Usefulness of pinhole collimator in differential diagnosis of metastatic disease and degenerative joint disease in the vertebrae; Evaluation by receiver operating characteristics (ROC) analysis

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In order to evaluate the diagnostic efficacy of pinhole collimator (PHC) imaging combined with an X-ray for vertebral metastasis, our prospective study has employed receiver operating characteristics (ROC) analysis in 21 patients, 11 with osseous metastasis and 15 with degenerative joint disease in the lumbar vertebrae.

PHC imaging provided better anatomic information on the extent of $^{99m}$Tc-MDP accumulation. PHC vertebral scintigraphy had a considerable impact on the decision-making process, although with variations and not very satisfactory results among the physicians with little experience. Our study suggests that PHC imaging and X-ray film are useful in differentiating between osseous metastasis and degenerative joint disease in the vertebra.

Key words: pinhole collimator, bone scintigraphy, Receiver operating characteristics analysis, Bone metastasis, Degenerative joint disease

INTRODUCTION

In aged patients with suspected vertebral metastasis, it is often difficult to differentiate early osseous metastasis from degenerative joint disease in the vertebrae on bone scan. It is well known that a pinhole collimator (PHC) provides clearer definition of small areas and can delineate lesions otherwise barely visualized with a parallel hole collimator.

The aim of our study is to evaluate the diagnostic efficacy of PHC imaging combined with X-raying for vertebral metastasis. The method used in our prospective study was receiver operating characteristics (ROC) analysis, to determine to what extent the usage of PHC in vertebral bone scan is able to improve diagnostic accuracy.

MATERIALS AND METHODS

Bone scans with $^{99m}$Tc-MDP were performed in 21 patients, 11 with osseous metastasis in the lumbar spine from various primary lesions (5 males, 6 females, mean age 64 yr) and 15 with degenerative joint disease in the lumbar vertebrae, that is, spondylosis deformans (6 males, 9 females, mean age 69 yr). In each case, the final diagnosis was established by biopsy or autopsy, and by reviewing each patient’s medical record, including subsequent clinical course over a 2-yr period of time, and correlation with X-CT or other radiological studies.

Posterior dual images were obtained at 3 hours after i.v. injection of 20 mCi (740 MBq) of $^{99m}$Tc-MDP in all of the patients, with a low energy all-purpose parallel hole collimator (LEAP) and PHC. The LEAP has 42,000 holes and the PHC has a 6-mm aperture, with a 10 cm focal length. PHC imaging was made at a source-aperture distance of 5 to 10 cm and 500 Kcount were obtained. The gamma camera used was Toshiba GCA 401 model.

The blinded observers, 1 junior resident (3 months’ nuclear medicine experience), 1 senior resident (1...
year's nuclear medicine experience), I nuclear medicine specialist, separately examined the films for each of the three different scintigraphic detection situations, that is, first, the spot film taken by LEAP only, second, the combination of spot films taken by LEAP and PHC, third, X-ray films in addition to the combination. The impact of PHC imaging and X-ray films on the physician's diagnostic confidence was evaluated by ROC analysis. The confidence ratings used to produce a ROC curve are shown in Table 1.

Further, we assessed accumulation patterns in the vertebra obtained by PHC scintigraphy. The PHC findings were characterized in terms of localization, appearance and homogeneity of abnormal radio-nuclide accumulation.

Table 1 The confidence rating used to produce a ROC curve

<table>
<thead>
<tr>
<th>Rating</th>
<th>Description</th>
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<tbody>
<tr>
<td>4</td>
<td>Metastasis definitely present</td>
</tr>
<tr>
<td>3</td>
<td>Metastasis possibly present</td>
</tr>
<tr>
<td>2</td>
<td>Metastasis probably not present</td>
</tr>
<tr>
<td>1</td>
<td>Metastasis almost certainly not present</td>
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Fig. 1 The ROC curves obtained by Doctor A, junior resident. By adding PHC information, he obtained a little increase in the true positive rate, but there is a crossing of the two curves.

Fig. 2 The ROC curve obtained by Doctor B, senior resident. He obtained a slight increase in the true positive rate by adding PHC information, but there are crossings among the three curves.

Fig. 3 The ROC curves obtained by Doctor C, nuclear medical specialist. PHC information apparently offers a better detection performance and a lot better one by including the information from X-ray films. PHC and X-ray information contributed to the decrease in the false positive rate.
Table 2  Accumulation patterns in the vertebra, obtained from PHC scintigraphy

<table>
<thead>
<tr>
<th>Accumulation patterns</th>
<th>Metastasis</th>
<th>Deformans</th>
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<tbody>
<tr>
<td>Hot spot accumulation</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Diffuse homogeneous accumulation</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Short segmental accumulation</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>End-zone accumulation in two opposing end-plates</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>Board-like accumulation</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Inhomogeneous accumulation</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>11</strong></td>
<td><strong>15</strong></td>
</tr>
</tbody>
</table>

Fig. 4  An 88-year-old male with a history of bladder cancer. He had been complaining of lower back pain for 3 mo. The LEAP image shows increased tracer accumulation in the fifth vertebra (arrow), but offers no anatomic information beyond that. The PHC scintigram shows end-zone accumulation of radiotracer, typical of degenerative joint disease. The radiography of this patient shows definite degenerative joint disease of the lumbar vertebra, and no finding of osseous metastasis.
RESULTS

The ROC curves obtained by three interpreters, a junior resident (Doctor A), a senior resident (Doctor B) and a specialist in nuclear medicine (Doctor C), are shown in Figs. 1, 2, 3, respectively. The area of each curve is shown on the top of each figure.

The junior and senior residents’ detection performances were relatively poor, and PHC imaging did not greatly affect the differential diagnosis between osseous metastasis and degenerative joint disease in the vertebra. It is difficult to evaluate the X-ray film’s impact on the detection performances because the ROC curves cross. On the other hand, in the case of the specialist in nuclear medicine, the PHC information apparently makes a better detection performance (area under the ROC curve; 0.83) possible, compared with the LEAP information only (area under the ROC curve; 0.69). The information obtained from the X-ray makes possible an even better detection performance (area; 0.98).

Table 2 shows accumulation patterns for the vertebra, obtained from PHC scintigraphy. End-zone accumulation in the two opposing end-plates and board-like accumulation were relatively characteristic patterns for degenerative joint disease in the vertebrae. PHC imaging provided superior anatomic information of the extent of $^{99m}$Tc-MDP accumulation (Figs. 4, 5, 6).

DISCUSSION

Bone scintigraphy is at present the most common imaging procedure used in nuclear medicine. The major advantage of the bone scan is its extreme sensitivity. Studies comparing bone scans with skeletal surveys find that about one-third to one-half of lesions noted on the scan are not seen in the conven-

Fig. 5 A 77-year-old male with a history of prostate cancer. The LEAP image shows an increased accumulation of radiotracer in the fourth lumbar vertebra, and PHC scintigram clearly reveals a diffuse, homogeneous accumulation, suggesting osseous metastasis. The X-ray film of this patient shows an osteoblastic change in the fourth lumbar vertebra. Autopsy confirmed osseous metastasis from the prostate cancer.
Fig. 6 A 61-year-old female with a history of bladder cancer. The LEAP image shows increased accumulations in the first and fourth lumbar and eleventh thoracic vertebrae. The PHC scintigram shows a board-like accumulation, suggesting a compression fracture. The X-ray discloses diffuse osteoporosis and deformity of the vertebrae and compression fractures of the first and fourth lumbar and eleventh thoracic vertebrae. No malignant change is seen.

Additional X-ray surveys; the false-negative rate for bone scan is about 2%1-5. Despite the spectacular growth of bone scanning, one major problem in osseous metastasis survey is that there is a considerable variation in the reported incidence of patients with primary malignancies.6-10 Especially a solitary lesion detected on the bone scan of a patient being assessed for osseous metastasis presents a major challenge to the diagnostic acumen of the physician. Miscellaneous benign bone lesions can frequently account for these focal areas of uptake. Every aged patient has more or less degenerative joint diseases in the vertebrae, so that early vertebral metastasis is often difficult to discriminate from degenerative joint disease by means of X-rays only. Several investigators reported that approximately 30 to 65% of solitary bone scan lesions in patients with known primary malignancies were found to be osseous metastasis.11,12 O’Connell13 reported that bone scan read as “equivocal” reached 22% of the total number interpreted. Also, interpreter variation can alter results.

In these circumstances, these variations are probably due, for the most part, to difference in the scanning technique and recognition of patterns such as can be seen in degenerative joint disease. We are convinced that high quality image and precise and careful interpretation of bone scans are needed in differential diagnosis.

PHC generally provides better resolution and greater magnification, although it has drawbacks such as lack of sensitivity, distortion of image and foreshortening. It is well known that PHC is particularly useful for the examination of the hips, the hands
and wrists or a localized area. Bahk et al.14 published an excellent paper on the usefulness of PHC imaging of the spine. However, they did not implement quantitative assessment of PHC imaging. We consider that the usefulness of PHC imaging should be evaluated quantitatively by some detection theory or in a meaningful way.

PHC imaging and X-ray film information did not have a significant impact on the decision-making process in the junior and senior residents. The fact that the area under the ROC curve of LEAP was less than 0.5 in the case of the junior resident is probably because he did not have a thorough understanding of the recognition patterns in bone scan and roentgenogram of both diseases. The detection of the senior resident was a little better than that of the junior resident, but PHC imaging and X-ray film information did not have a great impact on the decision-making process, either. The reason why there were crossings of the ROC curves seems to be that lesions with predominant uptake which read as osseous metastasis on the bone scans could not be clearly identified as an abnormal finding on the X-ray films.

On the other hand, the detection performance of the nuclear medicine specialist was much better and PHC and X-ray film information apparently had a great impact on the decision-making process, and were capable of improving diagnostic accuracy. PHC and X-ray film information contributed, not to the increase in the true positive rate, but to the decrease in the false positive rate in the case of the nuclear medical specialist, whereas it contributed to a little increase in true positive rate in the residents. The results reveal that the use of PHC results in a noticeable improvement in anatomic and spatial resolution. In reviewing the results obtained by the junior and senior residents, we believe that it is very important to have a full knowledge of recognition patterns of diseases in the bone scan, based on considerable experience in nuclear medicine. For the specialist, the X-ray findings were also useful for differentiation, although it is often difficult to differentiate osseous metastasis from degenerative joint disease in patients with both early osseous metastasis and mild degenerative joint disease in the same vertebra.

Another scintigraphic detection situation, that is, the combination of spot films taken by LEAP and X-ray was not evaluated in our study. In view of our ROC curve results (Figs. 1, 2, 3), we believe that X-ray film information has some degree of impact on the decision-making process, not for a resident but for a specialist.

In conclusion, PHC imaging provided better anatomic information on the extent of $^{99m}$Tc-MDP accumulation. PHC vertebral scintigraphy had a considerable impact on the decision-making process, although with variations and not very good results by physicians with little experience. Our study suggests that PHC imaging and X-rays are useful for differentiating between osseous metastasis and degenerative joint disease in the vertebra.

REFERENCES