

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ



MRI Sequences: From Contrast to Clinical Decision-Making

A practical guide for radiology technologists

By:

Elahe Hoseini
Neuroimaging Ph.D. Candidate of
Isfahan University of Medical Sciences (IUMS)

INTRODUCTION

Why does the same tissue look so different in different sequences?

- ✓ Each sequence probes a different tissue property — T1 relaxation, T2 decay, diffusion, susceptibility
- ✓ The sequence we choose defines what we see — **and what we may miss**
- ✓ Goal:
 - ❖ a practical framework — *appearance* → *clinical use* → *limitations*

OUTLINES

What is an MRI sequence?

1

Contrast weighting

2

Core sequence families

3

Specialized sequences

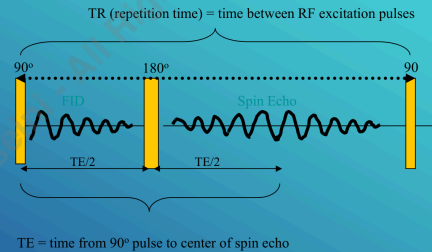
4

Q & A

5

MRI Pulse Sequences

SPINE ECHO(SE) : The basic principle



Spin Echo: Advantages & Limitations

Pros

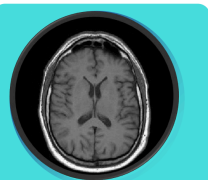
- ✓ Relatively insensitive to magnetic field inhomogeneity
- ✓ Less susceptible to susceptibility-related signal loss than GRE
- ✓ Provides reliable T1- and T2-weighted contrast
- ✓ Widely used in routine clinical imaging

Cons

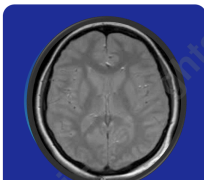
- Longer acquisition time than gradient echo techniques
- Higher RF energy deposition (higher SAR)
- Less suitable when very rapid imaging is required

Common uses: routine brain, spine, and musculoskeletal imaging

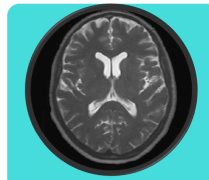
Spin Echo Contrast: T1, PD, and T2



T1W:
best for anatomy
post-contrast imaging



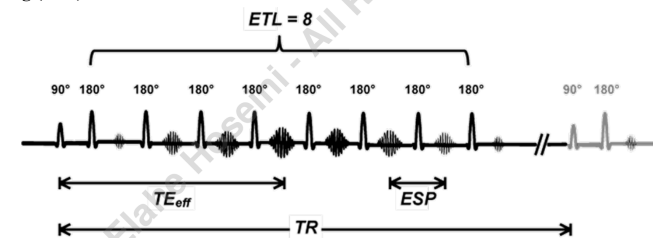
PD W :
structural detail
selected MSK
neuro applications



T2 W:
edema
inflammation
lesions

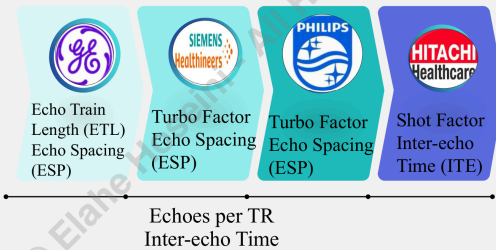
Fast/Turbo Spin Echo (FSE/TSE):

- Accelerating acquisition by acquiring multiple echoes (lines of K-space) per TR interval.
- **Effective TE (TE_{eff})**: The TE at which the central lines of K-space (which dictate image contrast) are encoded.
- **Echo Train Length (ETL) / Turbo Factor**: The number of 180° refocusing pulses per TR.
- **Higher ETL** = Shorter scan time.
- **Echo Spacing (ESP)**: Time interval between consecutive echoes

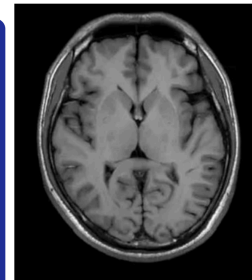


FSE Implementation: Terminology & Clinical Impact

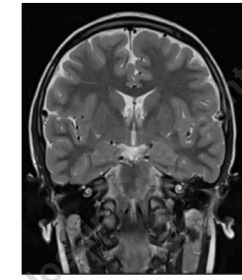
- High ETL: Leads to image blurring (due to T2 decay across the echo train) and increases SAR (RF heating).
- J-coupling disruption: Fat remains bright on T2-weighted FSE (unlike conventional SE), often requiring fat-saturation pulses.



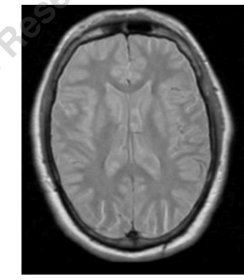
Clinical Weighting & Parameters



T1W FSE



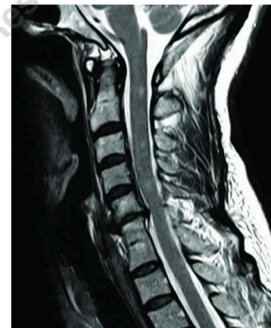
T2W FSE



PDW FSE

The Balance: Advantages, Artifacts & Limitations

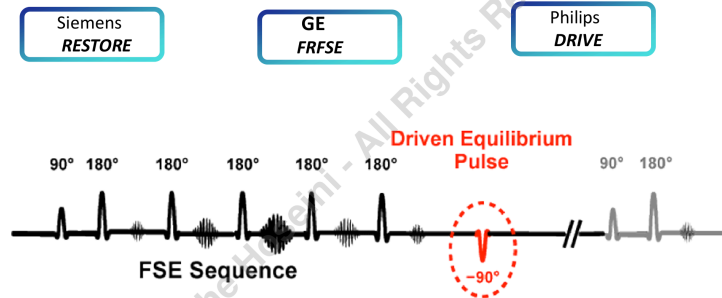
- 1 Significantly reduced scan time.
- 2 Reduced magnetic susceptibility artifacts (Great for metal implants).
- 3 Increased Matrix / High-resolution imaging



The Balance: Advantages, Artifacts & Limitations

- 1 **Blurring:** Due to T2 decay in long ETL → *Remedy: Decrease Echo Spacing.*
- 2 **Bright Fat on T2:** Due to J-coupling disruption → *Remedy: Use Fat Saturation.*
- 3 **High SAR:** Due to multiple 180° pulses → *Remedy: Reduce ETL or increase TR.*
- 4 **Normal disks appear darker on T2W.**

Driven Equilibrium *Fourier Transform*



13

SE Families

Artifacts

Special Families

GRE Families

IR Families

SE Families

HASTE / Single-Shot FSE: Rapid T2-Weighted Imaging

Acquires most or all of the required k-space data after a single excitation.

Uses a long echo train with partial-Fourier sampling

Produces heavily T2-weighted images with very short acquisition times.

Particularly useful when motion is expected.

GE/ HITACHI: (SS-FSE)

Philips: (SSH-TSE)



14

SE Families

Artifacts

Special sequences

GRE Families

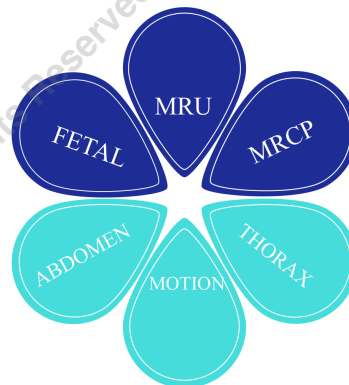
IR Families

SE Families

HASTE

Key Trade-offs and indications

Very fast acquisition
Lower spatial resolution
Blurring with long echo trains
Potential SNR and susceptibility limitations
RF power/SAR considerations



15

SE Families

IR Families

GRE Families

Special sequences

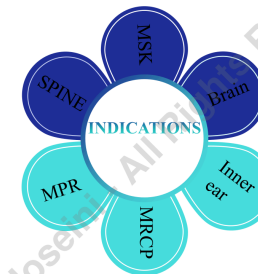
Artifacts

Q & A

3D Fast Spin Echo: Core Concept

A 3D fast spin echo technique optimized for isotropic imaging

Enables thin-section high-resolution datasets



Long echo train
Variable flip angles
Parallel imaging / partial Fourier

Vendor names: SPACE (Siemens), CUBE (GE), VISTA (Philips), isoFSE (Hitachi)



16

SE Families

IR Families

GRE Families

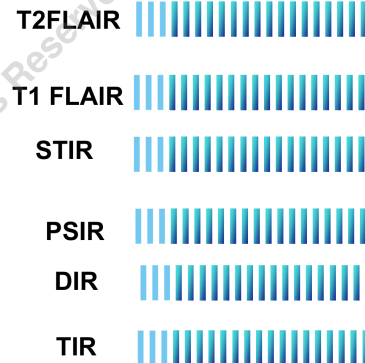
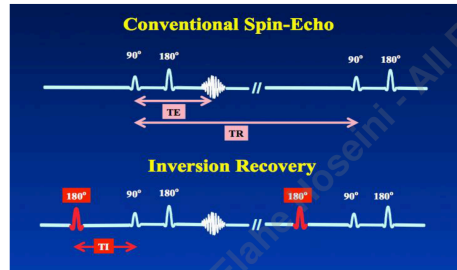
Special sequences

Artifacts

Q & A

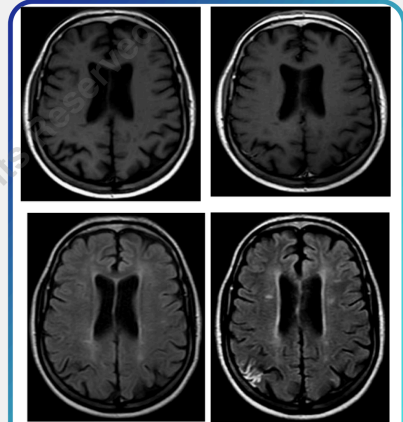
Inversion Recovery: Core Principle

- ✓ Starts with a **180° inversion pulse**
- ✓ After the **inversion time (TI)**, excitation and signal readout occur
- ✓ Selecting TI can **null the signal of a target tissue**
- ✓ IR is used for **contrast manipulation and selective tissue suppression**



T2 FLAIR: Clinical Use

- ✓ Suppresses CSF signal to improve lesion conspicuity near the ventricles and cortical sulci
- ✓ Part of most routine brain MRI protocols
- ✓ Highly useful for detecting subtle abnormalities in:
 - Multiple sclerosis
 - Infarction
 - Subarachnoid hemorrhage
 - Head trauma
 - Post-contrast FLAIR is sensitive to low-concentration gadolinium and is valuable for leptomeningeal disease such as meningitis



Female patient aged 36 years, known case of multiple sclerosis on follow up, presented by clinical signs of activity.

T1 FLAIR: Clinical Use

Typical appearances

MS plaques: hypointense

Cerebral infarction: hypointense

Brain and spinal cord tumors: variable signal, often iso- to hypointense

Hemorrhage: may appear hyperintense depending on stage and blood products

Neurodegeneration / atrophy: regional volume loss with dark signal replacement

Syringomyelia: hypointense fluid-filled cavity



STIR: Short-TI Inversion Recovery Core mechanism and limitations

•An inversion-recovery sequence that suppresses fat by exploiting its relatively short, field-dependent **T1 relaxation time**.

•More tolerant of **B0/B1 inhomogeneity** than frequency-selective fat suppression.

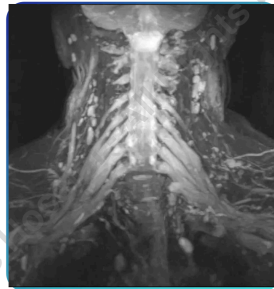
•Useful for large fields of view, off-center anatomy, and regions affected by susceptibility or metallic hardware.



- Avoid conventional STIR for evaluating gadolinium enhancement.
- Signal penalty
- Non-specific suppression

STIR: Short-TI Inversion Recovery indications

3D STIR: MRN
(MR neurography)



- MSK:** bone-marrow edema-like signal, occult fractures, osteomyelitis, and soft-tissue inflammation.
- Orbit and peripheral nerves:** useful when uniform suppression of surrounding fat improves lesion conspicuity.
- Spine:** trauma, tumor, infection
- Body and whole-body MRI:** protocol-dependent applications including inflammatory and oncologic assessment.

Other Fat Suppression Techniques: Choosing the Right Method

Technique	Principle	Clinical Indication	Clinical Limitation
CHESS / FatSat	Frequency-selective saturation	Routine imaging (Brain, Spine) where fast acquisition is needed.	Highly sensitive to field inhomogeneity ; poor results near metal or large FOV.
SPIR & SPAIR	Hybrid (Spectral + Inversion)	When high SNR and more robust fat suppression is needed (e.g., Breast, Body).	More complex to optimize; slightly longer scan times than standard FatSat.
Dixon	Water-fat phase separation	Challenging areas (Neck, Extremities) or post-Gd imaging where FatSat fails.	Requires complex post-processing; sensitive to patient motion between echoes.



SE Families

IR Families

GRE Families

Special sequences

Artifacts

Q & A

21



SE Families

Fat suppression

GRE Families

Special Sequences

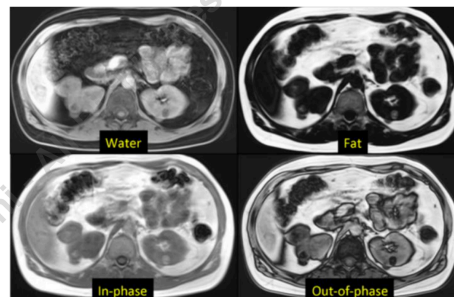
Artifacts

Q & A

22

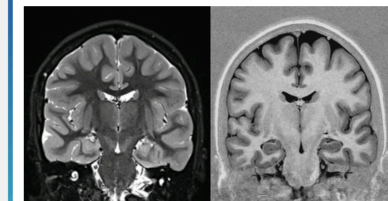
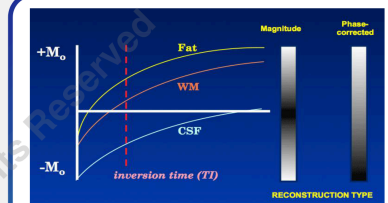
Other Fat Suppression Techniques: Choosing the Right Method

A practical disadvantage of Dixon imaging is that the acquisition usually requires two or more echoes, which may increase the minimum TR, echo-train duration, or reconstruction complexity. Nevertheless, Dixon techniques have become one of the most important and widely used approaches for modern water-fat separation.



Phase-sensitive inversion recovery (PSIR)

- ✓ a specialized technique used that enhances image quality by improving the contrast of the images.
- ✓ It's particularly useful in cases where precise differentiation of tissues is required, such as in **cardiac imaging** or in the **detection of lesions in the brain**.



SE Families

Fat Suppression

GRE Families

Special Sequences

Artifacts

Q & A

23



SE Families

IR Families

GRE Families

Special sequences

Artifacts

Q & A

24

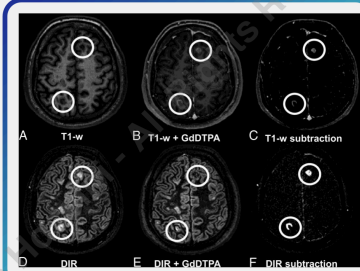
DIR & TIR: Multi-Inversion Techniques

DIR (Double Inversion Recovery):

Uses two 180° pulses to null two tissues (e.g., CSF + WM); superior for detecting subtle cortical MS plaques.

TIR (Triple Inversion Recovery):

Adds a third 180° pulse to null three tissue types simultaneously; provides maximum background suppression.

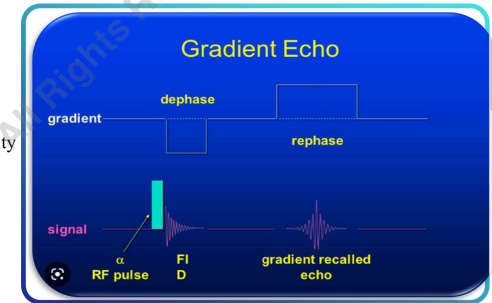


Clinical Utility:

- Neurology (MS lesions)
- Cardiovascular imaging ("black-blood" myocardium contrast).

Gradient Echo: How Is the Echo Generated?

- Variable flip-angle RF excitation
- No 180° refocusing pulse
- Gradient reversal generates the echo
- Fast acquisition, but high sensitivity to field inhomogeneity

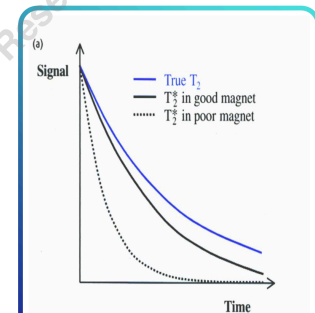


Spin Echo vs gradient Echo

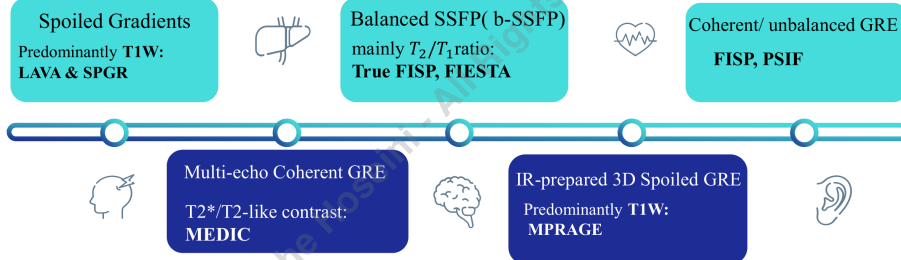
Feature	Spin Echo (SE)	Gradient Echo (GRE)
Echo formation	180° RF refocusing pulse	Gradient reversal
Contrast	T1, T2, PD	T1, PD, $T2^*$
Main parameters	TR and TE	TR, TE, and flip angle
Field inhomogeneity	Relatively less sensitive	Highly sensitive
Acquisition speed	Usually slower	Usually faster

$T2^*$ -Weighted GRE

- GRE signal decays according to $T2^*$, not true $T2$
- $T2^*$ reflects both spin-spin relaxation and local field inhomogeneity
- Susceptibility-sensitive: blood products, iron, calcium, air, and metal
- Important applications: hemorrhage, microbleeds, iron deposition, and SWI



GRE Families: Practical Classification



SPGR: A T1-Weighted Spoiled Gradient-Echo Sequence

Siemens: FLASH
GE: SPGR / FSPGR
Philips: Spoiled TFE or Turbo Field Echo

Indications

- Dynamic Imaging
- Angiography
- Abdominal Imaging
- Cardiac Imaging

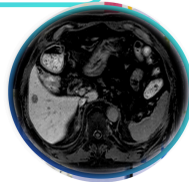
Basis for many **3D T1-W GRE** techniques

Short TR
Short TE
An appropriate flip angle
And often fat suppression

VIBE / LAVA: 3D T1W Spoiled GRE for Body MRI

Sequence Type

- 3D T1-weighted spoiled GRE sequence
- Short TR, short TE, and fat suppression or Dixon-based fat-water separation
- Optimized for rapid volumetric imaging before and after gadolinium administration

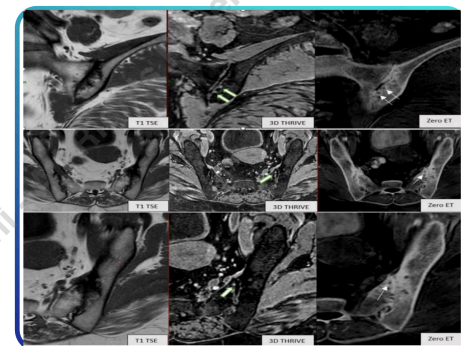


Vendor-Specific Names

- ✓ Siemens: VIBE — Volumetric Interpolated Breath-hold Examination
- ✓ GE: LAVA / LAVA-Flex — Liver Acquisition with Volume Acceleration
- ✓ Philips: THRIVE / e-thrive
- These are clinically comparable implementations of 3D spoiled T1-weighted GRE, although their technical details are not identical.

3D THRIVE MRI

Added value of 3D THRIVE MRI pulse sequence in the detection of bony erosions of sacroiliac joints in patients of spondyloarthritis

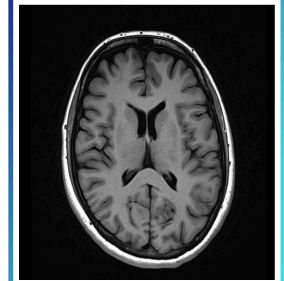


MPRAGE and MP2RAGE: Advanced 3D T1-Weighted Brain Imaging

❖ **MPRAGE** (*Magnetization Prepared Rapid Gradient Echo*) is an **inversion-recovery-prepared 3D spoiled GRE** sequence.

❖ **MP2RAGE** (*Magnetization Prepared 2 Rapid Acquisition Gradient Echo*) acquires two GRE readouts at **two different inversion times**.

•**Siemens: MPRAGE and MP2RAGE**
 •**GE: BRAVO** — an IR-prepared 3D SPGR sequence, conceptually similar to MPRAGE
 •**Philips: 3D IR-TFE / TFE-IR** — IR-prepared 3D GRE implementation



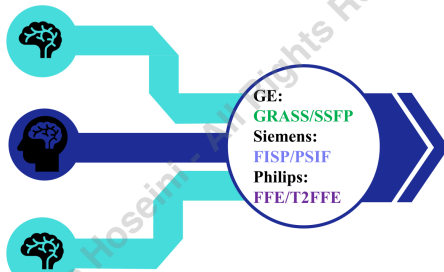
MPRAGE and MP2RAGE: Clinical Applications

- ✓ High-resolution **3D T1-weighted brain anatomy**
- ✓ **Volumetry**, cortical thickness analysis, and automated tissue segmentation
- ✓ Evaluation of brain atrophy in **multiple sclerosis**, dementia, epilepsy, and neurodegenerative disorders
- ✓ Pre-surgical, stereotactic, and radiotherapy treatment planning
- ✓ Post-contrast assessment of tumors, metastases, inflammation, and meningeal enhancement

FISP and PSIF: Coherent Steady-State GRE

FISP — Fast Imaging with Steady-State Precession
 A coherent GRE sequence in Siemens terminology.

PSIF — Reversed FISP
 PSIF reads a different echo pathway than FISP and is more sensitive to **diffusion, flow, and motion**.



- ✓ **MR neurography**
- ✓ It is most commonly incorporated into DESS for high-resolution 3D cartilage imaging—particularly of the knee.

PSIF: Specialized Applications & DW-SSFP

Diffusion-Weighted SSFP (DW-SSFP):
 Leverages multi-TR pathways to achieve high diffusion weighting with **very short TE**.

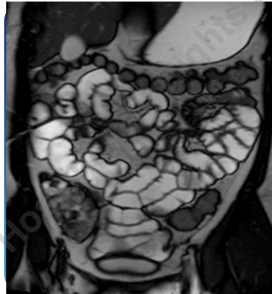
Clinical/Research Focus:
 Ultra-high-resolution **tractography** and MRI-histology validation in neurodegenerative research.
Peripheral Nerves

High-resolution **cartilage morphology**.
Combined FISP+PSIF:
DESS (Siemens)
MENSA (GE)

Balanced SSFP (bSSFP): Bright Fluid and Bright Blood Imaging

Principle

- All gradient moments are balanced within each TR, preserving transverse magnetization in a steady state.
- Signal is mainly related to the T_2/T_1 ratio; therefore, fluids and blood appear bright.



Vendor Names

Siemens: True FISP

GE: FIESTA

Philips: bTFE / balanced-FFE

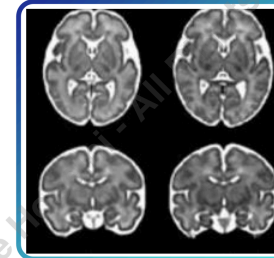
Balanced SSFP (bSSFP): Bright Fluid and Bright Blood Imaging

Clinical Applications and Advantages

Fast acquisition with high SNR and excellent blood/fluid–soft tissue contrast.

Major applications include

- cardiac cine MRI
- MRCP
- joint imaging
- fetal MRI
- abdominal/pelvic



Limitations

- ❑ Highly sensitive to B_0 inhomogeneity and off-resonance effects, which may cause **banding artifacts**—particularly at 3T, near air–tissue interfaces, and around metallic implants.
- ❑ It is useful for MRCP, but does not fully replace heavily T2-weighted FSE sequences.



SE Families

IR Families

GRE
FAMILIES

Special
sequences

Artifacts

Q & A



SE Families

IR Families

GRE
FAMILIES

Special
sequences

Artifacts

Q & A

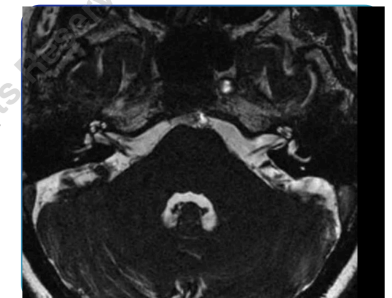
CISS: High-Resolution 3D BSSFP Imaging



- **CISS (Constructive Interference in Steady State)** is Siemens' high-resolution 3D balanced SSFP technique.
- It typically combines acquisitions with different phase-cycling schemes to reduce banding artifacts and improve CSF–nerve contrast.

CISS: Key Clinical Applications

- ✓ CPA and IAC imaging
- ✓ Cranial nerves, especially **CN VII and VIII**
- ✓ Small vestibular schwannomas and CPA lesions
- ✓ Trigeminal neuralgia and **neurovascular compression**
- ✓ Inner ear anatomy: cochlea, labyrinth, and semicircular canals
- ✓ CSF pathways, aqueductal stenosis, intraventricular cysts, and selected CSF leaks
- ✓ AVM in Spinal cord



SE Families

IR Families

GRE
Families

Special
sequences

Artifacts

Q & A



SE Families

IR Families

GRE
Families

Special
sequences

Artifacts

Q & A

CISS vs PSIF: Practical Comparison

Feature	CISS	PSIF
GRE family	3D balanced SSFP	Coherent / unbalanced steady-state GRE
Main contrast	High CSF-nerve contrast	Sensitive to diffusion, flow, and motion
Primary target	Cranial nerves within CSF	Peripheral nerves, roots, and plexuses, cartilage
Typical use	CPA, IAC, trigeminal nerve, inner ear	MR neurography, radiculopathy, plexopathy
Main limitation	Banding artifact / off-resonance	Motion, flow sensitivity, and protocol dependence



SE Families

IR Families

GRE Families

Special Sequences

Artifacts

Q & A

41

MEDIC: Multi-Echo Data Image Combination



Sequence Type

Siemens-specific **2D multi-echo coherent GRE** sequence. Multiple echoes are acquired and combined, providing **T2*-weighted / T2-like contrast**, improved SNR, and good tissue-edge definition.

Key Imaging Features

High anatomical edge definition
Good CSF-cord and cartilage-fluid contrast
Improved SNR through multi-echo combination
Relative sensitivity to susceptibility and B_0 inhomogeneity



Main Clinical Applications

Spine: spinal cord, CSF-cord interface, neural foramina, nerve roots, and disc-osteophyte complex
Musculoskeletal MRI: cartilage, menisci, tendons, ligaments, and fine joint anatomy
Inner ear: selected protocols for fine fluid-soft-tissue interfaces and labyrinthine anatomy



SE Families

IR Families

GRE Families

Special Sequences

Artifacts

Q & A

42

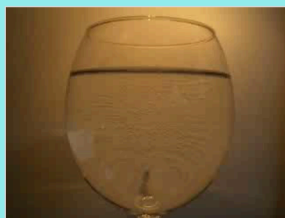
Diffusion-Weighted Imaging (DWI): Basic Principle

DWI measures the random Brownian motion of water molecules within tissue.

Diffusion-sensitizing gradients cause signal loss in freely diffusing water; tissues with **restricted diffusion remain hyperintense on high-b-value DWI**.

Diffusion weighting is controlled by the **b-value**:

$$S(b) = S_0 e^{-b \cdot ADC}$$



SE Families

IR Families

GRE Families

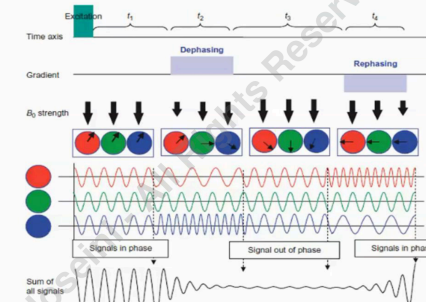
Special sequences

Artifacts

Q & A

43

DWI Dephase-rephase experiment by gradient application



- Red, green, and blue circles indicate three water molecules located at different positions.
- Thick arrows indicate the strengths of magnetic field strength (B_0).
- Narrow arrows indicate phases of MR signals from each molecule.



SE Families

IR Families

GRE Families

DWI

Artifacts

Q & A

44

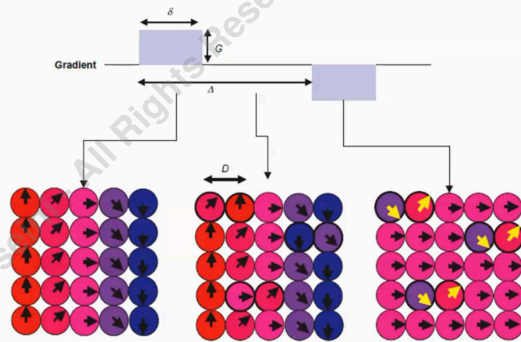
b-value

B value measures the degree of diffusion weighting applied, thereby indicating the amplitude (G), time of applied gradients (δ) and duration between the paired gradients (Δ) and is calculated as:

$$b = \gamma^2 G^2 \delta^2 (\Delta - \delta/3)$$

Therefore, a larger b value is achieved by increasing the gradient amplitude and duration and by widening the interval between paired gradient pulses.

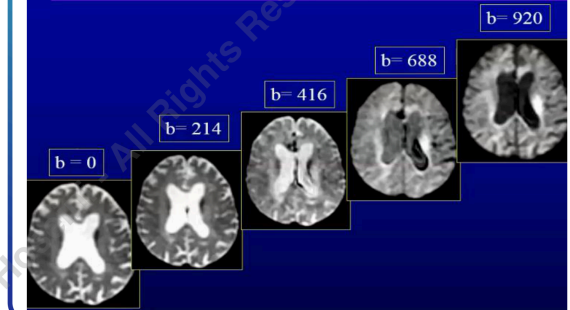
Parameters affecting results of diffusion weighting



b-value

T2 shine-through refers to a high signal on DWI images that is not due to restricted diffusion, but rather to a high T2 signal which 'shines through' to the DWI image. T2 shine through occurs because of long T2 decay time in some normal tissue.

Diffusion-Weighted-Imaging Physics



SE Families

IR Families

GRE Families

DWI

Artifacts

Q & A



SE Families

IR Families

GRE Families

DWI

Artifacts

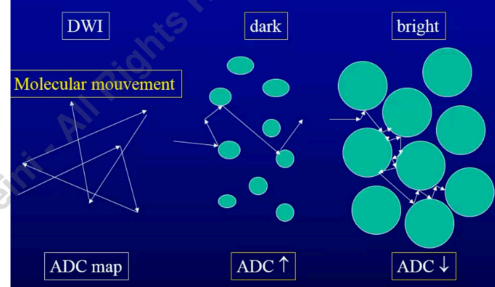
Q & A

The **Apparent Diffusion Coefficient (ADC)** map helps distinguish true restricted diffusion from **T2 shine-through**:

True restriction: High signal on DWI + low signal on ADC

T2 shine-through: High signal on DWI + normal/high signal on ADC

Diffusion-Weighted-Imaging Physics



DWI: Main Clinical Applications

Acute ischemic stroke

- Early detection of cytotoxic edema, often within minutes of symptom onset
- Identification of infarct core and evaluation of stroke distribution

Abdominal, pelvic, and musculoskeletal MRI

- Liver, pancreas, kidney, prostate, uterus, ovaries, and lymph-node assessment
- Bone-marrow lesions, metastases, and inflammatory processes

Oncology and infection

- Tumor detection
- cellularity assessment
- treatment response
- whole-body MRI
- Identification of abscesses and differentiation from necrotic tumors
- Detection of cholesteatoma and selected inflammatory lesions



SE Families

IR Families

GRE Families

DWI

Artifacts

Q & A



SE Families

IR Families

GRE Families

DWI

Artifacts

Q & A

RESOLVE: Readout Segmentation Of Long Variable Echo-trains

Siemens-specific readout-segmented EPI (rs-EPI) DWI technique. (Philips: Msh-DWI)

Instead of acquiring all k-space data in one long EPI readout, RESOLVE divides the readout into multiple shorter segments. Shorter echo trains reduce:

- ❖ Geometric distortion
- ❖ Susceptibility artifacts
- ❖ Image blurring
- ❖ T2* signal decay

Advantages and Clinical Applications

Higher spatial resolution and improved anatomical fidelity compared with single-shot EPI

Brain: skull base, posterior fossa, orbit, temporal bone, and small lesions

Head and neck: tumor staging, lymph nodes, salivary glands, and nasopharynx

Spine: spinal cord, vertebral marrow, and epidural lesions

Prostate and pelvis: improved lesion localization when distortion is problematic

❑ ZOOMit: Reduced Field-of-View DWI

- ✓ Uses 2D spatially selective RF excitation to excite only the region of interest.
- ✓ A smaller field of view permits: Shorter EPI readout
- ✓ Reduced geometric distortion
- ✓ Reduced susceptibility artifacts
- ✓ Higher in-plane spatial resolution

Vendor Names

Siemens	ZOOMit
GE	FOCUS
Philips	ZOOM

Major Clinical Applications

Prostate MRI: improved visualization of peripheral-zone and transition-zone lesions
Head and neck MRI: tongue, oral cavity, larynx, hypopharynx, and neck nodes

Spinal cord MRI: cervical cord, conus medullaris, and focal cord lesions

Breast MRI: selected high-resolution diffusion protocols

Rectal and gynecologic MRI: local tumor staging and pelvic lesion assessment



SE Families

IR Families

GRE
FAMILIES

DWI

Artifacts

Q & A



SE Families

IR Families

GRE
Families

DWI

Artifacts

Q & A

SWI: Susceptibility-Weighted Imaging

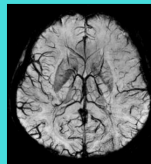
- Combining magnitude and phase to reveal what conventional GRE cannot
- SWI is a **long-TE, high-resolution GRE** technique that acquires both **magnitude** and **phase** images.
- The phase image preserves information about **local field changes**.
- A **phase mask** is created and multiplied (typically raised to the power of 4) into the magnitude image.
- This enhances the contrast of **paramagnetic** substances such as deoxyhemoglobin, hemosiderin, ferritin, and iron.

GE: SWAN,

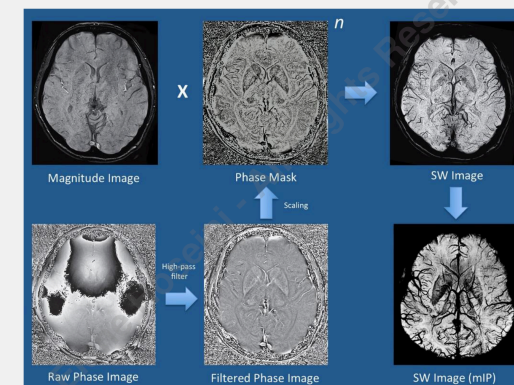
Siemens: **SWI with mIP**

Philips: VenBOLD, SWIp

All generate a **minimum intensity projection (mIP)** to better visualize veins and microbleeds.



SWI: Susceptibility-Weighted Imaging



SE Families

IR Families

GRE

SWI

Artifacts

Q & A



SE Families

IR Families

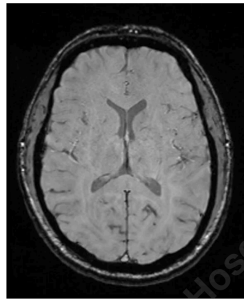
GRE

SWI

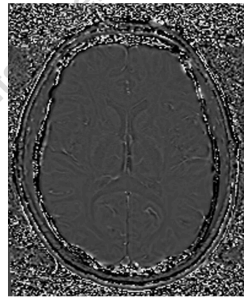
Artifacts

Q & A

SWI: Susceptibility-Weighted Imaging



SWI:
MAGNITUDE IMAGE



SWI: PHASE IMAGES



SE Families

IR Families

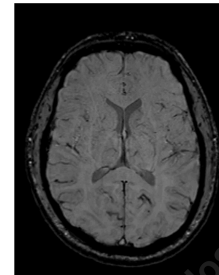
GRE

SWI

Artifacts

Q & A

SWI: Susceptibility-Weighted Imaging



SWI: MAGNITUDE+ PHASE
IMAGE



SWI: (MAGNITUDE + PHASE)
MIN IP IMAGES



SE Families

IR Families

GRE

SWI

Artifacts

Q & A

SWI: Clinical Applications & Limitations

- ✓ Microbleeds and CAA (more sensitive than T2*-GRE)
- ✓ Hemorrhagic transformation and DAI
- ✓ Cavemoma, venous malformations, and Developmental Venous Anomaly (DVA)
- ✓ Iron deposition in Parkinson's disease and neurodegenerative disorders
- ✓ Multiple Sclerosis: **Central Vein Sign (CVS)** and **rim lesions**
- ✓ Non-contrast evaluation of cerebral veins

- Longer scan time than simple GRE.
- High sensitivity to motion and dental artifact at the skull base.
- Phase interpretation requires experience; Iron, calcium, and blood can produce similar signal; differentiation may require CT or QSM.



SE Families

IR Families

GRE

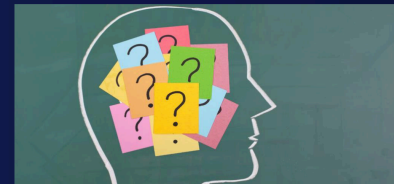
SWI

Artifacts

Q & A



56



از حسن توجه شما عزیزان
متشکرم...

پاسفکوی سوالات شما هستم

© Elahe Hoseini - All Rights Reserved