1-2015

# Additional results for "Joint entropy of continuously differentiable ultrasonic waveforms" [J. Acoust. Soc. Am. 133(1), 283-300 (2013)]

M S. Hughes
*Washington University School of Medicine in St. Louis*

J N. Marsh
*Washington University School of Medicine in St. Louis*

S A. Wickline
*Washington University School of Medicine in St. Louis*

John E. McCarthy
*Washington University in St Louis*, mccarthy@wustl.edu

# Additional results for "Joint entropy of continuously differentiable ultrasonic waveforms" [J. Acoust. Soc. Am. 133(1), 283–300 (2013)] (L)

M. S. Hughes,[a)] J. N. Marsh, and S. A. Wickline
*Washington University School of Medicine, Washington University in St. Louis, St. Louis, Missouri 63110*

J. E. McCarthy
*Department of Mathematics, Washington University in St. Louis, St. Louis, Missouri 63110*

(Received 27 September 2014; accepted 18 November 2014)

Previous results on the use of joint entropy for detection of targeted nanoparticles accumulating in the neovasculature of MDA435 tumors [Fig. 7 of M. S. Hughes *et al.*, J. Acoust. Soc. Am. **133**, 283–300 (2013)] are extended, with sensitivity improving by nearly another factor of 2. This result is obtained using a "quasi-optimal" reference waveform in the computation of the joint entropy imaging technique used to image the accumulating nanoparticles.
[http://dx.doi.org/10.1121/1.4904531]

[KGS] Pages: 501–501

In this Comment we report on a further improvement in sensitivity of ultrasonic detection of targeted nanoparticle contrast agents *in vivo* beyond that reported in Fig. 7 of a recent publication in this journal.[1] These results were obtained using the joint entropy, $H_{f,g}$ [Eq. (4) of Ref. 1], of the backscattered radio frequency ultrasound and a reflection of the insonifying pulse, $g(t)$, as a reference waveform.

A theoretical analysis of average performance of this type of signal processing in the presence of Gaussian noise leads to a general strategy for finding a much better choice of reference in many experimental circumstances.[2] This search requires extensive computer time but results in a further *2.5-fold* increase in sensitivity as quantified by the statistical confidence of the measurements means and standard deviations [Eq. (6) of Ref. 1].

All data acquisition and analysis parameters are the same as described previously.[1] The new feature of the analysis presented here is the use of a more nearly optimum reference waveform, $g(t)$, for the computation of joint entropy, $H_{f,g}$.

The reference, $g(t)$, was found by searching for the maximum confidence obtained using step-like functions having jumps at the extrema of the reflection of the transducer insonifying pulse from a stainless steel-reflector. These functions are specified by location of jumps, low-value, and high-value. The search spanned the following parameter ranges. Shift values: from −0.02 to 0.10 in increments of 0.01, high-values: from 100.0 to 10000.0 in decades, low-values: from 0.01 to 0.001 in decades values.

[a)]Author to whom correspondence should be addressed. Electronic mail: mshatctrain@gmail.com

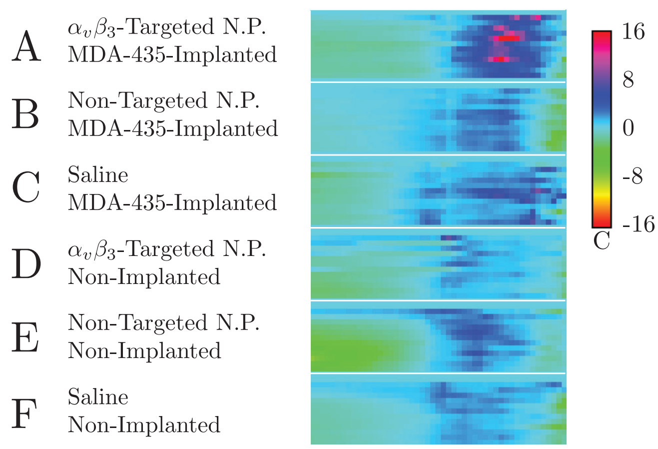


FIG. 1. Confidence, **c**, panels for $\Delta H_{f,g}$ for all groups used in our study. (A) MDA 435-implanted mice injected with $\alpha_v\beta_3$-targeted nanoparticles ($N = 5$); (B) MDA 435-implanted mice injected with non-targeted nanoparticles ($N = 5$); (C) MDA 435-implanted mice injected with saline ($N = 5$); (D),(E),(F) same injections into $N = 5$ tumor-free mice.

The color lookup table of Fig. 1 is chosen to be the same as that of Fig. 7 published previously.[1] However, the confidence values in the panels cover the range −7.7 to 30.1 so that the upper range of values, which appear on the upper right of panel (A) are actually saturated. These are roughly twice the magnitude of the largest confidences (−16) obtained previously.[1]

Funding was provided by Grant Nos. NIH EB002168, 5R21EB018095, and NSF DMS 1300280.

[1]M. Hughes, J. McCarthy, J. Marsh, and S. Wickline, "Joint entropy of continuously differentiable ultrasonic waveforms," J. Acoust. Soc. Am. **133**(1), 283–300 (2013).
[2]M. Hughes, J. McCarthy, J. Marsh, and S. Wickline, "Entropic vs. energy waveform processing: A comparison based on the heat equation," in *Proceedings of the Fall 2014 Acoustical Society Meeting*, 2014.