Noise variance of an RF receive array reflects respiratory motion: a novel respiratory motion predictor

Anna Andreychenko[1], Sjoerd Crijns[1], Alexander Raaijmakers[1], Bjorn Stemkens[1], Peter Luijten[1], Jan Lagendijk[1], and Cornelis van den Berg[1]

[1]*Imaging Division, UMC Utrecht, Utrecht, Utrecht, Netherlands*

Purpose: MRI is a relatively slow imaging modality. Patient respiratory motion significantly reduces diagnostic image quality, especially in the abdomen. Usually, motion is detected with a respiratory belt and/or navigators[1]. The belt is an extra device which demands careful positioning on the patient to be a reliable indicator of the respiratory motion. The navigator[2] is an MR based sensor and, thus, contact free. However, it requires additional planning and can interfere with the steady state magnetization, leading to image artifacts. As an alternative to the latter methods, it has been shown that patient motion can be monitored with the RF coil impedance measurements[3,4]. Since an RF coil is a part of every MRI system, there is no need for a separate sensor (i.e. pneumatic belt) or extra MR acquisition (i.e. navigator). Nevertheless, the method requires additional hardware: directional couplers[3] or pick-up coils[4]. We propose to detect the motion induced impedance variation by means of noise measurements. It is well-known that thermal noise variance ($\langle V_{noise}^2 \rangle$) in an RF coil is directly proportional to the coil's resistance (real part of impedance) and, thus, can potentially be an alternative to the direct RF coil impedance measurement. Here, using clinical MR systems we investigated the feasibility of monitoring the respiratory motion with the RF coil's $\langle V_{noise}^2 \rangle$. Moreover, noise covariance matrix of a receive array contains spatial information which can potentially be used for motion prediction.

Methods: The experiments were performed on clinical 1.5/3 T MR scanners with 16 channel body receive arrays. RF and gradients were switched off during a standard GRE MR sequence. Signal was collected with a dwell time of 1.35/1 µs (max BW), TR=3.1/2.5 ms, number of collected points per TR: 1000. At the same time, signal from the respiratory belt was recorded. Subjects were asked to perform free breathing (~1 min), deep breathing (~1 min) and breath holds in exhale and inhale positions for ~16 seconds. In addition, at 3T, the subject was asked to perform four breathing scenarios: free, deep, deep with holds and fast. $\langle V_{noise}^2 \rangle$ was calculated for each TR. The obtained temporal modulation of $\langle V_{noise}^2 \rangle$ was evaluated and compared to the respiratory belt signal. A moving average filter (length 1.2 s) was applied to the temporal modulation of $\langle V_{noise}^2 \rangle$. Power spectra were calculated of both $\langle V_{noise}^2 \rangle$ and respiratory belt signals to compare their dominant frequencies. For each coil of the 16 channel receive arrays, a relative amplitude of their $\langle V_{noise}^2 \rangle$ modulation (i.e. sensitivity to the respiratory motion) was calculated.

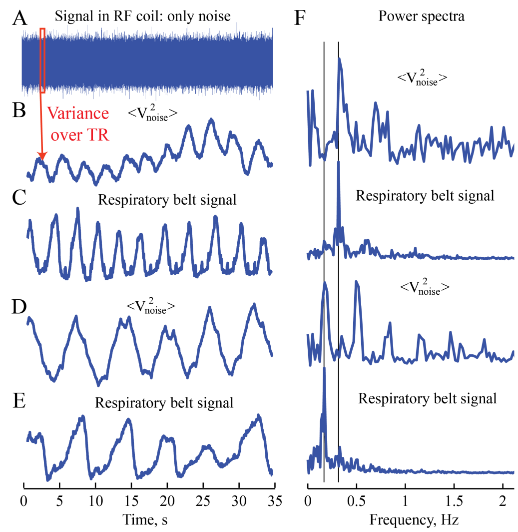

Fig 1. RF coil $\langle V_{noise}^2 \rangle$ picks up the respiratory motion. A: signal picked up by the RF coil. Temporal modulation of signal variance (i.e.$\langle V_{noise}^2 \rangle$) for free (B) and deep (D) breathings. C, E: the corresponding respiratory belt signals. F: power spectra of $\langle V_{noise}^2 \rangle$ and respiratory belt signals.

Results: The signal picked up by the RF coil consisted only of thermal noise (Fig 1A). Calculated and filtered variance of this signal revealed an apparent periodic modulation of the $\langle V_{noise}^2 \rangle$ (Fig 1B) similar to the respiratory belt signal (Fig 1C). For the deep breathing the modulation was slower and had larger amplitude (Fig 1D) analogous to the respiratory belt signal (Fig 1E). The spectral analysis (Fig 1F) showed that the dominant frequencies of both $\langle V_{noise}^2 \rangle$ and respiratory belt signals were the same. The base line drift of the signal (Fig 1B) appeared at very low frequency (~0.05Hz) in the power spectrum. Higher harmonics were present in the $\langle V_{noise}^2 \rangle$ modulation. Noise measurements at 3T also showed periodic, respiratory motion induced change of the $\langle V_{noise}^2 \rangle$. The sensitivity of the RF coil to the motion depends on its' location with respect to the body (Fig 2A). Four out of 16 coils' $\langle V_{noise}^2 \rangle$ temporal modulations are shown in Fig 2B. Their location (close to the diaphragm) is illustrated in Fig 2A. During the breath holds the thermal noise variance had no periodic modulation and only negligible fluctuations occurred. Similar results (not shown) were observed for 1.5T. Note, that a movement (or start of breathing) of the subject at the end of the second breath hold led to a clearly visible increase of the $\langle V_{noise}^2 \rangle$ in all four coils (Fig 2, arrows). Dominant frequencies of the respiratory belt signals were also dominant (except for the first breathing condition) in the $\langle V_{noise}^2 \rangle$ power spectra (Fig 3). Similar to 1.5T, RF coil $\langle V_{noise}^2 \rangle$ had higher frequency harmonics which did not appear in the respiratory belt power spectra.

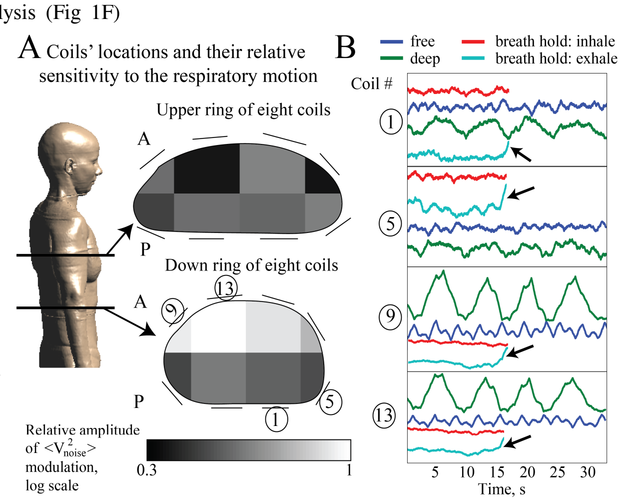

Fig 2. A:Location of 16 RF coils on the body and relative sensitivity of their $\langle V_{noise}^2 \rangle$ to the respiratory motion. B: $\langle V_{noise}^2 \rangle$ temporal modulation in four RF coils of the array for different breathing conditions.

Discussion: Thermal noise variance of RF coil is sensitive to the subject motion because of the motion induced changes of RF coil resistance. Noise sampling was performed within a standard MR sequence by switching off the RF and gradient parts of the sequence. In order to combine noise measurements with an actual MR experiment, noise sampling can be easily performed during "dead time" of TR. To exclude/minimize signal from the residual transverse magnetization, the demodulation frequency can be shifted by 1 or 2 MHz during the noise measurements. Alternatively, one channel of receiver array can be tuned to a different resonance frequency and used to monitor continuously the respiratory motion with the noise measurements. The RF coil's sensitivity to motion depends on its' location and, thus, noise covariance matrix of an array of RF coils can be potentially used for motion fields estimation.

Conclusions: Within clinical MR systems, we have demonstrated that the thermal noise variance of the RF coil can effectively pick up the respiratory motion. The method is contact free and does not require any additional hardware and/or MR acquisition and can be implemented within many MR sequences.

References: [1] Bernstein M, et al. Handbook of MRI pulse sequences (2004); [2] Nehrke K, et al. MRI 17 (1999); [3] Buikman D, et al. MRI 6 (1988); [4] Graesslin I, et al. ISMRM 18: 3045 (2010).

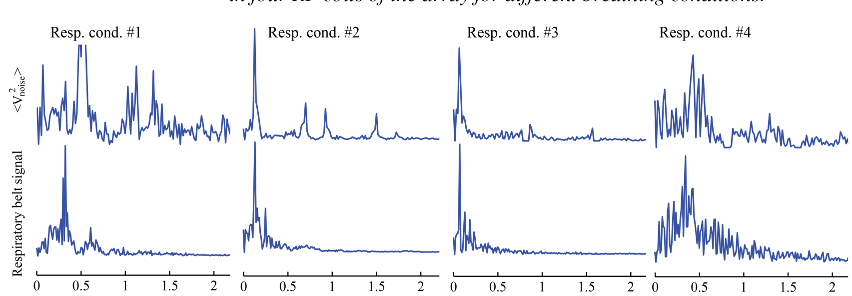

Fig 3. Comparison of $\langle V_{noise}^2 \rangle$ and respiratory belt power spectra for four distinct respiratory conditions (measured at 3T).