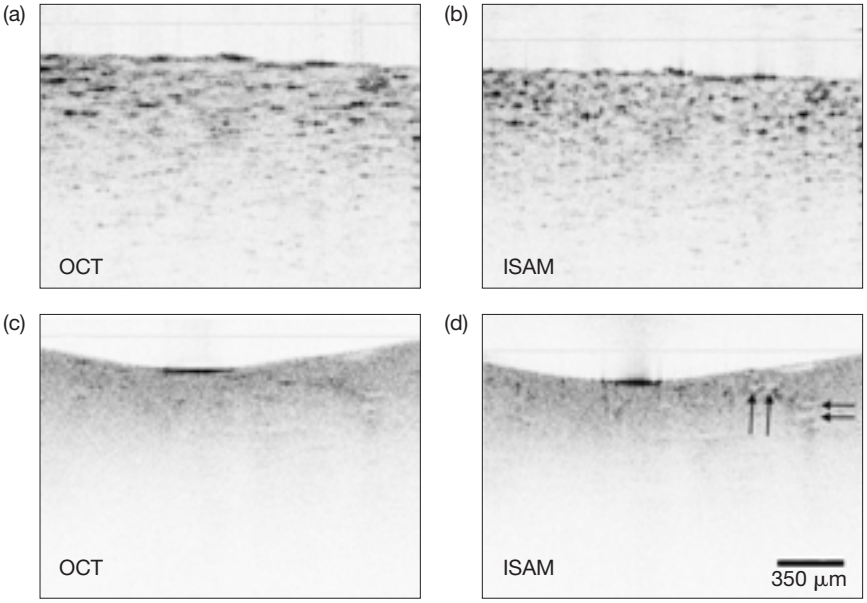
Real-Time Interferometric Synthetic Aperture Microscopy for Clinical Applications

Tyler S. Ralston, Steven G. Adie, Daniel L. Marks, Brynmor J. Davis, P. Scott Carney and Stephen A. Boppart

A number of modern coherent—i.e., interferometric or holographic—imaging techniques produce high-resolution images of biological specimens. For instance, optical coherence tomography (OCT) is a low-coherence imaging technique that generates microtomographic images in two or three dimensions.[1] OCT has been shown to be useful in medical and surgical specialties, including surgical guidance,[2] with real-time designs providing immediate diagnostic feedback.

OCT works under the assumption that a low-numerical-aperture lens produces a beam that is both well-collimated and well-confined, so that a 1D pulse-echo model is applicable, as is the case in many modalities of radar and sonar imaging. Advancement beyond the 1D model requires the solution of an inverse scattering problem (ISP). Solution of the ISP for radar is the basis of synthetic aperture radar (SAR), and solution of the ISP for broadband optical microscopy is the basis of interferometric synthetic aperture microscopy (ISAM).[3,4] There are several advantages associated with both ISAM and SAR, including that regions of the sample may be reconstructed everywhere simultaneously with spatially uniform resolution, undoing the effects of beam spreading that limit the 1D model. By providing at every depth resolution equal to that seen in OCT at the focus, ISAM makes it possible to reliably interpret biomedical images across the entire sample volume.

Recent advancements to the ISAM algorithm and hardware have made real-time acquisition and display possible, thus enabling *in situ* surgical feedback.[5] As a demonstration of real-time ISAM on a clinical system, we have imaged a portion of human breast tissue excised during routine surgery. The clinical ISAM system has been designed with the capability of capturing raw spectral-domain OCT data as a subset of its functionality. The source (Praevium Research Inc.) bandwidth of 105 nm is centered about 1,310 nm, the focused spot size is 7 μm, and the confocal parameter is 56 μm in air.



(a) Standard OCT imaging in a breast adipose tissue, with (b) co-located ISAM imaging and (c) standard OCT imaging in a suspected breast tumor, with (d) co-located ISAM imaging. Horizontal arrows indicate selected features near the beam focus that are detectable in both (c) OCT and (d) ISAM images. Vertical arrows indicate selected features (possibly tumor foci) that are only visible in the ISAM image.

The figure displays OCT images and ISAM reconstructions of breast tissue *ex vivo*, taken at two different locations in the sample. Resolution improvements can be seen across the adipose tissue, where cell boundaries are obscured by defocus in (a) the OCT image but are made distinct in (b) the ISAM images. The highly scattering regions in (c) and (d), which are suspected to be from a tumor, show features near the surface that are best resolved by ISAM. The increased resolution and image quality are expected to be beneficial in clinical applications such as optical biopsy guidance and image-guided surgery.

Tyler S. Ralston (tralston@engineering.uiuc.edu), Steven G. Adie, Daniel L. Marks, Brynmor J. Davis, P. Scott Carney and Stephen A. Boppart (boppart@illinois.edu) are with the Beckman Institute for Advanced Science and Technology, department of electrical and computer engineering, University of Illinois at Urbana-Champaign, U.S.A.

References

1. B.E. Bouma and G.J. Tearney. *Handbook of Optical Coherence Tomography*, Marcel Dekker, New York, 2002.
2. A.M. Zysk et al. "Optical coherence tomography: A review of clinical development from bench to bedside," J. Biomed. Opt. **12**, 051403 (2007).
3. T.S. Ralston et al. "Interferometric Synthetic Aperture Microscopy," Nature Phys. **3**, 129-34 (2007).
4. B.J. Davis et al. "Interferometric Synthetic Aperture Microscopy: Computed Imaging for Scanned Coherent Microscopy," Sensors 2008, **8**, 3903-31 DOI: 10.3390/s8063903.
5. T.S. Ralston et al. "Real-time interferometric synthetic aperture microscopy," Opt. Express **16**, 2555-69 (2008).