Low-dose Three-dimensional CT of Paranasal Sinuses

LIANG-KUANG CHEN1,2,3 YUH-FENG TSAI1 BO-LIN LIU1 CHIN-SI LIN1,3 CHEN-LI LU1,3 AN-CHENG SHIAU4 CHONG-HONG TSAI4 MING-CHONG TSENG1,3 KUN-MU LU1,3 CHENG-TAU SU1,2 MIN-SZU YAO5

Department of Diagnostic Radiology1, Department of Radiation Oncology4, Shin-Kong Wu Ho-Su Memorial Hospital School of Medicine1, Fu Jen Catholic University Department of Radiotechnology2, Yuanpei Institute of Science and Technology College Department of Diagnostic Radiology3, Taipei Medical University-Municipal Wan Fang Hospital

The goal of this study was to develop an optimal radiologic techniques for low-dose 3D CT of paranasal sinus to enhance the image quality in a reasonable absorbed x-ray dose for the patients. The ultimate aim is to provide higher quality images for physicians to identify pathological changes from the image, to make preoperative planning, to evaluate the risk of the operation of paranasal sinus and to minimize the occurrence of intra-operative complications.

We analyzed spatial resolution and noise signals generated by various groups of mAs by using the dual technique of Plexiglas phantom and water phantom. In addition, Rando phantom was used to measure CTDI (computed tomography dose index) in the same scan area in a function of different slice thicknesses and spacings. The concept of MSAD (Multiple-scan average dose) was applied to calculate patient’s absorbed dose. From July 2001 to January 2002, 19 patients were enrolled in the study and underwent CT examinations of paranasal sinuses. Among these patients, 19 were male and 5 female.

Conventional 2D CT had been generally used with satisfactory results, especially for patients with chronic paranasal sinusitis. However, 3D CT not only provides a better anatomical information of the paranasal sinuses but also follows the ALARA principle.

The acceptable image quality could be achieved under the imaging parameters of 90 mAs and 77 mAs for axial and coronal sections, respectively. Three-dimension images could further be analyzed with SSD (shaded surface display), MPR (multiplanar reformats), and MIP (maximum intensity projection) to provide more information for both radiologists and clinicians.

Key words: 3D CT; ALARA; Paranasal sinuses; Spatial resolution

Computed tomography has been widely used to image paranasal sinuses, depicting anatomical pathologies in related diseases, such as chronic paranasal sinusitis, tumor, face trauma, etc. However, possible body damage caused by radiation dose is often neglected, when patients undergo axial and coronal slice scanning. When post-contrast scanning is required, the exposure dosage will be higher. The study is to reconstruct the 3D paranasal sinus images with low-dose CT scanning to reduce the radiation dose in the body while provide better anatomic images for radiologists and otorhinolaryngologist, etc. Surgeons can make better preoperative plans and risk evaluations and further reduce side effects. In the meanwhile, patients receive lower doses of x-ray exposure than with traditional axial and coronal CT examination. Less artifacts were generated with this technique when patient wears dentures. 3D images can be viewed from different angles and thus, provides more anatomical information.

METHODS AND MATERIALS

The tomoscanner is a Siemens PLUS4 A. The choices of the phantom and procedure were based on the image characteristics. The directions were as follows:
Materials

1. Plexiglas phantom: It was built of six groups of lead thread couples. The bar size is used for the determination of spatial resolution. The spacing between the groups are, 0.5, 0.6, 0.8, 1, 1.3 and 1.6 mm respectively.

2. Water phantom: Imaging was developed by homogenized water to measure noise signals.

3. Rando phantom: It was a phantom emulating actual body exterior but contained true bone inside. It was used to measure the computed tomography dose index (CTDI).

Methods

Plexiglas phantom experiment

1. Under the conditions of 219 mAs and 171 mAs for the axial and coronal sections respectively, plexiglas phantom scan was performed at 140 kVp, 3 mm slice thickness and 4 mm spacing. That was the conventional technique used for paranasal sinus scanning.

2. Under the conditions of 219, 194, 166, 141, 116, 90 and 65 mAs for axial scan and 171, 159, 146, 111, 94, 77 and 60 mAs for coronal sections respectively, plexiglas phantom scan was performed at 140 kVp, 2 mm slice thickness and 4 mm spacing.

3. The bar sizes (mm), namely, spatial resolution was analyzed under conventional fashion or different mAs scan conditions. (see Fig. 1).

Water phantom experiment

1. Under the condition of 219 mAs and 171 mAs for axial and coronal sections respectively, Water phantom scan was performed at 140 kVp, 3 mm slice thickness and 4 mm spacing. That was the conventional technique used for paranasal sinus scanning.

2. Under the conditions of 219, 194, 166, 141, 116, 90 and 65 mAs for axial scan and 171, 159, 146, 111, 94, 77 and 60 mAs for coronal sections respectively, water phantom scan was performed at 140 kVp, 2 mm slice thickness and 4 mm spacing.

3. The regions of interest (ROIs) were marked out at four places in equal distance; then, the noise signals generated in various groups of mAs were determined by the given software (see Fig. 2).

Rando phantom experiment

The images of Rando phantom were processed with the Plus 4 software to calculate the CTDI under various scanning parameters, respectively.

CTDI converted to MSAD

After scanning the axis and coronal section, the CTDI is converted to the MSAD using the following formula:

$$\text{MSAD} = \text{CTDI} \times \frac{T}{\text{BI}}$$

where BI refers to table feeding (mm), and T means slice thickness [3].

Clinical application

A group data of lowest MSAD, with spatial resolution and noise signals approaching those in conventional techniques, were chosen to image patients. The 3D image was obtained by reconstructing the selected thin cut slices containing suspected lesions and was presented to radiologists and otorhinolaryngologists for lesion identification and analysis. From July 2001
to January 2002, 19 patients underwent 3D CT examinations of paranasal sinuses. The 2D scan image and 3D reconstructed image were presented to radiologists and otolaryngologists who did not know factual scanning conditions. The images of 19 patients were analyzed in one session. The diseases of these 19 patients included 11 chronic paranasal sinusitis, 1 rhinopolyps, 2 mucocele, 1 fracture of orbital floor, 1 fistula between nonnasal cavity and nasal sinuses, and 3 tumors extruded nasal cavity and sinuses.

RESULTS

We scanned Plexiglas phantom, water phantom and Rando phantom with CT under different conditions. The data for the axial section are shown in Table 1. When the mAs value was reduced from 219 mAs to 90 mAs, spatial resolution degraded to 0.8 from 0.6. The noise signals rose from 4.2 to 8.12. If it was further reduced to 65 mAs, spatial resolution was degraded to 1 mm, and noise signals further rose to 9.2. In this circumstance, the image quality significantly differed from that was obtained in conventional imaging parameter. The MSAD would be higher when we scan an equidistance in 39 thinner sections with >141 mAs than that in 20 thicker sections with 219 mAs. Therefore, this condition is in appropriate for thin slice scan. Because of the low reduction rate of MSAD at 90 mAs, the group of scanning parameters at 90 mAs was chosen for axial scan.

The data for the coronal section are shown in Table 2. When the mAs value was reduced 77 mAs, there was no obvious change in spatial resolution as compared with the original 171 mAs (all are 0.8), but noise signals rose from 4.9 to 8.9. For a value of 60 mAs, spatial resolution degraded to 1 mm and noise signals rose to 10, seriously affecting image quality. If we applied over 111 mAs to scan an equidistance of

Table 1. The relation between spatial resolution, noise signals, CTDI, MSAD and section during axial scanning under different mAs, slice thicknesses and spacings condition

<table>
<thead>
<tr>
<th>Axial Sections</th>
<th>mAs</th>
<th>Spatial resolution (mm)</th>
<th>Noise signals (standard error)</th>
<th>CTDI (mGy)</th>
<th>MSAD (mGy)</th>
<th>Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>219</td>
<td>0.60</td>
<td>0.60</td>
<td>Region 1 of interest</td>
<td>4.20</td>
<td>5.40</td>
<td>32.00</td>
</tr>
<tr>
<td>219</td>
<td>0.60</td>
<td>0.80</td>
<td>Region 2 of interest</td>
<td>4.50</td>
<td>5.40</td>
<td>41.00</td>
</tr>
<tr>
<td>194</td>
<td>0.80</td>
<td>0.80</td>
<td>Region 3 of interest</td>
<td>4.00</td>
<td>5.40</td>
<td>36.20</td>
</tr>
<tr>
<td>166</td>
<td>0.80</td>
<td>0.80</td>
<td>Region 4 of interest</td>
<td>4.10</td>
<td>5.30</td>
<td>21.30</td>
</tr>
<tr>
<td>141</td>
<td>0.80</td>
<td>0.80</td>
<td>Total</td>
<td>16.80</td>
<td>21.00</td>
<td>24.60</td>
</tr>
<tr>
<td>116</td>
<td>0.80</td>
<td>0.80</td>
<td>Average</td>
<td>4.20</td>
<td>5.25</td>
<td>32.00</td>
</tr>
<tr>
<td>90</td>
<td>0.80</td>
<td>0.80</td>
<td>Slice thickness/ spacing</td>
<td>3/4</td>
<td>2/2</td>
<td>171</td>
</tr>
<tr>
<td>65</td>
<td>1.00</td>
<td>1.00</td>
<td>CTDI (mGy)</td>
<td>32.00</td>
<td>41.00</td>
<td>32.00</td>
</tr>
</tbody>
</table>

Note: data in the first column are the original conditions used previously. Data in the seventh column is the data applied in the clinical practice after the experiment.

Table 2. The relation between spatial resolution, noise signals, CTDI, MSAD and section during coronal scanning under different mAs, slice thicknesses and spacing conditions

<table>
<thead>
<tr>
<th>Coronal Sections</th>
<th>mAs</th>
<th>Spatial resolution (mm)</th>
<th>Noise signals (standard error)</th>
<th>CTDI (mGy)</th>
<th>MSAD (mGy)</th>
<th>Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>171</td>
<td>0.80</td>
<td>0.80</td>
<td>Region 1 of interest</td>
<td>4.80</td>
<td>6.10</td>
<td>24.60</td>
</tr>
<tr>
<td>171</td>
<td>0.80</td>
<td>0.80</td>
<td>Region 2 of interest</td>
<td>5.20</td>
<td>5.60</td>
<td>32.00</td>
</tr>
<tr>
<td>159</td>
<td>0.80</td>
<td>0.80</td>
<td>Region 3 of interest</td>
<td>5.00</td>
<td>5.40</td>
<td>29.70</td>
</tr>
<tr>
<td>146</td>
<td>0.80</td>
<td>0.80</td>
<td>Region 4 of interest</td>
<td>4.50</td>
<td>5.60</td>
<td>21.30</td>
</tr>
<tr>
<td>111</td>
<td>0.80</td>
<td>0.80</td>
<td>Total</td>
<td>19.80</td>
<td>22.70</td>
<td>171</td>
</tr>
<tr>
<td>94</td>
<td>0.80</td>
<td>0.80</td>
<td>Average</td>
<td>4.90</td>
<td>5.60</td>
<td>32.00</td>
</tr>
<tr>
<td>77</td>
<td>0.80</td>
<td>0.80</td>
<td>Slice thickness/ spacing</td>
<td>3/4</td>
<td>2/2</td>
<td>24.60</td>
</tr>
<tr>
<td>60</td>
<td>1.00</td>
<td>1.00</td>
<td>CTDI (mGy)</td>
<td>24.60</td>
<td>32.00</td>
<td>24.60</td>
</tr>
<tr>
<td>24.60</td>
<td>29.70</td>
<td>29.70</td>
<td>MSAD (mGy)</td>
<td>18.50</td>
<td>32.00</td>
<td>18.50</td>
</tr>
<tr>
<td>12.00</td>
<td>22.00</td>
<td>22.00</td>
<td>Section</td>
<td>20.00</td>
<td>39.00</td>
<td>20.00</td>
</tr>
</tbody>
</table>

Note: data in the first column are the original conditions used previously. Data in the seventh column is the data applied in the clinical practice after the experiment.
39 cuts, the MSAD is instead higher than that with 171 mAs and 20 thicker slice. Thus, this condition also is improper for thin slice scan. Because its reduction rate of MSAD is 22.2% at 77 mAs, the imaging parameters at 77 mAs is suitable for coronal section scan.

With a fixed kVp value and image algorithms filter, at 77 mAs and 90 mAs, 2 mm slice thickness and 2 mm spacing, we perform scanning at the axial and coronal sections. Comparing the images obtained in conventional fashion, all physicians agreed the image quality degraded as the imaging parameters declined from 171 mAs to 90 mAs, but the change couldn’t interfere with the interpretations (see Fig. 3). They all agreed 3D image could display more diagnostic details about adjacent anatomic structures, and facilitate the otolaryngologist more information to make preoperative planning and to evaluate the risk of the operation.

**DISCUSSION**

The objective of this study was to reasonably reduce mAs in CT scanning so that we can obtain three sets of thin cut slices for reconstruction image without increased patient’s dose. As shown in Table 1. and table 2., the reduction of mAs would decrease the output of X-ray. Two effects occur: 1. it displayed the detail of CT radiograph resulted in increasing spatial resolution. 2. X-ray photons that reach the detector would have wide distribution and increase the noise signals. After the different ROI calculations, the effect not only occurred in those of specific gray scales, even the images with some statically variance, which would not affect the ability of the analytical method.

According to the different image characteristics, low-dose 3D CT of paranasal sinuses could be reconstructed into 3D images in three algorithms of pattern, including SSD (shaded surface display), MPR (multiplanar reformats) and MIP (maximum intensity projection).

SSD could achieve the delicate visualization of the bony injuries. The details of bone could be displayed more clearly. The 3D images of parenchyma and bone tissue can be contrasted out and be viewed in different angles. We can adjust the threshold values to remove the metal artifacts resulting from dentures. (see Fig. 4, 5).

MIP images could provide the reconstructed image with more hierarchy than the original image scanned under conventional conditions. The correlation of parenchyma, bone tissue and the focus could be easily shown by contrast. The images also could be visualized in different angles (see Fig. 6).

MPR images could depict the images on the basis of standard coronal scans with additional axial and sagittal scans if necessary. More information was generated so that the clinicians could anticipate the depth and angles when performing endoscopic examinations. (see Fig. 7-9).

**Figure 3.** The original image under coronal section with low dose (77 mAs) and the fistula between left nonnasality and paranasal sinuses (marked with arrow).

**Figure 4.** SSD (shaded surface display) shows the reconstructed coronal image of bone contrast and the fistula between left nonnasality and paranasal sinuses (marked with arrow).
In addition, exposure dose of radiation to patients could be reduced. According to the literature, radiation damage had been proved when paranasal sinus was imaged with both axial and coronal scanning or 3D CT scanning. In general, the exposure dose of eyeballs in conventional scanning was 0.5 and 2 Gy in 3D CT scanning, respectively; about 1/3 of the dose was absorbed by the eyeballs. If the absorbed dose over 5 Gy, the cataract may occur [1, 2, 3].

Therefore, the mAs is reduce from 171 mAs to 90 mAs, while the kVp and image algorithms were kept constant, there was no significant effect on the image quality and the interpretation of the pathological region and regional anatomy.

CONCLUSION

Comparison of the results with other reports in the literature yielded the following useful information.
Because scanning parameters and sampling counts are different and the imaging perception may be subjective to radiologists and clinicians, the results of every study aren’t consistent. According to the ALARA principle, that is, lowest absorbed dose with acceptable images quality is appreciated. This study showed that the original image quality was acceptable for diagnosis under the scan condition of 90 mAs and 77 mAs for axial and coronal sections respectively. Three dimensional images not only offered lower exposure to radiation than that of conventional CT, but also could provide further information for radiologists and clinicians in preoperative planning, evaluation of surgical risk for paranasal sinus and minimizing the risk of intra-operative complications.

REFERENCES


應用低劑量三度空間電腦斷層的副鼻竇檢查

陳良光123 蔡裕豐1 呂柏麟1 林清禧123 劉建利123 蕭安成4 蔡忠宏4
曾明宗123 呂坤宇13 蘇憶道12 姚敏思5

新光吳火獅紀念醫院 放射診斷科1 腫瘤科1
天主教輔仁大學醫學院 醫學系2
元培科技學院 放射技術系3
臺北醫學大學 •市立萬芳醫院 放射診斷科5

本文研究的目的是想利用低劑量的三度空間電腦斷層攝影，於副鼻竇檢查的病患中取得吸收劑量與影像的品質取其平衡點。並可提供更多的影像資訊給放射科或耳鼻喉科醫師等做影像之判讀、治療前的計劃和手術風險之評估。

本研究以丙烯酸酯假體（plexiglas phantom）、水假體（water phantom）去分析各組不同 mAs 所造成的空間解析度及誤訊，另外用人形假體（Rando phantom）去測量相同掃描範圍，不同的切片厚度（slice thickness）及間隔下的電腦斷層劑量指標（Computed Tomography Dose Index、CTDI）值，並由多個掃描平均劑量（Multiplescan average dose、MSAD）的觀念計算病人所接受的劑量。同時我們於2001年 7月至 2002年1月共收集19名病患接受副鼻竇電腦斷層攝影之檢查，其中男性14名女性5名

研究結果：腺狀及冠狀面分別以 90mAs、77mAs 為醫師可接受影像品質的掃描條件，三度空間影像部份還可以做表面陰影顯像（Shaded Surface Display，SSD）、多平面重構（Multiplanar Reformat, MPR）、最大強度投射（Maximum Intensity Projection, MIP）提供給放射科或臨床醫師做參考，而劑量部份，還可以讓病人接受較少的吸收劑量以達到合理抑低（ALARA)的精神！

關鍵詞：三度空間電腦斷層，合理抑低，副鼻竇，空間解析度