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ORIGINAL ARTICLE

# Reduction in Lens Dose in Temporal Bone Computed Tomography by Modification of Scanning Plane

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## ABSTRACT

***Objectives:*** *To evaluate the radiation dose reduction to the lens by modifying the scanning plane to exclude the orbit in temporal bone computed tomography (CT). The effect on diagnostic image quality was also evaluated.*

***Methods:*** *Radiation dose reduction was evaluated using a phantom head and calibrated thermoluminescent dosimeters. Image quality was assessed in 34 patients. Two radiology fellows independently reviewed the image and assessed the image quality of 20 temporal bone structures. The image quality was scored on a 4-point scale and analysed with Mann Whitney* U *test.*

***Results:*** *We demonstrated a 31.4% to 46.1% dose reduction to the lens by excluding the orbit in the scan field. The dose-length products before and after the modification were comparable (p = 0.267). None of the assessed temporal bone structures demonstrated any significant difference in image quality (p > 0.05).*

***Conclusion:*** *Modification of the scanning plane in temporal bone CT can reduce radiation dose exposure to the lens and preserve the diagnostic image quality. This protocol should be considered to minimise the radiation exposure to patients.*

***Key Words:*** *Radiation dosage; Temporal bone; Tomography, X-ray computed*

## 中文摘要

### 進行顳骨電腦斷層掃描時改變掃描角度以減低眼晶體所接觸的輻射劑量

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**目的：**進行顳骨電腦斷層掃描時改變掃描角度來剔除眼眶部分，以減低眼晶體接觸到的輻射劑量，並評估因此對圖像質量所造成的影響。

**方法：**使用假體的頭部和校準熱釋光劑量計來評估減少了的輻射劑量。測量了34個圖像的質量。兩名放射科醫生獨立審查各圖像，並評估20個顳骨結構圖像。利用4分制為圖像質量進行評分，並以Mann Whitney *U*檢驗進行分析。

**結果：**剔除眼眶範圍後發現眼球所接觸的輻射劑量減少了31.4%至46.1%。改變掃描角度前後的劑量—長度乘積沒有顯著差異（p=0.267）。顳骨結構的圖像質量並無任何顯著差異（p>0.05）。

**結論：**進行顳骨電腦斷層掃描時改變掃描角度可以減低眼晶體接觸的輻射劑量，同時可令圖像質量保存不變。應考慮這種做法來確保病人接觸輻射的劑量減至最少。

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## INTRODUCTION

High-resolution computed tomography (CT) is the modality of choice for imaging the temporal bone. The fine bony anatomy of the temporal bone can be depicted clearly by the modern multidetector CT (MDCT) scanner. The MDCT scanner can produce thin-slice volumetric data capable of being reformatted into different anatomical planes, greatly aiding diagnosis.[1] Conventional axial scanning of the temporal bone using a plane parallel to the orbitomeatal line or gabellomeatal line results in direct irradiation of the lens.[2,3] At our institution, we also obtain axial scans of the temporal bone parallel to the orbitomeatal line. The lens of the eye is one of the most radiation-sensitive organs in the body. A single exposure of 0.5 Gy to 2.0 Gy results in detectable opacity in the lens.[4] Although one single exposure from CT of the temporal bone is well below this level, repeated exposures may pose an increased risk for cataract formation. In most clinical conditions where CT of the temporal bone is indicated, the orbits are rarely the region of interest (ROI). Thus moving the orbit out of the field of primary radiation of the X-ray beam is justified based on the 'as low as reasonably achievable' principle.

A previous study has demonstrated a lens dose reduction effect by excluding the lens from the radiation field when performing CT scan of the head.[5] Another study by Torizuka et al[2] who used an older-generation CT scanner also demonstrated that scanning parallel to the hard palate to exclude the lens did not adversely affect the quality of the image obtained. The study by Niu et al[3] also showed the reduction in lens dose by scanning in an acanthiomeatal line. Nonetheless, there has been no detailed evaluation of image quality after such modification on a modern CT scanner. We believe that image quality of the CT scan must be maintained after modification of the scanning plane. Our aims in this study were to measure the reduction in radiation dose to the lens by modification of the scanning plane and to assess the image quality after the modification.

## METHODS

### Phantom Study

The estimated dose absorbed by the lens of the eyes was evaluated using a head phantom and thermoluminescent dosimeters (TLDs). TLDs were calibrated with a superficial X-ray treatment machine using applicable energy at 120 kVp and half-value layer of 6 mm Al, similar to our CT machine. The output of the superficial X-ray treatment machine was calibrated using a secondary standard ion chamber. The error of the TLDs was less than 2%. Six calibrated TLDs were placed over the position of the lens on both eyes, three on each side. One was placed directly over the centre of the eye and the other two over the medial and lateral canthal regions. Scanning was performed using a Toshiba Aquilion CX 64-detector MDCT (Toshiba Medical Systems Corporation, Otawara-shi, Tochigi, Japan) using 120 kV, automated tube current modulation, 0.5 s rotation time, 0.5 mm x 64 collimation and 0.641 pitch. Images were reconstructed in 1-mm slice thickness. Each scan of the phantom's temporal bone consisted of a set of scanograms in frontal and lateral projections followed by axial scan of the temporal bone. Axial scanning of the temporal bone was performed in the following protocol: (1) head in neutral position and scanning plane aligned to the orbitomeatal line; (2) head in neutral position with gantry tilting and scanning plane aligned to the acanthiomeatal line; (3) head in extension and scanning plane aligned to the acanthiomeatal line (Figure 1). The entire craniocaudal span of the petrous temporal bone from the petrous ridge to the lowest margin of the mastoid was included in the scanning. Each protocol was scanned twice. The TLD readouts for each protocol were obtained and the mean value was calculated. The results of the TLD readout were taken as the absorbed dose of the lens.

### Evaluation of Diagnostic Image Quality

Two imaging protocols were evaluated — the original protocol with scanning plane aligned to the orbitomeatal line and the proposed modified protocols with scanning plane aligned to the acanthiomeatal line, by gantry tilting and / or head tilting. The study period was from January 2013 to August 2013 and 17 consecutive patients (11 male and 6 female; median age, 55 years; age range, 17-80 years) scanned using the new protocols for temporal bone CT scan in our institute were included. Only normal temporal bones were assessed. For completely normal scan, one side was randomly selected for assessment. Patients with bilateral temporal bone disease were excluded. Another 17 consecutive patients constituting the control group (12 male and 5 female; median age, 54 years; age range, 20-80 years) were scanned using the old protocol. All images were obtained using the same Toshiba 64-detector MDCT scanner with identical parameters as in the head phantom study, i.e 120 kV and automated tube current modulation, 0.5 s rotation time, 0.5 mm x 64 collimation and 0.641 pitch. The scan range was from the petrous ridge to the lowest margin of the mastoid.

Images were reconstructed using bone algorithm. Image quality was assessed by two radiology fellows (5 and 6 years of experience in reading CT scans of temporal bones) independently who were blinded to the protocol used. Nineteen temporal bone structures were assessed (Table). Images were reviewed on a workstation using Vitrea software package from Toshiba. The reviewers were allowed to adjust the windowing and reformat the images in any plane so as to simulate routine reporting practice. The image quality was scored according to a 4-point scale: 1 = non-diagnostic, 2 = significant blurring hindering diagnosis, 3 = adequate for diagnosis with only slight blurring, or 4 = excellent with sharp depiction of bony structures. Scores from two reviewers were pooled for analysis. Image quality scores between the old and new protocols for each structure were compared using Mann-Whitney *U* test. A p value of <0.05 was taken as statistically significant.

The dose-length products of the examinations for both new and old protocols were obtained as reported by the CT scanner. The values were compared using *t*-test.

Objective measurement of image quality was done using contrast-to-noise ratio (CNR). CNR of the images was measured using the following formula[6]:

$$\mathrm{CNR} = \frac{\mathrm{CT\#}_{\mathrm{brainstem}} - \mathrm{CT\#}_{\mathrm{air}}}{\sqrt{\dfrac{\mathrm{SD}_{\mathrm{brainstem}}{}^{2} - \mathrm{SD}_{\mathrm{air}}{}^{2}}{2}}}$$

where $\mathrm{CT\#}_{\mathrm{brainstem}}$ and $\mathrm{CT\#}_{\mathrm{air}}$ denotes the density (in Hounsfield unit, HU) with the ROIs placed over the

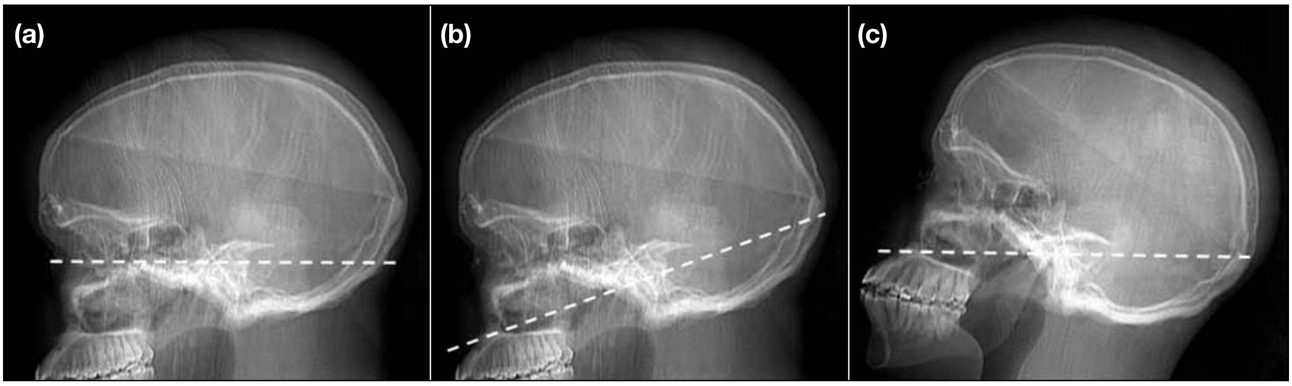


**Figure 1.** Phantom study: scanning using the (a) orbitomeatal line, (b) acanthiomeatal line with gantry tilting, and (c) acanthiomeatal line with head extension.

**Table.** Mean image quality scores for original and new protocols of 19 temporal bone structures.

| Structure | Mean score for original protocol | Mean score for new protocol | p Value |
|---|---|---|---|
| Cochlear | 4.0 ± 0 | 4.0 ± 0 | 1.0 |
| Modiolus | 3.35 ± 0.597 | 3.29 ± 0.524 | 0.590 |
| Vestibular aqueduct | 3.82 ± 0.387 | 3.88 ± 0.327 | 0.497 |
| Cochlear nerve canal | 3.91 ± 0.288 | 3.85 ± 0.436 | 0.667 |
| Internal acoustic meatus | 4.0 ± 0 | 4.0 ± 0 | 1.0 |
| Facial nerve canal, cochlear | 4.0 ± 0 | 4.0 ± 0 | 1.0 |
| Facial nerve canal, tympanic | 4.0 ± 0 | 3.94 ± 0.239 | 0.154 |
| Facial nerve canal, mastoid | 4.0 ± 0 | 4.0 ± 0 | 1.0 |
| Malleus | 3.97 ± 0.171 | 4.0 ± 0 | 0.317 |
| Incus | 3.97 ± 0.171 | 4.0 ± 0 | 0.317 |
| Stapes | 3.74 ± 0.448 | 3.62 ± 0.493 | 0.303 |
| Round window | 3.94 ± 0.239 | 3.88 ± 0.327 | 0.396 |
| Oval window | 3.97 ± 0.171 | 3.85 ± 0.359 | 0.09 |
| Tegmen tympani | 4.0 ± 0 | 3.97 ± 0.171 | 0.317 |
| Tympanic membrane | 3.53 ± 0.563 | 3.41 ± 0.701 | 0.589 |
| Superior semicircular canal | 4.0 ± 0 | 3.97 ± 0.171 | 0.317 |
| Lateral semicircular canal | 4.0 ± 0 | 3.97 ± 0.171 | 0.317 |
| Posterior semicircular canal | 4.0 ± 0 | 3.97 ± 0.171 | 0.317 |
| Vestibule | 4.0 ± 0 | 3.97 ± 0.171 | 0.317 |

region of brainstem and air (outside of external auditory meatus), respectively. $SD_{brainstem}$ and $SD_{air}$ denotes the standard deviation of HU (i.e. noise) in the respective ROI. The CNRs of the old and new protocols were compared using *t*-test.

# RESULTS

## Phantom Study

The average dose absorbed by the lens according to the TLD readouts was 35.63 mGy, 19.20 mGy, and 24.43 mGy by protocol 1, 2, and 3, respectively. This resulted in a radiation dose reduction to the lens by 31.4% to 46.1% after modifying the scanning plane to protocols 2 and 3.

## Image Quality

Results of the image quality scores are presented in the Table. The assessed temporal bone structures showed no evidence of significant difference in image quality ($p > 0.05$, Mann Whitney *U* test). Selected reformatted images from the new and old protocols are shown in Figure 2.

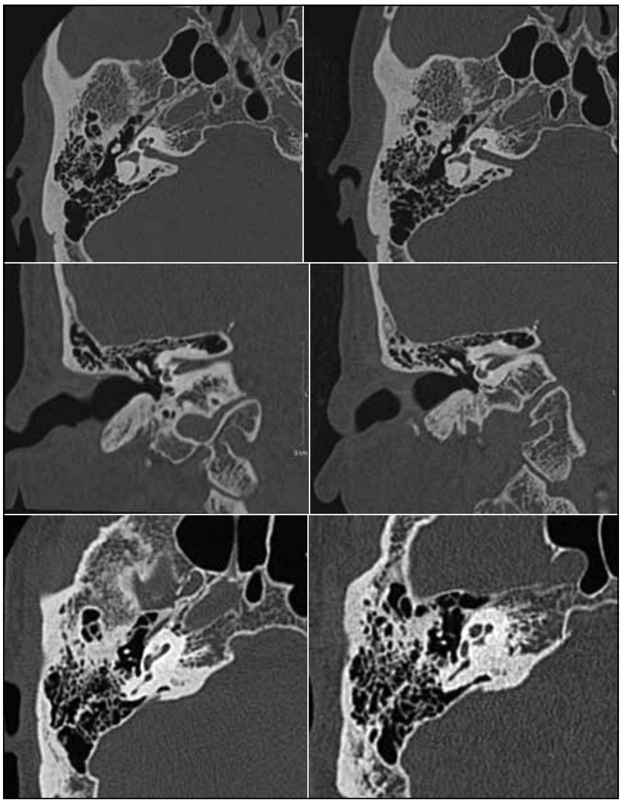

**Figure 2.** Axial and coronal reformatted computed tomographic images using the old (left) and new (right) protocol. There is very little discernible difference in image quality. Small temporal structures can also be sharply demonstrated.

The mean dose-length product of the new and old protocols was 487.3 ± 51.5 mGy-cm and 465.3 ± 59.3 mGy-cm ($p = 0.267$, *t* test), respectively, showing no significant difference in overall radiation dose between the two. The mean CNR of the new and old protocols was 7.88 ± 0.73 and 8.34 ± 0.77 ($p = 0.083$, *t* test), respectively, which also showed no statistical significance.

# DISCUSSION

Previous studies have demonstrated the dose reduction effect when the lens is excluded in brain and temporal bone CT. The effect on diagnostic image quality and image noise as a result of a change in scanning plane has been less well-documented. Study by Torizuka et al[2] showed comparable or even superior image quality when using a scanning plane parallel to the hard palate, compared with scanning in the orbitomeatal line. This study, however, cannot be entirely applied to modern MDCT scanners that produce thin slice images without intervening space and isometric voxel allowing multiplanar reformatting. We showed that we could significantly reduce the dose absorbed by the lens by changing the image plane to the acanthiomeatal line. With regard to diagnostic image quality, we found no significant difference between the new and old protocols. Although statistically insignificant, we nonetheless observed a slight increase in image noise as demonstrated by CNR measurement. We postulate this may in part be because changing the scanning plane results in the X-ray beam passing through an increased amount of high attenuating bone in the skull base and paranasal sinuses, thus producing slightly noisier images.

The absorbed dose in our study after modification of the scanning protocol remained slightly higher when compared with that of other studies.[3,5] Direct comparison, however, is difficult because the CT machines and settings were different. It is our aim to produce similar image quality with a lower lens dose. We aim to further lower the radiation dose. This may involve changing other scanning parameters or using an additional device. Nonetheless this may result in a greater impact on the overall image quality and require further evaluation. Use of a lens protection device may be considered to reduce radiation dose to the lens.[7,8] Using a low-voltage protocol may also reduce overall dosage in temporal bone CT. A previous report, however, suggested that this may result in insufficient assessment of small structures.[9] Further study is required to identify a better protocol. Dose reduction and image quality often go in opposite directions. One must determine the level of image quality that can be sacrificed before there is a clinically significant impact on diagnosis.

One potential pitfall from the use of this protocol is the artefacts from dental fillings. This has not been addressed in previous studies. We experienced significant artefacts in subsequent cases due to high-density metallic dental filling. In such case, the beam-hardening artefact due to dental filling is directed towards the temporal bone and significantly obscures part of the temporal bone. We recommend better patient preparation by obtaining a dental history and ensuring dentures are removed wherever possible prior to scanning. Careful inspection of the scanogram can reveal high-attenuating dental material. In case of dental filling, meticulous planning of the scanning plane by the radiographer is needed. In many cases, artefact from dental fillings can be avoided by strict alignment in a plane parallel to the acanthiomeatal line, orbital floor, or hard palate. If high-attenuation dental material cannot be moved out of the scanning range, we would resume our original protocol, i.e. scanning in the orbitomeatal line. The decision to revert back to the original protocol can be made after inspection of the scanogram without subjecting the patient to a repeated scan.

Our study is limited by the small sample size. The tissue attenuation of the head phantom may not exactly simulate a real patient. The lack of soft tissue components in the head phantom decreases the X-ray attenuation and may have affected the final TLD reading, but we believe this effect would be minor as the lens is a superficial structure.

# CONCLUSION

Radiation is an increasing concern in the field of diagnostic radiology. We have shown that it is possible to reduce the radiation dose inflicted on the lens by modification of the scanning plane in temporal bone CT. There is no loss in diagnostic image quality. This protocol should be implemented to minimise the radiation exposure of the lens.

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