QUIPSS II with interleaved thin-slice TI1 periodic saturation for FAIR sequence

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Introduction: Quantitative changes in the tissue perfusion rate can yield relevant information about the function of organs in abnormal conditions. In the kidneys, functional impairment occurs in association with renal cancer [1]. Accurate measurement of the kidney perfusion rate is of great interest in early diagnosis and management of these diseases and would facilitate timely therapeutical interventions. Therefore, a non-invasive and repeatable method to detect and quantify renal tissue perfusion alterations would be desirable. Renal tissue perfusion has been assessed by using Arterial Spin Labeling (ASL) [2,3]. A challenge with current renal ASL techniques is that the tagged blood spins experience variable transit delays before they enter the imaging slice which may affect the accuracy of the perfusion quantification. In this work we present a possible solution for this issue, a modified Q2TIPS (quantitative imaging of perfusion using a single subtraction (QUIPSS II) with thin-slice TI_1 periodic saturation) sequence [4]. In this quantitative technique, a periodic train of thin-slice saturation pulses is alternatively applied to both sides of the imaging slice in a FAIR (flow-sensitive alternating inversion recovery) method [5], ensuring that spins on both sides of the imaging slice are properly saturated at time TI_1. As a consequence the accurate perfusion rate could be quantified due to the elimination uncertainty that had been introduced by the variable transit delay effect and the associated un-controlled bolus width.

Method: Since the blood can flow in the imaging slice in any direction and we must choose FAIR-like methods to measure the perfusion rate in the kidney, the saturation pulses are required on both sides of the imaging slice for QUIPSS II-like quantitative methods. In contrast Q2TIPS, here periodic thin-slice saturation pulses were applied *alternatively on both sides* of the imaging slice from TI_1 to TI_{1S} (TI_1 stop time). This ensures that all the spins at both sides of the imaging slice are saturated at approximately the same time TI_1 (the difference of actual TI_1 on each side is just a few milliseconds depending on the duration of the saturation pulse, and therefore can be ignored). This technique was combined with a FAIR True-FISP pulse sequence (Fig. 1), and implemented on a clinical 3T whole body MRI scanner (Magnetom Trio, Siemens, Erlangen, Germany). An adiabatic RF FOCI (frequency offset corrected inversion) pulse was utilized to obtain a better slice profile of the slice selective inversion [6].

The measurement parameters were as follows: TE = 1.88ms, acquisition bandwidth = 606Hz/Pixel, flip angle = 70°, matrix=192 x 184, FOV = 320 – 350mm, imaging slice thickness /tagging slice thickness = 8/16mm, TR = 5s, and measurements = 30 (15 control/tagging pairs). A centric-reordered k-space acquisition scheme was applied. To minimize artifacts from the transient signal oscillations in TrueFISP, a variable flip angle preparation of 20 rf pulses was implemented [7]. The excitation frequency was carefully chosen to avoid the banding artifacts within the kidney by a few pre-scans before the perfusion measurement. TI_2 was set to 1.2s, and TI_1 and TI_{1S} were changed in order to determine the optimum value for accurate perfusion quantification. The slice thickness of the periodic saturation pulses was 2cm, and the interval between successive saturation pulses on each side was 30ms. It ensures that the blood at velocities below 67cm/sec was saturated, which is well above renal blood velocity of approximately 50cm/s[8]. Five healthy volunteers were studied after informed consent was taken. Quantitative perfusion maps were computed on a pixel-by-pixel basis from the magnetization ΔM using a tissue/blood partition coefficient λ of 0.8, T_1 of 1.15s for the kidney cortex, and an inversion efficiency of 0.95.

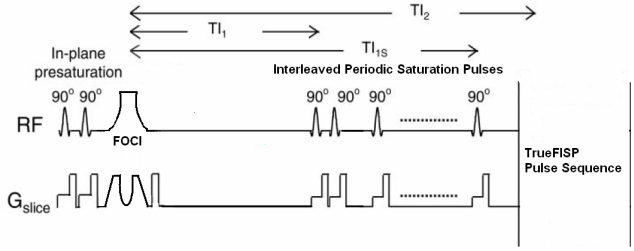

Fig. 1. Pulse sequence for the modified Q2TIPS. The periodic pulse alternatively saturates both side of the imaging slice.

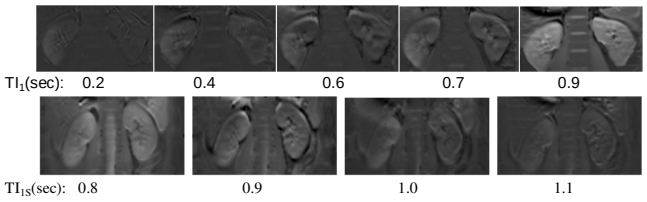

Fig. 2. Top: ΔM images with TI_{1S} = 1s while TI_1 is varied from 0.2 to 0.9s. Botteom: ΔM images with TI_1 = 0.7s and a series of TI_{1S}. TI_2 = 1.2s.

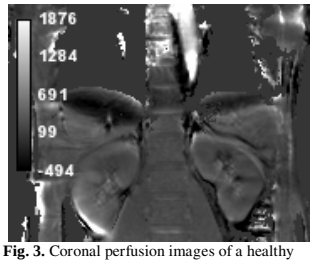

Fig. 3. Coronal perfusion images of a healthy volunteer

Results and Discussion:

Perfusion maps averaged from raw difference images, ΔM, as a function of TI_1 are shown in Fig. 2 (top) where TI_{1S} was fixed at 1.1s. ΔM is initially very weak, and increases with TI_1 as bolus width increases. Although higher perfusion signal could be obtained with longer TI_1, the remaining blood in the tissue vessels could produce errors in the estimation of the perfusion rate. Based on the results from Fig. 2 (top) the optimum TI_1 is approximately ranged from 0.6 to 0.7s. Fig. 2 (bottom) shows the mean ΔM images with different TI_{1S} and a constant TI_1 of 0.7s. Stronger signal in the image with TI_{1S} = 0.8s could be caused by renal blood that flows into the imaging slice again after the periodic saturation pulses, and thus TI_{1S} should be large enough to ensure that the renal blood can not re-enter the imaging slice after the periodic saturation pulses. We found that TI_{1s} of approximately one second should be used in the measurement of the renal perfusion rates.

Typical coronal perfusion images for a healthy volunteer are presented in Fig. 3. The dark band in the liver was caused by the banding artifact as mentioned in the method section. Renal perfusion rates ranged from 219 to 300 ml/100g/min in the five healthy volunteers with this technique. This is in agreement with other studies reported in literature[2,3].

It should be pointed out that the selection of the tagging slice thickness is very important in measuring the renal perfusion rate. It should be thick enough to prevent the imaging slice from moving out of the tagging region due the respiration or other motions. However, if the tagging slice is too thick, perfusion signals are very hard to detect. Only coronal slices were studied in this work as the motion in anterior/posterior direction is considerably smaller. Based on a study performed in our laboratory, the maximum displacement caused by respiratory motion along this direction is approximately 2mm. Therefore we conclude that 16mm inversion slice thickness should be sufficient to keep the imaging slice always within tagged regions.

As pointed out by Luh et al [4], periodic thin-slice TI_1 saturation pulses achieve a better matched slice profile compared to a single thick-slice saturation pulse. In the quantification of the renal perfusion rate, the thick-slice saturation could interfere with the navigator signal if navigators are used to gate the respiratory motion. In contrast, this presented interleaved thin-slice technique could be readily combined with any navigator method.

In conclusion, QUIPSS II with interleaved thin-slice TI_1 periodic saturation has been developed and integrated into a FAIR TrueFISP sequence for the quantification of renal perfusion. It has been shown that the bolus width can be controlled by changing TI_1 and the better matched saturation slice profiles can be achieved. The renal perfusion rate could be quantified more accurately with our technique.

References:

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