SSSR
Swiss Society of
Musculoskeletal Radiology

MRI Metal Artifact Reduction

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University of Zurich

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EXPERTISE IN MOTION

OUTLINE

Metal Artifact Reduction
Basics and Protocol Optimization

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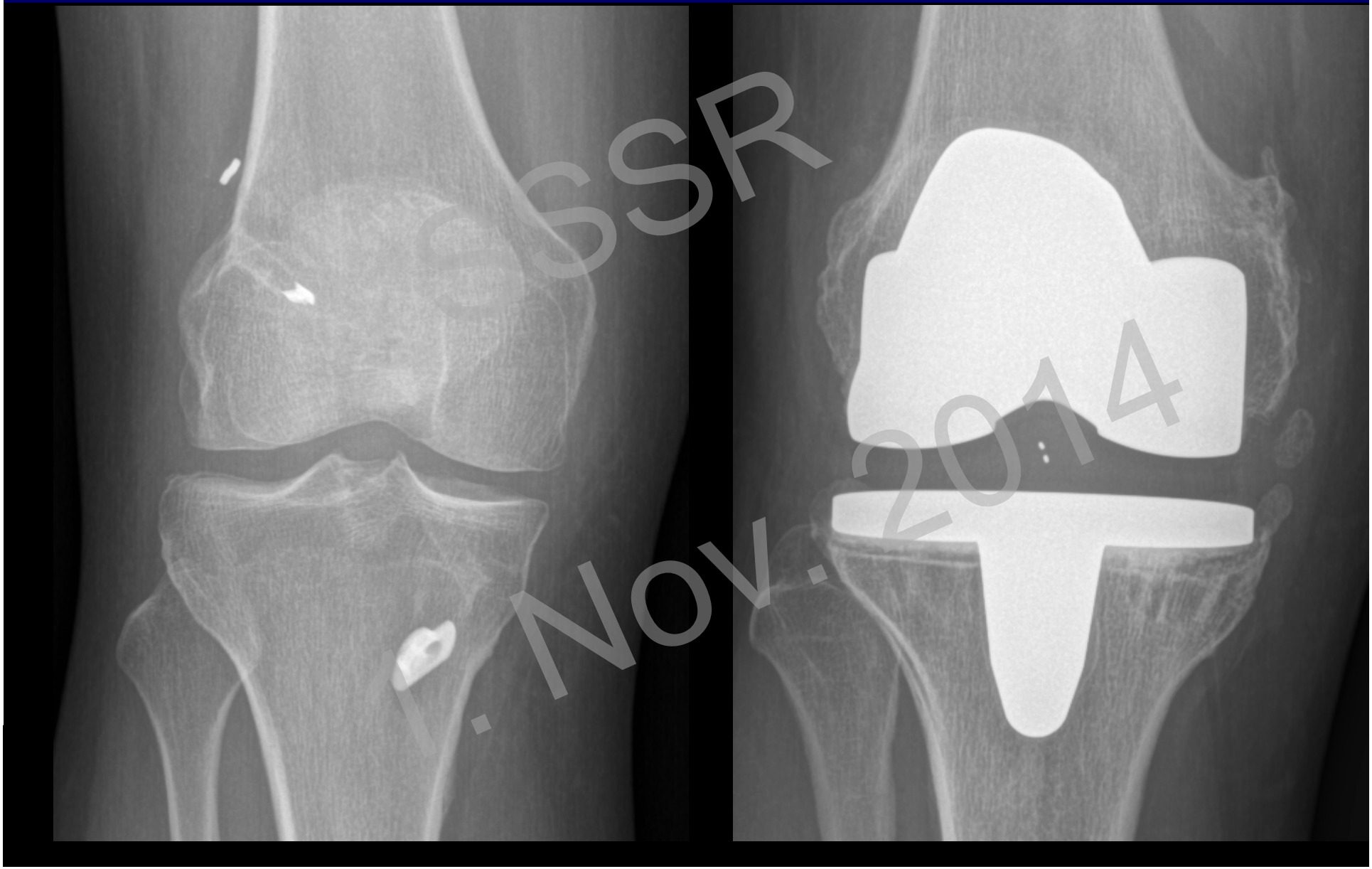
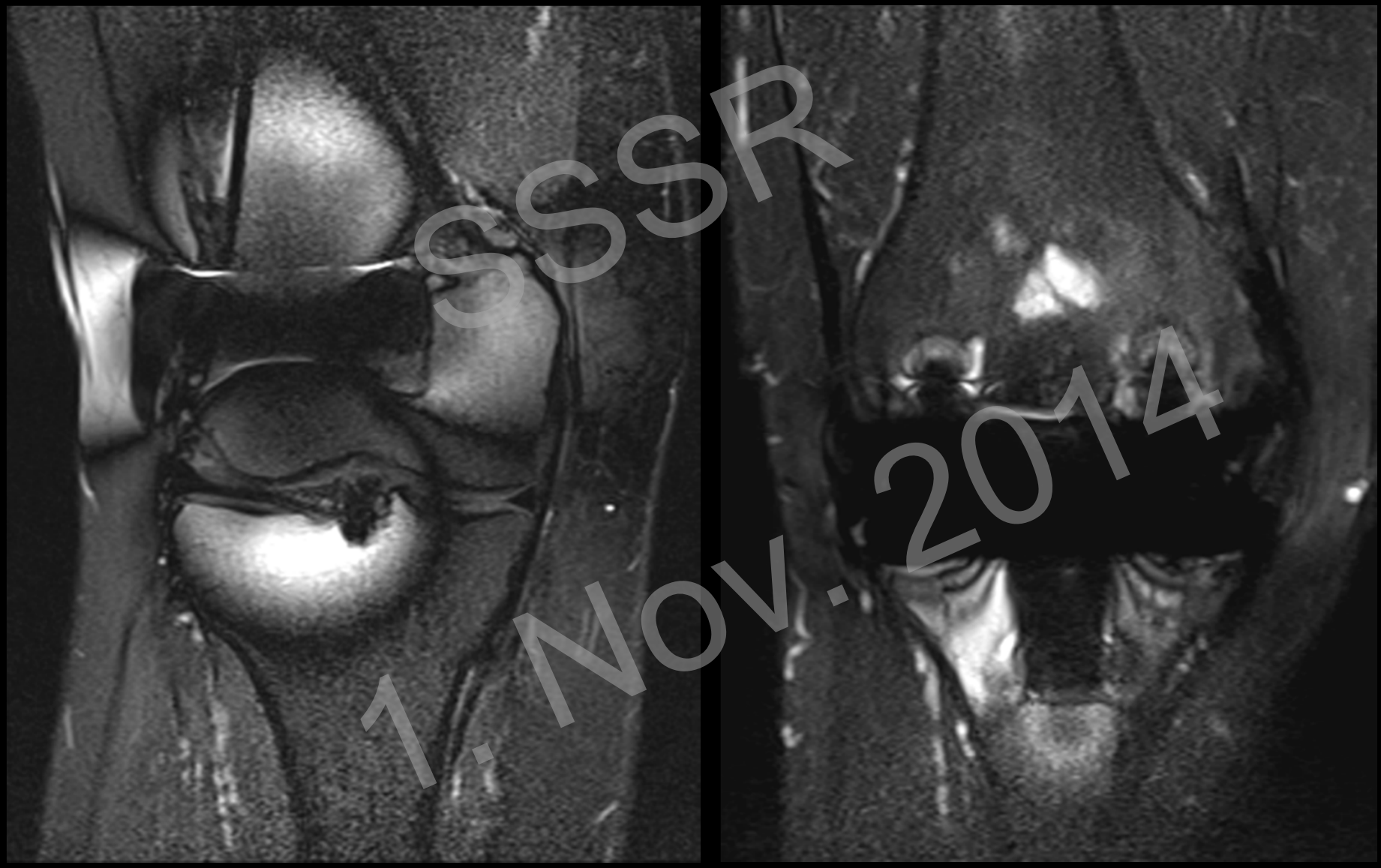
Metal artifact reduction



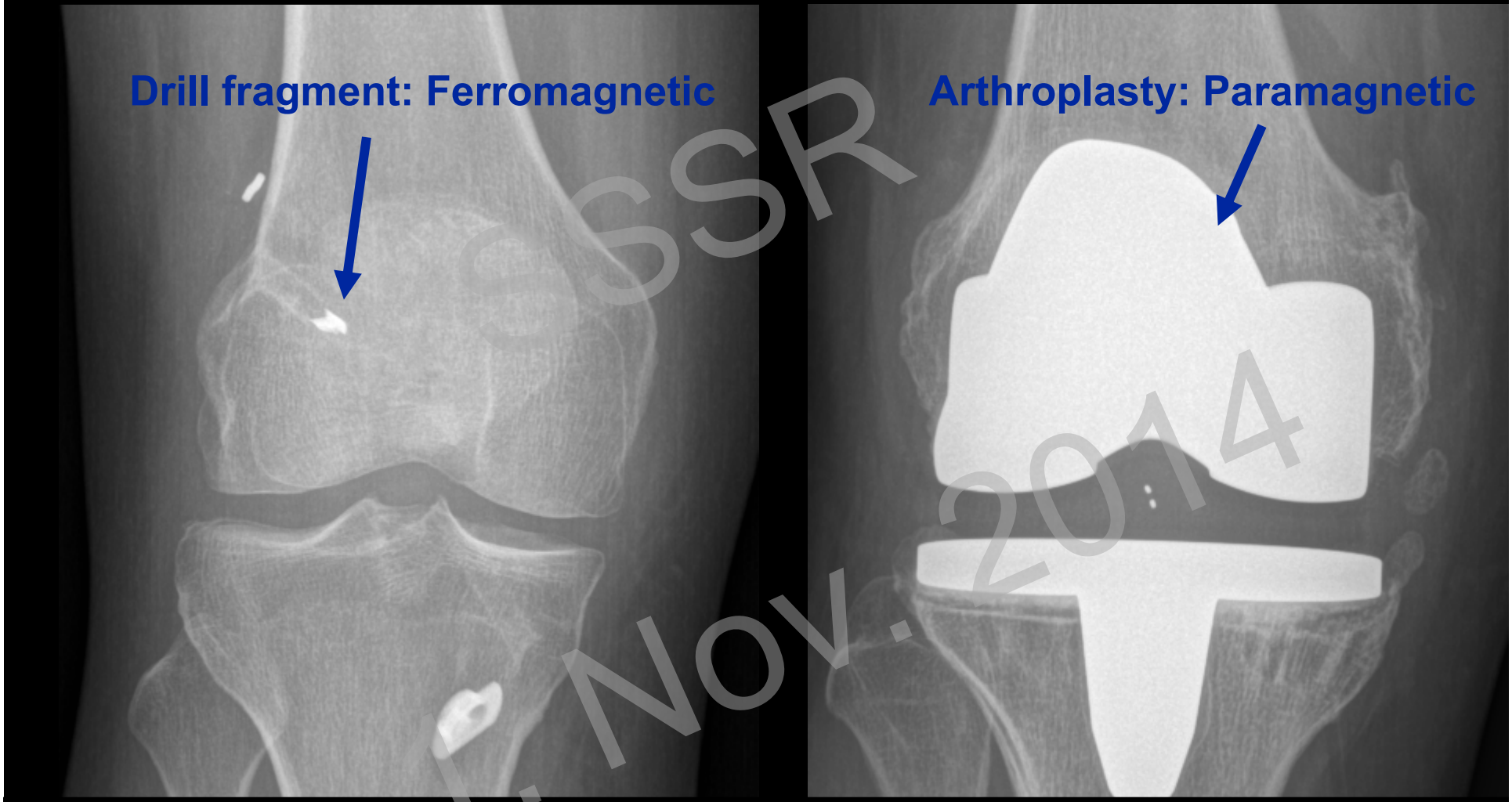
Is this Patient suitable for MR Imaging?



Magnetic Susceptibility

- **Diamagnetic materials** slightly oppose the applied magnetic field
  - Calcium, water, and most organic materials
- **Paramagnetic materials** slightly enhance the local magnetic field
  - Titanium, some blood degradation products, gadolinium contrast
- **Ferromagnetic materials** substantially augment the external magnetic field
  - Iron, cobalt, and nickel

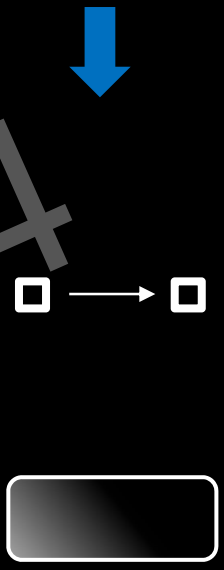
Is this Patient suitable for MR Imaging?



Metal artifacts at MRI

Predominant types of artifacts

- **Signal loss** (due to spin dephasing)
- **Geometric distortion and Displacement artifacts** (due to frequency variations; can induce signal loss and pile-up)
- **Insufficient fat suppression** (due to frequency variations)

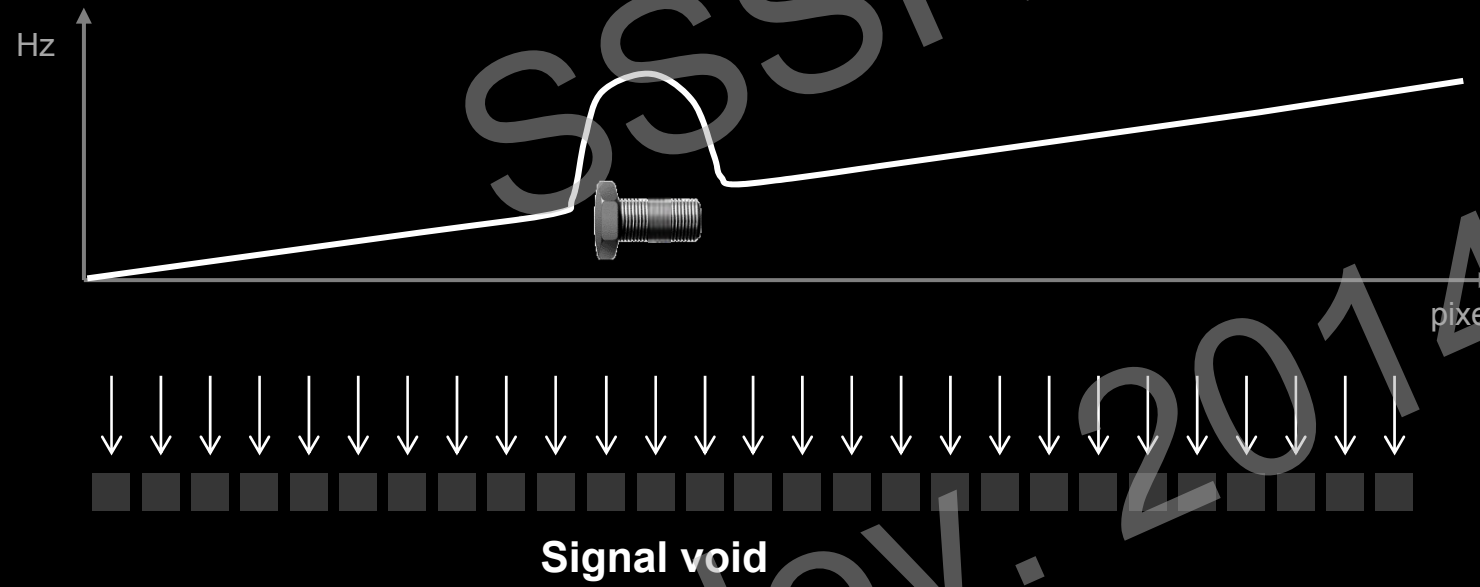


Metal artifacts at MRI

Signal displacement

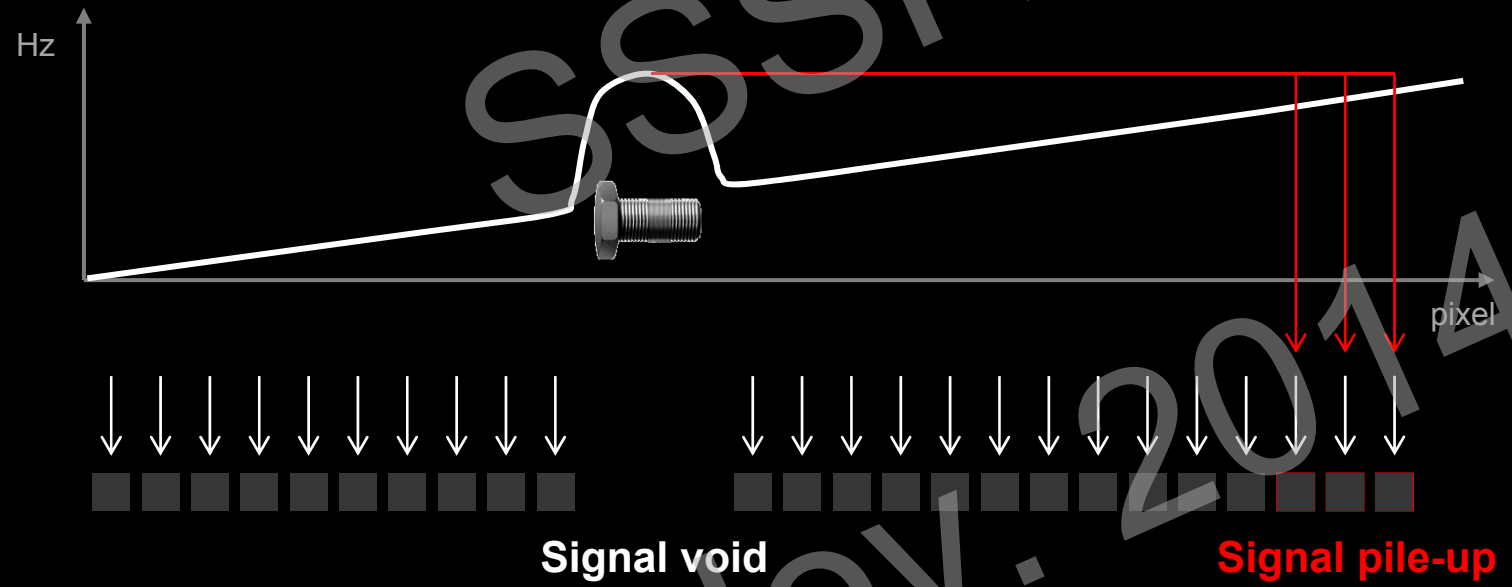
Metal artifacts at MRI

Signal displacement

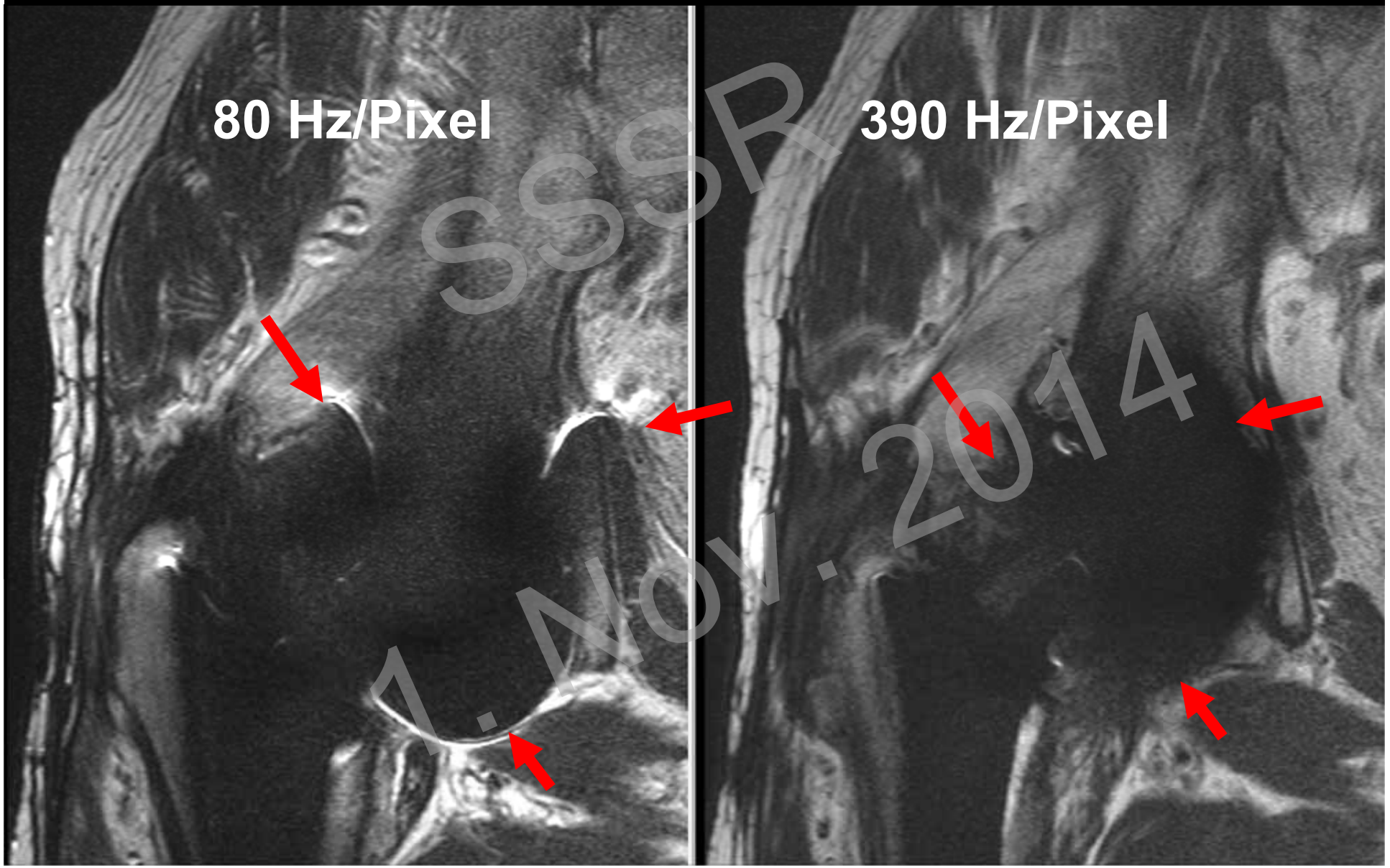


Metal artifacts at MRI

Signal displacement

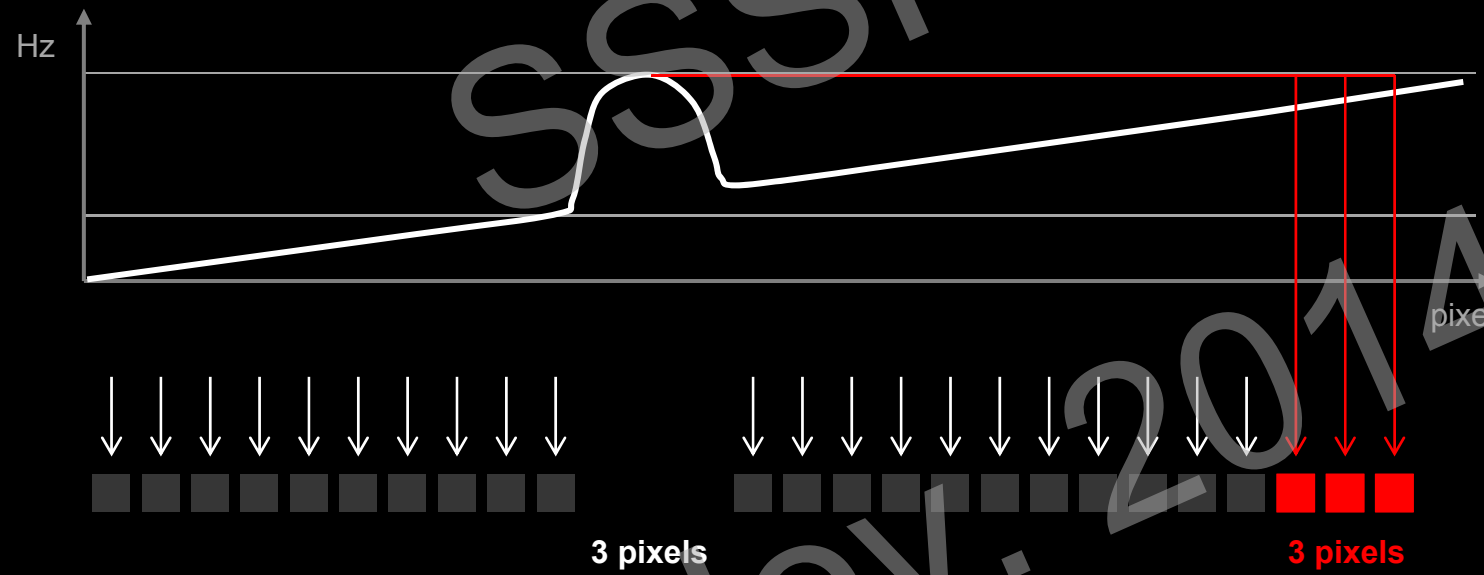


Increased bandwidth



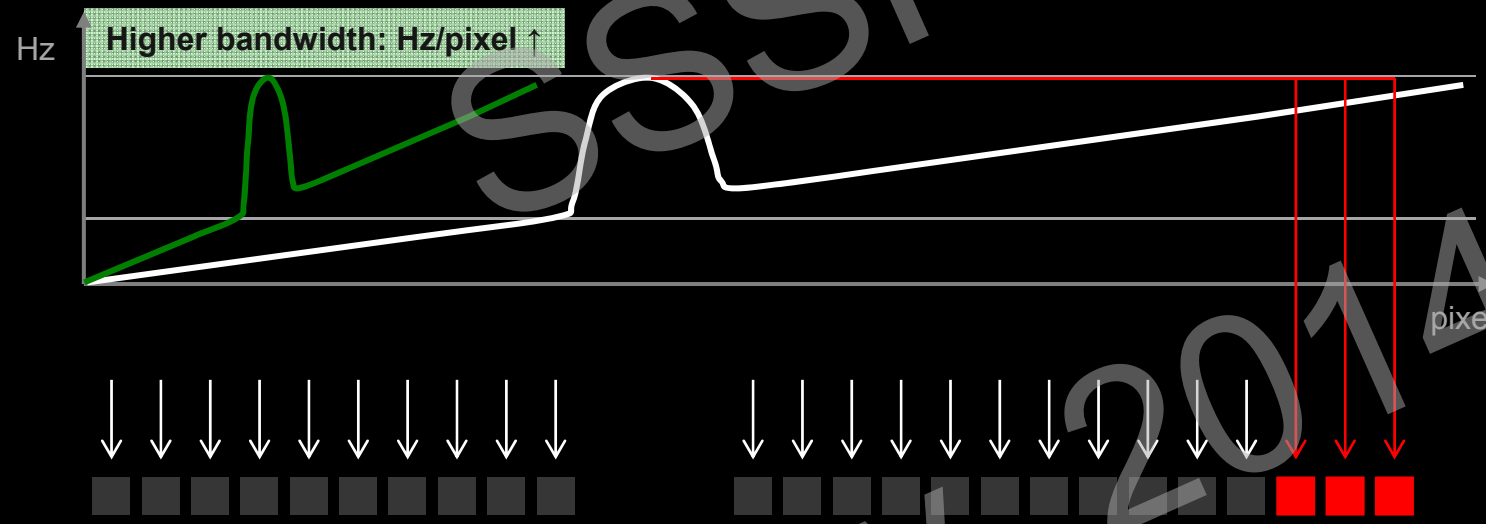
Protocol optimization

Higher bandwidth decreases signal displacement



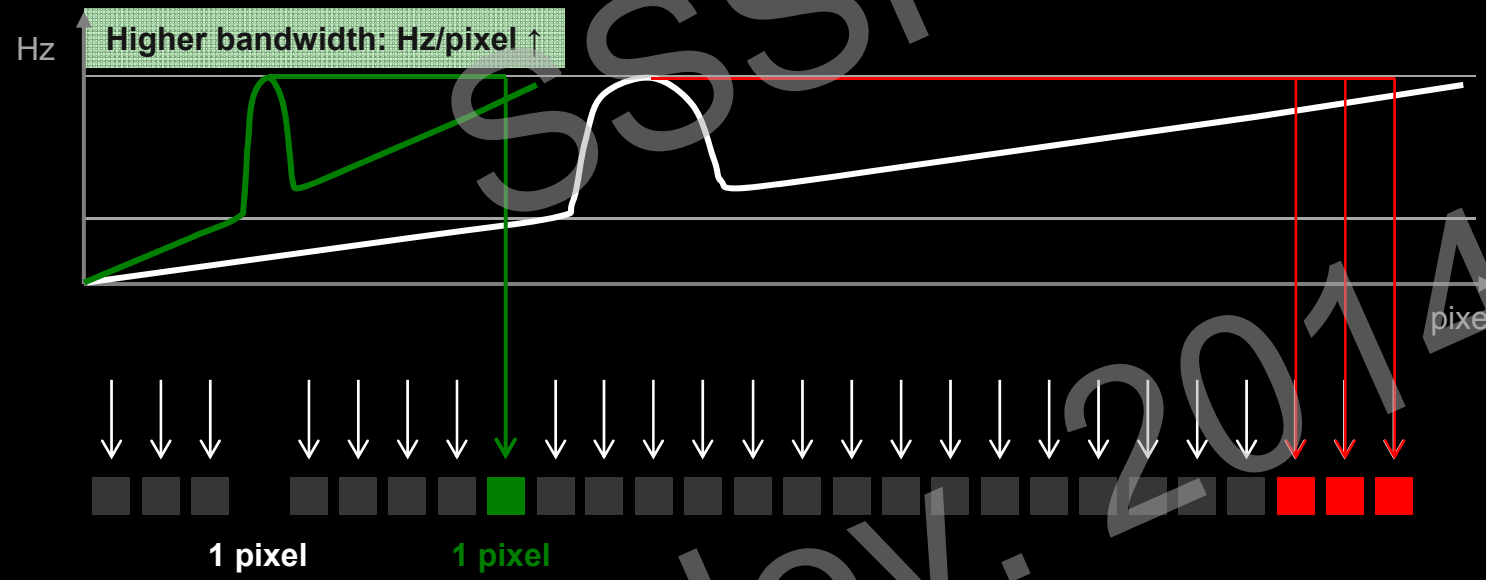
Protocol optimization

Higher bandwidth decreases signal displacement



Protocol optimization

Higher bandwidth decreases signal displacement



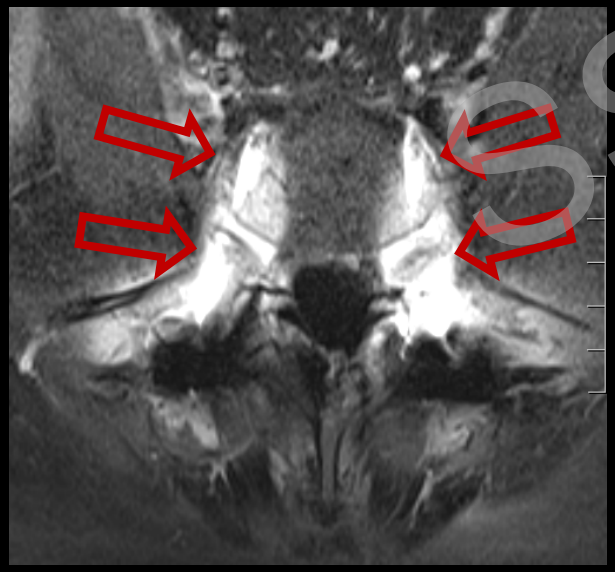
Disadvantage: SAR ↑ (excitation bandwidth)
SNR ↓ (readout bandwidth)

Protocol optimization

Optimization for Clinical Use:

- Increase excitation and readout bandwidth
- Thin sections, small voxel size, small FOV
- 1.5T much better than 3T
- Fast spin echo
  (no gradient-echo sequence or 3D-sequence)
- Long Echo-train-length
- Frequency encoding gradient parallel to
  long axis of prosthesis/implant
- Fat saturation?

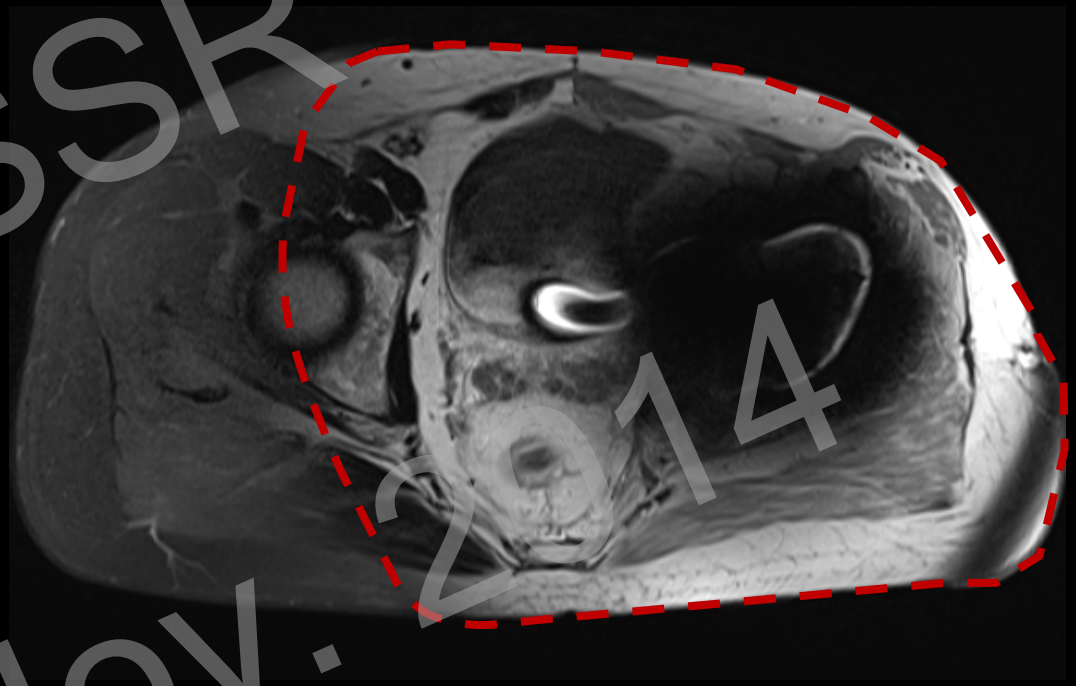
Insufficient fat saturation



Spondylodesis

T1 fat sat

failed fat saturation



Total hip arthroplasty

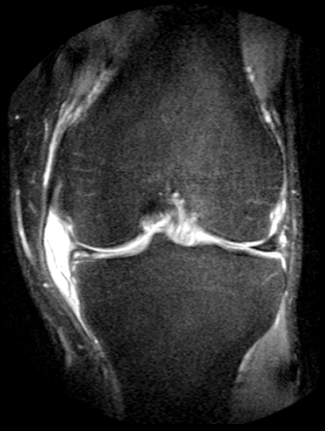
T1 fat sat

failed fat saturation

Fat saturation techniques

Spectral Fat Saturation

based on different
resonance frequency of water and fat



Advantage:

- Good soft tissue contrast (Ligaments, tendons)
- Several image contrasts available

Disadvantage:

- Susceptible to B_0 and B_1 inhomogeneities

STIR (Short Tau Inversion Recovery)

based on different
relaxation time of water and fat

Advantage:

- Stable for B_0 inhomogeneities

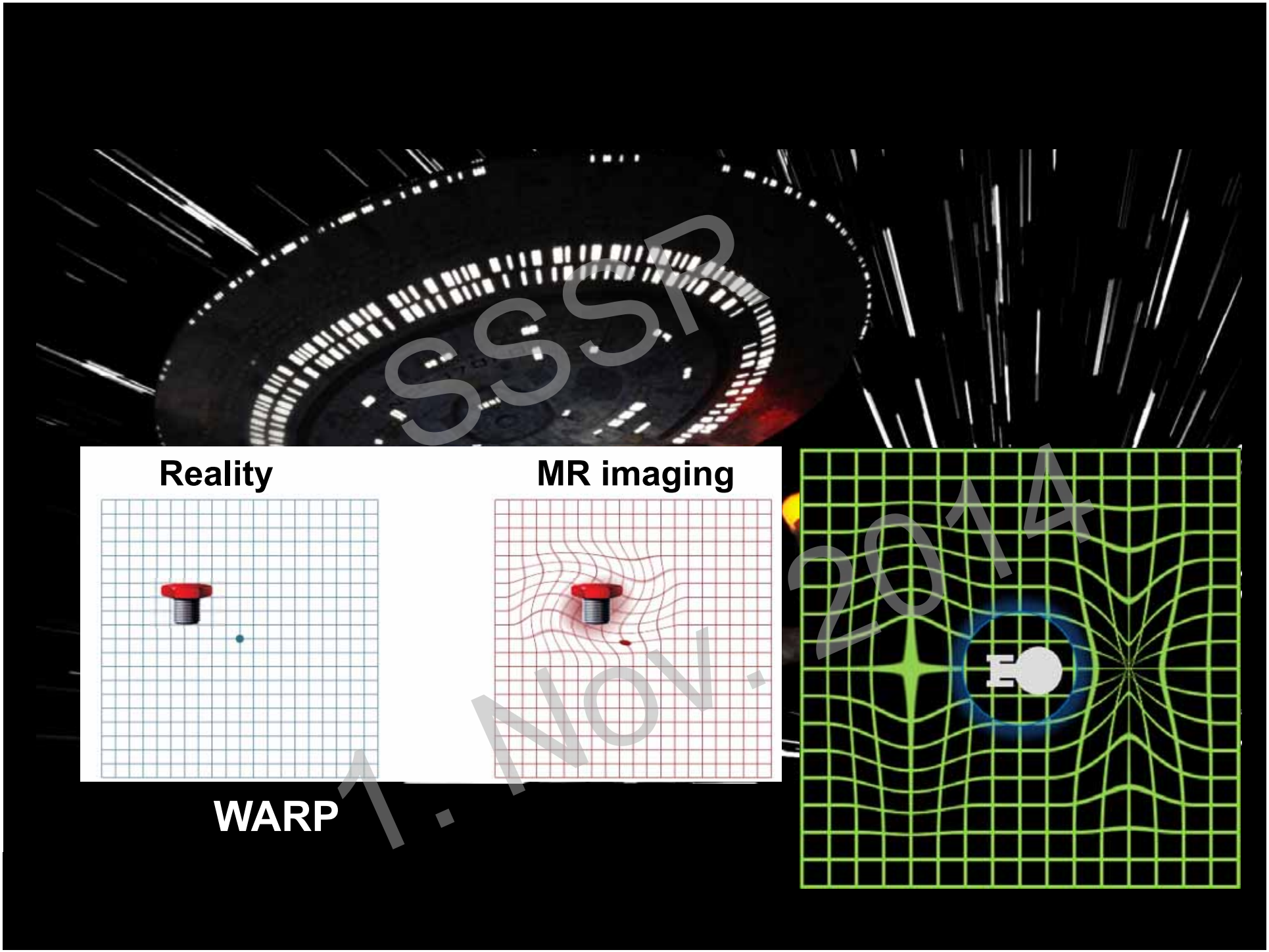
Disadvantage:

- Low SNR
- Not usable for contrast enhancement
- Susceptible to B_1 inhomogeneities

Sutter R., et al. Radiology 2012; 265: 204-14.
Blankenbaker D.G., et al. AJR 2008; 190: W1–W7.

MARS

Metal Artifact Reduction Sequence



OUTLINE

New MRI techniques

New MRI techniques

- STIR with optimized inversion RF pulse (STIR WARP)
- Dixon technique
- View-angle tilting (VAT)
- Through-plane distortion correction (SEMAC, MAVRIC)

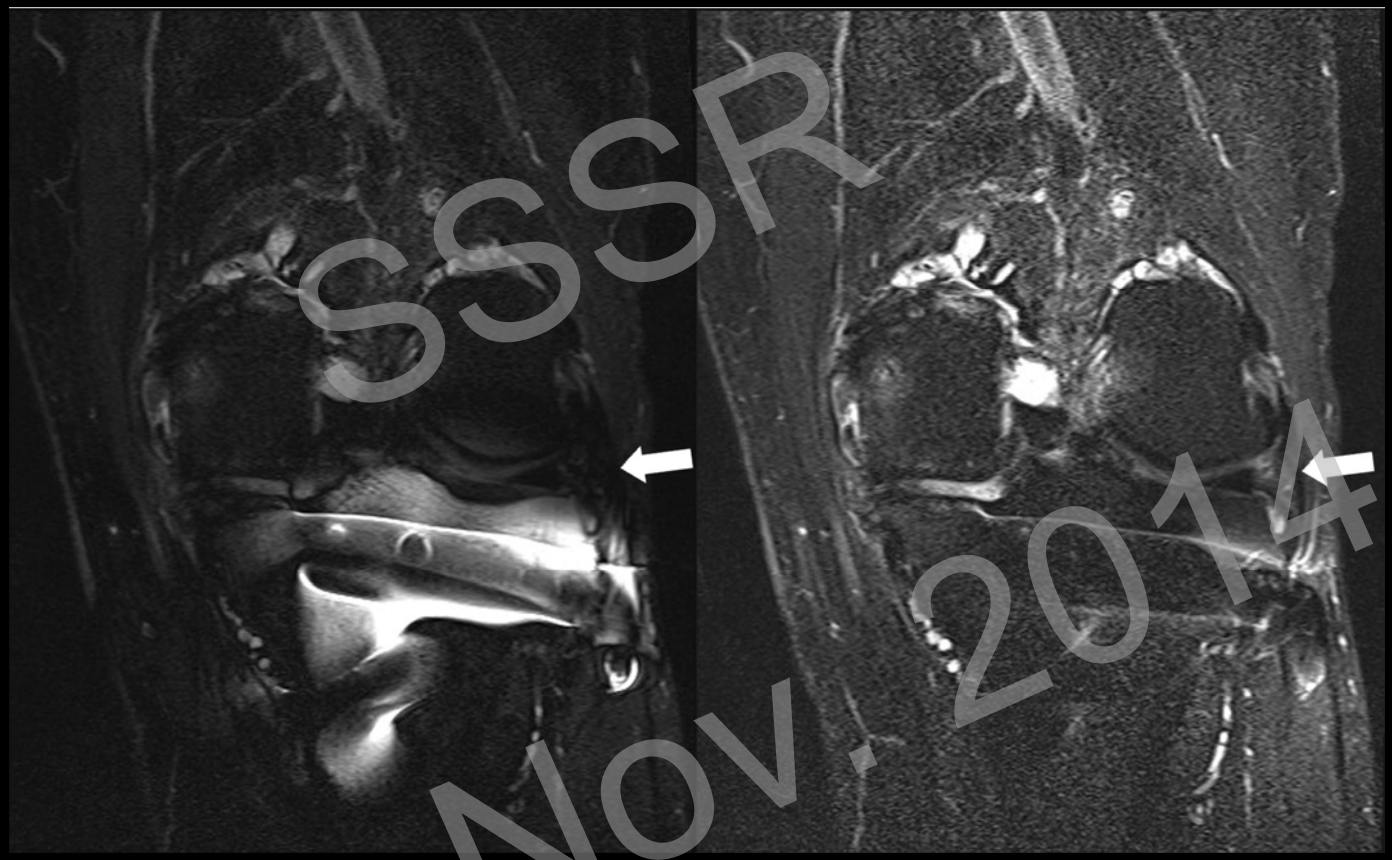
1. STIR WARP

Standard STIR sequence
Inversion RF pulse with reduced bandwidth → lower SAR

STIR with Optimized Inversion Pulse = STIR WARP
increased bandwidth of inversion RF pulse, matches increased bandwidth of excitation RF pulse

➔ robust STIR contrast around metal implants

STIR WARP



STIR highBW

STIR WARP
(optimized inversion pulse)

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Ulbrich EJ et al. AJR 2012 Dec;199(6):W735-42.

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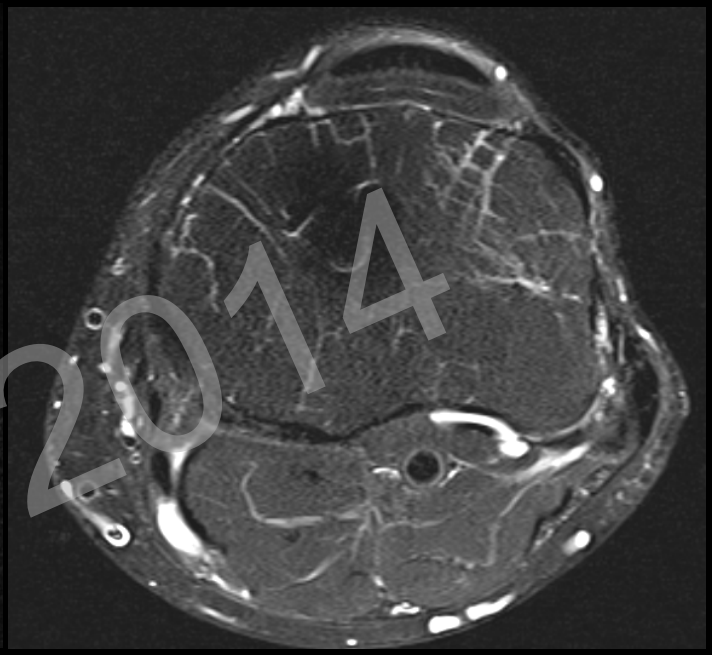
STIR WARP

PD fs high BW

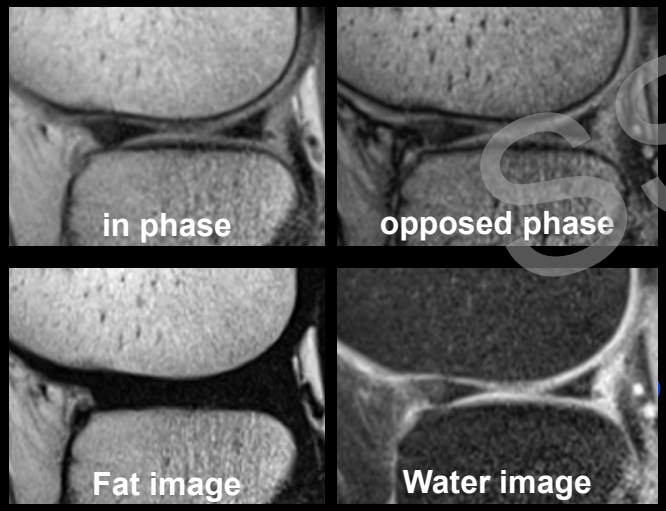
failed fat saturation



STIR WARP

2. Dixon technique

Based on different
resonance frequency of water and fat



Advantage :

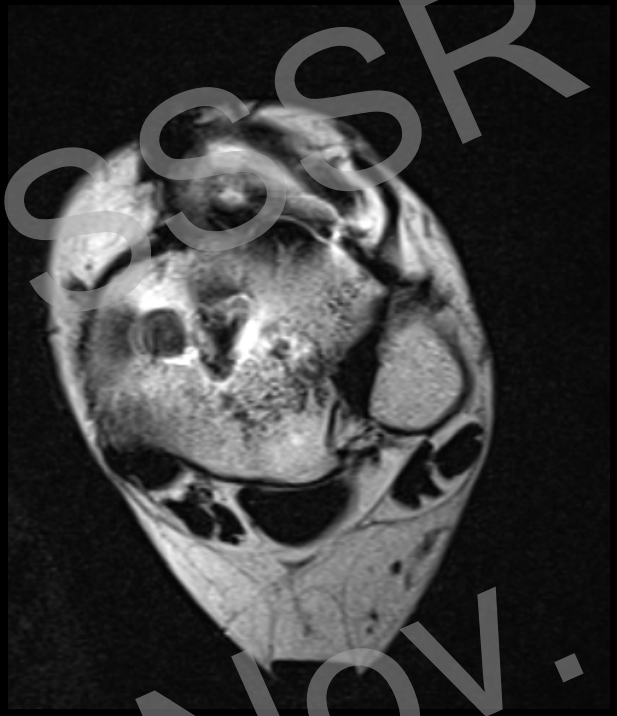
- Stable for B_0 and B_1 inhomogeneities
- Extensive anatomic coverage feasible
- 4 image contrasts in a single sequence

Disadvantage :

- Residual artifacts at bone-metal interface
- Prolonged acquisition and image reconstruction

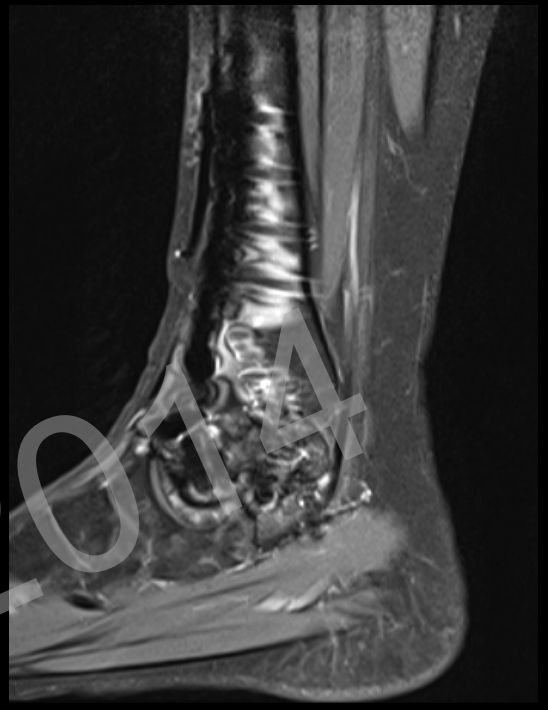
Low R.N., et al. J MRI 2011; 33: 390-400.
Rampton J.W., et al. AJR 2013; 201: 1303-1308.

Dixon technique



tra T1 fat sat highBW
after iv gadolinium

failed fat saturation



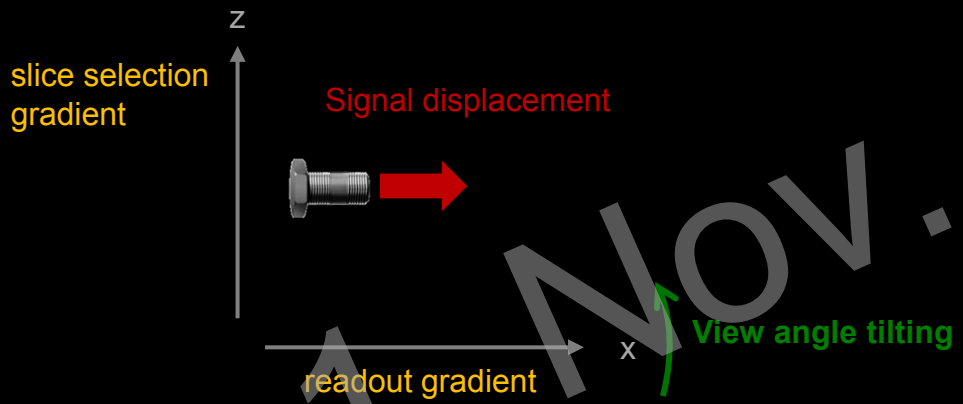
Dixon (water image)
after iv gadolinium

3. View-Angle Tilting

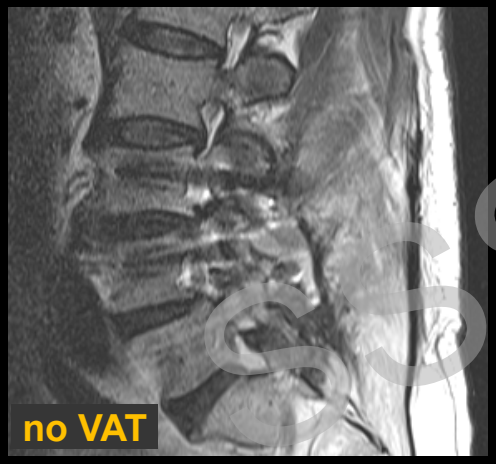
View-angle tilting (VAT)

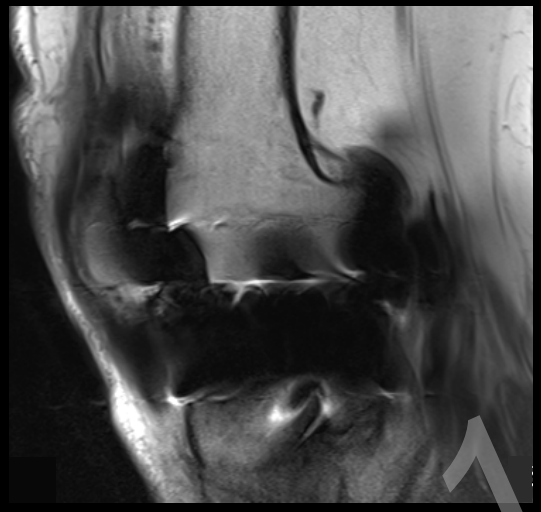
Additional compensation gradient shifts the view-angle during readout

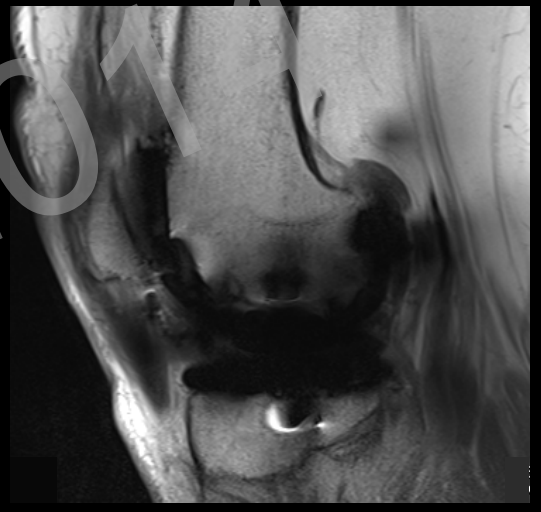
➔ View-angle displacement cancels in-plane displacement



View-Angle Tilting







Standard

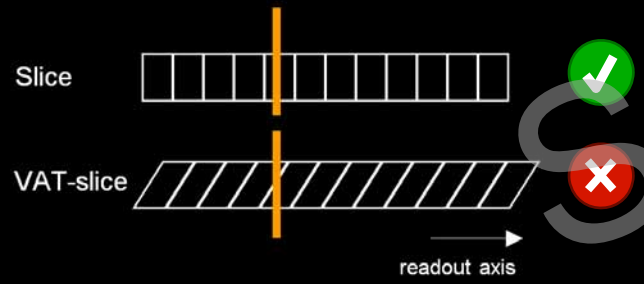
+ high rf pulse and readout bandwidth

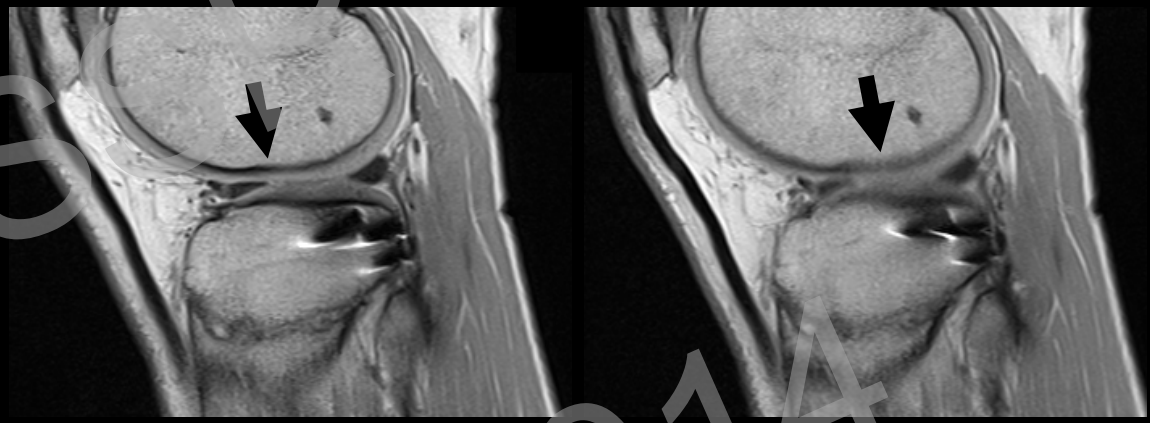
+ VAT

View-Angle Tilting

Slice shearing effect

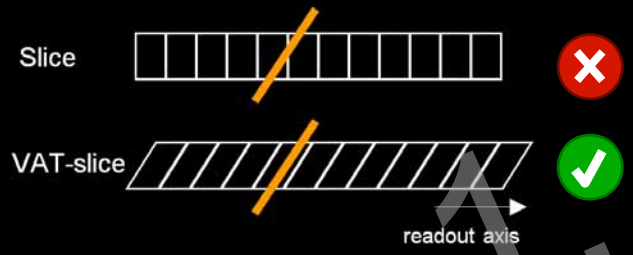
Blurring of some anatomic structures

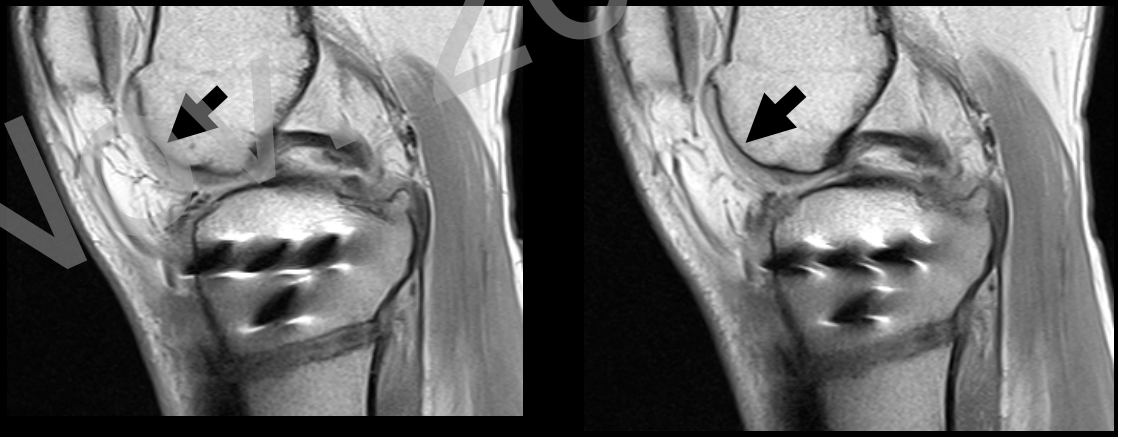




no VAT | with VAT

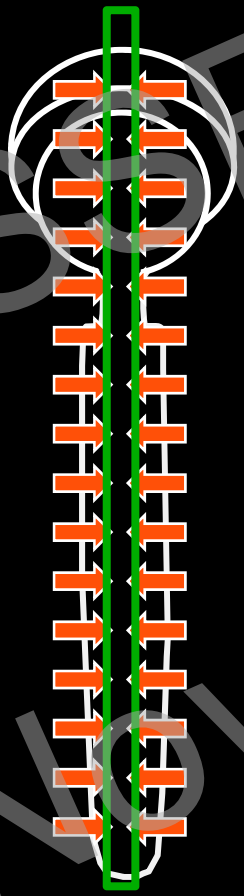
Opposite effect for other structures





4. Through-plane artifacts

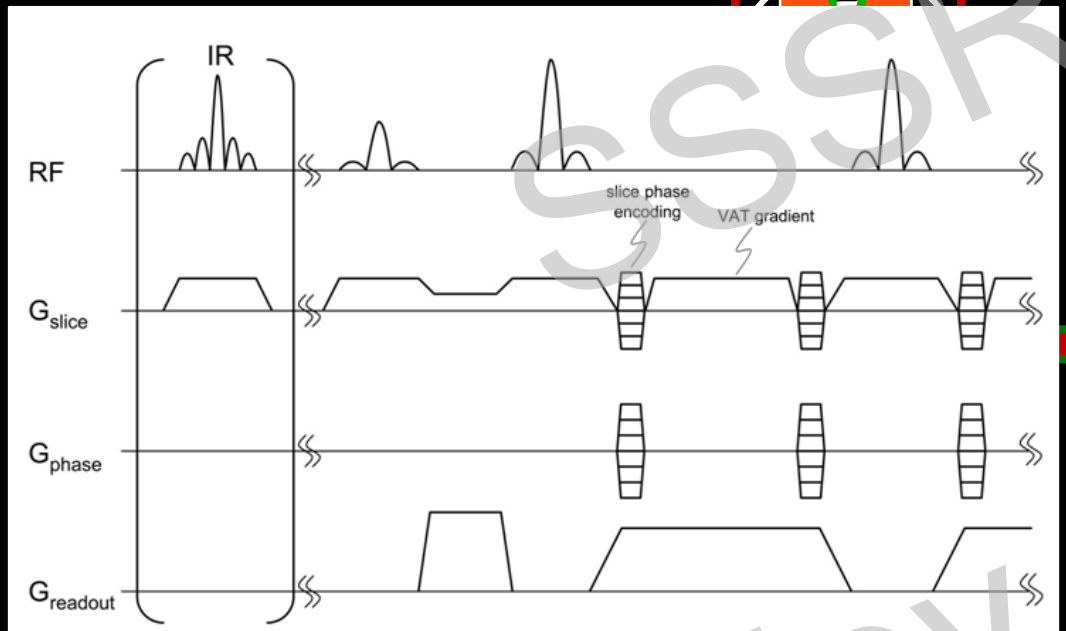
Only in-plane artifact reduction



Through-plane artifacts

Only in-plane artifact reduction

Additional through-plane artifact reduction



Additional gradients applied:

- Slice phase encoding (SEMAC)
- View-angle tilting (VAT)

Slice Encoding for Metal Artifact Correction (SEMAC)

Lu W, et al. Magn Reson Med 2009; 62: 66-76.
Sutter R, et al. Radiology 2012; 265: 204-14.

SEMAC for Total Hip Arthroplasty

transverse T1-hiBW

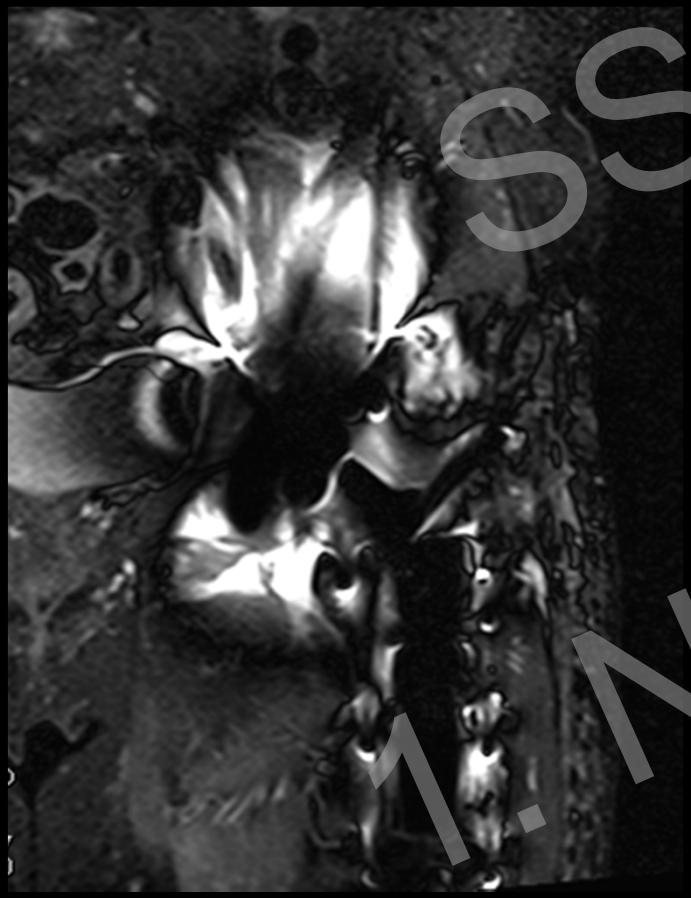
transverse T1-SEMAC

Sutter R, et al. Radiology 2012 Oct;265(1):204-14.

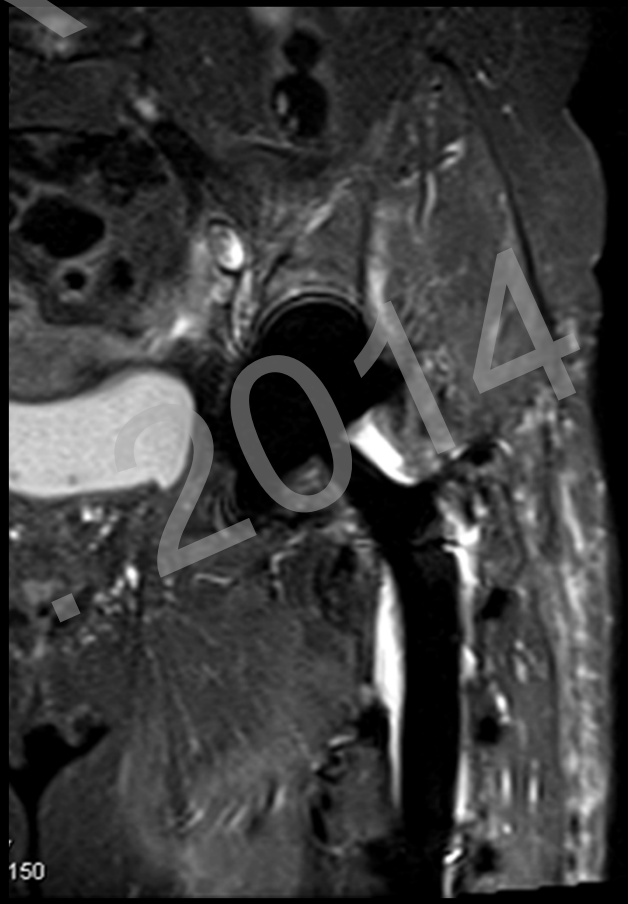
SEMAC for Total Hip Arthroplasty

conventional STIR

(high bandwidth)



STIR SEMAC TSE



Sutter R, et al. Radiology 2012 Oct;265(1):204-14.

SEMAC for Total Knee Arthroplasty

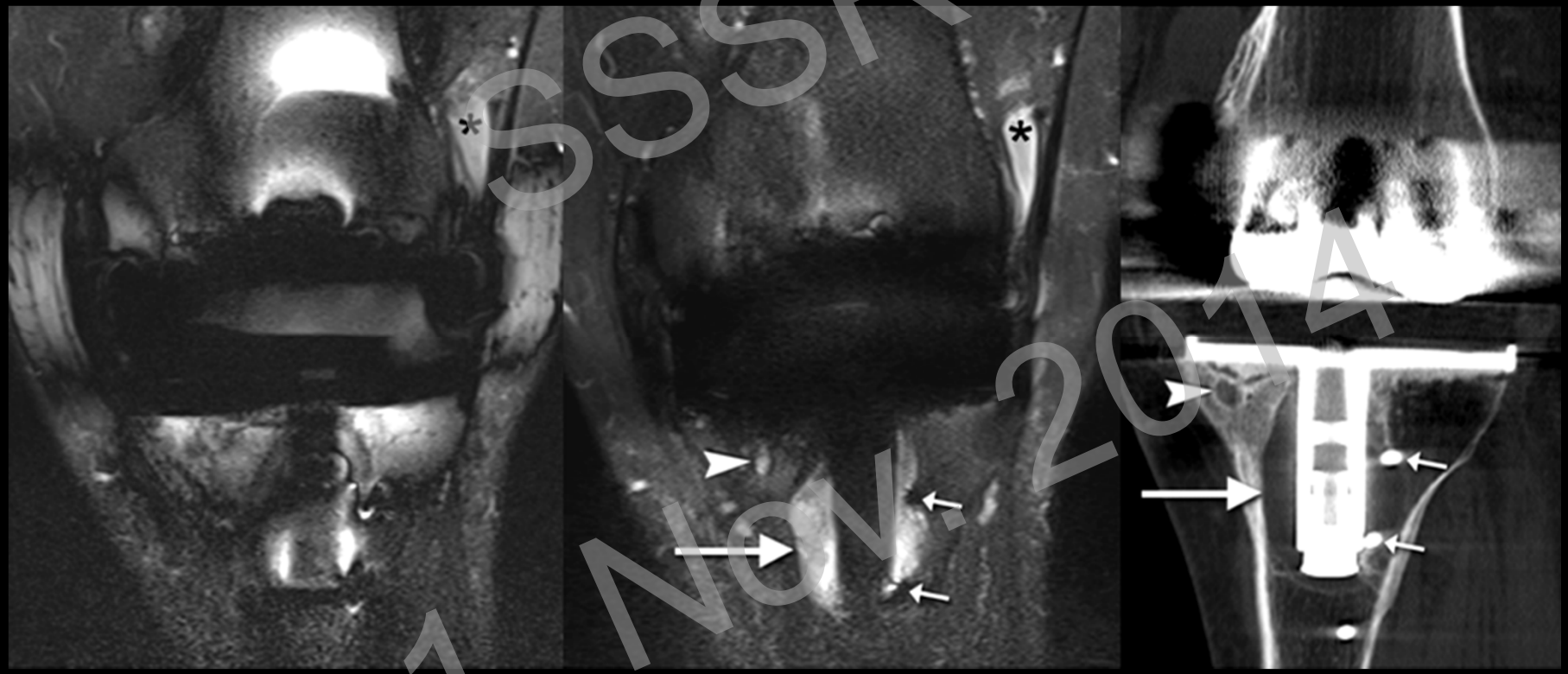
sag PD-hiBW

sag PD-SEMAC

Sutter R, et al. AJR 2013 Dec; 201:1315–1324.

SEMAC for Total Knee Arthroplasty

Periprosthetic osteolysis better seen at SEMAC



cor STIR-hiBW | cor STIR-SEMAC | CT

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Sutter R, et al. AJR 2013 Dec; 201:1315–1324.

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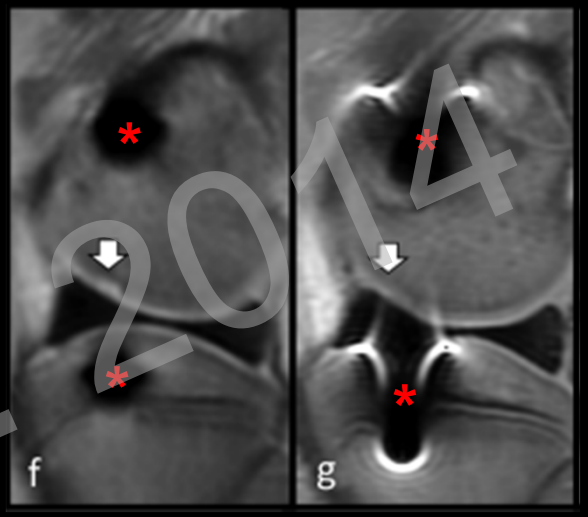
MAVRIC

MAVRIC
(multi-acquisition variable-resonance image combination)

MAVRIC-STIR

MAVRIC-SL
Combined MAVRIC-SEMAC

MAVRIC-SL PD PD (FSE)



Pig model with screws (*)

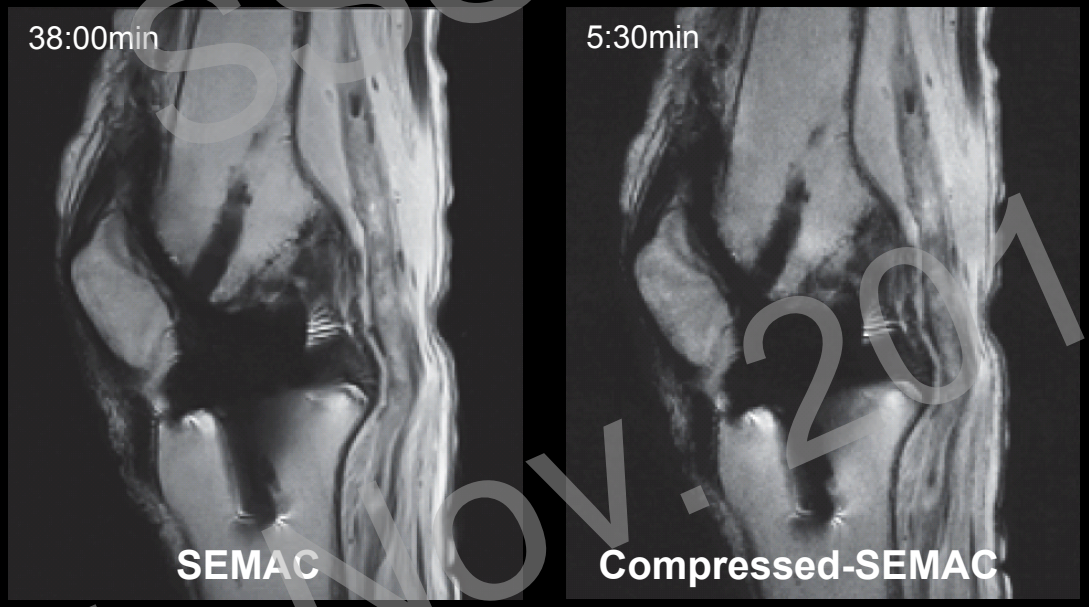
Liebl H, et al. J Magn Reson Imaging 2014 Jun 10.
Fritz J, et al. Radiographics 2014;34(4):E106-32.

OUTLINE

Next steps

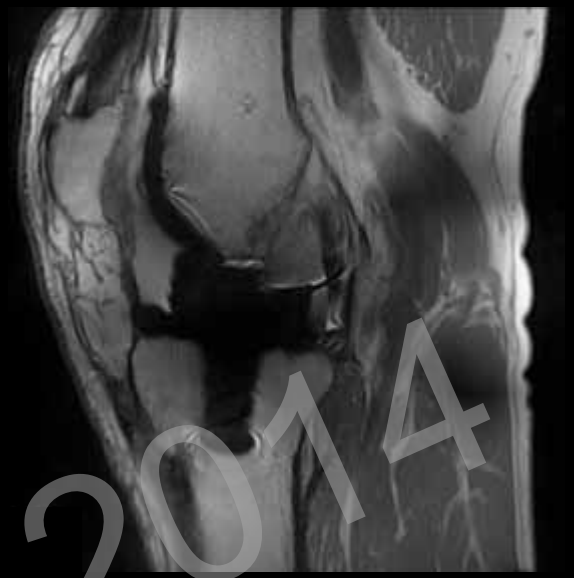
Compressed sensing

Mathematical concept that creates high-resolution data sets from low-resolution samples



MRI with knee prosthesis at 3T

PD sag



Standard sequence
high-bandwidth

Ultra high bandwidth RF-Pulse+SEMAC
RF-pulse with 4000 Hz
local transmit coil with high B_1 amplitude

University of Zurich

Bachschmidt T, et al. J MRI 2014 (Aug) online before print

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TAKE HOME MESSAGE

- MR imaging of metal implants is feasible
- New MRI techniques have clinically relevant advantage and will become even faster in the next 5 years
- MRI is part of diagnostic algorithm for patients with total hip / knee arthroplasty at Balgrist

Thank you

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