CT Radiation Dose for Computer-Assisted Endoscopic Sinus Surgery: Dose Survey and Determination of Dose-Reduction Limits

BACKGROUND AND PURPOSE: Computer-assisted navigation is increasingly used in functional endoscopic sinus surgery (FESS) to prevent injury to vital structures, necessitating preparative CT and, thus, radiation exposure. The purpose of our study was to investigate currently used radiation doses for CT in computer-assisted navigation in sinus surgery (CAS-CT) and to assess minimal doses required.

MATERIALS AND METHODS: A questionnaire inquiring about dose parameters used for CAS-CT was sent to 30 radiologic institutions. The feasibility of low-dose registration was tested with a phantom. The influence of CAS-CT dose on technical accuracy and on the practical performance of 5 ear, nose, and throat (ENT) surgeons was evaluated with cadaver heads.

RESULTS: The questionnaire response rate was 63%. Variation between minimal and maximal dose used for CAS-CT was 18-fold. Phantom registration was possible with doses as low as 1.1 mGy. No dose dependence on technical accuracy was found. ENT surgeons were able to identify anatomic landmarks on scans with a dose as low as 3.1 mGy.

CONCLUSIONS: The vast dose difference between institutions mirrors different attitudes toward image quality and radiation-protection issues rather than being technically founded, and many patients undergo CAS-CT at higher doses than necessary. The only limit for dose reduction in CT for computer-assisted endoscopic sinus surgery is the ENT surgeon’s ability to cope with impaired image quality, whereas there is no technically justified lower dose limit. We recommend, generally, doses used for the typical diagnostic low-dose sinus CT (120 kV/20–50 mAs). When no diagnostic image quality is needed, even a reduction down to a third is possible.
applicable low-dose protocol for our institution, and to investigate the lowest dose thresholds for safe navigation.

Materials and Methods
No consent from the local ethics committee was required for this experimental study.

Dose Survey
A questionnaire was sent to 30 radiology departments, among them university hospitals, primary care hospitals, and private radiology CT practices. We included only institutions that were supposed to use CT-based navigation tools. Information on model and manufacturer of the CT scanner and the navigation system and dose-relevant scanning parameters (tube voltage, tube current-time product, and volumetric CT-dose index [CTDI\text{vol}]) for CAS-CT and diagnostic sinusitis CT was requested.

Evaluation of Registration Feasibility and Dose Dependence of Navigation Accuracy
To investigate potential problems associated with low-dose scanning and to define the lowest possible dose for registration, navigation, and FESS, we conducted phantom and cadaver head experiments. For CAS-CT, overlapping 1.25-mm sections with a FOV of 20 cm were acquired with an 8-section scanner (Lightspeed Ultra; GE Healthcare, Milwaukee, Wis.). Images were reconstructed in edge-enhancing algorithms. The face from the upper edge of the frontal sinus to the upper tooth row, including the tip of the nose, was imaged to allow reliable registration. To assess registration feasibility at very low doses, we scanned a tissue-equivalent head phantom (XR-100; Alderson Research, Stamford, Conn) with low-dose scanning (Table), and registration was performed with each dataset. In a second step, dose dependence of navigation accuracy was evaluated with 4 human cadaver heads. As a reference dose, the initially used high dose (120 kV/210 mAs) was also included.

| Scanning parameters used in the experiments with phantom and cadaver heads |
|-----------------------------|-------|-------|
| CTDI\text{vol} (mGy)       | kV    | mAs   |
| 65                          | 120   | 210   |
| 9.5                         | 120   | 30    |
| 6.3                         | 120   | 20    |
| 4                           | 100   | 20    |
| 3.1                         | 120   | 10    |
| 2                           | 100   | 10    |
| 1.1                         | 80    | 10    |

Note: CTDI\text{vol} indicates volumetric CT-dose index.

When preparing computer-assisted endoscopic navigation, a correlation between the dataset and the patient’s facial contours (ie, registration process) must be performed first. For this purpose, the system calculates a 3D surface-rendered model from the image data. Correlation is then achieved touching firmly attached markers, such as bone-anchored screws or fiducials glued onto the skin, with a pointer, which is tagged with reflection markers (see the paragraph on the optical link below). Alternatively, multiple discrete surface landmarks can be defined by touching the face with a pointer or setting laser light points (surface registration). Screw-based registration has proved to be the most accurate method and was, therefore, chosen for our study to keep influential factors, other than dose-associated image quality, as limited as possible.

Correlation between the patient’s position and the instruments is maintained during the intervention by an optical, electromechanical, electromagnetic, or sonographic link. During the intervention, the CT data, including multiplanar reformations in coronal and sagittal orientations, are displayed by the navigation system (Fig 2). At our institution, an optically guided system (VectorVision; BrainLAB, Feldkirchen, Germany) is in service. Optically guided systems use infrared light, which is reflected by markers attached to the patient’s head and the instruments, allowing determination of the instrument position in relation to patient anatomy.

For the evaluation of navigation accuracy, reference points, which can be identified on the CT scan and on the cadaver specimen, were defined. For this purpose, small screws were drilled into the bone in the region of the frontozygomatic suture (screws 1 and 2), the nasion (screw 3), the nasal spine (screw 4), the pterygoid process (screw 5), and the sphenoid (screw 6). Screws 5 and 6 were placed endoscopically. Additionally, the screw holding the reflection marker in place on the forehead was included (screw 7). The screw heads had a central pit where the pointer used for accuracy measurement could be placed jiggie-free. These points were marked with the software iPlan (BrainLab, Feldkirchen, Germany) (Fig 3) at adequate magnification.

When the pointer tip is put exactly at the marked location, accuracy is calculated as the root mean square error (RSME) by the navigation system (BrainLab). This value indicates the maximal deviation between patient and image data. RMSE was recorded after placing the pointer tip in the screw head pit in line with the main axis of the screw. Screws 1–4 were used as bone-anchored fiducials for registration.

Statistical Analysis
For descriptive statistics of the measured accuracy values, a linear regression line of accuracy, depending on CT dose, was constructed to illustrate a potential influence of low CT dose on low accuracy. For inferential statistical analysis of the dose dependence of the accuracy, a nonparametric Wilcoxon signed rank test with a Bonferroni correction for multiple comparison was used.

Endoscopy with Low-Dose CAS-CT
CT scans of a cadaver head were obtained with low-dose scanning. Computer-assisted endoscopy was performed by 5 ENT surgeons ex-
experienced from 1 to 12 years (median, 3 years). Six anatomic locations (carotid canal, optic canal, middle concha attachment, uncinate process, ethmoid bulla, and anterior wall of sphenoid sinus) had to be identified on both sides. Anatomic locations to be assessed were chosen according to their relevance to the surgeon. For example, not the optic nerve (which is not well delineated on edge-enhanced CT-im-
Endoscopy with Low-Dose CAS-CT

Fig 4. Results of the dose survey. Doses used for CAS-CT (gray) and diagnostic sinus CT (black) in 15 CT scanners. 0 is our institution before the CAS-CT protocol was adapted.

ages) but the bony borders defining the dangerous space around the optic nerve should be discernable. In addition, overall image quality had to be judged on a scale from 1 to 10, considering the question “Would you be able to perform endoscopy on a real patient with these images?” One week before the experiment, participants were informed about the study background and low-dose scanning was demonstrated. During the following week, opportunities were given repeatedly for becoming acquainted with low-dose image quality. During the experiment, participants were blinded to the doses.

Results

Dose Survey

Nineteen of 30 questionnaires were returned (response rate, 63%). 5 institutions did not perform CAS-CT, and 14 institutions reported data for 15 scanners. Scanners reported included 10 different models from 4 manufacturers; all scanners were multisection technology (2 section to 64 section). CTDIvol for CAS-CT and sinusitis CT is shown in Fig 4. Variation between minimal and maximal doses used for CAS-CT was 18-fold. In 9 of 15 scanners, the same dose was used for CAS-CT and for sinusitis CT; the dose for CAS-CT was higher in 4 scanners and lower in 2 scanners. Five of 14 institutions used an image-guidance system from the same manufacturer as ours. Other systems used included Stryker Leibinger (Freiburg, Germany), Pole Star (Medtronic, Minneapolis, Minn), and Instattrak (GE Healthcare, Milwaukee, Wis).

Evaluation of Registration Feasibility and Dose Dependence of Accuracy

Phantom surface registration was readily possible with all scanners. Multisection technology, though, and the difference cannot be explained by...
technical factors alone. This opinion was supported by Koller et al., who found a sevenfold CTDIvol difference for diagnostic sinus CT between institutions, all of which used the same scanner model. Isolated high doses found in sinus CT when compared to other institutions do not reflect this controversy.

Because for sinusitis, only structures with a high intrinsic contrast need to be visualized, sinus CT is particularly suitable for low-dose scanning. On the other hand, such a limited approach might fail to show alternative diagnoses like an intracranial tumor clinically imitating a sinusitis (“frontal headache”). There is a controversy among radiologists about low-dose sinus scanning, and some radiologists reject low-dose scanning, preferring full tissue contrast for every examination in order to avoid missing alternative findings. In our eyes, the vast dose variation between different institutions mainly reflects this controversy.

Nevertheless, the results of our dose survey allow the conclusion that there is no technical factor justifying a higher radiation dose for CAS-CT than for sinusitis CT. Most institutions perform both examinations with the same parameters, some with a dedicated low-dose protocol; and those that use different doses do not show evidence of a uniform trend toward using a higher dose for CAS-CT.

Because we found that low-dose computer-assisted navigation is feasible and already being performed by other institutions, we modified our CAS-CT protocol stepwise in collaboration between neuroradiologic and ENT departments until the dose used for sinusitis CT was reached. We apply this protocol now to those patients in whom clinically an uncomplicated inflammatory mucosal affection (sinusitis or polyposis) is probable. The image-quality degradation on lowering from 210 to 30 mAs is not well perceived on the edge-enhanced images used for navigation (Fig 6) and is tolerated well by the ENT surgeons. To smooth the surfaces produced by the surface-rendering algorithm, we adapted thresholds once during the dose-adaptation process. No problems were observed during patient registration or interventions afterward.

In the second experimental part of our study, minimal doses required for registration and safe navigation were investigated in experimental models. Registration proved to be feasible, irrespective of radiation dose, and for navigation accuracy, no statistically significant dose-dependence was observed. The accuracy values we found for our VectorVision tool are comparable with others cited in the literature. Therefore, technical accuracy does not need to be considered as a factor limiting dose reduction.

Our experiment testing surgeon performance with low-dose scanning showed that image quality is not very critical either because ENT surgeons were able to identify anatomic structures with doses as low as approximately a third of our diagnostic low-dose protocol. Surgeons do not primarily use the CT scanning for orientation but work with the endoscope, and CT images are used more to verify the position of the instruments within anatomic compartments. They, therefore, only need a basic image quality. Besides, images calculated with an edge-enhancing algorithm are used for navigation, and in these images, soft-tissue details are not easily discernible anyway. In practice though, dose reduction is limited by the fact that CAS-CT usually serves diagnostic purposes as well and that conspicuousness of anatomic details, beyond those details the surgeons needs to identify, should be warranted for the radiologist.

Therefore, we do not advocate the use of extremely low-dose CT for navigation in FESS on a routine basis. However, the findings of our study point out 2 relevant points: Many patients undergo CAS-CT at much higher doses than necessary, and dose reduction is far less critical than might be expected. We consider the results of the present study of particular interest in light of the growing awareness of potential hazards from CT-associated radiation exposure in the public and among radiologists. Neuroradiologists are increasingly called on to reduce radiation exposure from CT; and in this context, questions concerning the feasibility of dose reduction in CAS-CT will arise.

In practice, in regard to performing CAS-CT, we recommend checking the currently used dose parameters and carrying out, where appropriate, a pragmatic dose reduction down to a level typically used for low-dose diagnostic scans, such as those used for patients treated for rhinosinusitis. For modern multissection scanners, generally 120 kV and 20–50 mAs will suffice. A recent publication showed that significant dose reduction can result from the use of dose-modulation techniques in neuroradiologic CT. Using dose modulation also for CAS-CT is, therefore, recommended. In this case, an upper limit for the tube current must be set to avoid excessive tube currents induced by metallic dental implants.

Low-dose scanning should not be used, of course, when soft-tissue contrast is an issue, as in the case of tumor surgery. At our institution, approximately 100 sinus surgery procedures are performed annually with computer-assisted naviga-

AJNR Am J Neuroradiol 30:617–22 | Mar 2009 | www.ajnr.org 621
tion, 90 of these for chronic rhinosinusitis; hence, most patients benefit from the new dose-reduced protocol.

When a recent diagnostic scan is available and a dataset must be acquired only for navigation purposes and/or when radiation protection is a major concern (as for pregnant women or children), even lower doses (about a third of a typical diagnostic dose level) may be considered. Moreover, we scan all patients for whom FESS might be necessary in the future a priori with a wide FOV (including the tip of the nose), allowing the dataset to be used for navigation later, thus avoiding excessive radiation exposure from repeat scanning.

Apart from the stochastic risk resulting from radiation exposure, there is 1 potential deterministic risk associated with radiation in sinus CT: That is the risk of cataract development. A recent study found lens doses in navigation CT for pituitary surgery far below the threshold inducing cataracts in humans. As for intracranial navigation, a far better tissue contrast is required and, therefore, considerably higher radiation doses are applied than for sinus navigation; the lens dose in a single sinus CT is negligible.

Our study has some limitations. Different scanner types may need significantly higher or lower doses for the same image quality; hence, dose-relevant parameters mentioned in our study cannot be transferred directly to other scanners. That is why we give our recommendation in a rather generic way (use a dose level as typically used in low-dose diagnostic sinus scans, and generally 120 kV and 20–50 mAs will suffice). Other navigation systems (especially if they should use a significantly different image processing and registration method) may be more susceptible to image-quality degradation induced by low radiation dose.

The significance of the findings from our experimental low-dose endoscopy is somewhat limited by the fact that endoscopy in a cadaver head, where no mucosal swelling and bleeding occur, is easier than in a real patient and that the recognition of bony lamellae in a diseased patient may be hampered by chronic inflammation. As a consequence of these limitations, we recommend proceeding stepwise and in close collaboration with the ENT surgeon to find an acceptable image quality when undertaking dose reduction.

Last, our study is only an experimental trial under laboratory conditions, and the clinically most relevant issue (the number of complications) was not investigated. Evaluation of the noninferiority of low-dose CAS-CT in the clinical routine would have to be investigated in a clinical trial, which needs to include a large number of patients because of the low frequency of intraoperative complications.

Conclusions
In this study, the first radiation-dose survey for CT used for computer-assisted navigation in FESS is presented, and minimal radiation doses required are investigated experimentally. A wide dose range is used among radiology departments, reflecting varying attitudes toward diagnostic needs and concern about radiation exposure among radiologists.

The only practically relevant limit for dose reduction for CAS-CT is imposed by the ENT surgeon’s need for a basic image quality and the radiologist’s need for diagnostic image quality, whereas the navigation system tested does not impose technical limits for dose reduction. The radiation doses for CAS-CT can be reduced far below those currently applied by most institutions. We recommend using those doses that are commonly applied in typical low-dose diagnostic sinus CT. When no diagnostic image quality is required, dose reduction down to approximately a third of a typical diagnostic low-dose sinus CT can be considered.

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