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● *Original Contribution*

ECHO-POWER ESTIMATION FROM LOG-COMPRESSED VIDEO DATA IN DYNAMIC CONTRAST-ENHANCED ULTRASOUND IMAGING

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Abstract—Ultrasound (US) scanners typically apply lossy, non-linear modifications to the US data for visualization purposes. The resulting images are then stored as compressed video data. Some system manufacturers provide dedicated software for quantification purposes to eliminate such processing distortions, at least partially. This is currently the recommended approach for quantitatively assessing changes in contrast-agent concentration from clinical data. However, the machine-specific access to US data and the limited set of analysis functionalities offered by each dedicated-software package make it difficult to perform comparable analyses with different US systems. The objective of this work was to establish if linearization of compressed video images obtained with an arbitrary US system can provide an alternative to dedicated-software analysis of machine-specific files for the estimation of echo-power. For this purpose, an Aplio 50 system (Toshiba Medical Systems, Tochigi, Japan), coupled with dedicated CHI-Q (Contrast Harmonic Imaging Quantification) software by Toshiba Medical Systems, was used. Results were compared with two approaches that apply algorithms to estimate relative echo-power from compressed video images: commercially available VueBox software by Bracco Suisse SA (Geneva, Switzerland) and in-laboratory software called PixPower. The echo-power estimated by CHI-Q analysis indicated a strong linear relationship versus agent concentration *in vitro* ($R^2 \geq 0.9996$) for dynamic range (DR) settings of DR60 and DR80, with slopes between 9.22 and 9.57 dB/decade ($p = 0.05$). These values approach the theoretically predicted dependence of 10.0 dB/decade (equivalent to 3 dB for each concentration doubling). Echo-power estimations obtained from compressed video images with VueBox and PixPower also exhibited strong linear proportionality with concentration ($R^2 \geq 0.9996$), with slopes between 9.30 and 9.68 dB/decade ($p = 0.05$). On an independent *in vivo* data set (N = 24), the difference in echo-power estimation between CHI-Q and each of the other two approaches was calculated after excluding regions that contain pixels affected by saturated or thresholded pixel values. The mean difference in estimates (expressed in decibels) was −0.25 dB between VueBox and CHI-Q (95% confidence interval: −0.75 to 0.26 dB) and −0.17 dB between PixPower and CHI-Q (95% confidence interval: −0.67 to 0.13 dB). To achieve linearization of data, one of the approaches (VueBox) requires calibration files provided by the software manufacturer for each machine type and setting. The other (PixPower) requires empirical correction of the imaging dynamic range based on ground truth data. These requirements could potentially be removed if US system manufacturers were willing to make relevant information on the applied processing publically available. Reliable echo-power estimation from linearized data would facilitate inclusion of different US systems in multicentric studies and more widespread implementation of emerging techniques for quantitative analysis of contrast ultrasound. (E-mail: lori.bridal@upmc.fr)

Key Words: **Contrast-enhanced ultrasound, Echo-power, Linearization, Log compression, Microbubbles, Perfusion quantification, Video compression.**

INTRODUCTION

Quantifying organ perfusion is essential in diagnosing and treating diseases such as cancer (Jain et al. 1997) and cardiovascular dysfunctions (Blankstein et al. 2009; Chung et al. 2010; Folkman 1995). Non-invasive imaging

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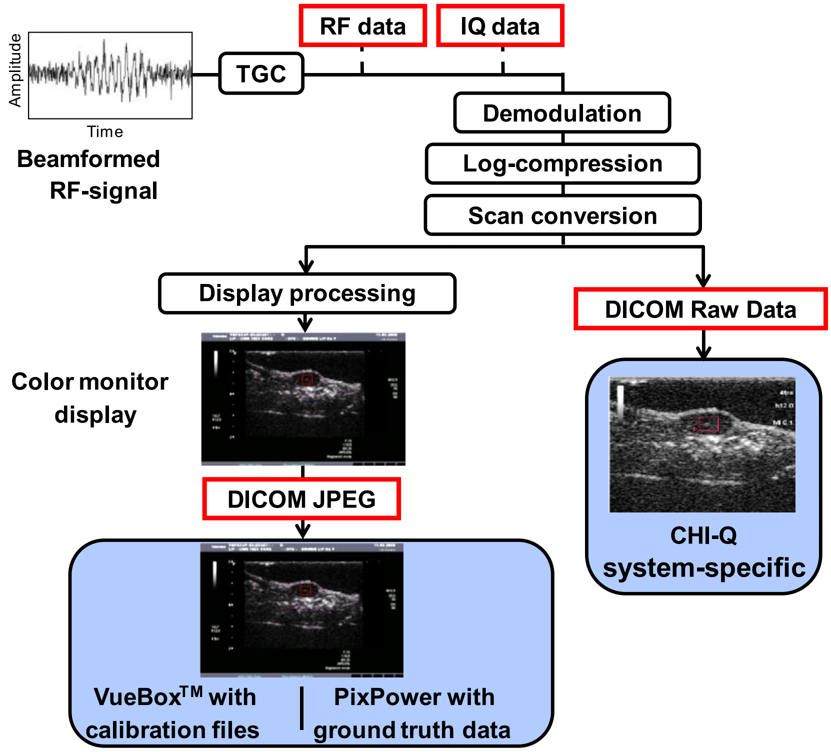

Fig. 1. Block diagram relating the main processing system steps after echo reception to image display and file storage for Raw Data and JPEG file formats. The software applied in this work to linearize each type of file is shown with a note on its limitations: machine-specific, requires calibration files for the machine and settings used, requires empirical calibration relative to dose-ranging experiments. RF = radiofrequency, IQ = quadrature, TGC = time gain compensation.

has a central role to play in the clinical assessment and repeated follow-up measurements of perfusion in tumors or organs. Among the many imaging modalities available, ultrasound (US) is of particular interest because it is a well-tolerated, bedside and well-accepted technique that can be repeated often. Recent studies have indicated that dynamic contrast-enhanced ultrasound (DCE-US) offers the possibility to obtain perfusion information by assessing contrast agent uptake (Dietrich et al. 2012; Gauthier et al. 2012a; Guibal et al. 2010; Lamuraglia et al. 2010; Leen et al. 2012; Quaia 2007). Over a large range of concentrations, the echo-power resulting from the acoustic response of contrast microbubbles is proportional to their concentration in the region of interest (ROI) (de Jong and Hoff 1993; Lampaskis and Averkiou 2010; Moran et al. 2002). Detection of microbubble tracers in the blood and appropriate perfusion models can, thus, provide a valuable assessment of microvascular flow and relative blood volume (Arditi et al. 2006; Hudson et al. 2011; Lucidarme et al. 2003; Wei et al. 1998). These flow parameters cannot be reliably estimated, however, if robust measurements of the echo-power are not obtained from the DCE-US sequences.

The lack of accessibility to machine-dependent echo signals can make it difficult to compare analyses of data from different US systems, between departments within a hospital or in multicentric studies. Raw radiofrequency (RF) signal and quadrature (IQ) signal (Powers et al. 1980) analyses are the gold standards for echo-power estimation. However, RF and IQ signals are generally not made available on machines for clinical use, primarily because of the large storage space required to handle this type of data. US systems usually perform a variety of processing operations on the echo signal for visualization purposes, as described in Figure 1. Demodulated echo signals are typically log-compressed to remap the dynamic range of meaningful ultrasound echoes at each depth (~60–70 dB) to the range of perception for the human eye of a monitor display (~30 dB) (Kremkau 1998). Results are then provided as compressed video images in DICOM (Digital Imaging and Communications in Medicine) JPEG files (DICOM JPEG). DICOM JPEG files are generally considered unsuitable for echo-power estimation for two main reasons. First, straightforward echo-power estimation from DICOM JPEG files is hindered by a lack of publically available information on the process used to create the displayed color images. In particular, information on the log-compression is not available (Gauthier et al. 2011; Rognin et al. 2008;