POINT/COUNTERPOINT

Suggestions for topics suitable for these Point/Counterpoint debates should be addressed to Colin G. Orton, Professor Emeritus, Wayne State University, Detroit: ortonc@comcast.net. Persons participating in Point/Counterpoint discussions are selected for their knowledge and communicative skill. Their positions for or against a proposition may or may not reflect their personal opinions or the positions of their employers.

Cone beam x-ray CT will be superior to digital x-ray tomosynthesis in imaging the breast and delineating cancer

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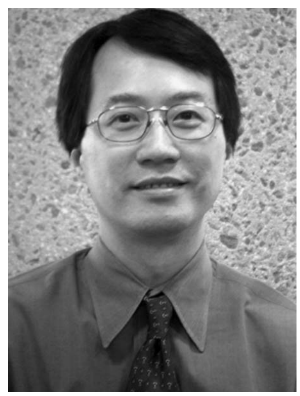
OVERVIEW

Recent advances in cone beam CT and digital x-ray tomosynthesis suggest that three-dimensional (3D) systems may soon replace conventional planar mammography as the modality of choice for imaging the breast and delineating cancer. Both of these new technologies exhibit clear advantages over planar mammography but which one of these two is most likely to dominate is debatable. This is the topic of this month's Point/Counterpoint.

Arguing for the Proposition is Andrew Karellas, Ph.D. Dr. Karellas received his Ph.D. in Medical Physics from UCLA in 1984 and is currently Professor of Radiology in the University of Massachusetts Medical School, Worcester, MA. He is a Diplomate of the ABR in Diagnostic Radiologic Physics and a Fellow of the AAPM. His interests include digital mammography, tomosynthesis, and tomographic and 3D imaging of the breast. He is a member of the Medical Physics Board of Editors and serves as a Deputy Editor, and has been the Chairman of the AAPM Diagnostic X-ray Imaging Committee and TG 15 on Digital Mammography for Stereotactic Localization. He is a Past President of both the New England and Southeast Chapters of the AAPM.



Arguing against the Proposition is Joseph Lo, Ph.D. Dr. Lo received his Ph.D. in Biomedical Engineering from Duke University, Durham, NC. Between 1993 and 1995 he was a postdoctoral research associate in the Department of Radiology, Duke University Medical Center. He is currently Assistant Professor of Radiology and Biomedical Engineering, and serves on the faculty of the medical physics graduate program at Duke. His interests cover many aspects of breast cancer research including breast tomosynthesis and CT, bioinformatics, computer-aided diagnosis, and digital image processing.

FOR THE PROPOSITION: Andrew Karellas, Ph.D.

Opening Statement

The general concepts of digital breast tomosynthesis (DBT) and dedicated breast computed tomography (DBCT) have been known for many years, but they could not be practically implemented without advanced flat panel detectors of the type that are now used for digital radiography and mammography.[1–6] Recent advances in flat panel detector technology have provided a strong impetus for the development of improved and computationally efficient image reconstruction algorithms for DBT and DBCT.[7] In parallel, research and development efforts in digital mammography have been directed toward improvements in the physical aspects of planar imaging of the breast. However, imaging in planar mammography is limited by the inability to visualize tissues in a tomographic or three-dimensional mode. Therefore a suspicious abnormality can be obscured by interfering breast tissue because the three-dimensional anatomy is represented in a two-dimensional image. DBT and DBCT hold considerable promise in overcoming the limitations of mammography, particularly in dense breasts, but DBT may be viewed as a limited tomographic extension of digital mammography rather than a true tomographic and 3D imaging modality. Breast tomosynthesis can be performed in a number of ways by varying the projection geometry, detector characteristics, exposure technique, reconstruction algorithm, and mode of image display. Developers of the technology may claim unique advantages of a particular tomosynthesis approach based on the implementation of various improvements. For example, we are likely to see improvements in radiation dose efficiency, speed of acquisition, image reconstruction speed, and reconstruction artifacts. Despite such advances, DBT is fundamentally limited by its constraints in the projection geometry. In DBT the tomographic slice is not well defined, which can cause loss of resolution in the axial direction that can affect visualization of subtle features such as amorphous microcalcifications.

Dedicated computed tomography can image the entire breast in a more complete tomographic approach and with essentially isotropic resolution. This technology is in its infancy and several improvements have yet to be made that relate to parameters like voxel size, cone beam reconstruction, x-ray scatter suppression, radiation dose, and breast coverage. Dedicated breast CT can generate true tomographic and 3D images of the breast hitherto unavailable by any other x-ray imaging technique of the breast, and it does not require physical compression of the breast. It is likely to be of particular value for imaging dense breasts and breasts with implants. Given the choice between limited tomography with breast compression offered by tomosynthesis and full tomography with 3D imaging of the breast without compression, dedicated breast CT offers a more powerful alternative to tomosynthesis. Although I am strongly in favor of continued research on DBT, we should make an even greater commitment in DBCT because of its true tomographic and 3D capability.

AGAINST THE PROPOSITION: Joseph Lo, Ph.D.

Opening Statement

Digital tomosynthesis will replace mammography, and soon, while breast CT will not. This strong claim is justified because tomosynthesis (often abbreviated as "tomo") has all the advantages of mammography, while providing 3D images to address mammography's main problem of overlapping tissue.

Breast tomo is based upon modifications to existing full-field digital mammography (FFDM) systems. The result is high resolution in the x-y plane parallel to the compression paddle, with lower but acceptable resolution (e.g., 1 mm) in the z, or depth, direction. In comparison, breast CT resolution within each slice is likely to be several times worse, possibly affecting the ability to detect and characterize calcification morphology. Even for masses where resolution is likely not the limiting factor, one study showed no significant difference in performance between breast tomo and CT.[8] Although research continues in order to optimize tomo acquisition[9,10] and reconstruction,[11–14] clinical trials with federal and industrial funding are already in progress involving multiple sites/vendors and well over 3000 subjects to date.

Tomo is technically just limited-angle cone beam CT, but angular range is not the only important difference between the modalities. Tomo compresses the breast in a standing position just like mammography, while breast CT uses no compression and thus requires prone positioning. This distinction is actually a very big deal for many clinically relevant reasons. First and foremost, tomo provides far better posterior tissue coverage than CT. Because the patient lies on a table with finite thickness and there is no compression to pull the breast into position, the chest wall and axilla cannot be effectively imaged. Moreover, just getting some patients into the prone position will slow down the workflow or just be impossible, such as for women who may be arthritic, morbidly obese, or otherwise infirm. For these women, posterior tissue coverage will be even more challenging.

Breast tomo also has several practical advantages. Minimal re-training is necessary for technologists (as positioning and operation are virtually the same as for FFDM) or radiologists (because tomo images already resemble mammograms). In contrast, breast CT is a whole new modality and may require substantial re-training. Consider as well infrastructure and cost. While a tomo system can do double duty as a conventional FFDM system, a breast CT unit cannot, which means hospitals would need to buy both mammography and CT units. The unit cost for breast CT is also likely to be much greater than that of a much simpler FFDM/tomo system. Finally, the larger footprint of the breast CT table may not fit into existing mammography rooms, which would require even more costly renovations and downtime.

In summary, although breast CT will play some role in future breast imaging, it is not practical for primary screening. Breast tomo will have comparable performance and much wider clinical acceptance than breast CT. Ultimately, breast tomo will likely replace mammography, at least for screening and, perhaps, for diagnostic examinations as well.

Rebuttal: Andrew Karellas, Ph.D.

Breast tomosynthesis is not likely to provide the final solution to circumventing the limitations of planar mammography. Tomosynthesis systems are not likely to evolve as simple upgrades of existing digital mammography systems. Major redesign with regard to the mechanics of the motion of the x-ray tube and detector must be made and the beam quality (kVp, target, filtration) is likely to be different from that in planar mammography in order to maintain low radiation dose. This would also require modifications of the detector in the form of larger pixel size, pixel binning and thicker x-ray detector that would result in lower spatial resolution than in digital mammography. The adaptation of breast tomosynthesis systems to a dual function for digital mammography and tomosynthesis is attainable but such systems will not deliver true tomographic and 3D information. Breast tomosynthesis relies on limited projections (typically about 10–25) and the reconstructed images are inherently prone to artifacts that may render some features difficult to interpret. Its spatial resolution in the depth (z) direction presents a particular concern in depicting the geometry and morphology of clustered microcalcifications due to its non-isotropic resolution and propensity to artifacts.

By comparison, dedicated breast CT delivers isotropic spatial resolution for true tomographic and 3D depiction of anatomic detail, and it is less prone to image reconstruction artifacts in the absence of highly attenuating tissues and large cone beam angle. DBCT is critically dependent on advances in detector and electronics technology for attaining good spatial resolution, fast data acquisition and lower radiation dose. Slip ring technology can be implemented for fast acquisition in order to avoid any motion effects. In view of recent advances in detectors and electronics and gantry design and rotational mechanics, further improvements in DBCT are very realistic. Simultaneous imaging of the axial and medial aspects of the breast presents a significant challenge with DBCT but, with innovative gantry design, rotational mechanics and patient positioning techniques, this challenge can be met. Finally, unlike tomosynthesis, DBCT does not require physical compression of the breast and this represents a radical departure and a great improvement over existing techniques.

Rebuttal: Joseph Lo, Ph.D.

I agree with Dr. Karellas that the limited angle acquisition of tomosynthesis is a limitation. I disagree, however, on its impact. Tomo consistently provides compelling images that have radiologists clamoring for the technology. In a recent clinical study, tomosynthesis outperformed mammography in sensitivity and specificity.[15] Radiologists do not mind the artifacts or depth resolution. They *are* concerned, however, with workflow implications of interpreting dozens of images per breast for tomo and possibly 200 or more for breast CT.

Breast CT will probably play an important role as a diagnostic adjunct to mammography or tomosynthesis. I agree that CT will image implants far better. As for 100% dense breasts, tomo can often image them quite well already, but CT may do even better. CT may also facilitate future quantitative applications such as contrast enhanced imaging.

Microcalcifications are a controversial issue for both modalities. Tomosynthesis has higher in-plane resolution but may suffer from artifacts. Clinical results to date are mixed, and this is an active area of research. Others have suggested hybrid scan sequences which avoid the whole problem by acquiring a conventional FFDM in mid-tomosynthesis scan.[16] In comparison, breast CT's lower in-plane resolution may make calcification detection and characterization quite challenging.

At this moment, neither of these modalities has received approval in the US or elsewhere. This may change quickly, of course, but clearly both are nascent technologies and there is much potential for improvement. On this point, my colleague and I certainly agree.

In conclusion, while breast CT yields "true" 3D images, it has important practical limitations including prone positioning, poor posterior coverage, and likely higher cost. Tomosynthesis delivers practical and effective 3D images without such limitations. From the patient's point of view, we may use slightly less compression to achieve dose reduction, positioning, and immobilization while avoiding pain. Tomosynthesis is therefore likely to become the new standard for screening and perhaps diagnostic breast imaging.

[1] C. H. Chang, J. L. Sibala, and J. H. Gallagher *et al.*, "Computed tomography of the breast: A preliminary report," Radiology **124**, 827–829 (1977).

[2] V. Raptopoulos, J. K. Baum, M. Hochman, and A. Karellas *et al.*, "High resolution CT mammography of surgical biopsy specimens," J. Comput. Assist. Tomogr. **20**, 179–184 (1996).

[3] L. T. Niklason, B. T. Christian, and L. E. Niklason *et al.*, "Digital tomosynthesis in breast imaging," Radiology **205**, 399–406 (1997).

[4] S. Suryanarayanan, A. Karellas, and S. Vedantham *et al.*, "Comparison of tomosynthesis methods used with digital mammography," Acad. Radiol. **7**, 1085–1097 (2000).

[5] J. M. Boone, T. R. Nelson, K. K. Lindfors, and J. A. Seibert, "Dedicated breast CT: Radiation dose and image quality evaluation," Radiology **221**, 657–667 (2001).

[6] B. Chen and R. Ning, "Cone-beam volume CT breast imaging: Feasibility study," Med. Phys. **29**, 755–770 (2002).

[7] T. Wu, A. Stewart, and M. Stanton *et al.*, "Tomographic mammography using a limited number of low-dose cone-beam projection images," Med. Phys. **30**, 365–380 (2003).

[8] X. Gong, S. J. Glick, B. Liu, A. A. Vedula, and S. Thacker, "A computer simulation study comparing lesion detection accuracy with digital mammography, breast tomosynthesis, and cone-beam CT breast imaging," Med. Phys. **33**, 1041–1052 (2006).

[9] I. Sechopoulos, S. Suryanarayanan, S. Vedantham, C. D'Orsi, and A. Karellas, "Computation of the glandular radiation dose in digital tomosynthesis of the breast," Med. Phys. **34**, 221–232 (2007).

[10] Y. Chen, J. Y. Lo, N. T. Ranger, E. Samei, and J. T. Dobbins, III, "Methodology of NEQ (f) analysis for optimization and comparison of digital breast tomosynthesis acquisition techniques and reconstruction algorithms," in Medical Imaging 2007: Physics of Medical Imaging, San Diego, CA, Proc. SPIE **6510**, 651011 (2007).

[11] T. Wu, R. H. Moore, E. A. Rafferty, and D. B. Kopans, "A comparison of reconstruction algorithms for breast tomosynthesis," Med. Phys. **31**, 2636–2647 (2004).

[12] Y. Zhang, H. P. Chan, B. Sahiner, J. Wei, M. M. Goodsitt, L. M. Hadjiiski, J. Ge, and C. Zhou, "A comparative study of limited-angle cone-beam reconstruction methods for breast tomosynthesis," Med. Phys. **33**, 3781–3795 (2006).

[13] J. T. Rakowski and M. J. Dennis, "A comparison of reconstruction algorithms for C-arm mammography tomosynthesis," Med. Phys. **33**, 3018–3032 (2006).

[14] T. Wu, R. H. Moore, and D. B. Kopans, "Voting strategy for artifact reduction in digital breast tomosynthesis," Med. Phys. **33**, 2461–2471 (2006).

[15] S. P. Poplack, T. D. Tosteson, C. A. Kogel, and H. M. Nagy, "Digital breast tomosynthesis: Initial experience in 98 women with abnormal digital screening mammography," AJR, Am. J. Roentgenol. **189**, 616–623 (2007).

[16] R. M. Nishikawa, I. Reiser, P. Seifi, and C. J. Vyborny, "A new approach to digital breast tomosynthesis for breast cancer screening," in Medical Imaging 2007: Physics of Medical Imaging, San Diego, CA, Proc. SPIE **6510**, 65103C (2007).