PASTeUR : Package of Anatomical Sequences using parallel Transmission UniveRsal pulses

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| Description | This current release of the PASTeUR package contains three sequences including Universal RF pulses to mitigate B1+ inhomogeneity at 7T. |

| Platform | XA60 |

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2 Overview

The PASTeUR package contains 3D anatomical sequences – a GRE, a SPACE (with FLAIR and DIR preparations) and a MP(2)RAGE sequence – that use Universal RF pulses to mitigate B1+ inhomogeneity. These Universal Pulses are based on an off-line pulse design performed on a database of different subject field maps to be robust with respect to inter-subject variability. The PASTeUR package provides a plug and play solution for pTx systems that suppress the ubiquitous B1+ artefacts observed with the CP excitation mode. This TerraX release is based on Universal Pulse solutions that have been deisgned on a database acquired on 7T Terra systems.

Restrictions / optimal usage conditions:

- The sequences are meant to be used on the NOVA 8Tx 32Rx coil for which the pulses have been optimized. Tests on phantoms can be attempted to verify that the sequences run properly. However, good image quality should not be expected as the pulses and flip angle trains are designed for adult human heads.

- The NOVA coil center (cross) should be positioned at scanner iso-center during acquisition to achieve the best performance.

Comments and remarks:

- Small artefacts might remain in the images due to B0/B1 inhomogeneity variability across subjects. They can be seen particularly at the bottom of temporal lobes and at the periphery of the cerebellum.

- B0 shimming and frequency adjustment must be performed before any PASTeUR sequence to prevent artifacts. Off-resonance acquisition would result in non-homogeneous RF excitation.

- Adjusting the reference voltage has no effect on the pulses. The pulses were designed to work at specific voltages by taking into account field maps variability across subjects.

- The sequences of PASTeUR can be played in TrueForm (CP) mode. Comparing the Universal Pulse result with the one of TrueForm can be a sanity check that the pulses are played as expected.

3 Installation

3.1 Summary of files

The PASTeUR package contains three different sequences. Reconstruction used are the standard reconstruction from Siemens environment. The following sequence (.dll, .so, .lic) and pulse files (.ini) must be manually copied to the %CustomerSeq% directory on the scanner. The .lic files are mandatory license files that require yearly renewal. Pulse and sequence improvements, bug-fixes that way will be provided.

The Siemens procedure to add the NeuroSpin certificate to the system must be performed once. The certificate is provided in the package as a .cer file.

```
C:/ProgramData/Siemens/Numaris
└─MriCustomer
  └─CustomerSeq
    ├─ns_gre_v1.dll
    ├─ns_gre_v1.lic
    ├─libns_gre_v1.so
    ├─ns_tfl_v1.dll
    ├─ns_tfl_v1.lic
    ├─libns_tfl_v1.so
    ├─ns_space_v1.dll
    ├─ns_space_v1.lic
    ├─libns_space_v1.so
    ├─RFPulses
    │ ├─GRE
    │ │ ├─pTXGreHighFA.ini
    │ │ ├─pTXGreMedFA.ini
    │ │ └─pTXGreLowFA.ini
    │ ├─TFL
    │ │ └─pTXRFPulseExc.ini
    │ ├─SPACE
    │ │ └─pTXRFPulseVFA.ini
    │ └─SBB_IR
    │   ├─pTXRFPulseInv.ini
    │   └─pTXRFPulseT2p90.ini
    └─ParameterCards/SequenceSpecific
      └─ns_gre_v1_ParameterCardConfiguration.xml
```

```
├── ns_tfl_v1_ParameterCardConfiguration.xml
└── ns_space_v1_ParameterCardConfiguration.xml
```

3.2 Installation procedure

The content of 'MriCustomer' in the zip file should be manually copied on the host into C:/ProgramData/Siemens/Numaris/MriCustomer.

3.3 Optimized protocols

A set of suggested protocols can be found on the GitHub page via this `link`. These protocols have been tested in vivo with Siemens current SAR supervision limits.
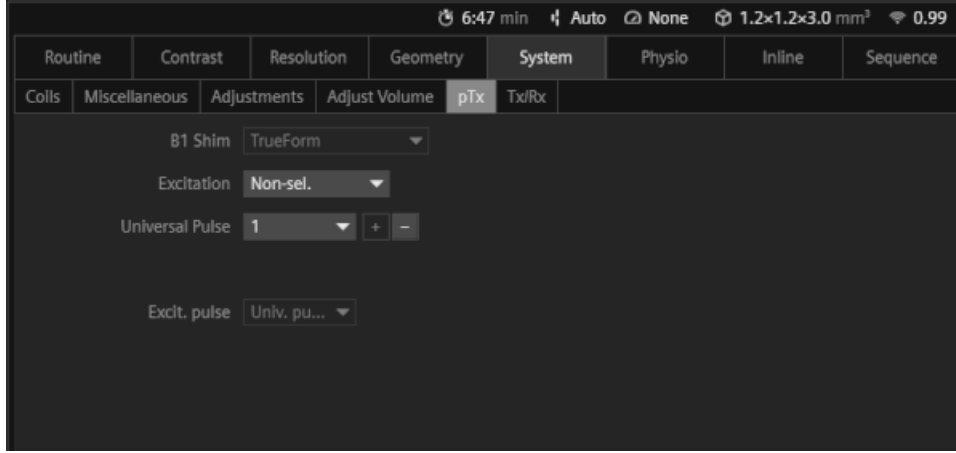
Figure 1: Activation of Universal Pulses in "System > pTx" card.

4   SPACE sequence

The sequence user interface is similar to that of the product VE12 space sequence. To activate Universal Pulses, the user must click the "Universal Pulse" button located in "System > pTx" card (figure 1).

4.1   RF refocusing train

The flip angle of the refocusing train is generated by using T_1/T_2 relaxation times of a given tissue. Depending on these T_1/T_2 values, the energy of the train could change drastically. For this reason, it is recommended to use the default values set as $T_1 = 1400ms$ and $T_2 = 50ms$ (figure 2).

4.2   Magnetization preparation

A set of magnetization preparations is available within the "Contrast > Common" card of the SPACE sequence. Optionnaly, the type of preparations pulses can be switched between "Universal" ans standard in the " System > pTx" card independently of the excitation pulse type.
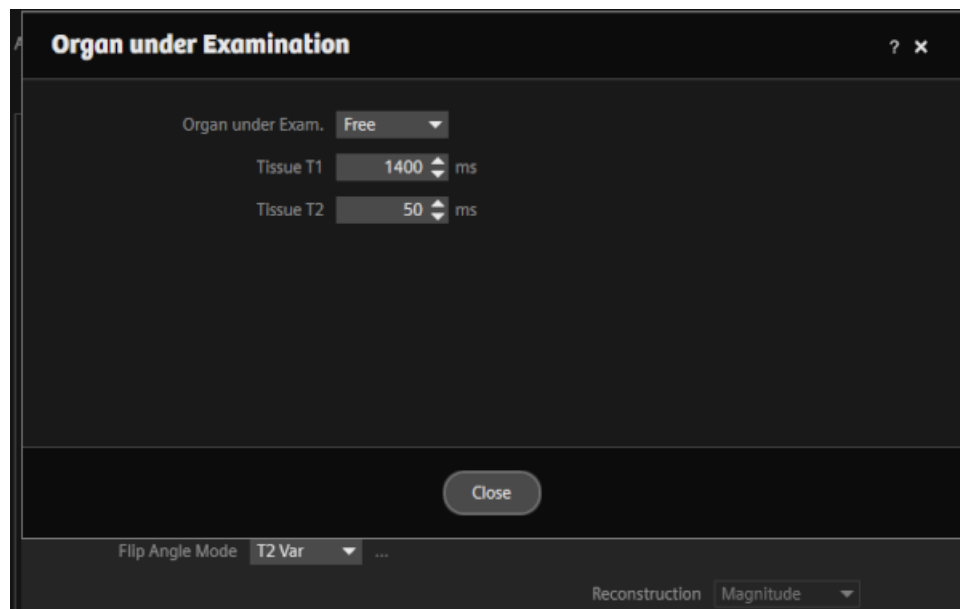
Figure 2: T_1 and T_2 values used for the flip angle calculation can be set using the "Flip angle mode" parameter in "Contrast > Common". This parameter is a standard parameter from the Siemens sequence, but the default values have been changed in the ns_space_v1 sequence.

4.3 Restore option

The "Restore" option in the contrast card is avalaible and uses a "Universal Pulse" along with the excitation and refocusing train.

4.4 Fat saturation & other preparations

At the moment, fat saturation and dark blood preparations do not use any optimized pTx pulses. In other words, they are played in TrueForm. If you are trying to use these options, your feedback is welcomed.

5 GRE3D sequence

The sequence user interface is similar to the product VE12 GRE sequence. The sequence is available in a 3D acquisition mode with non-selective pulses. To activate Universal Pulses, the user must select "Universal Pulse" button located in "System > pTx" card (figure 1).

5.1 RF pulse types

In the GRE sequence, RF pulse type can be used to select excitation Universal Pulses with different properties. Pulse duration as well as power deposition are modified when switching between the different options as show in table 1.

Pulse Type	Duration in us	Maximum allowed Flip Angle
FAST	160	10°
NORMAL	240	20°
LOW SAR	480	60°

Table 1: Pulse characteristics in the GRE sequence depending on RF pulse type options.

6   MP(2)RAGE sequence

The sequence user interface is similar to the product VE12 tfl sequence. The sequence is available in a 3D acquisition mode with non-selective pulses. To activate Universal Pulses, the user must click the "Universal Pulse" button located in "System > pTx" card (figure 1).

6.1   Universal pulse

Both excitation and inversion Universal Pulses are GRAPE pulses as described in Van Damme et al. (9). Pulse durations are mentioned in table 2.

The flip angle of the excitation Universal Pulse can be set between 0° and 8° in the protocol via the standard "Flip angle" parameter in "Contrast > Common" card.

Pulse Type	Duration in us
Excitation	120
Inversion	3000

Table 2: Universal pulse duration for MP(2)RAGE sequence.

7   Advanced features

7.1   RF Pulse ini files

To integrate new pTx RF pulses into the available sequences in the PASTeUR package, one can replace the ini files located the subfolder RFPulses. The following list describes the use case of each ini file:

- pTXGreHighFA.ini $\rightarrow$ used for excitation with pulse type LOW_SAR in GRE sequence

- pTXGreMedFA.ini $\rightarrow$ used for excitation with pulse type NORMAL in GRE sequence

- pTXGreLowFA.ini $\rightarrow$ used for excitation with pulse type FAST in GRE sequence

- pTXRFPulseExc.ini $\rightarrow$ used for excitation in MP(2)RAGE sequence

- pTXRFPulseInv.ini $\rightarrow$ used for inversion in MP(2)RAGE sequence

- pTXRFPulseT2p90.ini $\rightarrow$ used for 90° excitation pulse in T2 prepared inversion module of SPACE sequence

- pTXRFPulseVFA.ini $\rightarrow$ used for 90° excitation pulse, the variable FA refocusing pulses and restore pulse in SPACE sequence

The rotation matrix used in the PASTeUR sequences is the unitary matrix, meaning that in the ini file, gradients must be defined as follow: considering the standard head first supine position, first column is played in antero-posterior direction, 2nd column is played in left-right direction, 3rd column is played in feet-head direction. Once properly set, the FOV can be tilted or protocol orientation can be changed without requiring modifications of the ini file.

8 Your feedback

Your feedback is welcome regarding the use of this package. In particular, we are interested in having feedbacks on the following topics:

- if you encounter unexpected artifacts

- if you have suggestions for protocol improvements

- if you find out bugs while scanning

- if you think of specific features or wanted sequences

- if you have any tips to share

Please contact the authors of this package.

References

1 Gras, V., Boland, M., Vignaud, A., Ferrand, G., Amadon, A., Mauconduit, F., Le Bihan, D., Stöcker, T. and Boulant, N. (2017), 'Homogeneous non-selective and slice-selective parallel-transmit excitations at 7 Tesla with universal pulses: A validation study on two commercial RF coils', *PLOS ONE* **12**(8), e0183562.
URL: *https://dx.plos.org/10.1371/journal.pone.0183562*

2 Gras, V., Mauconduit, F., Vignaud, A., Amadon, A., Le Bihan, D., Stöcker, T. and Boulant, N. (2018), 'Design of universal parallel-transmit refocusing k_t-point pulses and application to 3D T_2-weighted imaging at 7T: Universal Pulse Design of 3D Refocusing Pulses', *Magnetic Resonance in Medicine* **80**(1), 53–65.
URL: *http://doi.wiley.com/10.1002/mrm.27001*

3 Gras, V., Pracht, E. D., Mauconduit, F., Le Bihan, D., Stöcker, T. and Boulant, N. (2019), 'Robust nonadiabatic T_2 preparation using universal parallel-transmit k_t-point pulses for 3D FLAIR imaging at 7 T', *Magnetic Resonance in Medicine* **81**(5), 3202–3208.
URL: *http://doi.wiley.com/10.1002/mrm.27645*

4 Gras, V., Vignaud, A., Amadon, A., Bihan, D. and Boulant, N. (2017), 'Universal pulses: A new concept for calibration free parallel transmission', *Magnetic Resonance in Medicine* **77**(2), 635–643.
URL: *https://onlinelibrary.wiley.com/doi/10.1002/mrm.26148*

5 Jamil, R., Mauconduit, F., Gras, V. and Boulant, N. (2021), 'General gradient delay correction method in bipolar multispoke rf pulses using trim blips', *Magnetic resonance in medicine* **85**(2), 1004–1012.

6 Stirnberg, R., Brenner, D., Stöcker, T. and Shah, N. J. (2016), 'Rapid fat suppression for three-dimensional echo planar imaging with minimized specific absorption rate', *Magnetic resonance in medicine* **76**(5), 1517–1523.
URL: *http://dx.doi.org/10.1002/mrm.26063*

7 Stirnberg, R., Huijbers, W., Brenner, D., Poser, B. A., Breteler, M. and Stöcker, T. (2017), 'Rapid whole-brain resting-state fmri at 3 t: Efficiency-optimized three-dimensional epi versus repetition time-matched simultaneous-multi-slice epi', *NeuroImage* **163**, 81–92.
URL: *http://dx.doi.org/10.1016/j.neuroimage.2017.08.031*

8 Stirnberg, R. and Stöcker, T. (2021), 'Segmented k-space blipped-controlled aliasing in parallel imaging for high spatiotemporal resolution epi', *Magnetic resonance in medicine* **85**(3), 1540–1551.
   URL: *http://dx.doi.org/10.1002/mrm.28486*

9 Van Damme, L., Mauconduit, F., Chambrion, T., Boulant, N. and Gras, V. (2021), 'Universal nonselective excitation and refocusing pulses with improved robustness to off resonance for Magnetic Resonance Imaging at 7 Tesla with parallel transmission', *Magnetic Resonance in Medicine* **85**(2), 678–693.
   URL: *https://onlinelibrary.wiley.com/doi/10.1002/mrm.28441*

10 Wu, X., Gras, V., Vignaud, A., Mauconduit, F., Boland, M., Stoecker, T., Ugurbil, K. and Boulant, N. (2018), The travelling pulses: multicenter evaluation of universal pulses at 7T., *in* 'Proceedings of the International Society for Magnetic Resonance in Medicine', Paris, France.