Supporting Material S1

SIEMENS MAGNETOM Avanto_fit syngo MR D13B

\\USER\PengHu\Jiaxin\MOLLI_Study\MOLLI_5(3)3_FA35
TA:8.1 s PAT:2 Voxel size:1.8×1.8×8.0 mm Rel. SNR:1.00 :tfi

Properties

Prio Recon	Off
Load to viewer	On
Inline movie	Off
Auto store images	On
Load to stamp segments	Off
Load images to graphic segments	Off
Auto open inline display	Off
Wait for user to start	On
Start measurements	single

Routine

Nr. of slice groups	1
Slices	1
Dist. factor	20 %
Position	L68.1 P5.6 F3.7 mm
Orientation	S > C31.9 > T18.6
Phase enc. dir.	A >> P
AutoAlign	---
Phase oversampling	0 %
FoV read	340 mm
FoV phase	80.2 %
Slice thickness	8.0 mm
TR	740.00 ms
TE	1.05 ms
Averages	1
Concatenations	1
Filter	Distortion Corr.(2D)
Coil elements	BO1-3;SP1-3

Contrast

Magn. preparation	Non-sel. IR T1map
TI	200 ms
Flip angle	35 deg
Fat suppr.	None
Averaging mode	Short term
Measurements	1
Reconstruction	Magn./Phase
Multiple series	Off

Supporting Material S1

Resolution

Base resolution	192
Phase resolution	81 %
Phase partial Fourier	6/8
Trajectory	Cartesian
Interpolation	Off
PAT mode	GRAPPA
Accel. factor PE	2
Ref. lines PE	24
Reference scan mode	Integrated
Image Filter	Off
Distortion Corr.	On
Mode	2D
Unfiltered images	Off
Prescan Normalize	Off
Normalize	Off
B1 filter	Off
Raw filter	Off
Elliptical filter	Off
POCS	Off

Geometry

Nr. of slice groups	1
Slices	1
Dist. factor	20 %
Position	L68.1 P5.6 F10.7 mm
Phase enc. dir.	A >> P
Phase oversampling	0 %
Multi-slice mode	Sequential
Series	Interleaved
Nr. of sat. regions	0
Position mode	Offcenter-Shift
Fat suppr.	None
Special sat.	None
Special sat.	None
Set-n-Go Protocol	Off
Table position	P
Inline Composing	Off

Supporting Material S1

System

Body	Off
BO1	On
BO2	On
BO3	On
SP5	Off
SP6	Off
SP7	Off
SP8	Off
SP1	On
SP2	On
SP3	On
SP4	Off
Position mode	Offcenter-Shift
Positioning mode	REF
Table position	F
Table position	0 mm
MSMA	S - C - T
Sagittal	R >> L
Coronal	A >> P
Transversal	F >> H
Save uncombined	Off
Coil Combine Mode	Adaptive Combine
AutoAlign	---
Coil Select Mode	Default
Shim mode	Cardiac
Adjust with body coil	Off
Confirm freq. adjustment	Off
Assume Dominant Fat	Off
Assume Silicone	Off
Adjustment Tolerance	Auto
? Ref. amplitude 1H	0.000 V
! Position	L48.1 A27.2 F9.6 mm
! Rotation	14.499991 deg
! F >> H	126 mm
! A >> P	120 mm
! R >> L	123 mm
Frequency 1H	63.661924 MHz
Correction factor	1
PrepExc 1H	201.384 V
Gain	High
Table position	7 mm

Supporting Material S1

Img. Scale. Cor.	1.000

Physio

1st Signal/Mode	ECG/Trigger
Average cycle	No Signal ms
Captured cycle	-not set-
Acquisition window	740 ms
Trigger pulse	1
Trigger delay	0 ms
Segments	74
Adaptive Triggering	Off
Tagging	None
Magn. preparation	Non-sel. IR T1map
TI	200 ms
Dark blood	Off
Phases	1
Cine	Off
Trajectory	Cartesian
Inline Evaluation	Off
Resp. control	Off
Dummy heartbeats	0

Inline

Inline Composing	Off
Distortion correction	Off

Supporting Material S1

Sequence

Introduction	Off
Dimension	2D
Averaging mode	Short term
Multi-slice mode	Sequential
Reordering	Linear
Asymmetric echo	Weak
Contrasts	1
Bandwidth	1002 Hz/Px
Optimization	Min. TE
Allowed delay	0 s
Echo spacing	2.5 ms
Sequence type	Trufi
Define	Shots
Shots per slice	1
Trufi delta freq.	0 Hz
RF pulse type	Fast
Gradient mode	Fast
Excitation	Slice-sel.
Flip angle mode	Constant
Cine	Off
Parameter Map Type	T1 Map
Inversion pulse Type	Short(2ms)
No. of preps	2
TI start	120 ms
TI increment	80 ms
Motion correction	On
Goodness of fit map	Off
Synth MagIR and PSIR	Off
Acquisition Type	Normal
No. of bSSFP Ramps	10
TX/RX delta frequency	0 Hz
TX Nucleus	None
TX delta frequency	0 Hz
Coil elements	BO1-3;SP1-3
Acquisition duration	0 ms
Mode	Off

Supporting Material S1

BOLD

Subtract	Off
StdDev	Off
MIP-Sag	Off
MIP-Cor	Off
MIP-Tra	Off
MIP-Time	Off
Save original images	On
Distortion Corr.	On
Mode	2D
Unfiltered images	Off
Contrasts	1
Save original images	On

Supporting Material S2

SIEMENS MAGNETOM Avanto_fit syngo MR D13B

\\USER\PengHu\Jiaxin\T1_T2Map_IR_SE\ir_se_T50_TR10000
TA:21:32 Voxel size:1.8×1.8×8.0 mm Rel. SNR:1.00 :ir

Properties

Prio Recon	Off
Load to viewer	On
Inline movie	Off
Auto store images	On
Load to stamp segments	Off
Load images to graphic segments	Off
Auto open inline display	Off
Wait for user to start	Off
Start measurements	single

Routine

Nr. of slice groups	1
Slices	1
Dist. factor	50 %
Position	L47.1 P56.5 H3.5 mm
Orientation	Coronal
Phase enc. dir.	R >> L
AutoAlign	---
Phase oversampling	0 %
FoV read	230 mm
FoV phase	100.0 %
Slice thickness	8.0 mm
TR	10000.0 ms
TE	4.6 ms
Averages	1
Concatenations	1
Filter	None
Coil elements	BO1-3;SP1-3

Supporting Material S2

Contrast

MTC	Off
Magn. preparation	Slice-sel. IR
TI	50 ms
Flip angle	90 deg
Fat suppr.	None
Water suppr.	None
Averaging mode	Short term
Measurements	1
Reconstruction	Magnitude
Multiple series	Each measurement

Resolution

Base resolution	128
Phase resolution	100 %
Phase partial Fourier	Off
Interpolation	Off
Image Filter	Off
Distortion Corr.	Off
Prescan Normalize	Off
Normalize	Off
B1 filter	Off
Raw filter	Off
Elliptical filter	Off

Geometry

Nr. of slice groups	1
Slices	1
Dist. factor	50 %
Position	L47.1 P56.5 H3.5 mm
Phase enc. dir.	R >> L
Phase oversampling	0 %
Multi-slice mode	Interleaved
Series	Interleaved
Nr. of sat. regions	0
Position mode	Offcenter-Shift
Fat suppr.	None
Water suppr.	None
Special sat.	None
Special sat.	None
Set-n-Go Protocol	Off
Table position	P
Inline Composing	Off

Supporting Material S2

System

Body	Off
BO1	On
BO2	On
BO3	On
SP5	Off
SP6	Off
SP7	Off
SP8	Off
SP1	On
SP2	On
SP3	On
SP4	Off
Position mode	Offcenter-Shift
Positioning mode	FIX
Table position	H
Table position	0 mm
MSMA	S - C - T
Sagittal	R >> L
Coronal	A >> P
Transversal	F >> H
Save uncombined	Off
Coil Combine Mode	Adaptive Combine
AutoAlign	---
Coil Select Mode	Default
Shim mode	Tune up
Adjust with body coil	Off
Confirm freq. adjustment	Off
Assume Dominant Fat	Off
Assume Silicone	Off
Adjustment Tolerance	Auto
? Ref. amplitude 1H	0.000 V
Position	Isocenter
Rotation	0.00 deg
R >> L	350 mm
A >> P	263 mm
F >> H	350 mm
Frequency 1H	63.661924 MHz
Correction factor	1
this pIRsel 1H	369.543 V
Gain	High
Table position	0 mm

Supporting Material S2

Img. Scale. Cor.	1.000

Physio

1st Signal/Mode	None
Magn. preparation	Slice-sel. IR
TI	50 ms
Dark blood	Off

Inline

Inline Composing	Off
Distortion correction	Off

Sequence

Introduction	On
Averaging mode	Short term
Multi-slice mode	Interleaved
Asymmetric echo	Off
Contrasts	1
Bandwidth	399 Hz/Px
Allowed delay	0 s
RF pulse type	Fast
Gradient mode	Fast
TX/RX delta frequency	0 Hz
TX Nucleus	None
TX delta frequency	0 Hz
Coil elements	BO1-3;SP1-3
Acquisition duration	0 ms
Mode	Off

BOLD

Subtract	Off
StdDev	Off
MIP-Sag	Off
MIP-Cor	Off
MIP-Tra	Off
MIP-Time	Off
Save original images	On
Distortion Corr.	Off
Contrasts	1
Save original images	On

Supporting Material S3

SIEMENS MAGNETOM Avanto_fit syngo MR D13B

\\USER\PengHu\Jiaxin\T1_T2Map_IR_SE\se_TE5_TR10000
TA:21:32 Voxel size:1.8×1.8×8.0 mm Rel. SNR:1.00 :se

Properties

Prio Recon	Off
Load to viewer	On
Inline movie	Off
Auto store images	On
Load to stamp segments	Off
Load images to graphic segments	Off
Auto open inline display	Off
Wait for user to start	Off
Start measurements	single

Routine

Nr. of slice groups	1
Slices	1
Dist. factor	50 %
Position	L47.1 P56.5 H3.5 mm
Orientation	Coronal
Phase enc. dir.	R >> L
AutoAlign	---
Phase oversampling	0 %
FoV read	230 mm
FoV phase	100.0 %
Slice thickness	8.0 mm
TR	10000.0 ms
TE	5.0 ms
Averages	1
Concatenations	1
Filter	None
Coil elements	BO1-3;SP1-3

Supporting Material S3

Contrast

MTC	Off
Magn. preparation	None
Flip angle	90 deg
Fat suppr.	None
Water suppr.	None
Averaging mode	Short term
Measurements	1
Reconstruction	Magnitude
Multiple series	Each measurement

Resolution

Base resolution	128
Phase resolution	100 %
Phase partial Fourier	Off
Interpolation	Off
Image Filter	Off
Distortion Corr.	Off
Prescan Normalize	Off
Normalize	Off
B1 filter	Off
Raw filter	Off
Elliptical filter	Off

Geometry

Nr. of slice groups	1
Slices	1
Dist. factor	50 %
Position	L47.1 P56.5 H3.5 mm
Phase enc. dir.	R >> L
Phase oversampling	0 %
Multi-slice mode	Interleaved
Series	Interleaved
Nr. of sat. regions	0
Position mode	Offcenter-Shift
Fat suppr.	None
Water suppr.	None
Special sat.	None
Special sat.	None
Set-n-Go Protocol	Off
Table position	P
Inline Composing	Off

Supporting Material S3

System

Body	Off
BO1	On
BO2	On
BO3	On
SP5	Off
SP6	Off
SP7	Off
SP8	Off
SP1	On
SP2	On
SP3	On
SP4	Off
Position mode	Offcenter-Shift
Positioning mode	FIX
Table position	H
Table position	0 mm
MSMA	S - C - T
Sagittal	R >> L
Coronal	A >> P
Transversal	F >> H
Save uncombined	Off
Coil Combine Mode	Adaptive Combine
AutoAlign	---
Coil Select Mode	Default
Shim mode	Tune up
Adjust with body coil	Off
Confirm freq. adjustment	Off
Assume Dominant Fat	Off
Assume Silicone	Off
Adjustment Tolerance	Auto
? Ref. amplitude 1H	0.000 V
Position	Isocenter
Rotation	0.00 deg
R >> L	350 mm
A >> P	263 mm
F >> H	350 mm
Frequency 1H	63.661924 MHz
Correction factor	1
VExcit 1H	474.908 V
Gain	High
Table position	0 mm

Supporting Material S3

Img. Scale. Cor.	1.000

Physio

1st Signal/Mode	None
Magn. preparation	None
Dark blood	Off

Inline

Inline Composing	Off
Distortion correction	Off

Sequence

Introduction	On
Averaging mode	Short term
Multi-slice mode	Interleaved
Asymmetric echo	Off
Contrasts	1
Bandwidth	399 Hz/Px
Allowed delay	0 s
RF pulse type	Fast
Gradient mode	Fast
TX/RX delta frequency	0 Hz
TX Nucleus	None
TX delta frequency	0 Hz
Coil elements	BO1-3;SP1-3
Acquisition duration	0 ms
Mode	Off

BOLD

Subtract	Off
StdDev	Off
MIP-Sag	Off
MIP-Cor	Off
MIP-Tra	Off
MIP-Time	Off
Save original images	On
Distortion Corr.	Off
Contrasts	1
Save original images	On

Supporting material S4: Influence of magnetization transfer (MT) effect and inversion factor on T1 estimations

Methods

To evaluate the influence of MT effect on measured inversion factor and the influence of inversion factor on T1 estimations, the "MOLLI+M0" sequence and the MOLLI 5(3)3 sequence as described in the main manuscript were simulated at FA=35°, HR=60 bpm. The MT simulation approach for the MOLLI sequence was the same as described in (24). The tissue parameters used in the MT simulation were the same as that of cardiac muscle used in (24), i.e. T1f = 1175 ms, T2f = 54.4 ms, T1r = 1000 ms, T2r = 8.5 us, F=0.07, k_f = 4.1 s^{-1}. The sequence parameters were the same as the actual sequence parameters used in this work, including simulation of the adiabatic inversion pulse and excitation pulse.

After the "MOLLI+M0" sequence without and with MT effect was simulated, the BLEESPC 4-parameter fit was applied to the simulated signal to calculate the inversion factor without and with MT effect, respectively. After the MOLLI 5(3)3 sequence without and with MT effect was simulated, the four T1 estimation algorithms, BLESSPC, InSiL, IG fit and original fit were applied to calculate T1 values assuming a fixed inversion factor from 0.88 – 1.00 (0.01 increment).

Results

The inversion factor (δ) estimated using our BLESSPC 4-parameter fit based on the simulated non-MT "MOLLI+M0" data was 0.97, which was similar to the average δ of 0.96 measured in our phantom study. It was 0.89 when the MT effect was included in our simulated "MOLLI+M0" data, which was similar to the average δ of 0.88 measured in our in vivo study. Therefore, MT appears to be a major cause for the greatly reduced inversion factor in vivo compared to in phantom experiments.

The T1 estimation results using different inversion factors and algorithms for the MOLLI 5(3)3 sequence without and with MT effect were shown in Figure S1. The results showed that all the four methods are sensitive to MT effect and choice of inversion factor. However, using the δ measured using "MOLLI+M0" helped to reduce T1 estimation error, e.g. using the measured inversion factor δ considering MT effect (δ=0.89) the T1

estimation error was reduced to -0.8% using BLESSPC for the MOLLI 5(3)3 sequence considering MT effect.

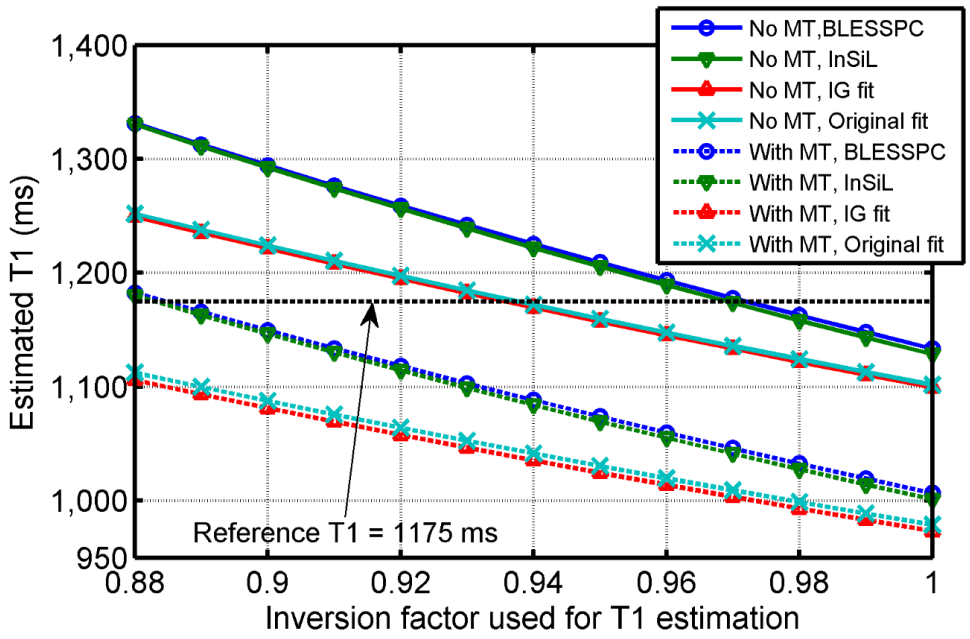

Figure S1: Simulation – comparison of estimated T1 values using BLESSPC, InSiL, IG fit and original fit for the MOLLI 5(3)3 sequence with and without MT effect over different inversion factors. All the four methods are sensitive to MT and choice of inversion factor for T1 estimations. Using the measured inversion factor considering MT effect (δ=0.89) reduced the T1 estimation error due to the MT effect.

Supporting Material S5

Supporting material S5: Simulation of ShMOLLI pulse sequence

Additional simulations were performed to compare BLESSPC and InSiL T1 estimation with ShMOLLI's T1 estimation algorithm (conditional 3-parameter exponential fitting) in terms of accuracy and precision for the ShMOLLI sequence. Specifically, the simulations were performed with 5(1)1(1)1 acquisition scheme, FA = 35° , T2 = 50 ms, HR = 60 bpm and T1 values varied from 220 ms, 400 ms to 1800 mc (200 ms increments); T1 estimation precision were estimated using Monte-Carlo simulation with 65,536 trials by adding the amount of Gaussian noise described in the main manuscript. The other simulated sequence parameters were the same as described in the simulation section in the main manuscript. Figure S2 shows the simulation results of T1 estimation accuracy and precision at T1 values ranges from 220 ms to 1800ms using BLEESPC, InSiL and ShMOLLI's conditional fit using the 5(1)1(1)1 acquisition scheme.

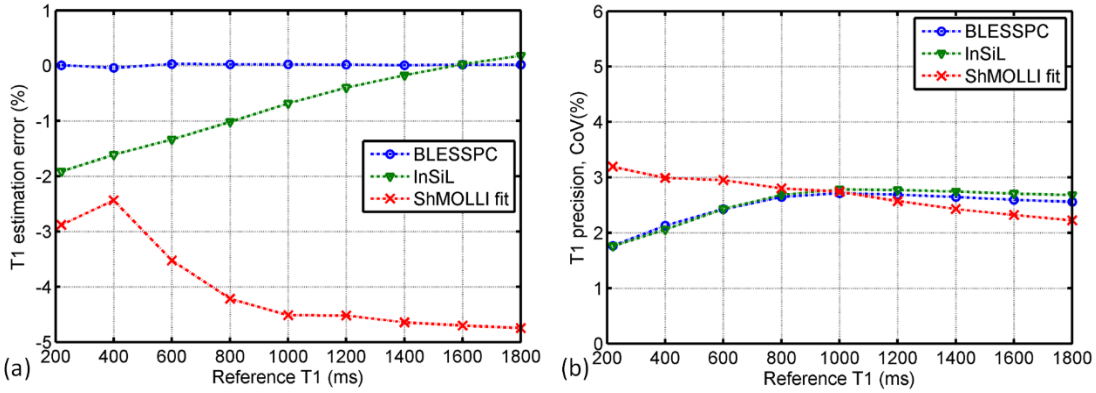

Figure S2: Simulation - comparison of BLESSPC, InSiL and ShMOLLI fit for the ShMOLLI pulse sequence in terms of T1 estimation accuracy (a) and precision (b) for T1 range from 220 ms - 1800 ms. Overall, BLESSPC and InSiL were more accurate than ShMOLLI fit. BLESSPC was slightly better than InSiL. The ShMOLLI fit had superior precision over the other two methods for T1 > 1000 ms, while for T1<1000 ms, BLESSPC and InSiL were more precise.