J Digit Imaging (2013) 26:109–114
DOI 10.1007/s10278-012-9466-6

Preliminary Evaluation of Biplane Correlation (BCI) Stereographic Imaging for Lung Nodule Detection

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Published online: 16 March 2012

Abstract A biplane correlation (BCI) imaging system obtains images that can be viewed in stereo, thereby minimizing overlapping structures. This study investigated whether using stereoscopic visualization provides superior lung nodule detection compared to standard postero-anterior (PA) image display. Images were acquired at two oblique views of ±3° as well as at a standard PA position from 60 patients. Images were processed using optimal parameters and displayed on a stereoscopic display. The PA image was viewed in the standard format, while the oblique views were paired to provide a stereoscopic view of the subject. A preliminary observer study was performed with four radiologists who viewed and scored the PA image then viewed and scored the BCI stereoscopic image. The BCI stereoscopic viewing of lung nodules resulted in 71 % sensitivity and 0.31 positive predictive value (PPV) index compared to PA results of 86 % sensitivity and 0.26 PPV index. The sensitivity for lung nodule detection with the BCI stereoscopic system was reduced by 15 %; however, the total number of false positives reported was reduced by 35 % resulting in an improved PPV index of 20 %. The preliminary results indicate observer dependency in terms of relative advantage of either system in the detection of lung nodules, but overall equivalency of the two methods with promising potential for BCI as an adjunct diagnostic technique.

Keywords Chest radiographs · 3D imaging (imaging, three dimensional) · Digital display · Image acquisition · Imaging · Three dimensional · Radiographic magnification · Radiography · Biplane correlation imaging · Stereomammography · Stereoradiography

Introduction

Although lung cancer is consistently the leading cause of death due to cancer in the USA [1], a viable screening method has been elusive [2]. Chest radiography is inherently limited by overlapping structures which may hide cancerous nodules, making them undetectable [3]. A recent study performed by the National Lung Screening Trial (NLST) using computed tomography (CT) showed a 20 % reduction in death due to lung cancer mortality [4]. However, CT is controversial due to the higher radiation doses required, higher cost, and the large number of indeterminate nodules [5–8]. The speed of acquisition available with flat panel imaging technology has made biplane stereoscopic systems feasible. Stereoscopic mammography has shown promising

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results for identifying nodules in the breast [9]. It is natural to explore whether stereoscopic chest imaging may also provide a cost-effective, time-sensitive imaging technique for lung nodule detection.

In our lab, we developed a biplane correlation (BCI) imaging system that generates images for stereoscopic viewing [10]. The stereoscopic images may be used to determine if a BCI stereoscopic system is a viable option for lung nodule detection. Overlapping anatomical structures are minimized in the stereoscopic view, providing more accurate nodule detection. Three images are acquired, two at oblique angles and a third at the postero-anterior (PA) position. Total dose is equivalent to a standard PA chest radiography procedure [11], and the images are acquired in one breath hold, less than 10 s. This study investigates whether using stereoscopic visualization provides superior lung nodule detection compared to standard PA image display.

Methods

The BCI system shown in Fig. 1 [10] was used to acquire image data containing lung nodules as well as normal cases from human subjects under institutional review board approval. After requesting permission from the referring physician, the study coordinator recruited subjects referred for CT exams. The study coordinator initially identified subjects with primary or metastatic cancer for positive cases as well as those without abnormality for normal cases. Clinical co-investigators reviewed the subject clinical notes to verify general good health, the presence or absence of cancer, and the absence of acute pulmonary abnormalities. Pregnant women were excluded as well as students or patients of any key personnel in the study. Once the study coordinator and clinical co-investigators reviewed the clinical notes and confirmed the subject was a candidate for the study, the study coordinator approached the subject for potential recruitment. If the subject agreed to participate and was competent to give consent, the study coordinator arranged for image acquisition. The images were acquired using a Varian Medical Systems, Inc. PaxScan 4030CB system which has an imaging area of 40×30 cm with an image matrix size of 2,048×1,536 pixels and pixel size of 194 μm. A source-to-image distance of 183 cm and full-resolution mode at one frame per second were used for image acquisition as determined in a previous study [12]. The raw image data were offset and gain corrected as instructed by the manufacturer. Data were acquired without an antiscatter grid.

Fig. 1 BCI acquisition system

Human subjects consisted of men and women to comprise a dataset of 60 total subjects. Three images were acquired, one at the PA position and two at oblique angles of ±3° of PA (Fig. 2). The system geometry used was studied in previous works which determined the optimal operating angles for acquisition [13, 14]. The X-ray tube moves along the horizontal axis to acquire the three images. The subject data were acquired with effective tube current adjusted accordingly for patient thickness at the chest. Total effective dose was equivalent to standard chest radiography procedures as estimated from data presented by Mettler et al. [11]. Raw image data were postprocessed using histogram equalization and filtering. The window/level was adjusted for optimal viewing on the stereoscopic display.

Examples of processed images are shown in Fig. 3a, b. Figure 3a is shifted 3° to the left of PA, and Fig. 3b is shifted 3° to the right of PA. The arrow indicates a lesion which is zoomed in Fig. 3c, d. Figure 3d shows that the lesion appears to be obscured by a rib, but in Fig. 3c, the lesion is unobstructed.

For the observer study, four radiologists who specialize in chest radiography, each with over 7 years of experience, were asked to view the PA image and BCI image of each subject on a stereoscopic display. The stereoscopic display used was a prototype 5-megapixel medical display (Dome C5iGRAY by Planar Systems, Inc., Beaverton, OR). Two of the monitors are mounted as shown in Figs. 4 and 5 [15] with an approximate 110° separation and a semitransparent mirror bisecting the angle. As illustrated in Fig. 5, the image from the top monitor is reflected off the mirror while the image from the bottom monitor is transmitted through the mirror. Cross-polarized lenses are required such that each eye only sees an image from one monitor. The left eye receives the image from the bottom monitor, and the right eye receives the image from the top monitor. The human visual system effectively sums the two views often referred to as binocular summation. The

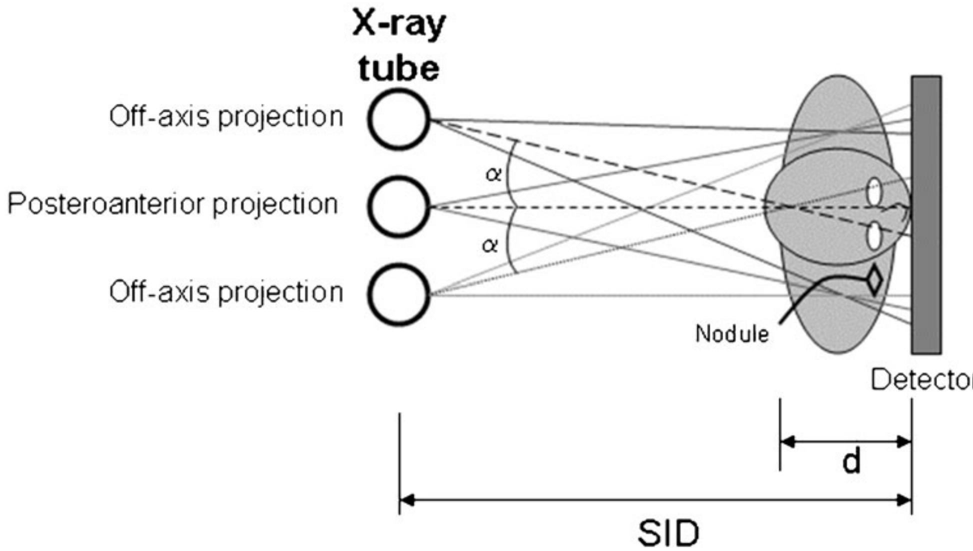


Fig. 2 BCI acquisition geometry where the angle α=3° as measured from the center of the beams

monitors were calibrated geometrically by visual alignment of a matrix of dots and squares on a flat background.

The PA image was displayed on both monitors simultaneously, thus appearing as a flat image similar to standard chest radiographic image display. The oblique images at ±3° were displayed simultaneously, one on each monitor. Then, with the cross-polarized glasses provided which pass the right and left view to only the right and left lens, respectively, a 3D

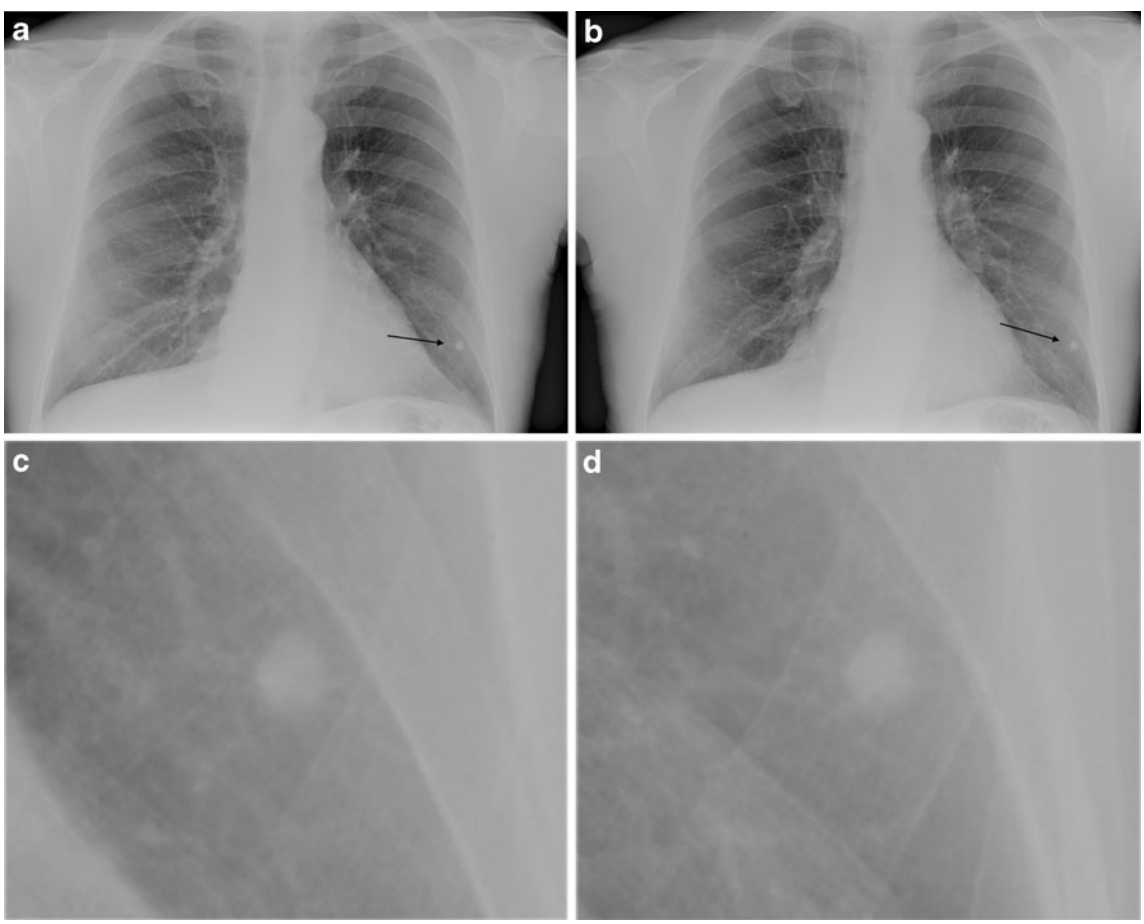


Fig. 3 Sample images (**a**, **b**) and zoom images of lesion (**c**, **d**)

Fig. 4 Stereographic viewing system

image was displayed. The radiologists were trained to view the BCI stereoscopic image before proceeding with the full study. For each subject in random order and using a sequential reading method, the radiologists viewed the PA image monoscopically and provided a score and then immediately viewed the BCI stereoscopic image of the same subject and provided a score.

The cases considered positive were independently determined by CT data acquired the same day as the BCI data. A total of eight nodules were confirmed. Performance was evaluated by comparing the scores of the PA viewing and the BCI stereoscopic viewing to the CT results. Receiver operating characteristic (ROC) analysis was performed for each radiologist and across all radiologists. The ROC analysis considered the left and right lung as separate entities. Evaluation of the stereoscopic view compared to the PA view was based on three figures of merit which were sensitivity, positive predictive value (PPV) index, and false positives per subject [14].

Results

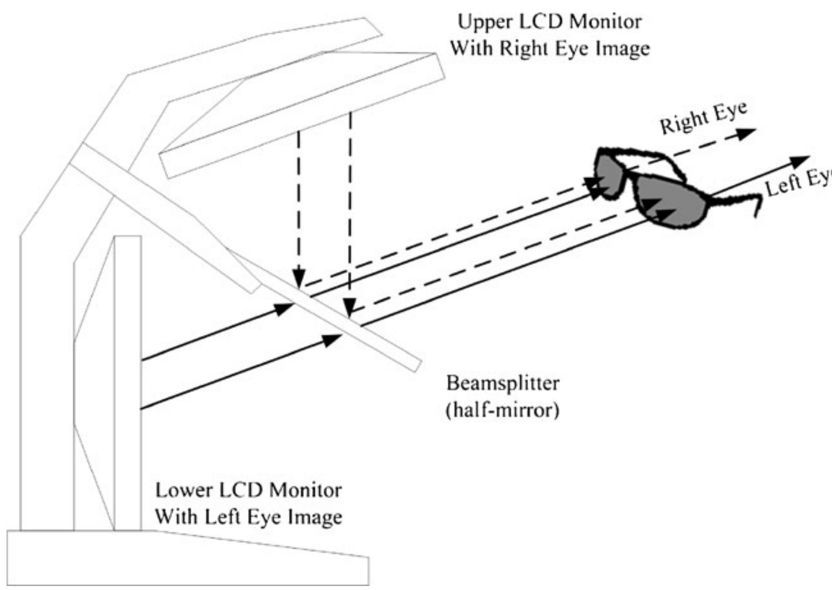
The system and observer study performed for the BCI stereoscopic images showed a reduction in the total number of false positives of 35 % compared to the PA images. The reduction in false positives led to an increase of 20 % in the PPV index with the BCI images having a PPV of 0.31 and the PA images having a PPV of 0.26. Sensitivity for the BCI images was 71 % compared to 86 % for the PA images, a reduction of 15 %. The ROC curves for each radiologist can be seen in Fig. 6a–d and the average of the ROC curves can be seen in Fig. 6e. The ROC curves show that BCI improved performance of the fourth radiologist and generally performed similarly to viewing the PA image alone. Radiologists commented that viewing the stereoscopic image took some adjustment, but by the end of the study, most were comfortable with the 3D image view.

Table 1 lists specific values of observer performance statistics. As can be seen, all readers except one experienced a reduction in the number of false positives perceived.

Discussion

Recently, the NLST reported that screening high-risk individuals with CT is associated with a 20 % reduction in lung cancer mortality and a 6 % decrease in overall mortality [4]. However, the dose and frequency of CT in asymptomatic individuals need to be considered. Stereomammography has

Fig. 5 Schematic of stereoscopic image formation



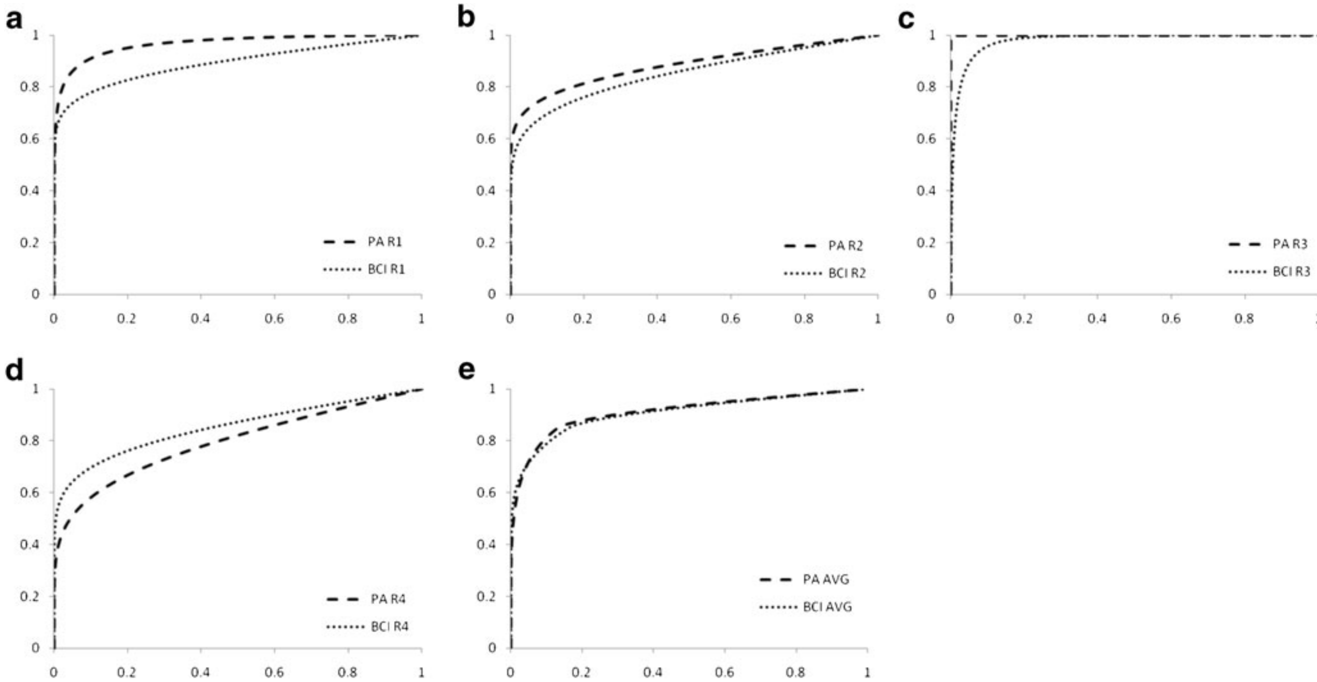


Fig. 6 ROC performance of PA study as *dashed lines* and BCI study as *dotted lines* for four radiologists (**a**–**d**) and **e** average of ROC curves

generated positive results, leading to the current effort of a newly proposed BCI stereoscopic system for use as a system for lung nodule detection. The proposed system provides advantages over CT in that the dose is notably lower. One study reported that the average effective dose from a chest PA exam is 0.02 mSv while the average effective dose of a chest CT exam is 7 mSv [11]. Although efforts towards CT dose reduction have shown a 67 % decrease in dose without affecting lung nodule detection, optimal acquisition parameters and adequate detection are still debated [16].

Samei et al. demonstrated that anatomic noise prevents detection of subtle lung lesions more than radiographic noise [3, 17]. For a reader to distinguish a lesion in a background of anatomical noise, the lesion needs to be an order of magnitude larger than the same lesion on a quantum-limited background [3]. Another report determined that anatomical obstructions result in a 71 % miss rate [18]. Viewing biplane images stereoscopically provides the radiologist with a visual reduction of anatomical noise. Stereoscopic photography was popular at the turn of the twentieth century, and physicians at that time developed techniques for viewing medical images stereoscopically [19]. Viewing the X-ray films required awkward handheld viewing devices and involved difficult alignment of the images [19]. However, stereoscopic imaging was used in radiology departments until CT and MRI systems became available [19]. The introduction of flat panel detectors and stereoscopic display systems has provided improved technology for viewing stereoscopic image pairs as 3D images. Although CT provides superior data for 3D visualization, stereoscopic imaging provides a 3D visualization that minimizes anatomical noise compared to chest radiography at a reduced cost and dose compared to CT.

Preliminary studies have been performed with phantom and human subject data to assess how correlating suspect lesions from multiple views of a standard CAD algorithm may eliminate false positives [14, 20–22]. One of those studies of BCI for lung nodule detection demonstrated a

Table 1 Observer performance statistics

	FPs PA	FPs BCI	Area PA	Area BCI	Sensitivity PA (%)	Sensitivity BCI (%)	PPV PA	PPV BCI
Reader 1	25	12	0.97150	0.90936	100	71	0.22	0.29
Reader 2	23	10	0.90208	0.87717	86	57	0.21	0.29
Reader 3	8	13	1	0.98339	100	100	0.47	0.35
Reader 4	12	9	0.83136	0.87745	57	57	0.25	0.31
Average	1.1 per subject	0.7 per subject	0.92623	0.91184	86	71	0.26	0.31

FPs false positives

sensitivity of 62.5 %, 1.5 false positives per image, and a 0.885 PPV index [14]. The BCI reduced sensitivity by 20 % compared to single-view CAD but also reduced false positives by 94 % yielding a 140 % improvement in the PPV [14]. A multiprojection CAD scheme for the chest was used in a study of phantom and human subject data [22]. Compared to single-view CAD at a sensitivity of 65 %, the multiprojection correlated CAD reduced false positives by 79 % in the phantom study and 78 % in the human subject study [22]. Advantages of multiprojection CAD have been demonstrated successfully on small datasets. Applying CAD to the subject data from this study with stereoscopic visualization may prove beneficial. The current study indicated promising results for a BCI system in that it compares comparably to chest radiography and established proof of principle for the new imaging modality. However, the number of subjects was small and cannot fully establish the effectiveness of detecting lung nodules with BCI stereoscopic imaging. Further research is proceeding to use the BCI stereoscopic system in conjunction with the PA image as a supplemental tool for nodule detection. The lesions in the study were considered obvious lesions that were easily detected by standard chest radiography; therefore, full benefits of BCI stereoscopic imaging were not exploited. Future endeavors should include more subtle lesions to examine improved detection compared to chest radiography. The BCI stereoscopic score was probably biased by requesting the observer to score the PA image first, thus resulting in similar ROC curves between PA images and BCI stereoscopic images. To more accurately determine the benefits of the BCI stereoscopic system, the design of the observer study will be improved, so the effectiveness of BCI stereoscopic imaging is more deterministic. A larger dataset is also needed to completely verify the validity of the new system. Advantages of using multiprojection correlated CAD results in a reader study should also be explored. As a previous study showed, this study further demonstrated the variability of observers when viewing stereoscopic images [23], and future work should include a stereoscopic depth acuity test for the readers.

Acknowledgments The authors would like to thank Anne Jarvis, Brenda Prince, Rob Saunders, Ben Pollard, Amar Chawla, and Xiang Li for the help in coordinating the clinical trial. Thanks are also due to Nicole Ranger and Jin Wooi Tan for coordinating the observer study, and Varian Medical Systems, Inc. and Planar Systems, Inc. for the equipment. The authors would also like to thank Michael Flynn of Henry Ford Health Systems, Detroit, MI for the tshow software to optimize images for display, and David Getty of BBN Technologies for the SDMViewer software used for image display.

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