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● *Original Contribution*

CLINICAL EVALUATION OF SYNTHETIC APERTURE HARMONIC IMAGING FOR SCANNING FOCAL MALIGNANT LIVER LESIONS

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Abstract—The purpose of the study was to perform a clinical comparison of synthetic aperture sequential beamforming tissue harmonic imaging (SASB-THI) sequences with a conventional imaging technique, dynamic receive focusing with THI (DRF-THI). Both techniques used pulse inversion and were recorded interleaved using a commercial ultrasound system (UltraView 800, BK Medical, Herlev, Denmark). Thirty-one patients with malignant focal liver lesions (confirmed by biopsy or computed tomography/magnetic resonance) were scanned. Detection of malignant focal liver lesions and preference of image quality were evaluated blinded off-line by eight radiologists. In total, 2,032 evaluations of 127 image sequences were completed. The sensitivity (77% SASB-THI, 76% DRF-THI, $p = 0.54$) and specificity (71% SASB-THI, 72% DRF-THI, $p = 0.67$) of detection of liver lesions and the evaluation of image quality ($p = 0.63$) did not differ between SASB-THI and DRF-THI. This study indicates the ability of SASB-THI in a true clinical setting. (E-mail: andreaskr5@gmail.com) © 2015 World Federation for Ultrasound in Medicine & Biology.

Key Words: **Synthetic aperture, Sequential beamforming, Tissue harmonic imaging, Image evaluation, Liver lesion.**

INTRODUCTION

Ultrasound plays a major role in medical imaging and is used for diagnosis and assessment in a variety of medical specialties. Hence, the improvement of ultrasound techniques will benefit a large group of patients and health care workers. Tissue harmonic imaging (THI) is an ultrasound technique that improves image resolution and contrast and provides gray-scale imaging with fewer artifacts (Averkiou et al. 1997; Tranquart et al. 1999; Ward et al. 1997). Combining conventional ultrasound algorithms with THI is therefore a standard method to improve the image quality of gray-scale imaging (Desser and Jeffrey 2001; Hann et al. 1999; Shapiro et al. 1998; Tranquart et al. 1999). However, conventional B-mode imaging techniques have several technical constraints, as images are acquired sequentially one image line at a time. The frame rate is limited by the speed of sound in tissue, the scanning depth and the number of image lines. The high image resolution with a large number of image lines is, thus, obtained at the expense of frame rate. Image generation is further affected by a fixed transmit focus, causing the image to be optimally focused at only one depth. This can be improved by using multiple transmit foci, but the weakness of this solution is an increased number of emissions, which reduces the frame rate even further (Holm and Yao 1997).

High image resolution and high frame rate can be obtained with synthetic aperture (SA) (Sherwin et al. 1962). SA was originally developed from radar systems for geologic and sonar applications, but has been modified for medical imaging (Burckhardt et al. 1974). The basic idea underlying SA is generation of a high-resolution image from a number of low-resolution images (Jensen et al. 2006). An active element is selected stepwise through the array. At each step, an unfocused

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beam is emitted, and all the elements in the array receive echoes to create the low-resolution images.

Several different implementations of SA exist. However, a common disadvantage hindering real-time implementation on a commercial scanner is the high system requirements (Behar and Adam 2005; Gammelmark and Jensen 2003; Karaman et al. 1995). Synthetic aperture sequential beamforming (SASB) was introduced to reduce the system requirements of SA. SASB is a dual-stage procedure using two separate beamformers (Kortbek et al. 2008). The first beamformer reduces the data throughput requirement to that of a single output signal, that is, a factor of 64 for a 64-channel receive system. The second beamformer recombines a set of emissions to create the final high-resolution image (Hemmsen et al. 2012a; Kortbek et al. 2013). Previous studies have evaluated the image quality of SASB against conventional dynamic receive focusing (DRF) and reported equally good image quality, indicating that SASB is applicable to medical imaging (Hemmsen et al. 2011, 2012b, Hansen et al. 2014). SASB can generate an acoustic field intense enough to create harmonics for THI, and it has been suggested that these techniques be combined to improve the image quality of SASB even further. The pulse inversion technique was used to generate THI, and the beamforming steps for the final SASB-THI image are illustrated in Figure 1 (Hemmsen et al. 2014b; Rasmussen et al. 2012; Yigang et al. 2011). In a preliminary study in which healthy volunteers were scanned, two radiologists evaluated the image quality of SASB-THI as equal to that of a conventional imaging technique combined with THI (DRF-THI), indicating that SASB-THI can be used for medical imaging (Rasmussen et al. 2013).

The purpose of this study was to perform a clinical comparison of DRF-THI and SASB-THI using liver scans of patients with confirmed malignant focal liver cancer. The image sequences generated, SASB-THI and DRF-THI videos, were evaluated by radiologists for detection of malignant focal liver lesions and to assess the image quality of SASB-THI compared with that of DRF-THI in a clinical setting.

METHODS

Patients

Forty-three patients with different kinds of malignant focal liver cancer (primary liver tumor or liver metastasis) were asked to participate in the study. All patients were included after providing informed consent and on approval by the Danish National Committee on Biomedical Research Ethics (Journal No. H-1-2011-124). Before the study, liver lesions were diagnosed by biopsy or computed tomography/magnetic resonance (CT/MR). Surgery was scheduled the day after the ultrasound examination for all patients. Before the experimental scan, an orientation scan was performed with a conventional ultrasound scanner (UltraView 800, BK Medical, Herlev, Denmark), and if available, CT/MR was used to ensure correct scan position. Included were only patients in whom the pathology was visible on the orientation scan, which was performed without contrast enhancement. Twelve patients were excluded because the pathology was not visible; thus, a total of 31 patients with focal liver cancer (28 colorectal liver metastases and 3 hepatocellular carcinomas) were examined with the experimental setup. Among the patients examined were 10 women and 21 men, ranging in age from 37 to 82 y (mean ± standard deviation [SD]: 65.1 ± 10.4 y) and in body mass index from 16.8 to 33.0 kg/m^2 (mean ± SD: 24.7 ± 4.4 kg/m^2).

Scanning

The patients were scanned in three positions where the liver lesions were visible and in three areas where no pathology was visible. The patients were positioned supine and were told to hold their breath and lie still during recording. All scans were performed by P.M.H. and A.H.B. The aim was to record six sequences for each patient, but because of technical challenges, this was possible for only 28 patients. One patient had only three recordings, and two patients had seven recordings because of errors made while saving and noticed after the scan session. A total of 185 image sequences were recorded.

The acoustic output of SASB-THI was determined before scanning. Intensities must be those recommended by the Food and Drug Administration (FDA) for abdominal scanning. The limits are given by the mechanical index, MI ≤ 1.9; the derated spatial peak, pulse average intensity, $I_{sppa} \leq 190$ W/cm^2; and the derated spatial peak, temporal average intensity, $I_{spta} \leq 94$ mW/cm^2 (Food and Drug Administration 2008). As SASB-THI and DRF-THI use the same transmit profile equal acoustic outputs are obtained. The intensities were MI = 0.9, $I_{sppa} = 81.2$ W/cm^2 and $I_{spta} = 16.2$ mW/cm^2 and, hence, were lower than the FDA limit.

Equipment and data acquisition

Experimental scans were performed with a conventional ultrasound scanner (UltraView 800, BK Medical, Herlev, Denmark) equipped with a research interface and an abdominal 3.5-MHz CL192-3 ML convex array transducer (Sound Technology, State College, PA, USA). The ultrasound scanner was connected to a stand-alone PC. With the experimental setup, images generated with SASB-THI and DRF-THI were recorded