Brain Perfusion Imaging using Contrast Agent Specific Imaging Modes

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Motivation

Assessment of Perfusion Conditions

Clinical Value

- various diseases are linked to perfusion abnormalities
  - cardiac infarction
  - stroke: infarction in the brain
  - tumors

Advantages of Medical Ultrasound

- no radioactive tracers
- bedside examination
  - available to critically ill or restless patients
  - cost effective
- may detect perfusion defects earlier than other imaging modalities

Shortcomings of the Art

- blood flow velocities too low to be measured with Doppler-based flow imaging techniques
- extremely difficult imaging conditions
  - brain: attenuation of transtemporal bone window
  - heart: motion artifacts

Perfusion Imaging Approach

Proposed Method for Perfusion Estimation

- evaluation of time-intensity-curves (TICs) after a bolus injection of contrast agent
  - ultrasound contrast agent used as tracer substance
  - use of contrast agent specific imaging modes
  - automated evaluation of measured curves

Contrast Agent Specific Imaging Modes

- contrast harmonic imaging CHI
  - sensitive to nonlinear scattering from microbubbles
- contrast burst imaging CBI
  time-variance imaging TVI
  - sensitive to changes in the acoustic properties of microbubbles that are due to the insonification

Contrast Specific Imaging Modes

Contrast Harmonic Imaging

- 2 transmits per beam line
- 180 degrees phase shift between transmits
- summation of resulting echoes, Fig. 1
  - linear scattering:
    echoes cancel each other out in the sum
  - non-linear scattering:
    incomplete cancellation ⇒ detection
  - side effect:
    detection of bubble destruction

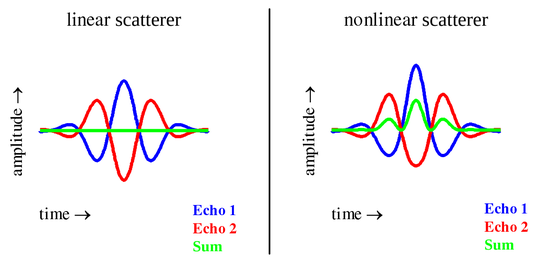

Fig. 1. Echoes resulting from 2 transmit pulses, 180° phase shift. Echoes from linear scatterers are canceled out in the sum.

Contrast Burst Imaging

- CBI is a modified power mode
  - short pulse sequences, e. g. 6 pulses per beam line, high pulse repetition frequency, e. g. 5 kHz
    ⇒ less sensitive to flow and motion artifacts
  - broadband, high power (MI > 1) pulses
    ⇒ improved resolution, bubble destruction
  - high wall filter cutoff frequency
    ⇒ suppresses flow signals
- changes in the acoustic properties of the microbubbles ("destruction") cause wideband noise in the Doppler spectrum ⇒ "bubble signature"
- signal components that are not suppressed by the wall filter are displayed, Fig. 2

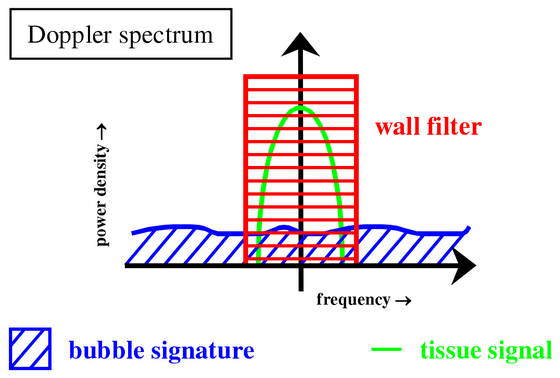

Fig. 2. Bubble destruction causes broadband noise indicating the presence of contrast agent ("bubble signature").

Time-Variance Imaging

- pulse sequence similar to the one used for CBI, N = 10 pulses per beam line, Fig. 3
- at a given depth
  - extraction of two parameters from the N echoes
    - amplitude
    - "spectral slope", describes asymmetry of rf spectrum
  - stochastic analysis of the two sets of measurements, comparison with model for "bubble destruction"
- nonlinear filter combines results for amplitude and spectral slope, Fig. 4

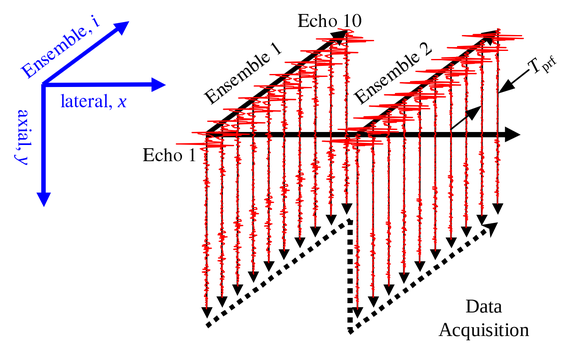

Fig. 3. Imaging sequence used for TVI. N=10 echoes corresponding to one beam line form an ensemble.

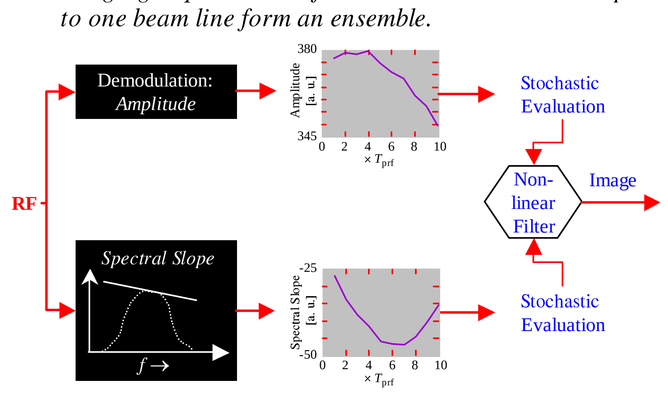

Fig. 4. RF data processing for the formation of TVI images.

Extraction and Evaluation of Time-Intensity Curves

Extraction of Time-Intensity-Curvess

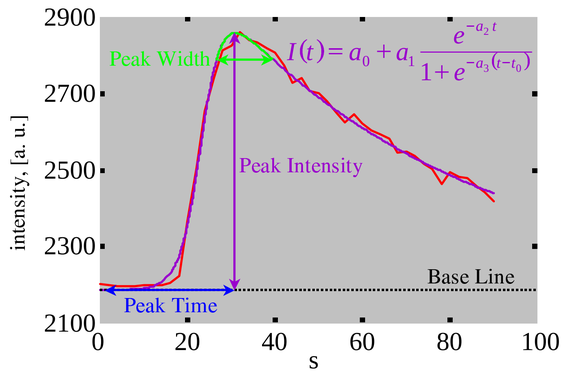

Fig. 5. Fitting of a model function to the measured time-intensity-curve.

- bolus injection of contrast agent
- registration of an imaging sequence
  - sequence covers wash-in and washout of the contrast agent
- measured time-intensity-curve
  - mean intensity within a region of interest (ROI) as a function of time
- model function $I(t)$ fitted to the measured curve in a least mean square-sense, Fig. 5
- parameters calculated from the fitted model
  - peak intensity
  - peak time (contrast arrival time)
  - peak width (duration of enhancement)

Formation of Parameter Images

- imaging plane divided into 1 mm by 1 mm resolution cells
- for all resolution cells:
  extraction and evaluation of TICs
- color coded display of parameters

Experimental Results

in vivo-Measurements

- healthy volunteers
- bolus injection of Levovist®
- ultrasound system: Siemens Sonoline® Elegra
  2.5 MHz phased array
- acquisition of 45-70 frames at 0.5 frames per second
- parallel acquisition of CHI/CBI or CHI/TVI

Results

- CHI, CBI, TVI: reliable extraction of TICs for bigger ROIs, e. g. 1 cm²
- CHI shows high resolution tissue harmonic images, Fig. 6
- CBI, TVI clearly show contrast enhancement, Fig. 7
- CBI, TVI allow the formation of parameter images, Fig. 8
- parameter images visualize results of TIC-evaluation in an easy-to-interpret way

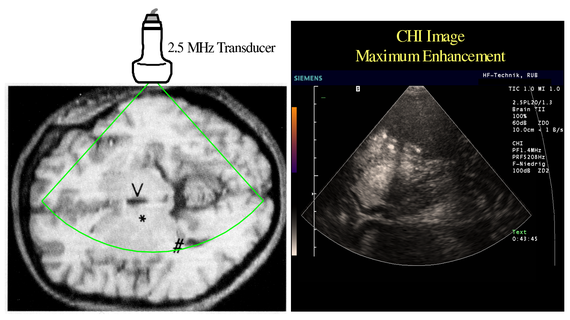

Fig. 6. Orientation of the imaging plane and contrasted CHI image.

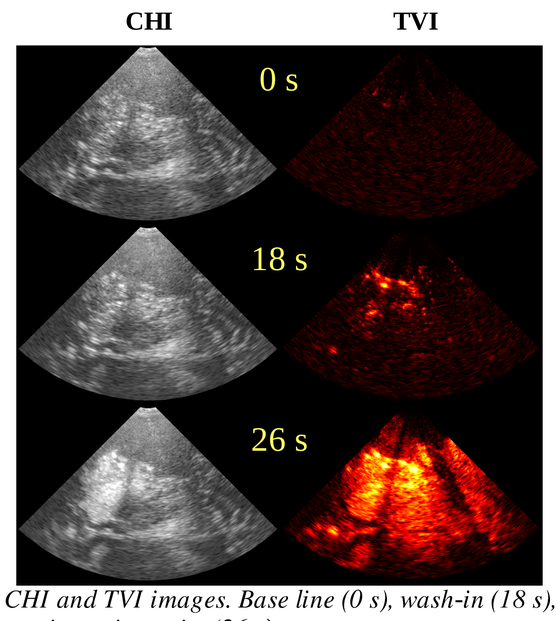

Fig. 7. CHI and TVI images. Base line (0 s), wash-in (18 s), maximum intensity (26 s).

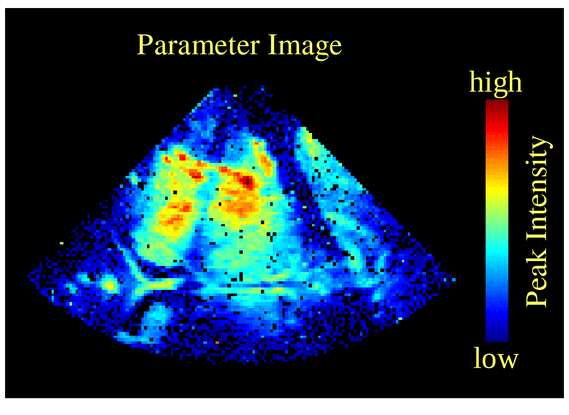

Fig. 8. Parameter image calculated from a TVI image sequence.