Photoacoustic tomography: a new imaging technology for inflammatory arthritis – as applied to tail spondylitis in rats

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Early diagnosis and optimized therapy of inflammatory arthritis would be improved by increased availability of inexpensive and noninvasive yet powerful joint imaging technologies. We report on a new imaging technology called photoacoustic tomography (PAT), an emerging hybrid of optical and ultrasound imaging that is noninvasive, nonionizing, with high sensitivity, satisfactory imaging depth and good temporal and spatial resolution (1, 2). PAT provides a potentially powerful tool for both clinical and laboratory study of inflammatory arthritis by presenting both morphological and physiological characteristics of joint tissues. In this work, we used PAT to image a model of spondyloarthritis, namely HLA-B27/human beta2-microglobulin (B27/hβ2m) transgenic rats (3). In particular, the tail spondylitis in this model provides a surrogate for human finger joints, considering their morphological similarity.

The PAT system for joint imaging has been introduced in detail in Refs. (1, 2). To be brief, a short-pulsed laser source illuminates the imaged joint and generates photoacoustic waves due to thermoelastic expansion. The input laser energy density at 700-nm wavelength is well below the ANSI human safety limit (4). The photoacoustic signals from articular tissues are then measured by wide-band ultrasonic transducers to reconstruct an image of the joint (5). PAT, therefore, generates optical contrast that is highly sensitive to molecular composition of biological tissues while presenting good ultrasonic resolution which is not limited by the strong light diffusion in articular tissues.

The age of B27/hβ2m rats was 237 and 348 days old; B27/hβ2m and normal rats each had similar body weight. Immediately after the rats were sacrificed, the tails were amputated and proximal vessels were cauterized. The same specimens were also imaged by microCT (ImTek Micro-Computer Aided Tomography (mCAT) with reconstructed imaging spatial resolution of 0.15 mm) and ultrasound (LOGIQ 9 GE with i12L linear array transducer working at 10 MHz) for comparison and verification of photoacoustic results.

Representative results from a normal and an arthritic specimen are shown in Fig. 1. The intraarticular tissue proliferation in the affected joint is represented clearly in the PAT image in Fig. 1A. Because the overgrowth of intraarticular tissues caused swelling and deformity of joint structures, some structures that can be recognized in the image

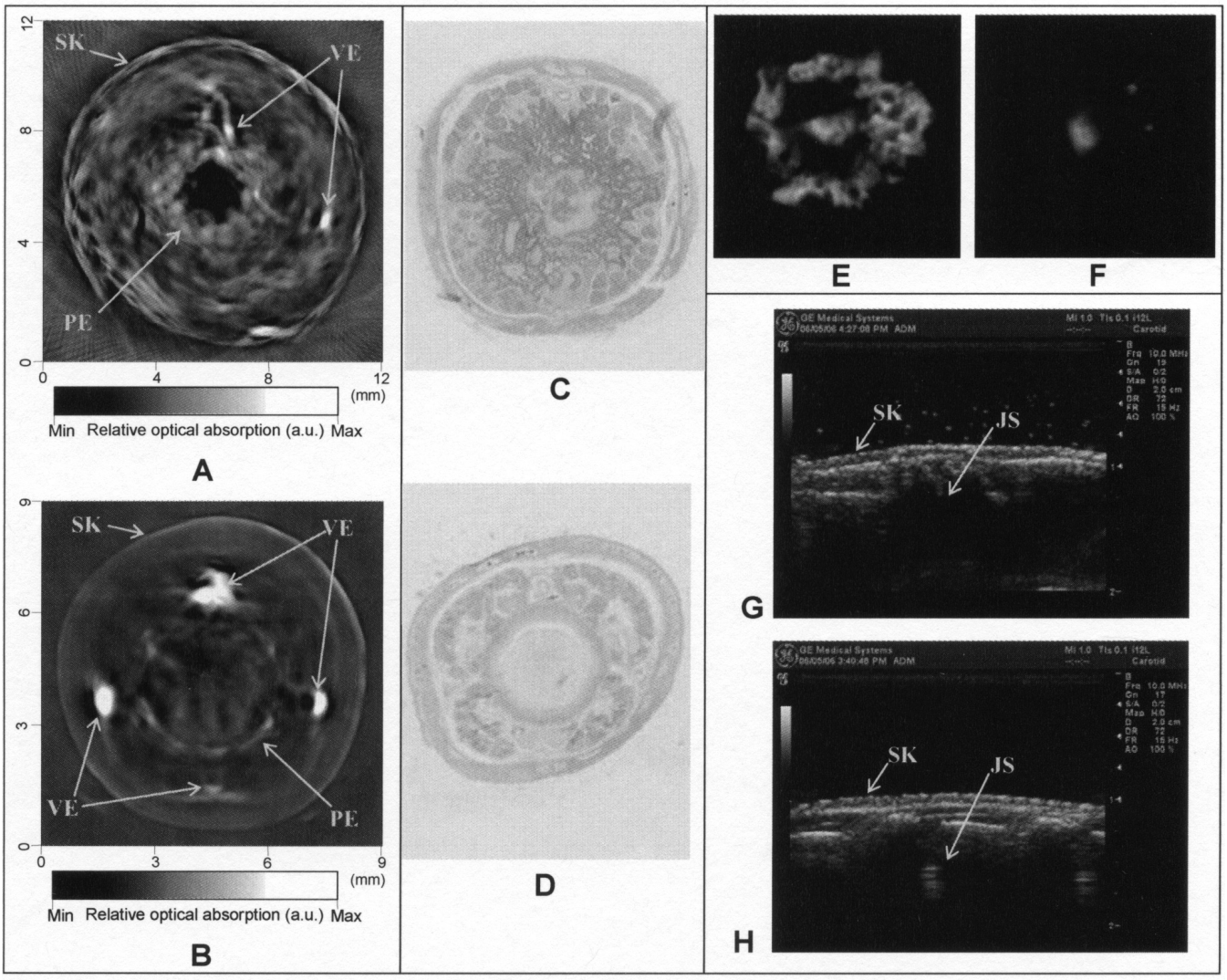

Fig. 1. Cross-sectional photoacoustic images of (**A**) the arthritic and (**B**) the normal rat tail joints. Histological photographs of the imaged cross sections in (**C**) the arthritic and (**D**) the normal joints. Cross-sectional microCT images of (**E**) the arthritic and (**F**) the normal rat tail joints. Ultrasound images of sagittal sections in (**G**) the arthritic and (**H**) the normal joints.
SK: skin; VE: vessel; PE: periosteum; JS: joint space.

of the normal joint in Fig. 1B cannot be identified in the image of the affected joint. Besides the distortion of articular structures, tissues in the arthritic joint also show much higher optical absorption in comparison with the normal joint. PAT results of the inflamed and the normal joints can be compared with their corresponding histological photographs in Figs. 1C and D respectively. The periostial proliferation and the deformity of morphological joint structures found in PAT images have been confirmed by histological findings. Figs. 1E and F show the microCT results in the joints taken along the similar cross sections as the PAT images. In comparison with the normal joint, the specimen from the transgenic rat shows clearly soft tissue proliferation. The morphological changes in the affected joint have been verified also by ultrasound examination of the same specimens. Figs. 1G and H present the pulse-echo ultrasound images of the sagittal sections in the affected and the normal joints, where the narrowing of joint space due to the proliferation of intraarticular tissues can be seen in Fig. 1G.

The results shown here provide evidence that photoacoustic tomography technique is suitable for the noninvasive, non-ionizing imaging of inflammatory arthritis. A unique feature of PAT is its ability to be readily combined with ultrasonography which does not show sufficient sensitivity for early detection of inflammatory arthritis when used alone (6). A future PAT-ultrasound dual-modality system may allow imaging of a joint based on both optical and ultrasound contrast. Because PAT is intrinsically sensitive to blood volume and blood oxygenation and ultrasound can quantify blood flow and vascular density, this dual-modality system may enable accurate evaluation of soft tissue hemodynamic properties which are believed to be closely related with the pathologic state of joint disease. With the comprehensive information provided by this system, the sensitivity and specificity in diagnostic imaging and therapeutic monitoring of inflammatory joint diseases may be enhanced significantly.

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D.L. CHAMBERLAND[1]
J.D. TAUROG[2]
J.A. RICHARDSON[3]
X. WANG[4]

[1]Division of Rheumatology, Department of Internal Medicine, and [4]Division of Basic Radiological Science, Department of Radiology, University of Michigan School of Medicine, Ann Arbor, Michigan, USA; [2]Rheumatic Diseases Division, Department of Internal Medicine, and [3]Department of Pathology, University of Texas Southwestern Medical Center, Dallas, Texas, USA.

Address correspondence to: Dr. X. Wang, Division of Basic Radiological Science, Department of Radiology, University of Michigan School of Medicine, Ann Arbor, Michigan 48109-0553, USA.
E-mail: xdwang@umich.edu

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