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Tips for cardiac black blood imaging (UPDATE)

Application Tip
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Application Tip

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Explorer / Nova Dual, Gradient, gradients, Master / Nova, Master / Quasar Dual, Nova, Nova Dual, Omni / Stellar, Power / Pulsar, Pulsar, Quasar, Quasar Dual
3T, BB, Cardiac, Cardiac Morphology

Tips for cardiac black blood imaging

Introduction

Black blood imaging is routinely used to visualize cardiac morphology. Black blood imaging can either be obtained by using SE-based scan techniques in which the outflow effect is used to suppress the signal of blood spins flowing through the slice, or by applying a dual-inversion pre-pulse to null the magnetization of the blood in the imaging slice.
This document provides tips to optimize sequences using a dual inversion prepulse.

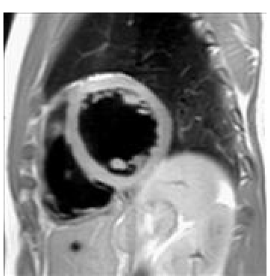
The principle of a black blood dual inversion prepulse is as follows:
The sequence starts with a non-selective inversion pulse, to invert all spins, immediately followed by a slice-selective inversion pulse. This second inversion pulse realigns all spins within the imaging slice again along the longitudinal plane, but all spins outside of the imaging slice remain inverted.

The magnetization of these inverted spins will return to equilibrium and after a specified inversion delay time, the signal of these spins is nulled.
While relaxing to zero, the inverted blood spins outside the imaging slice will flow into the imaging slice, and the trick is to acquire the data of the imaging slice once the signal of the inflowing blood spins is nulled: black blood imaging.
The slice thickness of the selective (second) inversion pulse is the so-called black blood slice thickness.

Tip 1: Avoiding myocardial signal loss using a dual-inversion pre-pulse

As the heart is contracting and relaxing during the cardiac cycle, the black blood slice thickness is usually thicker than the imaging slice thickness. This is to avoid that inverted myocardial spins from outside the imaging slice move into the imaging slice during the black blood delay time (time between the dual-inversion pre-pulse and data acquisition). These spins would be nulled as well, or at least have reduced signal intensity due to incomplete T1-relaxation.

This effect is mainly seen in SA-scans in the lateral free wall of the heart, where myocardial motion is the largest. **Increasing the black blood slice thickness** will solve the issue.



PDW_BB_TSE
BB slice 20 mm, imaging slice 8 mm. No myocardial suppression.

PDW_BB_TSE
BB slice 10 mm, imaging slice 8 mm. Myocardial suppression at the free lateral wall of the LV. Note the improved blood suppression in the RV, in the region of slow flowing blood (see tip 2...).

Tip 2: Avoiding incomplete black blood suppression using a dual inversion prepulse

The black blood slice thickness is usually thicker than the actual slice thickness of the sequence, to account for myocardial motion (see tip 1).

If **slow flow** or **in-plane flow** occurs, the re-inverted spins within the black blood slice thickness may not be completely replaced by nulled blood spins from outside the black blood slice thickness, resulting in high signal in the blood pool.

The **black blood slice thickness should be reduced** in this case.

Rule of thumb:
- BB slice thickness ~ 2-2.5x imaging slice thickness for through-plane flow (SA)
- BB slice thickness ~ 1-1.5 x imaging slice thickness for in-plane flow (e.g. 4CH)

The preset procedure database contains separate folders for BlackBlood SA and BlackBlood LA in which the black blood slice thickness is appropriately set.
Note: BB slice thickness = "2.5 x imaging slice thickness" if SW release is older than R2.6

PDW_BB_TSE
BB slice 12 mm, imaging slice 8 mm. Good blood suppression.

PDW_BB_TSE
BB slice 20 mm, imaging slice 8 mm. Incomplete blood suppression.

Tip 3: Improving blood suppression of in-plane flow

In slices where slow flowing blood is present, or where flow is exactly in-plane (e.g. aortic arch), it might be difficult to achieve good blood suppression, even if the black blood slice thickness is reduced (see tip 2). In the example of the aortic arch, the flowing spins have to travel out of the complete field of view before they can be refreshed by inverted, nulled blood spins. To optimally use the flow velocity of spins, it can be helpful to apply the dual inversion prepulse before systole (end-diastole in the first RR-interval) and to acquire the data after systole (early systole in the second RR-interval).

This can be achieved by using **trigger delay = user defined (motion page),** entered trigger delay in ms should be ~ 0.7 x TR. Note that actual TR is displayed on the info page.

The trigger delay must be adapted for each patient with this approach.

To check whether the black blood prepulse is now really applied before systole, subtract the black blood prepulse delay time from the user defined trigger delay. The calculated number is slightly shorter than 50% of the TR (corresponding to timing at the end of the first RR-interval)

Alternatively, use **trigger delay = user defined table (motion page).** If set to user defined table, the selected trigger delay is read from a table that must be entered in service mode. Please refer to tip 4 for instructions.

PDW_BB_TSE
Trigger delay mid-diastole, dual-inversion pre-pulse in same RR-interval.

PDW_BB_TSE
Trigger delay user defined, dual-inversion pre-pulse in previous RR-interval. Note: due to acquisition in early-diastole, cardiac motion blurring might be slightly

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Tip 4: Trigger delay "user defined table"

In some cases it is required to use a user defined trigger delay (see tip 3).
The optimal trigger delay varies with the patient's heart rate and should be set for each patient individually. It is possible to specify the optimal trigger delay per heart rate in a table in service mode. The optimal trigger delay is read from this table if the trigger delay parameter on the motion page is set to "user defined table". The used trigger delay is specified on the info page.

Note: service mode might be password protected. Please contact the local service organization.

Workflow:
Go to System, Advanced Tools, Scan Utilities

- enter Service mode
- Select 1. Control parameters
- Select 1. Scan control parameters
- Select parameter "trigger delay user defined"
- Enter the required trigger delay time per entry, and save the settings.

Entry 01 represents a heart rate of 30 beats per minute. The heart rate is increased by 5 beats for each next entry. The required trigger delay time per entry can now be specified. (The user defined trigger delay is interpolated if the actual heart rate is not a multiple of 5 beats.)

The table below specifies the user defined trigger delay per entry (per heart rate) according to the calculation "trigger delay = 0.7 x TR".

Entry	Bpm	Trigger delay	Entry	Bpm	Trigger delay
01	30	2800	17	110	730
02	35	2400	18	115	700
03	40	2100	19	120	672
04	45	1867	20	125	646
05	50	1680	21	130	622
06	55	1527	22	135	600
07	60	1400	23	140	579
08	65	1292	24	145	560
09	70	1200	25	150	542
10	75	1050	26	155	525
11	80	988	27	160	509
12	85	933	28	165	494
13	90	884	29	170	480
14	95	840	30	175	467
15	100	800	31	180	454
16	105	764	32	185	442

Tip 5: Solving trigger delay timing conflicts

The dual inversion black blood sequences are usually triggered towards mid-diastole. This to make sure that the acquisition of the TSE/TFE-shot occurs in the period of the cardiac cycle in which the least cardiac motion occurs.

If additional prepulses such as STIR prepulses are required, timing conflicts might occur as it is no longer possible to apply all prepulses with the appropriate inversion delay times between the detection of the R-top and mid-diastole.
Timing conflicts can also occur if the TSE/TFE shot duration is too long such that it extends over the maximum allowed trigger delay (see info page).

Solve the conflict by **changing the trigger delay time from mid-diastole to longest.**

The acquisition of the TSE/TFE shot is now moved as much as possible towards the end of the no-trigger period. The sequence is pushed to the 2nd cardiac cycle if the no-trigger period (motion page) = 2 beats.

It is also possible to use trigger delay shortest, but this might result in acquiring the TSE/TFE shot in early systole of the 2nd RR-interval, which might be less desirable.

Note that the trigger delay time can be ***shorter*** if "longest" is selected instead of "mid-diastole" if the TSE shot duration is too long to fit with trigger delay mid-diastole.

Tip 6: Black blood imaging using asymmetric TSE

TSE is the most commonly used sequence for black blood imaging. To avoid cardiac motion blurring, it is important that the acquisition of data is limited to the moment in the cardiac cycle in which the least cardiac motion occurs. Generally this happens in mid-diastole.

The TSE shot length should be adapted for each patient to optimally fit in the cardiac cycle of the patient. Modifying shot length in TSE sequences can be difficult though, as the shot length depends on:

- TSE factor
- echo spacing

while the echo spacing is a derived parameter of the:

- TSE factor
- echo time

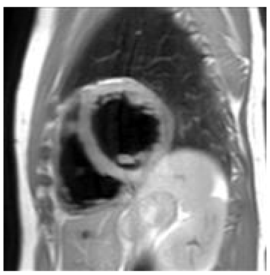
The echo spacing must be short to avoid blurring, and halfscan and/or startup echoes are commonly used to maintain a short echo spacing at a specific echo time.

With the introduction of R2, **asymmetric TSE** is available. Asymmetric TSE allows for the use of a user defined echo spacing and the shot length can now easily be defined by setting the required:

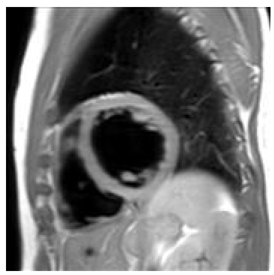
- echo spacing
- TSE factor

The echo time can be freely selected to define the required contrast in the image.

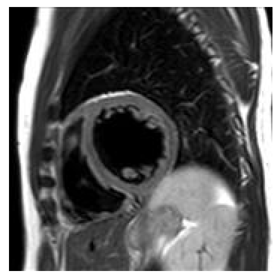
Asymmetric profile order is implemented in the dual inversion black blood preset procedures in the Philips database since SW release 2.6.3



PDW_BB_TSE
TE 9 ms, profile order low-high, shot length 102 ms
Halfscan might lead to some residual motion blurring.



PDW_BB_TSE
TE 9 ms, profile order asymmetric, shot length 130 ms.



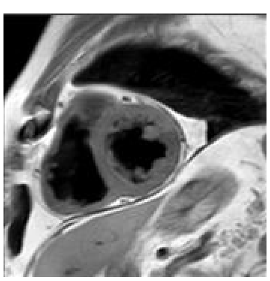
T2W_BB_TSE
TE 60 ms, profile order asymmetric, shot length 130 ms.

Tip 7: T1-weighted black blood imaging using TFE

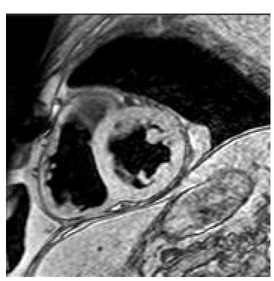
In TSE black blood imaging, repetition time TR is expressed in beats, meaning that the length of the cardiac cycle determines the length of the TR. For PD-weighted and T2-weighted black blood imaging, the TR is usually set to 2 beats, to be sufficiently long.
A shorter TR is required to obtain T1-weighting, but especially at low heart rates (less than 60-75 bpm), the shortest possible TR of 1 beat is too long to obtain real T1-weighting.

An alternative is to use a **TFE-sequence** with relatively short TR and sufficiently large flip angle to obtain real T1-weighting during the TFE-shot. The double-inversion black blood pre-pulse is used to null the signal of the blood in the imaging slice.

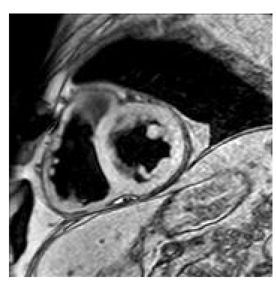
The TFE factor can be modified to **adapt the TFE shot length** to optimally fit in the most quiet period of the heart of the patient in diastole.



T1W_BB_TSE
TE 9 ms, profile order asymmetric, shot length 88 ms. TR 1 beat (923 ms).



T1W_BB_TFE
TR / TE 5.1 / 3.1 ms, flip angle 25 degrees, shot length 88 ms.



T1W_BB_TFE
TR / TE 5.1 / 3.1 ms, flip angle 25 degrees, shot length 120 ms.

Tip 8: Reducing the effect of heart rate variations in T1W_BB_TFE

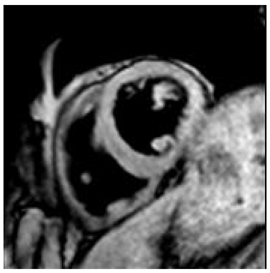
Black blood imaging sequences are generally multi-shot sequences. These sequences are cardiac triggered to make sure that each shot is acquired in the most quiet period of the heart in diastole, to minimize cardiac motion blurring in the images. Timing of the sequence is done by setting the

appropriate trigger delay (motion page).
The trigger delay is specified as the time between the detection of the R-peak and the acquisition of the data of each respective TSE or TFE shot.

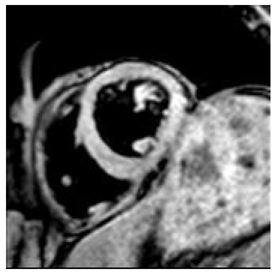
If heart rate variations occur during the scan, the acquisition of some (or more) shots will fall in a different period of the cardiac cycle than specified by the trigger delay. This in turn will lead to cardiac motion blurring. This effect is most pronounced if every RR-interval is used to acquire shots, and can be reduced by acquiring shots only once every two RR-intervals (as the average duration of two RR-intervals is usually more stable than the duration of one RR-interval).

For PD-weighted and T2-weighted TSE sequences, the TR is set to two beats (see tip 7), but in TFE sequences it is very common to acquire one shot every RR-interval.

The **TFE shot interval** (contrast page) can be used to define an interval between the acquisition of the respective TFE shots, to make sure that only one shot is acquired in every two RR-intervals. Doing so will double the total scan time, but longer T1-relaxation will also lead to increased SNR. This signal can be traded by reducing the number of averages (NSA) or by applying SENSE to reduce the total scan time.



T1W_TFE_BB 1 beat
T1-weighted TFE BB sequence, 3 NSA. Some image blurring is visible due to heart rate variations.



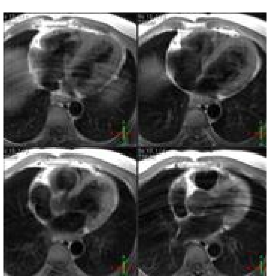
T1W_TFE 2 beats
T1-weighted TFE BB sequence, 2 NSA and shot interval of two beats. Reduced image blurring.

Tip 9: Black blood imaging using respiratory navigator

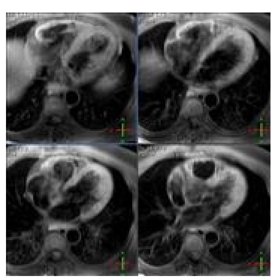
Black blood imaging requires some form of respiratory compensation. Breath-holds are generally performed, but this might be cumbersome in multi-slice sequences, where each slice requires a breath-hold. Additionally, if higher spatial resolution is required, breath-holding might no longer be feasible.

Respiratory compensation can also be performed by using a navigator signal. It is important that the collected navigator signal clearly differentiates between lung and liver, to optimally detect the position of the diaphragm, to obtain images that are free of residual respiratory motion.

Fat signals that are present close to or in the navigator beam, might disturb the collected navigator signal, reducing the efficiency of the navigator. This is mainly relevant at 3.0T, but might play a role at 1.5T as well. It is therefore advised to **enable fat suppression (SPIR or SPAIR) if a respiratory navigator is used.**



3.0T PDW_BB_TSE
No fat suppression



3.0T PDW_BB_TSE
SPAIR fat suppression

Tip 10: Acquiring resipiratory triggered single shot black blood images ("HASTE")

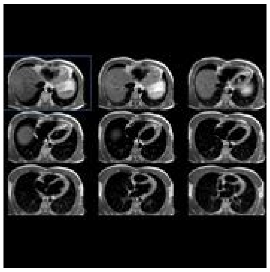
Single shot black blood images can be acquired to provide a quick overview of the patient's morphology. Halfscan and SENSE are used to reduce the acquisition time per slice. Multiple slices can be acquired in one breath-hold, or respiratory triggering can be used to acquire one slice per respiratory cycle.

The optimal black blood inversion delay time for respiratory triggered sequences is increased as the effective TR for the sequence is now equal to the respiratory cycle.
The black blood inversion delay time is automatically recalculated since SW release 2.6.1.

The sequence can be acquired on systems before R2.6.1 as well.

The workflow to **adapt black blood inversion delay time if respiratory triggering is enabled**:

- specify 1 slice per breath-hold (motion page)
- read BB-inversion delay (info page)
- enable respiratory triggering (motion page)
- select user-defined BB-inversion delay (contrast page), specify delay as just found on info page
- Increase TR in beats if timing conflict occurs



1.5T and 3.0T ExamCards are available:

1.5T / 3.0T Black blood cardiac imaging

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