Compressed Sense Technique in Neuroradiology

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Sabine Saroretti-Schefer
Erika Brüllmann and Michael Wyss
Barbara Eichenberger and Luc van Smoorenburg

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Compressed Sense CS

Speed done right, everywhere, every time !

Airport Schiphol The Netherlands

Tex Gunning,
CEO LeasePlan

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Speed done right, everywhere, every time !

What I have to know about «Compressed Sense»:

1. The scan time of nearly all sequences can be accelerated: in neuroradiological, musculoskelettal, abdominal MR imaging.

2. The spatial resolution of a sequence can be considerably improved without relevant increase in scan time.

3. CS can be used with nearly all sequences on 1.5 T and with 3T MR machines.

Part 1:
Scan time reduction: Speed up with CS

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Compressed Sense: Recommendations Philips ® for scan time reduction

	Standard sequence	Time reduction with CS
Compressed SENSE Brain	3D T1 TFE	50%
	3D FLAIR	30%
	3D T2 BrainView	40 %
	3D T2 DRIVE inner ear	25%
	SWIP	25%
	3D T1 Black Blood BrainView	25%
	3D TOF	30 – 40%
	3D PCA	???
	3D DIR	???
	2D Scans brain	???
	2D / 3D spine	???

Rule: Sequences with low “contrast-to-noise” should only get minor time reduction with CS

What do I have to know before I start with CS ?

1. The CS factor defines the time reduction of a sequence.
2. The higher the CS factor the shorter the scan time of a sequence.
3. The denoising grade determines the balance between “noise” and “smoothness” of the images acquired.
4. The denoising grade can be chosen: weak, medium, strong
5. System default is always denoising grade “medium”.
6. Sequences with high “contrast-to-noise” like 3D T2 DRIVE (used for inner ear or depiction of cranial nerves), 3D TOF or 3D T1 / T2 spine view allow a high denoising grade “strong”.
7. Sequences with a low “contrast-to-noise” like 3D FLAIR, 3D DIR, SWI, 3D T1 black blood allow low denoising grades “weak or medium”.

Compressed Sense CS

We wondered:

1. **How does an image acquired with CS technique does really look like ?**
2. **What happens with the image quality if a sequence is acquired with increasing CS factor ?**
3. **How is the image quality changed with different denoising grades «weak, medium,strong» ?**

Experiments with volunteers: Kantonsspital Winterthur

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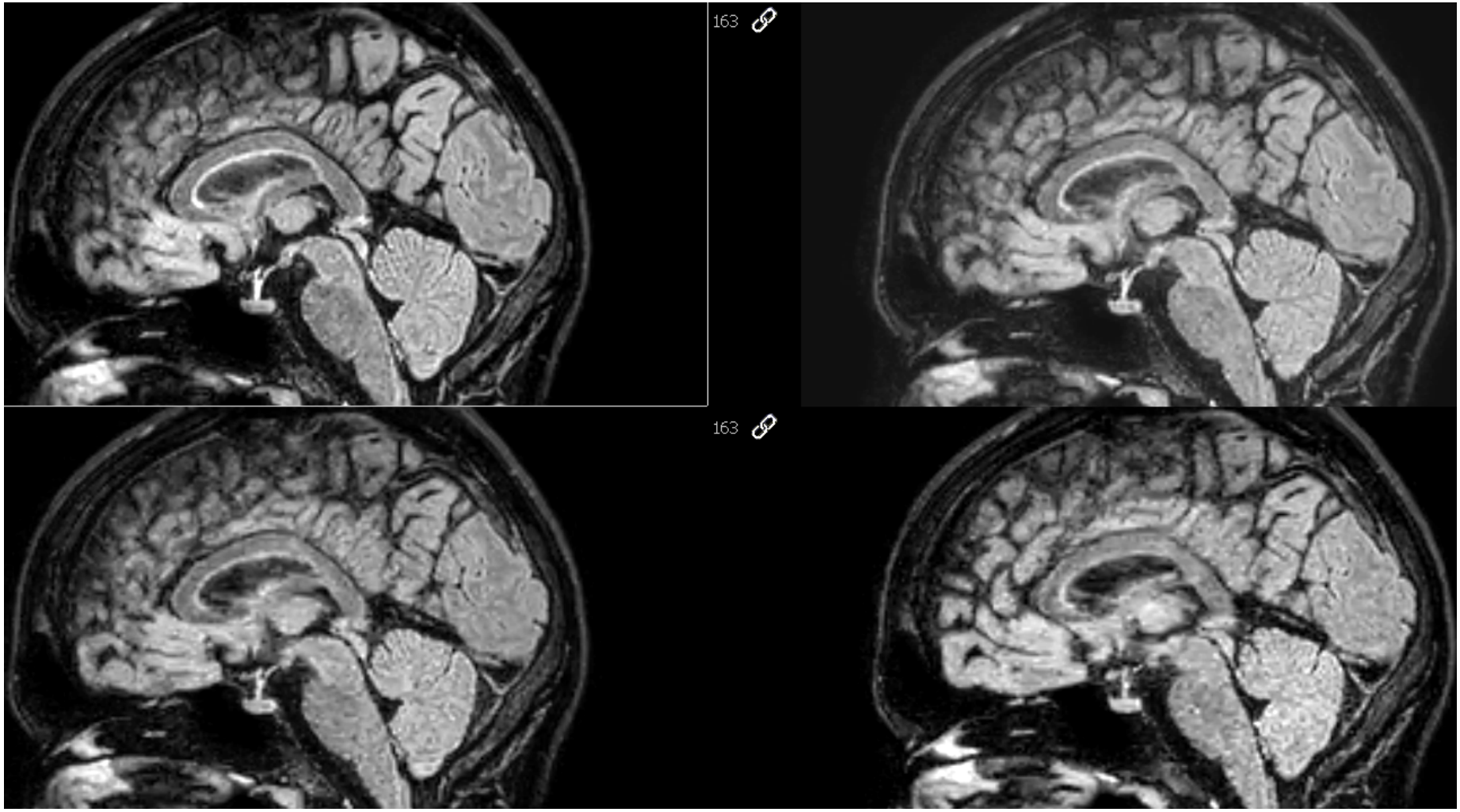
Sequence with low «contrast-to-noise» factor:3D FLAIR
→ INCREASING THE CS FACTOR

Normal midsagittal 3D FLAIR 1.5 T

3D FLAIR without CS

3D FLAIR **CS7** medium



3D FLAIR **CS9** medium

3D FLAIR **CS11** medium

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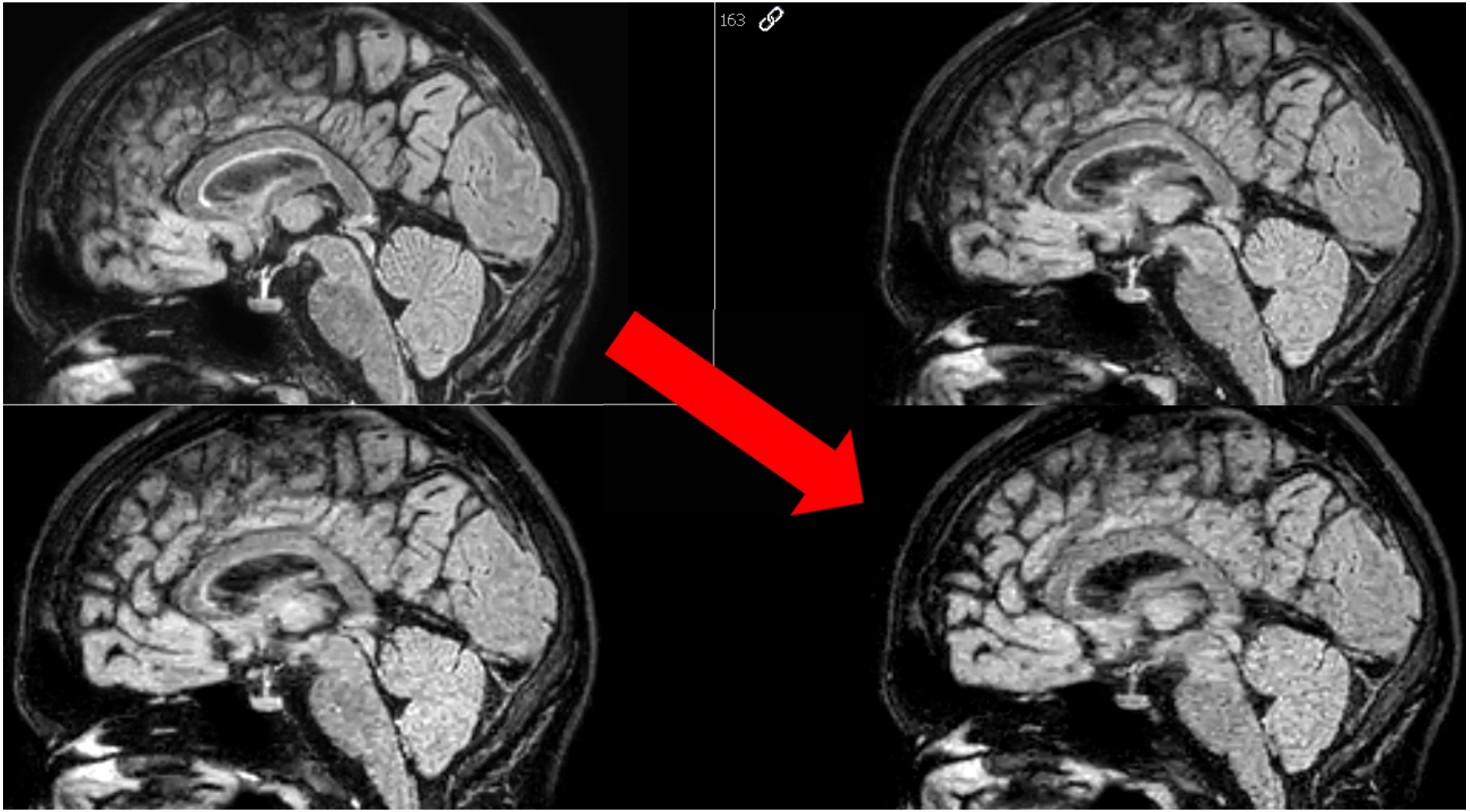
Normal midsagittal 3D FLAIR 1.5T

3D FLAIR without CS

3D FLAIR CS9 medium



3D FLAIR CS11 medium

3D FLAIR CS13 medium

Without CS → CS 13: blurred, noisy, granular, streaky, waxen

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Normal midsagittal 3D FLAIR 1.5T without / with CS: Big difference !

3D FLAIR without CS

3D FLAIR CS13 medium

Without CS → CS 13: blurred, noisy, granular, streaky, waxen

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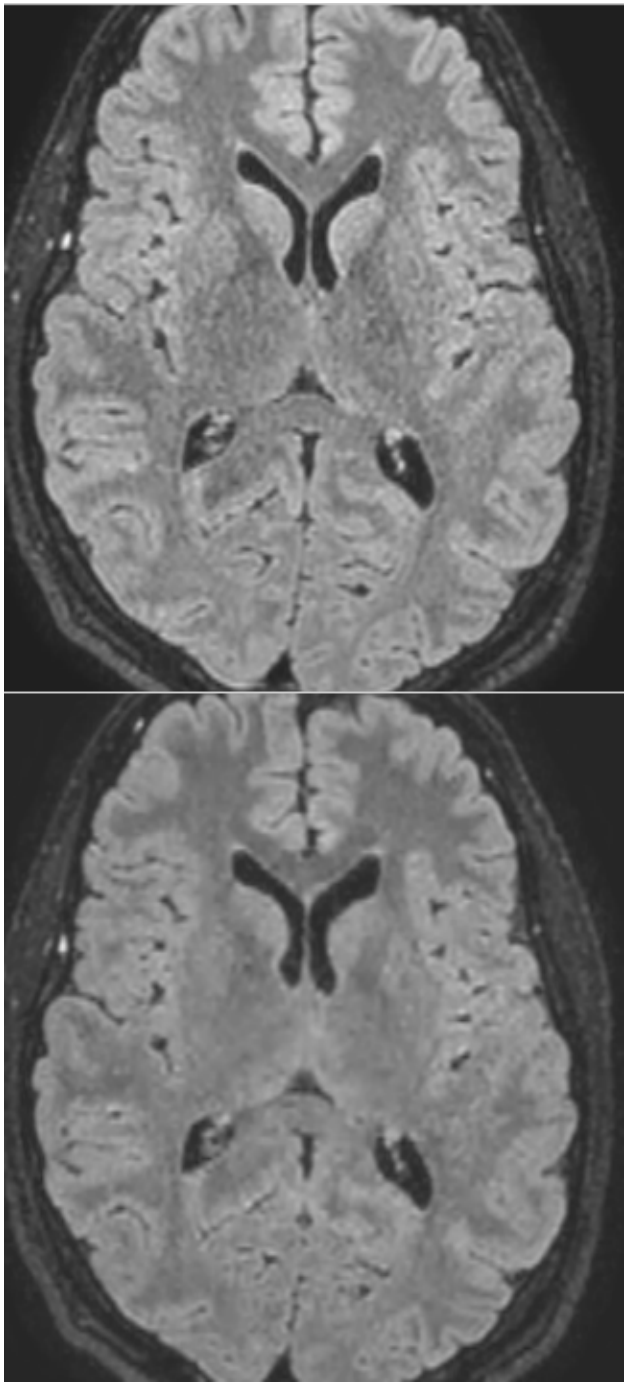
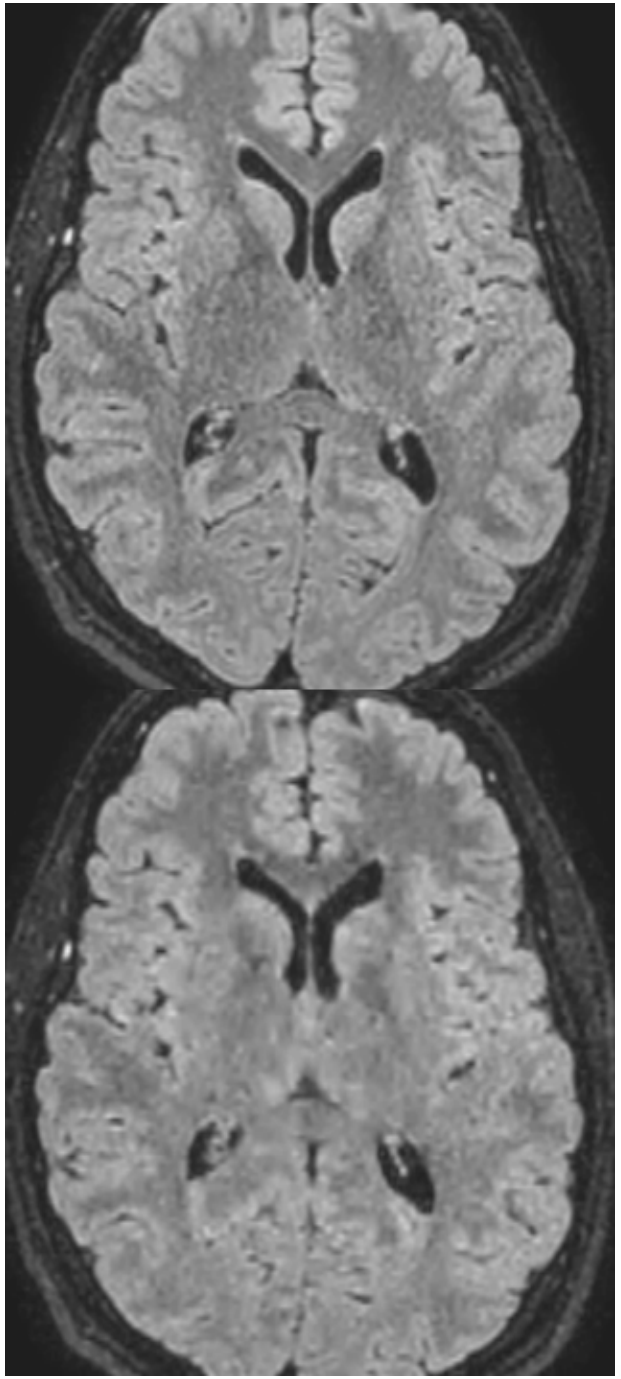
Normal transverse 3D FLAIR 1.5T



without CS

Without CS→CS11: blurred, less contrast gray-white matter, waxen

CS9
medium



CS7
medium

CS11
medium

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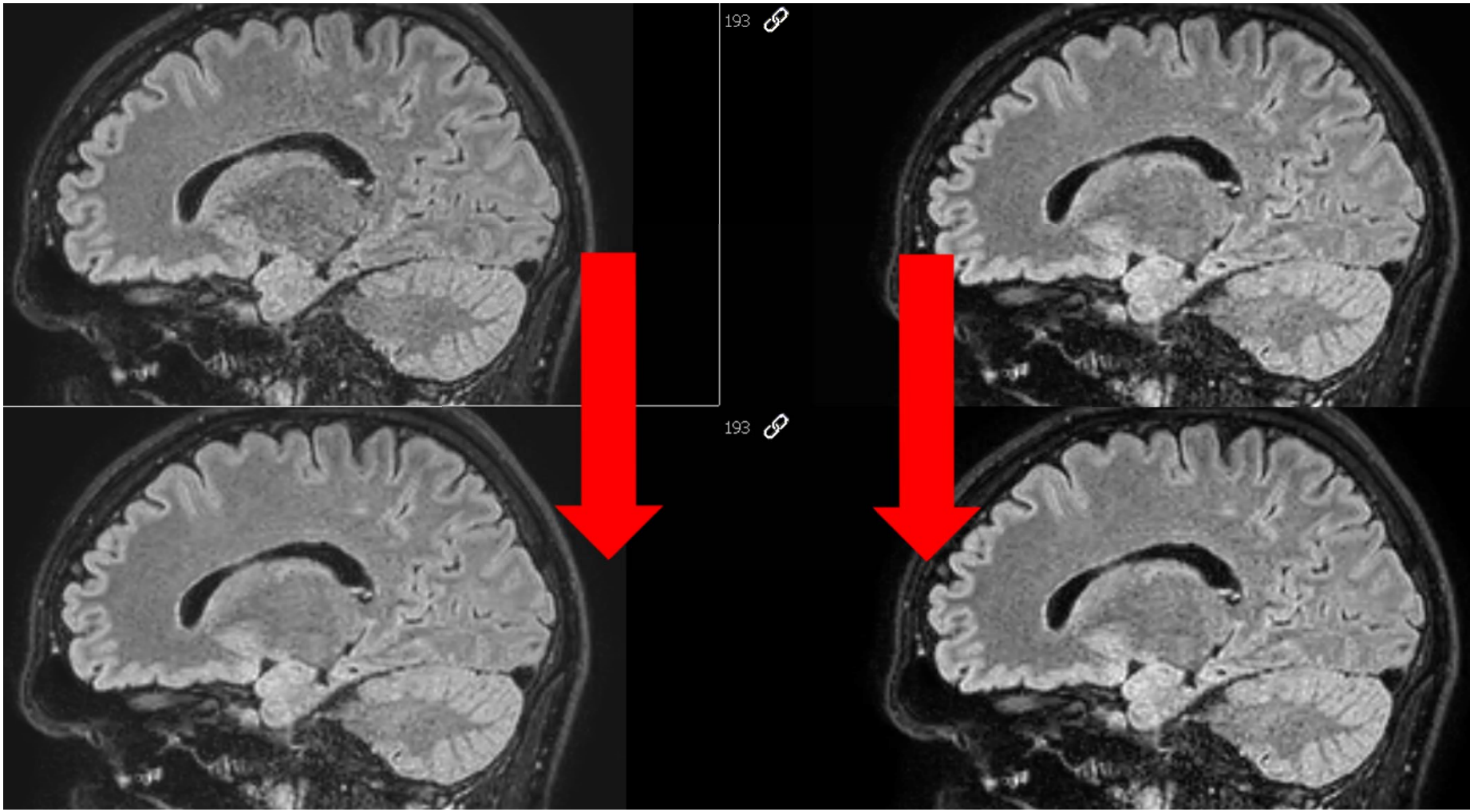
Denoising grade: weak, medium, strong with low CS factor

Denoising grade: 3D FLAIR, parasagittal, low CS 7,1.5T

3D FLAIR wihtout CS

3D FLAIR **CS7 weak**



3D FLAIR **CS7 medium**

3D FLAIR **CS7 strong**

Slight difference:

a. No CS→ medium: smoother, less noisy, less granular, less streaky
b. Weak → strong: smoother, less noisy, no loss of image details

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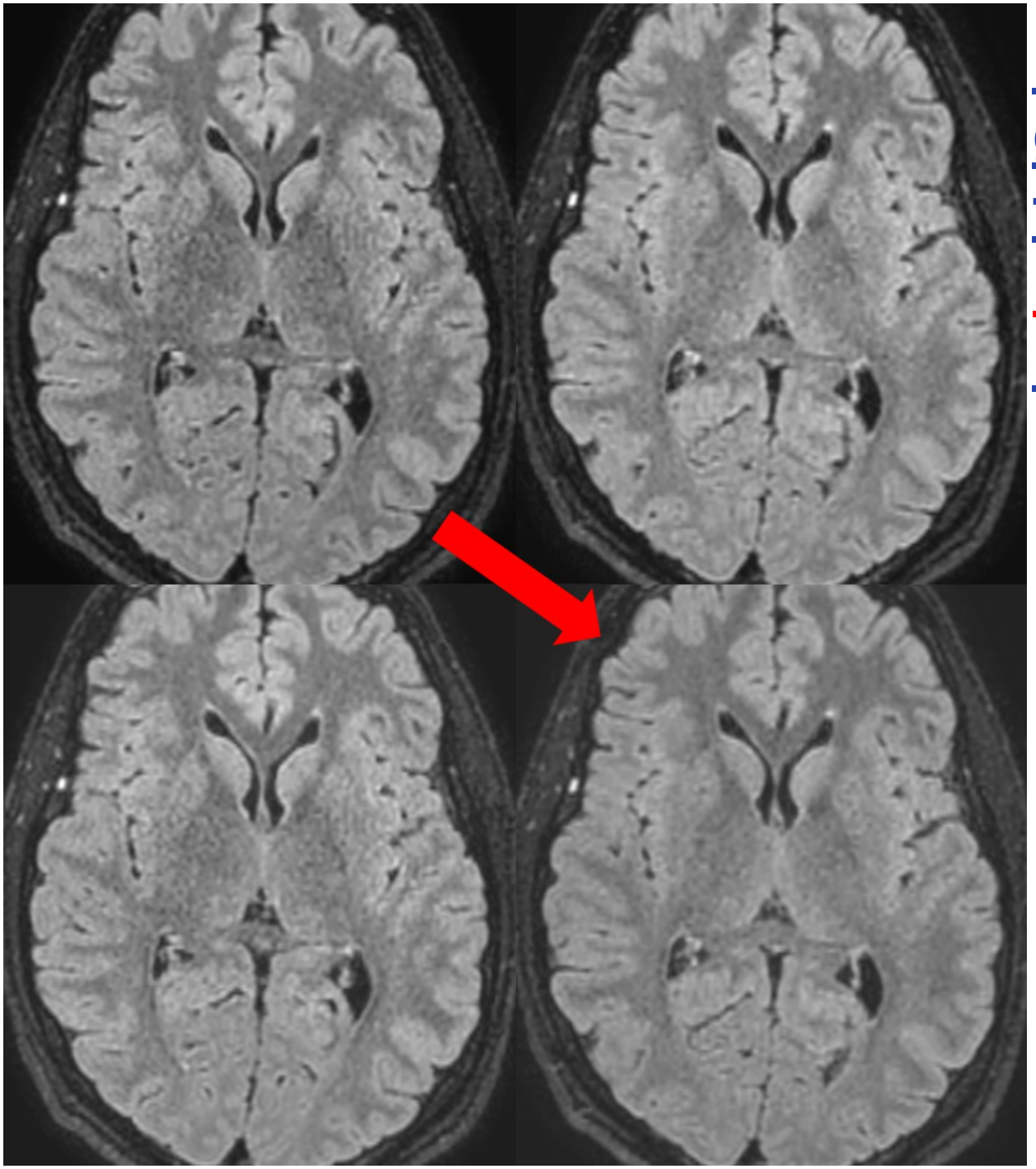
Denoising grade: transverse, low CS 7, 3D FLAIR 1.5T

no CS



CS7 weak

Slight difference

No CS or weak → strong: Smoother, less noisy, less granular, no loss of image details, contrast gray-white matter preserved

CS7 medium

CS7 strong

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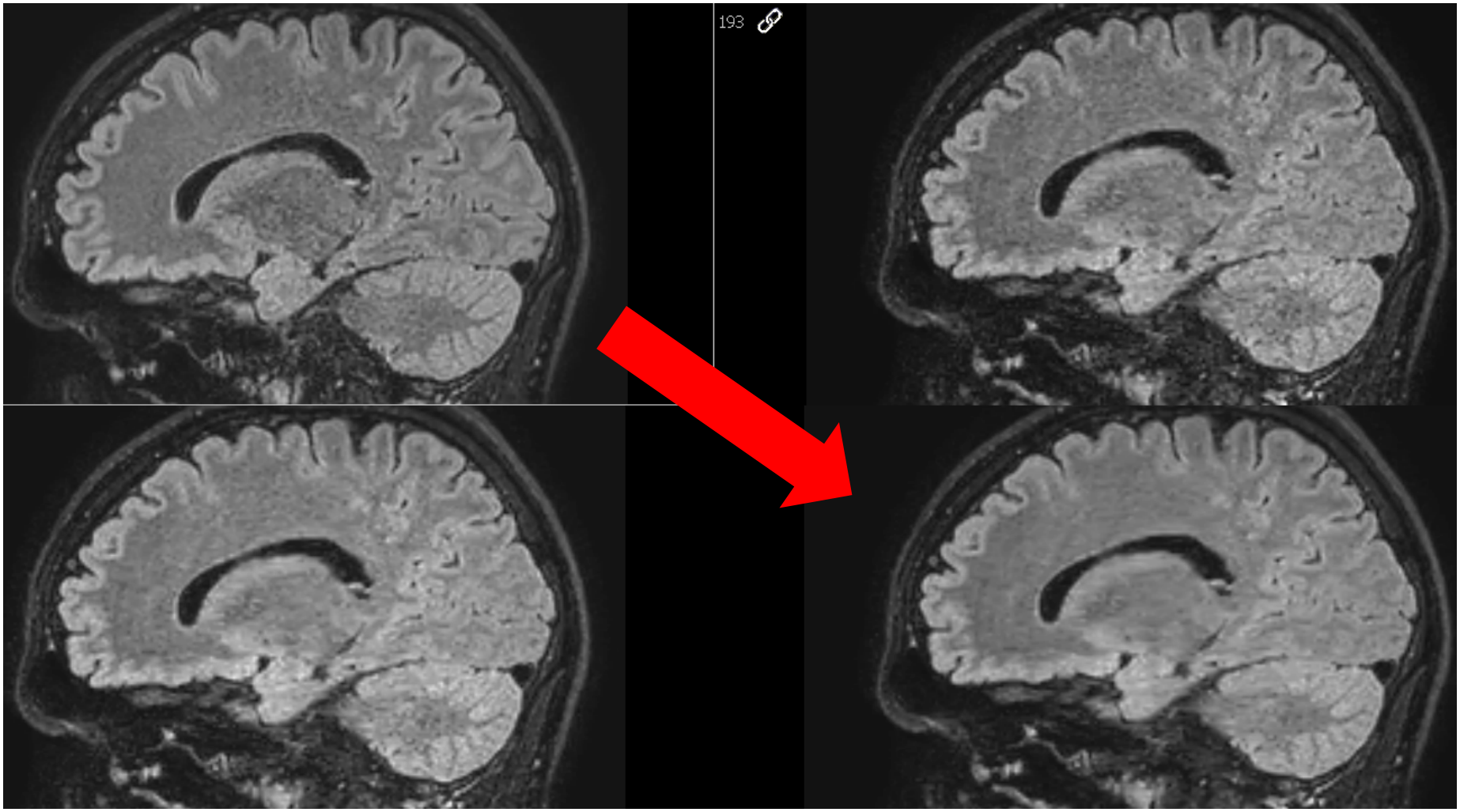
Denoising grade: weak, medium, strong with high CS factor

Denoising grade: 3D FLAIR, parasagittal, high CS11,1.5T

3D FLAIR wihtout CS

3D FLAIR **CS11**



3D FLAIR **CS11 medium**

3D FLAIR **CS11 strong**

Big difference: no CS / weak → strong:
blurred, waxen, streaky, loss of imaging detail, but less noisy

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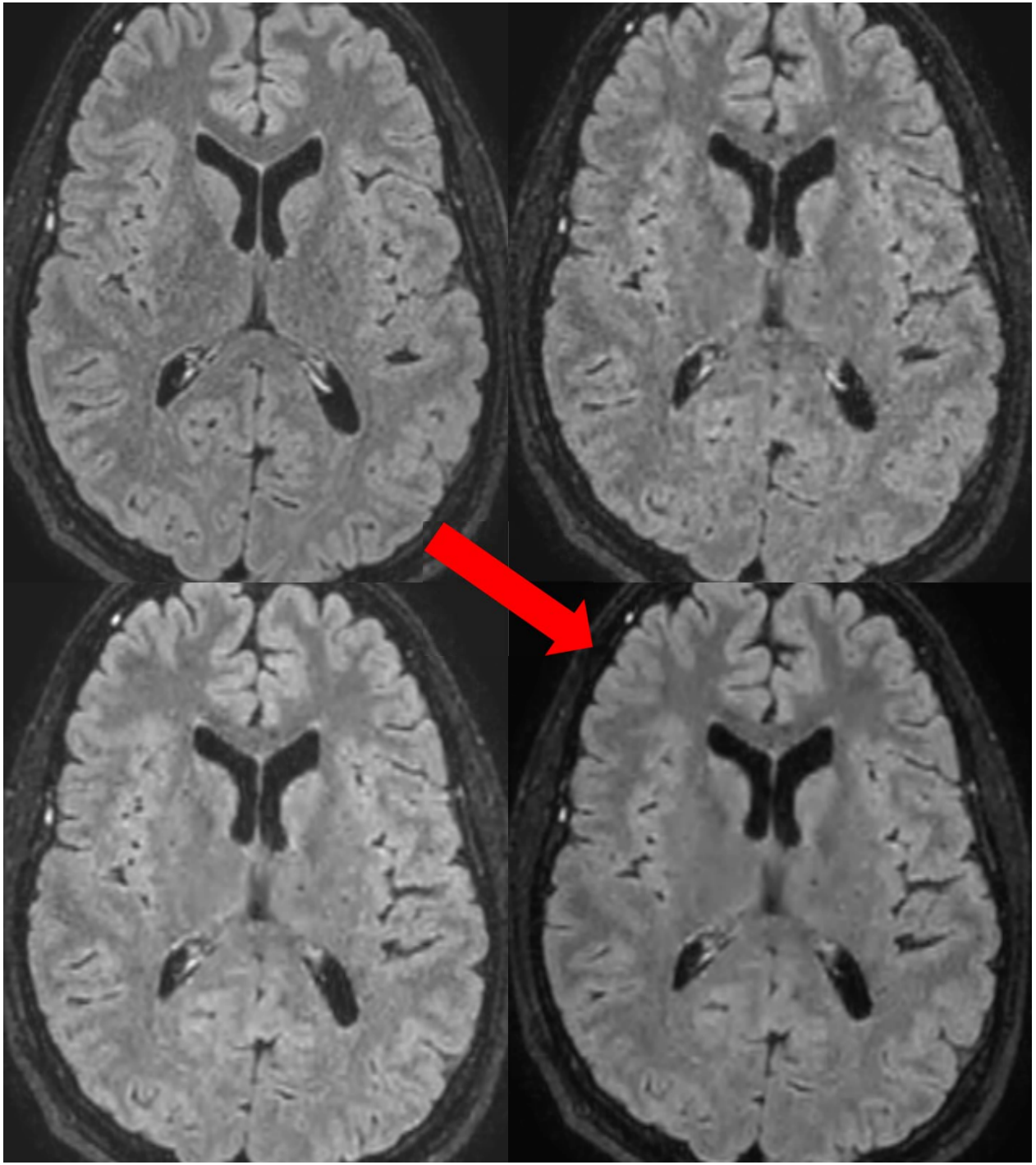
Denoising grade:Transverse, high CS11, 3D FLAIR, 1.5T

no CS



CS11 weak

Big difference no
no CS/weak → strong:
blurred, waxen, loss of image details, but less noisy

CS11 medium

CS11 strong

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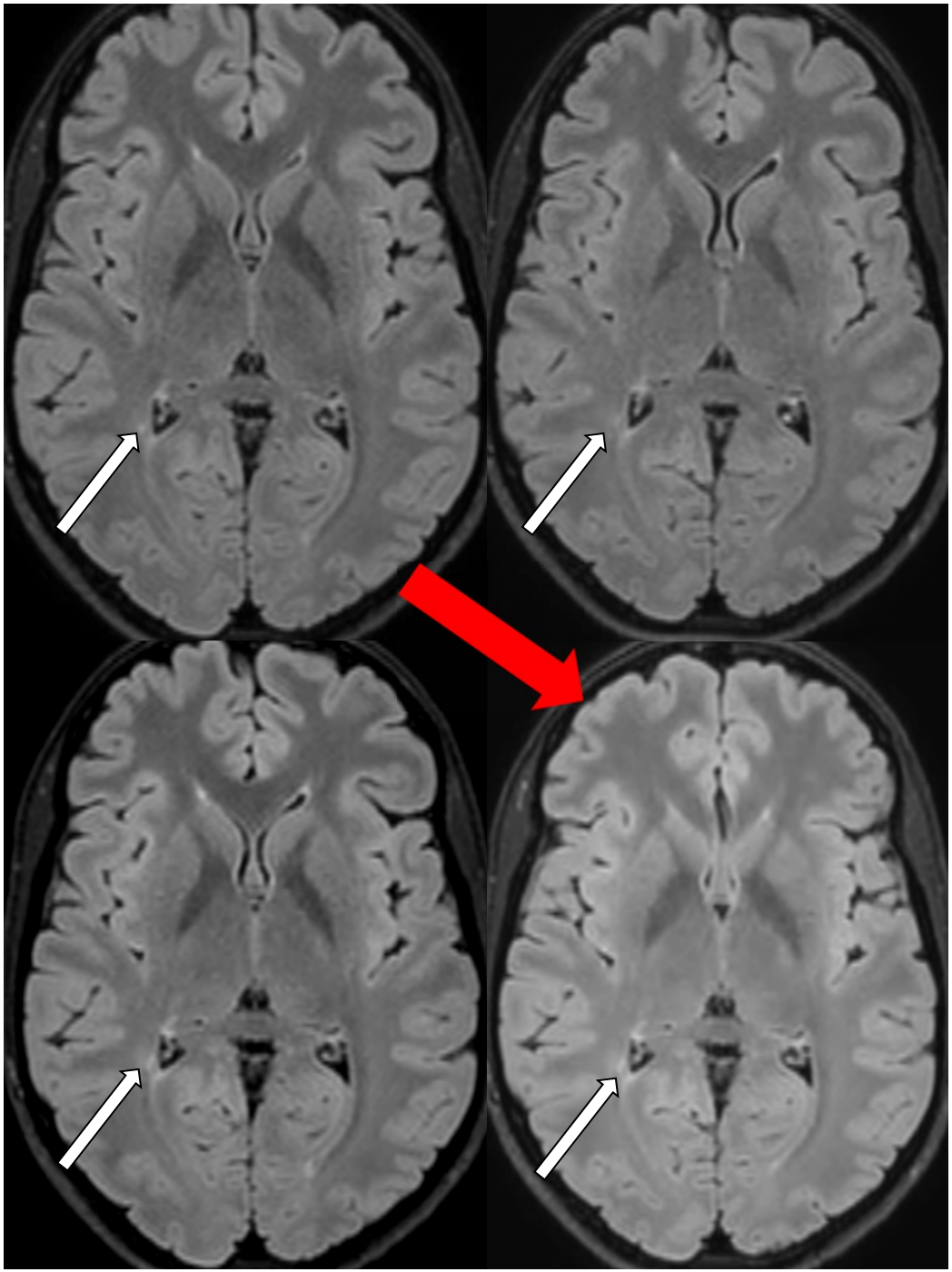
3D FLAIR 1.5 T und 3T: our choice CS Faktor 8.2 with different denoising grades

3D FLAIR
Original,
ohne CS



CS 8.2
weak

3D FLAIR, 3T, CS 8.2, 30%

CS weak→ strong:

a. Less noisy

b. Waxen background

c. Less contrast of deep gray matter to surroundings

d. Slight loss of details

CS 8.2
medium

CS 8.2
strong

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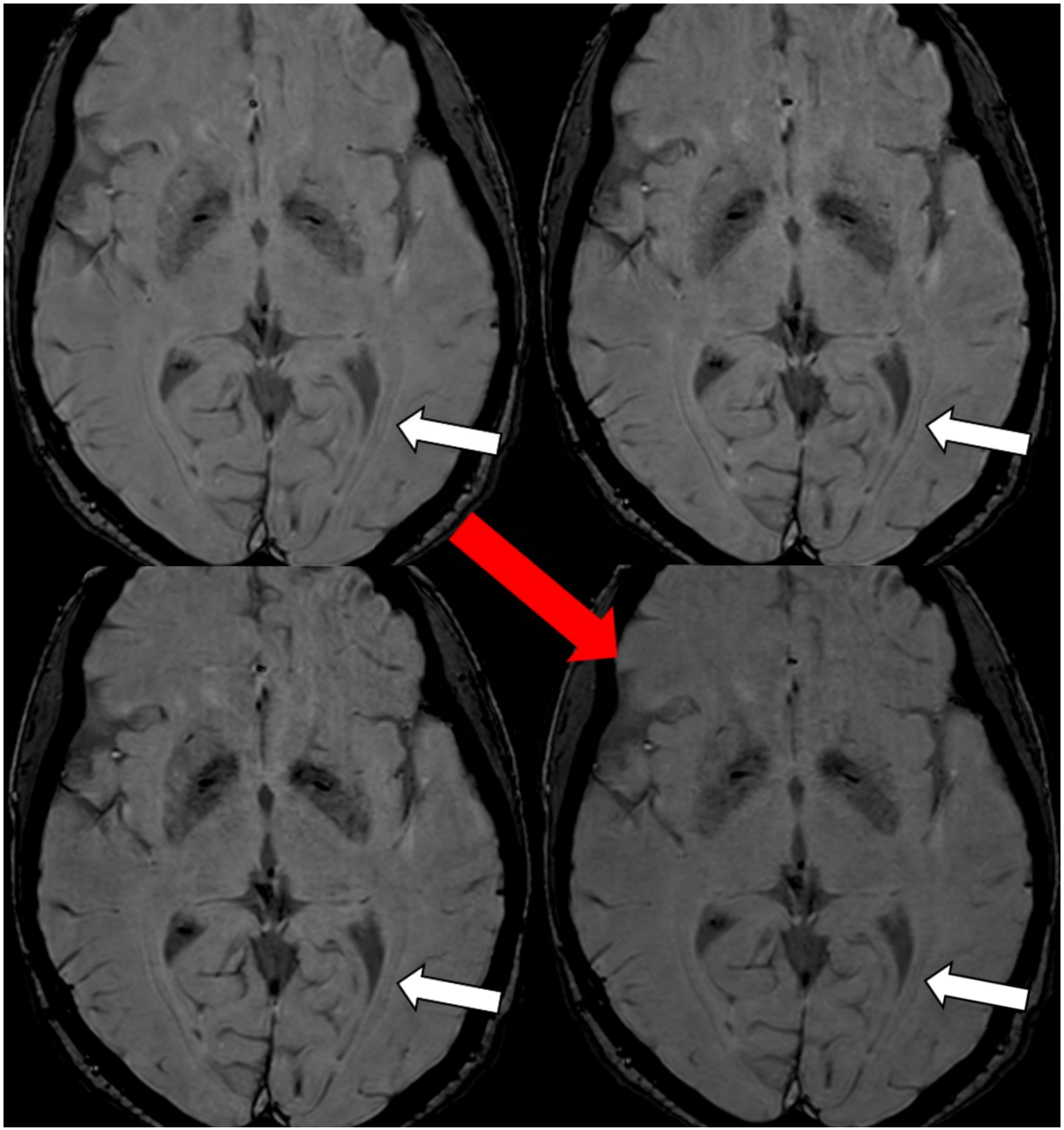
Our final choice:
3D FLAIR 1.5 T und 3T
CS Faktor 8.2 (30% time reduction)
with denoising grade medium

Increasing CS factor, sequence with low contrast-to-noise:
SWI

Transverse SWI 1.5 T

SWI **CS4**
medium



SWI **CS5**
medium

Big difference
CS4→CS7:
blurred, loss of
image details
(optic radiation)

SWI **CS6**
medium

SWI **CS7**
medium

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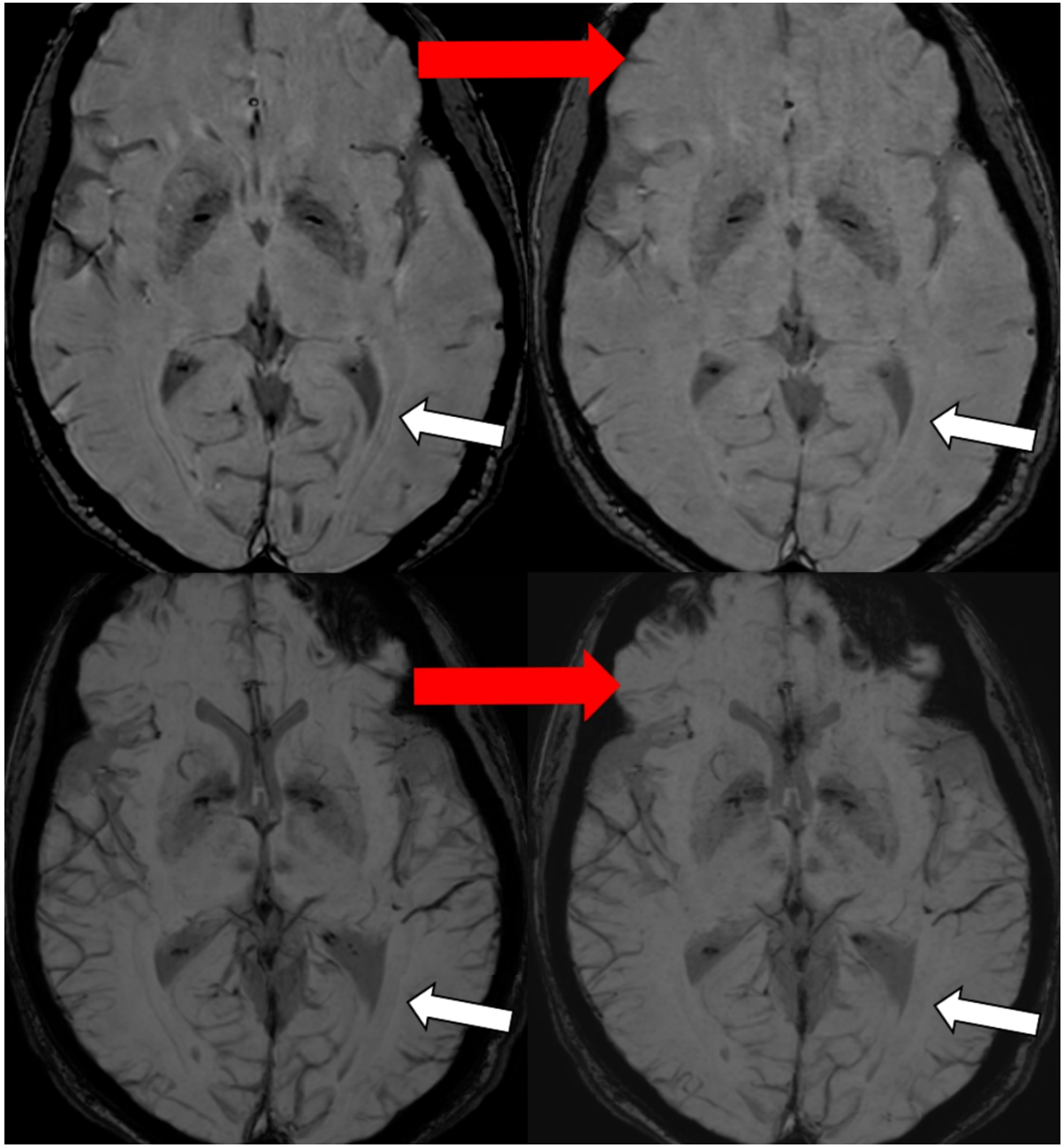
Transverse SWI 1.5 T: MinIP

SWI **CS4** medium



SWI **CS8** medium

Big difference
CS4→CS8: blurred, loss of image details (optic radiation)

SWI **CS4** medium **MinIP**

SWI **CS8** medium **MinIP**

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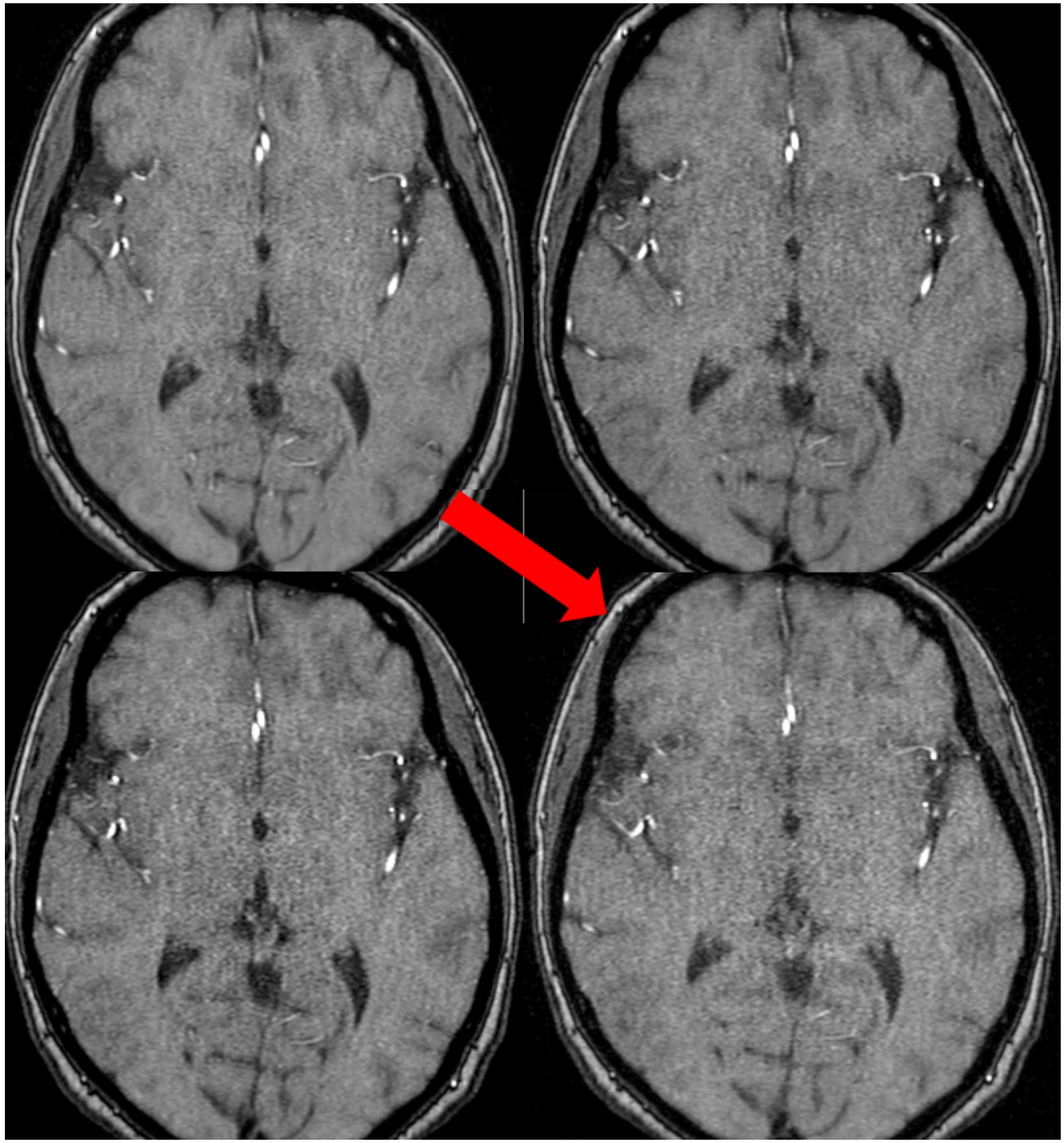
Increasing CS factor, sequence with high «contrast-to-noise»: 3D TOF

3D TOF 1.5T

no CS



CS 2.5
medium

No CS → CS 3.5:
more noise !

CS 3
medium

CS 3.5
medium

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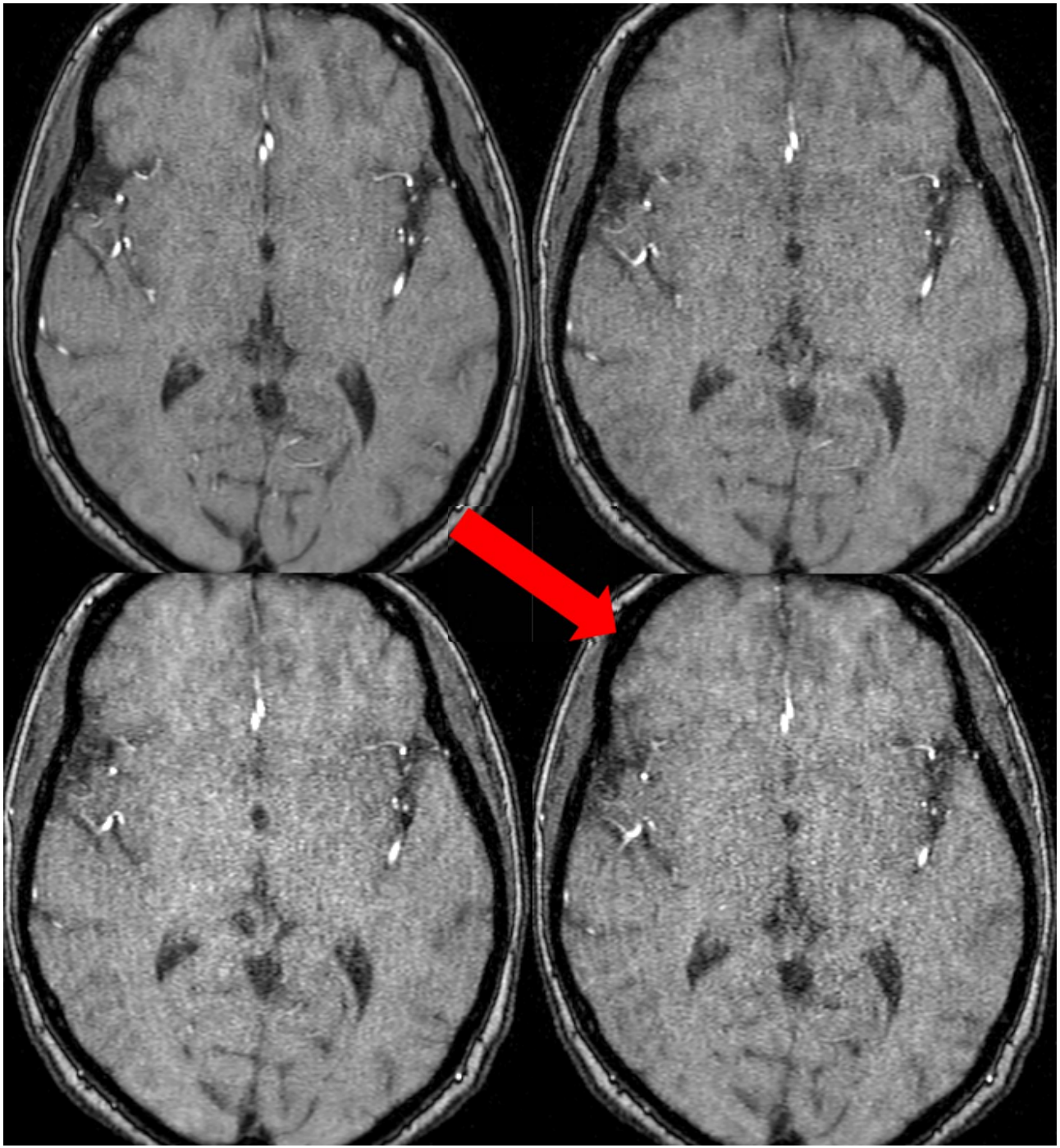
3D TOF 1.5T

No CS



CS 3.5
medium

Big difference
no CS → CS 4.5:
very noisy,
blurred

CS 4
medium

CS 4.5
medium

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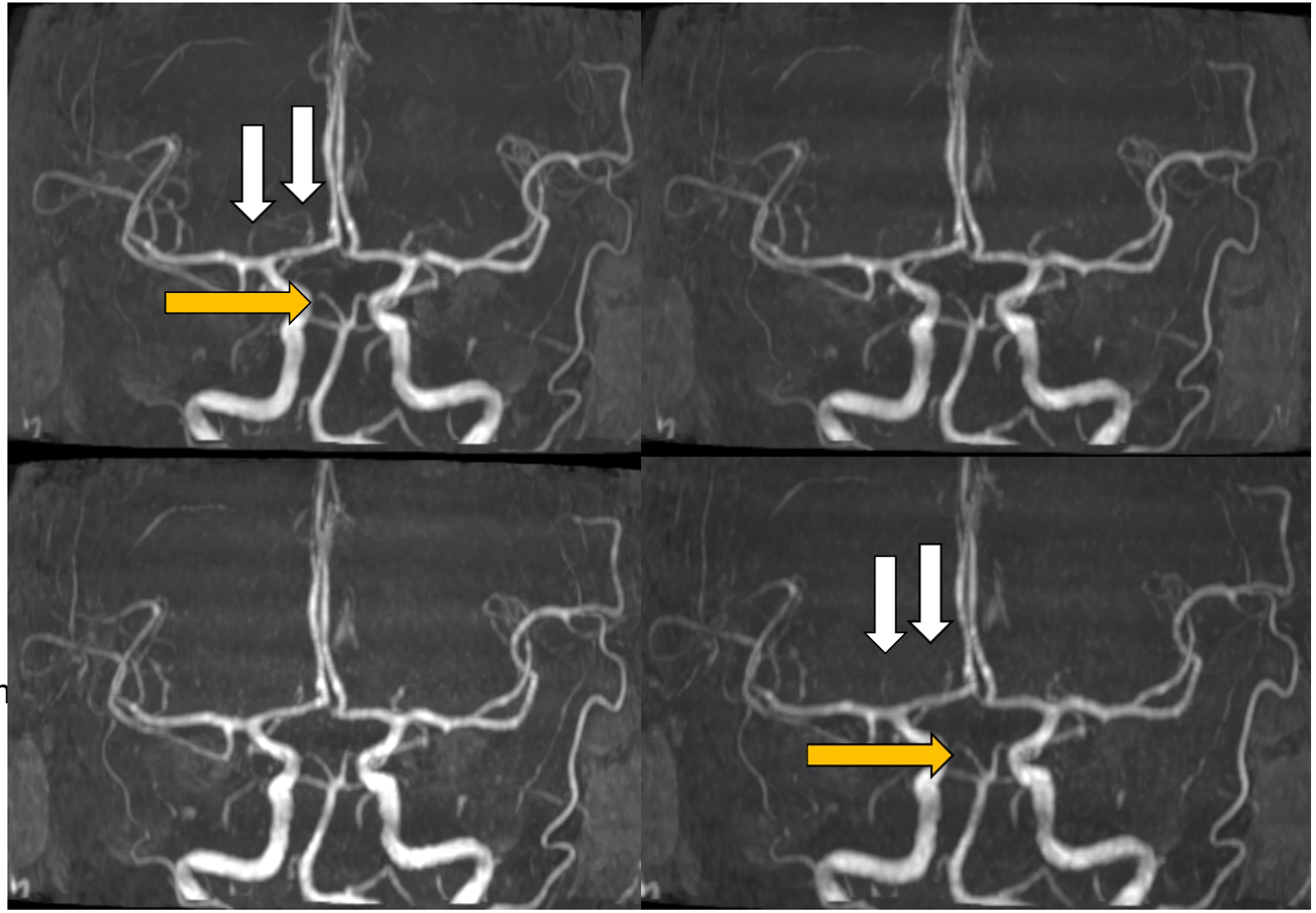
3D TOF MIP 1.5 T



Slight difference: no CS → CS 4.5: small vessels irregular, partly missing

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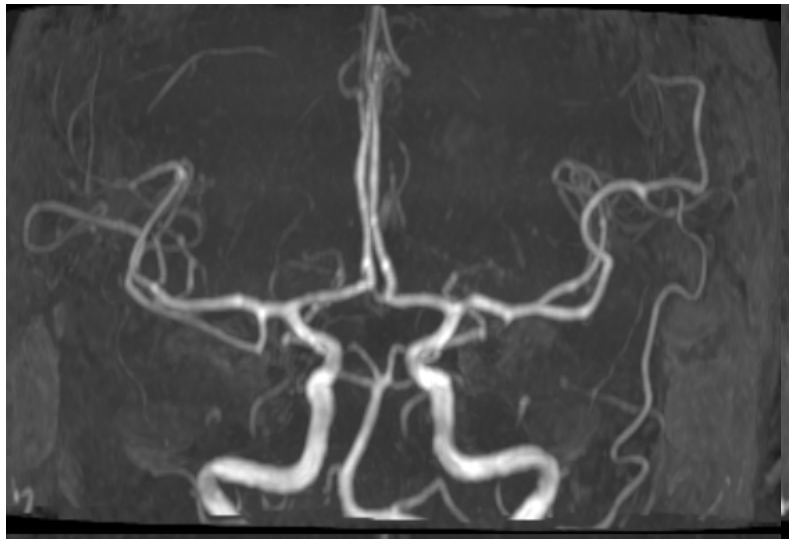
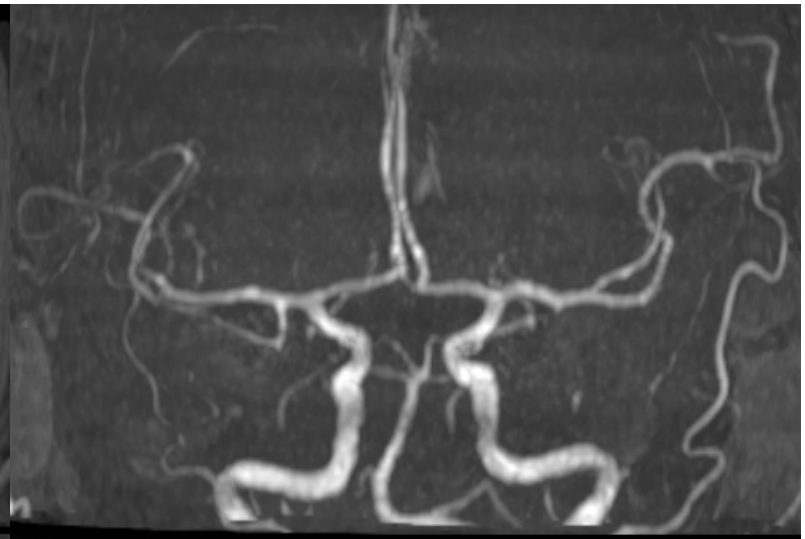
3D TOF MIP: Different denoising grades

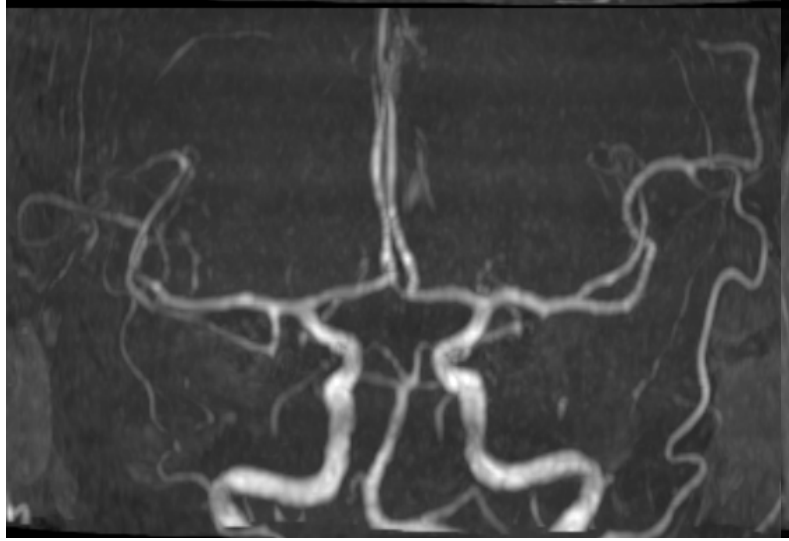
No CS



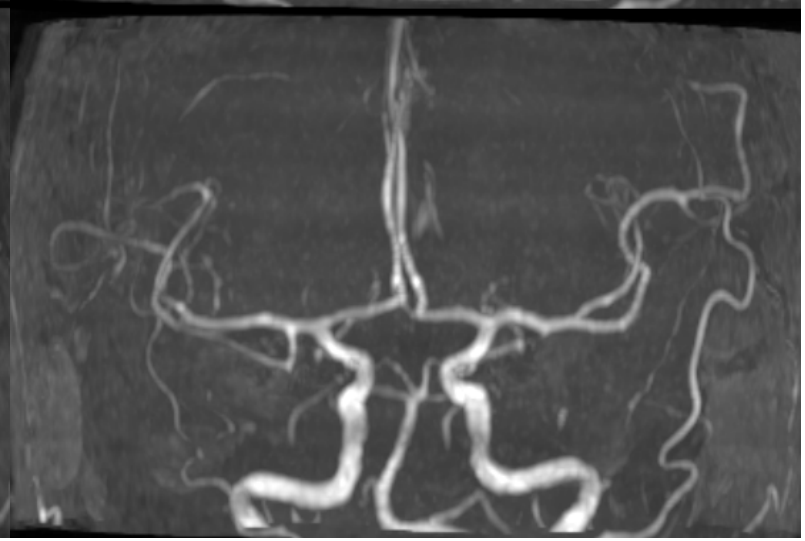
CS 4.5 **weak**



CS 4.5 **medium**



CS 4.5 **strong**



weak→strong: no difference

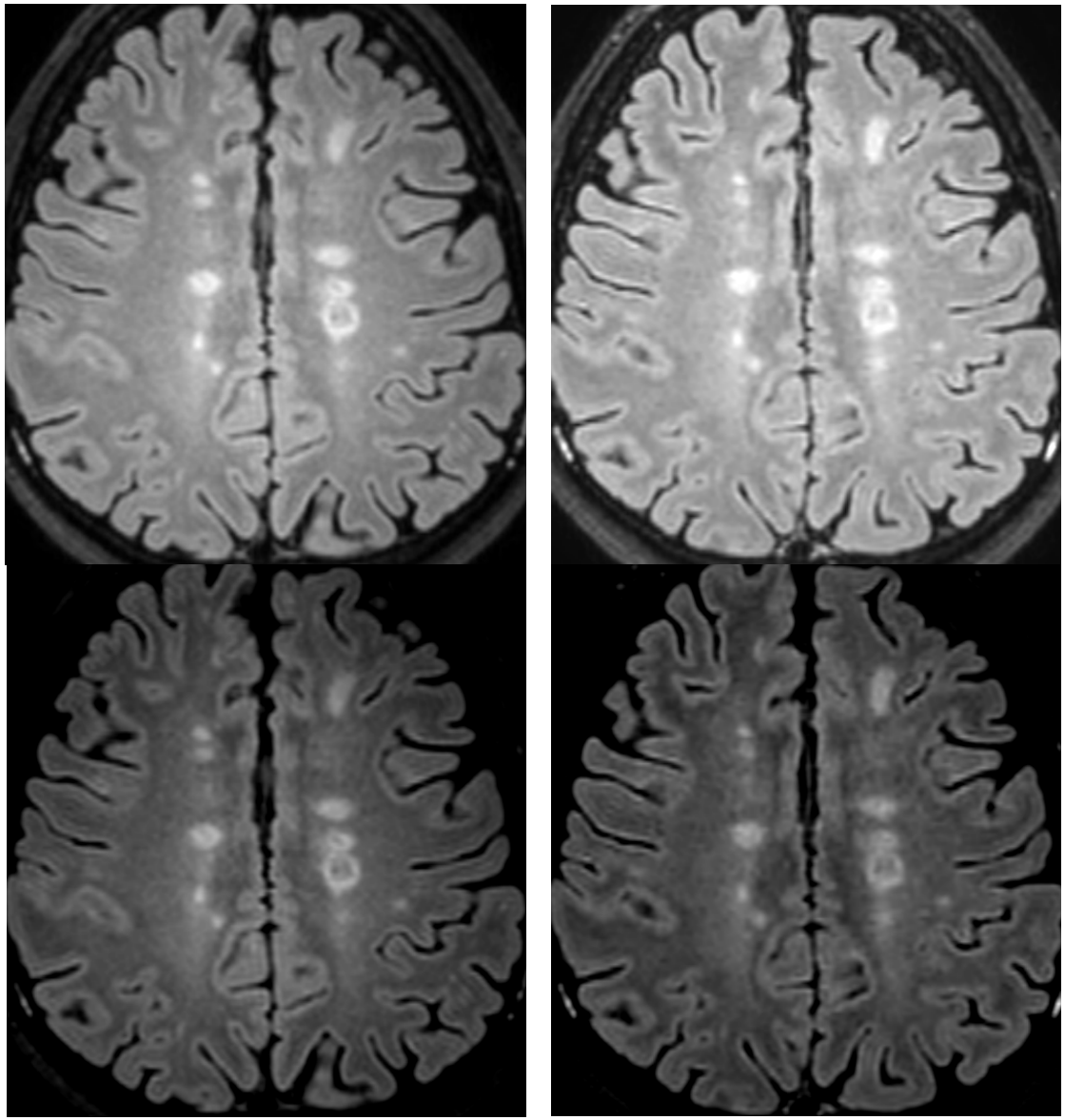
Compressed Sense: Our own recommendations for scan time reduction: CS factors

	standard sequence	sequence + CS: Philips®	sequence + CS: Winterthur
Brain	3D T1 TFE without/ with contrast	50%	CS 2.5: 50% weak
	3D T1 m-Dixon TFE with contrast	-	CS 7: 35%, medium
	3D FLAIR	30%, weak	CS 8.2: 30%, medium
	3D T1 Black Blood KM	25%	CS 5.75: 25%, weak
	3D T2 DRIVE inner ear	25%, strong	CS 2.9: 30%, strong
	SWIP	25%, weak	CS 5.7: 40%, weak
	3D TOF	30-40%, strong	CS3: 40%, strong
	3D PCA	???	CS 4: 50%, strong
	3D DIR	???, weak	CS 6.7: 30%, medium
	2D T2 cor Hippocampus	???	CS 1.5: 30%, weak

Application in patients

3D FLAIR without / with CS 8.2 medium, 3T, in multiple sclerosis

No CS, different window and level



CS 8.2 medium, different window and level

No CS→ CS 8.2:
a. little noise, unchanged
b. identical lesion detection rate and detectability

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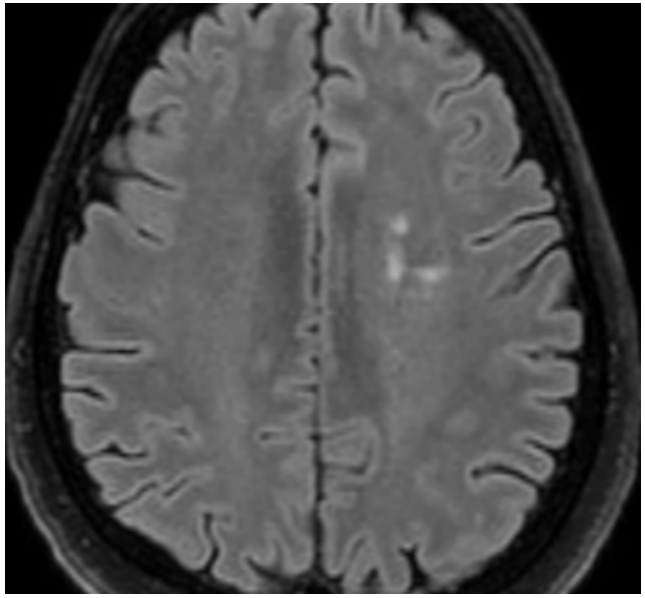
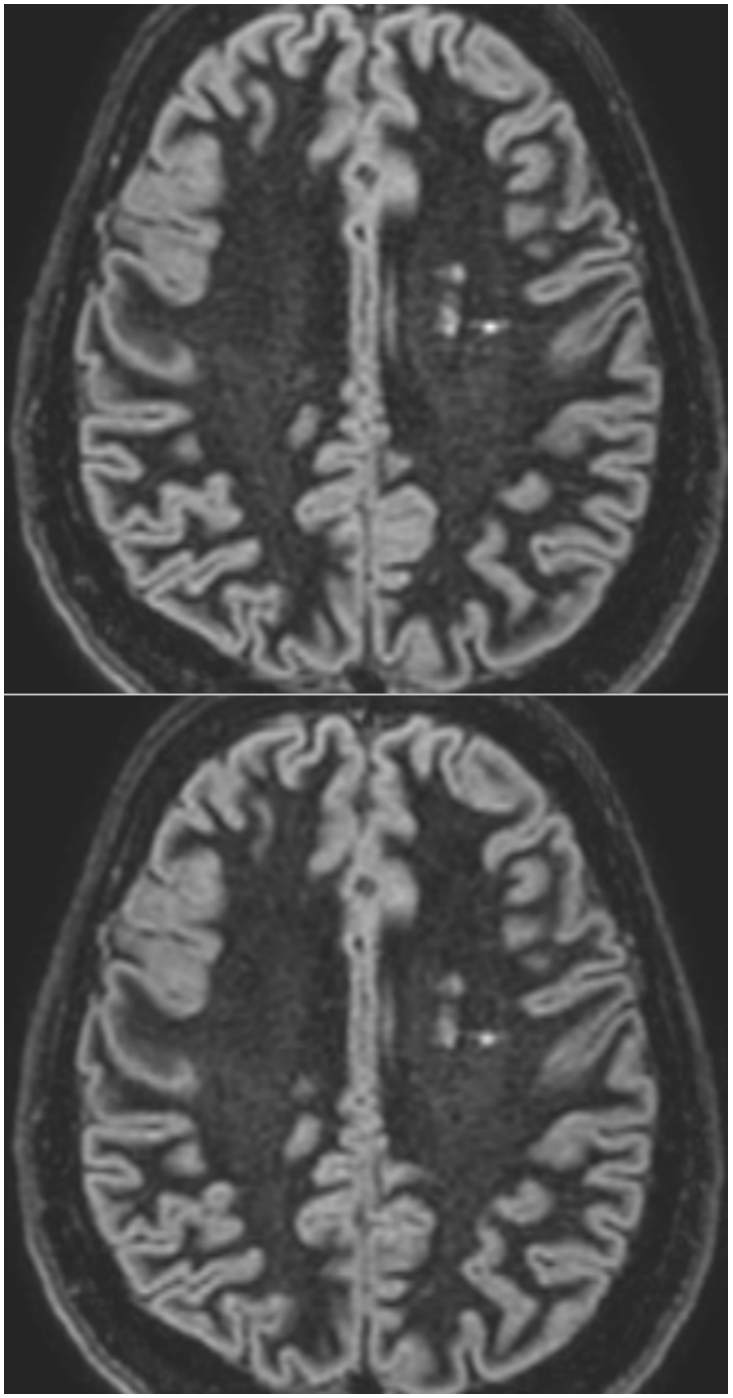
3D DIR without / with CS 6.7 medium, 3T, multiple sclerosis



3D FLAIR



No CS

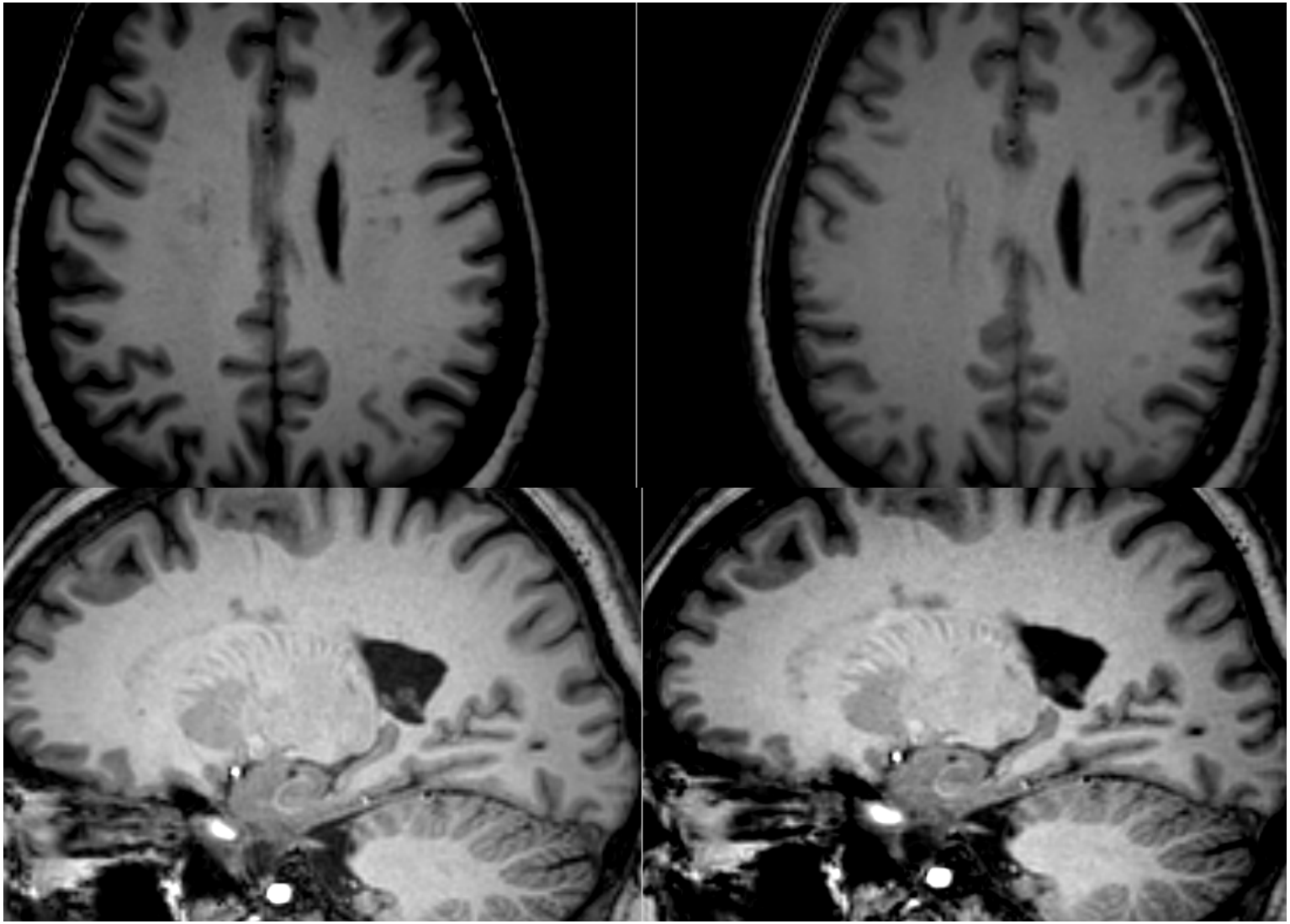
No CS→CS 6.7: identical lesion detection

CS 6.7 medium 30%

3D T1 TFE without / with CS 2.5 weak, 3T, in multiple sclerosis: black holes

No CS

CS 2.5 weak



No CS

CS 2.5 weak

No CS→
CS 2.5:
identical
lesion
detection

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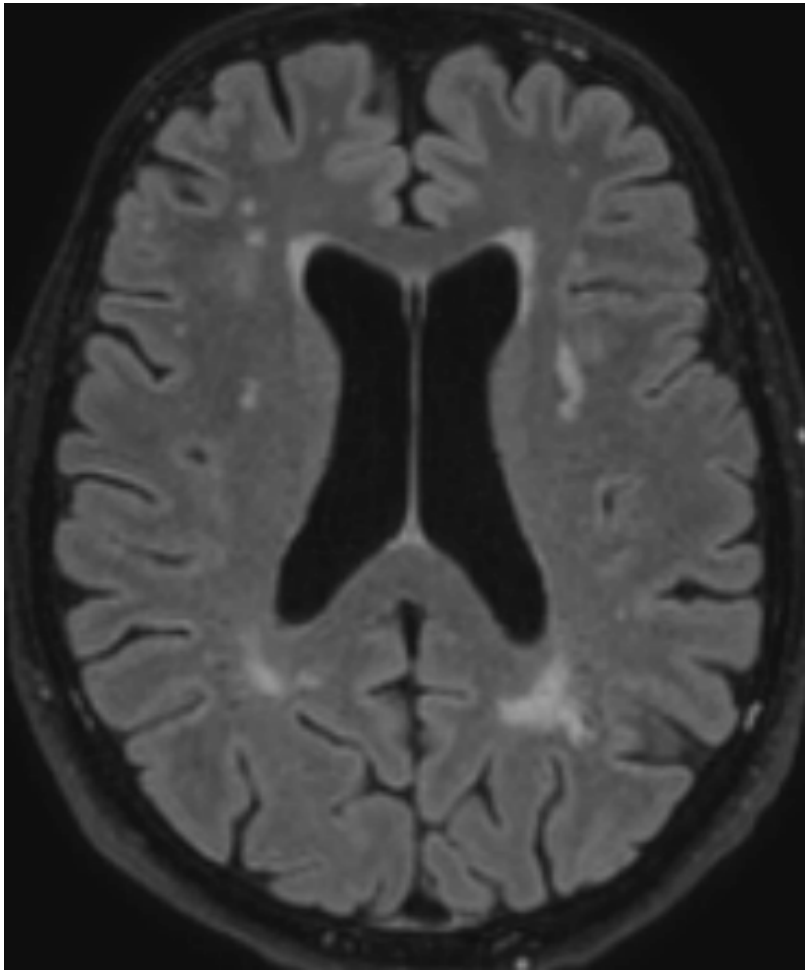
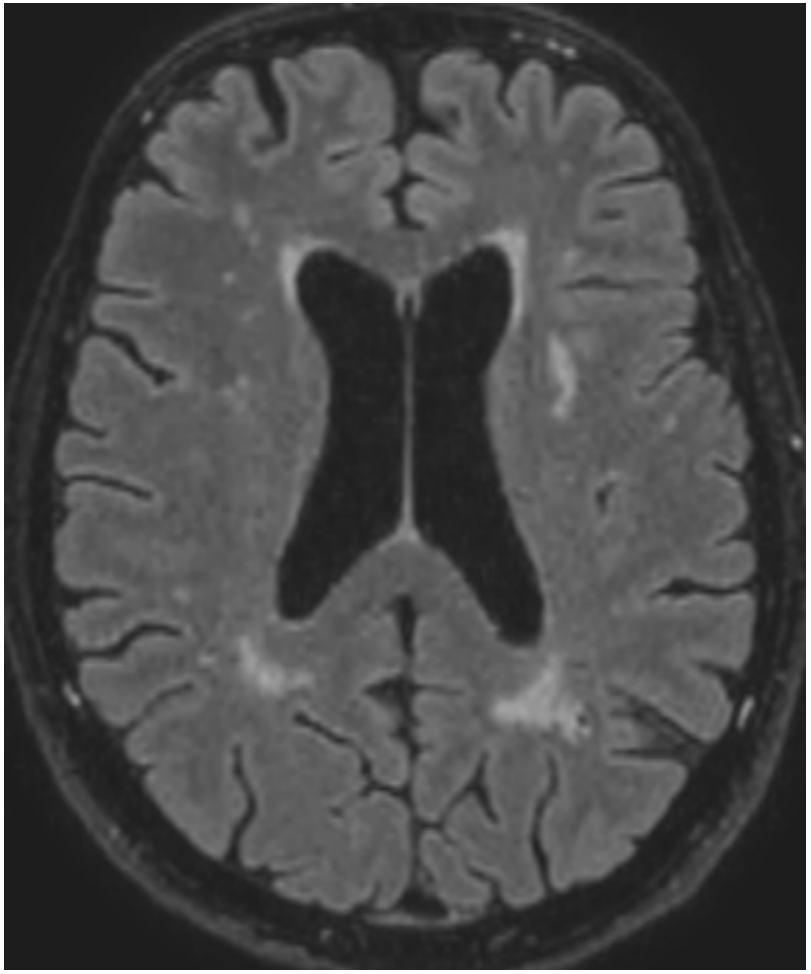
3D FLAIR without / with CS 8.2 medium 1.5T in microangiopathy



No CS



CS 8.2 medium

No CS→ CS 8.2

a.Slightly more background noise

b. Lesion detection identical

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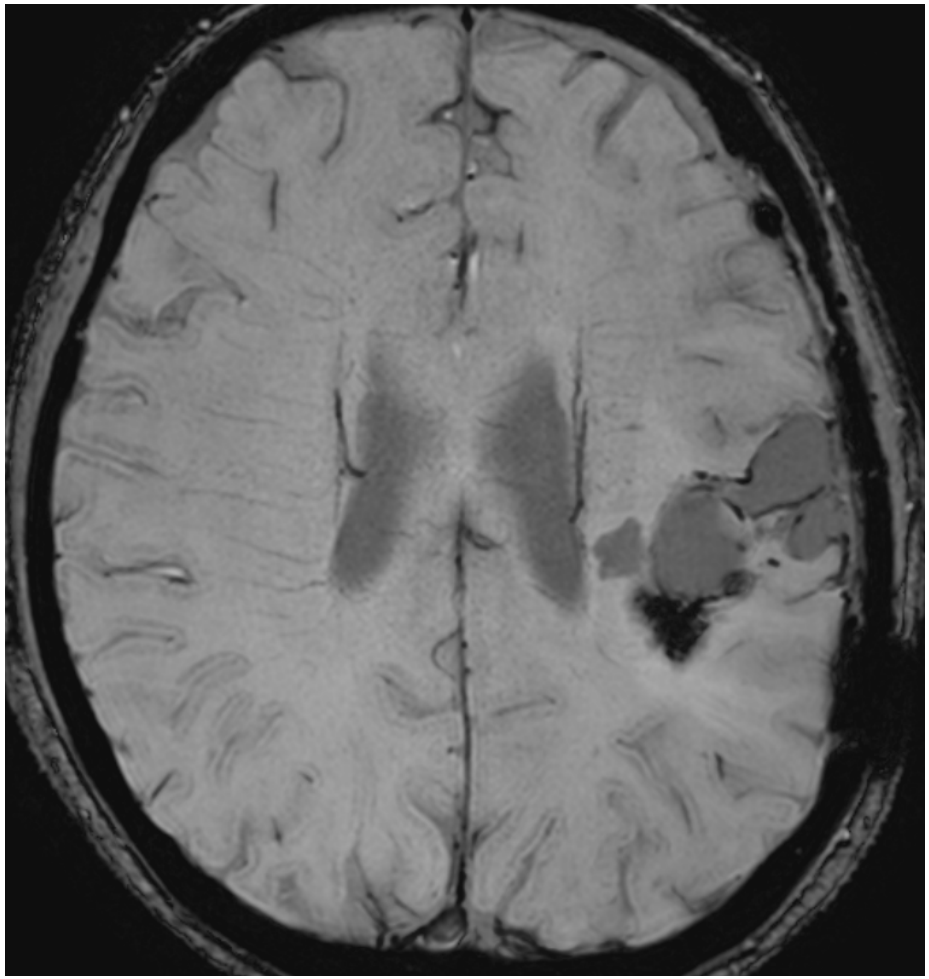
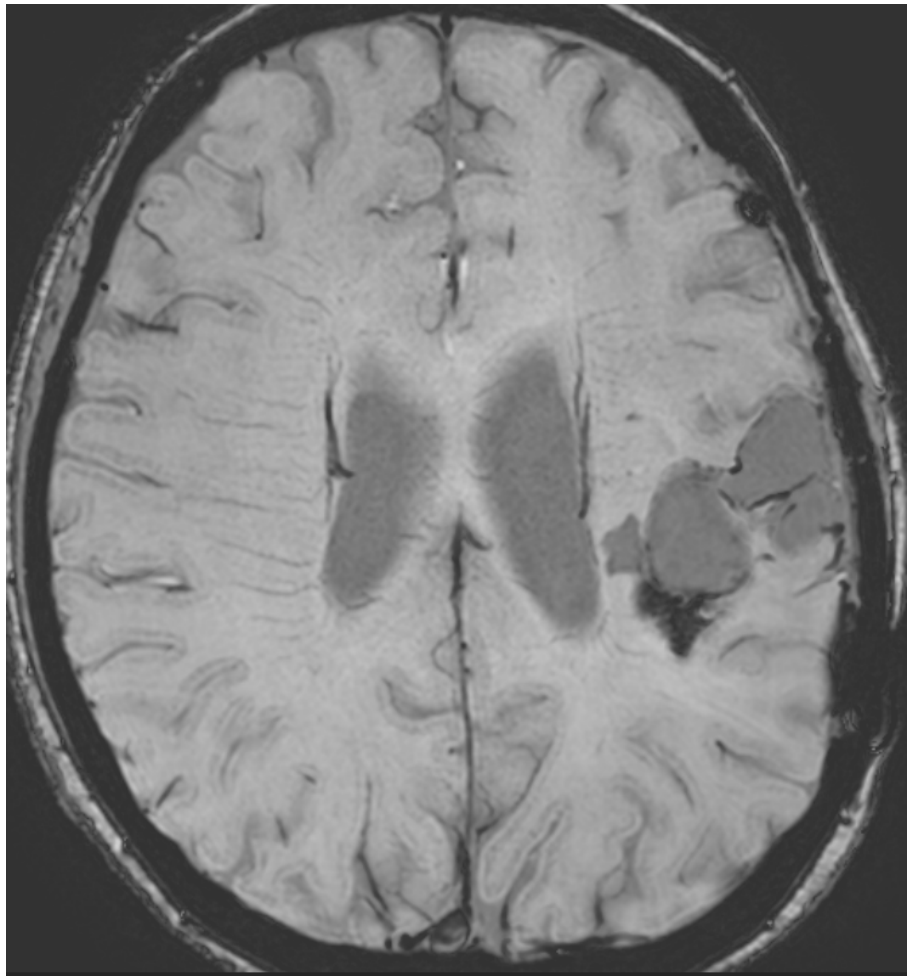
Postoperative contral after resection of oligodendroglioma: SWI CS 5.7, weak



Original



CS 5.7 weak

Lesion detection identical

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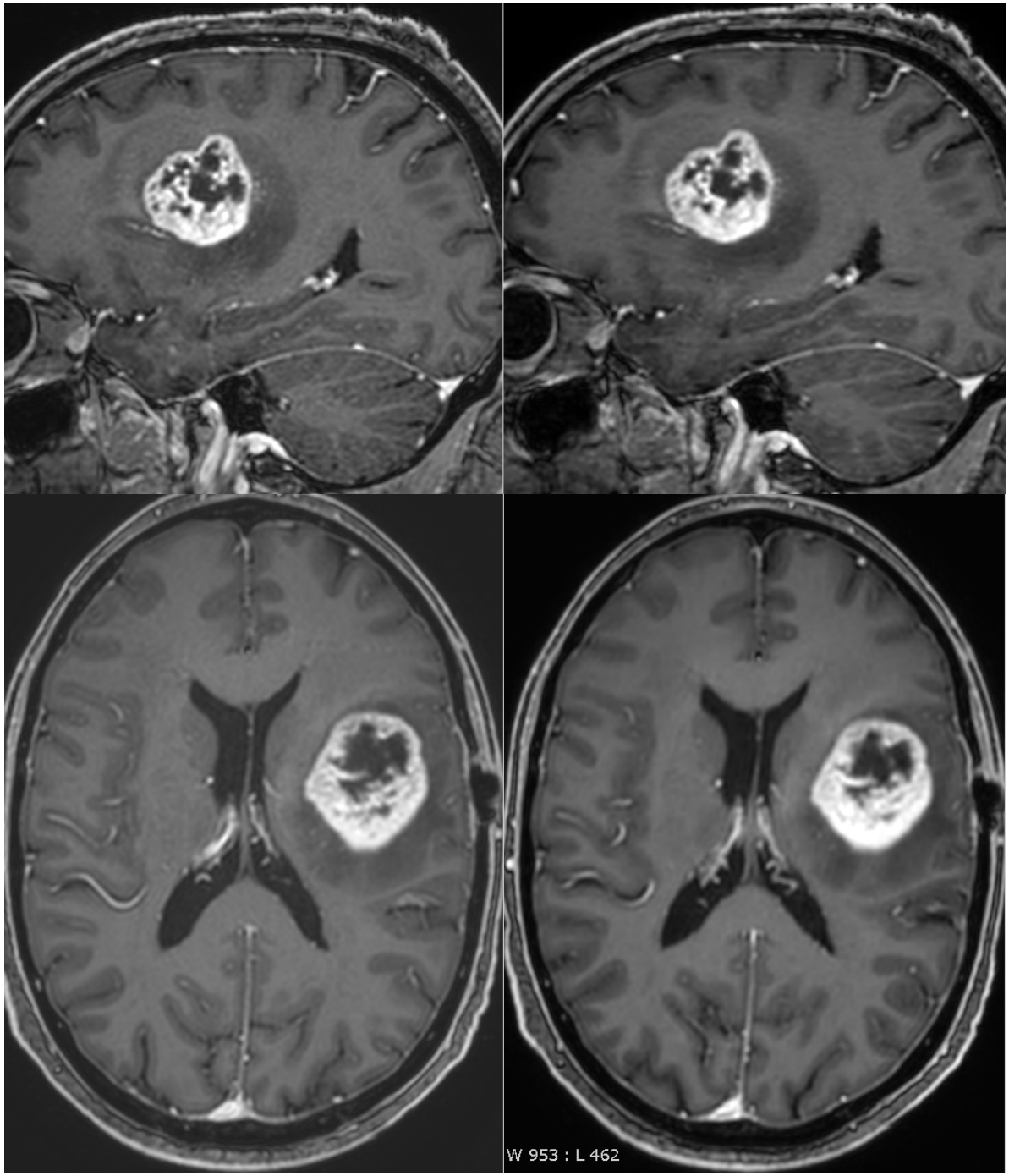
3D T1 TFE GD CS 2.5, 3T: Glioblastoma

No CS



CS 2.5 weak

No CS→ CS 2.5:
Good contrast gray – white matter, identical image details, sligthly blurred due to movement artefacts

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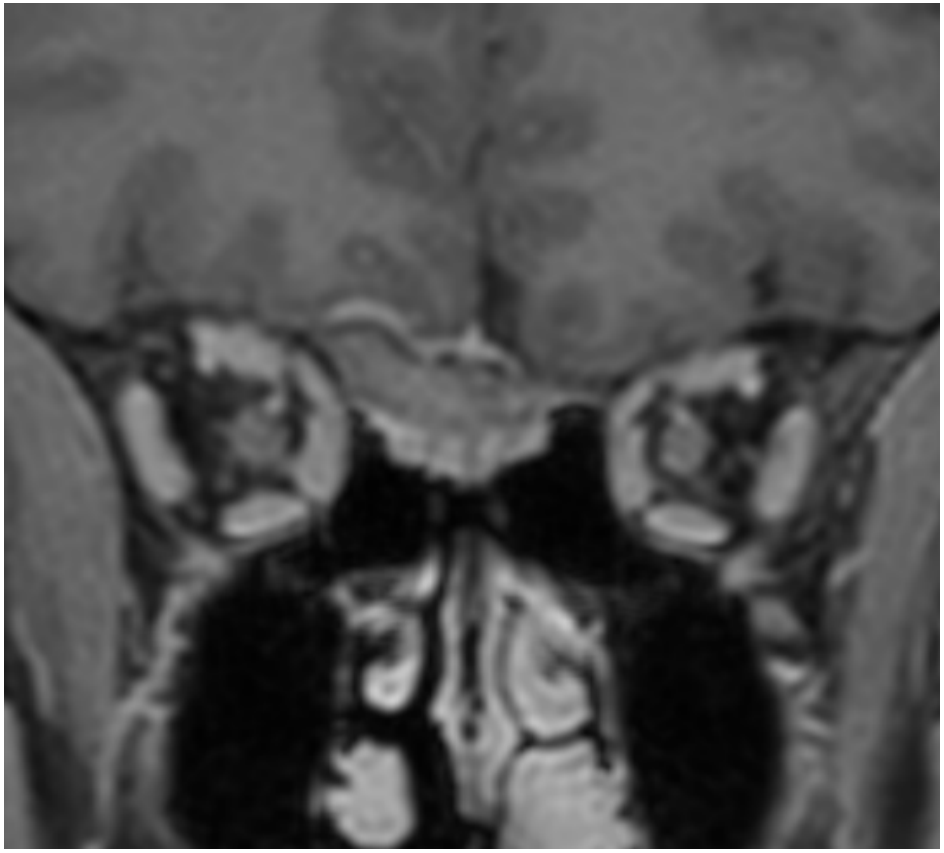
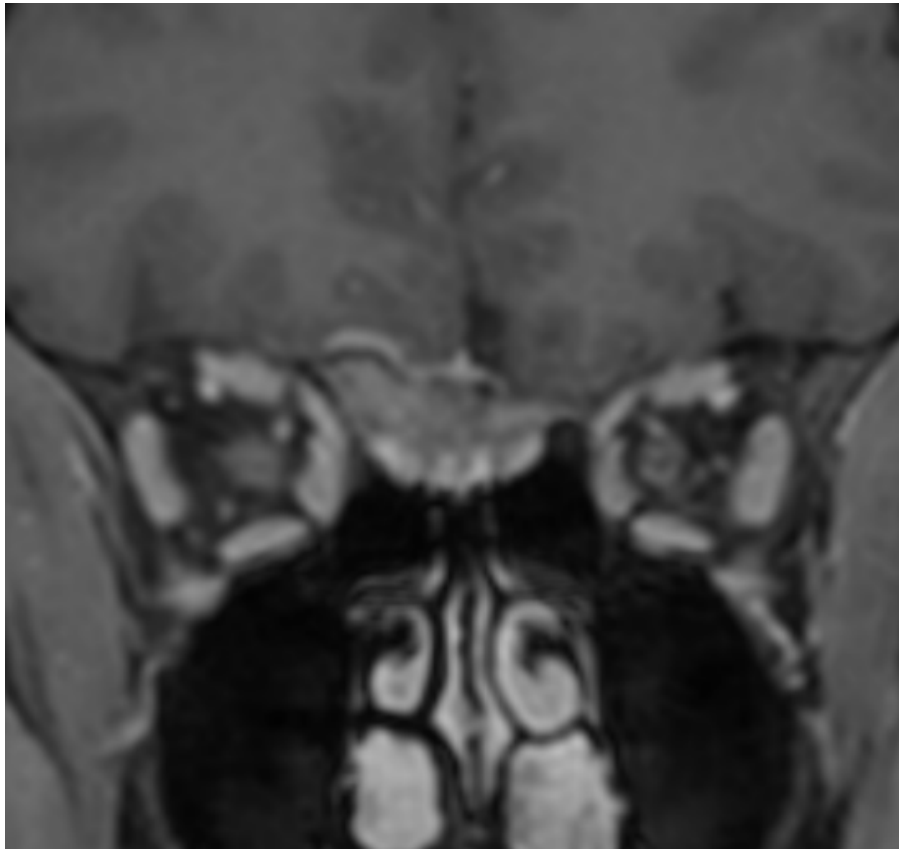
3D m-Dixon T1 TFE GD CS 7 medium 1.5 T: Intraosseous meningeoma



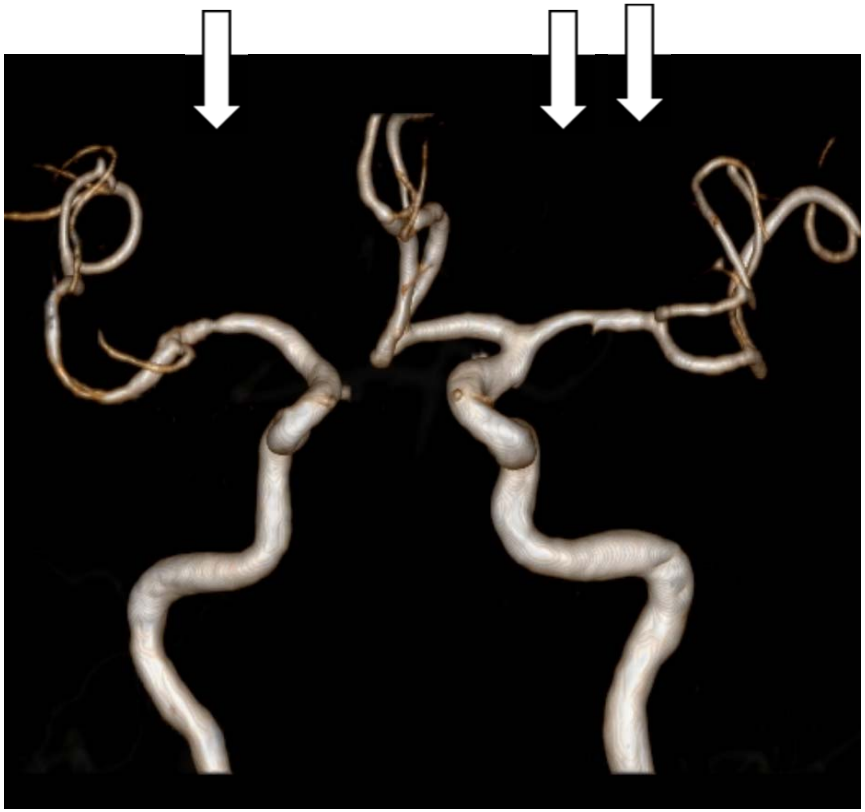
No CS

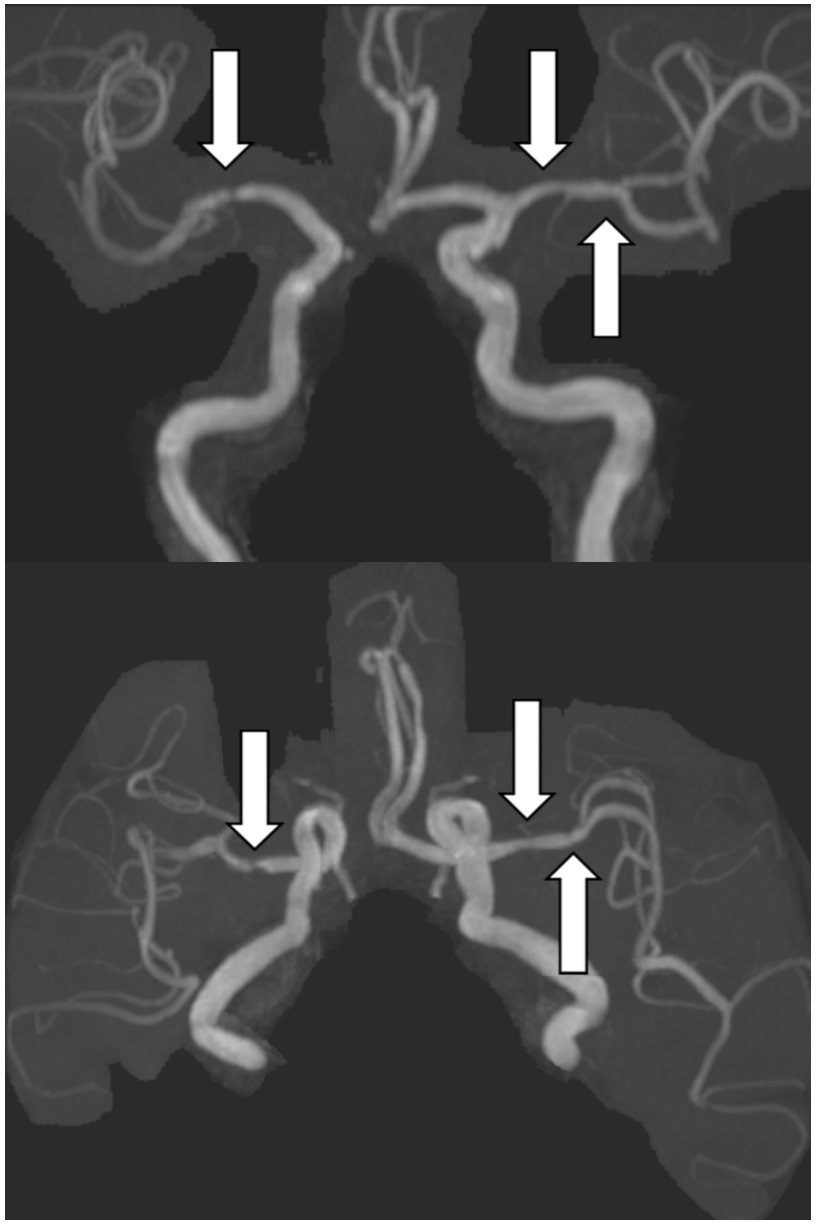


CS 7 medium

No → CS 7 medium: no difference

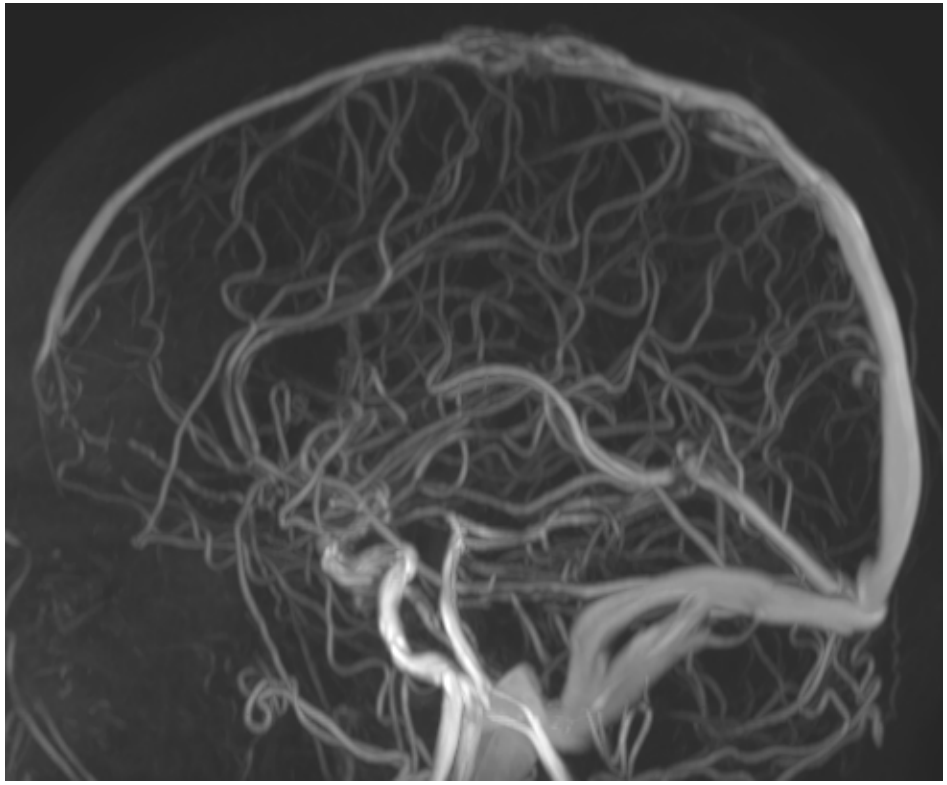
Asclerotic stenosis in both middle cerebral arteries on 3D TOF, MIP and 3D reconstruction



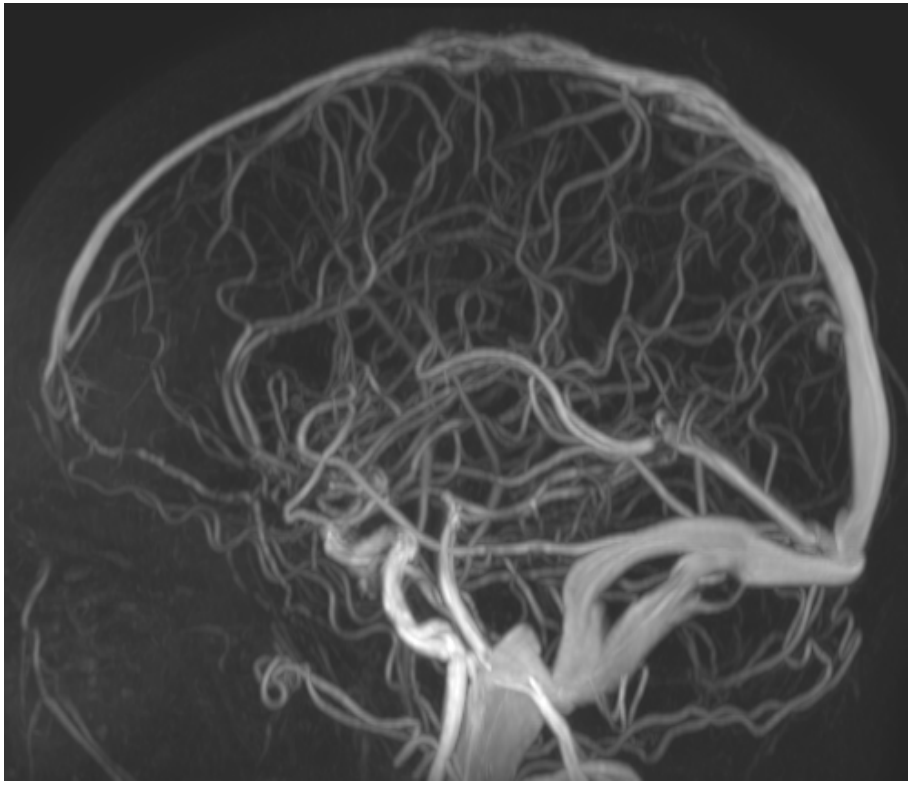


CS 3 strong

3D PC venography MIP, 3T: partially recanalized thrombosis of superior sagittal sinus 3T



No CS



CS 4 strong

No CS → CS 4 strong: no difference

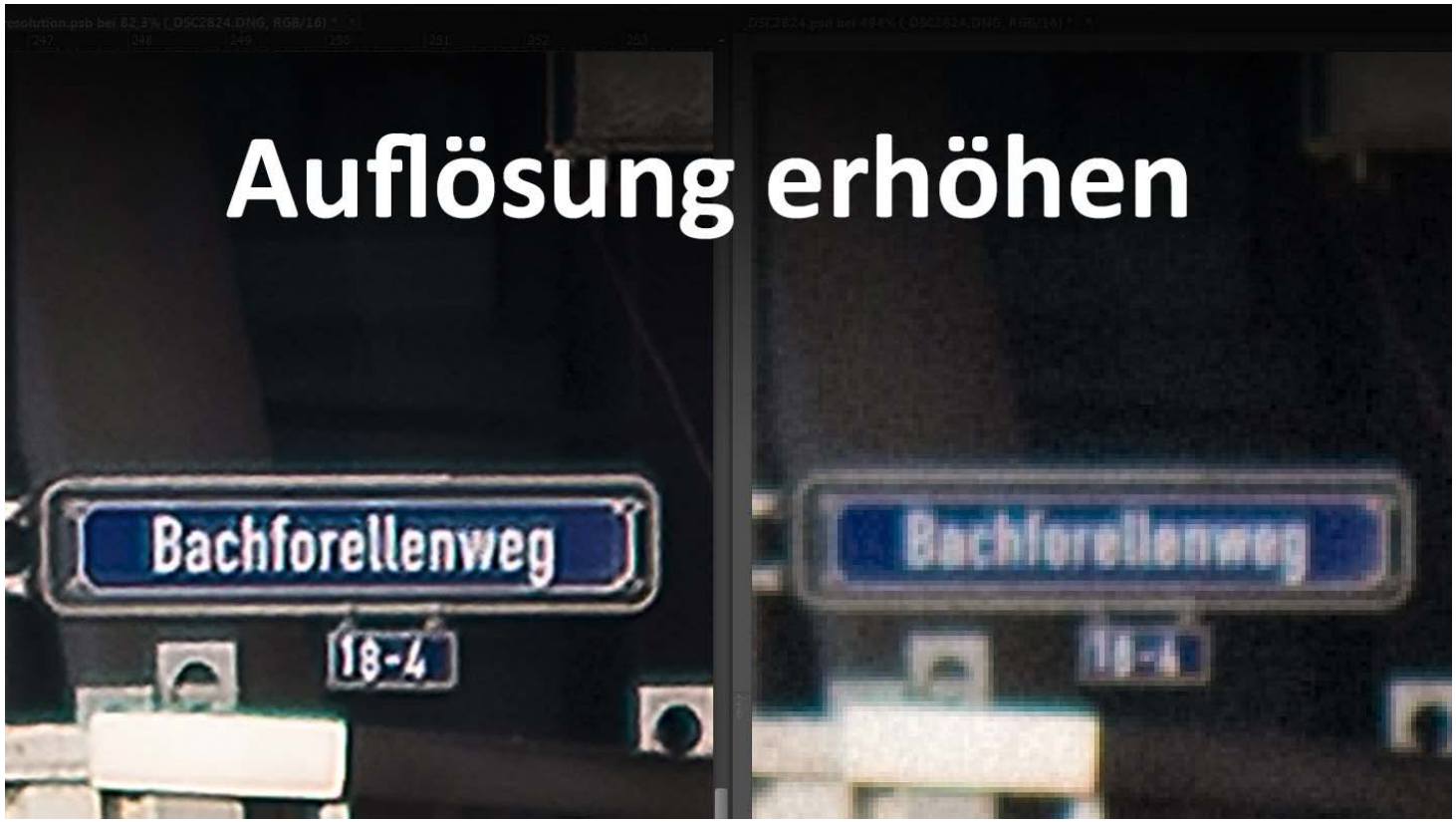
Compressed Sense: Scantime-Reduction 3T

	standard sequence	CS sequence: time reduction KSW	CS sequence: time reduction KSW
Compressed SENSE Brain	3D T1 TFE	CS 2.5: 50%, weak	7:32 min → 3:41 min.
	3D T1 m-Dixon TFE GD	CS 7: 35%, medium	→ 04:38 min.
	3D FLAIR	CS 8.2: 30%, medium	4:43 min. → 3:17 min.
	3D T1 Black Blood GD	CS 5.75: 25%, weak	4:37 min.→ 3:42 min.
	3D T2 DRIVE inner ear	CS 2.9: 30%, strong	5:39 min.→ 3:56 min.
	SWIP	CS 5.7: 40%, weak	4:33 min.→ 2:43 min.
	3D TOF	CS 3: 40%, strong	5:56 min. → 4:09 min.
	3D PCA	CS 4: 50%, strong	6:20 min. → 3:17 min.
	3D DIR	CS 6.7: 30%, medium	6:20 min. → 4:08 min.
	2D T2 cor Hipp.	CS 1.5: 30%, weak	4:32 min. → 3:04 min.

Compressed Sense: Scantime-Reduction 1.5 T

	standard sequence	CS sequence: time reduction Winterthur	CS sequence: time reduction Winterthur
Compressed SENSE Brain	3D T1 m-Dixon TFE nativ	Nativ: CS7, medium	5:37 min. → 3:41min.
	3D T1 m-Dixon TFE GD	CS 7: 35%, medium	5:37 min. → 3:41 min.
	3D FLAIR	CS 8.2: 30% medium	5:02 min. → 3:36 min.
	3D T1 Black Blood GD	CS 5.75: 25% weak	5:07 min. → 3:42 min.
	3D T2 DRIVE inner ear	CS 2.9: 30% strong	5:26 min. → 4:00 min.
	SWIP	CS 5.7: 40%, weak	4:54 min. → 2:48 min.
	3D TOF	CS 3: 40% strong	3:58 min. → 2:25 min.
	3D PCA	CS 4: 50% strong	6:49 min. → 3:31 min.
	3D DIR	CS 6.7: 30% medium	6:53 min. → 4:57 min.

Part 2:
Increase the spatial resolution with CS



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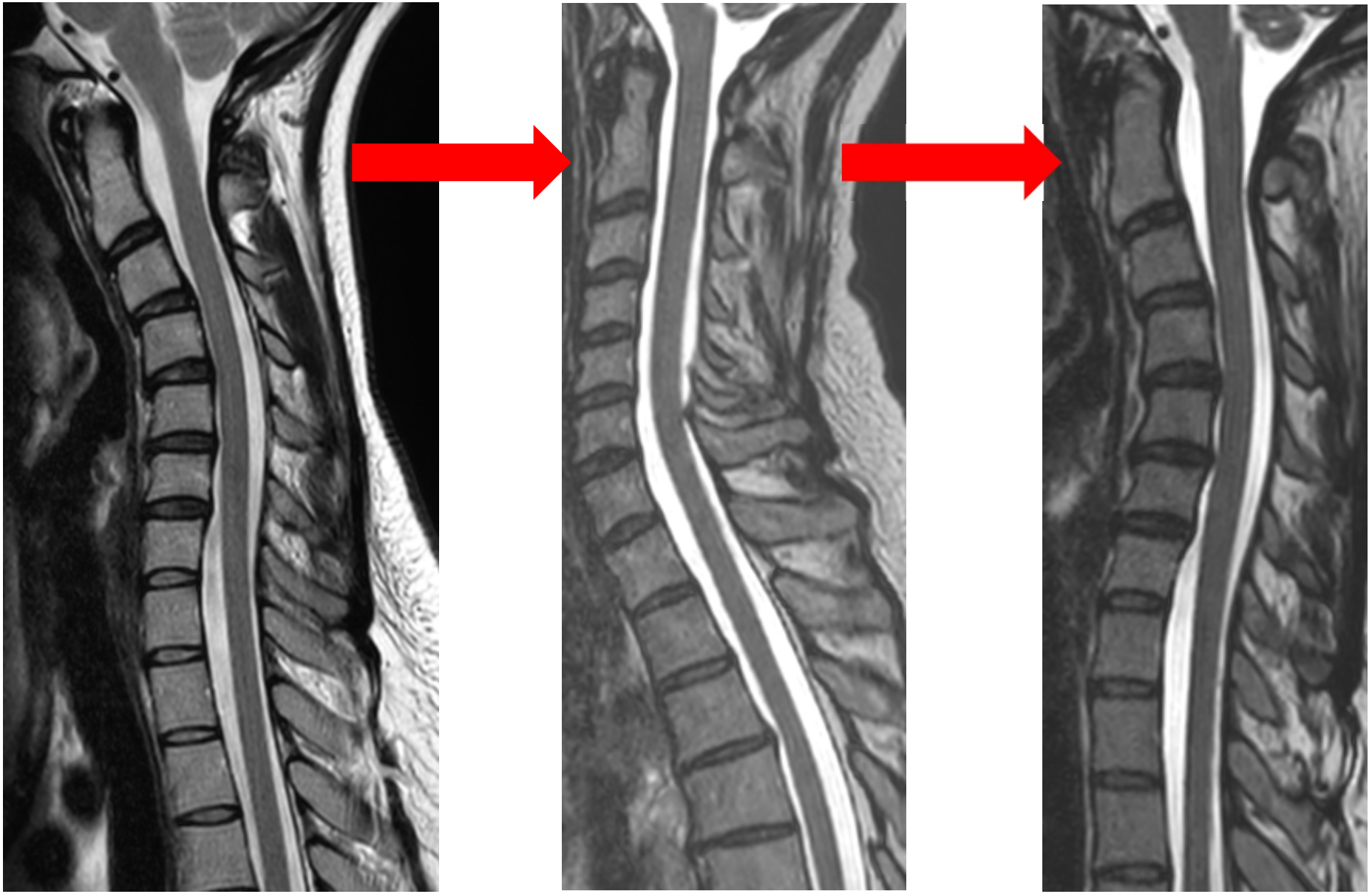
Cervical spine Ingenia 1.5T

3D T2 Spine View cervical spine 1.5 T

2D T2 TSE, 0.7 x 0.85 x 3mm, 03:36 min.

3D T2 spine view Philips®, 0.9 x 1 x 1.2, 05:21 min.

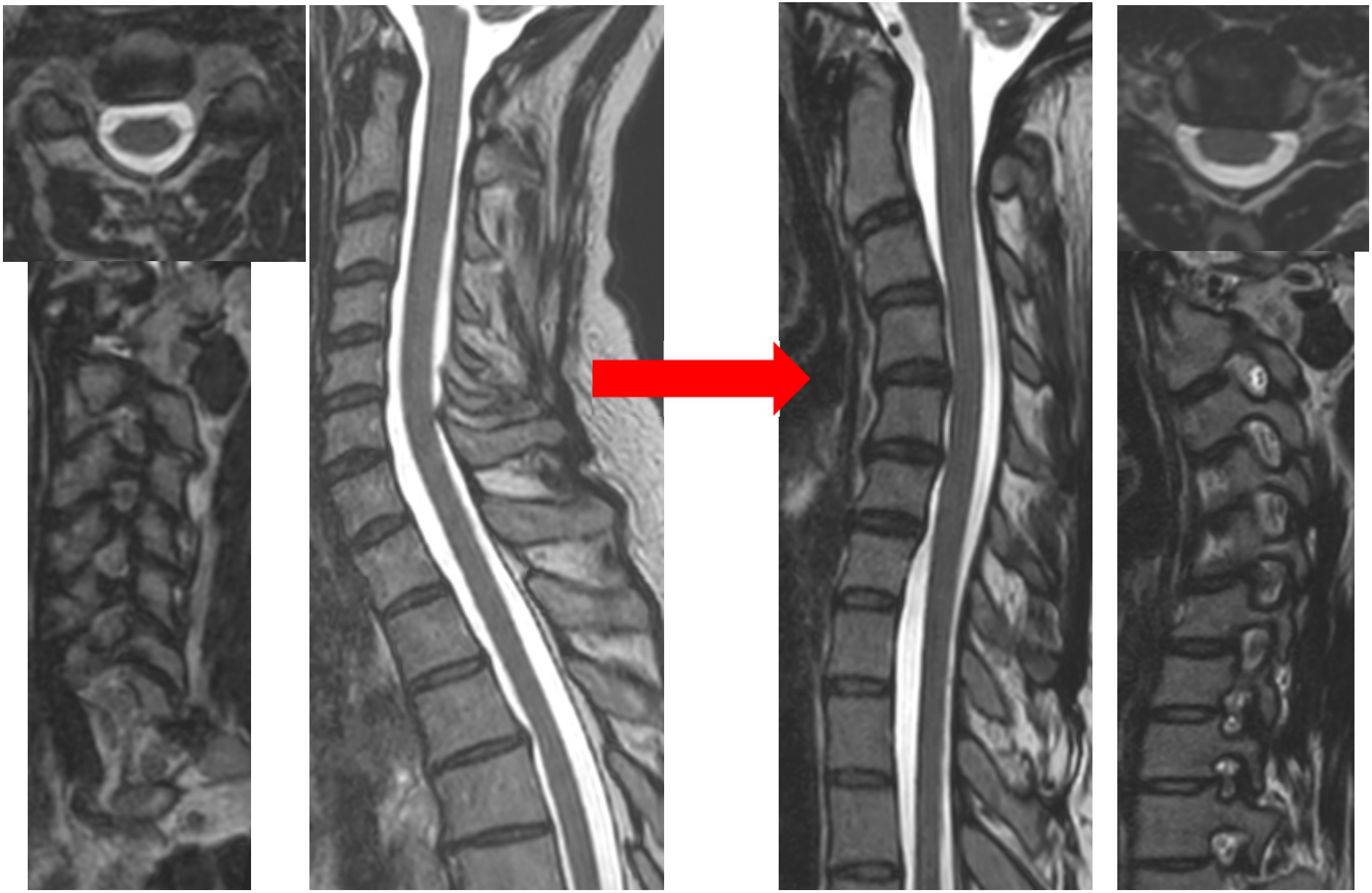
3D T2 spine view, 0.8 mm isotrop, CS 3.5, 6min.



3D T2 spine view cervical spine 1.5 T: reconstructions

Philips® sequence, no CS,voxel 0.9x1 x1.2 mm

high resolution, voxel 0.8 mm isotrop, CS 3.5



3D T2 spine view cervical spine CS 3.5 at 1.5 T

weak

medium

strong

voxel 0.8 mm, isotrop, 6min.

Denoising grade weak → strong: no difference in image quality

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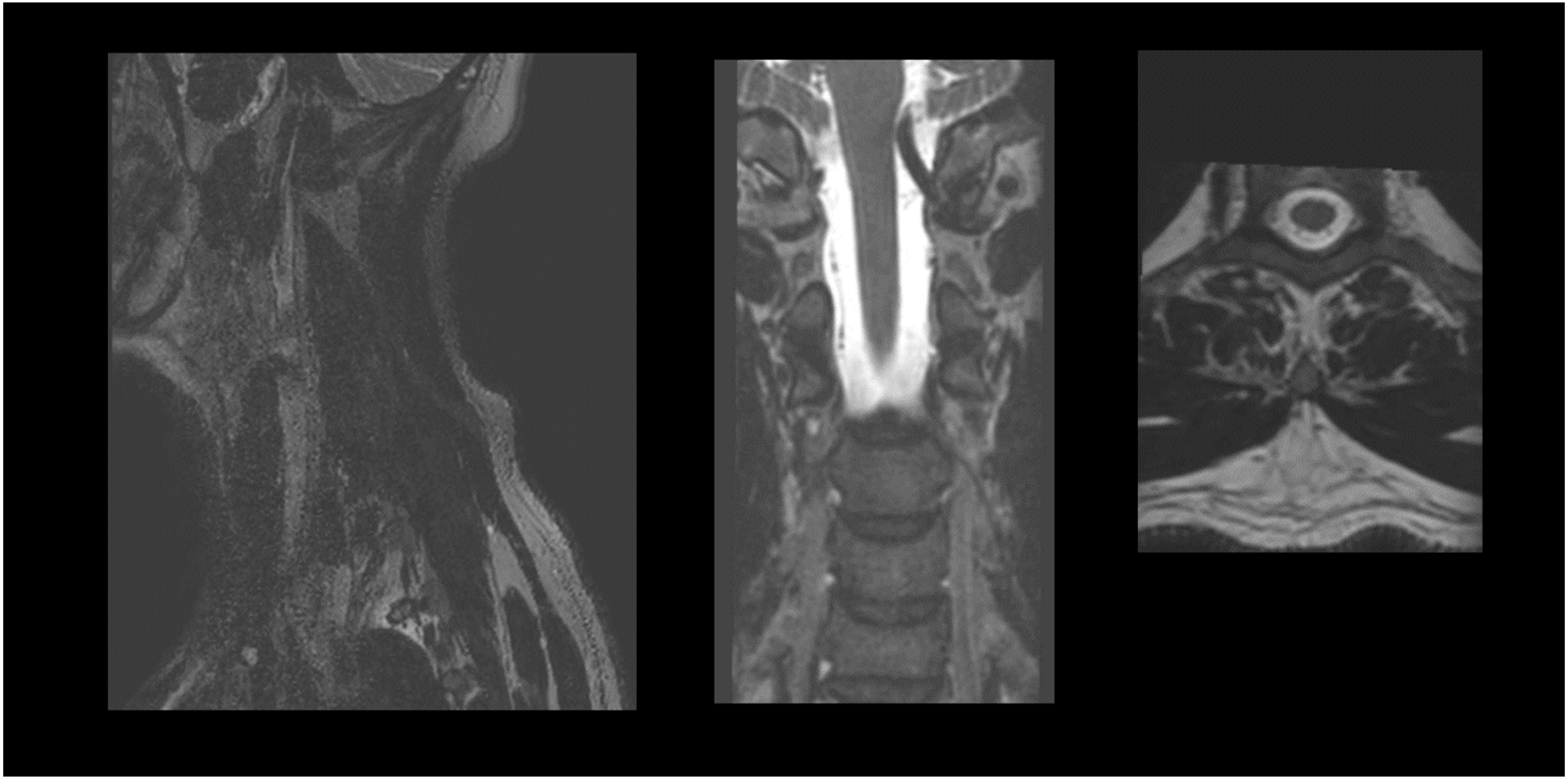
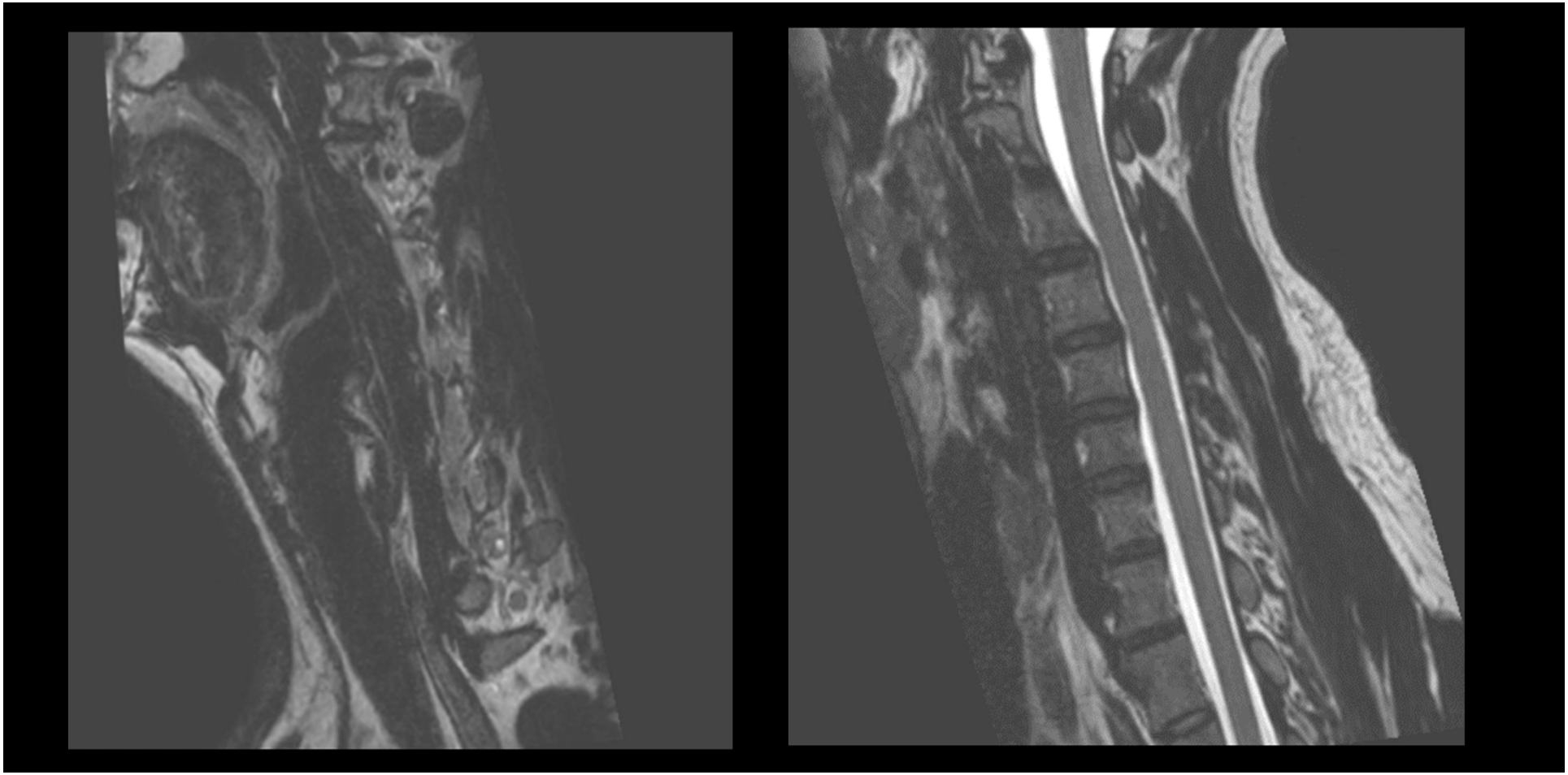
3D T2 spine view cervical spine 1.5T

3D T2 spine view cervical spine Ingenia 1.5 T



26.4.2018, 625660

3D T2 spine view cervical spine Ingenia 1.5T with sagittal oblique reconstructions



26.4.2018, 625660

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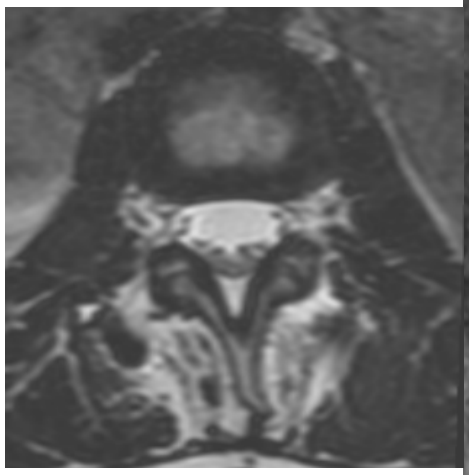
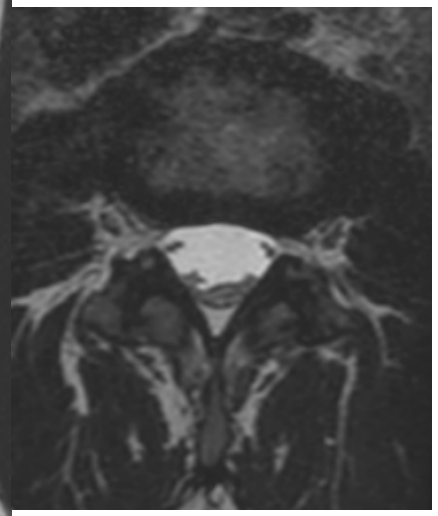
3D T2 spine view lumbar spine 1.5T

3D T2 spine view lumbar spine 1.5 T

3D T2 spine view Philips®; voxel 0.9 x 1 x 1.4 mm, 05:35 min.

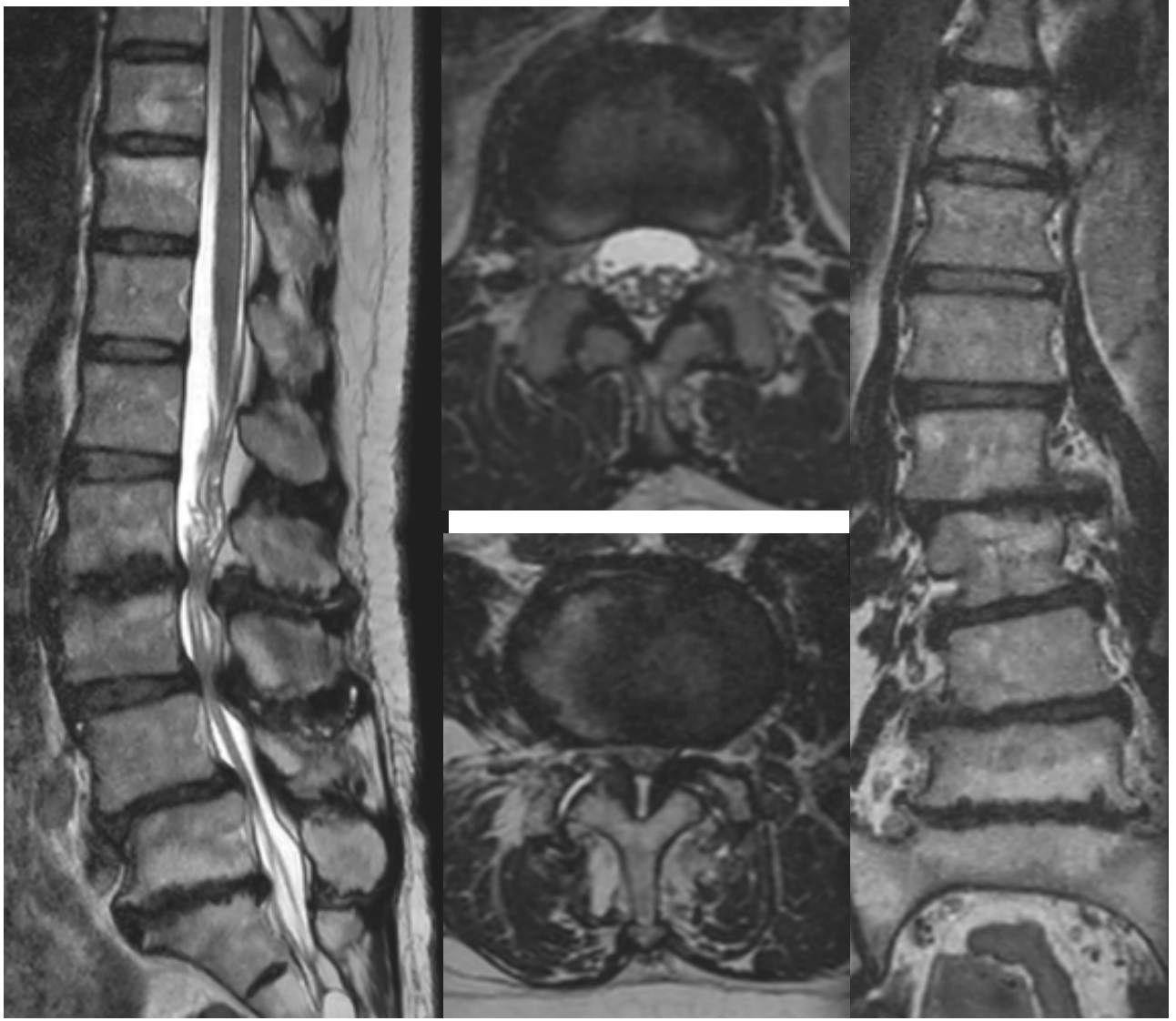


high resolution with aquisition voxel 0.8 x 0.8 x 1mm, CS7, strong, 4:46min.



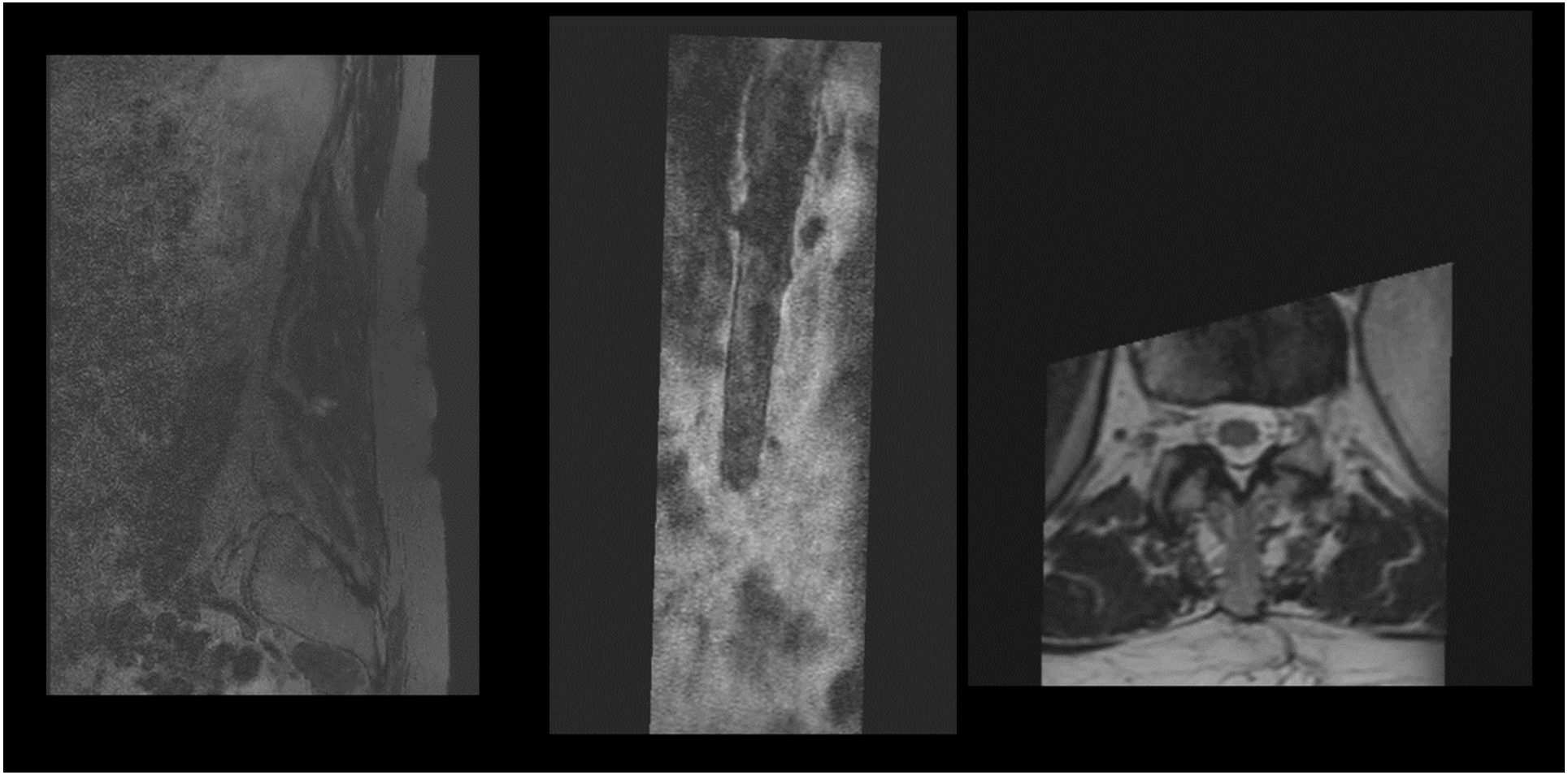
3D T2 Spine View lumbar spine 1.5 T

curved sagittal, transverse and coronal reconstructions



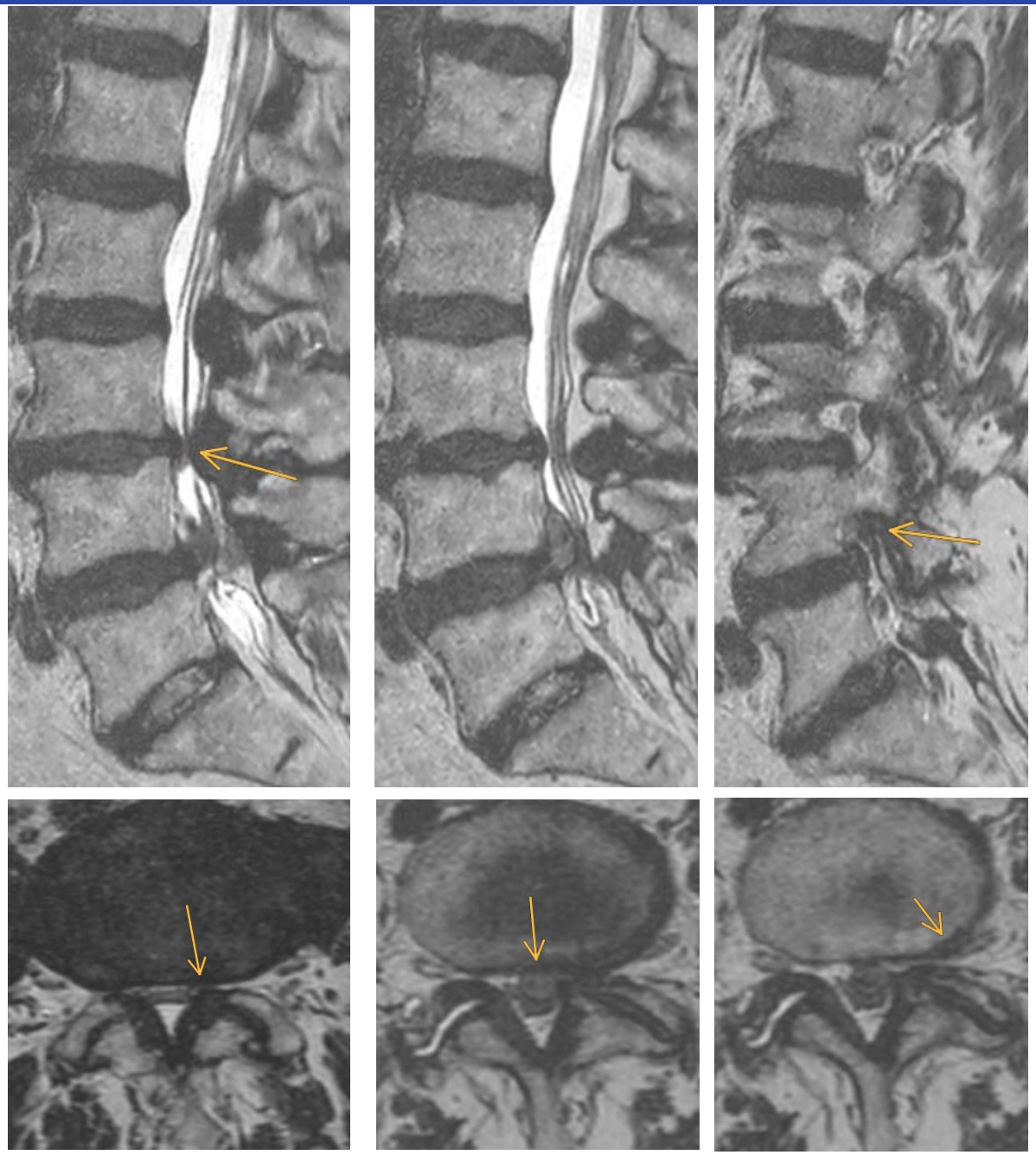
3D T2 spine view CS 7, strong, 0.8x0.8x1mm, 04:46min.

3D T2 spine view lumbar spine Ingenia 1.5T



7.5.2018, 325866

Pathological findings 3D T2 Spine View Ingenia 1.5T



CS 7, strong
0.8 x 0.8 x 1mm

7.5.2018, 325866

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Compressed Sense: Our own recommendations for increased spatial resolution 1.5 Tesla

	Standard 2D	**Standard 3D Philips®**	**High resolution 3D spine view + CS**
T2 lumbar spine	2D T2 TSE 0.8 x 0.95 x 4mm **03:00 min.**	3D T2 spine view 0.9 x 1 x 1.4 mm, **05:35 min.**	3D T2 spine view 0.8x0.8x1mm, CS7, strong; **04:46min.**
T1 lumbar spine	2D T1 TSE 0.75x0.95x4mm **03.27 min.**		3D T1 spine view 0.9x0.9x0.9mm,CS5.2, strong, **05:11 min.**
T2 cervical spine	2D T2 TSE 0.7 x 0.85 x 3mm **03:36 min**	3D T2 spine view 0.9 x 1 x 1.2mm **05:21 min.**	3D T2 spine view 0.8x0.8x0.8mm, CS 3.5, strong, **6min.**
T1 cervical spine	2D T1 TSE 0.7 x 0.87 x 3mm	3D T1 spine view 0.0 x 0.9 x 1.2mm 04:53 min.	

Compressed Sense: Our own recommendations for increased spatial resolution 3 Tesla

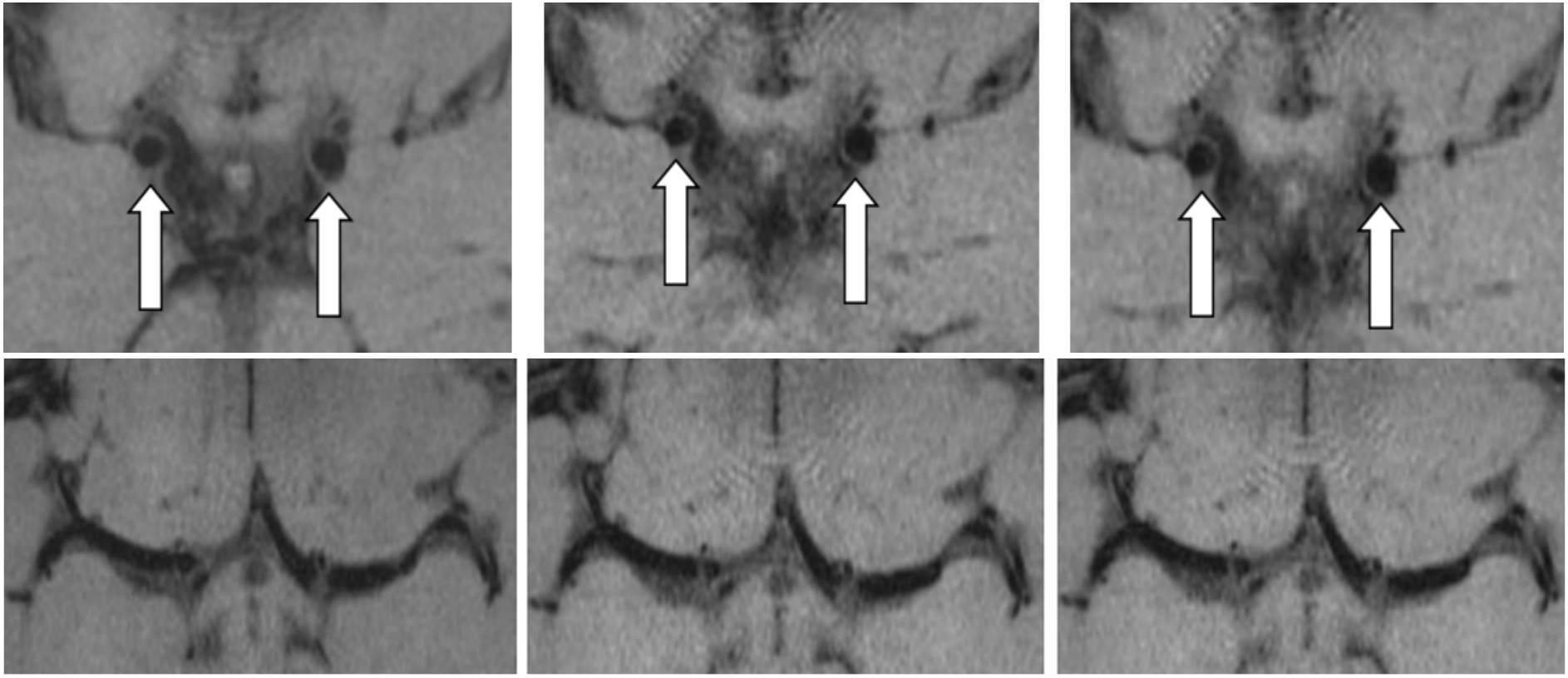
	Standard 2D	Standard 3D spine view Philips®	High resolution 3D spine view, no CS	High resolution 3D spine view + CS
T2 lumbar spine	2D T2 TSE sagittal	0.9 x 1 x 1.3mm CS 2.5, 05:45 min.	0.9 x 0.9 x0.9mm 06:41 min.	3D T2 spine view 0.9 x 0.9 x 0.9mm, strong CS6: 04:34 min. CS7: 03:56 min.
T1 lumbar spine	2D T1 TSE 0.8 x 1 x 4mm 03:18 min.			3D T1 spine view 0.9x0.9x0.9xmm, strong: CS6: 04:28 min.

3D T1 intracranial black blood vessel wall imaging

high resolution 0.5 x 0.5 x 1mm, 08:03min.

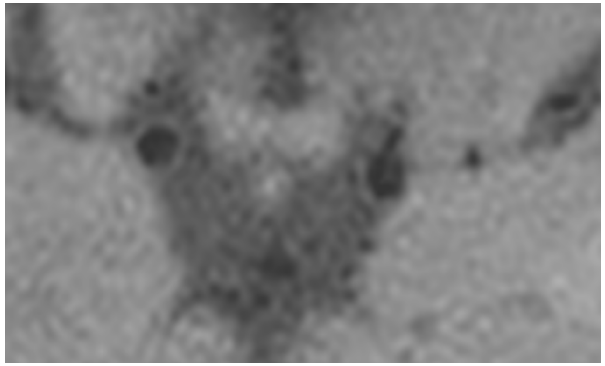
high resolution, 0.5 x 0.5 x 1mm; CS 2.5, weak 4:53 min.

high resolution, 0.5 x 0.5 x 1mm; CS 2.5, strong 4:53min.



3D T1 black blood whole head; 04:37 min.,0.75 x 0.75 x 0.75mm

→ Vessel wall slightly blurred



Denoising Grad weak
→ strong: lines, but identical depiction of vessel wall

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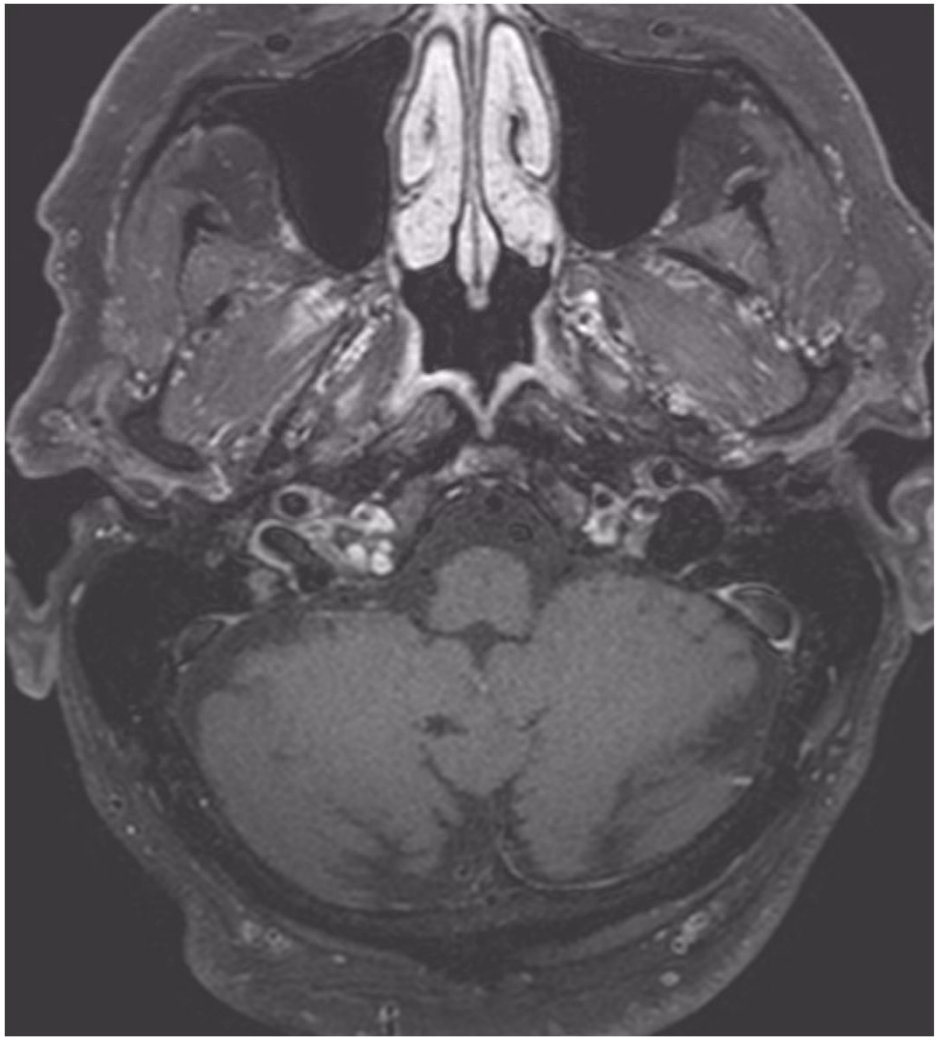
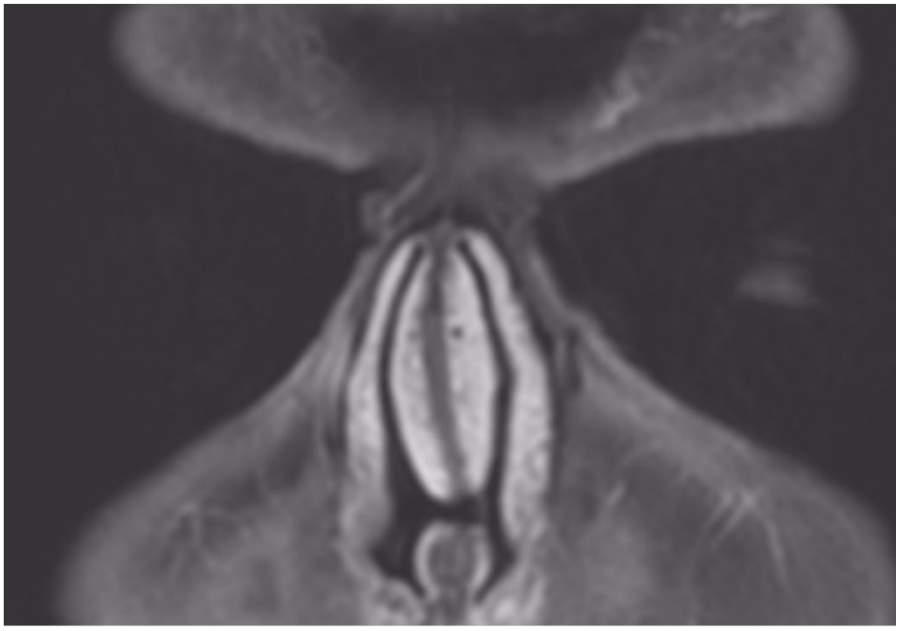
Hypophysis: 3D T1 black blood +/- contrast



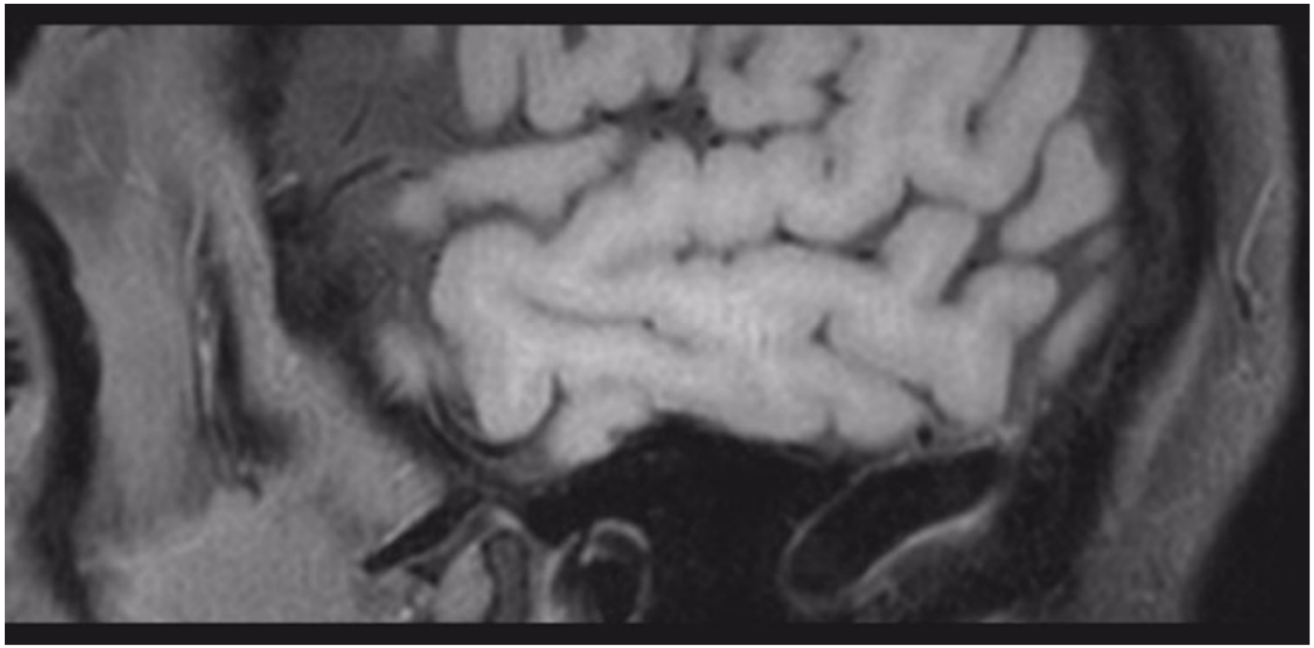
With contrast



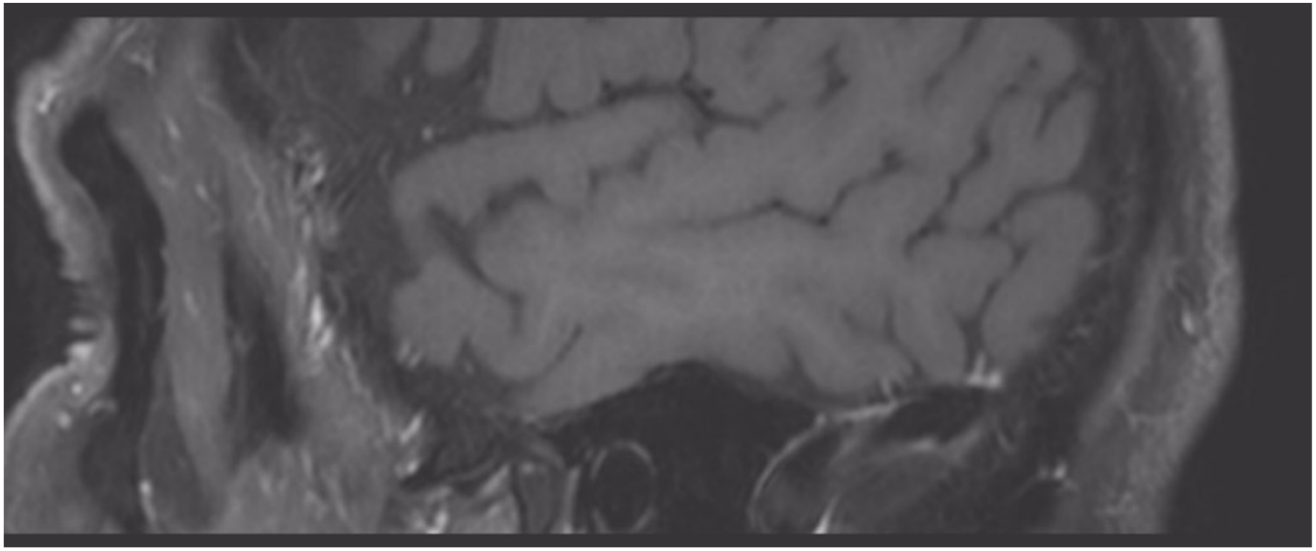
3D T1 black blood 0.75mm isotropic voxel, no CS, 6min.

3D T1 black blood , 0.75mm isotropic voxel, CS 3.2, 5:06 min.

Hypophysis: 3D T1 black blood +/- contrast



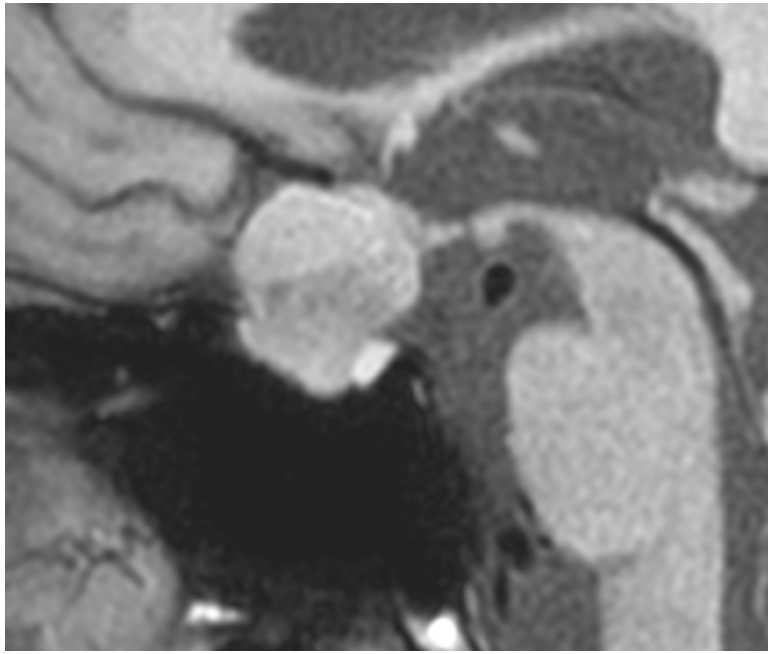
without contrast

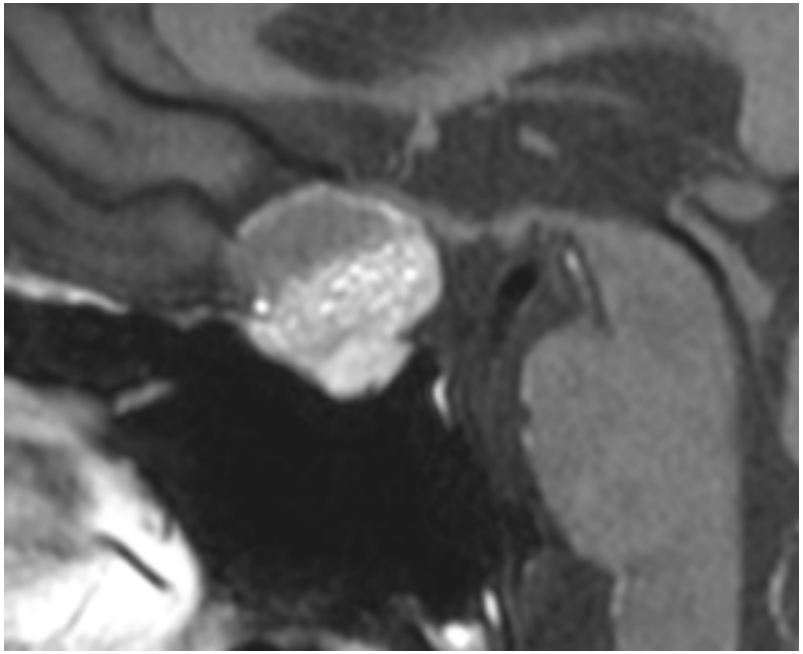


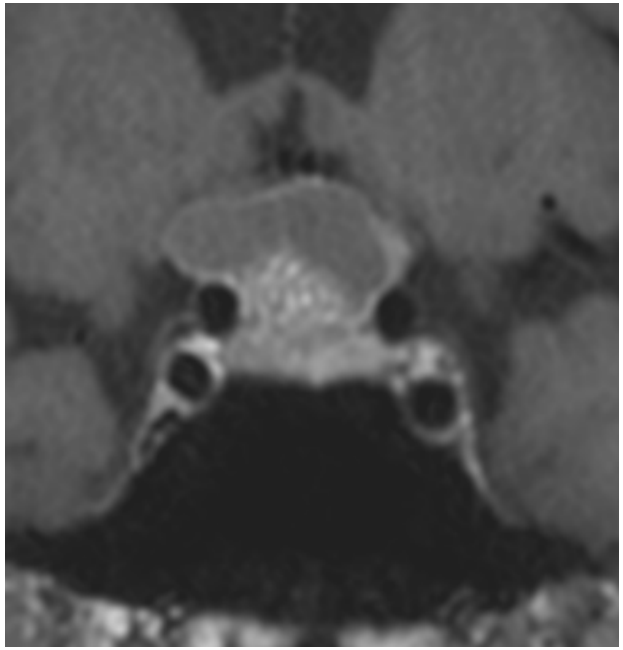
3D T1 black blood , 0.75mm isotropic voxel, CS 3.2, 5:06 min.

with contrast

Hypophysis: 3D T1 black blood +/- contrast







3D T1 black blood
0.75mm isotropic
voxel, CS 3.2,
5:06 min.

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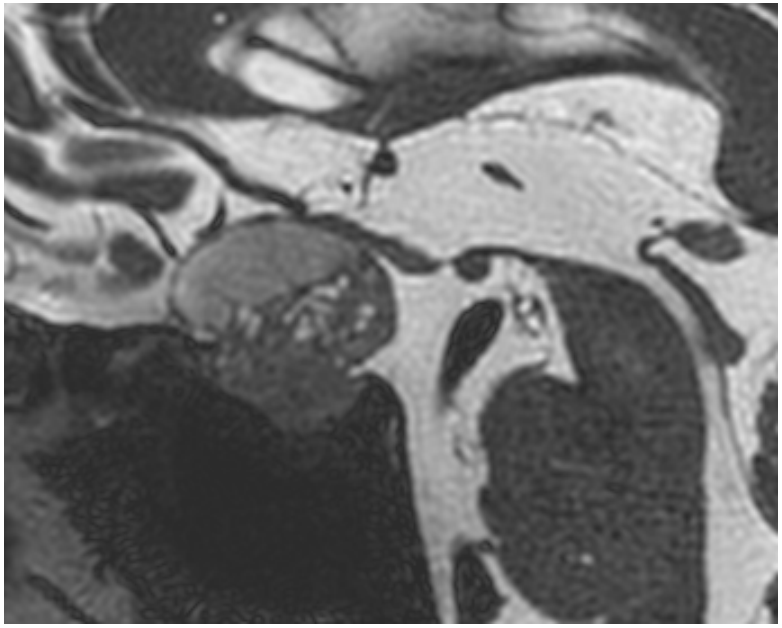
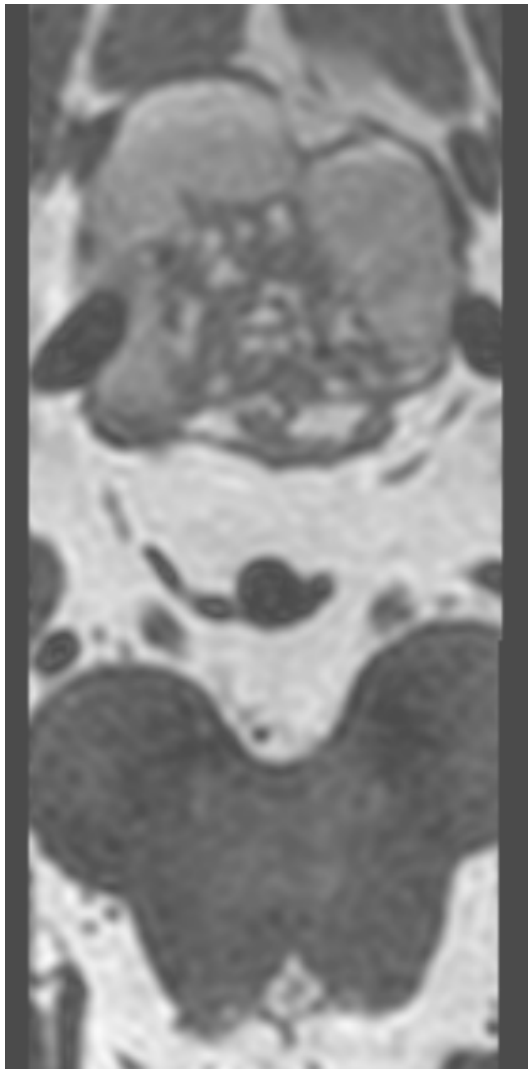
Hypophysis: 3D T2 DRIVE





3D T2 Drive TSE; 0.3mm isotropic voxel:

a. 05:39 min. without CS

b. 04:51 min. with CS 2.5

Hypophysis: Standard protocol with CS

	standard examination hypophysis with and without Gadolinium, with CS
sequences	With CS: 1. Transverse3D T1 black blood precontrats 2. Transverse 3D T1 black blood postcontrast 3. Sagittal 3D T2 Drive TSE sagittal
examination time	15:03 min.

Scan time reduction: Standard examination brain 3T

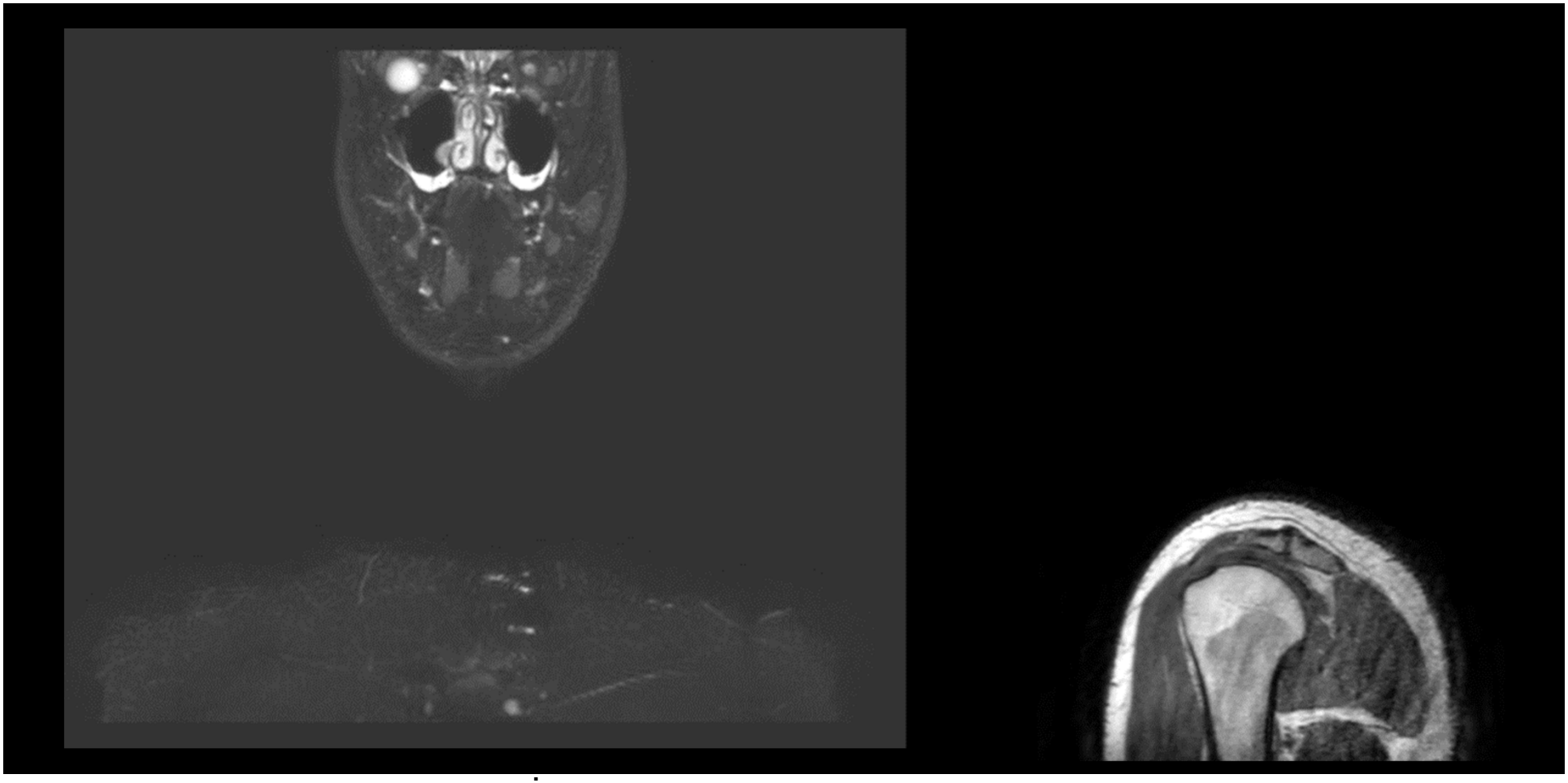
	standard examination head with Gadolinium, without CS	standard examination head with Gadolinium, with CS
sequences	DWI T2 transverse T1 transverse IR 3D FLAIR SWI 3D T1 TFE GD	without CS: DWI T2 ax T1 ax IR with CS: 3D FLAIR SWI 3D T1 TFE GD or 3D T1 m-Dixon TFE GD
examination time	24 min.	18 min.

Scantime-reduction: Lumbar spine 1.5T

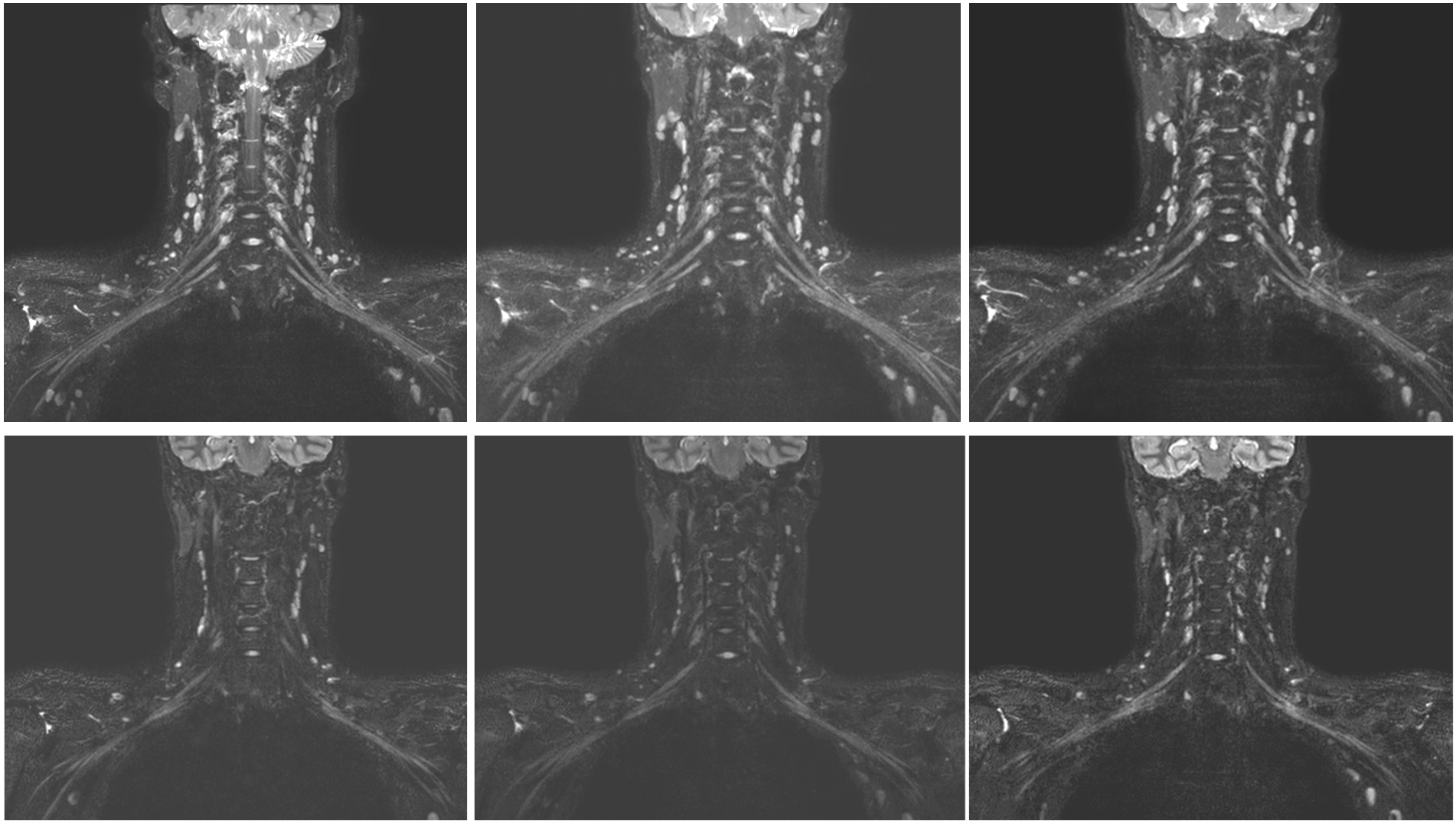
	Lumbar spine no CS	Lumbar spine with CS
sequences	2D T2 TSE sag 2D T2 TSE cor 2D STIR T2 sag 2D T1 TSE sag 2D T2 TSE ax → 5 sequences	without CS: STIR T2 sag 2D T1 TSE sag with CS: Highresolution 3D T2 spine view → 3 sequences
advantage of CS technique		coronal and transverse T2 images are reconstructed
examination time	18 min.	11 min.

Brachial plexus

3D Nerve ViewMIP and 3D PD sagittal



3D Nerve View: MIP and original scans 1.5T Ingenia



3D Nerve View 1.2 x 1.2 x 1.2mm, 06:16min., MIP 15mm

3D Nerve View 1.2 x 1.2 x 1.2mm , CS 5, 5:15min, MIP 15mm

3D Nerve View 1.2 x 1.2 x 1.2mm, CS 6 4:24min. MIP 15mm

very good depiction of nerves

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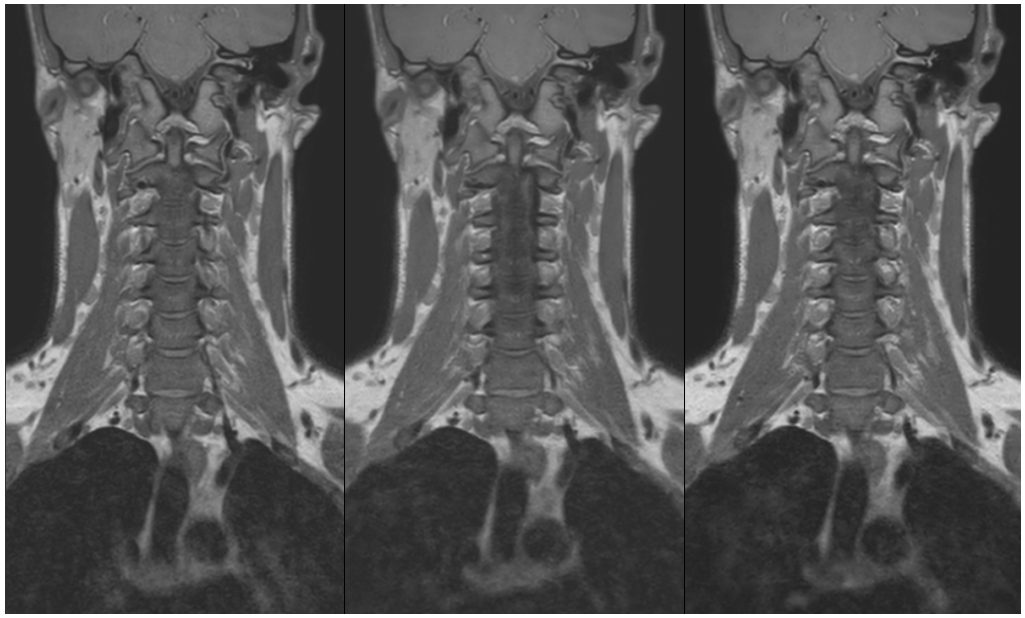
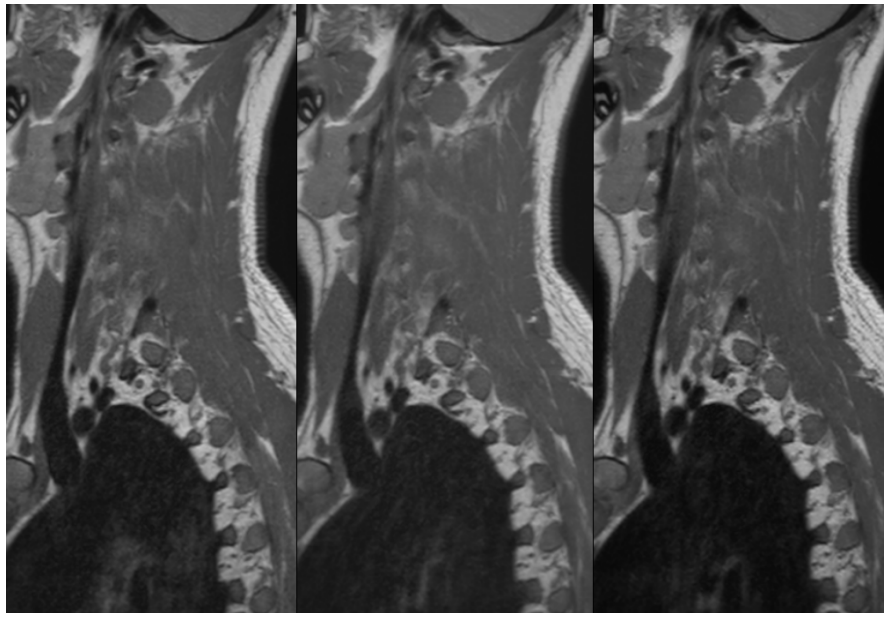
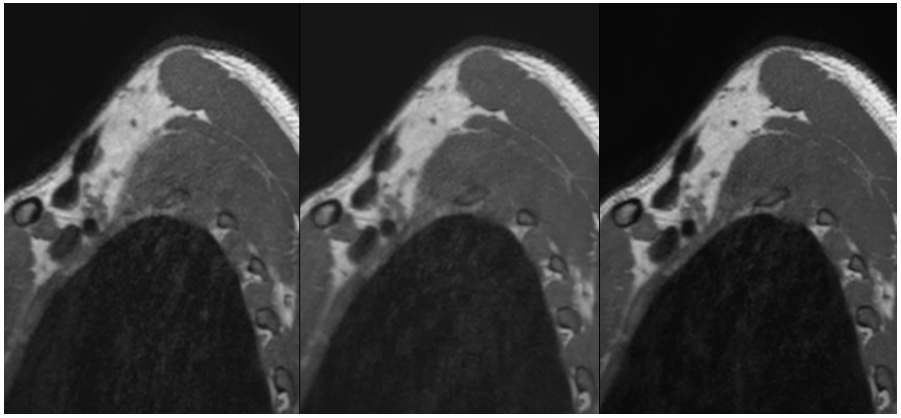
Coronal 3D PD 1.5T Ingenia + sag reconstructions







From left to right:

3D PD 0.9 x 0.9 x 0.9 mm, 05:43 min.

3D PD 0.9 x 0.9 x 0.9, CS 10, 4:55min, NSA 2

3D PD 0.9 x 0.9 x 0.9 mm, CS 8, 03:50min, NSA 1

No difference in image details

CS brachial plexus: Recommendations 1.5T

	High resolution, no CS	High resolution + CS
3D PD	0.9 x 0.9 x 0.9 mm 5:43 min.	0.9 x 0.9 x 0.9 mm CS 8, medium 3:50 min.
Nerve View	1.2 x 1.2 x 1.2 mm 06:16 min.	1.2 x 1.2 x 1.2 mm CS 5, medium 05:15 min.

CS brachial plexus: Recommendations 3T

	High resolution, no CS	High resolution + CS
3D PD	0.9 x 0.9 x 0.9 mm 06:48 min.	0.9 x 0.9 x 0.9 CS 9, medium 04:36 min.
Nerve View	1.1 x 1.1 x 2 mm 06:12 min.	1.1 x 1.1 x 2 mm CS 4.5, medium 05:08 min.

Artefacts and CS

1. Motion artefacts

2. Specific CS-related artefacts:

Artefacts are possible, but they are rare and they occur only on sequences with low contrast-to-noise:

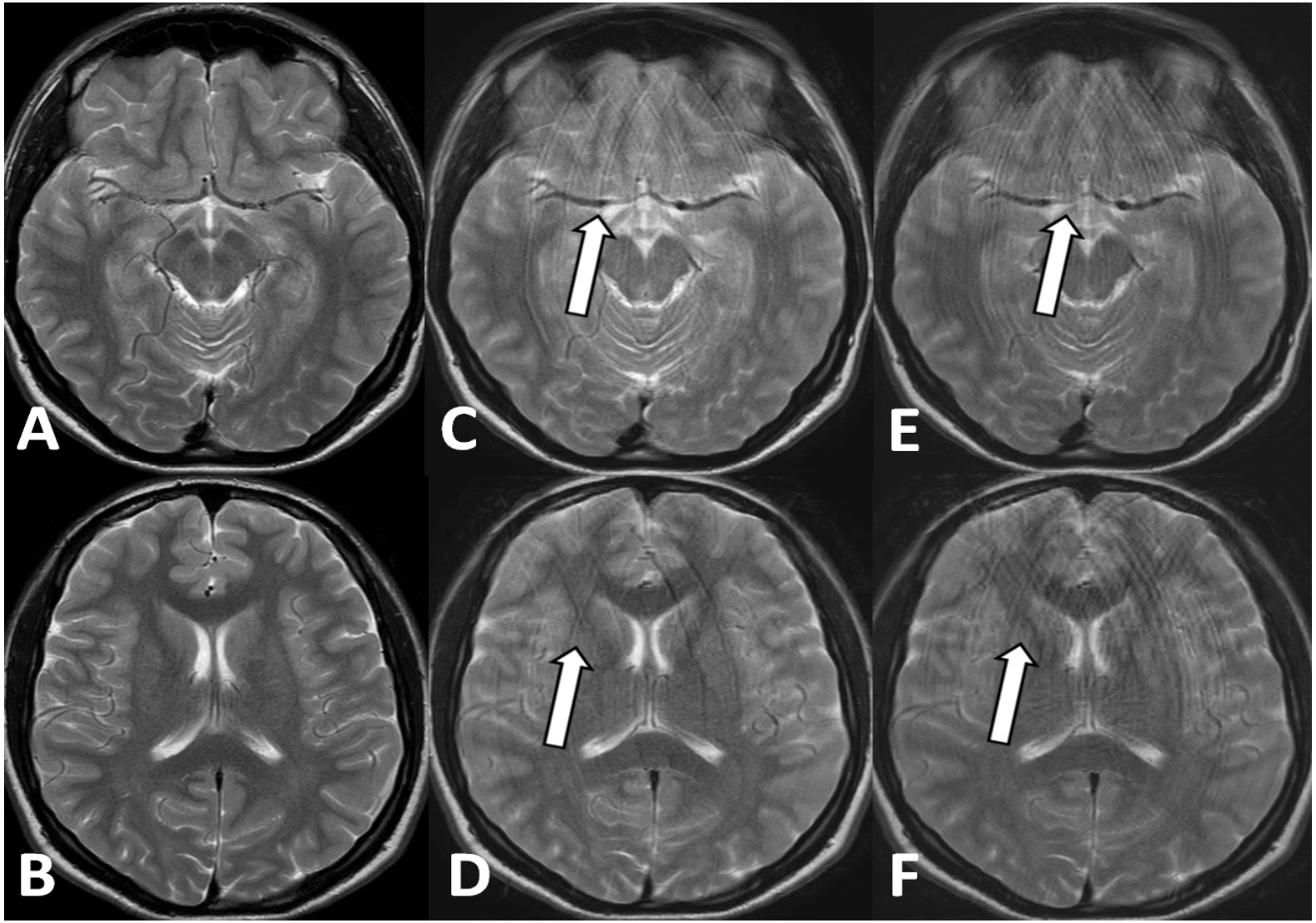
a. Wax layer artefact

b. Streaky - linear artefacts: transverse or oblique

c. Starry sky artefacts: mixture of lines, streaks, circles, points, dots

1. Motion artefacts

Motion artefacts



no movements | movements left-right | movements left-right with CS 2 high-frequency semicircular rings

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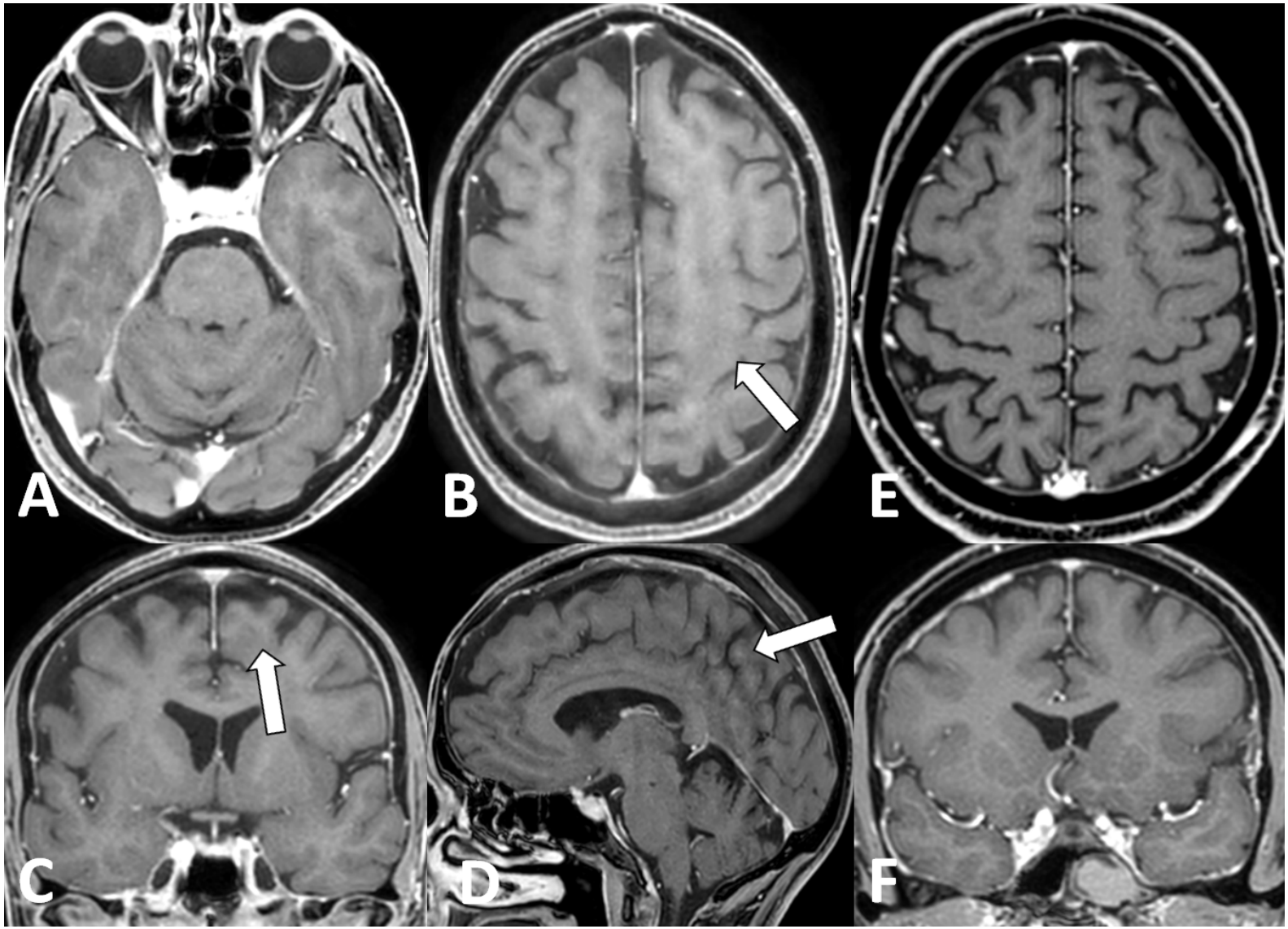
2a. Wax layer artefact

Patrick Lo Giudice. Photo with pigments in wax on wood with iron frame. Museum Franz Gertsch 2017. Landscapes.

2a. Wax layer artefact



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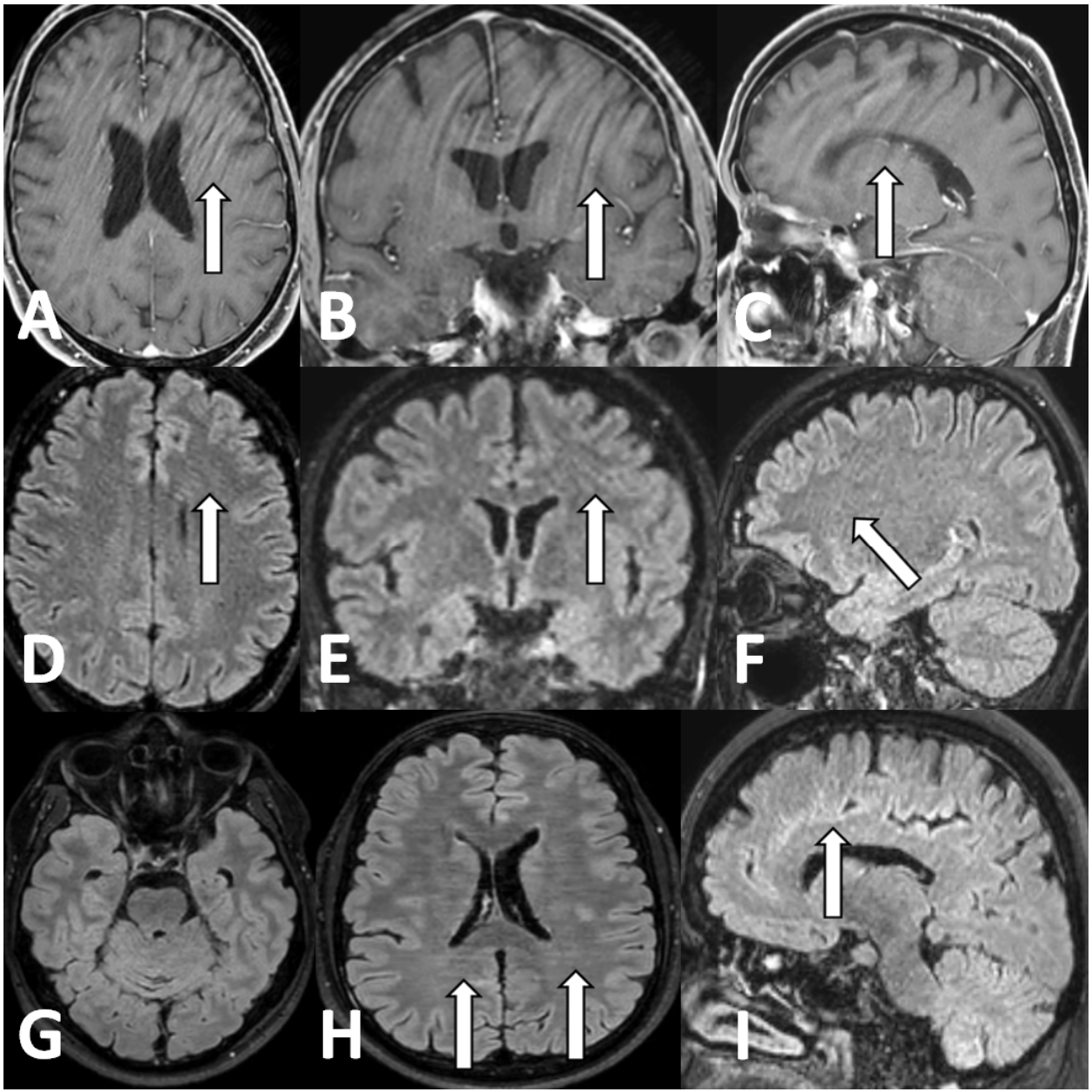
2b. Streaky linear artefacts

2b. Streaky linear artefacts



oblique
3D T1 m-Dixon TFE

oblique
3D FLAIR

transverse
3D FLAIR

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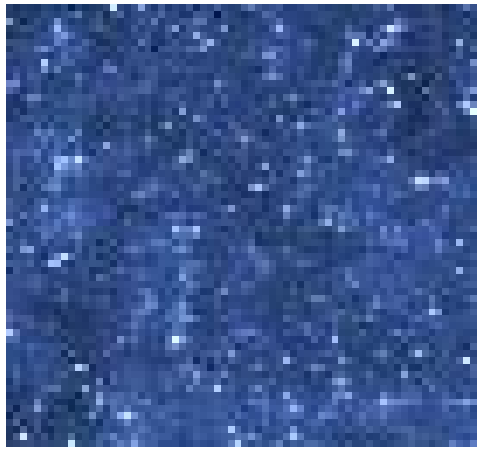
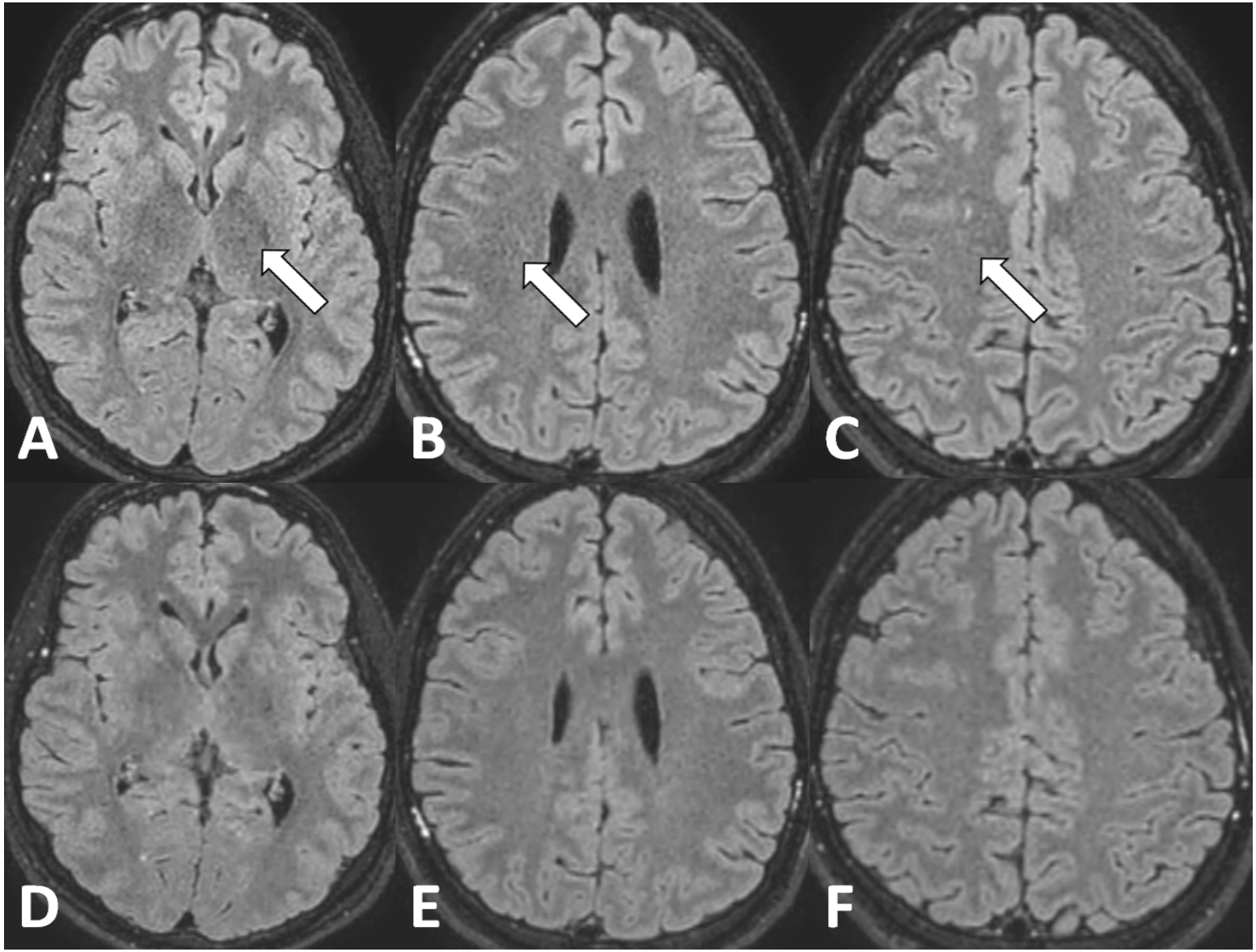
2c. Starry sky artefact



2c. Starry sky artefact



3D FLAIR
CS 8.2
medium,
with
artefact

3D FLAIR,
CS 8.2
medium,
without
artefact

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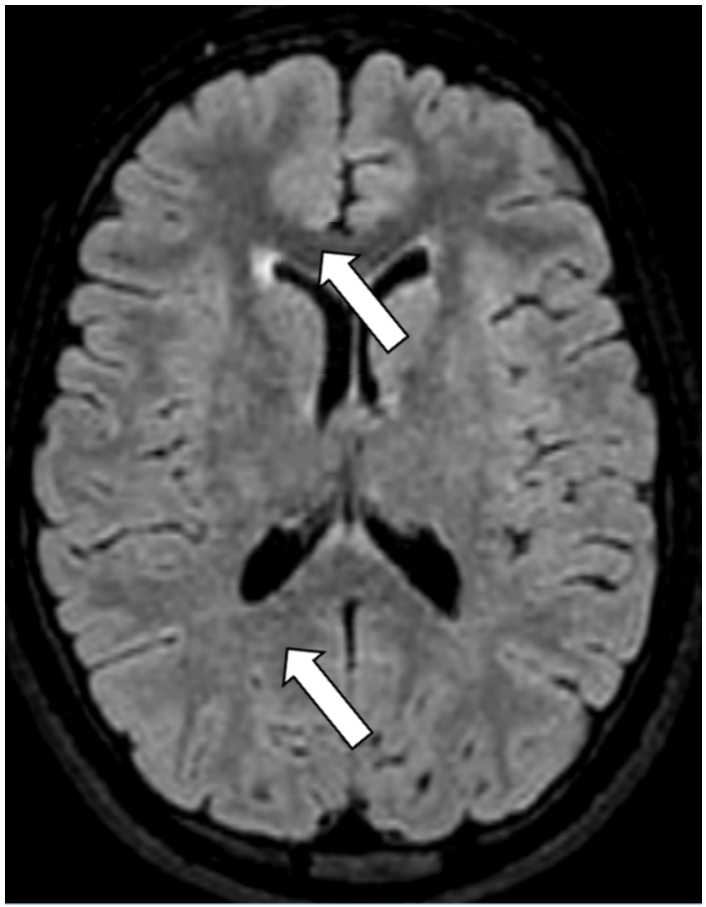
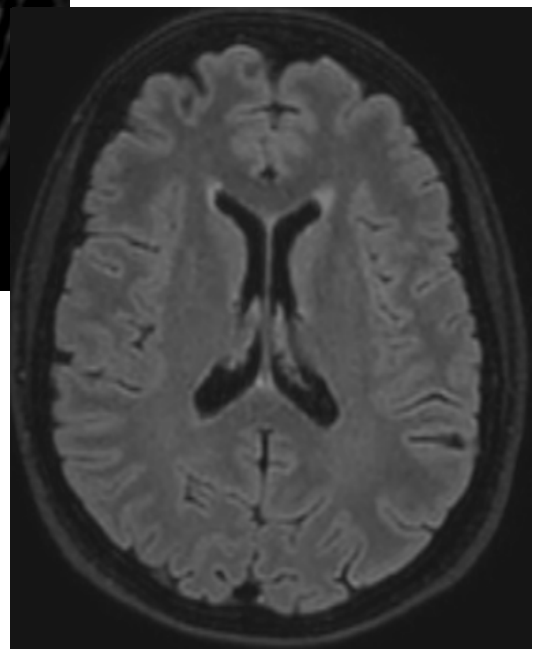
3D FLAIR 1.5 T CS 8.2 medium: starry sky artefact





3D FLAIR CS 8.2 medium without artefacts

Take Home Messages

- 1. The scan time can be significantly reduced by CS with unchanged image quality
- 2. A scan time reduction between 25% and 50% compared to the original sequence is possible
- 3. The reduction of the scan time depends on the sequence acquired: 2D versus 3D and sequence with low or high contrast-to-noise
- 4. The denoising grade (weak, strong, medium) affects the noise of the acquired image with CS
- 5. The image quality can be improved by CS with more or less identical scan time, especially in 3D sequences

Take Home Messages

- 6. Different artefacts are possible with CS; but artefacts are rare
- 7. Specific CS related artefacts are mostly seen on sequences with low contrast to noise: on 3D FLAIR, 3D T1 m-Dixon TFE; but they are not encountered on sequences with high contrast to noise as in 3D T2 DRIVE, 3D TOF, 3D T1 and T2 spine view
- 8. Sequences with CS do not show increased susceptibility to movements if compared with sequences without CS, however motion artefacts show itself as high frequence semicircular rings

Thank you for your attention

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