Stereoscopic Breast Imaging

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Limitations of Projection Radiography

- Mammography is a projection imaging process whereby 2D images are produced of 3D objects.
- 2D images cannot fully present the 3D arrangement of breast tissue, which results in loss of morphologic image information.
- 2D images superimpose non-adjacent tissues, thus the inter-relationship of breast tissues is diminished.

Limitations of Projection Radiography

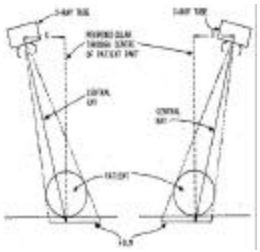
- It is difficult to detect subtle lesions due to superimposition of overlying and underlying tissues which mask the lesion's presence.
- Confirmation of a suspected lesion (a "density") as real requires that it be found in each of two orthogonal views.
- Constructing a mental image of the 3D structure of a lesion from two orthogonal projections is often difficult.

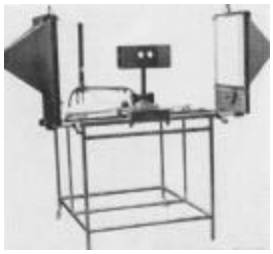
Adapted from David Getty

3-D Breast Imaging Methods

- X-Ray
  - Stereoscopy
  - Tomosynthesis
  - Limited-View Computed Tomography
  - Fully 3-D Computed Tomography
- MRI
- Ultrasound
- SPECT and PET
- Optical, Electrical Impedance, etc.

Stereoradiography





Proposed Advantages of Stereo Mammography

- Detection of suspicious lesions should improve:
  - Stereo mammography allows a radiologist to directly view structures within the breast in depth.
  - Detection is improved because overlying tissues are separated from the lesion in depth.
- Discrimination of suspicious lesions should improve:
  - Artifactual densities are reduced because normal tissues are not superimposed, and thus are unlikely to resemble a focal abnormality.
  - Able to directly perceive a lesion's volumetric shape.
  - For microcalcifications, the volumetric distribution can be appreciated.

Adapted from David Getty

Stereoscopic Vision

- Humans have binocular vision, with forward-facing eyes and visual fields that overlap by about 170°.
- Our two eyes are separated by about 65 mm, causing each eye to have a slightly different view.
- There is sufficient information in these two differing views for the visual system to determine the relative depth of different objects in the visual scene.
- The perceptual result is a single fused image with objects seen as distributed in depth—a process called “stereopsis.”

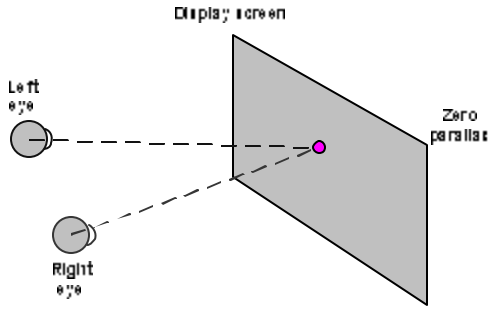
Courtesy of David Getty

Horizontal Parallax

- The basis of stereopsis is the angular horizontal disparity between corresponding points of an object in the two retinal images.
- In a stereo display, that disparity is created by horizontal parallax.
- Horizontal parallax is the separation of left-eye and right-eye points on the display screen that correspond to a single point of a displayed object.
- There are three types of horizontal parallax.

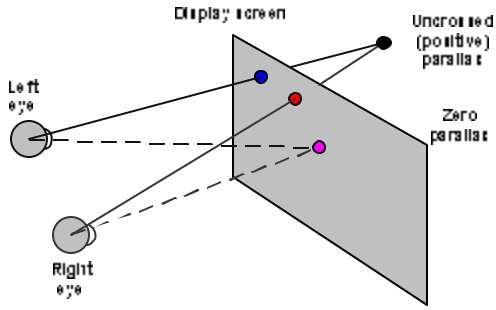
Courtesy of David Getty

Zero Parallax



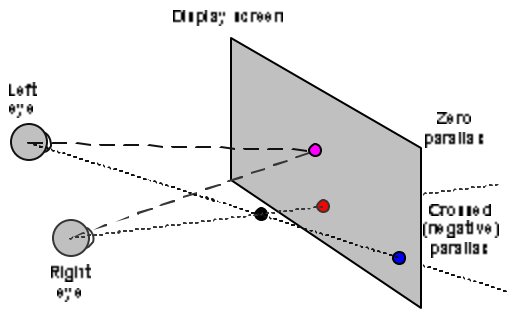
Courtesy of David Getty

Uncrossed Parallax



Courtesy of David Getty

Crossed Parallax



Courtesy of David Getty

Stereomammography Research at the University of Michigan

Mitch Goodsitt and Heang-Ping Chang

1) **3D Virtual cursor for depth measurements**
   a) **Developed cursor**
   b) **Investigated accuracy**
2) **Observer study of depth discrimination dependence on stereo technique**
3) **ROC study of breast lesion characterization**

3D Cursor Measurement Accurancy

Stereo Display System:

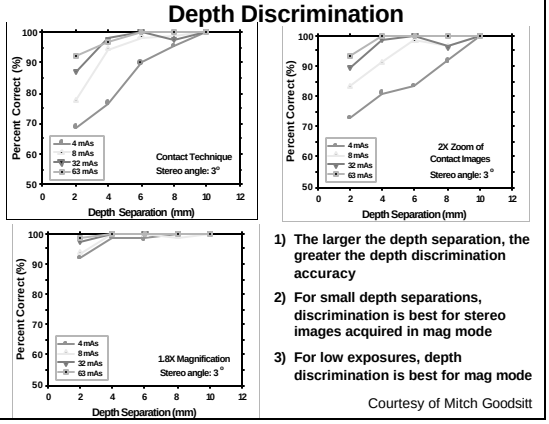
- Sun Ultra 10 computer
- Barco-Metheus stereo graphics card
- Barco 5 Megapixel monitor
- In-house developed graphical 3D cursor
- NuVision stereo LCD glasses

Stereo Cursor Measurement Accuracy
(RMS errors in mm)

3°	3°zoom	6°	6° zoom	3° mag	3° mag zoom	6° mag
1.4	1.4	0.7	0.7	0.6	0.6	0.2

Courtesy of Mitch Goodsitt

Depth Discrimination



1) **The larger the depth separation, the greater the depth discrimination accuracy**
2) **For small depth separations, discrimination is best for stereo images acquired in mag mode**
3) **For low exposures, depth discrimination is best for mag mode**

Courtesy of Mitch Goodsitt

Classification of malignant and benign lesions - ROC study using biopsy specimens

Average over 5 radiologists	Single Projection	Stereo	p value
A_z	0.71	0.73	0.03*
Partial area index (TPF>0.9)	0.10	0.13	0.02*

Courtesy of Mitch Goodsitt

Stereomammography Clinical Trials

David Getty, BBN

Carl D'Orsi, Emory University

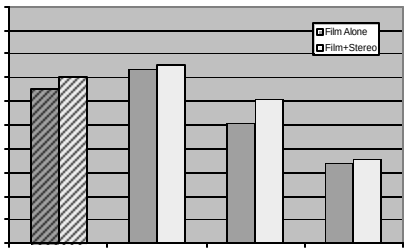
- Evaluate the improvement in diagnosis of breast cancer achieved by stereo digital mammography.
- Conduct reading study to compare the diagnostic accuracy of stereomammography
- Examine the capability of stereo mammography to detect subtle focal lesions not visible in the corresponding film studies.

Courtesy of David Getty

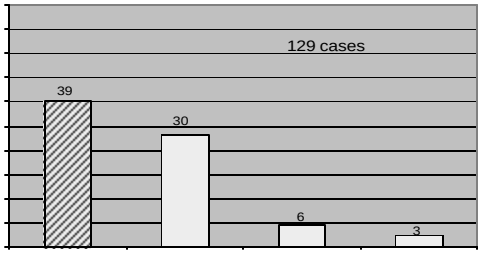
Case Set

Lesion type	Truth		Total
	Benign	Malignant	
Mass	34	15	49
Calcifications	69	10	79
Architectural Distortion	2	7	9
Total	53	23	137

Diagnostic Accuracy of Film Alone vs. Film + Stereo



Percent of Cases in Which a New Lesion Was Detected in Stereo (*Not Visible on Films)*



Project Conclusions

- Stereo mammography, as an adjunct to film, significantly improves diagnostic accuracy.
- Stereo mammography appears to be *more sensitive* than standard film mammography in detecting subtle lesions in the breast, enabling mammographers to detect lesions that are *not visible* on standard films.
- Stereo mammography would be *easy to implement* in the new digital mammography systems now emerging.

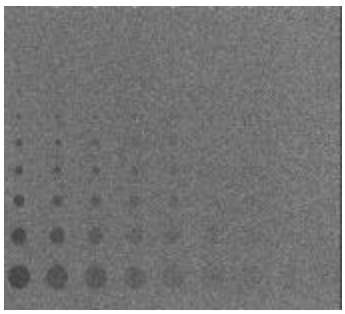
Dose Requirements

- Stereoscopy reduces ambiguity due to anatomic noise, but is previously reported to require double the dose.
- For a quantum-limited detector, theory suggests a decrease in dose by half, due to combining the left and right images by the human visual system.
- We hypothesized that each of 2 stereo images requires one half the dose for a single x-ray image viewed monoscopically.
- By corollary, for the same dose, stereoradiography will result in an effective increase in SNR by $\sqrt{2}$
- Experiments involved zero parallax

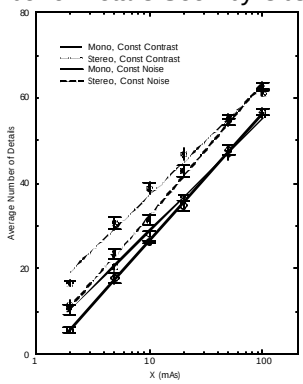
C-d Observer Study

- The study consisted of a series of contrast-detail (C-d) experiments with phantom images acquired over a range of exposures. Observers attempted to detect details in a C-d phantom both monoscopically and stereoscopically.
- Geometry of acquisition was the same, giving zero parallax. Thus, all objects appear in the imaging plane. This analysis therefore focuses on the quantum-noise reduction.

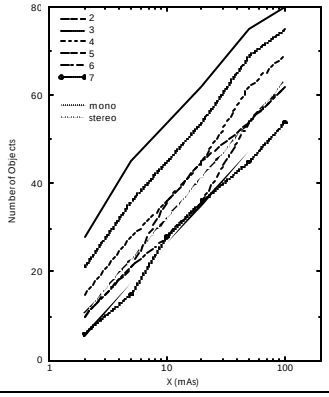
Example of a Phantom Image



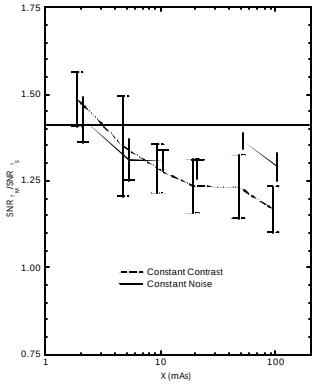
Number of Details Seen by Observers



Threshold SNR



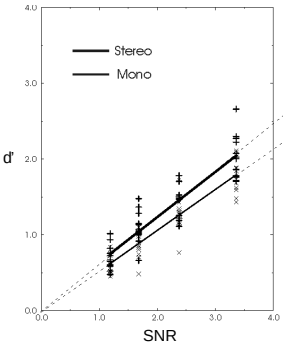
Relative Increase in SNR



2-AFC Observer Study

- We needed to develop a technique for performing further observer experiments, without having to acquire 100's or 1000's of phantom images
- The technique consisted of simulating a series images, which are presented using a 2-alternative forced choice (2-AFC) methodology.
- Observers attempted to detect which image contained a simulated mass both monoscopically and stereoscopically.
- Images were presented with zero parallax. Thus, all objects appear in the imaging plane. This again focuses on the issue of quantum-noise limitations.

Average Performance for All Observers: d'(SNR)



$dose_{2S} / dose_{1M} \sim 1.5$

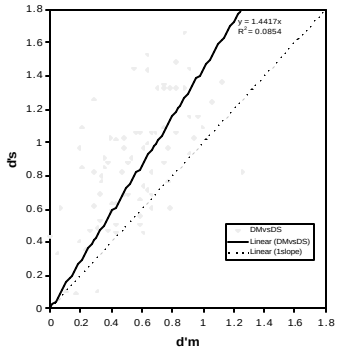
Discussion

C-d	2-AFC
Structured array of objects	Single objects with fiducial markers
Selection based upon edge and area estimation	Selection based upon overall intensity
SNR of 5-6	SNR of 1-3 (subclinical)
$Dose_S \cong 1.1\ Dose_M$	$Dose_S \cong 1.5\ Dose_M$

? Modify 2-AFC experiments for objects with higher SNR

? Add realistic backgrounds and non-zero parallax

2-AFC Discrimination Task

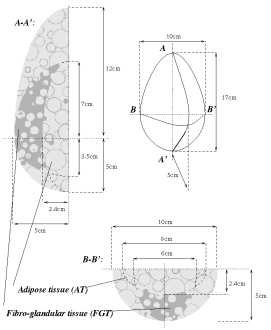


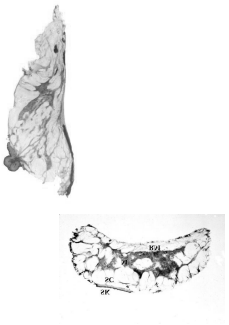
3-D Breast Model

- A volumetric model of the breast has been designed to allow simulation of mammography and stereomammography.
- This phantom will allow 2-AFC stereo-mammography studies to be conducted with realistic anatomic backgrounds

Synthetic Compartments

Real Compartments in Histologic Slices





Conclusions on Dose

- C-d experiments and 2-AFC discrimination tasks involving zero parallax indicate that the dose for stereoradiography is the same as the dose for projection imaging.
- 2-AFC detection tasks involving zero parallax indicate that the dose for stereomammography is ~1.5 times that for projection imaging (objects with subclinical SNR)
- Further analysis will use images with more realistic anatomic noise, simulated breast abnormalities and non-zero parallax.

Stereo Display of Volumetric Data Sets

- Digital imaging techniques such as CT and MR produce volumetric data sets.
- Volume-rendering applications are capable of displaying planar projections of the volumetric data from a user-specified point-of-view.
- One can create stereo pairs of projections by separating the point-of-view between two projections by about 6°.
- The image pairs can be viewed on a stereo display, enabling depth perception.
- With sufficient computing power, dynamic stereoscopic rendition is possible.

Courtesy of David Getty

Summary

- 3-D imaging techniques have application both in screening and diagnosis.
- Potential 3-D techniques include stereoscopy, tomosynthesis, and limited-view reconstructions.
- 3-D images reduce the likelihood of superposition errors and improve the separation of overlying tissues.
- Research suggests that stereo imaging may significantly improve detection of subtle lesions, and improve characterization of detected lesions.
- Doses in stereoscopy are similar to projection imaging.

Acknowledgements

Portions of this work were funded by the U.S. Department of Defense Grants DAMD 17-96-1-6280, DAMD 17-97-1-7143, and DAMD-17- 98-1-8169.