Should Chest Radiography and Chest Radiography for the Early Detection of Lung Cancer be the Same Examination?

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Although chest radiography has made enormous contributions to the public health, its practitioners have lacked one great advantage in the development of their examination that has benefitted the practitioners of breast radiography, i.e., that the latter examination is effectively used to detect only one disease - breast cancer. Radiography of the breast has been allowed to evolve in ways that are finely tuned not only to the anatomy of the breast but also to the subtle features of early breast cancer. This has lead to development of highly specialized radiographic equipment and imaging approaches, so much so that performance of the examination without these is now unthinkable. Conventional chest radiographs, on the other hand, are usually obtained with equipment and methods that most would consider quite ordinary and that have changed relatively little since the last generation [1], particularly when compared to mammography.

It is a reasonable exercise to wonder whether chest radiography, like breast radiography, would have developed into a highly specialized study were early lung cancer the only disease for which it was performed. The question is not without relevance. In the United States, for example, lung cancer kills nearly four times as many individuals as breast cancer, more than a third of these being women [2]. Although the results of screening trials are generally interpreted as showing that early detection of lung cancer with chest x-rays does not confer survival benefits to the screened population [3], dissent exists [4]. Recently Strauss et al. have reexamined the trials that serve as the basis for the bias against screening and found them wanting in significant ways [5]. Regardless, the lack of agreement on the utility of radiography to successfully screen for early lung cancer has led to the application of computed tomography to this purpose -- with promising early results [6].

There exists an extensive literature on image quality and lesion detectability in chest radiography. In the author's opinion, this literature gives a clear indication that, in a place where early lung cancer was the only thoracic disease of interest, chest radiographs would be performed differently than those done in present clinical practice. Further, these differences would warrant that such an early detection study, if actually done today, be considered an entirely separate
examination from the standard chest radiograph. The main features of this argument are summarized in the following.

Selecting the Signal Suppressing, at the outset, the need to see everything, the 1 cm, non-calcified, peripheral pulmonary mass can be taken as the minimum signal for detection by the specialized examination [6]. This does not aim too low. The 5-year survival for Stage 1 lung cancer (T1N0M0 or T2N0M0) is 70% when treated surgically but only 10% if not resected [7]. Further, lung cancers less than 1cm in size are usually not detected on chest radiographs, at least those performed conventionally [8,9]. The chest x-ray examination for the early detection of lung cancer should therefore be required to give a good indication of whether any 1 cm or larger pulmonary lesions are present. Positive or ambiguous findings would then be subject to further radiographic or cross-sectional imaging evaluation, much as is done with abnormalities seen on screening mammograms.

Once the target abnormality for the specialized chest examination is determined, one can list the findings that the examination need not detect. These would include many of the features important for the conventional examination to demonstrate such as fine lines, subtle interstitial or air space abnormalities, micronodular patterns and so forth. One might be pleased if the specialized technique allowed detection of smaller pulmonary mass lesions, e.g., 8 mm in size, but would not require this, choosing instead to decrease the interval between screening studies in order to assure that lesions within the likely reach of the examination would typically be detected in individual patients [10].

Basis for Signal Detection It is a given in the minds of many practitioners of radiography that images of high technical quality are more likely to yield high quality diagnoses than those that are not. This is certainly true in breast radiography where images having high quality transfer characteristics [11] (i.e., very sharp, low noise) and that are portrayed in a vivid fashion (i.e., high contrast) more usually depict the subtle detail needed to diagnose early breast cancer [12]. Sobering counterexamples to the technical quality/diagnostic quality correspondence exist for the detection of lung masses on radiographic images, however [13].

Signal detection theory proposes that a lesion will be detectable only if it can be distinguished from its background in a statistically reliable way [11,14]. This theory is usually considered in terms of signal-to-noise ratios in which lesion detection is likely only if that ratio is greater than a certain quantity [14]. In the simplest formulations, noise is taken to be quantum noise with detection being easiest, all other things being equal, on less noisy images.
A very important modification to simple signal detection theory arises in the chest with the concept of conspicuity [15,16,17]. The simplest definition of conspicuity [17]:

\[(1) \text{Conspicuity} = \frac{\text{Lesion Contrast}}{\text{Background Complexity}}\]

suffices for the present discussion. Lesions of higher conspicuity will generally be more detectable by human observers [17]. The background complexity results from the normal anatomic structures within the chest such as blood vessels and ribs with these findings also referred to as "structured noise" [16,17].

The last important considerations in establishing a basis for designing the early cancer-detecting examination are related to the known properties of human observers. These include the tendency of observers to detect more sensitively nodules having relatively abrupt margins [18,19] or having a certain spatial frequency range [20,21].

The many considerations just described give the possible basis for a chest radiographic examination designed solely to detect early lung cancer. First, the image should be as low in quantum noise as reasonably possible; second, target lesions should be displayed with as high a contrast as possible; third, the image should be as low in visual complexity as possible and, fourth, the image should be presented to the observer in a way that accounts for psychophysical effects.

Screen-Film Examination Breast radiography requires use of specialized x-ray tubes, generators and recording systems and so it is reasonable to expect that chest radiography done for the early detection of lung cancer might also. The most appealing prospect for x-ray production for the specialized chest examination would be the superkilovoltage approach that was of greatest interest during the late 1970's [22,23,24], with heavily filtered high kilovoltage x-rays using beam shaping possibly also sufficing [25]. These approaches allow the very important problem of structured noise arising from the ribs and other overlying osseous structures to be largely overcome [22,23]. At the same time, they provide better penetration of the retrocardiac and retrodiaphragmatic areas with these portions of the images then displayed on a more advantageous portion of the gray scale of the recording film - thereby increasing lesion contrast in these areas [26]. The latter notwithstanding, lung coverage and rearrangement of the structured noise would still warrant that PA and lateral views be obtained.

There existed limitations in the superkilovoltage, 350 kVp technique, as commercially available during the 1970's that argued against its use in day to day practice [25,27]. The mechanism for generating the super high kVp beams
required a large focal spot and so resulted in considerable geometrical unsharpness [27]. It is very important to note, however, that unsharpness on these scales does not affect the visibility of lung masses [18,28] and should, in fact, reduce the visual complexity or structured noise in the image [29] thereby increasing lesion conspicuity [30].

Another problem with superkilovoltage chest x-rays was their high level of quantum mottle [23]. As already discussed, high noise levels reduce the visibility of low contrast masses that are the target of the examination under discussion. In order to decrease quantum noise levels it is necessary to produce the image using a greater number of x-ray detections in the screen-film system. This generally requires that the patient receive a higher radiation dose. Radiation related risks in conventional chest radiography are extremely low [31], however, and a specialized examination performed for the detection of a very deadly disease might readily justify increasing doses by an order of magnitude, especially in an older patient population. Extremely high doses would likely not be justified, however, since internal observer noise might come to dominate were the images truly low in quantum noise [30].

The screen-film systems needed to record high levels of energetic radiation would have two properties, first, the screen phosphor layer would have to be very thick to absorb as much of the radiation exiting the patient as possible (remember that screen unsharpness is not a problem for this application) and, second, a very slow film. In order to maximize the visibility of lesions, film contrast would be as high as allowed by latitude effects [32], i.e., the anatomy of the chest, beam energy and scatter rejection, the latter being as efficient as possible.

Once the images were obtained, attention to viewing conditions would also be important. These conditions would include, much as in mammography, darkened reading areas and minimization of extraneous light from the viewbox, both tending to maximize perceived lesion contrast. Further, images might well be viewed through some sort of minifying device to increase perceived edge sharpness [18]. Viewing the images at variable distances to couple best all lesions to the human visual response curve could also be considered [20,21].

Summarizing, screen-film chest radiographs done for the early detection of lung cancer might be expected to be as specialized as mammograms are today. They would quite likely be performed with very energetic x-ray beams, captured with very slow, unsharp, relatively high contrast recording systems using higher than conventional patient radiation exposures and viewed under special conditions. It goes without saying that such an examination would be performed on a periodic basis for the detection of early neoplastic disease in asymptomatic patients known to be at increased risk. Patients with pulmonary, cardiac, constitutional or other symptoms would undergo conventional chest radiography.
Digital Examination Although digital mammography has not yet cleared regulatory hurdles to its routine use in screening, digital chest radiography is actively employed in many clinical departments. The large variety of image recording media, image processing and image display possibilities available [33] increases multiplicatively the number of strategies that might be used to detect early lung cancer on digital images. Only the most pertinent are described briefly below.

Decreasing structured noise related to the ribs is perhaps most readily accomplished digitally with dual-energy subtraction technique [34], shown to increase the detection of small soft tissue masses [35]. Such would obviate the need for highly energetic x-ray beams. The increased noise inherent in subtraction methods might be partially overcome by increasing patient exposures. Even so, changing system design parameters so to improve x-ray absorption, even at the cost of greater image unsharpness, might mitigate such increases.

Digital radiography, in that it decouples acquisition and display functions, would allow image processing that selectively enhances small masses to the detriment of non-pertinent image detail. Digital image acquisition also lends itself more directly to application of computer-aided diagnosis techniques that assist the radiologist in his or her detection tasks [36]. Such aid may help radiologists in overcoming the known limitations of human observers when encountering chest images [10,37]; limitations likely to persist even with decreased quantum and structured image noise.

Final Perspective It is, of course, possible that radiography, at least as performed with screen-film systems, may now never develop a role in the screening for early lung cancer, being supplanted rather by computed tomography [6] or sophisticated digital techniques [35]. It is nevertheless worthwhile to consider that the image detail needed for the early detection of lung cancer on chest radiographs is appreciably different than that commonly required of the conventional examination used in everyday practice. Were lung cancer the only disease of significance detected on chest x-rays it can be anticipated that chest radiography would be as specialized an examination as breast radiography is today. Technical issues must therefore not be ignored when contemplating the presently perceived inability of radiography to effectively intercept this most deadly disease.

References


