Planar Pinhole Scan and Pinhole SPECT: Means to Enhance Anatomic and Molecular Diagnosis of Skeletal Disorders

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Introduction

Structure presented as anatomy and *biofunction* expressed in terms of metabolism or molecular chemistry are two basic phenotypic manifestations of the life phenomenon. Hence, the sciences that deal with health and disease in men need to view and grasp the body from a well balanced, dualistic stand point of anatomy and biochemistry. Scintigraphy is probably the most efficient tool for the pursuit of this goal. Actually, scintigraphy has been extensively utilized in osteology, cardiology, endocrinology, neuroscience, and oncology with the accumulation of an enormous body of advanced knowledge. Biofunctional data derived from metabolic, molecular, neuroreceptor, and antigen-antibody scans of the skeleton, heart, brain, endocrine glands, and solid tumor are unique. In contrast, however, the feasibility of scintigraphy to depict anatomy in detail has been left being relatively less explored and understood creating an unbalance in the development of nuclear imaging science in terms of structure and biofunction. As is well known, planar scintigaphy in general lacks detailed anatomical information that is required for an analytical interpretation and hence accurate diagnosis. Thus, one customarily has to borrow wanted information from radiography, CT, and/or MRI. One of the reasons for this crucial problem for nuclear imaging is associated with the low resolution of planar scan that is usually displayed on a *miniatured format* (Fig. 1A) [1]. The level of resolution of small scintigraph ranks at the bottom among competing imaging modalities (Table 1). It is, therefore, logical and necessary to take measures to remedy the situation. There is a solution. It is optical magnification which is easily achievable by pinhole collimator.

Typical clinical situation is bone scintigraphic diagnosis. It was once the most widely performed and most rewarding nuclear imaging but is now losing its popularity because of anatomical ambiguity, low specificity, and frequent incorrect diagnosis [1-4]. According to a most recent survey conducted in European institutions, bone

Table 1. Representative Values of Limiting Spatial Resolution

Imaging Technique	Resolution (lp/mm)
Non-screen radiography	25 - 100
Screen radiography (200 - 600 speed)	5 - 10
Computed tomography	~0.7
Magnetic resonance imaging	~0.3
Ultrasound (axial resolution)	~0.2
Planar scintigraphy	<0.1
Pinhole scintigraphy	0.2*

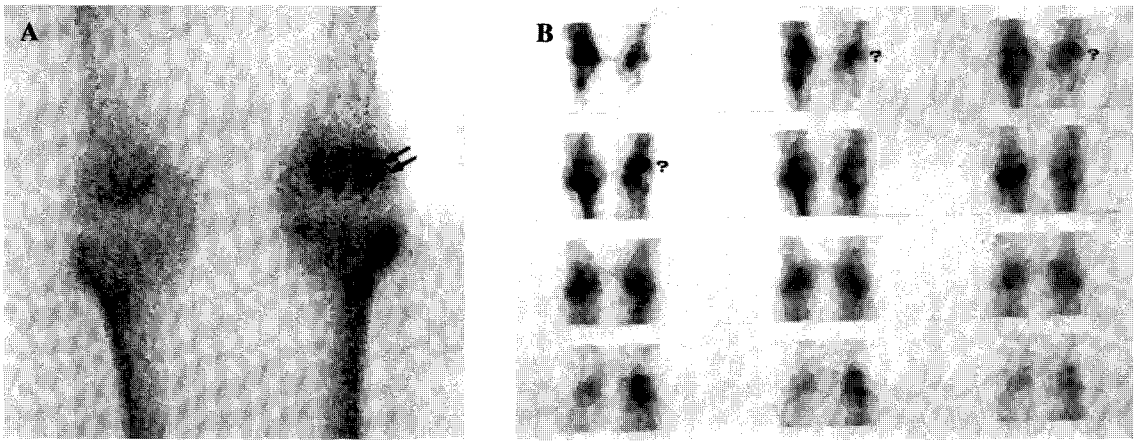

Fig. 1. Planar SPECT enhances contrast but not improves resolution. **A** Anterior planar scan of both knees with a cortical desmoid in the left lateral femoral epicondyle shows a small hot area (arrows). Note that the spot image is reduced to about one fifth of the original knee size not revaling anatomical detail. **B** Coronal planar SPET shows significant contrast enhancement revealing many hot areas. Of these the one marked with arrowhead is the lesion and all others are physiological hot areas. Note that contrast enhancement occurs in both normal and pathological bones causing confusion.

scan now ranks in the fourth place after cardiology, oncology, and endocrinology [5]. As already mentioned, the low diagnostic yield of planar bone scinitigraphy is related with the minification of displayd scan image. Indeed, the planar scintigraphy scales down the size of scan image to approximately 1/5 of the actual size on the spot view (Fig. 1A) and 1/15 on the whole-body scan, and the minification conceals anatomy as well as metabolic information. Increased or decreased tracer accumulation demonstrated on the ordinary bone scan is perceived and recognized simply as an amorphous hot or cold area without showing topography in any useful detail. SPECT might mistakenly be considered to enhance the resolution but it is not. SPECT is primarily designed for sectioning and separation of the plane of interest enhancing the contrast up to six fold but it does not improve the spatial resolution (Fig. 1B) [6, 7]. Technically, SPECT generates sectioned images from planar scans which have already been processed on small matrices. Thus, it is obvious that in order to raise the diagnostic feasibility of scan one must enhance the resolution by enlarging or, more correctly, normalizing minified scan to actual or near-actual size of the organ or part of the body imaged by appropriate magnification technique.

Technical Notes

Currently, four different magnification modes are available. They are the blowupzoom technique, the geometric magnification, the converging collimator magnification, and the pinhole magnification (Fig. 2). The blowup magnifies original image data through interpolation of surrounding pixel data for a new pixel value assigned between them. Consequently, notwithstanding apparent magnification the image quality is degraded without true improvement of resolution. Geometric magnification is achieved by the analogue change in the gain of digitally controlled amplifiers for displacement signals. After the

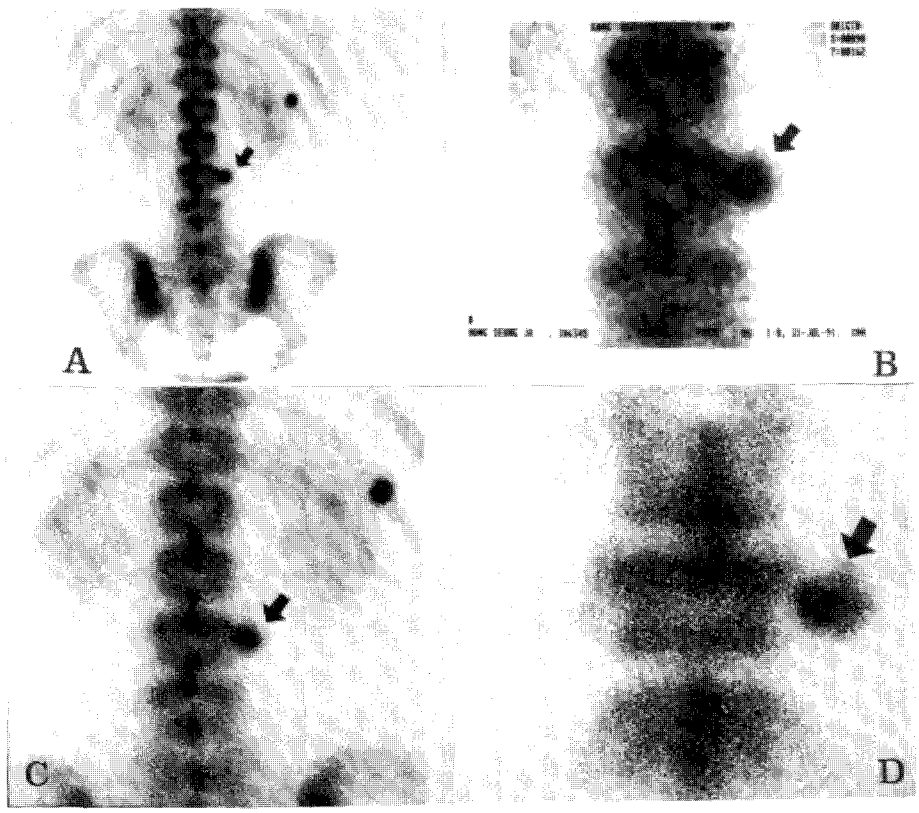

Fig. 2. Scintigrams of the lumbar spine(A-D) showing the difference in the grade of resolution among four different magnification modes used to portray metastasis in the L3 transverse process (arrow). **A** LEAP collimator scan, **B** Blowup or zooming, **C** geometric enlargement, and **D** pinhole magnification. Note the most clear identification of topography on pinhole scan.

factor of magnification is determined, acquisition data are also multiplied by magnification factor as desired. Since, in this method, pixel size is not changed with magnification option, the resolution remains the same as in the reference scintigram. The converging collimator magnification is optical. It is used with large-field-of-view gamma camera for the imaging of small organs. Magnification is dependent on focal distance which is the distance from the collimator surface. The resolution is similar to that of multihole parallel collimator with rapid loss with distance to object. The pinhole magnification, a magnification with true improvement of resolution, can be achieved using a collimator having pinhole aperture. The magnification principle is optical. It is to be mentioned that, because of acute change in the field-of-view size with distance, pinhole scintigraphy suffers from miniaturing distortion of image in the periphery. In practice, however, such distortion matters only when the evaluation of size is critical which is an extremely rare in actual clinical setting. Rather, miniaturing distortion can be beneficial since the minification of the structure out of interest contributes to close up the structure of interest in the foreground.

Technically, there are two different modes in pinhole scan. One is planar mode (Fig. 3B) [1]

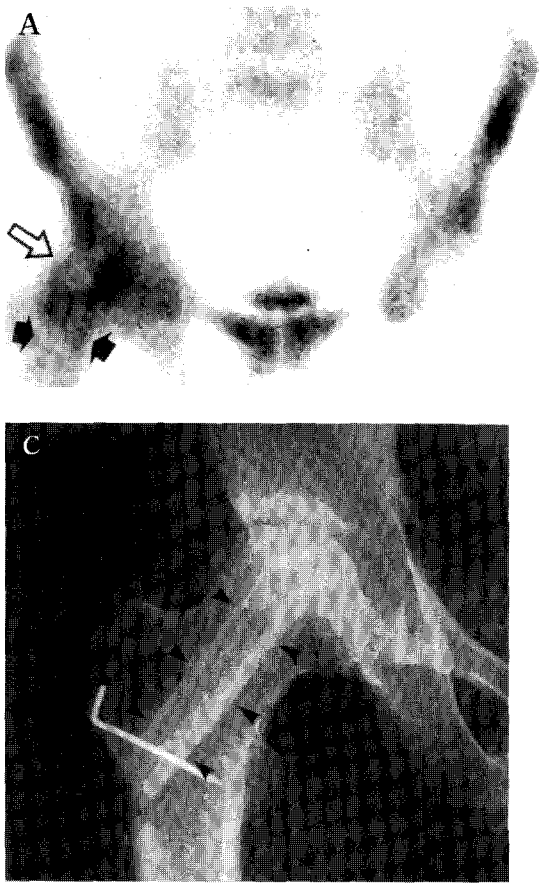

Fig. 3. Remarkable difference among diagnostic feasibilities of various scan modes used for imaging of vascularised fibular graft instituted for the treatment of avascular necrosis.
A Planar spot scan shows irregular tracer accumulation in the femoral neck denoting graft (*arrows*) and an ill-defined photopenia in avascular necrosis (*open arrow*). **B** Planar pinhole scan portrays the graft as a distinct photopenic intramedullary peg(*arrow- heads*). Necrosis is also clearly shown(*avn*).
C Anteroposterior radiograph shows fibular graft in the femoral neck(*arrowheads*). Note excellent topographic correlation and pinhole scans feasibility to portray metabolic profile of alive graft and avascular capital necrosis.

and the other is tomographic or SPECT mode (Fig. 4) [8]. Planar pinhole scan is achivable by simply replacing the multihole collimator with pinhole collimator. Pinhole SPECT is the hybrid of pinhole scan and body tomography. Both planar and SPECT mode enormously improve the spatial resolution pertmitting piecemeal analysis and more accurate diagnosis of bone and joint diseases without borrowing anatomical information from radiography, CT, or MRI (Figs. 3 and 4). Pinhole scans enhance not only the spatial resoluton but also the contrast. Formerly, pinhole scan consumed long time but with modification and refinement it can now be finished within 15-20 min. The time needed for planar pinhole scan is actually much shorter than the time required for planar SPECT. Of course, pinhole SPECT takes longer time than the conventional planar SPECT. Pinhole SPECT is used for the diagnosis of the thyroid gland [9] and its extendeded application to the brain, heart, and tumor is eagerly anticipated with future develop- ment of hardware technology and computor sciences. It is to be noted that generally analogue gamma camera produces better pinhole images than digital camera does.

Advantages and Pitfalls of Pinhole Scintigraphy and Pinhole SPECT

As mentioned, two different methods are available for the enlargement of scan image, the

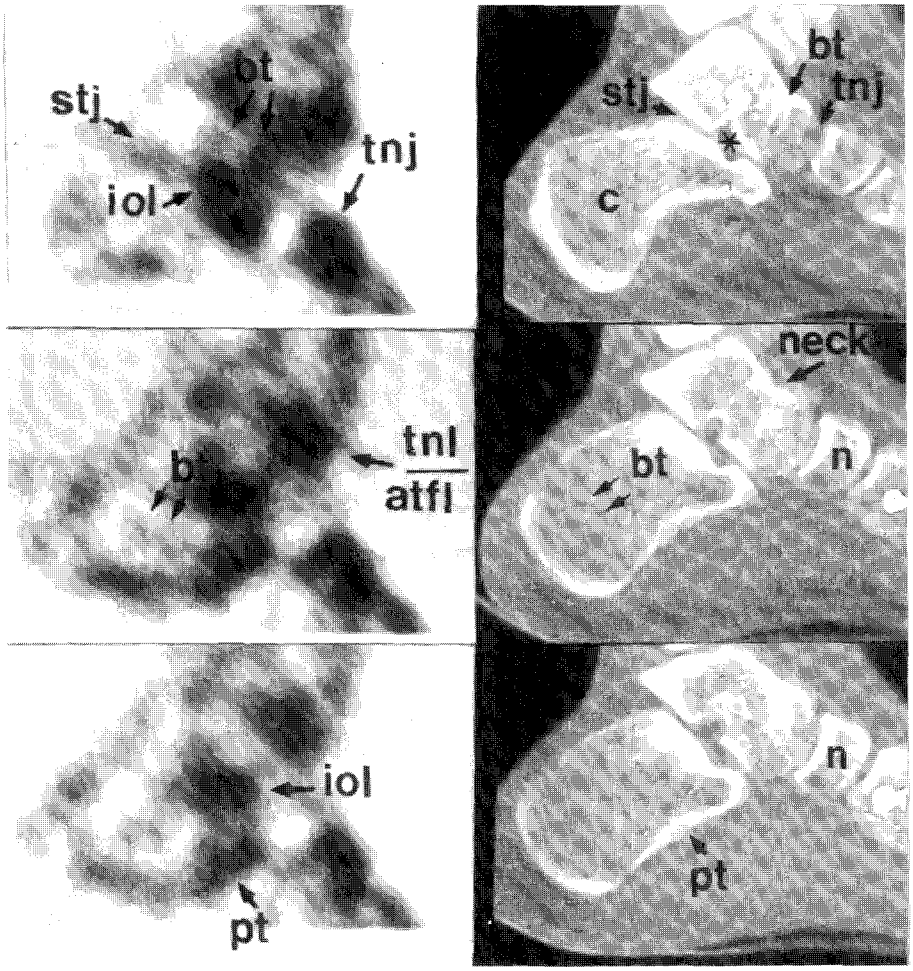

Fig. 4. Pinhole SPECT of normal ankle with CT correlation. **Left column** (top to bottom) Sagittal pinhole SPET scans show the subtalar joint (*stj*), interosseous ligamental insertion (*iol*), talonavicular joint (*tnj*) and intraosseous condensed bone trabeculae (*bt*), insertions of the talonavicular (*tnl*), anterior talofibular (*atfl*) and interosseous ligament (*iol*) and the peroneal tendon (pt). **Right column** (*top to bottom*) Sagittal CT scans show excellent correlation with SPET scans. c, *, n and c1 respectively denote the calcaneus, tarsal sinus, navicular bone and first cuneiform.

electronic and optical nethods. The former method includes zoom and geometric magnification and the latter includes pinhole and converging collimator magnification. Of these, the pinhole magnification is the most efficient and *truly* enhances the spatial resolution portraying the anatomy and biochemical profile in an amazing detail [1, 10 - 17]. The level of pinhole resolution is such that it can portray gross anatomy as clearly as radiography(Fig. 3). Pinhole scintigraphy depicts even very subtle and often specific metabolic alterations which can be detected by no other imaging modalities [14 - 16]. Benefits can further be increased by the use of the dual-head pinhole scintigraphy [18]. This method makes use of a dual-head gamma camera system and

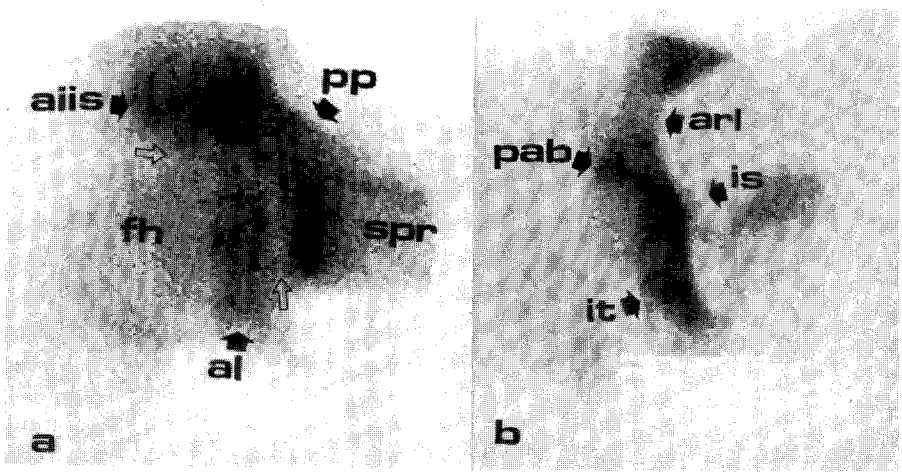

Fig. 5. Dual-head planar pinhole scan generates a pair of high-resolution images at one time. **A** Anterior planar pinhole scan of normal hip joint clearly delineates the foreground anatomy including femoral head (*fh*), joint space (*between arrows*), acetabular fossa and labrum (*al*), anterior inferior iliac spine (*aiis*), pecten pubis (*pp*) and superior pubic ramus (*spr*). **B** Posterior view delineates the background anatomy including ischial tuberosity (*it*), ischial spine (*is*), posterior acetabular brim (*pab*) and arcuate line (*arl*)

produces a pair of high-resolution pinhole images at one time reducing scan time by half for each image (Fig. 5). Dual-head images can clearly portray the structures in both the foreground and background of an object eliminating the blind zone that distracts the value of single-head pinhole scan.

Pinhole SPECT, hybrid of SPECT and pinhole scan, generates magnified sliced images of bone and joint with remarkably improving the resolution [8]. It is achieved using conventional single-head gamma camera system and the ordinary back-projection algorithm and a Butterworth filter. It can be applied to the fine anatomical assessment of small bones, joints, insertions of the tendons and ligaments (Fig. 4). Pinhole SPECT has been utilized for the diagnosis of fracture, osteoarthritis, rheumatoid arthritis, and reflex sympathetic dystrophy syndrome in the ankle and hindfoot. For reference, the value of the limiting spatial resolution of pinhole SPECT we developed was 0.2 line pair/mm approaching those of MR imaging and CT scan (Table 1), and actually the resolution of pinhole SPECT is comparable to that of CT scan (Fig. 4).

Drawbacks of Planar Single Photon Emission Computed Tomography

The advent of SPECT dates back to 1963 when Kuhl and Edwards published results of their study on Image separation radioisotope scanning [19] which was refined to a cylindrical section scanning a year later [20]. SPECT is a widely used nuclear imaging test in osteoarthrology, cardiology, oncology, neuroscience, and urology. It generates sliced images of an organ by either 360o or 180o rotary motion of gamma camera. The slices are generated by the reconstruction of the data set acquired using a multihole planar scintigraphy and the filtered back-projection algorithm and a Butterworth filter. Images are finally displayed on a minified format as ordinary planar images are. The unique advantage is the

separation and elimination of the radioactivities accumulated in the overlapping structure above or below the plane of interest enhancing the contrast up to six fold [21]. This enhanced contrast of SPECT along with multiple-projection display significantly raise the sensitivity or lesion detectability. Unfortunately, however, the spatial resolution remains not improved [6] or even degrade compared to ordinary planar scan [7] (Fig. 1B). Moreover, SPECT frequently enhances the contrast of not only pathological but physiological tracer accumulation making their distinction hard. Lowering of the resolution in SPECT is related with three limiting factors. The first factor is optical characteristics of multihole parallel collimator that is used in SPECT, the general design of which is focused on the system sensitivity. The second factor is that SPECT generates sliced images through the reconstruction of data set acquired by planar scintigraphy and formulated in a predetermined pixel size inevitably blurring the displayed images. The third factor is minification that reduces resolution. Furthermore, the lower concentration of tracer often prevents SPECT imaging of small bones and joints. Thus, the resolution of planar SPECT does not appear to any more significantly contribute to the enhancement of diagnostic feasibility of bone scan than the contrast does and pinhole SPECT is a more realistic alternative.

Conclusion

Bone scintigraphy is on the decline in recent years, and its reason has been related with anatomical ambiguity and diagnostic inaccuracy. In fact the resolution of the *minified* image of the ordinary planar scintigraphy and planar SPECT of bone is insufficient for the specific diagnosis to be made in most diseases. For their interpretation, therefore, additional information is to be borrowed from radiography, CT scan or MR imaging. Fortunately, pinhole scan can enhance the resolution and raise the diagnostic feasibility up to the level of radiography, CT and MR imaging as far as the anatomy is concerned. The benefits of planar pinhole bone scan can be amplified by the dual-head mode which generates a pair of high-resolution scan images at one time. It can reduce the scan time by half and eliminates the background blind zone. Furthermore, pinhole SPECT which makes use of conventional single-head gamma camera can produce optically magnified sliced scans whose resolution is close to that of MRI and CT. This hybrid imaging can visualize the small bones and joints, for example, in the ankle and hindfootl. It can also detect subtle change in bone metabolism. Planar pinhole scan, both single and dual head modes, and pinhole SPECT are not diffucult to perform, economical, and very informative for the diagnosis of a broad spectrum of bone and joint disorders.

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