the artifacts in the brain tissue at the edges of the bones that were present in the spiral images in the study of Bahner and colleagues. These artifacts were probably due to the relatively large section thickness of 8 mm used in that study, which can be expected to result in relatively large artifacts at bone edges due to the interpolation that is used in spiral CT. In our study, the effective section thickness was substantially smaller (1.3 mm). This reduces these artifacts considerably. Therefore, these artifacts were not present in the spiral CT images in the present study (Figs 3B and 4B).

The suboptimal visualization of brain tissue due to the increase of the mean CT value of the brain tissue near the top of the skull in standard sequential CT (Fig 3A) is a finding that, to our knowledge, has not been reported before. This increase of the CT values could possibly be ascribed to averaging of brain and skull in the relatively thick sections of sequential CT. However, a comparison with the combined, thinly collimated spiral CT images, which have a virtually identical section sensitivity profile, shows that this is not the case. The phenomenon can neither be explained by an incomplete correction of beam-hardening, because the same beam-hardening correction has been applied for both techniques, and the artifact appears only in the sequential technique. In our opinion, the artifact was caused by the partial volume effect, which also causes the streak artifacts in the skull base. In the upper part of the brain, it is caused by the slant angle of the bone relative to the scan plane. Because of the approximate circular symmetry of the skull, these artifacts show up as a general increase of the CT values of the brain tissue and not as streak artifacts, as in the skull base.

There was only a slight preference for the spiral technique with respect to image noise, gray/white matter differentiation, and visualization of hypointenueated lesions. The observer agreement for these aspects was relatively low. This can be explained by the subleness of the differences between the techniques.

Before the comparison of the images, we registered the spiral scan with the sequential scan. This way, corresponding images depict identical anatomic structures, which has the advantage of a more accurate comparison. In some cases, small amounts of mismatch were present that might be caused by a slight motion of the patient during data acquisition. In particular, the appearance of small hypointenuated lesions could be sensitive for these small mismatches. However, the quality of the match appeared satisfactory. Even if a slight amount of mismatch had been present in individual cases, no systematic bias would have been introduced.

In general, the outcomes of the comparisons of the complete scans were in good agreement with the outcomes of the comparisons of the individual images. For the complete scans, the judgment of the overall image quality of the sequential technique might be influenced by the streak artifacts in the skull base and hyperattenuated brain tissue near the skull in the upper cranium. This was not the case in the comparison of image pairs without these artifacts. This may explain the less strong overall preference for spiral CT in the first part of the observer study and the better observer agreement in the second part of the study with respect to the visualization of brain tissue near the skull and the overall image quality.

Clinical Relevance

With the CT scanner used in this study, the mean scan time of a thinly collimated spiral CT scan of the brain was 30 seconds, approximately 2 times longer than the mean scan time of a thickly collimated sequential CT scan. A minor disadvantage of this relatively long scan time is the increase of the risk of motion of the patient during data acquisition. In this study, at least 1 patient had moved during acquisition of the spiral scan, which affected the image quality and caused the observers to have a preference for the sequential technique. With the recent introduction of CT scanners with 16 to 64 detector arrays, this potential drawback will disappear because of the vastly reduced scan time.

Another potential drawback of thinly collimated spiral CT is the larger reconstruction time. Because of the relatively small reconstruction increment of the spiral scans, approximately 10 times more images are reconstructed. On our CT scanner, this resulted in an increase of the reconstruction time of approximately 4 minutes. With state-of-the-art CT scanners, which have a higher reconstruction speed, the additional reconstruction time will be negligible.

We used the same effective mAs value for the spiral scan and the sequential scan. By doing so, the amount of radiation used for both scans was the same. Consequently, the subjective noise level of the sequential and spiral scan was approximately equal. However, the geometric efficiency of the spiral technique, with a relatively narrow total beam collimation of 4 mm (4 × 1 mm), is worse than the efficiency of the broader beam collimation of the sequential technique of 20 mm (4 × 5 mm). This resulted in an increase of the effective dose of approximately 35% when using the spiral technique instead of the sequential technique for the CT scanner used in this study. Because the geometric efficiency improves when the total beam collimation increases, this disadvantage of thinly collimated spiral CT becomes insignificant when CT scanners with 16 or more thin detector arrays are used. The Mx8000 IDT 16-section CT scanner (Philips Medical Systems), for example, is identical to the scanner used in this study except for the number of sections. Scanning with this scanner with a beam collimation of 12 mm (16 × 0.75 mm) will result in an increase of the effective dose of only 11% compared with the sequential technique used in our study. If a beam collimation of 24 mm (16 × 1.5 mm) is used, the effective dose is the same (1.1 mSv) as that of the sequential technique.
When replacing the sequential technique with the spiral technique, the effects on the cost of the examination should also be considered. It is unlikely that the increased scanning time and reconstruction time will lead to an increase of the costs of the examination, as the additional time for the scanning and reconstruction is relatively small compared with the total time allocated for the examination. After (automatic) image combining, the number of images to be judged by the radiologist is equal to the number of images of the sequential scan technique. Therefore, no additional costs are expected.

Although in the present study it was not attempted to judge whether the use of thinly collimated spiral CT would have resulted in another diagnostic outcome, we think that this possibly could be the case. With respect to the depiction of small subdural or epidural hematomas, for example, which were present or had to be ruled out in 3 patients in this study, the improved visualization of spiral CT could lead to a more accurate diagnosis. No differences were found in the present study with respect to the visualization of small hypoattenuated lesions, for instance lacunar infarcts, which were present in 7 of 23 patients in this study.

A clear advantage of thinly collimated spiral CT is the high spatial resolution in the longitudinal direction of the patient. This allows for high quality multiplanar reformation (MPR) in all desired planes. Moreover, the high spatial resolution in all directions paves the way for the application of image processing techniques such as the registration of multiple scans. Registration of 2 or more CT scans of the same patient made at different moments will improve the visualization of the differences of anatomy or pathology between these moments, for example by making subtractions of the scans. Scans of hydrocephalus patients, for example, can be registered to determine the changes in the volume of the ventricles. Another possibility is the registration of CT scans of a patient with a brain tumor to visualize and quantify the course of the disease process. Differences will then no longer be obscured by variations in the depiction of the anatomy due to differences in the orientation of the patient’s head in the CT scanner.

**Conclusion**

The image quality of thinly collimated spiral CT of the brain with image combining is at least as good as that of thickly collimated sequential CT and, in some aspects, better. The better visualization of brain tissue near the skull in the calvaria, and the improved overall image quality are new findings of this study. The reduction of image artifacts in the skull base obtained with the thinly collimated spiral technique is a confirmation of earlier studies.

We conclude that, generally speaking, imaging of the brain should be performed with a thinly collimated spiral technique. For relatively old CT scanners, like the 4-section CT scanner used in this study, the slight increase in radiation dose and longer scan time are the only drawbacks of this technique. For state-of-the-art scanners, these disadvantages are absent.

**References**

15. Landis JR, Koch GG. The measurement of observer agreement for categorical data. *Biometrics* 1977;33:159–74