Cramer-Rao lower bounds for assessment of precision in T2* value evaluation by GRE multiecho sequence: application to iron overload measurements in thalassemia patients

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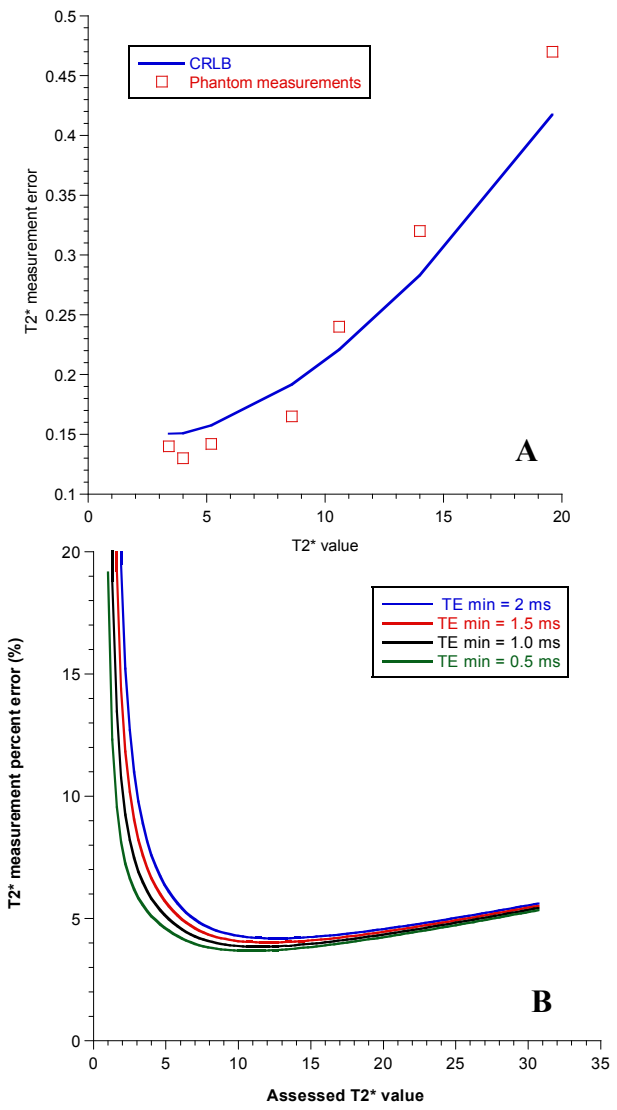
Introduction: T2* multiecho GRE magnetic resonance is the established methodology for assessment of iron overload in heart, liver, and other organs by the evaluation of the T2* value by fitting the signal curve to an appropriate decay model [1,2]. Due to technical constraints and to cover the whole range of expected T2* values, multiecho sequences used in the clinical practice typically sample the MR signal in the TEs interval 2-20 ms, with an increment of 2.2 ms (i.e. half of the period of fat-water phase oscillation). Is commonly recognized that the T2* measurement is optimized in the clinical range (i.e. T2* < 20 ms) [3], but the quantitative dependence of the expected error from measured T2* values and the choice of TEs is unknown. The objective of this study is to quantify the precision limit of T2* assessment exploiting the Cramer-Rao lower bounds theory (CRLB).

Materials and methods: CRLB provide a fundamental limit to the accuracy in determination of the T2* value from experimental data; for any estimation method, the error in the T2* value estimation (measured as the standard deviation or SD) must be greater that or equal to the CRLB. CRLB must be evaluated tacking into account the Rician distribution of MR noise [4], that it is important at low MR signal levels (i.e. later TEs in organs with severe iron overload). The CRLB for the T2* measurement can be expresses as:

$$CRLB(T2^*) = \sqrt{(F^{-1})_{T2^*,T2^*}} \quad F = \left(\frac{\partial A(TE,\beta)}{\partial \beta}\right)^T V^{-1} E[R] \left(\frac{\partial A(TE,\beta)}{\partial \beta}\right) \quad E[R]_{n,n} = -\frac{S_n^2}{\sigma_n^2} + E\left[\frac{M_n^2 I_1(z_n)^2}{\sigma_n^2 I_0(z_n)^2}\right] \qquad z_n = \frac{M_n}{\sigma_n^2} \tag{1}$$

where $\beta=[S_0, T2^*]$ are the parameters to be estimated and $S=S_0 exp(-TE/T2^*)+C$ is the used decay model. V is a diagonal matrix with elements equal to σ^2 (variance of the Gaussian noise in the complex MR data) and $E[R]$ represent a diagonal correction matrix that taken into account the Rician distribution of noise [4]. S_n represents the "true" MR signal that can be inferred from the measured signal M_n and noise statistics. CRLB were evaluated by numerical solving of equations (1). A dedicated phantom (20 borosilicate test-tubes, 2.4 cm diameter, increasing concentrations of Fe(III)Cl3 was used to validate the method. T2* values on MR images were evaluated by the HIPPO MIOT® software [5].

Results and Discussion: Figure A shows CRLB evaluated by Eq 1 and SD of T2* values evaluated on a series of 50 multiecho data sets acquired from the phantom (minimum TE 2 ms, 8 echoes, TE interval 3.232 ms, SD of background noise 9.5). Experimental results confirm the correctness of CRLB evaluation. Figure B shows percent error in T2* evaluation by the breath-hold sequence commonly used in iron overload assessment in thalassemia patients in dependence from minimum TE (minimum TEs 2, 1.5, 1.0, 0.5 ms, echo spacing 2.26 ms, 10 echoes) [1,2]. Representative values of M0 and σ were inferred from 50 images sets randomly extracted from the MIOT database [1]. Error slightly increase at high T2* values due to too short maximum TE, confirming qualitative results [3]. Anyway, minimum expected percent error is well lower than 10% in the range 3-40 ms. Percent error dramatically increase at low T2* values due to inadequate minimum TE. The minimum available TE strongly characterize the T2* measurement quality at high iron overload levels.



Conclusions: CRLB allow to evaluate the quality of T2* measurement in iron overload assessment in dependence on the adopted TE schema. Shortening of the first TE it is important in assessment of high iron overload levels. Currently available GRE multiecho sequences assure good precision in T2* assessment for T2* values greater than 3 ms. For patients with severe iron overload sequences with lower minimum echo time and/or lower echoes interval may be useful.

References: [1] Ramazzotti A et al. JMRI 2009 ;30:62-68; [2] Ghugre NR et al. JMRI 2006;23(1):9-16 [3] Wood JC Hemoglobin ;32:85-96 [4] Karlsen OT et al, MRM 41:614-623 [5] Positano V et al. NMR Biomed 2007;20(6):578-90