

merging data in the software. If the same detection hardware is used, overlaying the two data sets is easier because the patient doesn't have to be moved.

Ultrasound provides structural or morphological information about the disease, Miller said, which in its progression can alter tissue. Photoacoustics supplies functional and physiological information, such as angiogenesis and blood oxygenation changes.

"[Photoacoustics is] synergistic from a diagnostic standpoint as well as an instrument structural and design standpoint," he said.

Looking to the future and to cost savings, one option is to replace the lasers typically used in photoacoustics with LEDs, which would lower the cost of the system significantly. But, currently, the pulses produced by LEDs are too low energy, Miller said. Energy is tied to penetration depth, with a lower energy level leading to shallower imaging.

Despite the present drawbacks of the LED systems, Cyberdyne Inc. of Tsukuba,

Japan, is working on such an approach and offers its products to institutions for research purposes. According to a company spokesperson, the goal for developing the LED technology is to "turn it into a medical device that could be used for diagnostic imaging."

However, the best use of photoacoustic LED systems may be in unconventional diagnostic imaging, according to some investigators. Researcher Ali Hariri and colleagues from the University of California, San Diego said in a March 2018 paper¹ published in *Photoacoustics* that LED-based wearable photoacoustic devices may be useful in therapeutic drug monitoring applications that work by looking at the concentration of a drug in the blood.

While LEDs are used in Cyberdyne's systems, all other photoacoustic imaging systems offered today use lasers. Munich-based iThera Medical GmbH uses a wavelength tunable laser for a light source, said CEO Christian Wiest, adding that users can opt to image with only a

single wavelength. The deciding factor is the optical properties of the tissue and molecules being imaged.

"You choose the wavelength according to what you want to look at," Wiest said.

What resolution enables

Early in the last decade, iThera began offering preclinical, small animal imaging systems and has since moved on to equipment intended for clinical use. The company's systems have been used to image Crohn's disease, among other purposes. For Crohn's, breast cancer, and other bulk tissue disorders, penetration depth of the imager is important because the affected tissue can lie well below the surface. For imaging of the skin and microvasculature, however, resolution down to as small as 10 μm is more important.

According to Wiest, a trade-off exists between the resolution and penetration depth of imaging, which affects acoustic transducer specifications. The ability to pick up frequencies up to 100 MHz improves resolution but worsens imag-

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