INTRODUCTION

Sternal fractures are uncommon findings after blunt thoracic trauma, and they have been reported in approximately 8% of blunt chest trauma patients (1, 2). It is rare that a fracture is associated with cardiac or aortic injuries, but when it is combined with those injuries, such cases are often lethal. Thus, early diagnosis for sternal fracture is essential (3).

Because sternal fractures are clinically difficult to detect by inspection and palpation only, the diagnosis usually relies on imaging. Multidetector computed tomography (MDCT) scan is a major diagnostic tool for fractures, and it can usually detect sternal fracture in the emergency department. However, some patients are not diagnosed with the fracture on anaxial MDCT scan. Actually many doctors know sagittal reformation of chest MDCT is helpful for the diagnosis of sternal fracture after thoracic trauma.

MATERIALS AND METHODS

Patients and Examinations

Because this study was retrospective, institutional review board approval was waived; however, we did follow regional institutional review board policy.

We retrospectively reviewed medical records and chest CT scans of 716 patients who presented to the emergency department between January and December 2010. Two radiologists investigated chest CT images. We investigated numbers and locations of sternal fractures on axial images only and on both axial and sagittal images for each radiologist.
ment after trauma between January 2010 and December 2010. For the study, 82 patients (traffic accident 56, fall 13, crush injury 4, rolling down 2, post-cardiopulmonary resuscitation 1, and unknown causes 6) were diagnosed with sternal fracture under clinical and radiological evaluations. All of these 82 patients underwent bone scans and sternal fractures were confirmed by bone scan. An expert of nuclear medicine with 30 years of experience performed these confirmations. We informed the two reviewers of the trauma history, with some cases (n = 7) we also considered it a positive finding if there was abnormal increased uptake (means not shown on normal bone scan) at the sternum with just trauma history. The patients consisted of 53 men and 29 women, and their ages ranged from 20 to 85 years (mean age = 51 years). CT examinations were performed with a 64-MDCT scanner (Brilliance 64; Philips Medical Systems, Cleveland, OH, USA) with 2.5 mm axial thickness at 2.5 mm intervals. In addition, the MDCT scanner used 120 kVp and 200 mA with 35.64 table feed (pitch, 0.891). All images were reconstructed at 340 mm field of view with a standard B filter. All CT acquisition was done in one breath hold. Axial images were acquired from lung apex through upper pole of right kidney, and the reformation of sagittal images fully covered the area from the anterior skin to the back of the chest with 2.5 mm thickness.

Image Analysis

Two radiologists (First: 3-year-trained resident; Second: 6-year-experienced radiologist with chest-subspecialized fellowship) independently investigated the chest CT scans of these patients. We only informed the two reviewers of the trauma history, without any other clinical information. To avoid focusing on the sternum only, thus creating bias, and for them to make a similar routine practice, we requested full thoracic evaluations after trauma involving confirmations of the existence or absence of sternal fracture. Full thoracic evaluations involved the presence of hemothorax, the level and location of rib fracture, the presence and location of lung contusion and laceration, and the presence and level of aorta injury. At first, they reviewed axial images only and then they reviewed both axial images and sagittal reformation images in random order twice in 2-week intervals to minimize the recall bias. During the image review, if there was sternal fracture, the location (manubrium, body or xiphoid process) and grade according to severity, as introduced by Johnson and Branfoot (5), of sternal fracture were evaluated. A case positive for fracture was defined as one that had visible fracture lines involving the anterior or/and posterior side of the sternal manubrium, body, and xiphoid process. In addition, during the review of the axial images only, if there was sternal fracture, reviewers checked the presence of retrosternal hematoma. We removed the patients’ information from the Picture Archival and Communications System dataset and selected one from 82 patients in randomized order before allowing the two radiologists to review the axial sets and the axial and sagittal sets of this patient. They were allowed to change the window width and level, and all processes were achieved as blind analysis.

Statistical Analysis

We investigated numbers and locations of diagnosed sternal fractures on axial images only and on both axial and sagittal images for each radiologist. We compared the sensitivity for making the diagnosis before and after adding sagittal reformation images for each radiologist using the chi-square test, and the interobserver agreement between two radiologists on axial image only and on both axial and sagittal images, using dependant kappa value. Statistical analysis was performed using SAS (version 9.0; SAS institute, Cary, NC, USA) to compare sensitivity and to evaluate the interobserver agreement using dependent kappa. Statistical significance was calculated at the 95% confidence interval (p < 0.05).

RESULTS

Radiologist 1 found 58 sternal fracture patients (70.7%; manubrium 12, body 46, xiphoid process 0, missed 24) on axial image only, and 80 patients (97.5%; manubrium 21, body 56, xiphoid process 3, missed 2) on both axial and sagittal images. Radiologist 1 also found 42 (52.5%) retrosternal hematomas in 80 patients. These 42 patients found with retrosternal hematomas by radiologist 1 had sternal fractures. Radiologist 2 found 67 sternal fracture patients (81.7%; manubrium 15, body 49, xy-
sagittal images. Of 22, 10 (45.5%) were found to be grade I sternal fractures; 9 (40.9%) of 22 were found to be grade II; and III (13.6%) of 22 were found to be grade III. Radiologist 2 made the diagnosis in 14 additional patients (Fig. 3). Of 14, 10 (71.4%) were found to be grade I sternal fractures; 2 (14.3%) of 14 were found to be grade II; and 2 (14.3%) of 14 were found to be grade III. We also further classified the location and grade of additional fractures. There were 22 patients with sternal fractures (Table 1, Figs. 1, 2). Radiologist 1 additionally made the diagnosis in 22 patients with sternal fracture on both axial and sagittal images. Of 80 (97.5%) were found to be grade I sternal fractures; 9 (40.9%) of 22 were found to be grade II; and III (13.6%) of 22 were found to be grade III. Radiologist 2 made the diagnosis in 14 additional patients (Fig. 3). Of 14, 10 (71.4%) were found to be grade I sternal fractures; 2 (14.3%) of 14 were found to be grade II; and 2 (14.3%) of 14 were found to be grade III. We also further classified the location and grade of addition-

Table 1. Number and Location of Sternal Fractures for Each Radiologist

<table>
<thead>
<tr>
<th>Number of Fracture (%)</th>
<th>Manubrium</th>
<th>Body</th>
<th>Xiphoid Process</th>
<th>Missed</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Radiologist 1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>On axial images only</td>
<td>58 (70.7)</td>
<td>12</td>
<td>46</td>
<td>0</td>
</tr>
<tr>
<td>On axial and sagittal images</td>
<td>80 (97.5)</td>
<td>21</td>
<td>56</td>
<td>3</td>
</tr>
<tr>
<td><strong>Radiologist 2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>On axial images only</td>
<td>67 (81.7)</td>
<td>15</td>
<td>49</td>
<td>3</td>
</tr>
<tr>
<td>On axial and sagittal images</td>
<td>81 (98.7)</td>
<td>22</td>
<td>50</td>
<td>3</td>
</tr>
</tbody>
</table>

**Fig. 1.** The patient with traffic accident.
A. With axial images, two radiologists did not find any abnormality of sternum.
B. With sagittal reformation images, they found cortical disruption in anterior aspect of mid sternal body (white arrow).
C. Bone scan after 2 weeks, there was radioactivity in sternal body (white arrow). And there were some activities in Rt. 5th, Lt. 3-4th ribs due to multiple rib fractures (black arrowheads).

**Fig. 2.** The patient with traffic accident.
A. With axial images, two radiologists did not find any abnormality of sternum.
B. With sagittal reformation images, they found cortical disruption in posterior aspect of mid sternal body (white arrow).
C. Bone scan after 2 weeks, there was radioactivity in sternal body (white arrow). And there were some activities in Rt. 4-9th, Lt. 6-9th ribs due to multiple rib fractures (black arrowheads).
The Usefulness of Sagittal Reformation for Diagnosis of Sternal Fracture

Several previous studies have described the usefulness of sagittal reformation images of chest CTs for sternal fracture (4, 10, 11) and shown the diagnostic superiority of the sagittal reformation images over the axial or coronal reformation images (12). In addition to the previous studies, we specifically investigated the increased chance in making a diagnosis of the fracture by adding sagittal reformation images rather than observing axial images only. In particular, we analyzed results respectively for 2 radiologists with different experiences. Comparing these results, we could explain the decreased difference for diagnosis of sternal fracture between them.

Table 2. Location and Grade of Additionally Diagnosed Sternal Fractures after Adding Sagittal Images

<table>
<thead>
<tr>
<th>Radiologist 1</th>
<th>Grade I</th>
<th>Grade II</th>
<th>Grade III</th>
<th>Grade IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manubrium</td>
<td>5</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Body</td>
<td>5</td>
<td>4</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Xiphoid process</td>
<td>2</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>22</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Radiologist 2</th>
<th>Grade I</th>
<th>Grade II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manubrium</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Body</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Xiphoid process</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>14</td>
<td></td>
</tr>
</tbody>
</table>

DISCUSSION

CT is the modality of choice to evaluate anatomic detail as well as pathologic conditions of the sternum (6, 7). Sternal fracture may occur in any segment, but it most commonly affects the body of the sternum (8). Because the presence of sternal fracture implies high-energy trauma, the importance of sternal fractures lies in the high frequency of associated injuries such as fractured ribs, pulmonary and cardiac trauma, craniocerebral injuries, thoracic and lumbar spinal fractures, and so on (8, 9).

Several previous studies have described the usefulness of sagittal reformation images of chest CTs for sternal fracture (4, 10, 11) and shown the diagnostic superiority of the sagittal reformation images over the axial or coronal reformation images (12). In addition to the previous studies, we specifically investigated the increased chance in making a diagnosis of the fracture by adding sagittal reformation images rather than observing axial images only. In particular, we analyzed results respectively for 2 radiologists with different experiences. Comparing these results, we could explain the decreased difference for diagnosis of sternal fracture between them.

Because the sternum is fixed by articulations via clavicles and the superior seven costal cartilages of both sides (13), the vector of the force in trauma impacts the sternum from anterior to posterior (14), and the fracture line usually runs from anterior to posterior and fracture fragments displace anteriorly or poste-
Thus, if a fracture line is transverse or if displacement of a bony fragment is minimal, the diagnosis of the fracture is difficult to make on axial images only. However, sagittal reformation images make it possible to detect more sternal fractures by detecting small bony cortical discontinuity or displacement at the fracture site in other normal looking sternum on axial images. Many cases of additionally diagnosed sternal fractures in our study were classified as either grade I or II, and additional diagnosis on sagittal reformation led us to understand the usefulness of the images.

Further, sagittal reformation images decreased differences of diagnosis between the two radiologists owing to more precise confirmation for the fractures. Because of differences in experiences, it is sometimes difficult to distinguish sternal fracture from a motion or respiration artifact on axial images alone. When sagittal reformation images are added, they help in comparing suspicious findings with other body parts involving ribs and mediastinal structures, and that enables us to make a diagnosis of sternal fracture more easily and certainly. Therefore, we conclude that including sagittal reformation images can minimize the gap for making diagnosis of the fracture among radiologists, as our study result showed increased interobserver agreement for this reason.

Nevertheless, our study had several limitations. First, we investigated the confirmed patients with sternal fractures, and the study was not able to obtain other diagnostic performances such as sensitivity, specificity, or positive or negative predictive values. Second, we reviewed axial images and sagittal reformation images obtained with 2.5 mm thickness. Finally, we did not compare diagnoses based only on sagittal images with those made using axial images alone.

In conclusion, sagittal reformation of chest CT after trauma helps to diagnose sternal fracture. If sagittal reformation images of chest CT are added after trauma in emergency departments, it will enable physicians to make the diagnosis of sternal fracture more easily, thus leading to proper treatment.

REFERENCES

흉골 골절 진단에 있어서 CT Sagittal Reformation의 유용성

임동진 · 한 석 · 김영주

목적: 외상 후 발생한 흉골 골절의 진단에 흉부 전산화단층촬영 중 시상면 촬영의 유용성에 대하여 연구하였다.

대상과 방법: 2010년 1월부터 12월까지 외상 후 응급실을 방문한 환자 중 716명의 의무기록과 흉부 전산화단층촬영을 후향적으로 분석하였다. 두 영상의학과 의사가 각각 한 번은 오직 축상면 영상만, 한 번은 시상면과 축상면 영상 모두를 같이 보고 흉골 골절을 분석하였다.

결과: 첫 영상의학과 의사는 축상면 영상만 분석했을 때 70.7%의 흉골 골절을, 축상면, 시상면 모두를 분석했을 때 97.5%의 흉골 골절을 찾았다. 두 번째 영상의학과 의사는 축상면 영상만 분석했을 때 81.7%의 흉골 골절을 찾았으며, 축상면, 시상면 모두를 분석했을 때 98.7%의 흉골 골절을 찾았다. 시상면 영상을 추가했을 때 두 영상의학과 의사 모두의 민감도가 증가하였으며(\(p < 0.05\)), 두 영상의학과 의사 사이의 관찰자간합의(interobserver agreement)도 증가하였다.

결론: 흉부 전산화단층촬영의 시상면 영상은 흉골 골절 진단의 빠른 진단과 적절한 치료를 유도할 수 있다.

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