Adaptive compensation of TGC effects in contrast-free ultrasensitive ultrasound Doppler imaging for improved resistivity index map visualization

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1. Ultrasensitive Doppler

- Ultrasensitive power Doppler (µPD) ultrasound (US) has become an alternative for microcirculation imaging (Bercoff et al., IEEE UFFC, 2011)
- A µPD image is obtained as the mean power of the clutter filtered Doppler ensemble (CFDE), where clutter filtering is performed using a singular value decomposition (SVD) thresholding approach (Deméné et al., IEEE TMI, 2015)
- The µPD image can be used to calculate the resistivity index (RI), which is of great importance in clinical applications

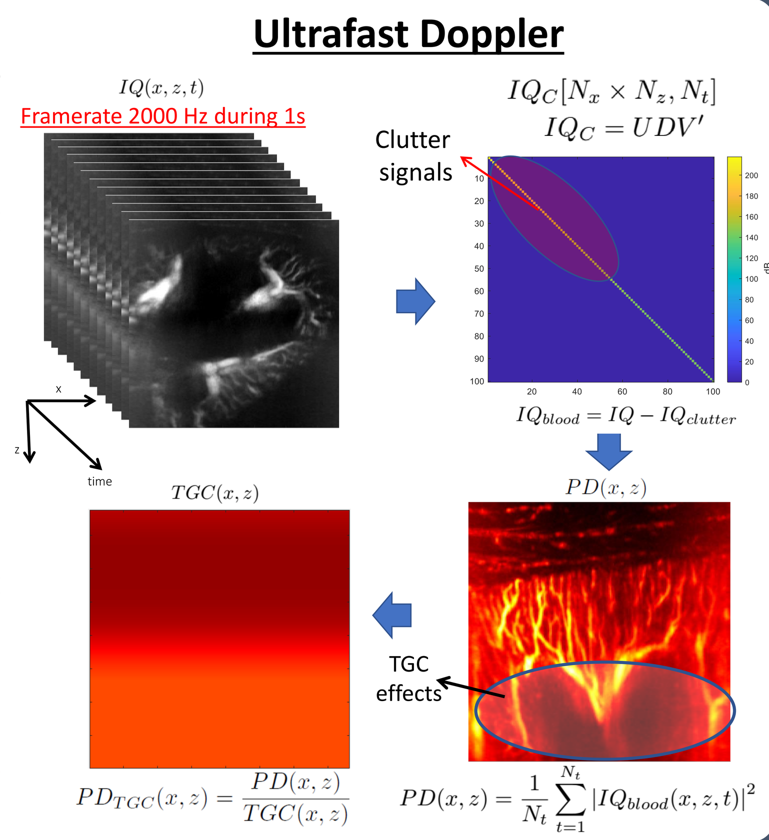
CHALLENGES:

- µPD in deep tissues (kidney and liver) is greatly affected by time gain compensation (TGC) effects, which drastically affect blood flow signals in deeper areas, making it difficult to visualize blood vessels in these regions
- Compensation for TGC effects by the equalization approach normally assumed that background noise is homogeneous over channels

AIM:

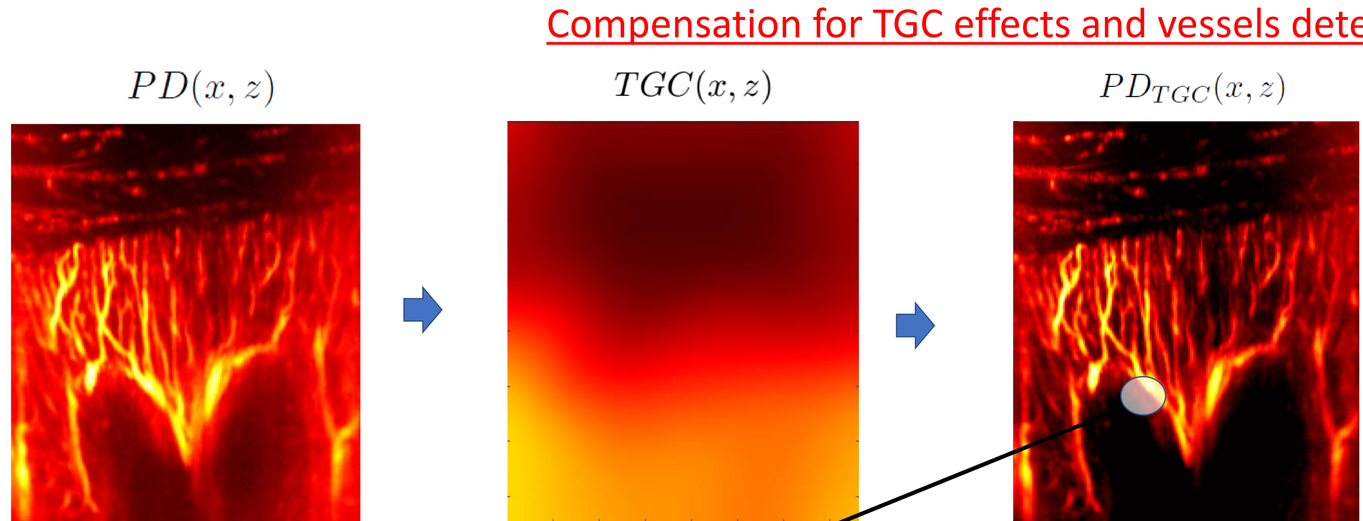
- Develop an alternative equalization method where the background noise is estimated considering inhomogeneity over the channels, thus obtaining an improved µPD image that is used to obtain a RI map

Ultrafast Doppler



2. Automatic computation of RI map using ultrasensitive Doppler

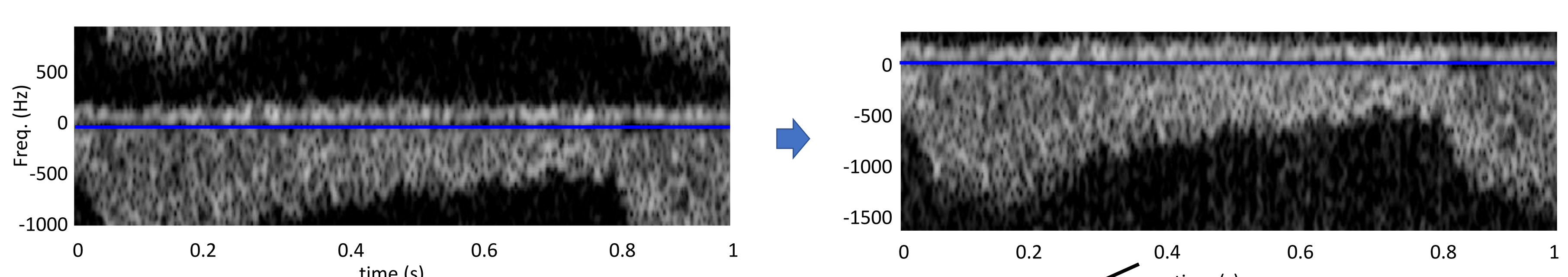
Compensation for TGC effects and vessels detection



$$PD_{TGC}(x,z) = \frac{PD(x,z)}{TGC(x,z)}$$

- TGC(x,z) is estimated from the PD image by using a combination of a median filter and a 2D Gaussian filter
- Vessels are detected at each depth using a thresholding approach

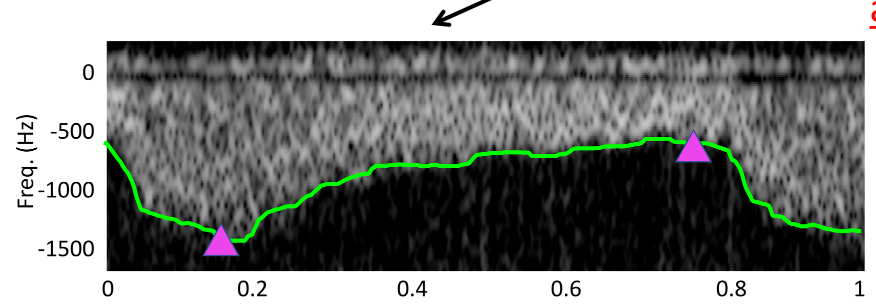
Automatic detection of spectrogram base-line for aliasing compensation



- The baseline is iteratively shifted until the relative error of the mean frequency calculated from the spectrogram is minimum.

$$PSD(x,z,f,t_0) = \left|\int_{t_0}^{t_0+t_w} \bar{s}(x,z,t)e^{-j2\pi ft}W\left(t-(t_0+\frac{t_w}{2})\right)dt\right|^2$$

Automatic detection of spectrogram envelope and RI computation

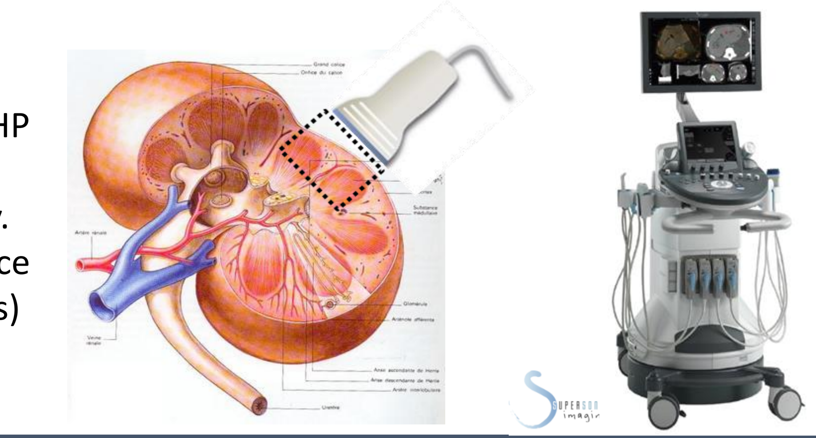


$$RI(x,z) = \frac{\max_t(|f_{env}(x,z,t)|) - \min_t(|f_{env}(x,z,t)|)}{\max_t(|f_{env}(x,z,t)|)}$$

- The spectrogram envelope is computed using the algorithm proposed by *Kathpalia et al., IEEE UFFC, 2016*

3. Data acquisition and processing

- Acquisitions were performed out by an experienced radiologist in a pilot study on 11 patients at Necker Hospital (ethical protocol APHP #NI18037J).
- RI measurements with the clinical and proposed methods were performed on the same day and in the same region of the transplanted kidney.
- The ultrafast ultrasound sequence consisted of 2 angles acquired at 4000 Hz during 1s (PRF = 2000 Hz) by using an ultrafast ultrasound device Aixplorer V12 (Supersonic Imagine, Aix-en-provence, France) with a linear probe SL10-2 (central frequency 5 MHz, pitch 0.2 mm, 192 elements)
- Acquired data were post-processed by using Matlab software (version 2020b)



4. Preliminary Results

Power Doppler Image

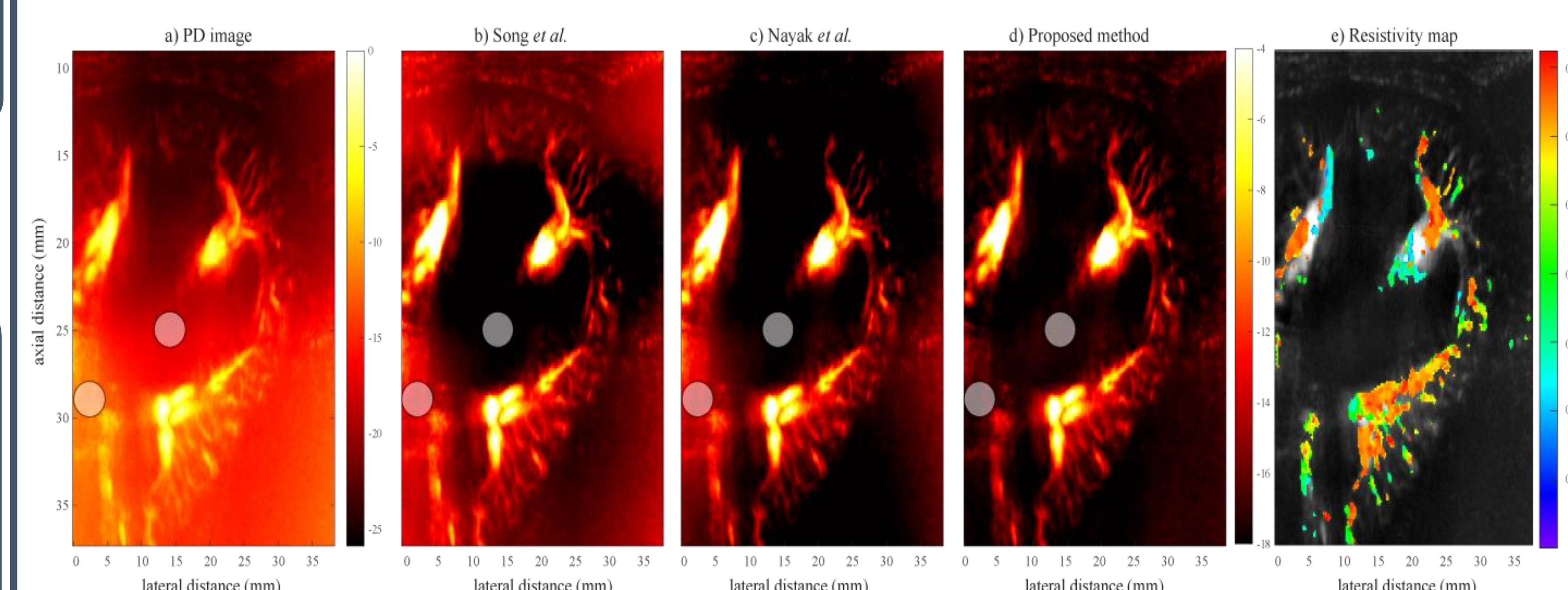


Fig. 1 Comparison between different methods used to compensate for TGC effects. a) PD image obtained from the CFDE. PD image compensated for TGC effects using the equalization method and estimating the background noise as proposed by b) Song et al., IEEE Trans Med Imaging, 2017, c) Nayak et al., Phys. Med. Biol., 2019 and d) this work. e) Resistivity map superimposed to the PD image d) in gray scale.

Clinical *vs* Proposed method

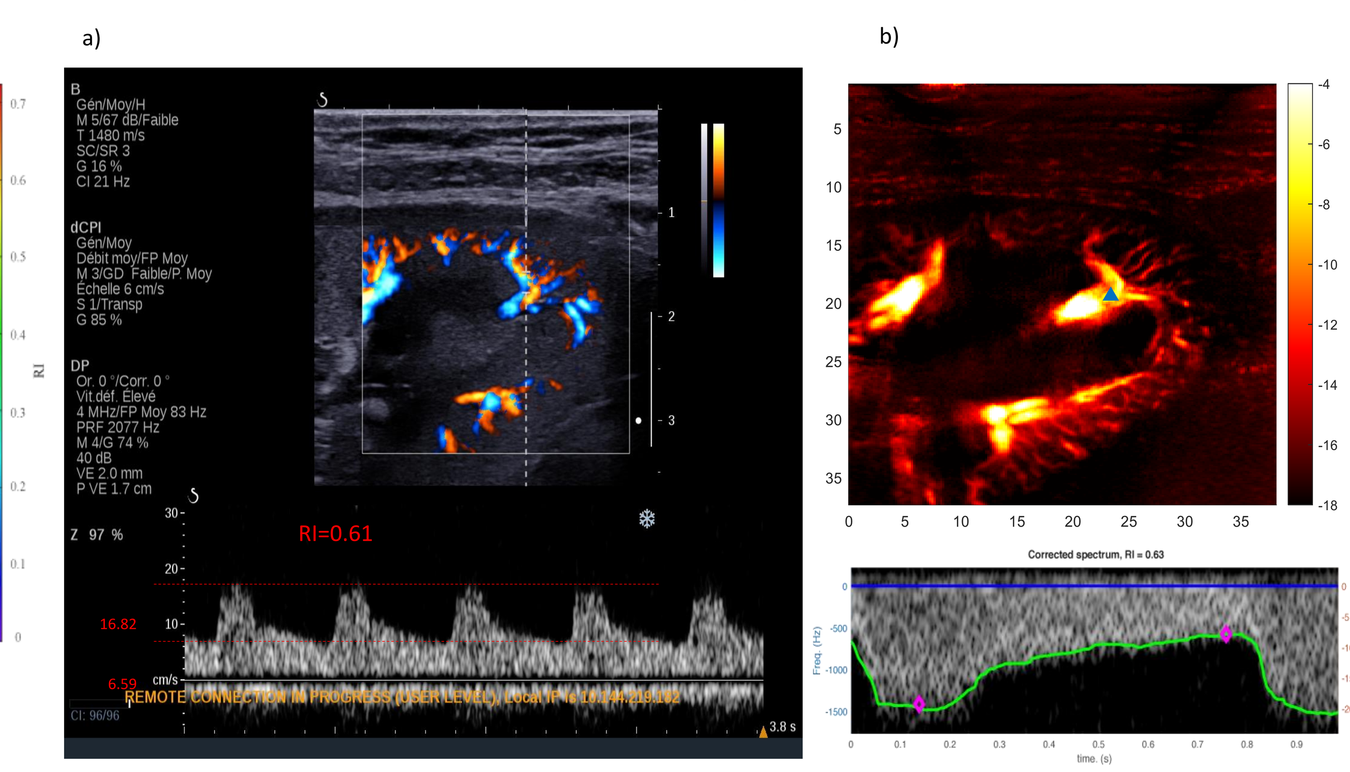


Fig. 2 RI Measurements on patient #3 **a)** at the Necker hospital, Paris, and b) using the proposed method on the same region as in clinical.

- The difference of noise level between regions of interest (white circles) decreased from 7.4 dB (Fig. 1**a**) to 0.4 dB (**Fig. 1d**, with 5.8 dB **Fig. 1b** and 4.7 dB **Fig. 1c**)
- The proposed method reduces globally the background noise level and increase contrast to noise ratio, leading to better visualization of vascularization and the RI map (**Fig. 1e**)

- Improved visualization of small vessels
- In clinical is not possible to obtain a RI map, but the RI at certain points
- Relative errors in RI were less than 10% (3 measurements)

Current challenges

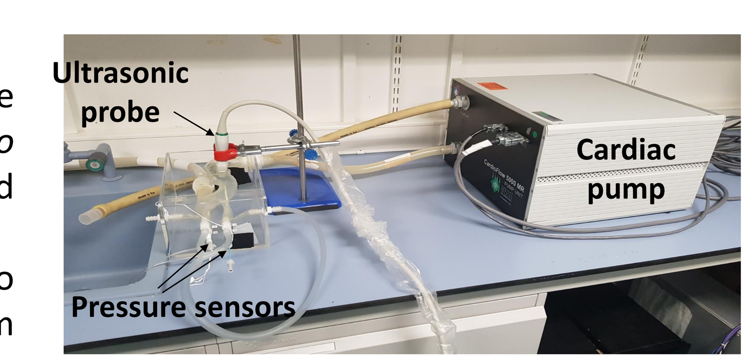
- The method to compensate for aliasing effects fails in cases of very low SNR (< 3 dB), leading to a biased estimation of RI values.
- The RI map must be post-processed to filter out values of non-pulsatile flows (RI values less than 0.2) and estimates of signals with low SNR.
- The minimum conditions for obtaining reliable RI values in terms of SNR have not been tested, since the comparison with clinical measurements was performed at points whose SNR was higher than 8 dB.

5. Conclusions

- An ultrafast ultrasound Doppler sequence has been developed and further improved by using patient acquisitions
- PD results were improved by applying compensation for TGC effects considering inhomogeneity over the channels
- Improved PD images were obtained as compared with other methods that consider homogeneity over channels
- Preliminary results were obtained from patients on vascularity, and resistivity index, which were evaluated using clinical measurements

6. Future works

- Verification of the limited conditions for obtaining reliable RI values will be carried out by simulations and *in vitro* experiments using tissue-mimicking phantoms of blood flow
- Further processing of the RI map will be developed to detect only pulsatile flow and discard values obtained from very low SNR signals



System for *in vitro* experiments by using and tissue-mimicking phantom of flow blood

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