A Comparative Study of Spinal Bone SPECT versus X-ray Radiograph, CT or MRI in Patients with an Acute Compression Fracture of a Thoracolumbar Vertebral Body

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We retrospectively studied the spinal bone SPECT images of 84 consecutive patients (27 men, 57 women; mean age, 71.3 years; age range, 52 to 89 years) with acute non-traumatic collapse of a vertebra in the thoracolumbar spine. Of the 84 patients, 59 (70.2%) had a history of malignancy. Twelve patients (14.3%) had a vertebral metastasis and 72 (85.7%) had an osteoporosis in the vertebra. There were no clear differences between the vertebral body uptake patterns in the group with metastasis and the group with osteoporosis alone, although a horseshoe pattern tended to occur in the patients with a osteoporotic lesion (25% vs. 42%). Increased pedicle uptake was seen in 20 patients (23.8%, 20/84), 9 of whom (75.0%, 9/12) had a vertebral metastasis and 11 (15.3%, 11/72) did not (p<0.001). A pedicle sign or invasion on radiographs and/or CT images was seen in all 9 patients with metastatic disease patients (100%) but not in any of the 11 patients with osteoporosis. When pedicle uptake on SPECT images and the pedicle sign or invasion were used to diagnose bone metastasis in these 84 patients, sensitivity, specificity, positive predictive value, negative predictive value were 75.0% (9/12), 84.7% (61/72), 45.0% (9/20), and 95.3% (61/64), respectively. Radiograph and CT remain to be important studies to diagnosis acute non-traumatic collapse of a vertebra, although a spinal SPECT study provides some additional information.

Key Words: bone fracture, SPECT, osteoporosis, bone metastasis, CT, MRI

1. Introduction

Compression fracture of the vertebral body arises when a vertebral body is forcibly driven into the neighboring fragment and is excessively flexed. The superior and inferior surfaces of the vertebral body are impacted against each other, usually producing a wedge-shaped deformity on diagnostic images. “Impaction fracture”, “crush fracture”, and “collapsed vertebra” are synonyms of compression fracture that relate to osteoporosis patients. Collapsed vertebra is a common clinical problem in the elderly. If the cause of acute collapse is either malignant disease alone or osteoporosis alone or combination of both, it results in severe or refractory back pain. Magnetic resonance imaging (MRI) plays a key part in differentiating between acute collapse caused by malignant and benign lesions, but it is sometimes impossible to determine whether the cause of an acute vertebral collapse is benign or malignant in patients with a history of malignancy.

The recent increase in the elderly population in Japan has been associated with an increase
in patients with both malignant neoplasms and osteoporosis. Cancer patients with acute vertebral collapse tend to be examined by means of bone scintigraphy to differentiate between malignant and benign lesions, and/or, to detect other bone metastases. The role of bone single photon emission CT (SPECT) in the diagnosis of the cause of acute vertebral collapse has not been specifically studied\(^\text{7-9}\). The purpose of this study was to analyze and to compare the SPECT patterns of increased tracer accumulation that are observed in acute collapse caused by osteoporosis and malignant vertebral collapse.

2. Materials and Methods

We retrospectively examined the spinal bone SPECT images acquired at our hospital between December 2000 and December 2007 except when only planar images had been acquired. We enrolled the images of the 84 consecutive patients (27 men, 57 women; mean age, 71.3 years; range, 52 – 89 years) with acute non-traumatic collapse of a single vertebra in the thoracolumbar spine. The collapses were classified into 4 types according to the radiographic findings: wedge-shaped, fish-vertebra, pancake-shaped, and hemi-body\(^\text{10}\).

Of the 84 patients, 59 (70.2%) had a history of malignancy and the other 25 (29.7%) had no history of malignancy. The histologically confirmed diagnosis of the primary malignant lesion was: breast cancer in 13 cases, prostate cancer in 11 cases, lung cancer in 8 cases, renal cell carcinoma in 7 cases, colorectal cancer in 4 cases, hepatocellular carcinoma in 4 cases, cervix cancer in 4 cases, esophageal cancer in 2 cases, and cancer of the hypopharynx, stomach, bladder, skin, ovary, and endometrium in one case each.

Patients who had initially been suspected of having either osteoporosis or a spinal metastasis had been examined by bone SPECT to make the differential diagnosis. Patients had acute back pain, “acute” in being defined as pain of less than 2 months duration with a mean duration, 31 days; range 1 – 58 days. A single collapsed vertebra was observed on spinal radiographs (anteroposterior and lateral view of every patient). All patients had first undergone whole-body skeletal scintigraphy that had revealed board-like (pancake-like or discoid) or symmetrical dumbbell-like increased accumulation in the vertebral body on a planar skeletal scintigram, and had undergone thoracic and/or lumbar SPECT study immediately after the whole-body scintigraphy.

The final diagnoses were obtained by conventional radiograph, repeat bone scintigraphy, and follow-up study during at least one year. CT and MRI examinations were added in 4 and 20 patients, respectively, within 10 days of each other in every patient. Histological finding in a biopsy specimen was performed in 6 patients.

Bone planar images were acquired with dual-head gamma cameras (Toshiba GCA-7200A/D1) with a high-resolution, low-energy, parallel hole collimator at 3 to 4 hours after injection of 740 MBq (20 mCi) of \(\text{\textsuperscript{99m}Tc-methylene diphosphonate (MDP)}\). Both whole-body imaging and posterior spot views of the thoracicolumbar spine were acquired. Immediately after planar imaging SPECT imaging of the thoracicolumbar spine was performed using a high-resolution SPECT system (Toshiba GCA-9300A/HG) with three-head rotating cameras equipped with high-resolution, low-energy, parallel-hole collimators. Data were accumulated for 30 angles (4 degrees a step, 120 degrees) with 42 seconds per angle for each detector. The acquisition
time for the projection data was 21 minutes. A Butterworth prefilter and filtered back projection with a Shepp and Logan filter at 0.18 cycles per pixel cutoff frequency were used for image reconstruction of axial, coronal, and sagittal sections in a 128 × 128 matrix. No tissue attenuation correction or scatter subtraction was performed. The resolution at the center of the reconstructed slice was 11.6 mm FWHM. Each reconstruction slice was two pixels thick (3.2 mm). The film-density characteristic curve algorithm that yielded the best quality film of vertebral SPECT was selected.

Two interpreters viewed and evaluated vertebral axial, sagittal, and coronal section SPECT images, referring to planar images, radiographs, and to CT or MRI images, if there were any. Pedicle sign was defined as disappearance of pedicle configuration due to osteolytic and/or osteoblastic metastasis on radiograph.

Statistical analyses were performed using chi-square test for independence.

3. Results

Of the 84 patients with acute collapse of a single vertebral body, 12 (14.3%) had metastatic collapse and 72 (85.7%) had osteoporosis alone. It was unable to differentiate between metastasis and osteoporosis based on the radiographic classification (Table 1).

The planar and SPECT images showed increased uptake in the collapsed vertebral body in every patient. Vertebral-body uptake was classified into three patterns: a diffuse pattern, a horseshoe pattern, and a hemi-body pattern. The horseshoe pattern means that there was uptake at the rim of the body and photon deficiency in the central part of the body. There were no clear differences in vertebral body uptake patterns between the vertebrae with metastasis alone and with osteoporosis alone, although the horseshoe pattern tended to occur in patients with an acute collapse due to osteoporosis (25% vs. 42%) (Table 1).

In addition to the increased vertebral body uptake, increased pedicle uptake was seen in 20 patients (23.8%, 20/84) (Fig. 1). Of the 20 patients, 9 (75.0%, 9/12) had vertebral metastasis and 11 (15.2%, 11/72) did not (p<0.001). The pedicle sign or invasion (destruction of the pedicle and/or posterior margin of the body of the vertebra) was observed on the radiographs and/or CT images of all 9 patients with metastasis, but not in any of the 11 patients with osteoporosis (Table 1, Fig. 2). More specifically, the pedicle sign or invasion was observed on the radiographs of 7 of the 9 patients, and on the CT images alone of the other 2 patients. When a combination of pedicle uptake on SPECT images and the pedicle sign and/or evidence of pedicle invasion finding was used to diagnose vertebral metastasis in patients with collapse of a single thoracolumbar vertebra, sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) were 75.0% (9/12), 84.7% (61/72), 45.0% (9/20), and 95.3% (61/64), respectively.

It was unable to differentiate between metastasis and osteoporosis based on MRI, because of the patients with acute osteoporotic collapse 26.7% (4/15) had low-signal intensity in the pedicle on T1WI (Table 1).

4. Discussion

The diagnosis of osteoporosis is based on bone mineral density (BMD) measurement, and dual-energy X-ray absorptiometry (DXA) is currently considered the gold standard for clinical measurement of BMD. However, DXA
Table 1   Comparison of results of SPECT, radiography, CT and MRI between positive pedicle uptake and negative pedicle uptake on vertebral SPECT images

<table>
<thead>
<tr>
<th>Metastases' 12 patients</th>
<th>Pedicle uptake (+)</th>
<th>Pedicle uptake (-)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPECT (n=12)</td>
<td>9*</td>
<td>3</td>
</tr>
<tr>
<td>Vertebral body uptake</td>
<td>D: 6, Hs: 1, Hemi: 2</td>
<td>D: 1, Hs: 2, Hemi: 0</td>
</tr>
<tr>
<td>Radiograph (n=12)</td>
<td>H: 3, P: 3, W: 2, F: 1</td>
<td>H: 0, P: 0, W: 3, F: 0</td>
</tr>
<tr>
<td>CT (n=2)</td>
<td>PD: 2</td>
<td>0</td>
</tr>
<tr>
<td>MRI (n=5)</td>
<td>L: 4</td>
<td>H/I: 1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Osteoporosis: 72 patients</th>
<th>Pedicle uptake (+)</th>
<th>Pedicle uptake (-)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPECT (n=72)</td>
<td>11**</td>
<td>61</td>
</tr>
<tr>
<td>Vertebral body uptake</td>
<td>D: 5, Hs: 5, Hemi: 1</td>
<td>D: 36, Hs: 25, Hemi: 0</td>
</tr>
<tr>
<td>Radiograph (n=72)</td>
<td>H: 1, P: 2, W: 6, F: 2</td>
<td>H: 0, P: 3, W: 36, F: 22</td>
</tr>
<tr>
<td>CT (n=2)</td>
<td>0</td>
<td>N: 2</td>
</tr>
<tr>
<td>MRI (n=15)</td>
<td>L: 2, H/I: 3</td>
<td>L: 2, H/I: 8</td>
</tr>
</tbody>
</table>

*: All of the 9 patients had pedicle sign on radiographs and/or CT.

**: None of the 11 patients had pedicle sign on radiographs.

D: diffuse uptake
Hs: horseshoe-like uptake (photon-deficiency in the center of the body)
Hemi: hemibody uptake
H: hemibody collapse
P: pancake-shaped collapse
W: wedge-shaped collapse
F: fish vertebra collapse
PD: pedicle destruction on CT
N: normal finding in the pedicle on CT
L: low signal intensity in the pedicle on T1WI
H/I: high or iso signal intensity in the pedicle on T1WI

is inaccurate in patients with vertebral compression fractures, bone hypertrophy, scoliosis, and extraosseous calcification. Clinically, it is important to become familiar with the radiologic findings of osteoporosis. Healing vertebral compression can lead to an increase in bone density due to compaction of trabeculae and callus formation, whereas osteoporosis results in greater radiolucency of vertebral bone.

In our series, only 20.3% (12/59) of the 59 patients with a primary cancer had vertebral metastasis and that none of the 25 patients with no history of malignancy had a vertebral metastasis. But the results of our study showed that it is impossible to differentiate between benign and malignant causes of acute vertebral collapse based on the radiologic classification. Three quarters of patients with a history of malignancy who develop an acute vertebral collapse have a benign disease or osteoporosis of the spine.\(^{10}\)

MRI is performed to differentiate between metastasis and osteoporosis in the patients with acute collapse. Reportedly, however, signal intensity characteristics on MRI are useful, but not enough for the differentiation\(^{30,4}\). Pedicle change with expansile lesion on MRI can exclude a benign cause\(^{11}\).
The tracer accumulation in the vertebral body on the SPECT images was not always uniform. The classification of vertebral body uptake patterns was also found to be incapable of being used to differentiate between benign and malignant causes of acute vertebral collapse, although horseshoe pattern tended to occur in patients with a collapse as a result of a benign cause approximately twice as often as when caused by a malignant lesion.

The horseshoe pattern was seen in 25% (3/12) of collapses caused by metastasis. The central part of the vertebral body seemed to exhibit photon deficiency in the patients with metastasis, first, as a result of the central part being completely replaced by a tumor mass because it is mainly composed of the marrow and usually the initial site of metastasis, and, second, because the tumor mass compresses the feeder vessels, which leads to decreased perfusion in the central part of the body.

SPECT images provided us with anatomic information in more detail than planar images\(^7\)\(^8\)\(^9\)\(^10\)\(^11\)\(^12\). Bone metastasis is suspected when increased uptake extending from the vertebral body into the pedicle is seen in a patient with
Fig. 2  A 70-year-old woman with a history of cervical cancer and acute back pain was examined by means of radiography, bone scintigraphy, and CT. The radiograph (upper left) shows a compression fracture of L-5, which exhibits osteoblastic change, but the margins of the pedicles are distinct. There is increased uptake in L-5 on the posterior view (upper right). Vertebral SPECT reveals increased uptake in the vertebral body and pedicles of L-5 (lower left). The CT image shows degenerative joint changes with normal appearing pedicles (lower right). The patient’s back pain resolved, and she was asymptomatic after follow-up for one-year.

acute collapse of a single vertebra. However, this SPECT finding is not very helpful for differentiating between benign lesions and malignant lesions, because increased tracer accumulation localized to the L4−L5 facet region is frequently noted in patients with articular facet osteoarthritis. Destruction of one or both pedicles of a vertebra seen on radiograph is well known evidence of skeletal metastasis and is called the pedicle sign. In this study, pedicle sign was defined as disappearance of pedicle configuration attributable to osteolytic and/or osteoblastic metastasis on radiograph.

It is often accompanied by the appearance of an empty vertebral body. Pedicle involvement usually occurs as a result of further extension of a metastasis within the posterior portion of the vertebral body. Nuclear medicine physicians should carefully interpret plain spinal radiographs as well, because the collapsed vertebra can obscure or erase a pedicle sign. MRI or CT should be performed immediately if a pedicle sign is uncertain or equivocal. A SPECT/CT acquisition will be clinically useful in differentiating between acute collapse caused by malignant and benign lesions, because it pro-
vides both functional and anatomical information in a single session\textsuperscript{10} -\textsuperscript{16}.

The results of this study showed that 75.0\% of the vertebral metastasis exhibited increased pedicle uptake and 15.2\% of the osteoporosis only did (p < 0.001), and that specificity and NPV were 84.7\% (61/72) and 95.3\% (61/64), respectively, when a combination of pedicle uptake on SPECT images and a pedicle sign or invasion was used to diagnose metastasis. The finding of increased pedicle uptake as well as the pedicle sign is a useful finding for making the differential diagnosis. The pedicle uptake in osteoporosis is mostly attributable to pedicle fracture affected by acute crush of the vertebral body.

In conclusion, radiograph and CT remain to be important studies to diagnosis acute non-traumatic collapse of a vertebra, although a spinal SPECT study provides some additional information.

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要 旨

急性胸腰椎圧迫骨折患者の脊椎骨 SPECT と
単純 X 線写真, CT, MRI との比較研究

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非外傷性急性胸腰椎圧迫骨折患者 84 例（男 27，女 57，平均年齢 71.3 歳，年齢分布 52 〜89 歳）の脊椎骨 SPECT を後向きに検討した。84 例中，59 例（70.2%）は急性疼痛の既往があった。12例（14.3%）が脊椎転移を伴い，72例（85.7%）が骨粗鬆症であった。馬蹄型集積が骨粗鬆症患者にみられる傾向があったが（脊椎転移25%，骨粗鬆症42%），脊椎転移と骨粗鬆症のみの各患者群において椎体集積分布パターンに明らかに差はみられなかった。20例（23.8%，20/84）に椎弓根集積がみられ，そのうち，9例（75.0%，9/12）が脊椎転移，11例（15.3%，11/72）が脊椎転移ではなかった（p<0.001）。単純 X 線写真または CT での pedicle サインあるいは椎弓根浸潤が脊椎転移 9 例（100%）にみられ，骨粗鬆症のみの 11 例にはみられなかった。84 例に，SPECT での椎弓根集積と pedicle サイン，椎弓根浸潤の所見を骨転移診断に用いると，感度は 92.8%，特異度は 71.4%（95%信頼区間は 92%），特異度は 71.4%（95%信頼区間は 92%）であった。脊椎骨 SPECT は非外傷性急性胸腰椎圧迫骨折に付加的情報を提供するが，単純 X 線写真，CT はその診断に依然重要な検査である。