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Understanding and simplifying inversion recovery

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ABSTRACT

The usage of magnetic resonance imaging (MRI) as a vital diagnosing tool has increased greatly since its beginnings in the late 1970's and early 1980's. One of the key features of MRI is its ability to create differing contrasts between tissues without the reliance on contrast enhancement drugs. Some atomic nuclei are capable of absorbing and emitting radio-frequency (RF) when placed in an external magnetic field, the most common atoms utilised in MRI are hydrogen (specifically the hydrogen proton), this being due to their high abundance in the body, especially in water and fat. By using RF waves to excite nuclear spin transition and magnetic gradients within the scanner to localise signal, it is possible to pick up signal from tissues, in essence MRI maps the location of tissues containing hydrogen. The properties (T1 relaxation/T2 decay) of the hydrogen protons differ depending on the tissue, which can be exploited by MRI to create contrast, this is further utilised in the inversion recovery (IR) pulse sequence. IR allows the radiographer to suppress signal from certain tissues which can enhance the contrast of the image and help differentiate between certain pathologies. *In conclusion* understanding how IR works allows the radiographer to alter scan parameters to enhance images and show certain pathology which would normally be impossible to show.

AIM

The aim of this article is to give radiographers who work within MRI a glimpse into the workings of one of the oldest and most utilised contrast altering techniques. Whilst some of the later information may not be relevant to some, this paper should hold information interesting and usable by all. In general this paper does not delve into specific areas in depth but instead gives the radiographer an overview of the physics, indications and parameters of IR.

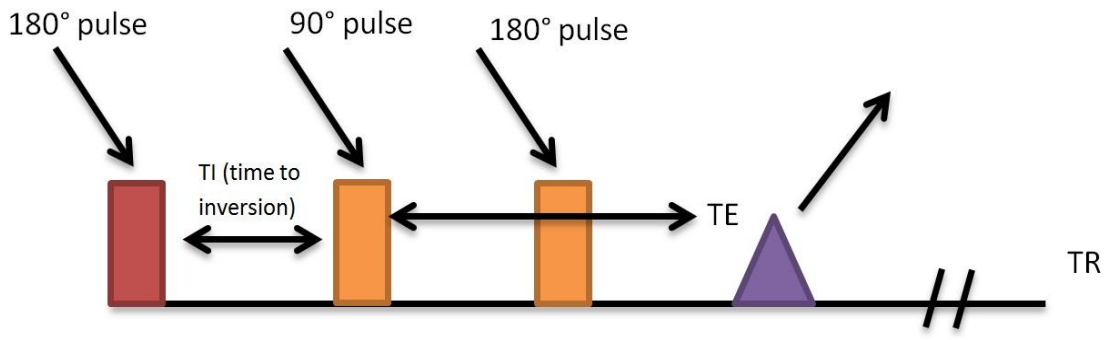
The following learning outcomes (LO) should have been achieved by finishing the paper; these will be next to each title so the reader knows which outcomes can be gained from that section:

a. A basic understanding of the physics associated with IR.
b. An understanding of what parameters are utilised in IR and why.
c. The main usages of IR.
d. A basic view of more complex uses of IR.

Introduction to inversion recovery *(LO a)*

Inversion recovery (IR) scans have been common scans since the earliest days of MRI, however due to the reliance of conventional spin echo (CSE) sequences they were often very long (15-25minutes), when fast spin echo (FSE) became common the speed of IR dramatically fell.[1] IR utilises a common pulse sequence preceded with a 180° inverting pulse when using a CSE it may be denoted as:

180°- {90°−180°−echo}



(Figure 1. CSE-IR Pulse sequence.)

The above figure (Figure. 1) shows IR working within a CSE; however it is more commonly seen in FSE sequences and can be applied to multiple pulse sequences to cause suppression of tissues which will be discussed later in the article. For the purposes of simplicity and understanding this article assumes that CSE is being used unless stated otherwise.

The time between the initial 180° pulse and the 90° excitation pulse is called the TI or time to inversion; this is what differentiates a CSE with a CSE-IR.[2]

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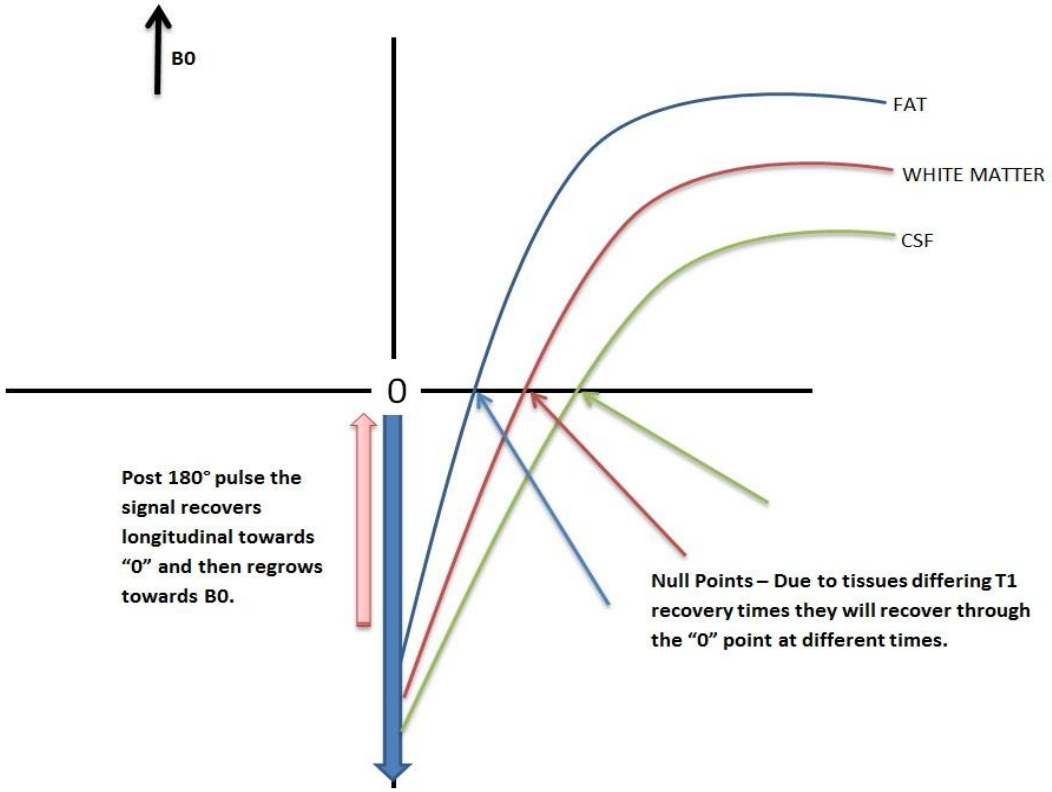
The purpose of the inverting pulse is to flip the initial longitudinal magnetisation (M0) of all tissues in the imaged slice or volume to point in the opposite direction of the main magnetic field (B0). The time interval between the initial 180° pulse and the 90° pulse allows for T1 relaxation to occur as the protons attempt to re-align with the B0 attraction. At the 90° pulse, spin echo signal generation commences however the transverse signals are now different due to the longitudinal magnetisations being different at the point of the 90° pulse. This occurs due to the intrinsic differences in tissue T1 relaxation times,[3] the amount of difference or separation between the tissues is governed by the TI parameter with other contrast effects coming from time to repetition (TR) and time to echo (TE).[3]

If a tissue's T1 recovery is at the "null point" when the 90° pulse is applied the longitudinal magnetisation of that tissue will be so small that it's subsequent transverse signal will be nullified or suppressed, which allows IR to suppress certain tissues such as fat, white matter and cerebrospinal fluid (CSF). For most tissues the equation: TI = T1 x 0.69 can be applied[4] to discover the "null point" of the tissue, with consideration that T1 values will alter based on B0, FSE (most common) apply extra 180° pulses altering the TI and tissue mix.



(Figure 2. Tissue differentiation based on T1 recovery.)

There are two reconstruction methods used for IR:

Magnitude reconstruction

Phase-corrected (sensitive) reconstruction

These reconstruction techniques can have a substantial effect on image contrast and appearance and will be discussed later within the article.

Advantages and Disadvantages of IR *(LO a & c)*

IR allows the radiographer to create contrast in unique and important ways:

a. Nullifying signal from tissue based upon its T1-value as described above in the introduction.
b. Superior differentiation of tissue due to T1 relaxation.
   Thanks to the initial 180° flip the tissues will go through twice the T1 relaxation of CSE/FSE. This means that small differences in tissue can be shown when compared with a standard CSE/FSE. (See figure 3)
c. Additive T1 and T2 effects.
   Most pathology has differing T1 and T2 values based upon their free fluid content which often differs from the surrounding tissue. In IR imaging when using short to medium TI values, an increase in T1 will result in increased signal intensity that adds to the positive signal effects due to increased T2. The reason for this is that when TI is less than that at the "null point" the magnetisation of the long T1 pathology will remain inverted and produce a high signal on magnitude reconstructed (most common) IR images.[4]

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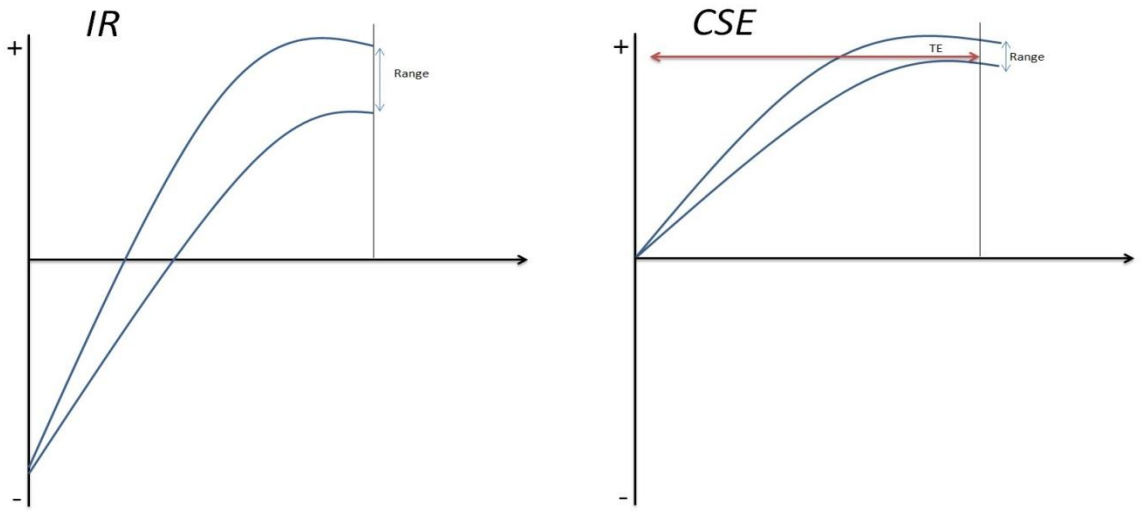
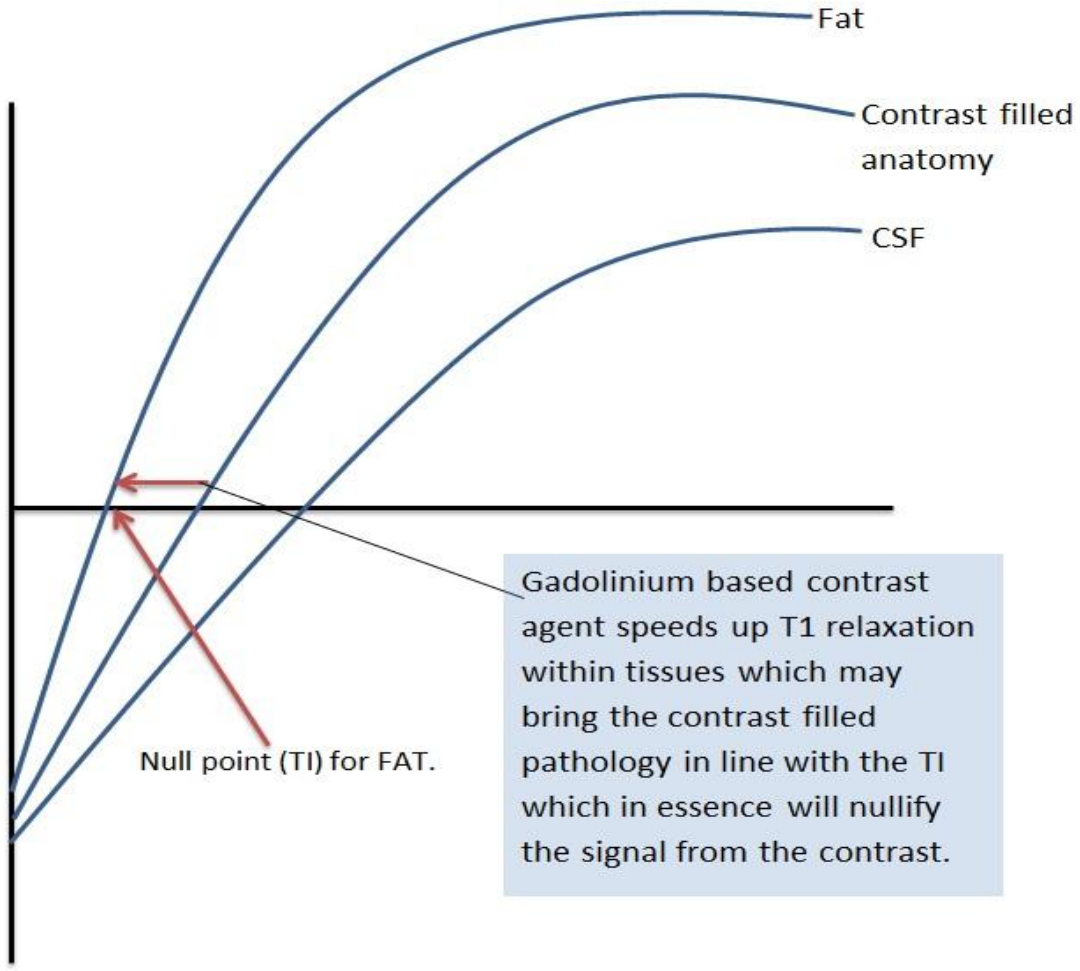


(Figure 3. Dynamic Range.)

IR Disadvantages

At this point in time IR sequences are integral to MRI scanning, they are intertwined into many departmental protocols and reporters of MRI images expect IR scans for certain pathologies. However IR does have some disadvantages:

1. Lengthened scan times.[3]
2. Increased artefact from flow.[3]
3. Increased SAR due to extra 180° pulses.[3]
4. IR sequences can nullify (in particular short TI) MRI contrast (gadolinium).[3]



(Figure 4. Gadolinium T1 and TI.)

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Choosing the TI *(LO a & b)*

The above sections highlight that the 180° pulse reverses the longitudinal magnetization for all tissues. The tissues then begin to re-grow via T1-relaxation seeking to restore their equilibrium with B0.

When the tissue has a longitudinal magnetisation near to 0 the tissue will produce little or no signal when the subsequent 90° pulse is applied.

Therefore by knowing the points at which tissues will recover through the "null point" allows the radiographer to nullify certain tissues, the following equations can be utilised when *e*-TR/T1 (TR controls T1-weighting) and in the case of FSE the last echo has impact on the overall image:

TI = T1 {In2 – In (1 + *e*-TR/T1)} for CSE

TI = T1 {In2 – In (1 + *e*-TR – TE final/T1)} for FSE

As described in the introduction the equation: TI = T1 x 0.69 can be utilised in most scenarios (TR>T1) however the equation is not perfect when considering FSE.[4]

Commonly utilised TI's in the more common FSE are:

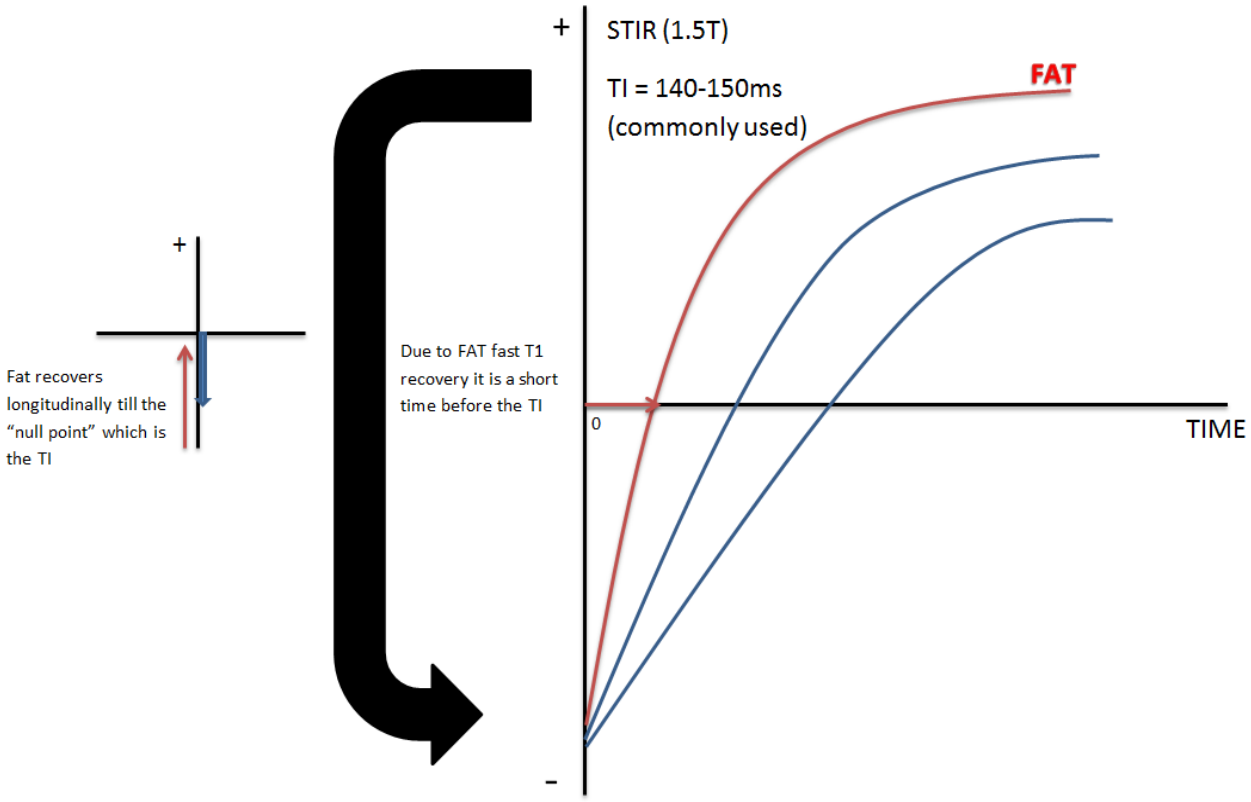
Tissue	TI at 1.5T(ms)	TI at 3T(ms)
Fat	140-155	150-180
White Matter	350-400	400-450
CSF (T2 imaging)	1800-2200	2000-2500
Grey Matter	610-650	650-700
Black Blood (60BPM)	630-650 (variable - automated)	650-680 (variable – automated)

(Table 1. Common TI points)

True TI's are often higher than utilised, due to all the variants possible TI's are lowered.

Short Tau Inversion Recovery (STIR) *(LO a, b & c)*

STIR is one of the most common IR scans, as it allows for homogenous fat suppression which is vital for ruling out pathology and allowing for easier contrast between fat and other tissues.[5] STIR has superior fat saturation when compared with spectral fat-sat in particular near metal artefacts, high susceptibility differences and across large field of views (FOV).



(Figure 5. STIR.)

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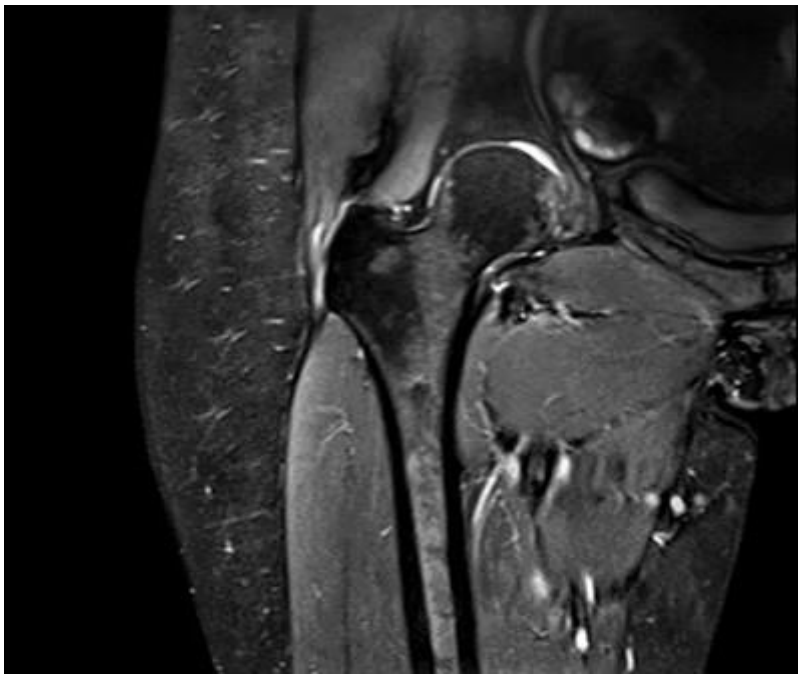
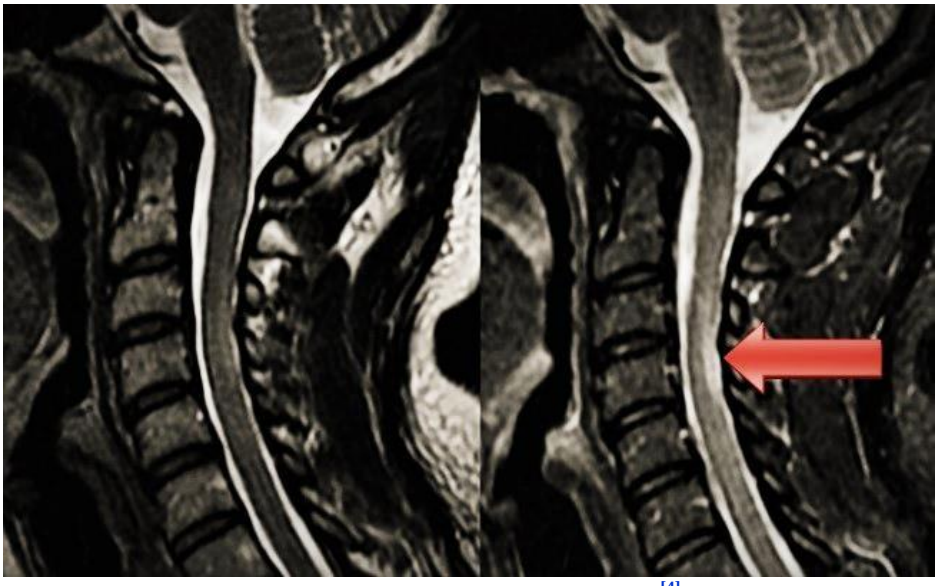


(Picture 1. STIR of hip.)[6]

Due to the STIR having a short TI it has the feature of additive T1-T2 contrast, T1 and T2 can have competitive effects on signal in conventional imaging, in short IR the longitudinal magnetisation of long T1 lesions remain inverted and help produce a high signal.



(Picture 2. Additive effects on STIR.)[4]

Fluid-attenuated Inversion Recovery (FLAIR) ***(LO a, b & c)***

CSF has a long intrinsic T1 value which is dependent on B0; in general CSF T1 values at 1.5 are between 2200-4000ms, the TI utilised is influenced by the TR. The FLAIR is commonly utilised in both T1 and T2 weighting guise[7]:

1. In T1-FLAIR the TR and TE are kept relatively short in an attempt to minimise T2-weighting, with this restricting the timeline of the sequence the TI for a T1-FLAIR is normally 850-1200ms (see Figure 6.) T1-FLAIR becomes highly important in stronger B0 (3T+) this is due to the increase in T1 causing anatomy close to CSF appearing more proton density (PD) weighted rather than T1.
2. In T2-FLAIR imaging TR and TE are often long to cause strong T2 weighting, TR's are often higher than standard T2 weighting imaging (8000+) allowing for the TI. The TI used in the T2-FLAIR is usually between 1800-2500ms. The T2-FLAIR allows for correct differentiation between lesions particularly in the brain, by removing the signal from CSF, MS plaques, periventricular and meningeal disease can be much easier to visualise.

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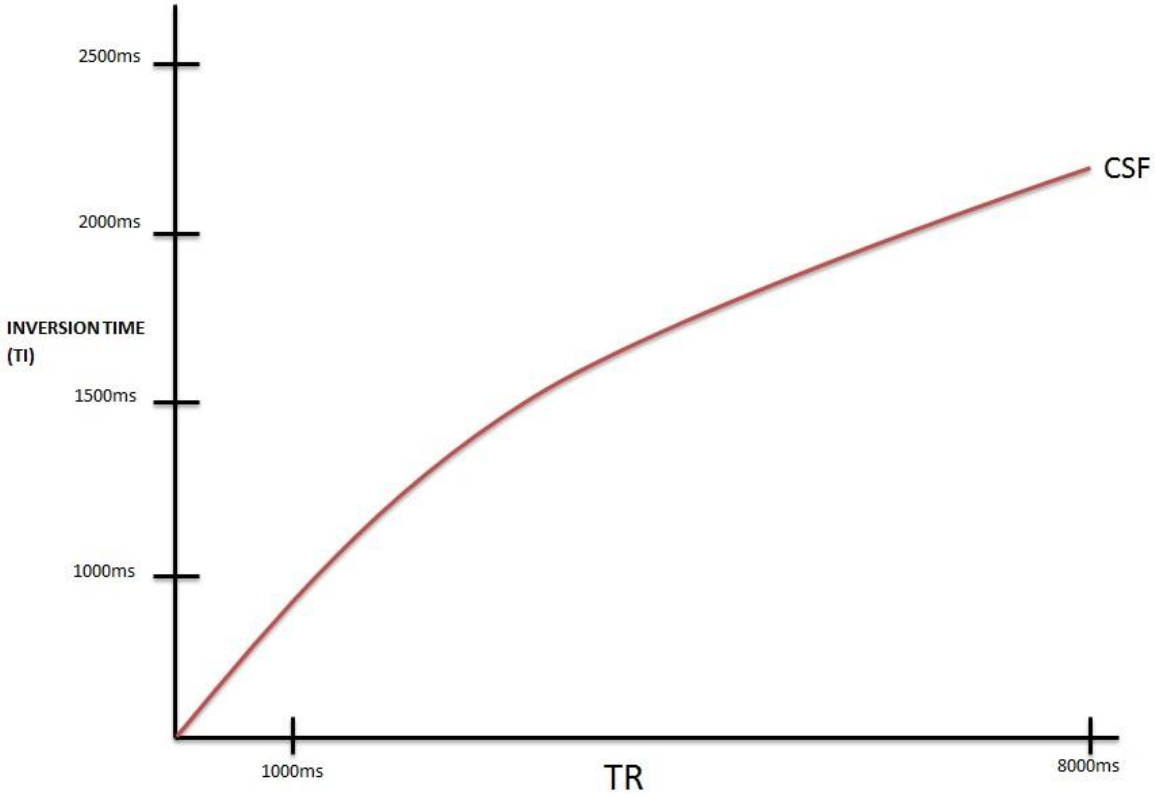
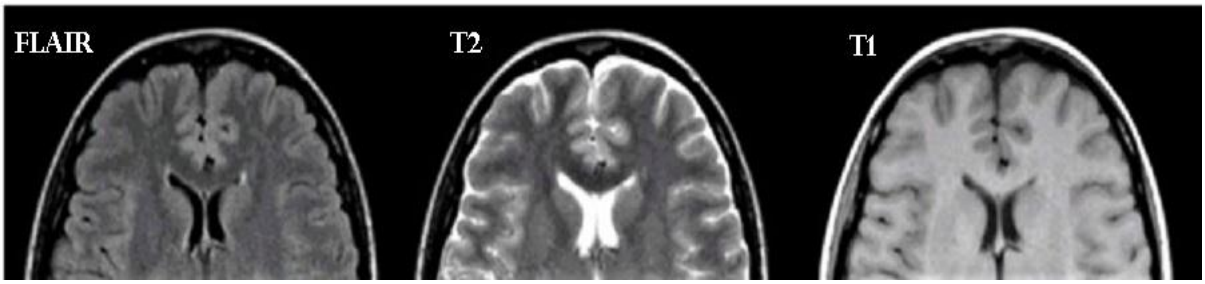
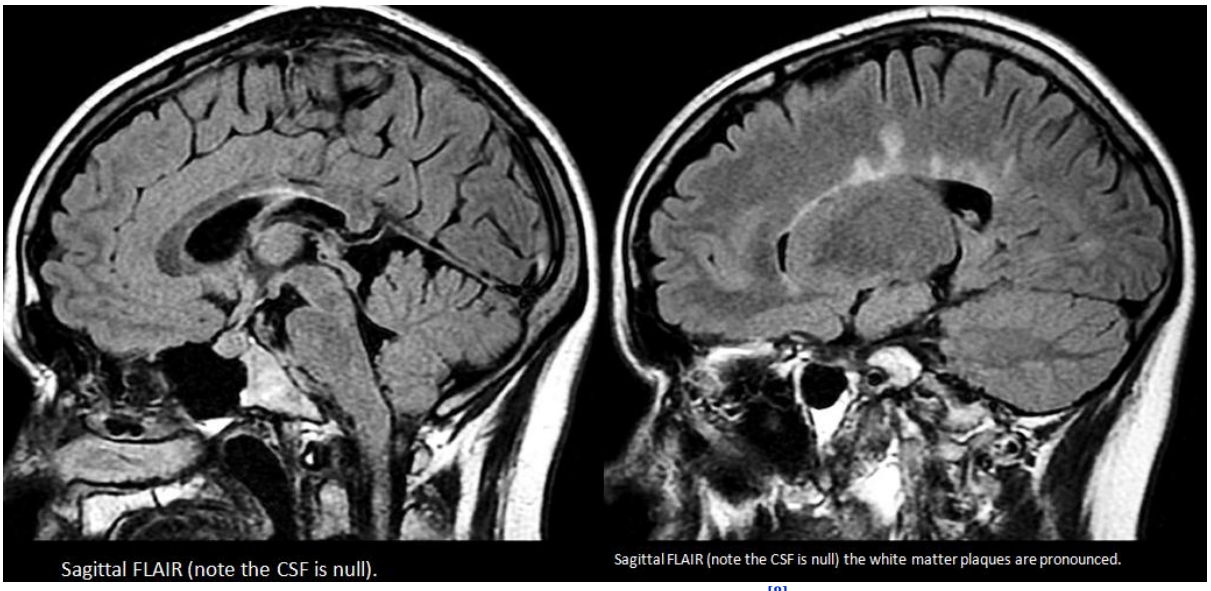


(Figure 6. TR/TI)



(Picture 3. FLAIR vs. T2 vs. T1.)



(Picture 4. FLAIR SAGITTAL.)[8]

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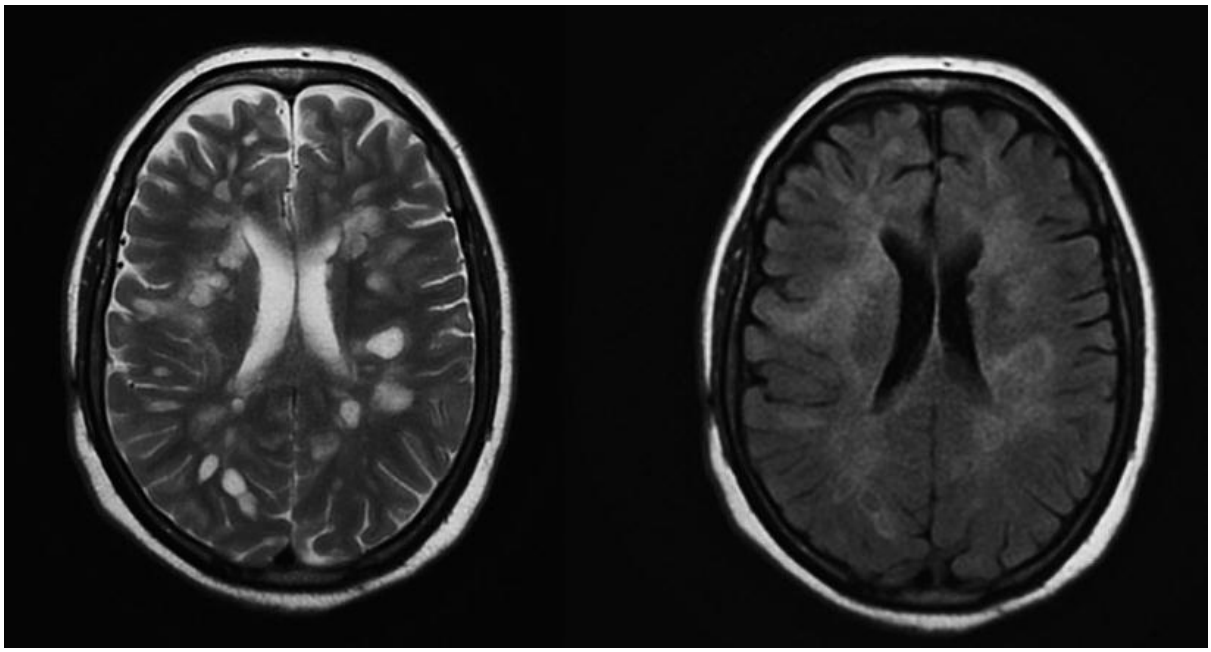
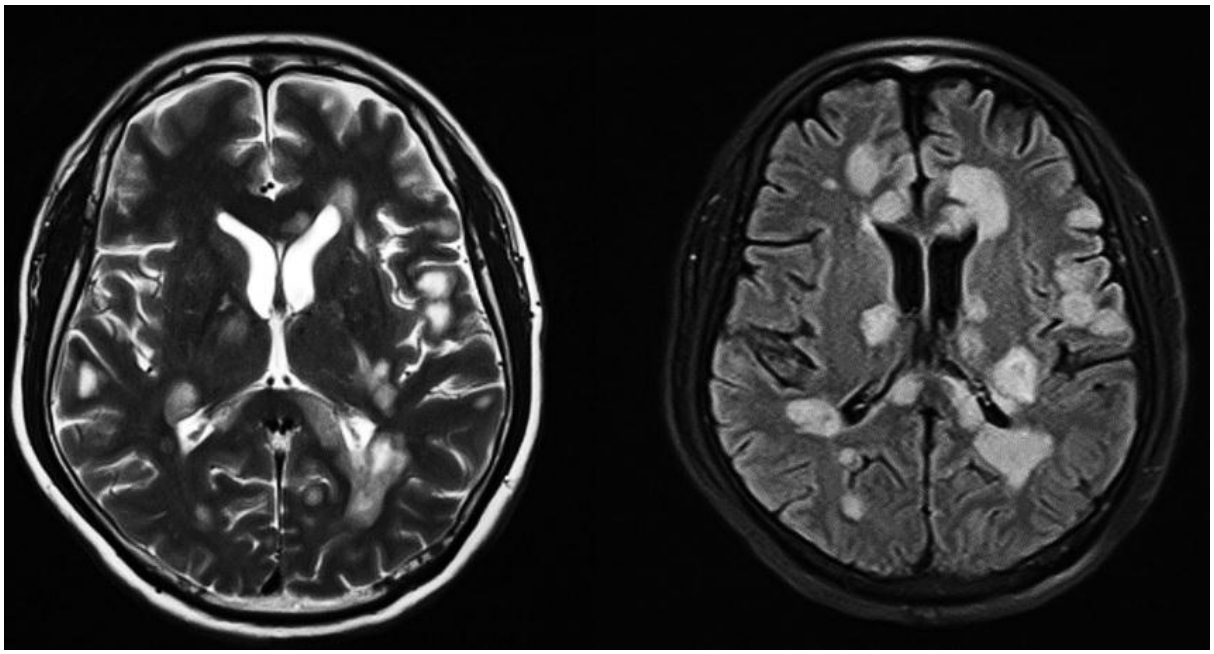


(Picture 5. FLAIR AXIAL.)[8]

In the above images (Picture 4 & 5) it is possible to see the nullifying affects of FLAIR on CSF, leaving the white matter plaques. This pattern is often noted as "Dawson's Fingers" and is a radiographic sign of MS. The below image (Picture 6) shows how utilising FLAIR can differentiate between CSF T2 weighted pathology and non-CSF pathology, the image shows a patient with radiographic signs of Acute disseminated encephalomyelitis (ADEM) which is an acute attack of widespread inflammation of the brain and spinal cord, affecting the myelin.[8]



(Picture 6. ADEM.)[8]

Magnitude Reconstruction (MRe) and Phase Sensitive Inversion Recovery (PSIR) ***(LO a, b, c & d)***

PSIR are distinguishable by their appearance with a grey background, some call this imaging "True Inversion Recovery". The majority of inversion recovery sequences utilise MRe and radiographers will be more accustomed to the image contrast.

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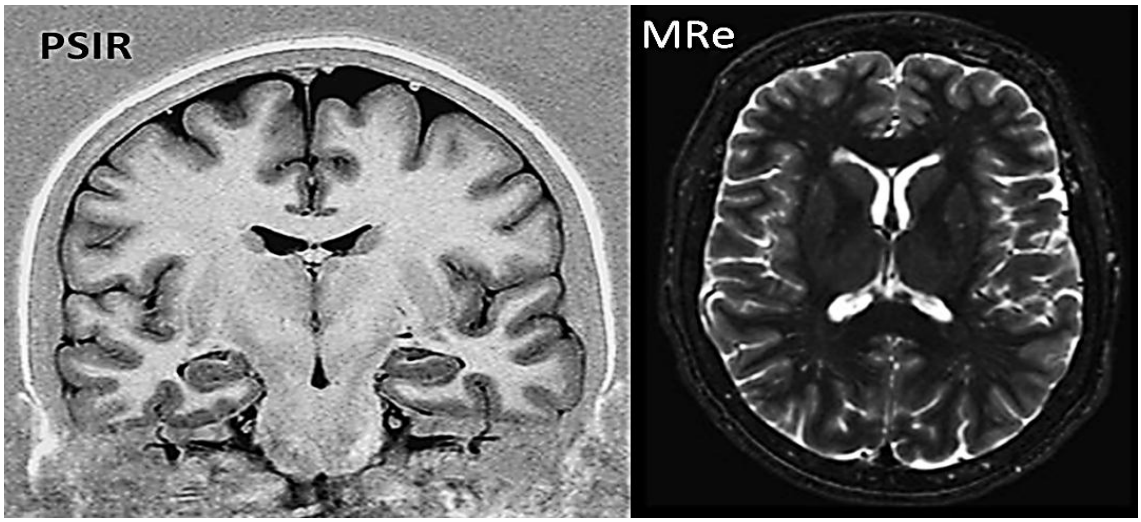


(Picture 7. PSIR vs. MRe.)[4]

MRe utilises the longitudinal component of magnetisation, the eventual rendering of pixels is dependent on the magnitude the longitudinal magnetisation, MRe makes air and any tissue at the 0 crossing point at TI black.

PSIR maintains the information from longitudinal magnetisation polarity, this gives a more grey scale affect with values rendered differently across the scale. Due to this PSIR actually provides more information when compared with MRe; however PSIR is more sensitive to phase error artefacts, longer scanning times and can require far more complex post-processing. MRe allows for selective nulling of tissues (STIR, FLAIR etc.) which is not the case for PSIR.[9]

Gradient Echo (GRE) IR-Prepped *(LO a, b, c & d)*

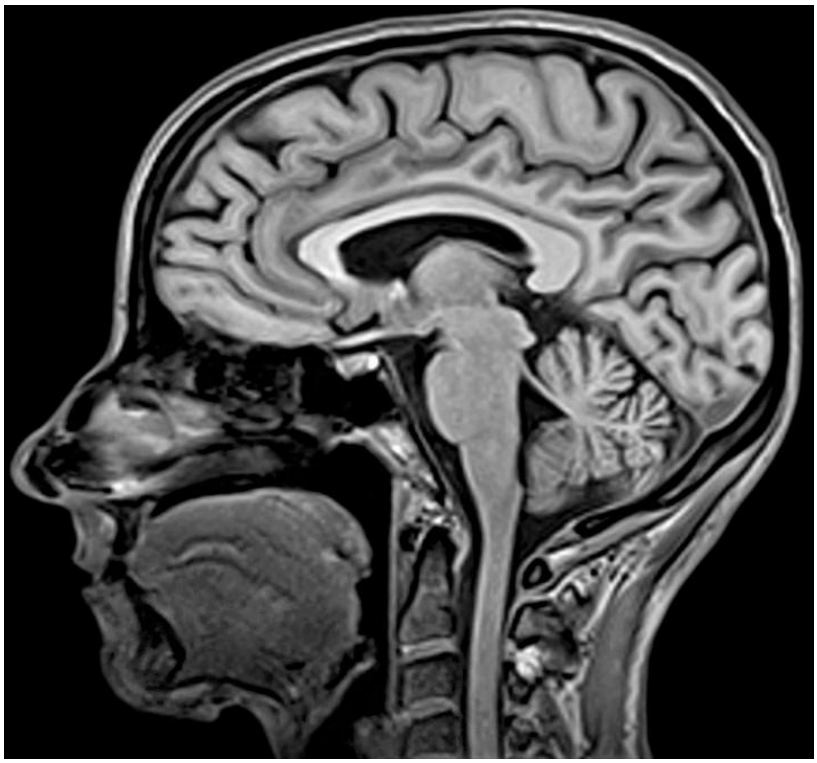
IR-prepped sequences utilise a 180° inversion pulse but unlike conventional IR it does not utilise FSE or CSE. We can break down a pulse sequence into three key areas:

Preparation - This is where certain aspects may take place before signal is acquired, this may be spectral fat-sat, flow saturation and inversion recovery.

Acquiring phase - This where the pulse sequence begins from, I.E GRE, FSE, CSE etc.

Recovery phase – A period of no signal generation however certain software alterations may kick in.

When we apply an IR before a spoiled GRE we create different contrasts and these can be seen in sequences such as MP-RAGE (BRAVO).[4]



(Picture 8. MP-RAGE TI 900.)[6]

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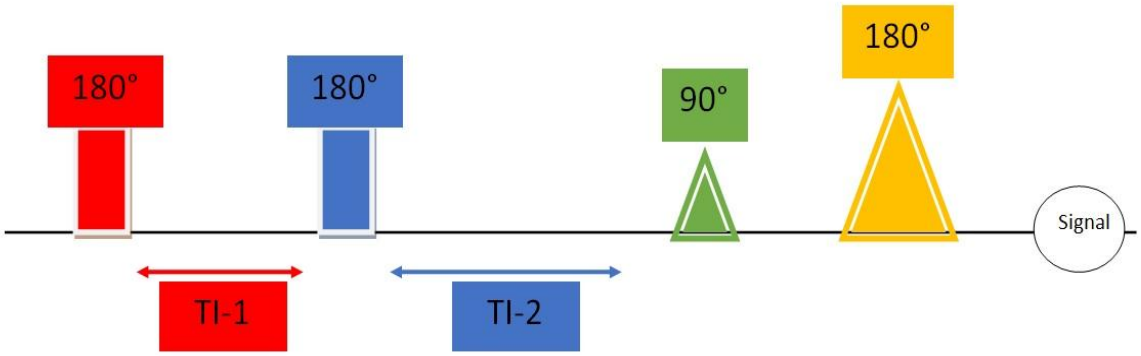
More than one IR? ***(LO a, b, c & d)***

It is possible that a sequence has more than on TI, these are often denoted as TI-1, TI-2 and so on, and this is handy when two or more contrasts need to be suppressed for specific pathology.



(Figure 7. Two TI's.)

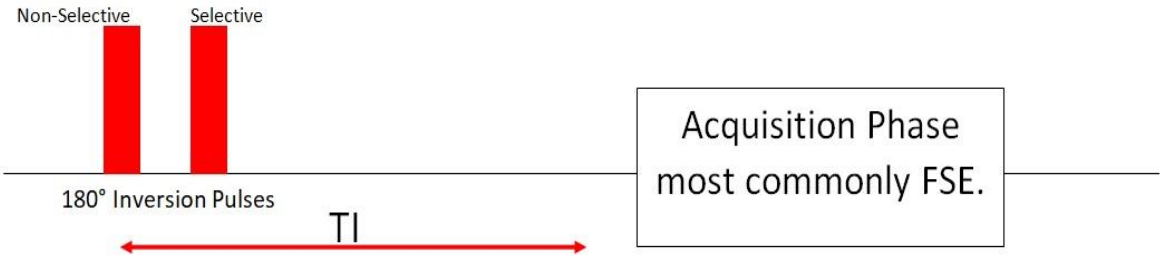
An example of utilising two TI's (DIR) would be when a radiographer may want to suppress both CSF and white matter; this can be helpful in distinguishing pathologies within the cerebellum and for locating MS plaques.

Most multiple IR pulses are utilised in cardiac/vessel imaging, the term "black blood" is a technique utilising two TI's useful for visualising the walls of cardiac chambers, major blood vessels and have been a MRI gold standard for coronary artery imaging. The sequence uses two inversion pulses in close succession and a trigger (ECG), the 1st pulse being non spatially selective meaning all spins become inverted with the second pulse being selective to the single slice being imaged, meaning that the second pulse restores longitudinal magnetisation for blood and the myocardium within the slice being imaged.

As the sequence continues two events occur:

1. Blood that has remained inverted recovers longitudinally towards B0, and therefore passing the "null point".
2. This blood which has flow replaces the blood within the imaged slice, therefore the TI is picked so that it is at or near the 0 point at the point of acquisition. This is determined by the strength of B0 and the pulse rate of the patient, most current scanners have an automatic TI in "black blood" imaging.

As in most IR sequences FSE is the most commonly utilised with a relatively short effective TE, however GRE and echo planar imaging (EPI) may also be utilised.



(Figure 8. Black Blood.)

Due to the variables within DIR imaging long scan times and artefacts may become an issue, slower pulse rates increase the TI and of course will have knock on affect to TR, newer scanners have had updates that allow for quicker imaging however in the past DIR of a coronary artery could have taken up to 15 minutes to image.[10]

It is possible to add further IR pulses creating triple (TIR) and even quadruple (QIR) pulse sequences, these again are utilised in cardiac and vessel imaging. One simple addition is to fat sat the above "black blood" sequence, in essence adding a STIR.

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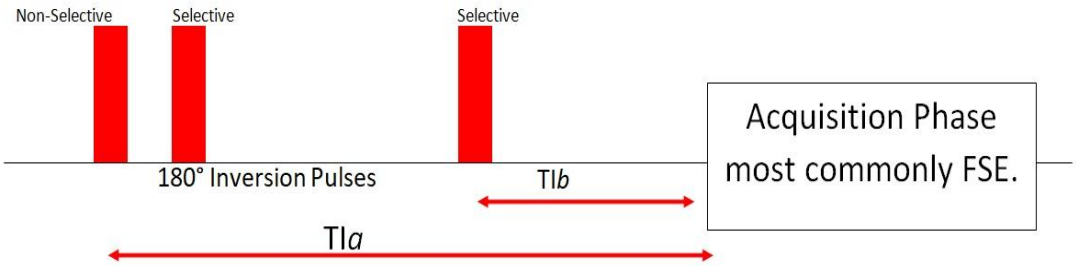


(Figure 9. Black Blood + STIR.)

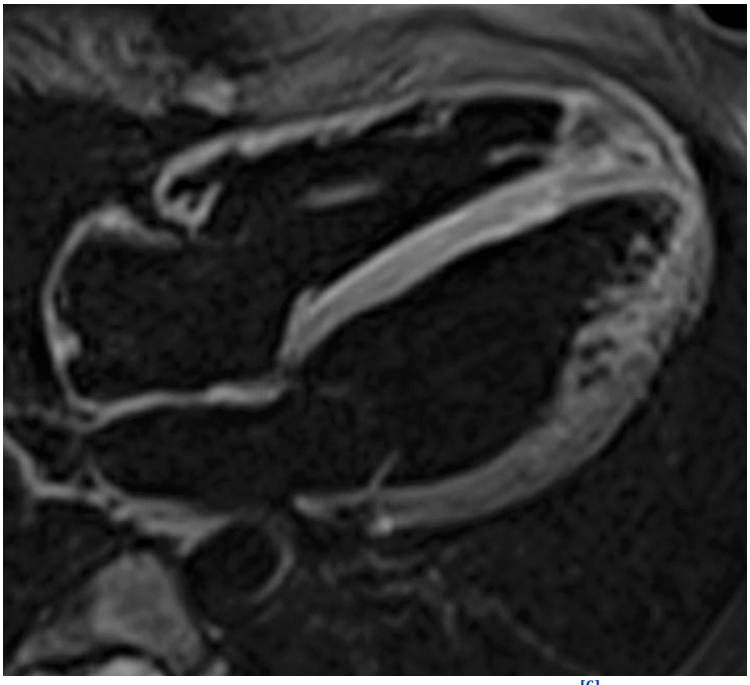
In the above figure (Figure 9.) the initial two inversion pulses (TI*a*) are responsible for nullifying the signal from blood with the second inversion pulse (TI*b*) nullifying the signal from fat. The complexity in this is added due to making TI*a* successful when TI*b* is taken into account, TI*b* nulls the signal of fat but also re-inverts the inflowing blood magnetisation. Therefore TI*a* must have a longer value then it would have been for a standard DIR.

QIR may sound like overkill, however this is one those times where contrast administration (CA) is used in conjunction with IR, the "black blood" method of imaging is utilised with the administration of contrast. It utilises two DIR pulses both having a non-selective and slice-selective pulses as shown in figure 8.[11][12] Time intervals within the sequence utilise an algorithm based upon the minimisation of the T1 range occurring in blood before and after CA, QIR is non sensitive to the variations in T1 and can provide suppression of flow signal, it is often used to find specific pathologies such as:

Atherosclerosis

Aortoiliac disease

General cardiovascular disease



(Picture 9. T2 Cardiac FS Black Blood.)[6]

CONCLUSION

In conclusion it is clear that IR is a vital part of a MRI radiographer/operators tool set, whilst most modern scanners allow for automated parameters, software automation and ease of use it is important for the operator to understand to some extent the physics, limitations and usages of IR. As stated in the aim this paper does not delve into depth of more specific applications of IR such as cardiac imaging, DIR, TIR, QIR and the usage of IR prepped SP/GRE as these are best explained in depth in their own separate papers.

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