Radiation Dose Reduction in Paranasal Sinus CT: With Feasibility of Iterative Reconstruction Technique

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Abstract

Objectives. To (1) compare the radiation dose of low-dose computed tomography (CT) to that of standard-dose CT, (2) determine the minimum optimal radiation dose for use in patients who need endoscopic sinus surgery, and (3) assess the reliability of iterative model reconstruction.

Study Design. Prospective single-institution study.

Setting. Tertiary care center.

Subjects and Methods. We recruited 48 adults with medically refractory sinusitis. Each patient underwent 4 scans with different CT parameters: 120 kV and 100 mAs (standard dose), 100 kV and 40 mAs (low dose), 100 kV and 20 mAs (very low dose), and 100 kV and 10 mAs (ultra-low dose). All CT scans were reconstructed via filtered back-projection, and ultra-low dose scans were additionally reconstructed through iterative model reconstruction. Radiation dose, image quality, and diagnostic performance were compared among the scans.

Results. Radiation doses decreased to 6% (ultra-low dose), 12% (very low dose), and 22% (low dose) of the standard-dose CT. The image quality of low-dose CT was similar to that of standard-dose CT. Ultra-low dose CT with iterative model reconstruction was inferior to standard-dose CT for identifying anatomic structures, except for the optic nerve. All CT scans had 100% agreement for diagnosing rhinosinusitis.

Conclusions. With low-dose CT, the radiation dose can be decreased to 22% of that of standard-dose CT without affecting the image quality. Low-dose CT can be considered the minimum optimal radiation for patients who need surgery. Iterative model reconstruction is not useful for assessing the anatomic details of the paranasal sinus on CT.

Keywords
radiation dose, paranasal sinus, iterative reconstruction, computed tomography, low-dose CT

Computed tomography (CT) is the gold standard for diagnosing inflammatory sinus disease, and it has become a routine radiologic examination. In addition, CT serves as a guide for identifying paranasal sinus anatomy when endoscopic surgery is being considered. Functional endoscopic sinus surgery has become the standard technique for treating medically refractory sinusitis. Recently, endoscopic approaches have gained popularity for treating many other sinonasal disorders.

Although CT is a relatively efficient diagnostic procedure, repeated examinations expose patients to high doses of radiation. Radiation exposure to the eyes, which are included in the scanning field of paranasal sinus CT, may cause opacification of the lens and radiation-induced cataract. Additionally, since the maximum image quality may not be critical to therapeutic decisionmaking in rhinosinusitis, great efforts have been made to decrease the radiation dose.

Several previous studies have reported on decreasing the radiation dose of paranasal sinus CT and the effect of dose reduction on image quality. Effects of adjusting the CT parameters, such as maximum tube current, tube potential, and pitch, have been studied; in particular, that of a lower tube current. Recently introduced iterative reconstruction algorithms are being considered, as they can decrease the radiation dose and image noise. The most recent
advancement is the knowledge-based iterative model reconstruction algorithm: Iterative Model Reconstruction (IMR; Philips Healthcare, Cleveland, Ohio).9,10

The objectives of this study were to (1) compare the effective radiation dose of low-dose (LD) CT with that of standard-dose CT, (2) determine the minimum optimal radiation dose for use in patients who need surgery, and (3) assess the reliability of ultra-low-dose (ULD) CT + IMR in patients with clinically suspected sinonasal disease.

Methods
This study was approved by the Ulsan University Institutional Review Board. To achieve approval from the board, we explained the additional radiation dose (ie, less than half a dose of a standard-dose [SD] CT) and the possible adverse effects from additional radiation exposure.

Subjects
During a 3-month period from September to December 2013, we prospectively screened 50 adult patients with medically refractory chronic rhinosinusitis at Ulsan University Hospital, Ulsan, Korea. Patients were diagnosed as having medically refractory chronic rhinosinusitis if at least 2 of the following symptoms persisted for at least 12 weeks despite therapy: nasal congestion, facial pain and pressure, and a diminished sense of smell. Patients were recommended to undergo CT before endoscopic sinus surgery. They received an explanation of the study, and all but 2 provided informed consent; hence, 48 patients were included.

CT Protocol
All CT examinations were performed with a 256-slice multidetector CT scanner (Brilliance iCT; Philips Healthcare) in the coronal plane with the patient in the supine position. All participants underwent CT with 3 settings (LD, very-low-dose [VLD], and ULD) immediately after SD CT. The SD CT scan was acquired at a peak tube voltage of 120 kVp and a maximum tube current of 100 mAs. The settings for the 3 low-dose CT scans were as follows: LD, 100 kVp and 40 mAs; VLD, 100 kVp and 20 mAs; and ULD, 100 kVp and 10 mAs. The following remaining scanning parameters were the same for SD and LD CT: detector configuration, 128 × 0.625; section thickness, 2 mm; interval, 2 mm; and rotation time, 0.4 seconds. Filtered back-projection (FBP) was used for reconstruction in SD and all LD CT. For ULD CT, IMR was also used.

Radiation Dose Estimation
We estimated the radiation dose using the dose-length product, an approximation of the total radiation absorbed by the patient during CT. The effective radiation dose of each scan was calculated in millisieverts (mSv) on the basis of the estimated dose-length product reported by the CT scanner, with a conversion factor of 0.0023.11

Image Quality Analysis
We evaluated the image quality of important anatomic structures surrounding the paranasal sinuses in a semiquantitative manner. All CT scans were reviewed by 2 radiologists with 9 and 20 years of experience with head and neck CT imaging (M.B. and S.H.C., respectively) who were blinded to the radiation parameters and types of reconstruction. Image analysis was performed individually, and the window setting was freely adjustable. We defined 6 critical and 5 noncritical anatomic features depending on importance. The critical features were the lamina papyracea, cribriform plate, ethmoid skull base integrity, anterior ethmoid artery location, optic nerve, and internal carotid artery. Noncritical features were the uncinate process, middle turbinate, anterior clinoid process, frontal recess, and septum. Each anatomic feature was assigned a score of 3 if completely visible, 2 if partially visible, and 1 if rarely visible. The total image quality score was defined as the sum of all scores for the critical features (0-18), which was used as a collective index of image quality assessment. We also evaluated the image score for each critical or noncritical feature separately.

To diagnose sinusitis, LD, VLD, and ULD CT ± IMR and SD CT scans were scored according to the Lund-Mackay system. Each side (the maxillary, anterior ethmoid, posterior ethmoid, frontal, and sphenoid sinuses) is assigned a score of 0 for no opacification, 1 for partial opacification, or 2 for total opacification. The ostiomeatal complex is assigned a score of 0 if patent or 2 if obstructed. Therefore, the Lund-Mackay score may range from 0 to 24.

Statistical Analysis
The radiation dose and image quality score are presented as mean ± standard deviation, and these data were compared with the Wilcoxon signed-rank test. SD CT was used as a reference method in all comparisons. Estimation of the sample size was based on our pilot study (n = 10), which demonstrated that the total image quality scores were 17.85 ± 0.34 for LD CT (assuming the best image quality among the LD CT protocols) and 18.00 ± 0.00 for SD CT. The effect size was calculated as 0.452; thus, to achieve a power of at least 80% through the Wilcoxon signed-rank test with a significance level of 0.05, at least 43 participants were needed. The interobserver agreement between the 2 independent radiologists was estimated via κ statistics. Statistical analyses were performed with STATA MP (version 12; StataCorp, College Station, Texas). All statistical tests were 2-sided, and P < .05 was considered significant.

Results
Radiation Dose
Forty-eight patients were evaluated (17 women and 31 men). Patients’ mean age was 43.1 ± 13.2 years. The mean dose-length products were as follows: 14.62 ± 1.02 for ULD CT, 29.23 ± 2.01 for VLD CT, 57.10 ± 3.96 for LD CT, and 239.35 ± 16.63 for SD CT. The effective radiation doses were 0.033 ± 0.002 mSv for ULD CT, 0.067 ± 0.004 mSv for VLD CT, 0.131 ± 0.008 mSv for LD CT, and 0.549 ± 0.049 mSv for SD CT. The effective radiation dose was significantly lower for each LD CT protocol than

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for SD CT (approximately by 6% for ULD CT, 12% for VLD CT, and 22% for LD CT; \( P < .001 \), all).

### Image Quality Analysis

The total image quality scores were as follows: 16.40 ± 0.89 for ULD CT, 17.49 ± 0.83 for ULD + IMR CT, 17.10 ± 0.86 for VLD CT, 17.89 ± 0.33 for LD CT, and 17.91 ± 0.28 for SD CT. ULD, ULD + IMR, and VLD CT had a lower total image quality score (\( P < .001 \)) when compared with SD CT, whereas LD CT did not (\( P = .312 \)).

<table>
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<tr>
<th>CT</th>
<th>LP</th>
<th>( P ) Value</th>
<th>CP</th>
<th>( P ) Value</th>
<th>ESI</th>
<th>( P ) Value</th>
<th>AEA</th>
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<td>ULD</td>
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<td>.302</td>
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<td>.005</td>
<td>2.83 ± 0.36</td>
<td>.003</td>
<td>2.91 ± 0.29</td>
<td>.025</td>
<td>2.92 ± 0.28</td>
<td>.157</td>
<td>3.00 ± 0.00</td>
<td>.317</td>
<td>3.00 ± 0.00</td>
<td>—</td>
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<tr>
<td>VLD</td>
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<td>2.85 ± 0.36</td>
<td>.008</td>
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<td>2.95 ± 0.21</td>
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<td>2.54 ± 0.45</td>
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<tr>
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<td>.988</td>
<td>2.98 ± 0.14</td>
<td>.317</td>
<td>3.00 ± 0.00</td>
<td>—</td>
<td>2.97 ± 0.16</td>
<td>.317</td>
<td>2.97 ± 0.16</td>
<td>.317</td>
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<td>Ref</td>
<td>3.00 ± 0.00</td>
<td>Ref</td>
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<td>3.00 ± 0.00</td>
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Abbreviations: AEA, anterior ethmoid artery; CP, cribriform plate; CT, computed tomography; ESI, ethmoid skull base integrity; ICA, internal carotid artery; IMR, Iterative Model Reconstruction; LD, low dose; LP, laminar papyracea; ON, optic nerve; Ref, reference; SD, standard dose; ULD, ultra-low dose; VLD, very low dose.

*Scores presented as mean ± standard deviation; \( P \) value based on comparison with the standard dose (Wilcoxon signed-rank test).

Table 1 shows the image quality scores for the predefined critical anatomic structures. ULD ± IMR and VLD CT were inferior to SD CT for detecting the laminar papyracea, cribriform plate, and ethmoid skull base integrity, but there was no significant difference between the LD and SD CT scans (Figure 1). ULD CT + IMR was similar or inferior to ULD CT + FBP for detecting cribriform plate, ethmoidal skull base, middle turbinate, anterior clinoid process, and nasal septum (Figure 2). The optic nerve was identified less often through ULD CT with FBP and VLD CT, whereas it was identified at a similar rate with ULD CT +

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**Figure 1.** Coronal computed tomography with filtered back-projection: A, ultra-low dose; B, very low dose; C, low dose; D, standard dose. The left lamina papyracea (arrows) was visible with low dose and standard dose, not very low dose and ultra-low dose.

**Figure 2.** Coronal non contrast sinus computed tomography: A, ultra-low dose with filtered back-projection; B, ultra-low dose with Iterative Model Reconstruction. With Iterative Model Reconstruction, the bone edge was smooth, making fine structures such as the nasal septum (arrows) difficult to identify.

**Figure 3.** Paranasal sinus ultra-low-dose computed tomography: A, coronal image with filtered back-projection; B, coronal image with Iterative Model Reconstruction. The optic nerve (arrows) was visible with Iterative Model Reconstruction, not with filtered back-projection.
IMR and LD CT versus SD CT (Figure 3). The anterior ethmoidal arteries and internal carotid arteries were clearly identified on all LD and SD CT scans. Regarding the noncritical anatomic structures, ULD + IMR and VLD CT had lower image quality than SD CT, whereas LD CT was comparable to SD CT (Table 2). The mean Lund-Mackay score was 8.83 ± 6.08. With LD, VLD, and ULD CT + IMR, opacifications of all the sinuses were graded the same as those with SD CT (100% agreement). The Lund-Mackay scores were the same among all CT scans.

Interobserver Variation

For scored image quality, interobserver agreement between the 2 independent radiologists was acceptable. For most critical anatomic structures and CT protocols, the percentages of agreement were >95%, and the \( \kappa \) values were significantly >0.6. However, identification of the anterior ethmoidal artery on VLD CT showed 96.9% agreement but a relatively low \( \kappa \) value (0.38). Identification of the optic nerve showed 89.5% agreement (\( \kappa = 0.42 \)) for ULD CT without IMR and 79.2% agreement (\( \kappa = 0.59 \)) for VLD CT.

Discussion

In the present study, all fine structures of the paranasal sinus area were clearly identified through LD CT with FBP for reconstruction, and the radiation dose was decreased to 22% of the SD. However, the radiologists could not accurately identify several critical and noncritical anatomic structures on VLD and ULD CT scans versus SD CT scans. Therefore, the LD CT radiation dose can be considered the minimum optimal radiation setting for evaluating paranasal sinuses before surgery. In addition, although the optic nerve could be appropriately assessed with ULD CT + IMR, other critical and noncritical anatomic structures could not be accurately evaluated. Therefore, the use of IMR may not be appropriate for decreasing the radiation dose of paranasal sinuses CT.

In CT for the paranasal sinus, the scanning field includes radiosensitive organs (eg, eye lens) that are usually subjected to high cumulative doses of radiation after a patient undergoes repetitive CT scans of the head and face. Radiation-induced cataract is scientifically based on a deterministic level, with 250 mGy for pediatric patients and 4 to 5 Gy for adults.\(^2\)\(\text{12-14} \) The effective dose for 1 CT examination of the paranasal sinus is lower than the yearly natural radiation (approximately 1 mSv), and the effective dose at the lens is substantially below the threshold for radiation-induced cataract.\(^15\) However, serial scanning cannot be avoided during the follow-up of chronic disorders, as patients are subjected to cumulative radiation exposure. Hence, many attempts have been made to decrease the radiation exposure during paranasal sinus CT.

Paranasal sinus CT can be performed with LD methods because the paranasal sinus area has high intrinsic contrast and the structures are small; furthermore, previous studies have proven that dose reduction does not affect diagnostic image quality.\(^16\) Several previous studies on radiation dose reduction have discussed tube current or tube voltage adjustments in paranasal sinus CT.\(^5\)\(^6\) Hagtvedt et al\(^5\) reported that LD CT (120 kVp, 40 mAs) and SD CT (120 kVp, 200 mAs) performed equally when diagnosing acute sinusitis. Abul-Kasim et al\(^6\) also reported that the maximal dose reduction during an LD examination (80 kVp, 17 mAs; effective dose, 0.045 mSv) was considered sufficient to replace SD CT (120 kVp, 70 mAs) in a clinical setting. Similarly, in our study, all anatomic structures were identified through LD CT (100 kVp, 40 mAs, 0.86 mSv; 22% of the effective dose for SD CT), and the diagnosis of sinusitis is possible through ULD CT (100 kVp, 10 mAs, 0.22 mSv; 6% of the effective dose for SD CT).

However, LD CT examination inevitably causes a decrease in the signal-to-noise ratio and an increase in image noise, resulting in compromised image quality. In addition to decreasing radiation exposure by adjusting the dose-related technical parameters, as in the conventional FBP technique, the development of CT systems through iterative reconstruction for additional dose reduction and image quality preservation has been suggested.\(^9\) In our study, we used a knowledge-based iterative reconstruction algorithm, the IMR, a pure iterative reconstruction algorithm. IMR models the process of physical data acquisition as accurately as possible through the iterative minimization of the difference between measured raw data and the estimated image.\(^9\)\(^10\) Yuki et al\(^17\) reported that when compared with conventional FBP, IMR images have significantly lower noise with better subjective quality of coronary vessels in coronary CT angiography. Furthermore, Oda et al\(^18\)
reported that image noise was lower with a higher visual score through IMR than FBP during LD cardiac CT with 20% of the standard tube current.

In our study, the optic nerve could be adequately visualized with IMR for ULD CT but not with FBP. Similarly, in a recently published report, VEO—a model-based iterative reconstruction technique from GE Healthcare—decreased image noise and improved the image quality of soft tissue lesions in the brain parenchyma, muscle, and optic nerve. However, fine bone structures cannot be accurately evaluated with VEO, because it has a smoothing effect on them. Schulz et al. also reported that paranasal sinus LD CT with the iterative reconstruction technique decreased image noise but did not improve image quality, especially of bony structures, owing to the overall increased softening of cortical structures and bone edges, as in our study’s finding. Therefore, IMR is not useful in the paranasal sinus area, as it has many fine bone structures.

The Lund-Mackay scores of LD, VLD, and ULD CT ± IMR and SD CT were in complete agreement. The Lund-Mackay score evaluates the degree of opacification in paranasal sinuses, which is a typical finding of sinusitis. Thus, VLD and ULD CT ± IMR can be used to diagnose sinusitis, but it cannot be used to evaluate detailed anatomy. Although VLD or ULD CT has 2 or 3 times more than the radiation dose of conventional paranasal sinus radiography, this modality may provide additional detailed information, such as extension of sinusitis

Conclusions

A dose reduction of up to 22% of SD CT can be obtained with LD CT (100 kVp, 40 mAs) without significant deterioration of the image quality. Thus, LD CT can be considered the minimum optimal radiation for use in patients who are being considered for endoscopic sinus surgery. However, the iterative reconstruction technique with paranasal sinus CT is not useful for surgical planning, because the fine details of thin bone structures are obscured.

Author Contributions

Jung Gwon Nam, data collection, data analysis, drafting, final approval, accountability for all aspects of the work; Minseoo Bang, data collection, data analysis, drafting, final approval, accountability for all aspects of the work; Seong Hoon Choi, data analysis, drafting, final approval, accountability for all aspects of the work; Jong Ha Park, data analysis, drafting, final approval, accountability for all aspects of the work; Woon Jung Kwon, data analysis, drafting, final approval, accountability for all aspects of the work; Byeong Seong Kang, data analysis, drafting, final approval, accountability for all aspects of the work; Tae Hoon Lee, data collection, drafting, final approval, accountability for all aspects of the work.

Disclosures

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