# PASTA++: B1- and T1-robust fat suppression at 3T

**A. J. Wheaton[1], and R. Anderson[1]**
[1]Toshiba Medical Research Inst. USA, Mayfield, OH, United States

## INTRODUCTION

Polarity Altered Spectral and Spatial Selective Acquisition [PASTA] is a fat suppression technique which leverages the chemical shift between fat and water [1]. Both fat and water are excited by a low bandwidth spatially-selective rf pulse. The low rf bandwidth [300-400Hz] generates a large displacement between fat and water selection due to chemical shift. The polarity of the slice selection gradient(s) of the following [high bandwidth] refocusing pulse(s) is reversed; this shifts fat selection in the opposite direction so the regions of fat selected by excite and refocus pulses do not coincide [Fig 1]. Thus the selected fat regions do not produce an rf echo and fat signal is attenuated in the image. PASTA has been used for diffusion [2] and breast [3] among other applications.

PASTA has several advantages and disadvantages. PASTA does not use an extraneous rf pulse like chemically selective saturation [CHESS] or inversion-based techniques [STIR, SPIR, SPAIR]. Therefore it is unaffected by B1 inhomogeneity and does not add SAR. Since PASTA does not operate on longitudinal magnetization, its fat suppression performance is unaffected by choice of TI or the distribution of T1 within lipid components [4]. PASTA is limited to spin-echo-based sequences, including fast spin echo [FSE]. Like any chemical-shift-based fat suppression technique, PASTA is affected by B0 inhomogeneity. The chemical shift which separates fat from water also attenuates off-resonance water. Also, the low bandwidth excitation pulse requires a long duration, low amplitude slice selection gradient which can be susceptible to distortion by background B0 variation. In the current implementation of PASTA, the long duration of the low bandwidth excitation pulse in PASTA necessitates a long minimum TE [20+ ms] or echo spacing [15+ ms].

## PASTA++ TECHNIQUE

At 3T, the general increase in T1 duration, B1 inhomogeneity, and SAR constraints make the T1- / B1-robustness and low SAR advantages of PASTA attractive. However, the increased B0 inhomogeneity and shorter T2s restrict the use of conventional PASTA at 3T. The purpose of this work is to propose an improved version of PASTA designed for 3T usage: PASTA++.

At 3T, refocusing pulse durations are often slightly longer to reduce their SAR contribution. The longer duration reduces their bandwidth [to ~730 Hz in our example] and increases chemical shift displacement between fat and water. The PASTA++ technique uses an excitation pulse with shorter duration and higher bandwidth [726 Hz] than the 1.5T counterpart [~400 Hz]. Due to the lower bandwidth of the refocus pulses, fat signal is still not refocused because the fat-water displacement of both pulses is ~60% slice width at 3T [Fig 1]. Although the excitation pulse is shorter in PASTA++, it still extends minimum TE / echo space by a few milliseconds. To maintain short echo spacing in FSE-based PASTA++, we use a longer initial echo space [8-10 ms] followed by a train of *ETL-1* short echo spaces [5-7 ms]. The irregular echo space approach is akin to the DIET idea [5], but in PASTA++ the initial echo space is increased to a much lesser extent.

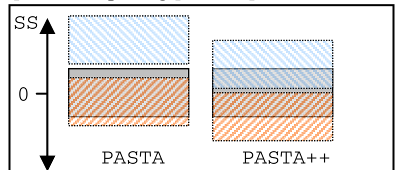


**Fig 1**. Slice displacement of fat excitation selection [blue hash] and refocus selection [orange hash] relative to water selection [gray] for PASTA and PASTA++. Center of water selection is marked by 0 on slice-select [SS] axis.

## MR EXPERIMENTS

To demonstrate the PASTA++ technique, sagittal and axial slices of the lower lumbar of a female volunteer was scanned under IRB protocol on a Toshiba 3T whole-body research system. Second order shims were used to improve B0 homogeneity. We used PASTA++ with FSE readout with the following parameters: TE/TR = 92/3000 ms, echo space = 7.0 ms, ETL = 23, matrix = 256 x 256, FOV = 25.6 x 25.6 cm, 5 slices, readout BW = 434 Hz/pixel, and 2 averages. Slice thickness was 4 mm in sagittal and 5 mm in axial images. The initial echo space was 8.0 ms to accommodate the longer excitation pulse as described above. For comparison, analogous CHESS images were acquired with identical parameters except TE = 91 ms, the slight difference due to regular echo spacing. SNR was measured in ROI at several locations in each image set.

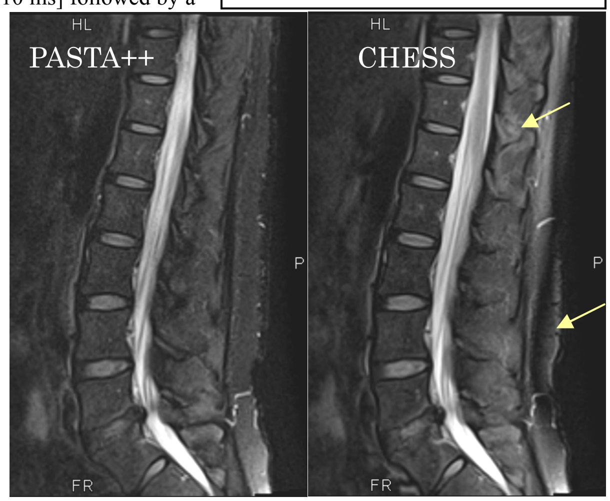


**Fig 2**. Comparison of PASTA++ and CHESS in representative sagittal slice. Areas of incomplete fat suppression are identified in CHESS.

## RESULTS AND DISCUSSION

The PASTA++ images [Fig 2 and 3] demonstrated uniform fat suppression over the whole FOV. For comparison, CHESS images exhibited regions of uneven or incomplete fat suppression. These results were consistent across all slices in both image sets. There was a 5-10% loss of SNR in PASTA++ relative to CHESS. We attribute the bulk of the SNR loss to attenuation of off-resonance water. Even the axial slices, with more B0 and B1 inhomogeneity across the FOV, PASTA++ generated images with uniform fat suppression without noticeable loss of water signal. Although PASTA++ is expected to struggle in regions of severe B0 inhomogeneity, it outperforms the original low bandwidth PASTA [data not shown].

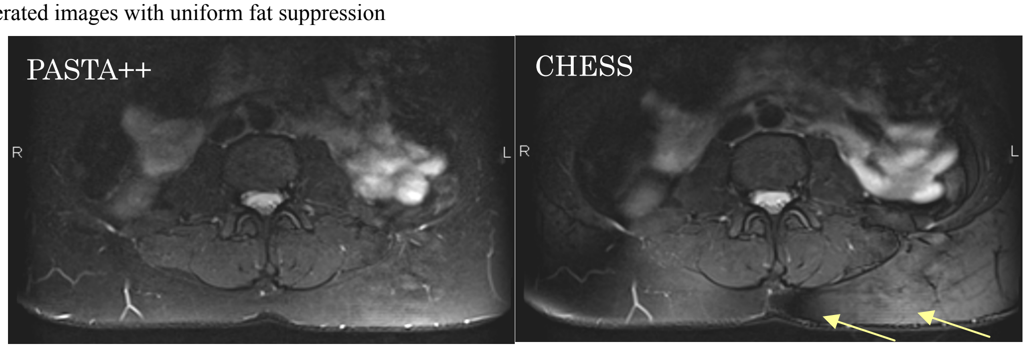


**Fig 3**. Comparison of PASTA++ and CHESS in representative axial slice of lower lumbar. Areas of nonuniform fat suppression in CHESS are evident in posterior subcutaneous fat.

## CONCLUSION

The PASTA++ technique produces uniform fat suppression that is robust to B1- and T1-variation. Sequence design of PASTA++ tailored to 3T maintains fat suppression performance with good performance in areas of B0 inhomogeneity while allowing short echo space FSE acquisitions.

## REFERENCES

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