The Effect of Heart Rate in Look-Locker Cardiac T_1 Mapping

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Introduction: Look-Locker inversion recovery produces images at multiple inversion times (TI) after a 180° inversion pulse (1). In non-cardiac and phantom experiments, the sequence timing can be carefully controlled. This allows the user to exactly specify both the TIs and the magnetization recovery time between inversions. In cardiac imaging, however, these timing variables are measured in units of the R-R interval (T_{RR}), which in routine practice is determined by the patient's heart rate as recorded only at the beginning of the scan. Because the heart rate can vary considerably during imaging, this heart rate dependency can result in significant errors in T_1 measurements. For example, when using inversion pulses with segmented imaging, there must be a delay time T_{rec} of up to $5 \times T_1$ before each subsequent inversion to allow the magnetization to fully recover. If the heart rate increases, the shortened T_{rec} will not allow full and consistent magnetization recovery. Furthermore, if there is any variation in T_{RR} during a scan, the TIs will not occur at the nominally expected times of $n \times T_{RR}$, where n is heartbeat number. Both of these situations will produce errors in fitting the relaxation curve and thus in calculating T_1. The goal of this work was to develop a Look-Locker sequence that will reduce the errors introduced by intra-scan heart rate variations.
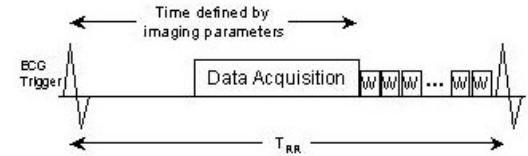

Figure 1. Cardiac cycle timing. After data acquisition in each heartbeat, short wait pulses "W" are played out repeatedly until the next ECG trigger is detected.

Methods: Look-Locker acquisitions are traditionally performed using inversion recovery. However, T_1 relaxation can also be measured using saturation recovery, which is particularly advantageous for cardiac imaging (3). Because it employs a 90° pulse, it ensures that the starting magnetization of each Look-Locker experiment is identical (M_z=0). This also eliminates the need for T_{rec}, thereby drastically reducing scan time ($T_{rec} \approx 5 \times T_1 \approx 5$ sec). To further address intra-scan heart rate variability, cardiac cycle timing is employed, whereby the pulse sequence records the duration of each cardiac cycle (Fig. 1). Although the time from ECG trigger to the end of data acquisition is defined by imaging parameters, the time until the next trigger is heart-rate-dependent. Therefore, to measure T_{RR}, a short wait pulse is played repeatedly after data acquisition until the next ECG trigger is detected.
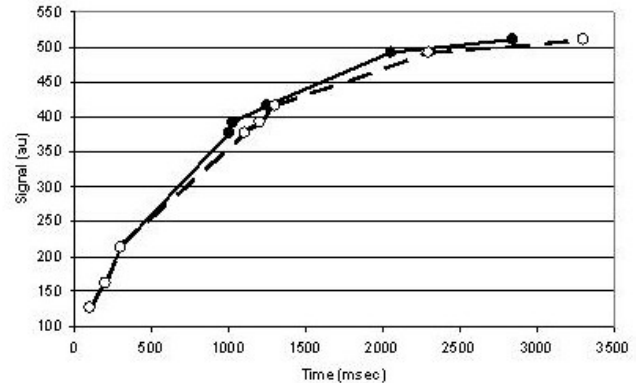
Two phantoms filled with diluted gadodiamide were scanned with a single-shot saturation-recovery Look-Locker sequence using cardiac cycle timing. Scans were performed twice, once with a constant heart rate of 60 bpm and once with a heart rate varying between 60 and 75 bpm. ECG signals were generated by an electronic ECG simulator. Eight interleaved TIs, nominally between 100 and 3300 msec, were obtained (2, 3).

Figure 2. T_1* relaxation curves for the variable-heart-rate data from Phantom 2. Solid curve: TIs using cardiac cycle timing. Dashed curve: TIs using assumed heart rate of 60 bpm. Signal intensity of the data points are identical for both curves but fall at different TIs. The first three TIs in both curves are the same because they occur within a cardiac cycle.

Results: Signal-to-noise ratio (SNR) versus TI was plotted for both phantoms and for both Look-Locker acquisitions. An additional plot was made for the variable heart rate data using the assumed nominal TIs (Fig. 2). Apparent T_1 (T_1*) values were determined by curve fitting and are shown in Table 1. When cardiac cycle timing is used to plot SNR versus actual measured TI, the T_1* values are in good agreement for both constant and variable heart rates (rows 1 and 2). When cardiac cycle timing is not used (last row), the nominal TIs are incorrect (dashed curve in Fig. 2), and T_1* is erroneous. T_1 will be similarly miscalculated.

Conclusions: A Look-Locker acquisition using saturation recovery and cardiac cycle timing provides several advantages for cardiac imaging. It substantially reduces scan times and will always yield more accurate T_1/T_1* measurements.

Heart Rate (beats per min)	T_1* (msec)	
	Phantom 1	Phantom 2
Constant, 60 bpm	505	918
Variable, 60-75 bpm	501	901
Variable heart rate data using constant heart rate TIs	541	991

Table 1. Heart rate dependence of T_1*. The last row shows that when cardiac cycle timing is not used and the TIs are assumed, rather than measured directly, an erroneous T_1* results.

References:

1. Look & Locker, Rev Sci Instrum, 41:250 (1970). 2. Messroghli, MRM, 52:141 (2004). 3. Slavin, SCMR, Rome, 324 (2007).