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Evaluation of the Continuous Wavelet Transform as a Potential Method for Postacquisition Water Suppression in Biomedical Proton Magnetic Resonance Spectroscopy

Hacene Serrai^a; Lotfi Senhadji^b; David Clayton^a; Jacques D. de Certaines^c

^a Department of Radiology, Philadelphia, PA, USA ^b Laboratoire de Traitement du Signal et d'Images (LTSI), INSERM, Université de Rennes, Campus de Beaulieu, Rennes, France ^c Laboratoire de Résonance Magnétique en Biologie et Médecine (LRMBM), Université de Rennes, Faculté de Médecine, Rennes, France

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**EVALUATION OF THE CONTINUOUS WAVELET TRANSFORM AS A
POTENTIAL METHOD FOR POSTACQUISITION WATER
SUPPRESSION IN BIOMEDICAL PROTON MAGNETIC RESONANCE
SPECTROSCOPY.**

Key Words: Magnetic Resonance Spectroscopy, Wavelet Transform, Water Suppression

Hacene Serrai^{1*}, Lotfi Senhadji², David Clayton³, and Jacques D. de Certaines³.

1: Department of Radiology, B 1 Stellar Chance building, 422 Curie Boulevard,
Philadelphia, PA-19104, USA

2: Laboratoire de Traitement du Signal et d'Images (LTSI), INSERM, Université
de Rennes1, Campus de Beaulieu, 35042 Rennes, France.

3: Laboratoire de Résonance Magnétique en Biologie et Médecine (LRMBM),
Université de Rennes1, Faculté de Médecine, 35000 Rennes, France.

* To whom correspondence should be addressed. Department of Radiology, B1
stellar chance Building, 422 curie Boulevard, Philadelphia PA-19104-6100, USA.

ABSTRACT:

The analysis of biological systems by means of Proton (^1H) Magnetic Resonance Spectroscopy (MRS) shows a prominent water resonance which obscures the small metabolite signals. Preacquisition techniques have been successfully used to remove the water resonance and to relatively enhance the other component signals. However, these methods may suffer from baseline distortion and signal saturation of metabolites close to the water peak. An accurate quantification of such components could be compromised.

The present work consists of the preliminary testing of the Continuous Wavelet Transform approach combined with the Data Shift Accumulation (WT-DSA) technique as a postacquisition water suppression method.

A qualitative comparison has been performed between WT-DSA and two selected preacquisition water suppression techniques *i.e.* Presaturation and Watergate. The comparison was achieved on a ^1H MRS unsuppressed water data collected from two different artificial test solutions using a whole body 4T and a high resolution narrow bore 11.7T MRS systems and based on the degree of water suppression, residual baseline distortion and signal saturation.

The WT-DSA technique appears to be a promising method to remove the water component without altering components near the water resonance.

1. INTRODUCTION:

The Free Induction Decay (FID) signals acquired in high-resolution or *in*

vivo proton (^1H) Magnetic Resonance Spectroscopy (MRS) studies are corrupted by the large water resonance, which conceals the dilute metabolite signals. A water suppression technique is needed to observe the signals arising from these metabolites. The accuracy of data analysis, especially metabolite quantification, greatly depends upon the quality and the degree of water suppression.

Two categories of water suppression methods are used. The first category consists of the preacquisition methods [1-4] which remove the water magnetization prior to data acquisition. These methods may be divided into the four following groups: i) methods which avoid the excitation of the water spins [5-7], ii) methods which destroy the longitudinal water magnetization using T_1 differences [8-11], iii) methods which destroy the transverse water magnetization [12-19], iv) and methods based on T_2 differences [20-22].

Most of these preacquisition methods are limited by technical problems such as radiation damping, poor selectivity and improper phase of the pulses, as well as homogeneities of the RF and B_0 fields. Consequently, the obtained spectrum may have incomplete solvent suppression, baseline distortion, artifacts and saturation of signals close to the water resonance [23].

To overcome these technical problems, other preacquisition methods have been developed. The Water-PRESS method [24, 25] was proposed to address the radiation-damping problem. A combination of soft and hard pulses [26, 27], and

repetitive use of the selective pulses followed by crusher gradients [28-30] have been used for complete destruction of the transverse water magnetization. To compensate for the inhomogeneous RF field, adiabatic full passage pulses have been proposed [31, 32]. These particular pulse sequences increase the quality of the obtained spectra, but they may not provide adequate water suppression for accurate data analysis. As a consequence, the small metabolites close to the water resonance are either strongly saturated or hidden by the remaining large baseline. Furthermore, water signal information that may be used as an internal reference in some studies [33-35], is lost using these preacquisition methods.

A second category of water suppression techniques known as postacquisition methods has been proposed [36-42]. They use different mathematical approaches to subtract the water signal component from the MRS data. These methods are based on band-pass filtering in the time or frequency domains [37, 38], data matrix representation using Singular Value Decomposition (SVD) or Toeplitz matrix decomposition [39, 40], or data fitting by means of a non-linear least-square method [41]. The major drawbacks of the postacquisition techniques are again the radiation damping which modifies the shape of the water component and the dynamic range problem which degrade the signal to noise ratio (SNR).

As a matter of fact, the quality of the resulting spectra using either pre or postacquisition techniques may be affected by residual water signal (baseline distortion), signal saturation and low SNR.

Recently, an iterative approach based on the Continuous Wavelet Transform (WT) was proposed for MRS data quantification and removal of the dominant solvent peak [43-45]. It analyzes the signal by transposing its representation from the time domain to the time-scale domain [46, 47]. The signal components are then extracted, quantified, and subtracted from the raw signal, one by one, according to their respective apparent relaxation time (T_2^*) values. The extraction of the signal components is based on their time duration rather than their magnitudes. This method was applied to unsuppressed water FID signals as a postacquisition technique to isolate, quantify and remove the water resonance while preserving the adjacent metabolite peaks.

As WT may be used based on different kernels and applied to particular signal models (Lorentzian, Gaussian, etc...), it is possible to choose these parameters according to the solvent component shape. Thus, the effect of the radiation damping may be addressed. A combination of WT and Data Shift Accumulation (DSA) was applied here to improve the quality of the resulting data in terms of baseline correction. The best way to reduce the effect of the inherent dynamic range problem (low SNR) is to increase the resolution of the A/D converter from 16 bits, used here, to 32 bits. This problem was addressed here by Line Broadening (LB) filtering or files averaging.

Two MRS experiments were considered. The aim of the first experiment was to demonstrate the potential usefulness of the WT as a water suppression technique, and confirm the previous work [44]. The second experiment was designed to qualitatively compare the performance of WT-DSA with two other

preprocessing techniques: Presaturation [19] and Watergate [26]. In both cases, the Lorentzian signal model and the Morlet Wavelet have been selected.

2. MATERIAL AND METHODS:

Experiment 1 : Unsuppressed water Proton MRS data were collected from a 2.7 L spherical phantom. The phantom consisted of 50 mM potassium phosphate monobasic (KH_2PO_4), 56 mM sodium hydroxide (NaOH), 12.5 mM N-acetyl-L-aspartic acid (NAA), 10 mM creatine hydrate (Cr), 3 mM choline chloride (Ch), 7.5 mM myo-inositol (mi), 12.5 mM L-glutamic acid (monosodium salt Glu), 5 mM DL-lactic acid (lithium salt Lac), and 0.10 % sodium azide. The data were acquired at 170 MHz on a 4T scanner whole body system with a 16 bit A/D converter (General Electric Medical Systems, Milwaukee, WI), with a slice selective spin echo sequence ($\text{TE} = 288\text{ms}$, $\text{TR} = 1.5\text{sec}$, 10 mm slice thickness, 32 accumulations, $\pm 1250\text{ Hz}$ spectral width, and 2048 data points).

A typical spectrum is shown in Figure 1a. The time domain data was processed by WT using a custom-made program written in IDL (Interactive Data Language, IRIX mipseb Ver. 5, Research Systems, Inc.) based on the iterative procedure described in [43, 45].

Experiment 2 : Three sets of high-resolution unsuppressed water proton MRS data were collected from a sample containing 90% H_2O , 10% D_2O , 2mM sucrose, 2mM NaNO_3 , and 0.5 mM trimethyl-silyl-propionate (TSP). The first two data sets

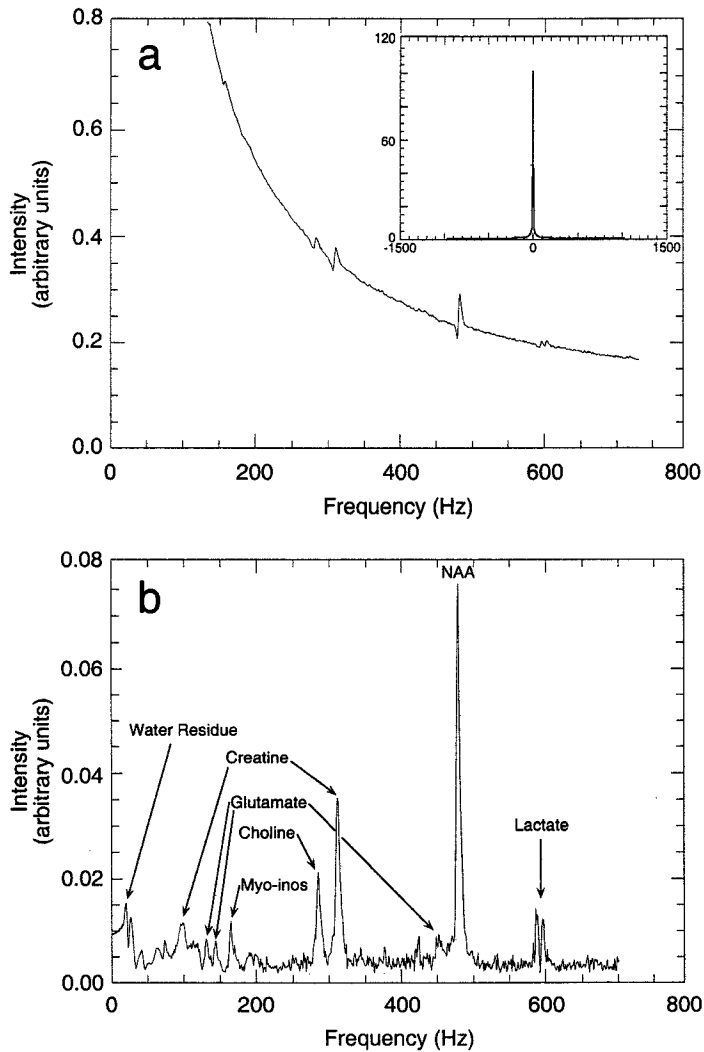


FIG. 1

a : Magnified view of the metabolite area of the unsuppressed water spectrum shown in the inset.

b : Spectrum of the metabolite signals obtained after water suppression using Wavelet Transform postacquisition method.

used Watergate and Presaturation water suppression techniques. The data were acquired at 500.13 MHz on an a high resolution 11.7T Advance DMX500 Spectrometer with a 16 bit A/D converter (Bruker, Wissembourg, France), with a 5 μ sec pulse width, 64 acquisitions, \pm 3500 Hz spectral width, receiver gain 128, and 16 K data points. To correctly apply the Watergate gradients, the pulse width was set to 5.5 μ s.

The third set consisted of unsuppressed-water data, collected using the same conditions as above with a receiver gain equal to 1. The data was processed by WT using the same iterative procedure as in the first experiment.

3. RESULTS:

Experiment 1: The WT iterative procedure converged after 4 iterations. The estimated water chemical shift value was $\delta = 0.00$ Hz, validating the method because the water peak was on-resonance. The extracted water component was then subtracted from the raw signal. In order to reduce the effect of baseline distortion, the first 7 points were removed (see Appendix). The metabolite region of the resulting spectrum is shown in Figure 1b. The result shows that WT sufficiently suppress the dominant water signal while the dilute metabolites are preserved.

Experiment 2: The results obtained by Watergate and Presaturation techniques are shown in Figures 2 and 3 respectively. For the set processed by WT, the iterative

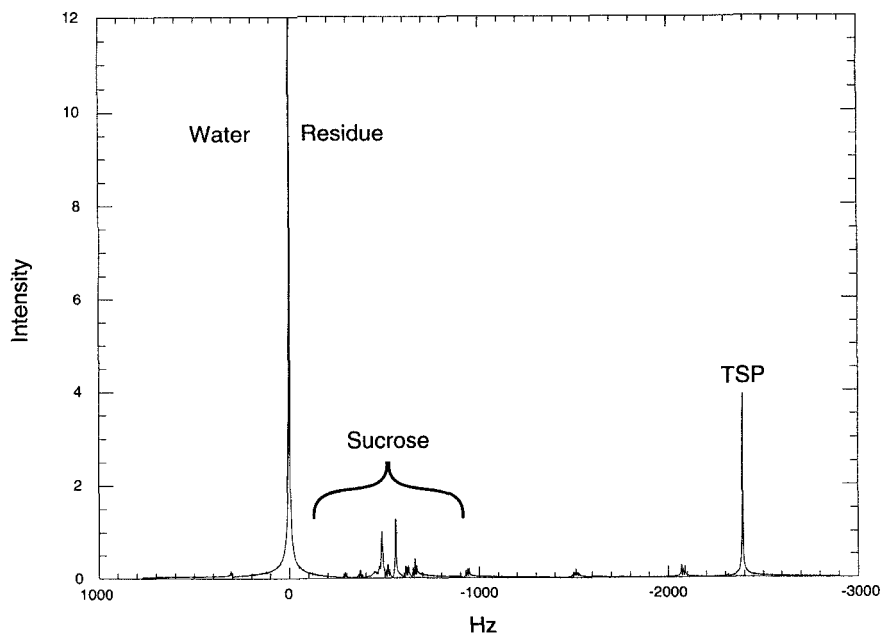


FIG. 2

Spectrum obtained after using Watergate method. The magnitude of the spectrum was divided by the receiver gain (128). The signals close to the water resonance are significantly saturated.

procedure converged after 5 iterations. The estimated values for the chemical shift (δ) = 0.00 Hz. The extracted water peak was subtracted from the signal. To attenuate the baseline effects, the first 54 points were removed from the residue (see Appendix), and the corresponding spectrum is shown in Figure 4a. However, dropping a large number of points may lead to the elimination of components with fast decay (short T_2^*). To preserve these components, the number of points

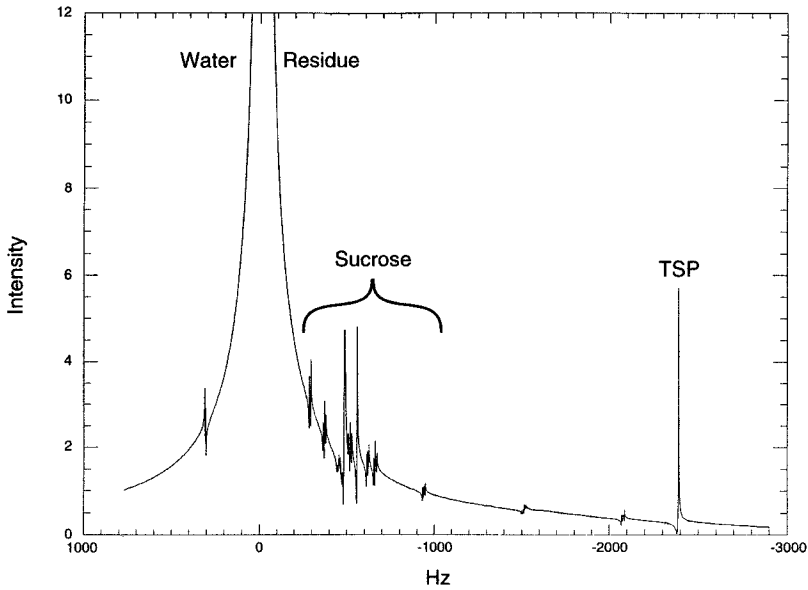


FIG. 3

Spectrum obtained after using Presaturation method. The magnitude of the spectrum was divided by the receiver gain (128). The spectrum contains large water residue and baseline distortion.

removed should be minimized. The DSA technique [42], which allows the water resonance to be reduced in unsuppressed water data, was applied prior to WT procedure. This resulted in the spectrum shown in Figure 4a after eliminating only the first 10 points. In order to increase the SNR of the previous spectrum classical methods (Line Broadening and file averaging) were used and the results are shown in Figures 4b and 4c, respectively.

4. DISCUSSION AND CONCLUSION:

The presented results demonstrates the potential ability of the Wavelet Transform method to strongly reduce the water signal while preserving the metabolite components close to the water resonance. Concerning the tested preacquisition techniques, we have seen that Watergate method allows the suppression of a large amount of the water resonance with no baseline distortion, but significantly saturates the sucrose signals close to the water peak (Fig. 2). The Presaturation technique better preserves the sucrose signals but does not efficiently reduce the water resonance leading to baseline distortion (Fig. 3). The WT-DSA method allows us to obtain results similar to those provided by the Watergate method (water resonance reduction and baseline elimination) while preserving the sucrose components as in the Presaturation method (Fig. 4b, 4c).

Moreover, as it is a postacquisition method, the problems generally encountered by the preacquisition techniques such as imperfections and power requirements of the RF fields were avoided. The method can quantify the water resonance, which may be used as an internal reference. It could also be used for electronic preacquisition suppression by the ERETIC method [48, 49]. Furthermore, the magnetic coupling between water and metabolites detected in brain and muscle may be affected, leading to an underestimation of the metabolite concentration when using the preacquisition water suppression techniques [50]. The proposed method could avoid the perturbation of the water and preserves the total metabolite concentration.

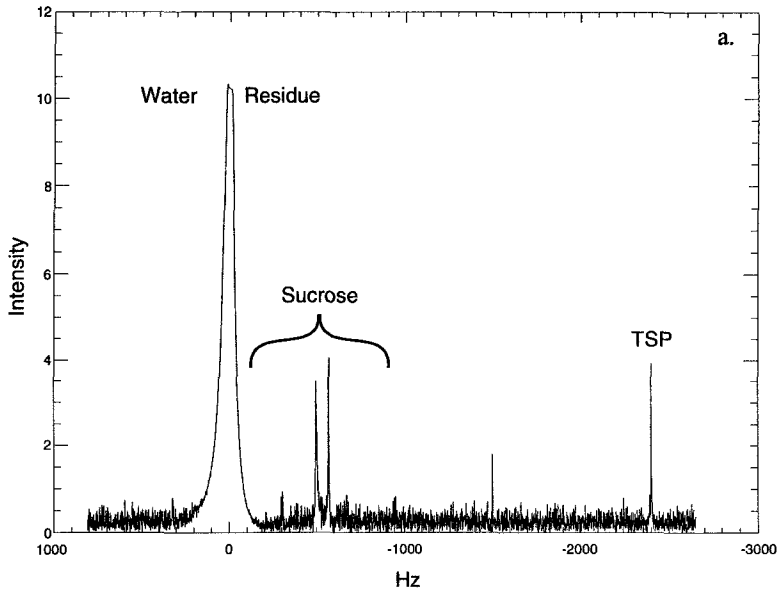


FIG. 4

a : Spectrum after using the DSA-WT method and removal of the first 10 points.

The signals close to the water resonance are preserved.

b : Improvement of the SNR by using a line broadening (LB=500 ms).

c : Improvement of the SNR by averaging 64 data files.

In order to improve the quality of the spectra in term of SNR, the resolution of the A/D converter should be increased by doubling the number of digits from 16 to 32 digits.

APPENDIX: Influence of removing initial data points on the quantification of MRS parameters.

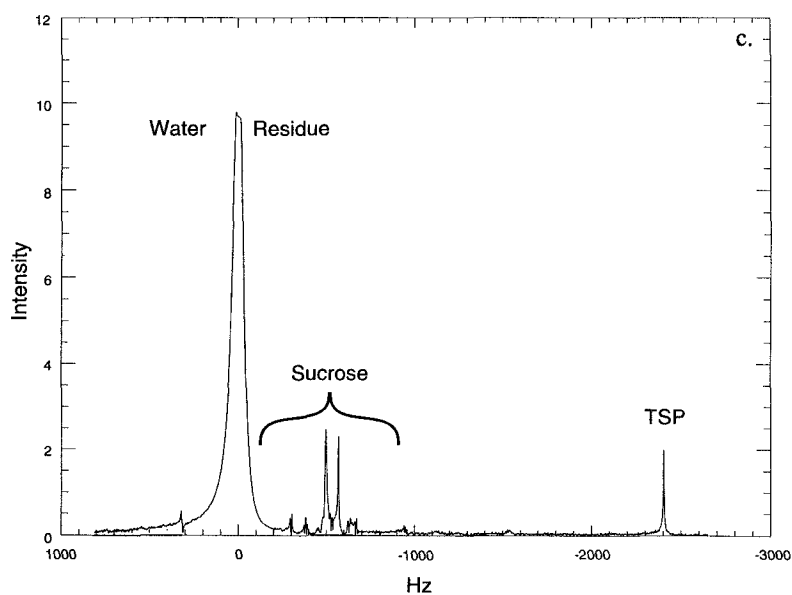
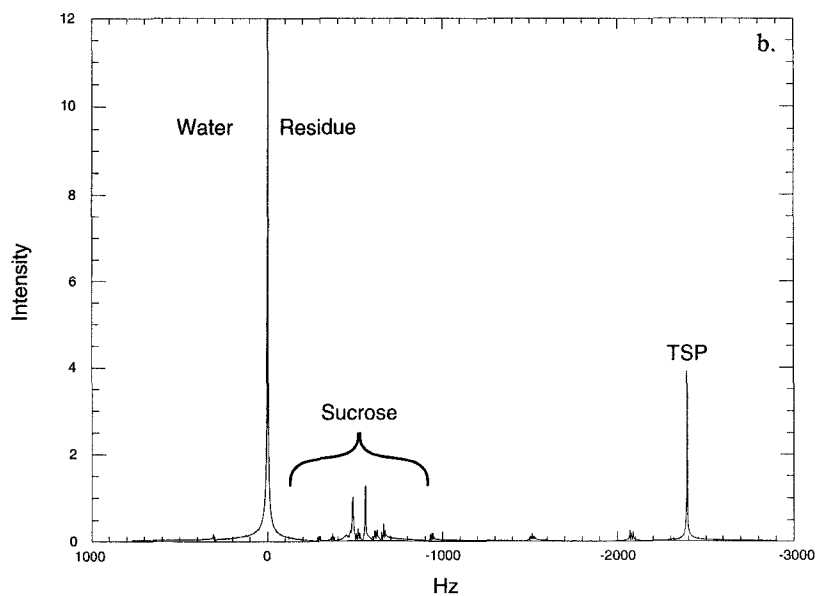


FIG. 4. Continued

The reduction of the baseline drift is often addressed by the elimination of the first data points. In this appendix we investigate the influence of this procedure on the parameters of MRS signals. Let $s(t)$ be a FID signal containing one component. $s(t)$ is then given by :

$$s(t) = Ae^{(-t/T_2^*)} e^{i(2\pi\delta t + \varphi)}, t \geq 0 \quad [A1]$$

Assume that the portion of $s(t)$ belonging to $[0, T]$ is removed. The resulting signal is then:

$$s_T(t) = s(t + T); t \geq 0 \quad [A2]$$

which is of the form: $s_T(t) = A' e^{(-t/T_2^*)} e^{i(2\pi\delta t + \varphi')}$, where $A' = Ae^{-t/T_2^*}$ and $\varphi' = \varphi + 2i\pi\delta T$.

Therefore, the quantification of the FID signal $s(t)$, after removal of the first data points, is equivalent to the quantification of the new FID signal $s_T(t)$ whose MRS parameters comply with the equations above. It is then possible to derive the MRS parameters of $s(t)$ from those of $s_T(t)$. Hence, the elimination of some initial values of the signal theoretically has less influence on the estimated MRS parameter values.

As an example, we generate a synthetic MRS signal containing two

components with a sampling frequency normalized to 1. The parameters of the first component are : $A = 1000$ a.u, $T_2^* = 150$ ms and $\delta = 0.5$. The parameters of the second are $A = 1$ a.u, $T_2^* = 100$ ms and $\delta = 0.2$. Using the iterative procedure method [42], the first component is quantified; the estimation of the parameters A , T_2^* and δ gives: 999.39 a.u, 149.794 ms and 0.5000, respectively.

The quantification of the second component, after subtracting the first one from the raw signal and removing the first 10 data points from the residue, leads to the following values of the estimated parameters A' , T_2^* and δ : 0.824878 a.u, 97.66 ms and 0.199526, respectively. Using the equations above, the derived estimated value for A is then equal to 0.913818 a.u.

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