

1. TECHNICAL FINDINGS

Case ID	SAMPLE FULL TBI REPORT			Study Type	Traumatic Brain Injury - Tier 3
Age		Sex	<input type="checkbox"/> Male <input type="checkbox"/> Female	Scan Date	
Height (cm)		Weight (kg)		Study Location	
Image Processing By:		Processing Date:		Reviewer:	Review Date:

1.1.
MR Imaging Protocol

- ☐ TBI Tier 1 Protocol
 ☐ TBI Tier 2 Protocol
 ☒ TBI Tier 3 Protocol
☐ CCSVI Protocol
 ☐ Partial Scan

Anatomical:

- ☒ 3D TOF MRA HEAD
☒ 3D CE MRAV NECK
 ☒ 3D CE VIBE NECK
 ☒ 2D TOF MRV NECK

Flow Quantification:

- ☒ C7/T1
 ☐ C6/C7
 ☒ C5/C6
 ☒ C2/C3
☒ CSF
 ☒ Dural Sinuses
 ☐ Azygos Upper
 ☐ Azygos Lower

Conventional Sequences:

- ☒ ALL
 ☐ FLAIR
 ☐ T2WI
 ☐ T1WI
 ☐ T1WI post-contrast

Additional Sequences:

- ☒ Diffusion Weighted Imaging (DWI)
 ☒ Perfusion Weighted Imaging (PWI)
☒ Diffusion Tensor Imaging (DTI)
 ☒ Susceptibility Weighted Imaging (SWI)

1.2. Discussion

2. Conventional MRI Sequences

2.1. Axial FLAIR Images

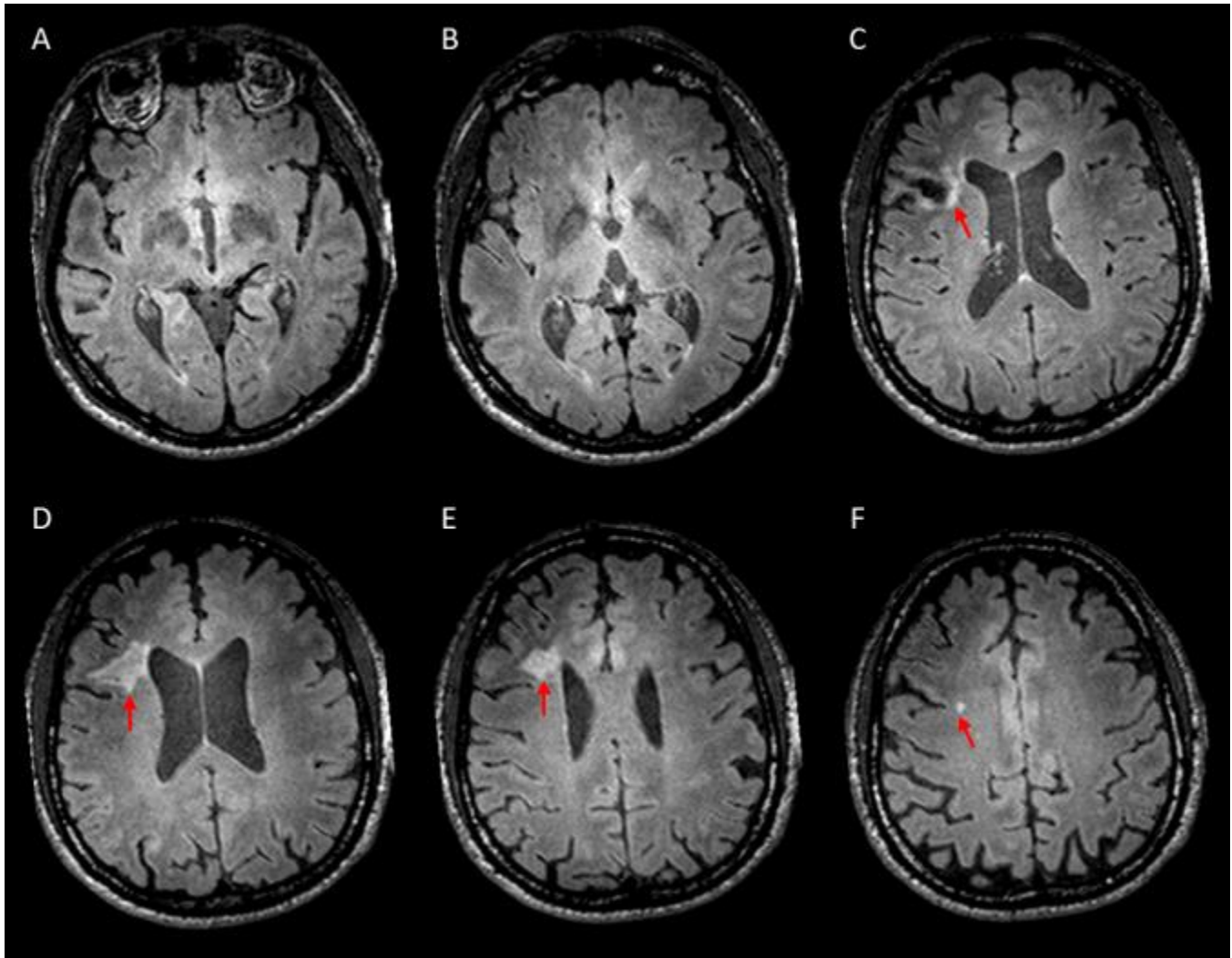


Figure Legend

A-F: Axial FLAIR of head from inferior to superior position (0.5x0.5x1.0mm³).

Discussion

Hyper intense signal is seen in right frontal region: Red arrows.

2.2. T2WI Images

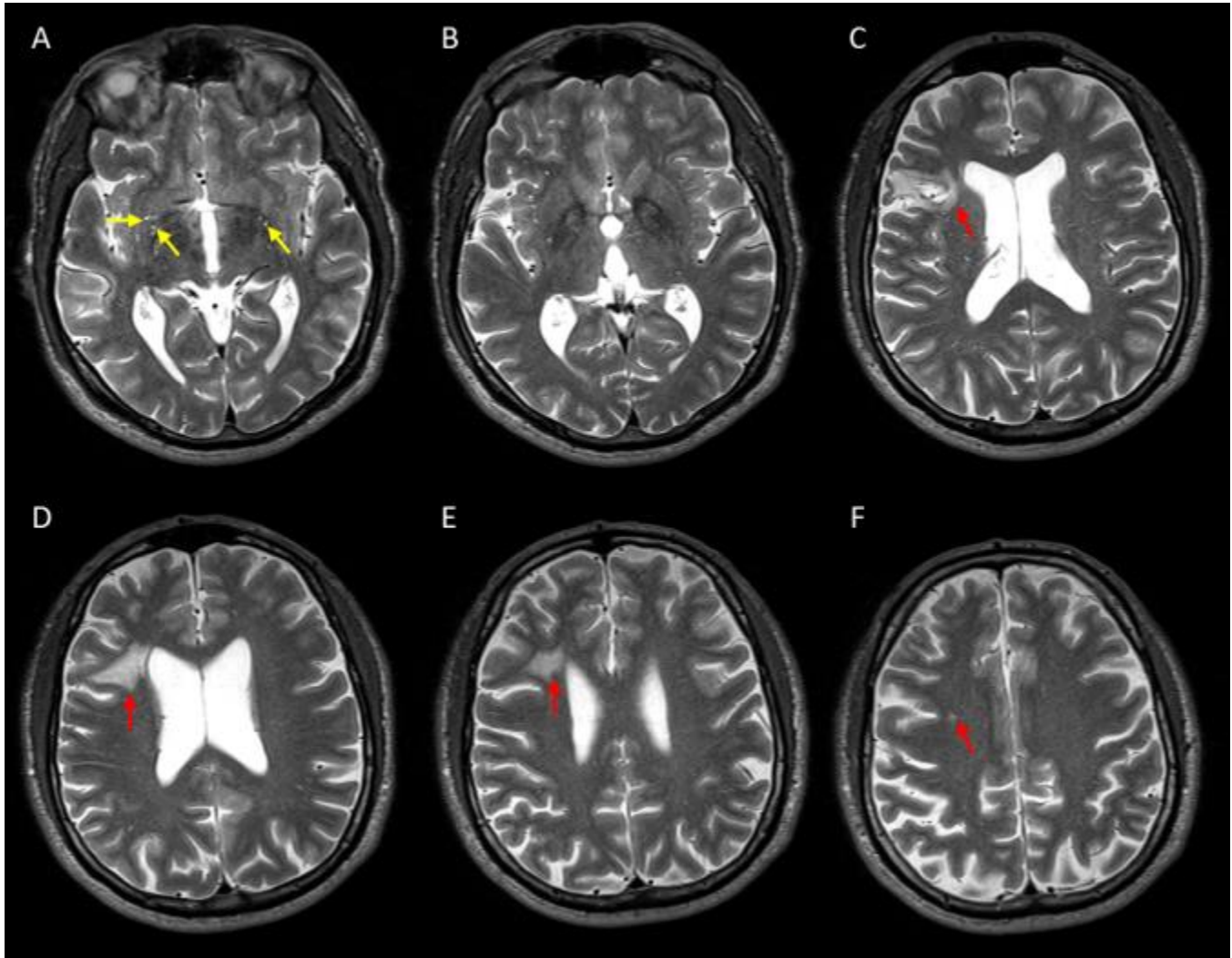


Figure Legend

A-F: T2WI from inferior to superior position (0.5x0.5x1.0mm³).

Discussion

Hyper intense signal is seen in right frontal region: Red arrows.

Dilated Virchow-Robin (VR) spaces in the basal ganglia: Yellow arrows in A.

2.3. T1WI Images

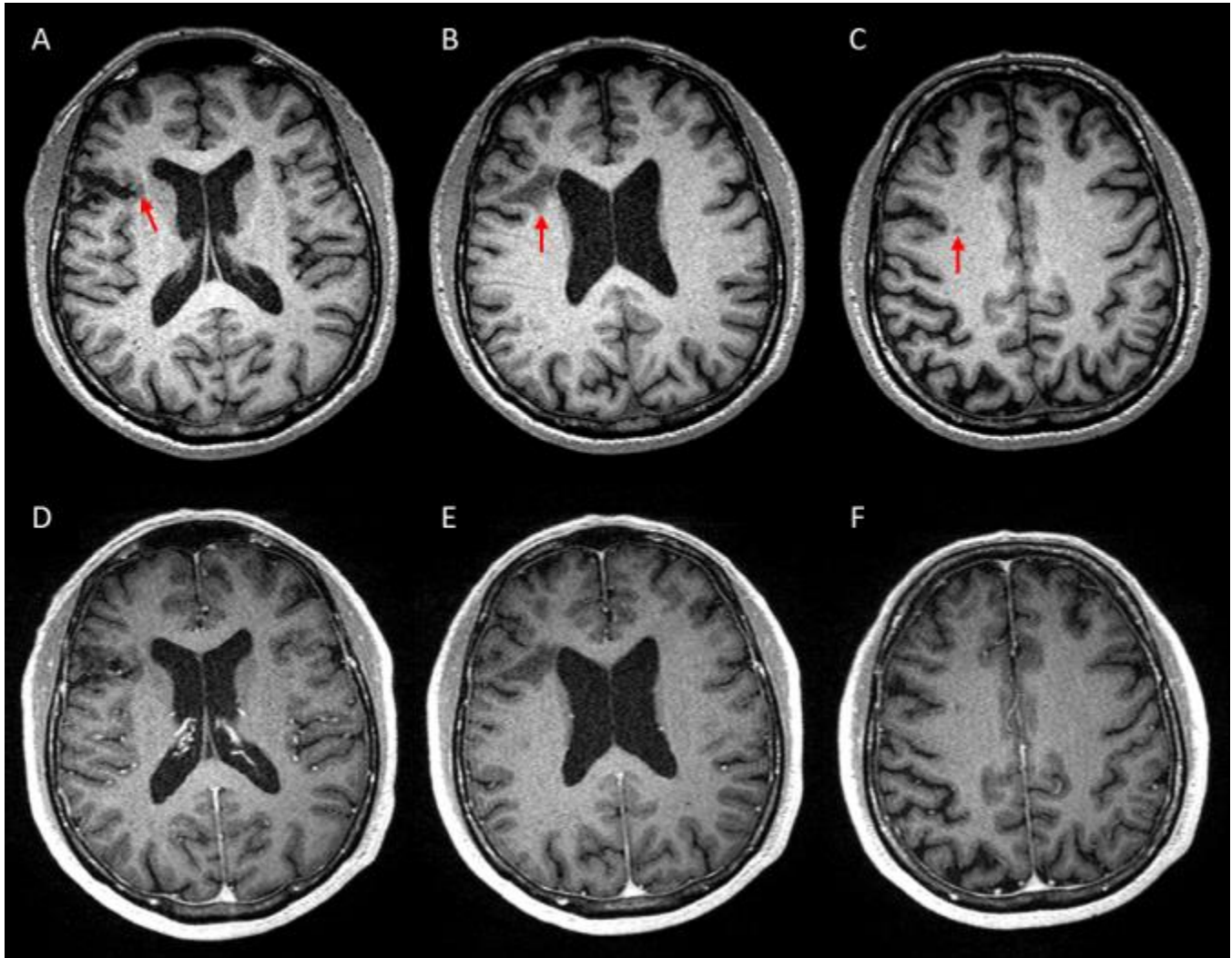


Figure Legend

A-C: Axial view of pre-contrast T1WI (0.5x0.5x1.0mm³).

D-F: Axial view of post contrast T1WI.

Discussion

Hypo intense signal is seen in right frontal region: Red arrows.

3. Susceptibility Weighted Imaging Findings

3.1.

Susceptibility Weighted Imaging (SWI) Phase Images

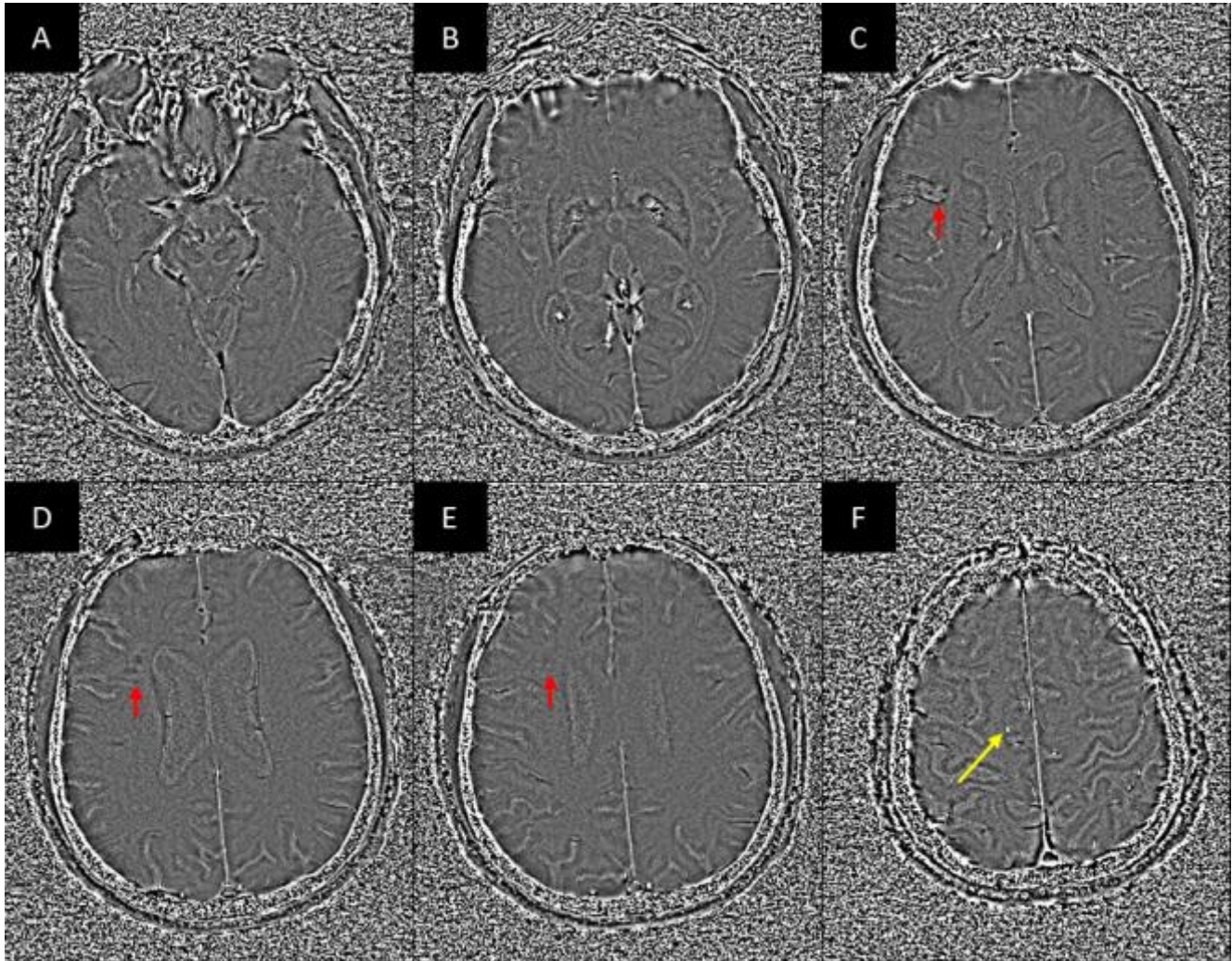


Figure Legend

A-F: SWI phase images at different brain levels (0.5x0.5x2.0mm³).

Discussion

Aberrant decreased signal in the right frontal region: red arrows in C-E.

A cerebral microbleed is observed in the WM in the right, superior region: yellow arrow in A.

3.2.

Susceptibility Weighted Imaging Minimum Intensity Projections (SWI mIPs)

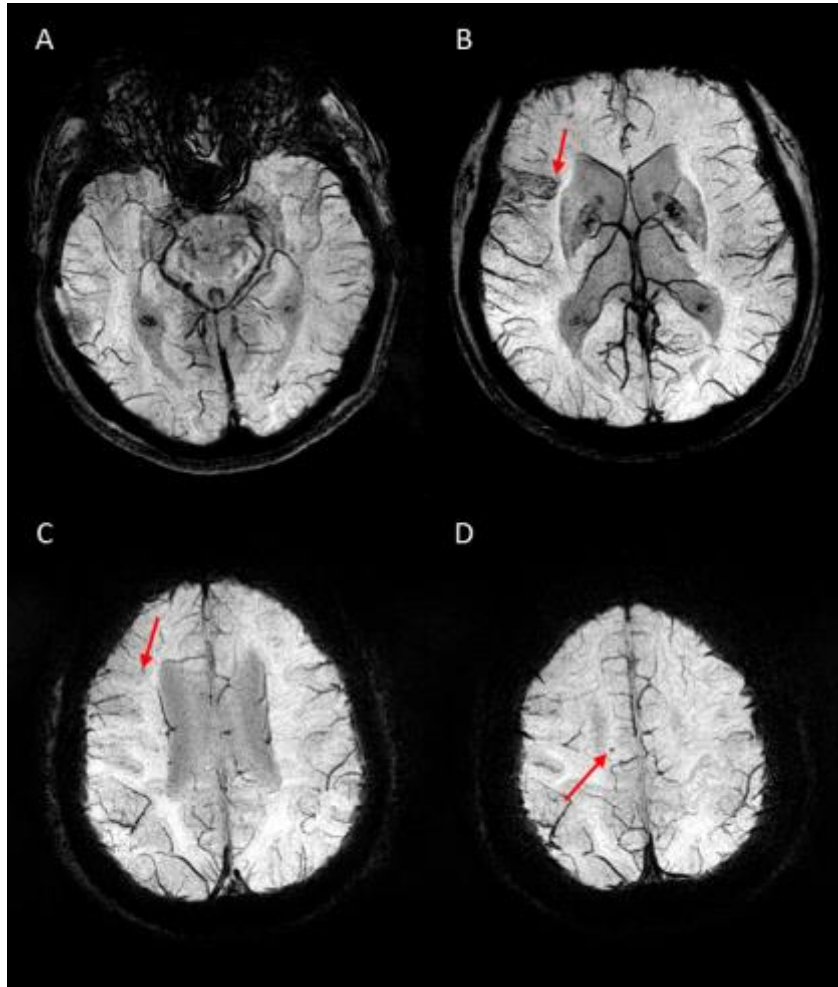


Figure Legend

A-D: SWI mIP images (12 slice)

Discussion

Midbrain veins (A) and the thalamostriate drainage system (B).

Aberrant decreased signal in the right frontal region: red arrows in B-C.

A cerebral microbleed is observed in the WM in the right, superior region: red arrow in D.

3.3.

Susceptibility Weighted Imaging Contrast Enhanced (SWI CE) MRA MIPs

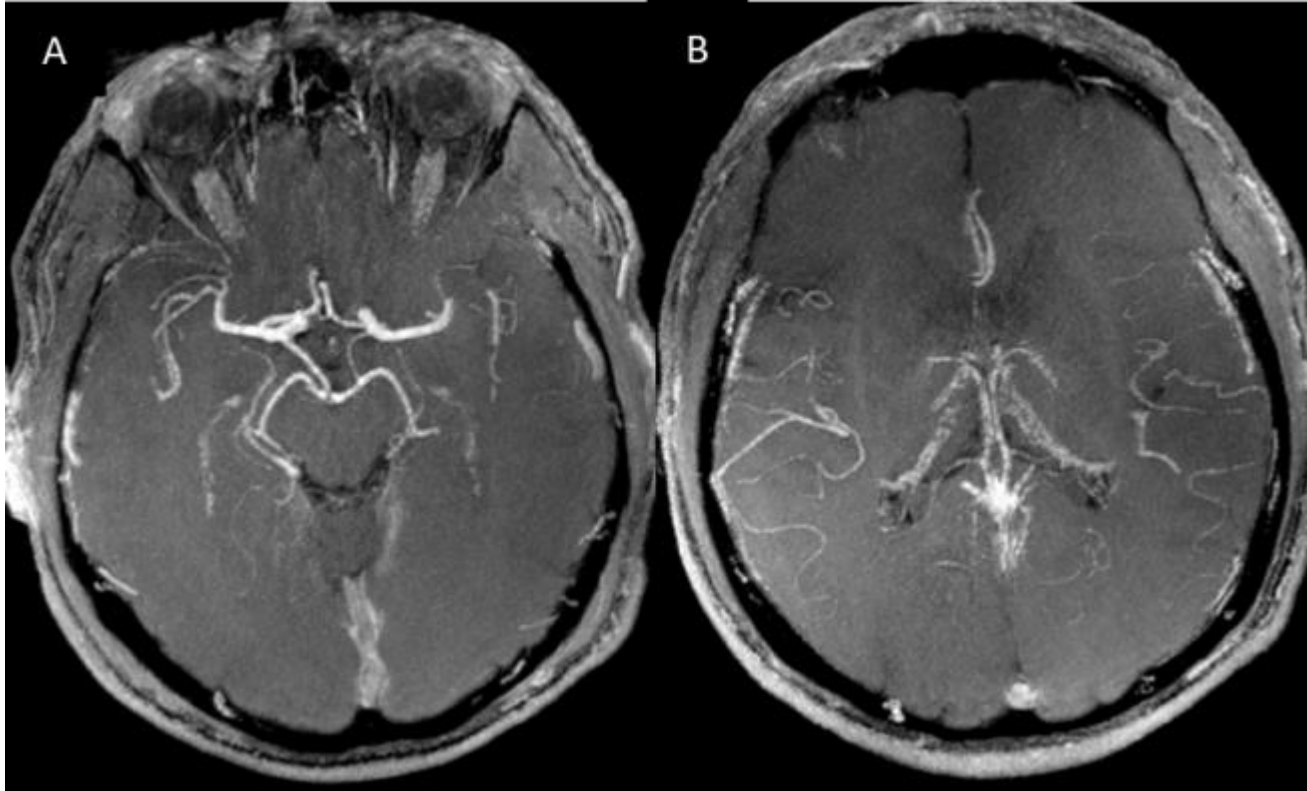


Figure Legend

A-B: MIP images of SWI magnitude images post-contrast.

Discussion

Arterial vessels in the midbrain (A) and the thalamostriate drainage area (B).

Susceptibility Weighted Imaging Mapping (SWIM) Phase and MIP Images

3.4.

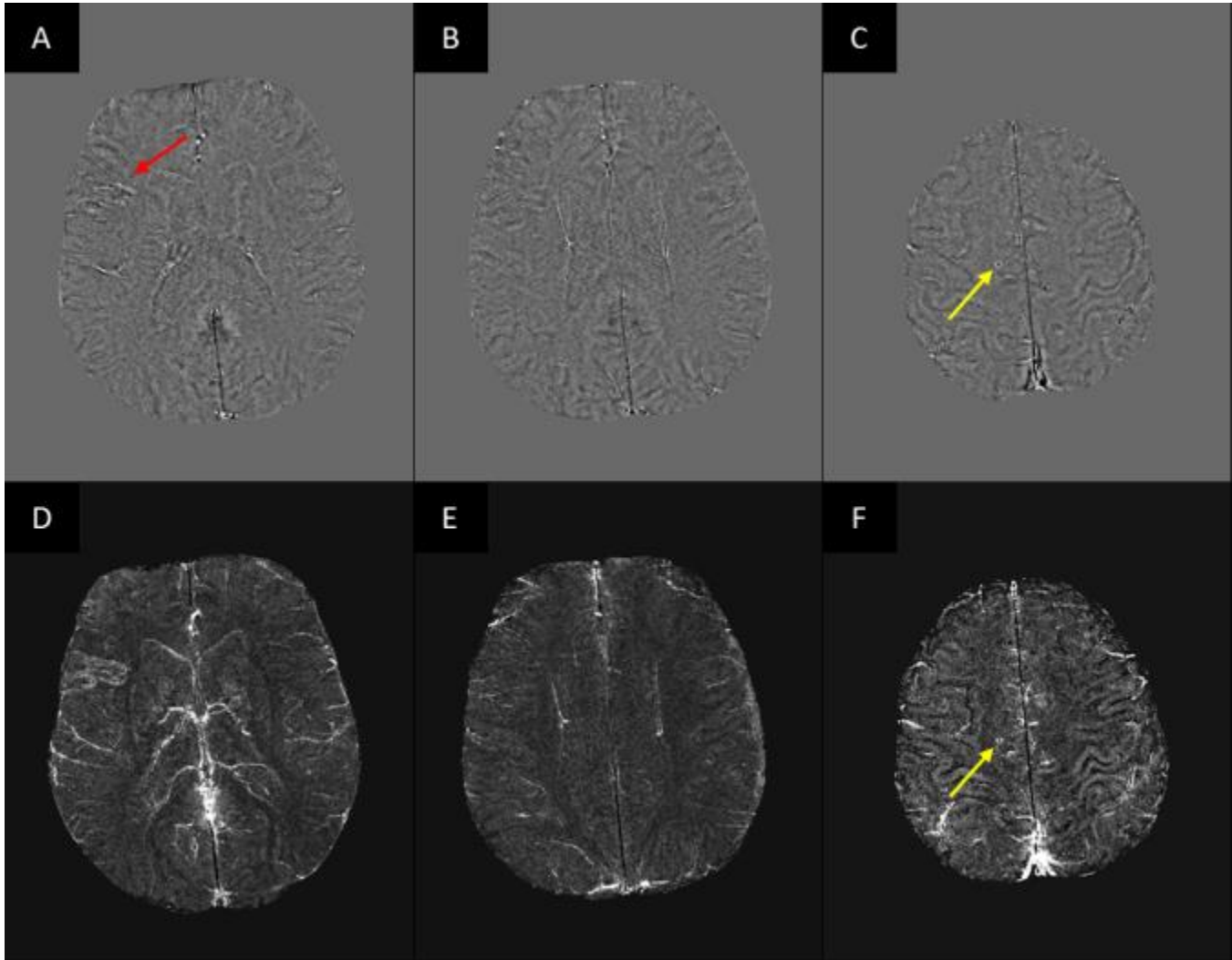


Figure Legend

A-C: Iterative SWIM phase images.

D-F: SWIM MIP images.

Discussion

Aberrant increased signal in the right frontal region: red arrow in A.

A cerebral microbleed with dipole effect, is observed in the WM in the right, superior region: yellow arrows in C, F.

Iron Quantification of the Deep Gray Matter

3.5.

Table 1.

Parameters	CN	GP	PUT	PT	RN	SN	THA
TR-AI	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
RII-TI	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
RII-AI	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
RII-NA	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Table 1. : Abnormal iron content was found in each selected structure for selected parameters (checked box).

TR-AI: Total Region - Average Iron per Voxel

RII-TI: Region II - Total Iron

RII-AI: Region II - Average Iron per Voxel

RII-NA: Region II - Normalized Area

- Caudate Nucleus.
- Globus Pallidus.
- Putamen.
- Pulvinar Thalamus.
- Red Nucleus.
- Substantia Nigra.
- Thalamus.

Discussion

No identifiable increased iron content and quantification within the seven gray matter structures.

4. Diffusion Weighted Imaging and Diffusion Tensor Imaging Findings

Diffusion Weighted Imaging (DWI) – Apparent Diffusion Coefficient (ADC) Maps

4.1.

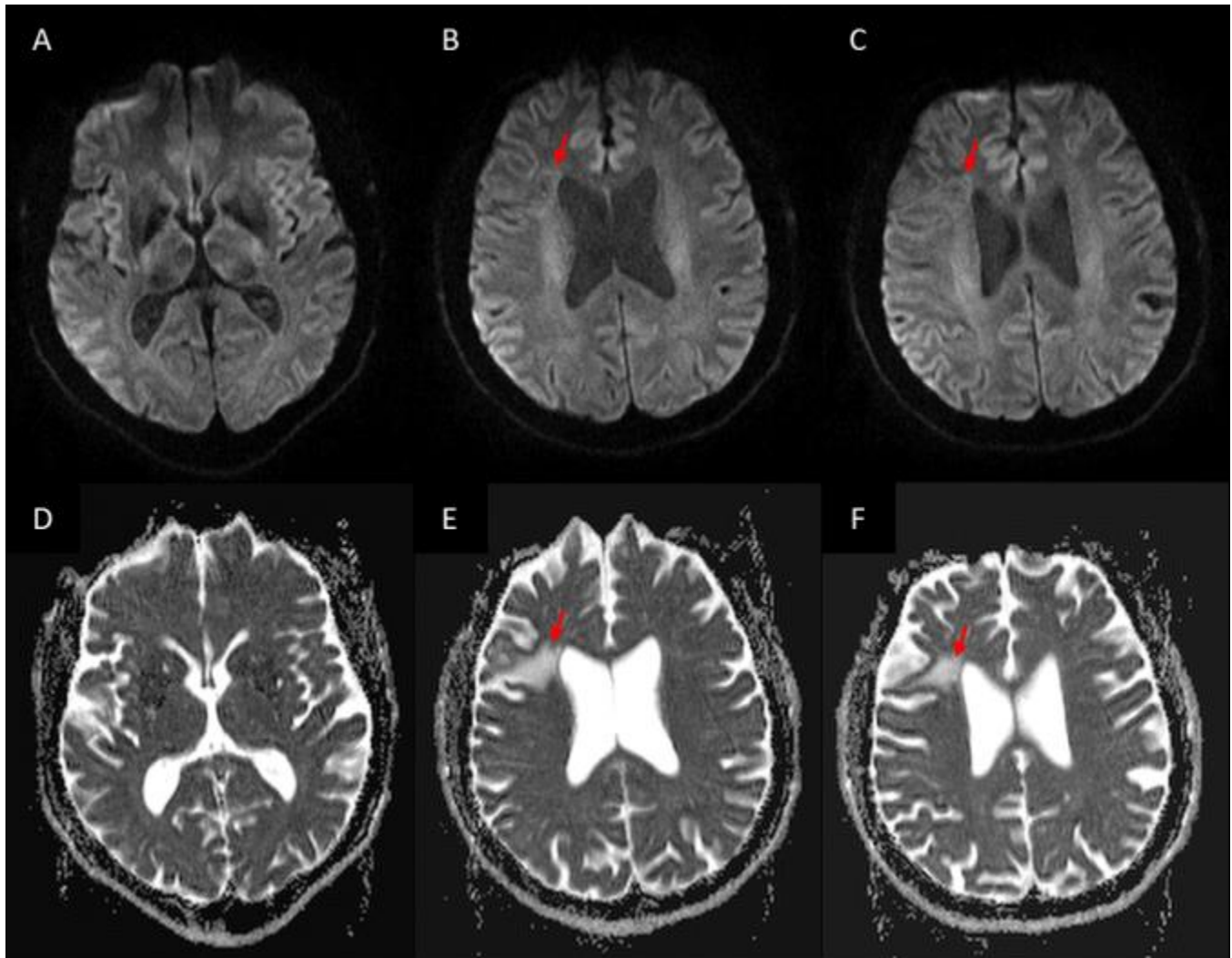


Figure Legend

A-C: Diffusion weighted imaging (DWI) images.

D-F: Apparent diffusion coefficient (ADC) maps.

Discussion

Hyper intense signal is seen in right frontal region: Red arrows.

4.2.

Diffusion Tensor Imaging (DTI) – Fractional Anisotropy (FA) Maps

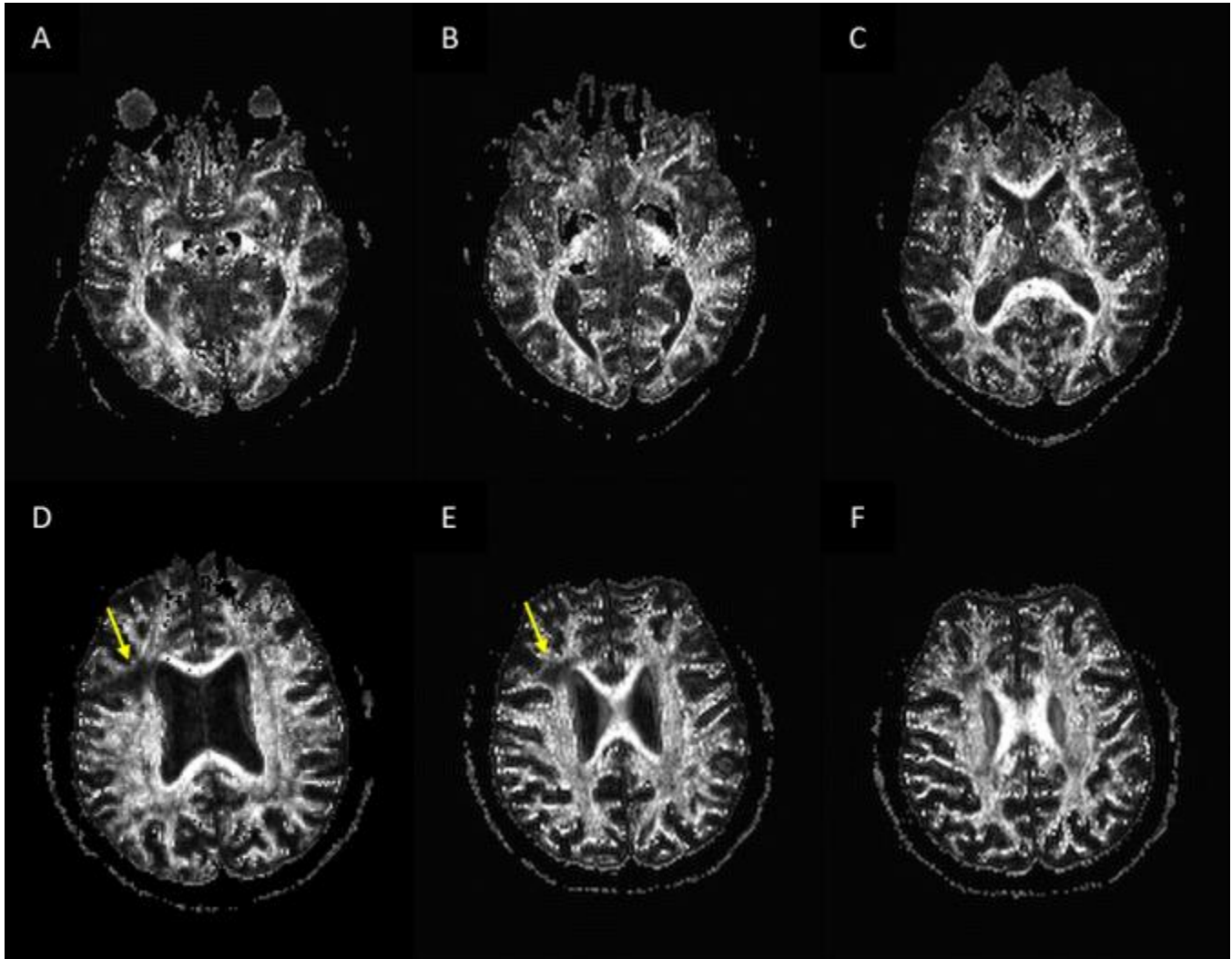


Figure Legend

A-F: Diffusion tensor imaging (DTI) - Fractional anisotropy (FA) maps.

Discussion

Reduced FA is seen in the right frontal region as indicated by decreased signal: yellow arrows in D-E.

Diffusion Tensor Imaging (DTI) – Inverse Fractional Anisotropy (FA) Maps

4.3.

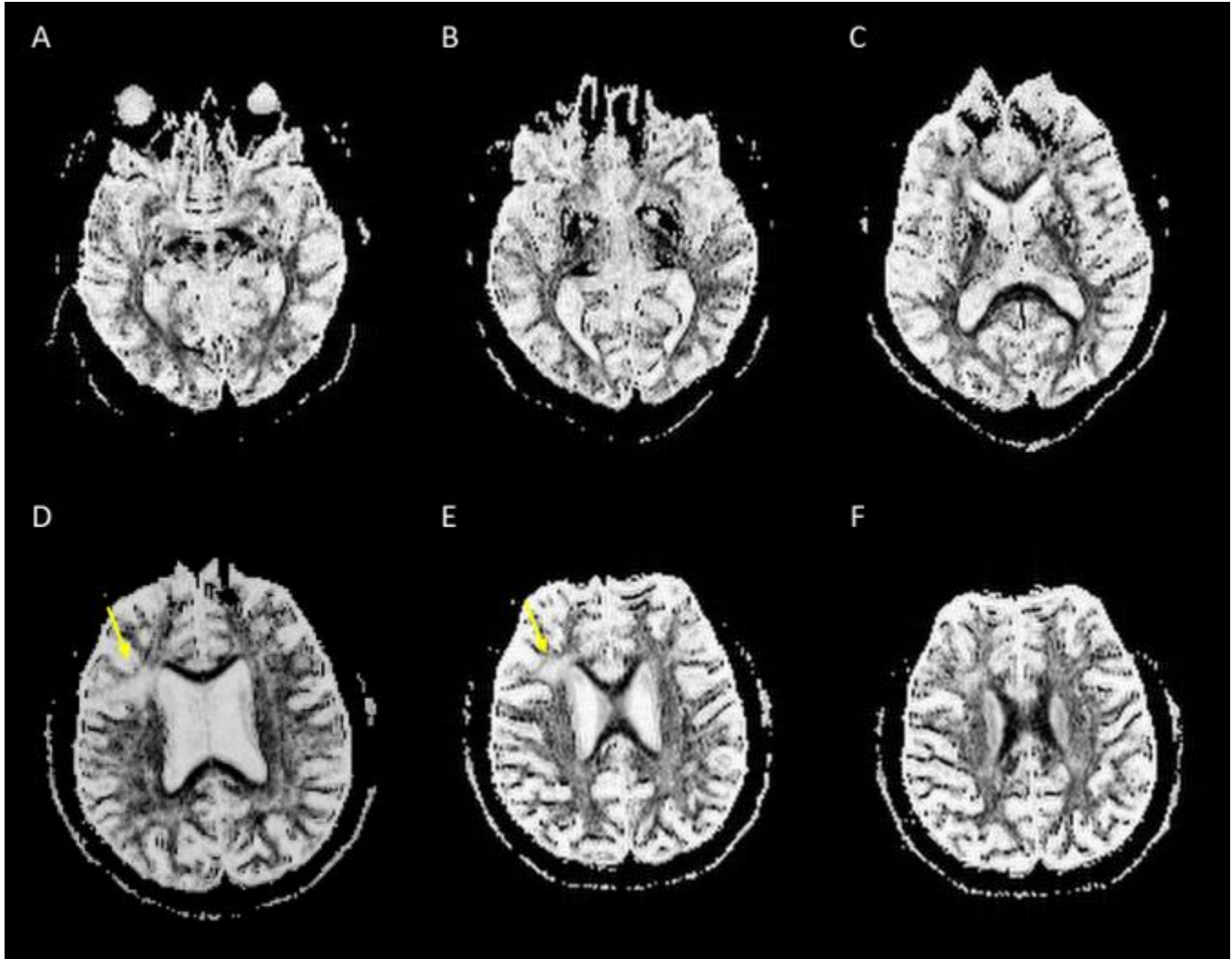


Figure Legend

A-F: Diffusion tensor imaging (DTI) – Inverse fractional anisotropy (FA) maps.

Discussion

Reduced FA is seen in the right frontal region as indicated by increased signal: yellow arrows in D-E.

5. Diffusion Tensor Imaging (DTI) Tractography Findings

Tractography - Corpus Callosum

5.1.

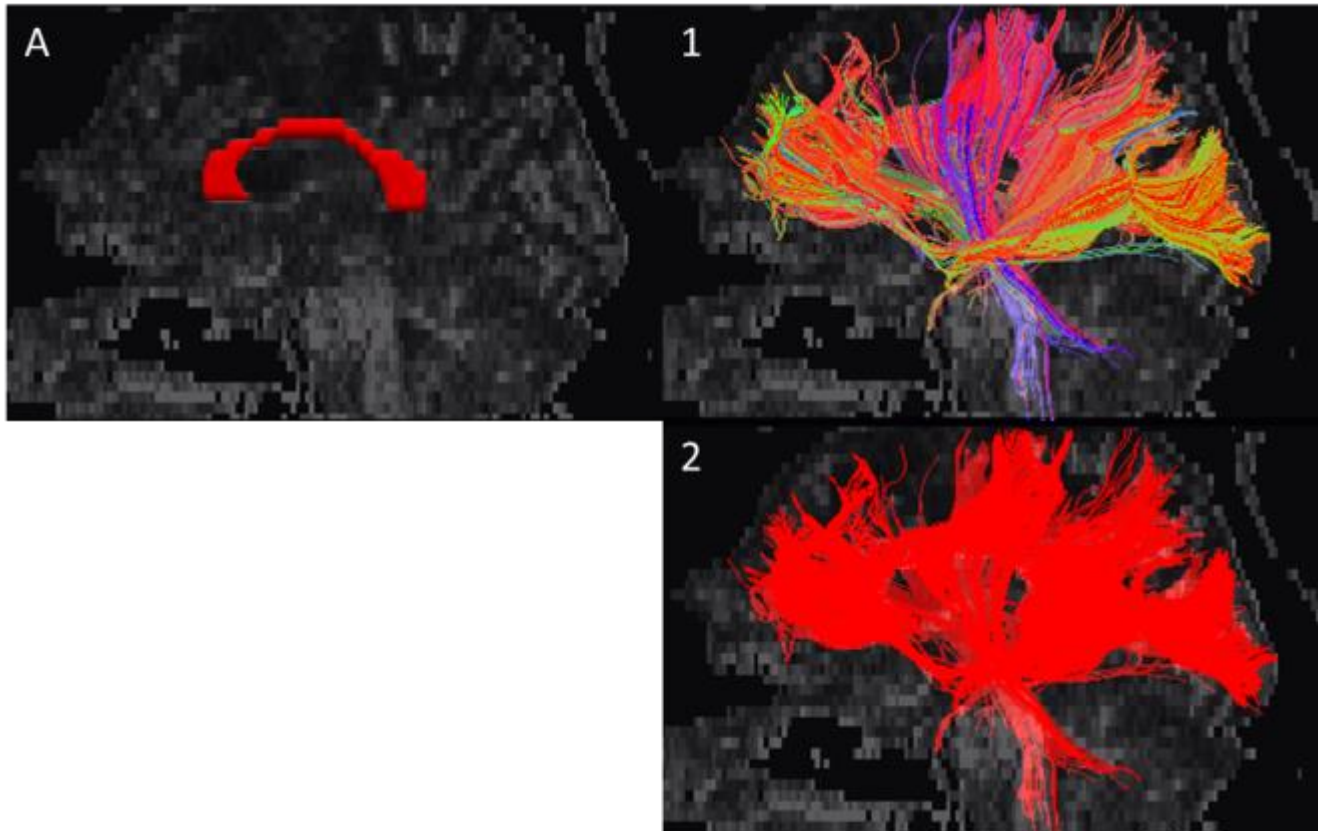


Figure Legend

A: Region of interest (ROI) for corpus callosum (red) seed.

1: Pseudo-colored white matter fiber tracts of the right and left hemispheres.

2: Structural colored white matter fiber tracts of the right and left hemispheres.

Discussion

No identifiable aberrance is observed.

5.2.

Tractography - Corticospinal Tract

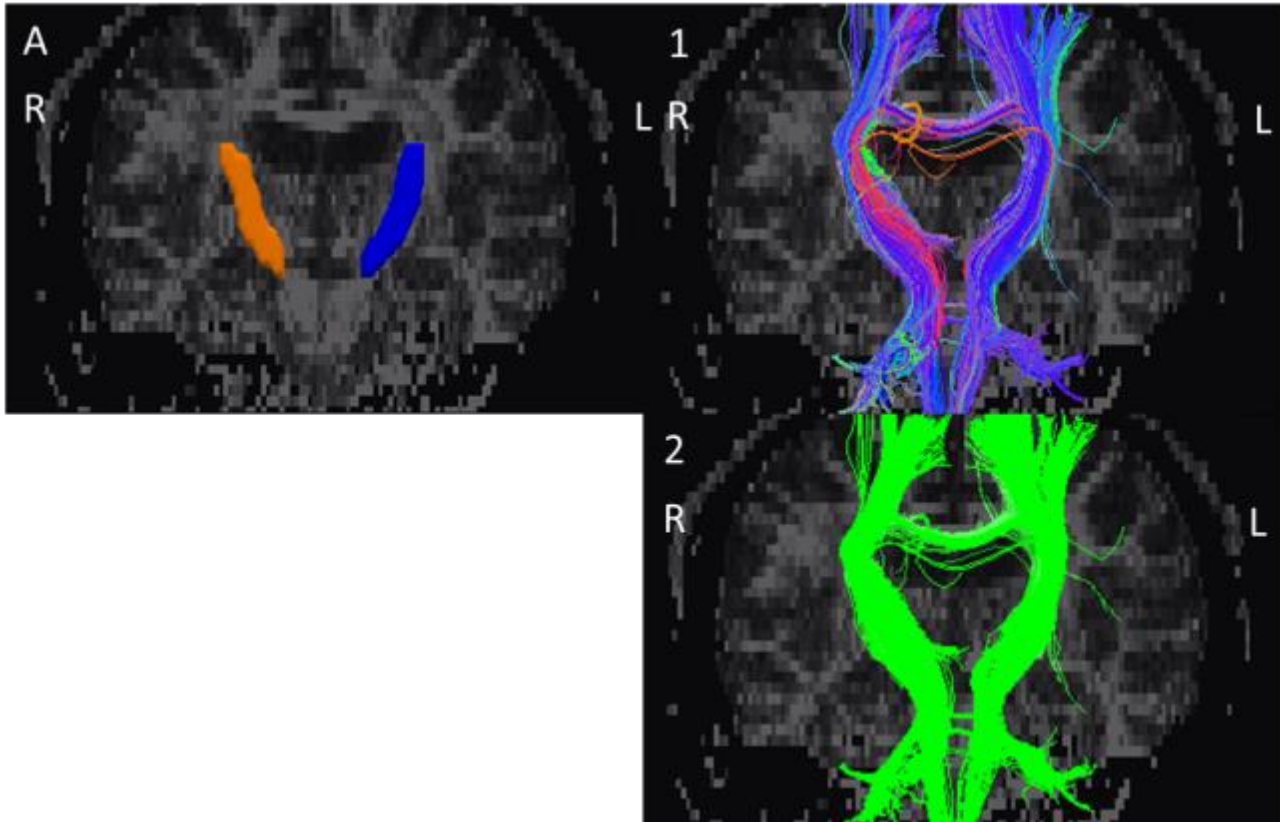


Figure Legend

A: Region of interest (ROI) for right (orange) and left (blue) corticospinal tract seed.

1: Pseudo-colored white matter fiber tracts of the right and left hemispheres.

2: Structural colored white matter fiber tracts of the right and left hemispheres.

Discussion

No identifiable aberrance is observed.

5.3.

Tractography - Internal Capsule

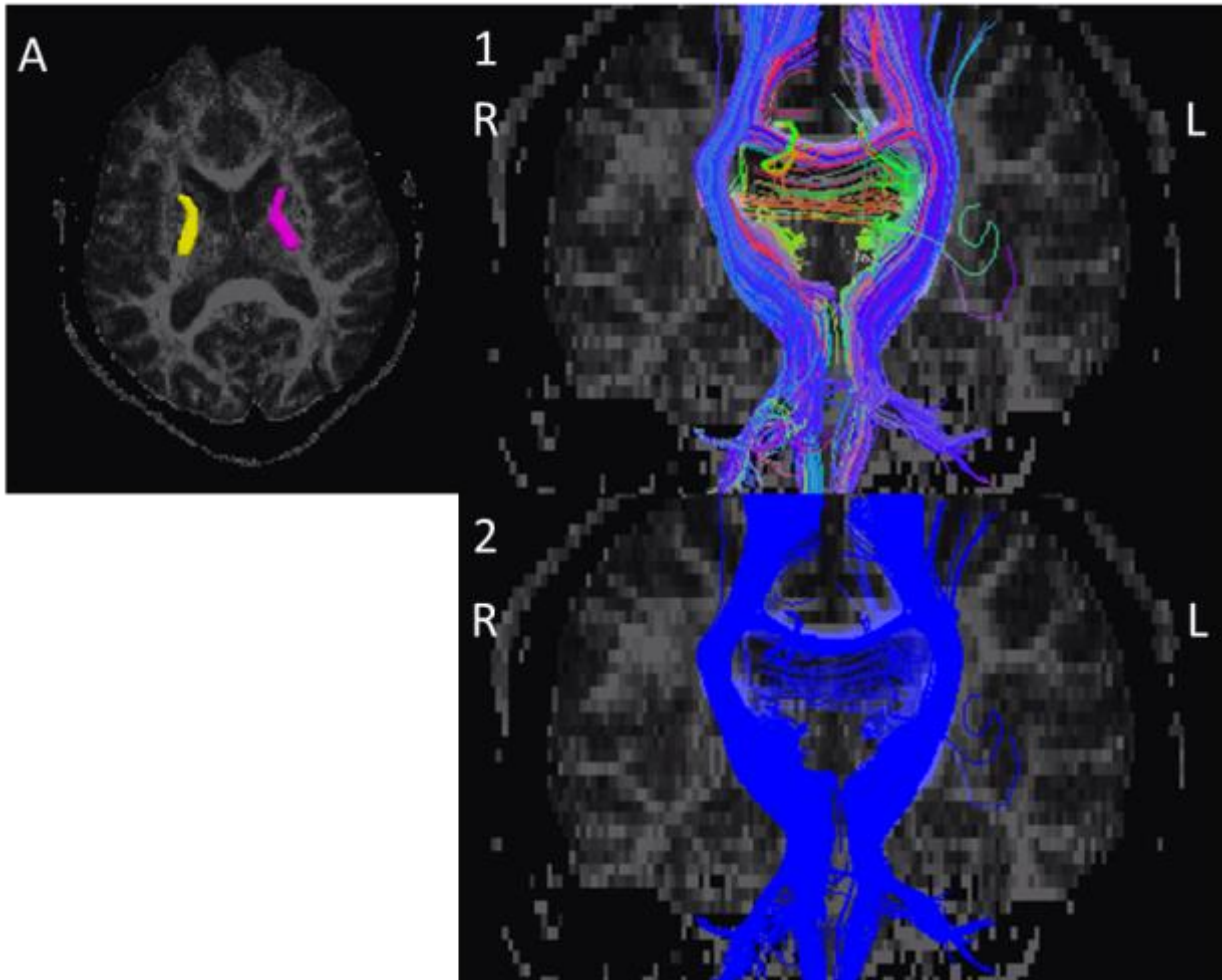


Figure Legend

A: Region of interest (ROI) for right (yellow) and left (pink) internal capsule seed.

1: Pseudo-colored white matter fiber tracts of the right and left hemispheres.

2: Structural colored white matter fiber tracts of the right and left hemispheres.

Discussion

No identifiable aberrance is observed.

Tractography - Brain Stem

5.4.

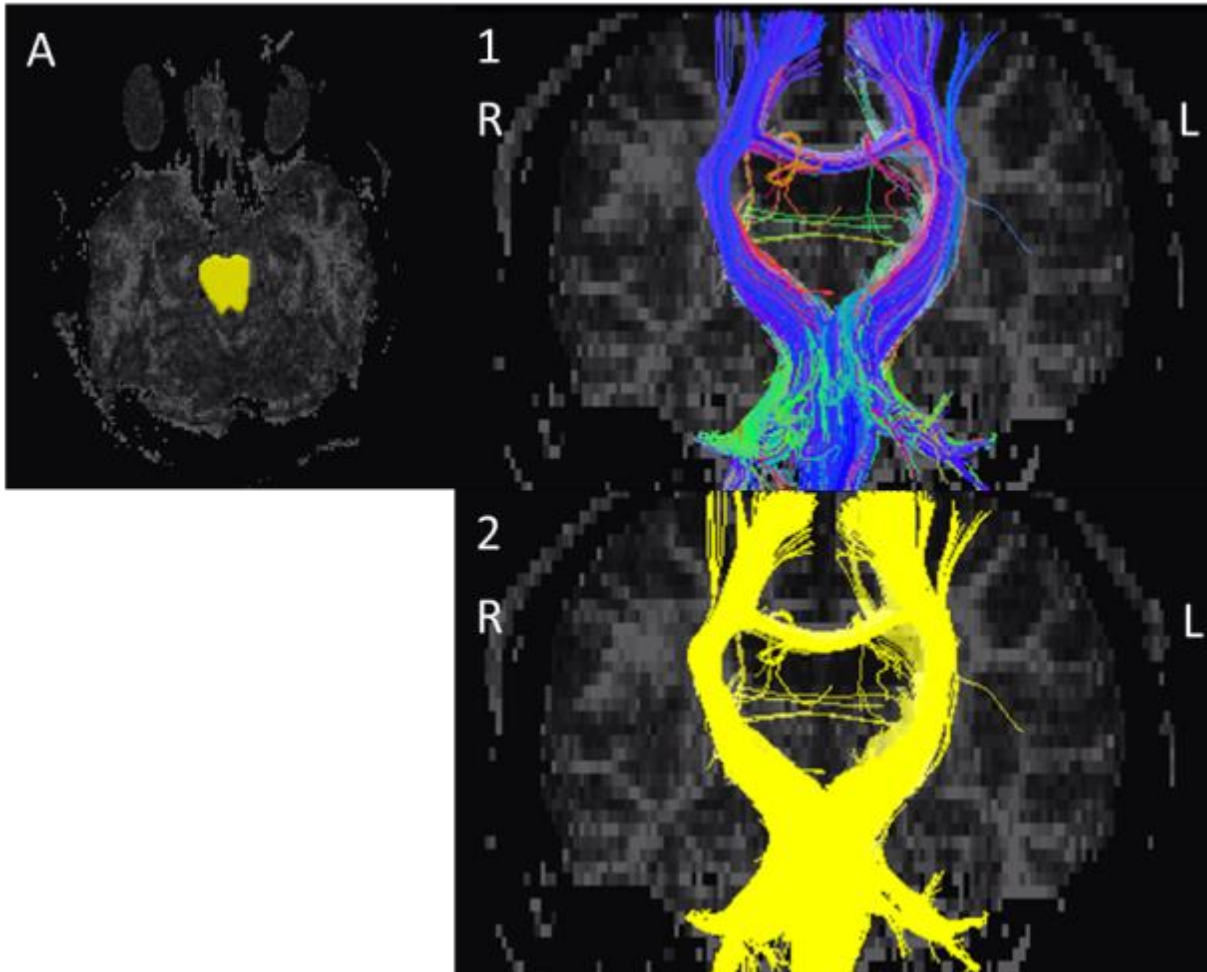


Figure Legend

A: Region of interest (ROI) for brain stem (yellow) seed.

1: Pseudo-colored white matter fiber tracts of the right and left hemispheres.

2: Structural colored white matter fiber tracts of the right and left hemispheres.

Discussion

No identifiable aberrance is observed.

Tractography - Optic Radiation

5.5.

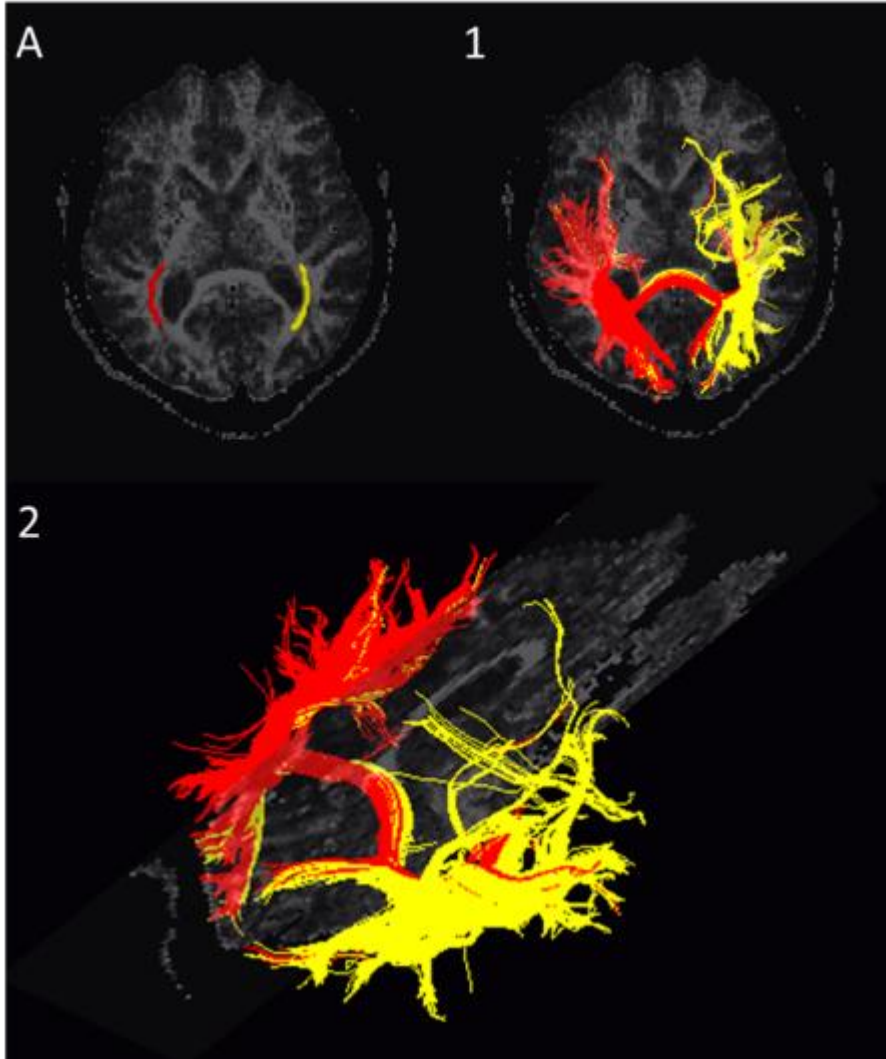


Figure Legend

A: Region of interest (ROI) for right (red) and left (yellow) optic radiation seed.

1: Structural colored white matter fiber tracts of the right and left hemispheres (axial view).

2: Structural colored white matter fiber tracts of the right and left hemispheres (sagittal view).

Discussion

No identifiable aberrance is observed.



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5.6. Statistics of All Regions on FA Images:

Table 2.

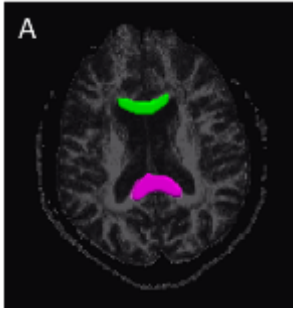
Seed #	Region	Pixels	Min.	Max.	Mean	Std.
1	Corpus Callosum	136	0.16	1.00	0.70	0.21
2	Brain Stem	284	0.14	1.00	0.70	0.16
3	Right Internal Capsule	91	0.24	0.97	0.73	0.12
4	Left Internal Capsule	87	0.36	0.91	0.69	0.14
5	Right Corticospinal Tract	69	0.27	1.00	0.75	0.15
6	Left Corticospinal Tract	72	0.27	1.00	0.78	0.14
7	Right Optical Radiation	51	0.44	0.86	0.66	0.10
8	Left Optical Radiation	54	0.41	0.82	0.66	0.09

Discussion

The above table gives the statistics of evaluated regions on the diffusion tensor imaging fractional anisotropy (DTI FA) maps.

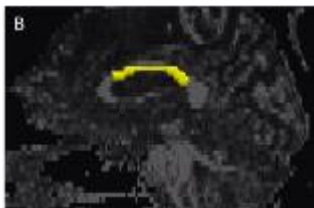
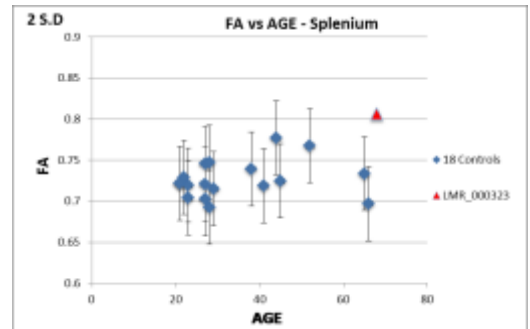
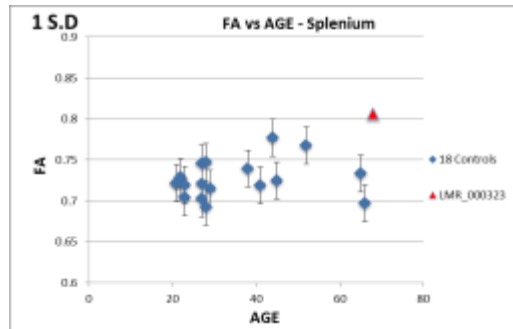
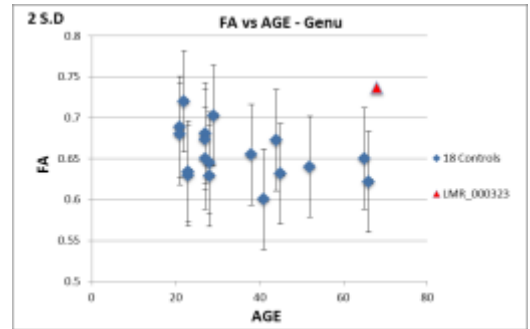
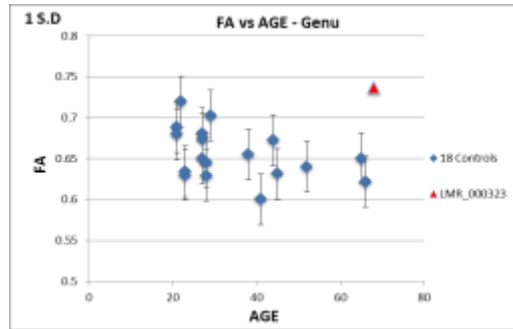
5.7.

Corpus Callosum Contours and Graphs

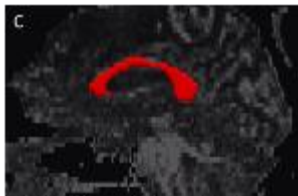
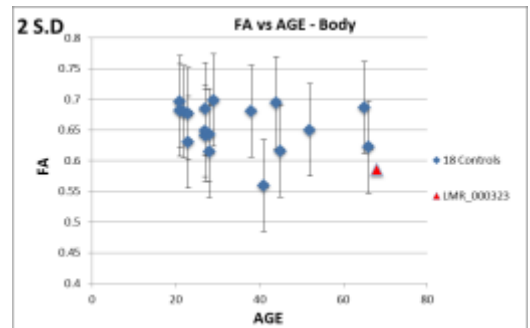
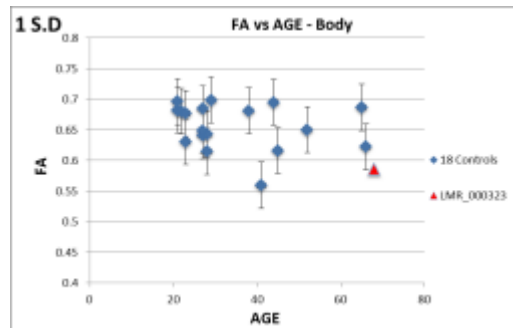


Light Green: Genu

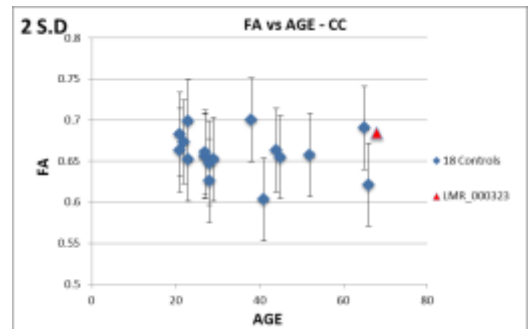
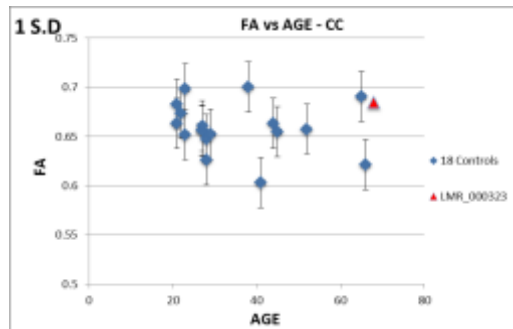
Pink: Splenium



Yellow: Body



Red: Entire Corpus Callosum





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5.8. FA Results Compared with 18 Normal Controls

Table 3.

Control Number	Age	FA Mean-Genu	FA Mean-Splenium	FA Mean-Body	FA Mean-Corpus Callosum
1	23	0.6631	0.6692	0.7478	0.6054
2	45	0.6198	0.6751	0.654	0.5942
3	22	0.6558	0.7282	0.6326	0.5623
4	27	0.6419	0.7151	0.5480	0.5995
5	23	0.6203	0.7305	0.6014	0.5797
6	21	0.6853	0.7205	0.6419	0.6441
7	65	0.6786	0.7746	0.6515	0.6384
8	52	0.7756	0.7835	0.6092	0.6273
9	44	0.6462	0.6853	0.6657	0.6375
10	41	0.6218	0.6703	0.5195	0.5519
11	28	0.6730	0.6927	0.6634	0.6504
12	27	0.6448	0.7681	0.7249	0.6645
13	29	0.7309	0.7461	0.6244	0.6355
14	27	0.7187	0.7352	0.6181	0.622
15	66	0.6132	0.6427	0.6078	0.6334
16	38	0.7174	0.7628	0.6783	0.6804
17	28	0.6318	0.7089	0.5507	0.5938
18	21	0.6873	0.6910	0.7122	0.5833
SAMPLE	68	0.7368	0.8060	0.5861	0.6848

6. Perfusion Weighted Imaging Findings

Perfusion Weighted Imaging (PWI) Region Maps

6.1.

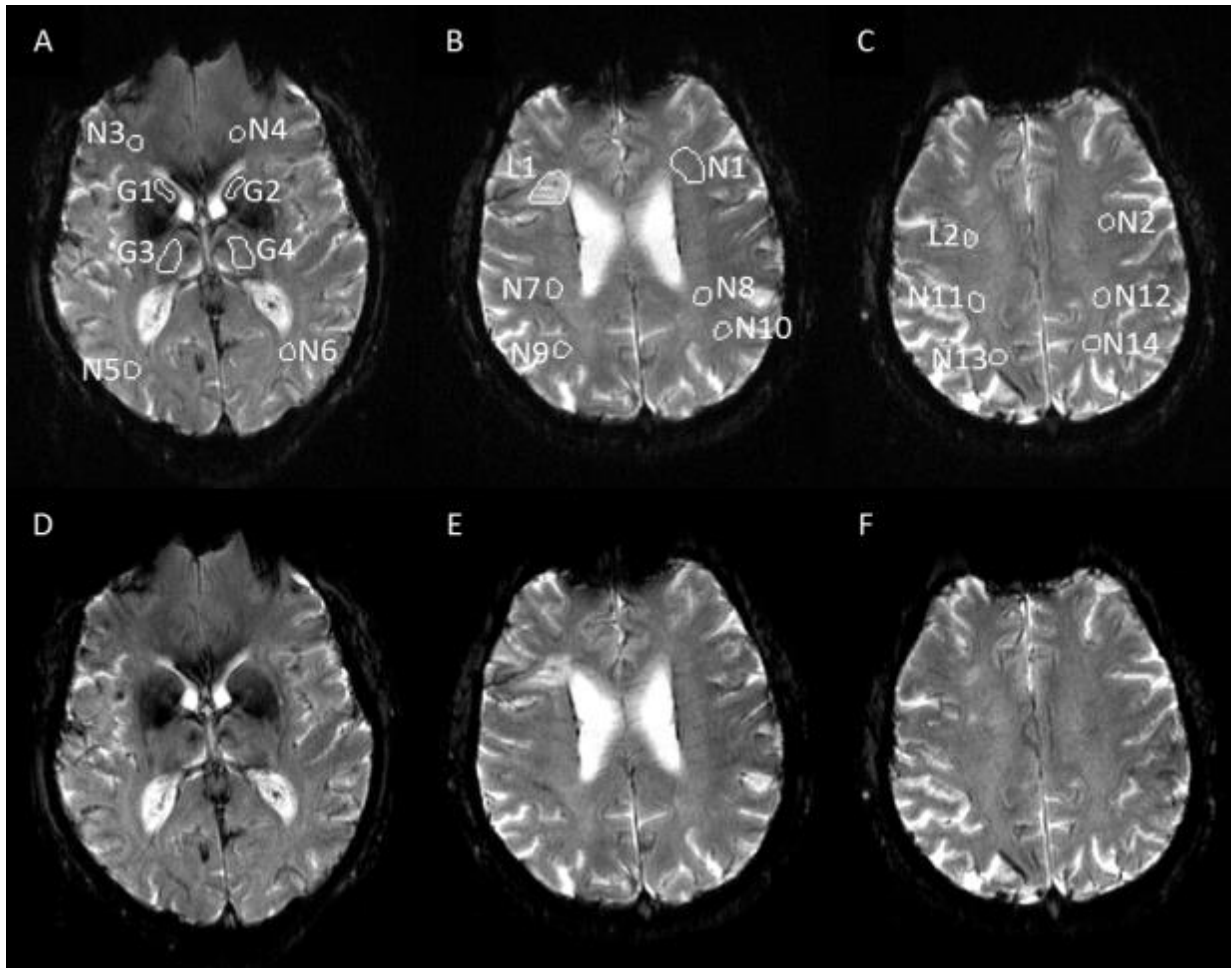


Figure Legend

A-C: PWI at the first of 50 time points ($1.0 \times 1.0 \times 4.0 \text{ mm}^3$).

D-F: PWI at the 30th time point, the point at which contrast passing through the tissue has the maximum effect on the signal.

Normal (N1-N14) and abnormal (L1-L2) appearing white matter regions are defined.

Normal and abnormal regions are paired by number (L1:N1, L2:N2, etc.) either as a neighbor or as a contralateral.

The deep gray matter structures, the caudate nuclei (G1-G2) and the thalami (G3-G4) are defined.

Perfusion Weighted Imaging (PWI) Region Descriptions

6.2.

Table 4.

Normal Appearing White Matter						
Region	CSA (pixels)	Location	T1WI	Post contrast T1WI enhance	SWI	FLAIR
N1	130	L-Frontal	--	--	--	--
N2	24	L-Frontal	--	--	--	--
N3	23	R-Frontal	--	--	--	--
N4	22	L-Frontal	--	--	--	--
N5	27	R-Occipital	--	--	--	--
N6	25	L-Occipital	--	--	--	--
N7	30	R-Frontal	--	--	--	--
N8	33	L-Frontal	--	--	--	--
N9	28	R-Occipital	--	--	--	--
N10	28	L-Occipital	--	--	--	--
N11	32	R-Frontal	--	--	--	--
N12	32	L-Frontal	--	--	--	--
N13	27	R-Frontal	--	--	--	--
N14	29	L-Frontal	--	--	--	--
Lesion/Abnormal Appearing White Matter						
Region	CSA (pixels)	Location	T1WI	Post contrast T1WI enhance	SWI	FLAIR
L1	151	R-Frontal	Hypo-Int.	No	Hypo-Int.	Hyper-Int.
L2	21	R-Frontal	Hypo-Int.	No	--	Hyper-Int.
Deep Gray Matter Structures						
Region	CSA (pixels)	Location	T1WI	Post contrast T1WI enhance	SWI	FLAIR
G1	23	Right CN	--	--	n/a	--
G2	29	Left CN	--	--	n/a	--
G3	99	Right THA	--	--	n/a	--
G4	97	Left THA	--	--	n/a	--

Figure Legend

The above table describes the regions of perfusion analysis.

Cross section area (CSA) is given in pixels.

Signal on provided sequences (T1WI pre and post-contrast, SWI, and FLAIR) are described.

Perfusion Weighted Imaging (PWI) Region Maps

6.3.

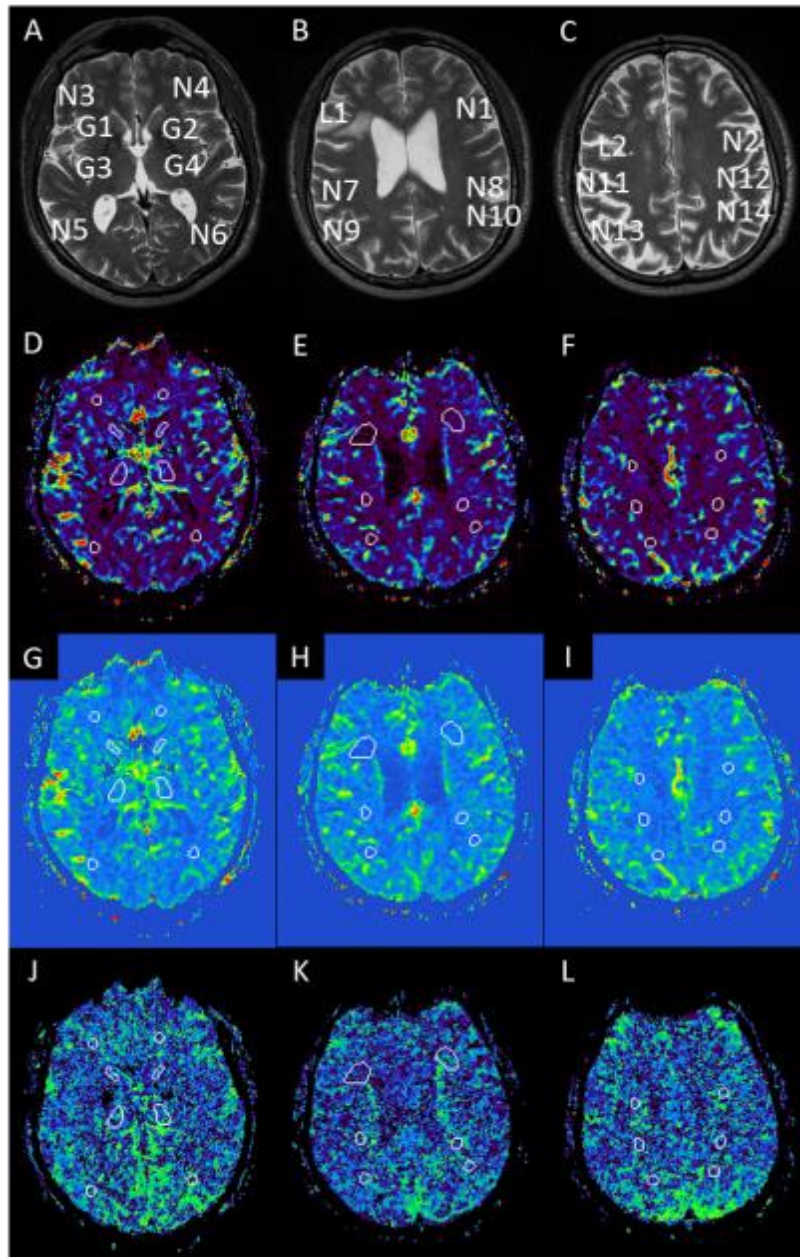


Figure Legend

A-C: Axial T2WI. Defined regions are numbered corresponding with descriptions on previous Figure 6.1.

D-F: Cerebral Blood Volume (CBV). Units are ml/100g tissue.

G-I: Cerebral Blood Flow (CBF). Units are ml/100g tissue/minute.

J-L: Mean Transit Time (MTT). Units are seconds.

Perfusion Analysis Results

6.4.

Table 5.

Region	Identity	Cerebral Blood Volume (CBV)		Cerebral Blood Flow (CBF)		Mean Transit Time (MTT)	
		mL per 100g of tissue		mL per 100g of tissue per minute		seconds	
		AVERAGE	ST. DEV.	AVERAGE	ST. DEV.	AVERAGE	ST. DEV.
N1	NAWM	0.9	0.3	5.1	1.7	6.6	1.6
N2	NAWM	0.7	0.2	3.5	1.4	6.3	1.5
N3	NAWM	0.9	0.2	5.1	1.2	6.3	1.7
N4	NAWM	1.0	0.3	4.2	2.1	6.0	1.6
N5	NAWM	0.7	0.2	4.3	1.6	6.6	1.8
N6	NAWM	0.5	0.1	3.5	1.1	6.2	2.0
N7	NAWM	0.9	0.2	4.5	1.8	5.9	1.6
N8	NAWM	0.9	0.2	4.8	1.2	5.6	1.9
N9	NAWM	0.6	0.2	3.1	1.2	6.4	1.7
N10	NAWM	0.6	0.2	3.3	1.1	6.8	1.3
N11	NAWM	0.6	0.2	3.2	1.6	6.2	1.3
N12	NAWM	0.7	0.2	4.6	1.7	6.3	1.5
N13	NAWM	0.6	0.1	3.4	1.2	5.9	1.2
N14	NAWM	0.7	0.1	3.1	0.7	5.8	1.6
L1	Lesion	0.4	0.2	2.1	1.3	5.4	1.4
L2	Lesion	0.4	1.1	2.3	0.8	6.3	1.5
G1	R CN	1.7	0.2	9.8	3.0	6.2	1.4
G2	L CN	1.5	0.4	7.8	0.2	6.3	1.3
G3	R THA	1.3	0.4	7.6	2.3	6.4	1.8
G4	L THA	1.4	0.4	7.0	2.3	6.8	1.5

Figure Legend

The above table gives the values calculated from signal intensity on the perfusion weighted imaging maps. **Cerebral Blood Volume (CBV)** shows the fraction of volume of tissue occupied by blood in ml per 100g of tissue within the defined region.

Cerebral Blood Flow (CBF) shows the rate at which blood volume passes through the microvasculature of 100g of tissue per minute within the defined region.

Mean Transit Time (MTT) shows the average time in seconds for a molecule of contrast agent to pass through the tissue within a defined region.

Discussion

L1 and L2 shows lower CBF compared to N1 and N2, respectively.

7. Structural and Anatomical Findings

3D Time of Flight (TOF) MRA

7.1.

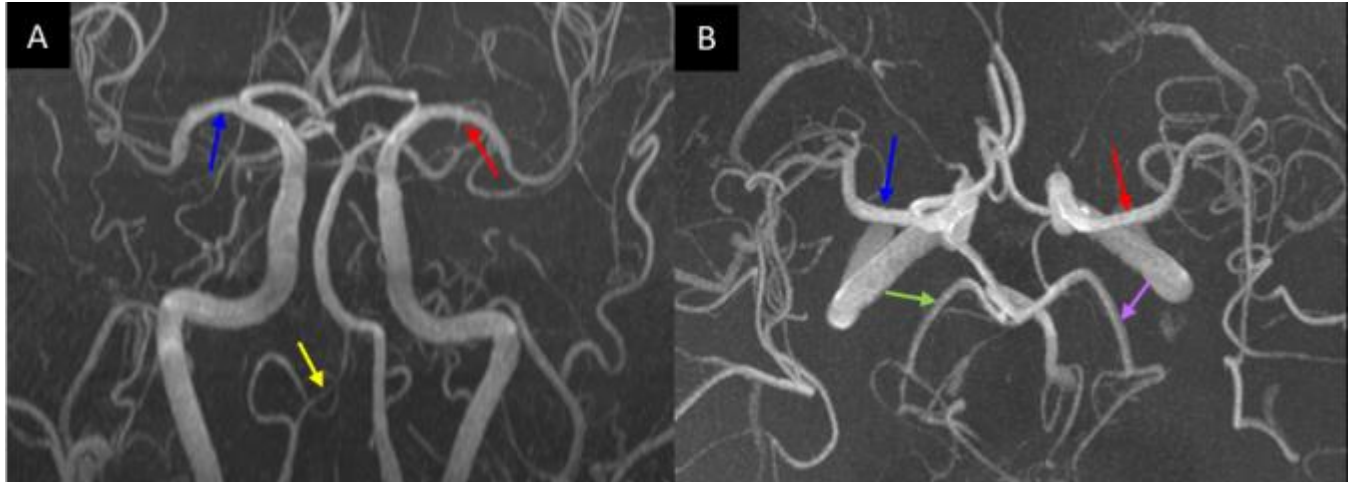


Figure Legend

A: 3D TOF MRA – coronal view.

B: 3D TOF MRA – axial view.

Discussion

A: Structure: Arrow color

- Right middle cerebral artery (RMCA): Blue.
- Left middle cerebral artery (LMCA): Red.

B: Structure: Arrow color

- Right posterior cerebral artery (RPCA): Green.
- Left posterior cerebral artery (LPCA): Pink.

Right vertebral artery appears very thin: yellow arrow in A.

Enhancement of Vessels at Different Phases

7.2.

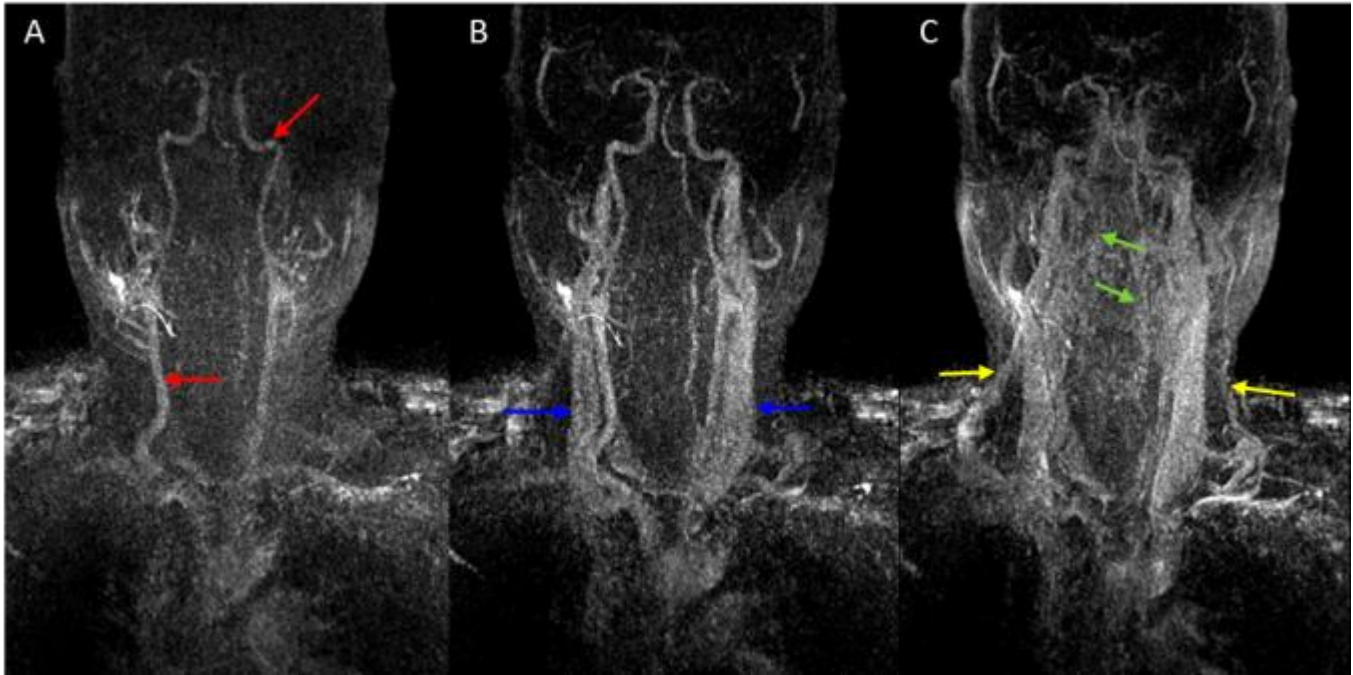


Figure Legend

MIP of 96 slices (the whole image set) of 3D dynamic contrast enhanced (CE) MRAV of the head and neck ($0.9 \times 0.9 \times 0.9 \text{ mm}^3$).

A: Arterial phase.

B: Early venous phase; internal jugular veins (IJVs) are enhanced.

C: Later venous phase; smaller veins are enhanced.

Note: signal is poor in these images, interpretation may be subject to bias.

Discussion

Arterial system shown in A:

- **Structure: Arrow color**
 - Right common carotid artery (RCCA): Lower red.
 - Left internal carotid artery (LICA): Upper red.

The venous system shown in B:

- **Structure: Arrow color**
 - Internal jugular veins (IJV): Blue.

Venous system further enhances in late venous phase in C:

- **Structure: Arrow color**
 - External jugular veins (EJV): Yellow.
 - Vertebral venous system (VV): Green. (partially enhanced in the late venous phase)

3D Contrast Enhanced (CE) MRAV of Internal Jugular Veins

7.3.

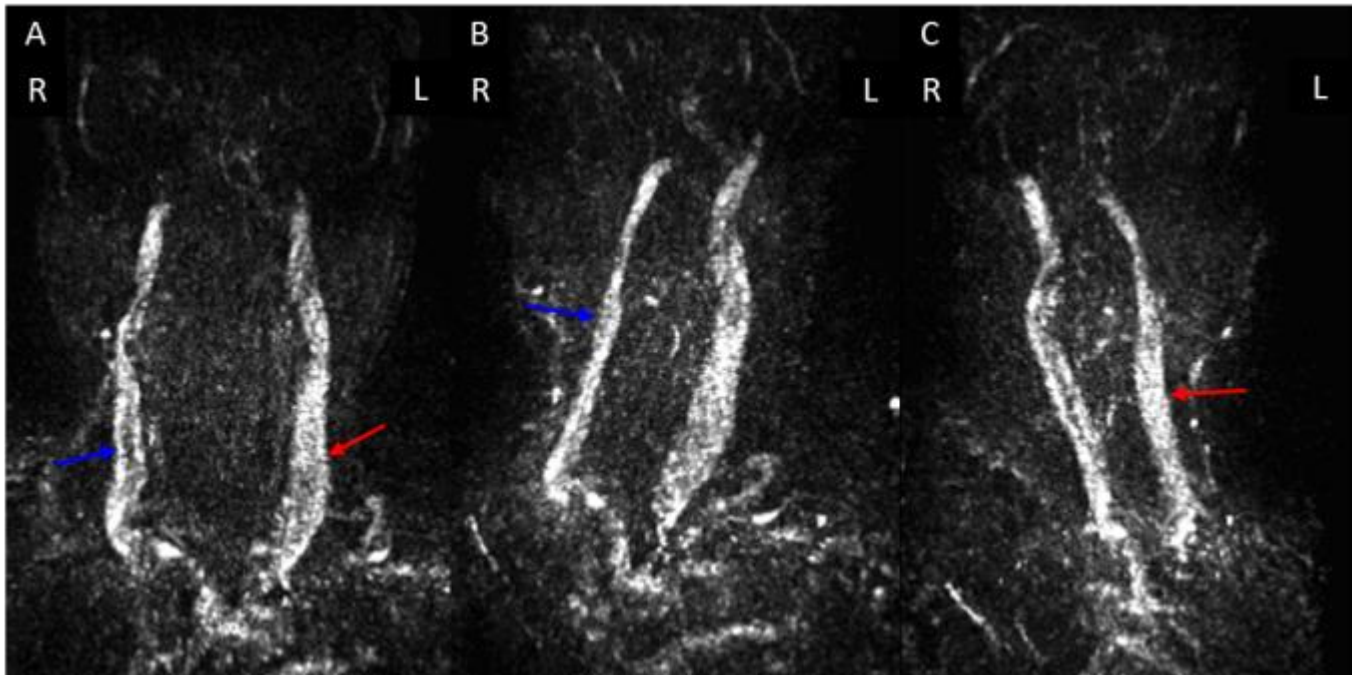


Figure Legend

A: MIP of 96 slices of subtracted 3D CE MRAV.
(arterial enhancement subtracted from early venous enhancement)

B and C: 3D rotations of subtracted MRAV at different angles.

Note: signal is poor in these images, interpretation may be subject to bias.

Discussion

Right internal jugular vein (RIJV) demonstrates:

- Weak enhancement through the length of the vessel: Blue arrows in A&B.

Left internal jugular vein (LIJV) demonstrates:

- Weak enhancement through the length of the vessel: red arrows in A&C.

2D Time of Flight (TOF) MRV of Internal Jugular Veins

7.4.

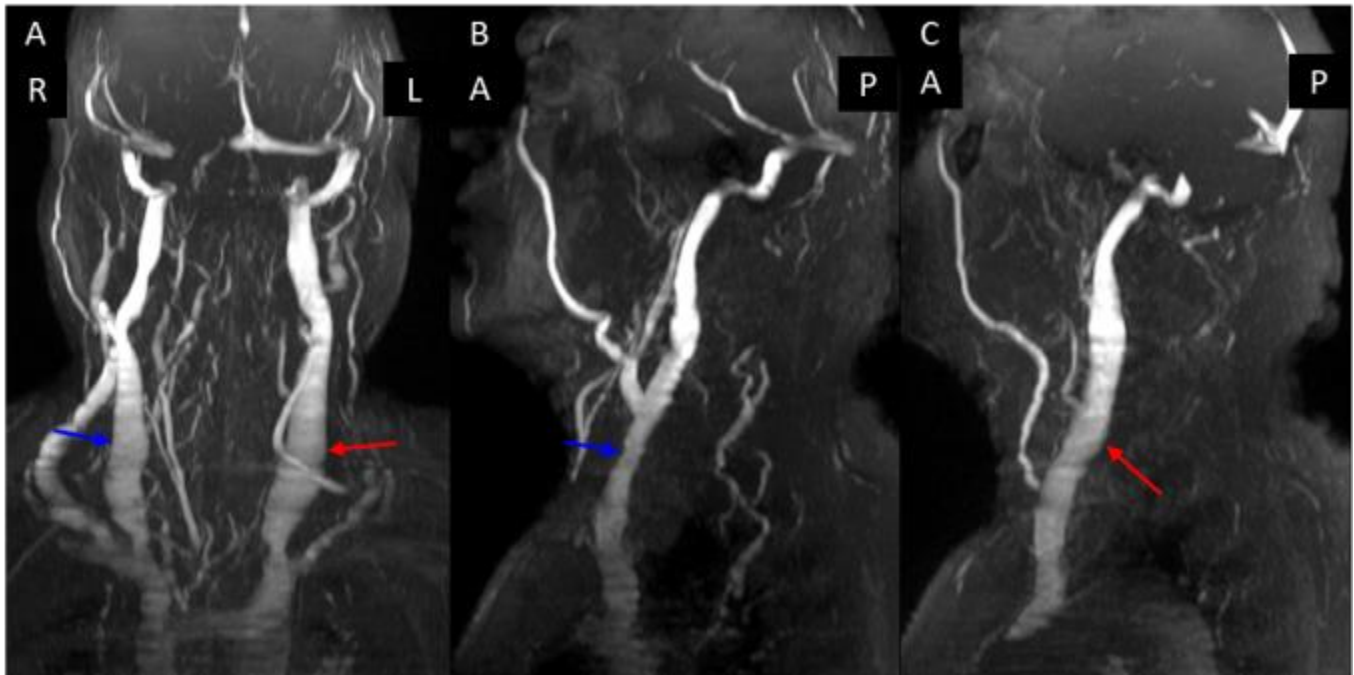


Figure Legend

A: Reformatted view of the 2D TOF MRV data, MIP of 185 slices; (0.6x0.6x3.0mm³).

B: Sagittal view of the 2D TOF MRV data, MIP of 58 slices showing the right internal jugular vein (RIJV).

C: Sagittal view of the 2D TOF MRV data, MIP of 57 slices showing the left internal jugular vein (LIJV).

Discussion

Right internal jugular vein (RIJV) demonstrates:

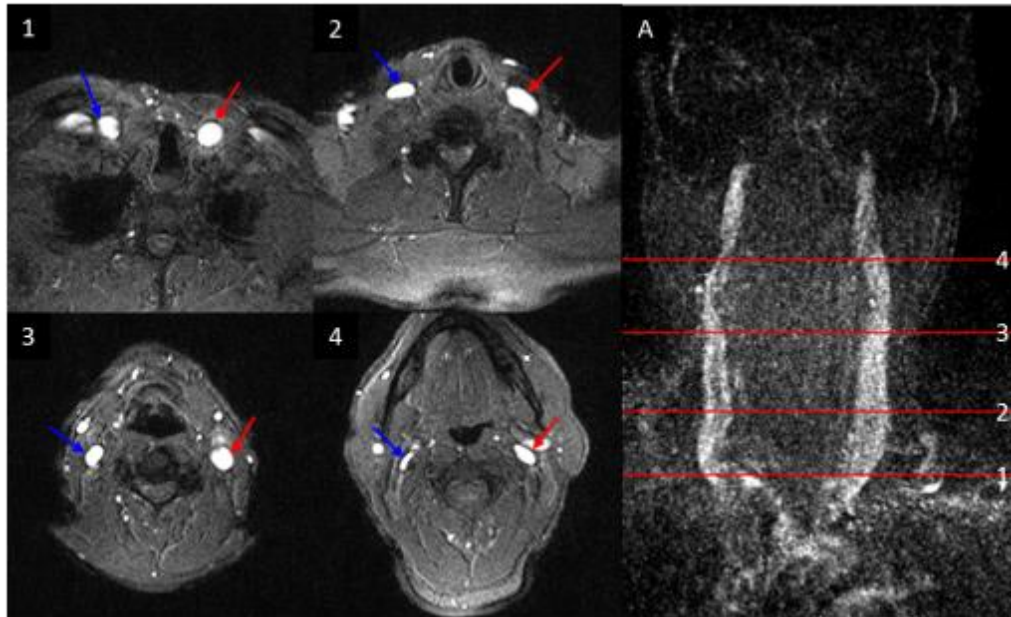
- Clear and consistent caliber: Blue arrows in A&B.

Left internal jugular vein (LIJV) demonstrates:

- Clear and consistent caliber: Red arrows in A&C.

2D Time of Flight (TOF) MRV of Internal Jugular Veins

7.5.



**CSA Measurements
(in mm²)
Stenosis in *Italics***

Right IJV

Slice	CSA
1	150.04
2	134.37
3	105.85
4	47.65

Left IJV

Slice	CSA
1	185.93
2	232.42
3	158.20
4	97.26

Figure Legend

1-4: Axial view of 2D TOF MRV (0.6x0.6x3.0mm³) slices selected sequentially (non-continuous) from the lower to the upper regions of the neck.

A: MIP of subtracted 3D CE MRAV. The red lines in A are localizations of 1-4.

Cross sectional area (CSA) of both IJVs are measured when a stenosis is suspected.

For the upper neck region:

- CSA equal to or less than 12.5mm² is defined as stenosis.

For the lower and middle neck regions:

- CSA equal to or less than 25mm² is defined as stenosis.

Discussion

Right internal jugular vein (RIJV) demonstrates:

- Slight flattening at the upper neck level: Blue arrow in axial slices 4.

Left internal jugular vein (LIJV) demonstrates:

- Clear and consistent caliber: Red arrows in axial slices 1-4.

2D Time of Flight (TOF) MRV of the Vertebral Venous System

7.6.

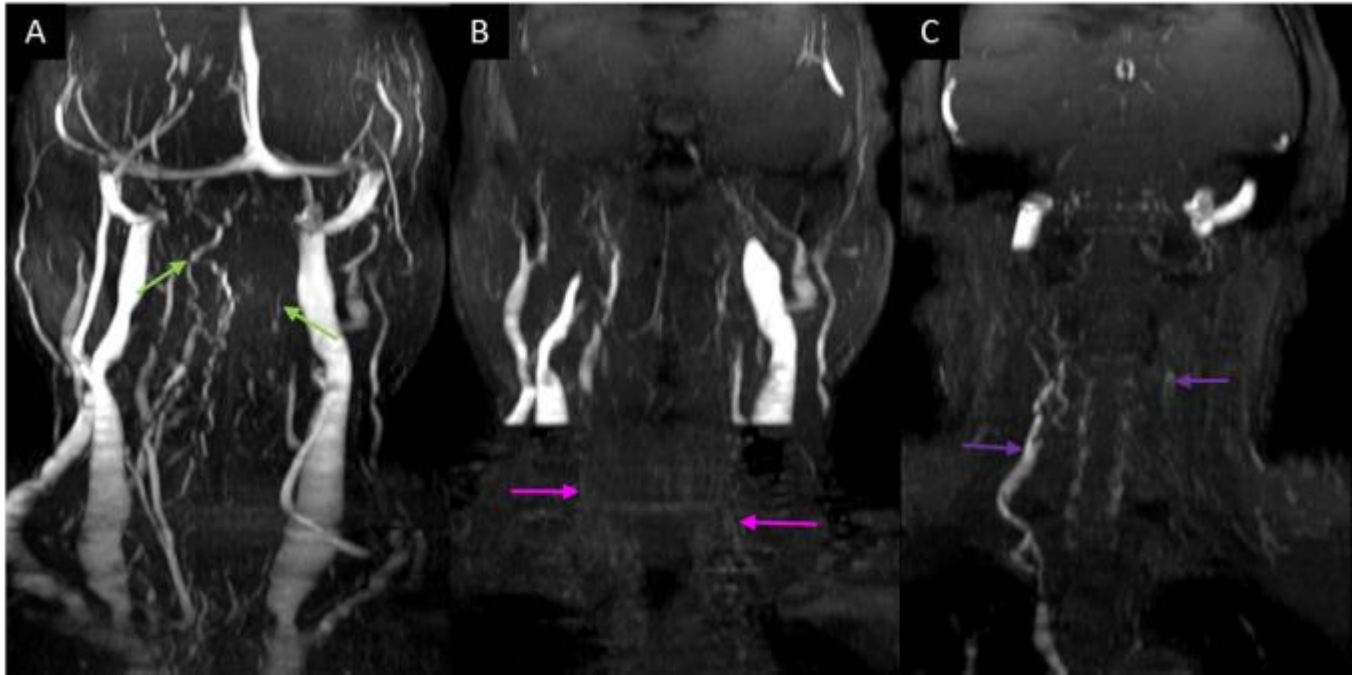


Figure Legend

MIPs generated from 2D TOF MRV data.

A: A full MIP (290 slices) encompassing the vertebral venous system.

B: A thinner MIP (36 slices) encompassing the vertebral veins.

C: A thinner MIP (34 slices) encompassing the deep cervical veins.

Discussion

The vertebral plexus is shown: Green arrows in A.

The vertebral veins are weak signal: Pink arrows in B.

The deep cervical veins are shown (C), the left deep cervical shows weak signal: Purple arrows in C.

Transverse Sinus Anatomy

7.7.

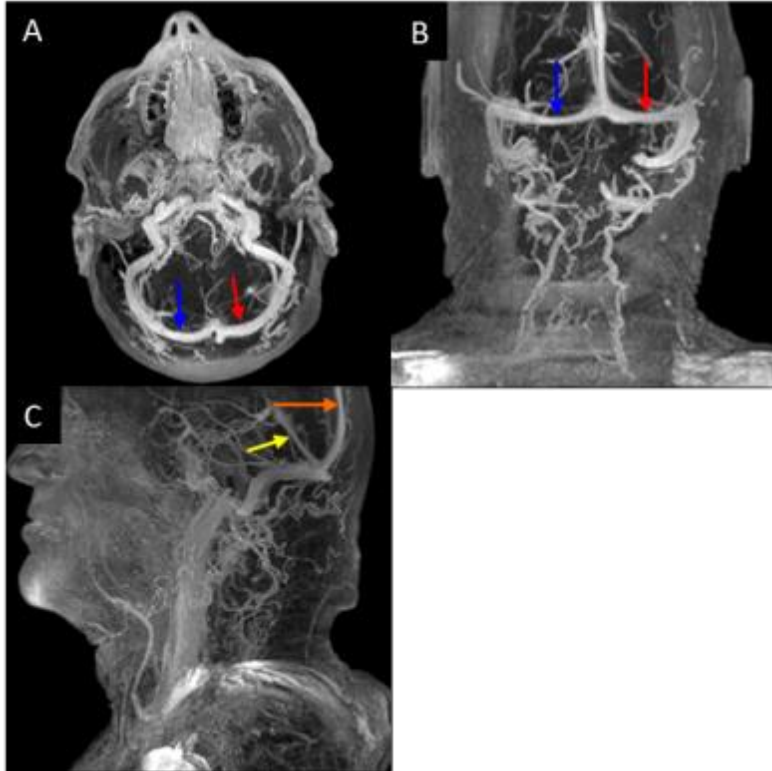


Figure Legend

A: Axial MIP of 3D post-contrast VIBE of head (39 slices) ($0.9 \times 0.9 \times 0.9 \text{ mm}^3$).

B: Coronal MIP of 3D post-contrast VIBE of head (70 slices).

C: Sagittal MIP of 3D post-contrast VIBE of head (256 slices).

Discussion

A-B: Structure: Arrow Color

- Right transverse sinus (RTSV): Blue.
- Left transverse sinus (LTSV): Red.

C: Structure: Arrow Color

- Superior sagittal sinus (SSSV): Orange.
- Straight sinus (STSV): Yellow.

Sagittal C-Spine

7.8.

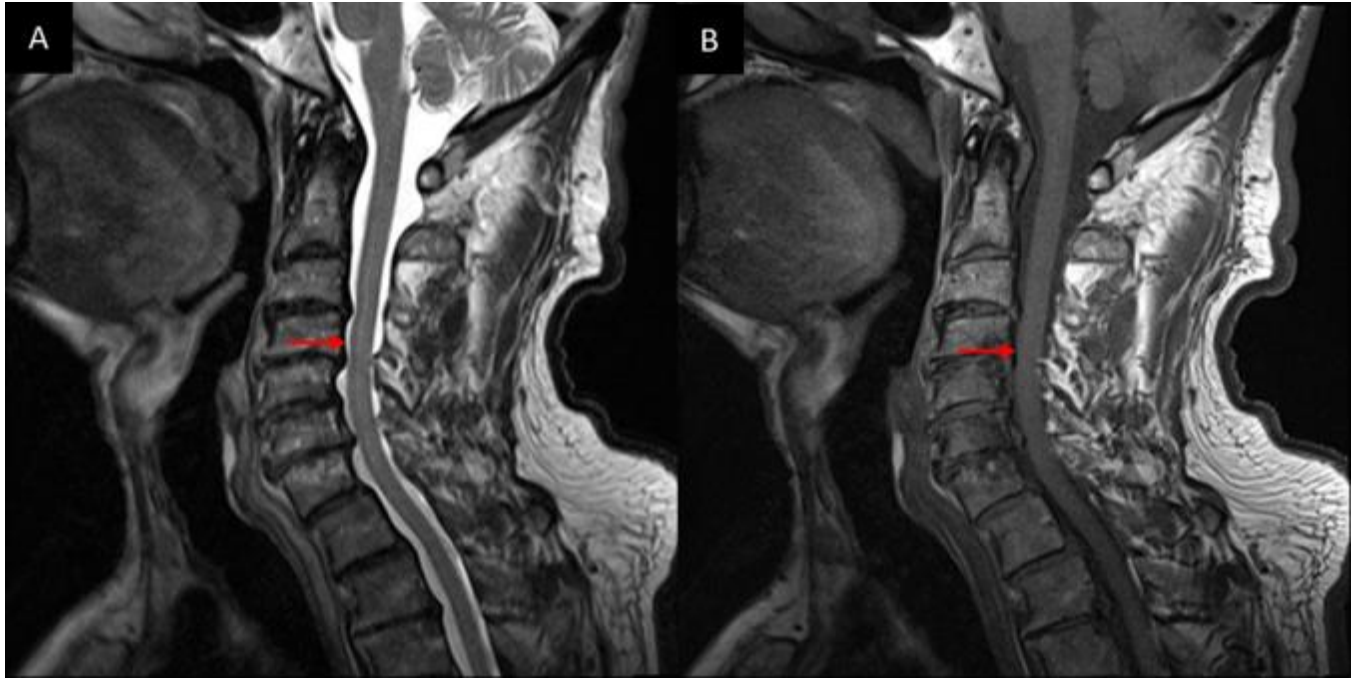


Figure Legend

A: Sagittal T2WI C-Spine image.

B: Sagittal T1WI C-Spine image.

Discussion

The cervical spinal cord is shown: Red arrows in A and B.

Irregular CSF signal is observed on anterior and posterior side of the spinal cord.

8. Flow Quantification Findings

Dural Sinuses

8.1.1.

Description: Flow quantification is performed using a special MRI sequence to encode the blood flowing inside the blood vessels. This sequence generates two sets of images: a magnitude image, and a phase image. The magnitude image shows the vessel anatomy while the phase image can be used to quantitatively measure the velocity and direction of the blood flow. For a Siemens MRI scanner, dark areas on a phase image indicate flow towards the heart. The darker the area, the more quickly the blood is moving toward the heart. Inversely, bright areas indicate blood flow toward the brain, the brighter the area, the faster the flow. (Additional explanation is provided at the end of this report).

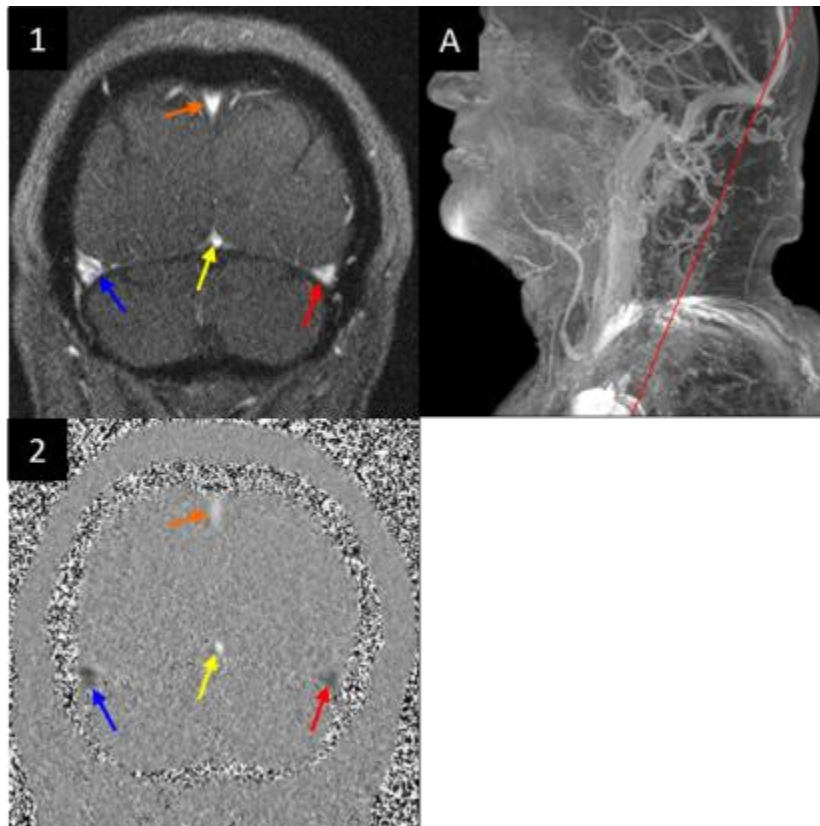


Figure Legend

1: Magnitude image. **2:** Phase image. **A:** Sagittal view. Red line acts as localization of 1-2.

1-2: Structure: Arrow color

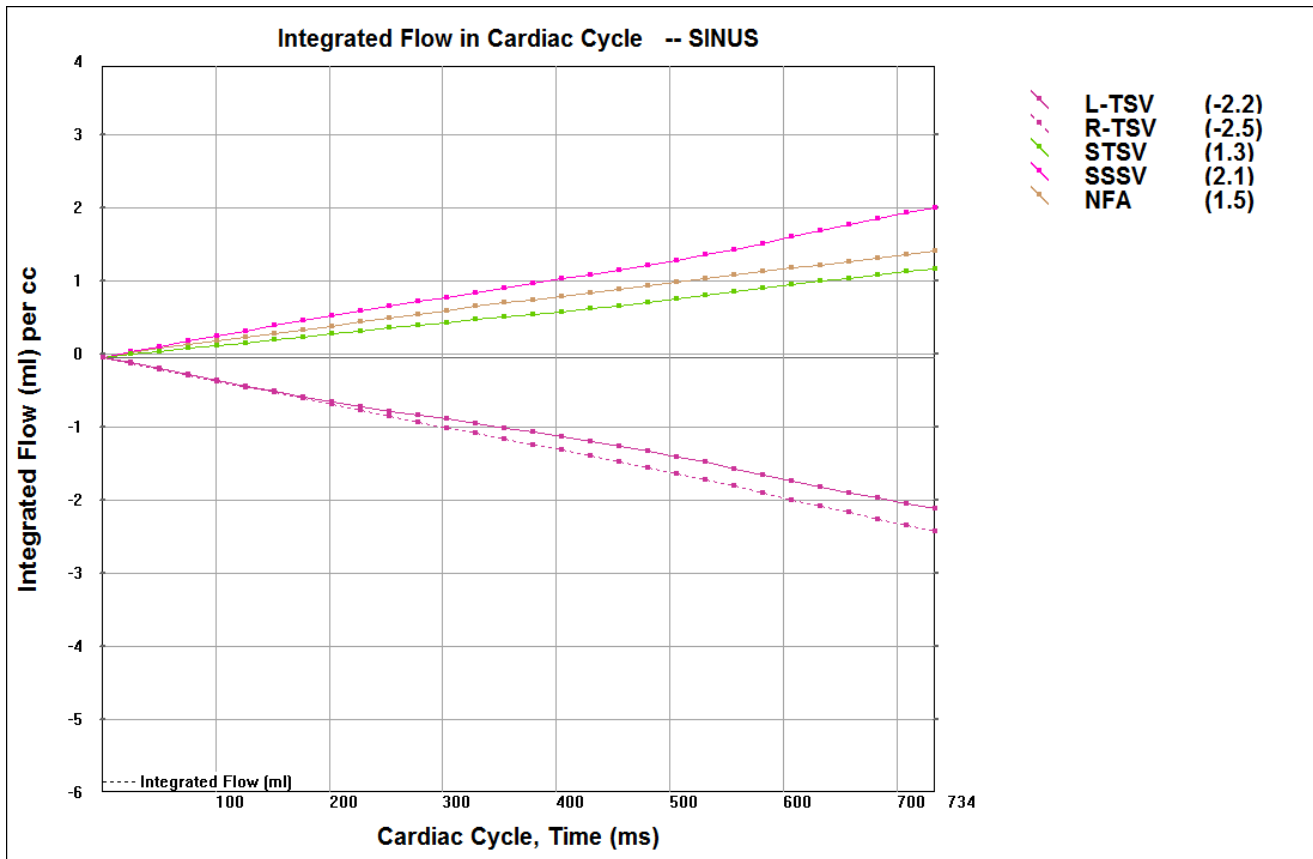
- Right transverse sinus (RTSV): Blue.
- Left transverse sinus (LTSV): Red.
- Superior sagittal sinus (SSSV): Orange.
- Straight sinus (STSV): Yellow.

Integrated Volume Flow

Dural Sinuses

8.1.2.

Integrated volume flow (ml): the blood volume that has flowed through the vessel over time.



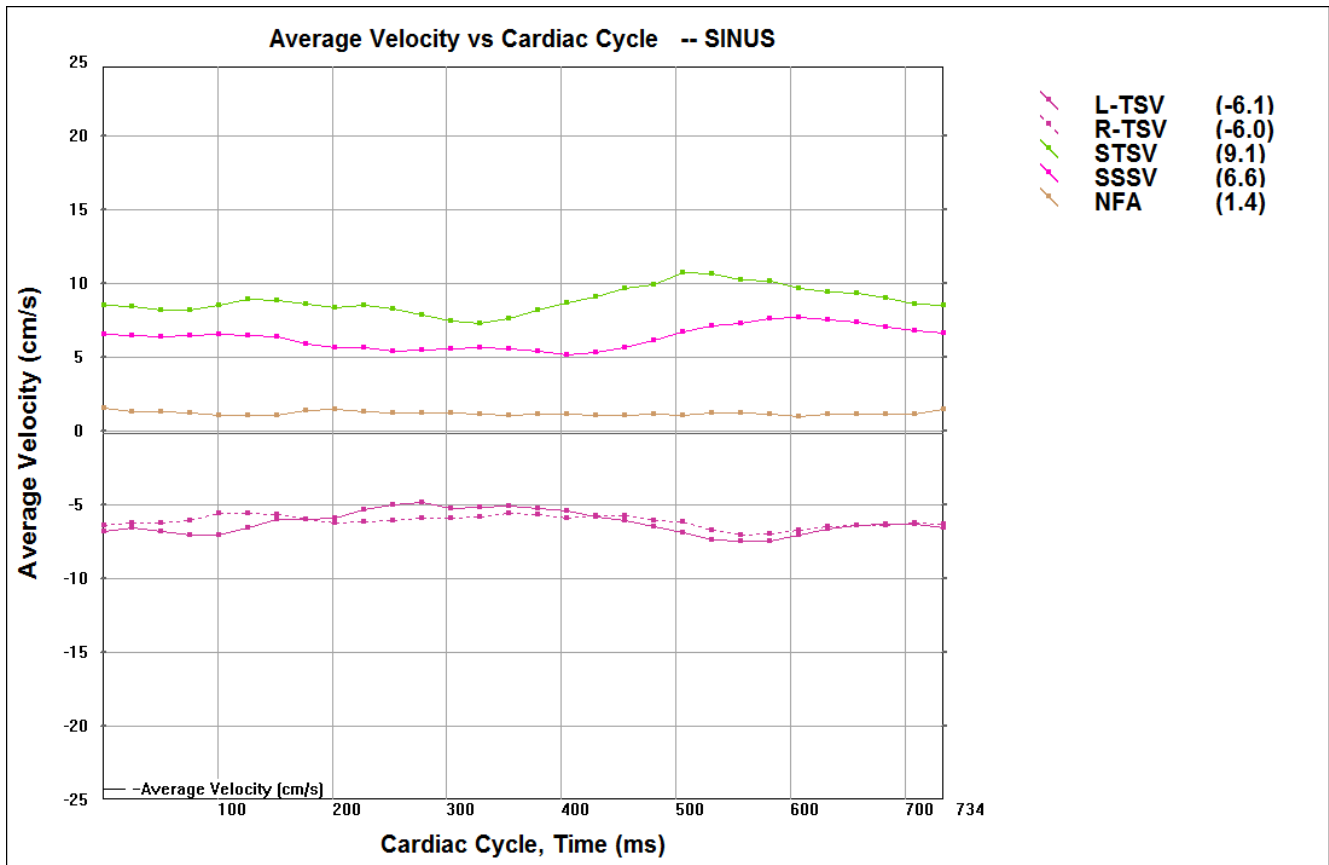
Discussion

Average Velocity

Dural Sinuses

8.1.3.

Average velocity (cm/sec): the average flow velocity for all the voxels inside the vessel over time.



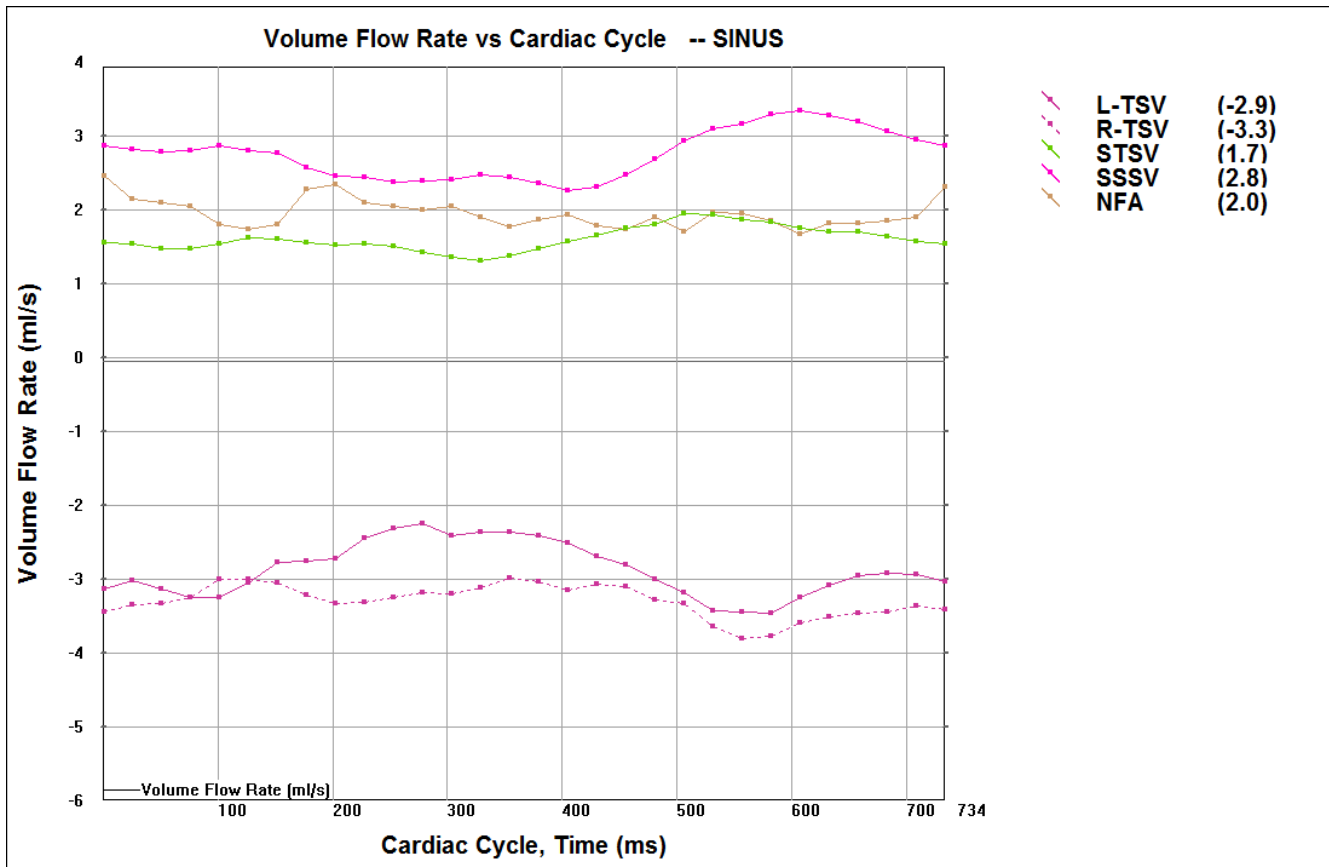
Discussion

Volume Flow Rate vs. Time

Dural Sinuses

8.1.4.

Volume flow rate (ml/sec): the blood volume flow rate through the vessel over time.



Discussion

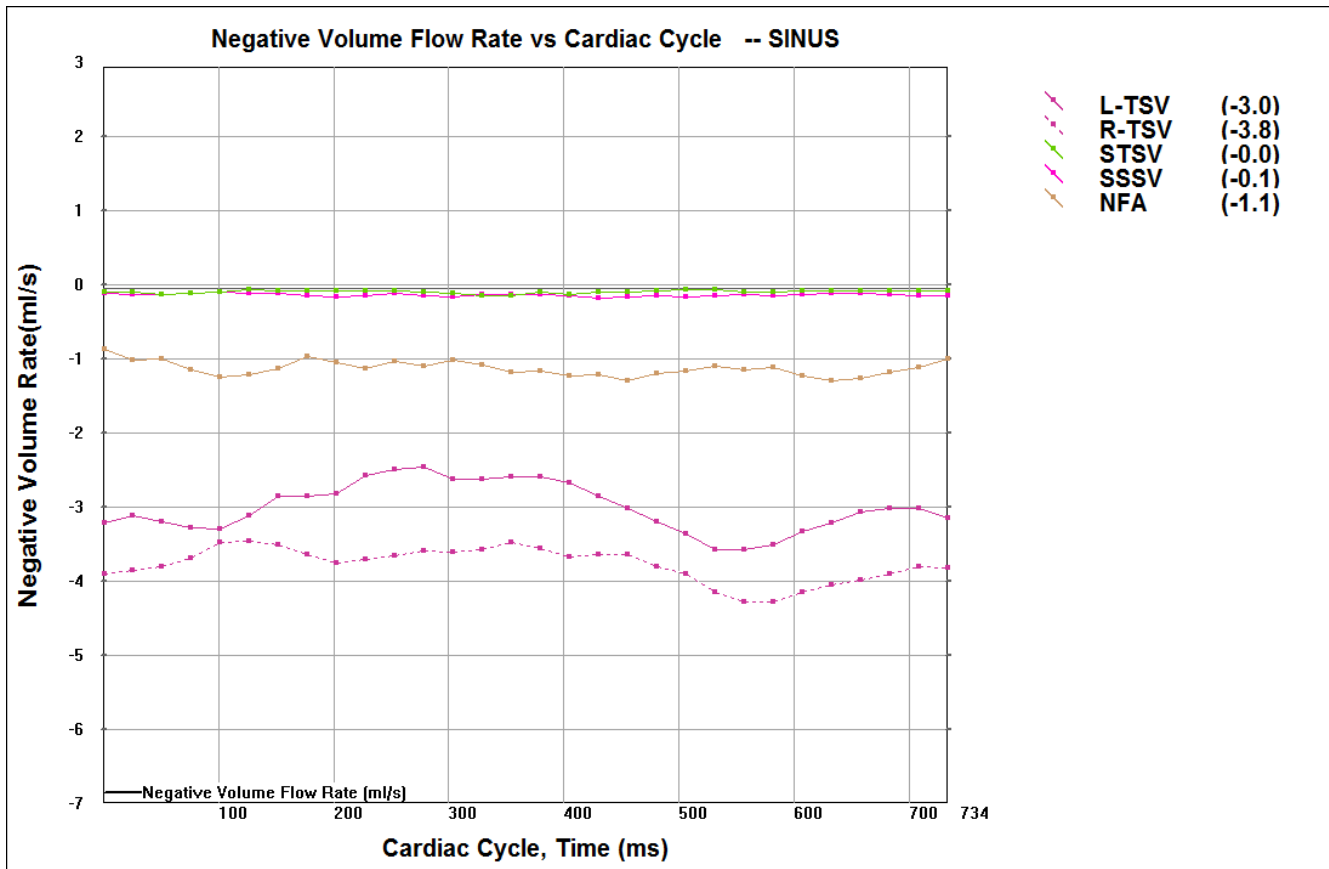
Ratio of right transverse sinus (RTSV) flow rate: left transverse sinus (LTSV) flow rate is 1.1:1.

Negative Volume Flow Rate vs. Time

Dural Sinuses

8.1.5.

Negative volume flow rate (ml/sec): the blood volume flow rate that is in the negative direction through the vessel over time (In some situations, the blood flow has reflux, which means that some of the blood is flowing in the wrong direction).



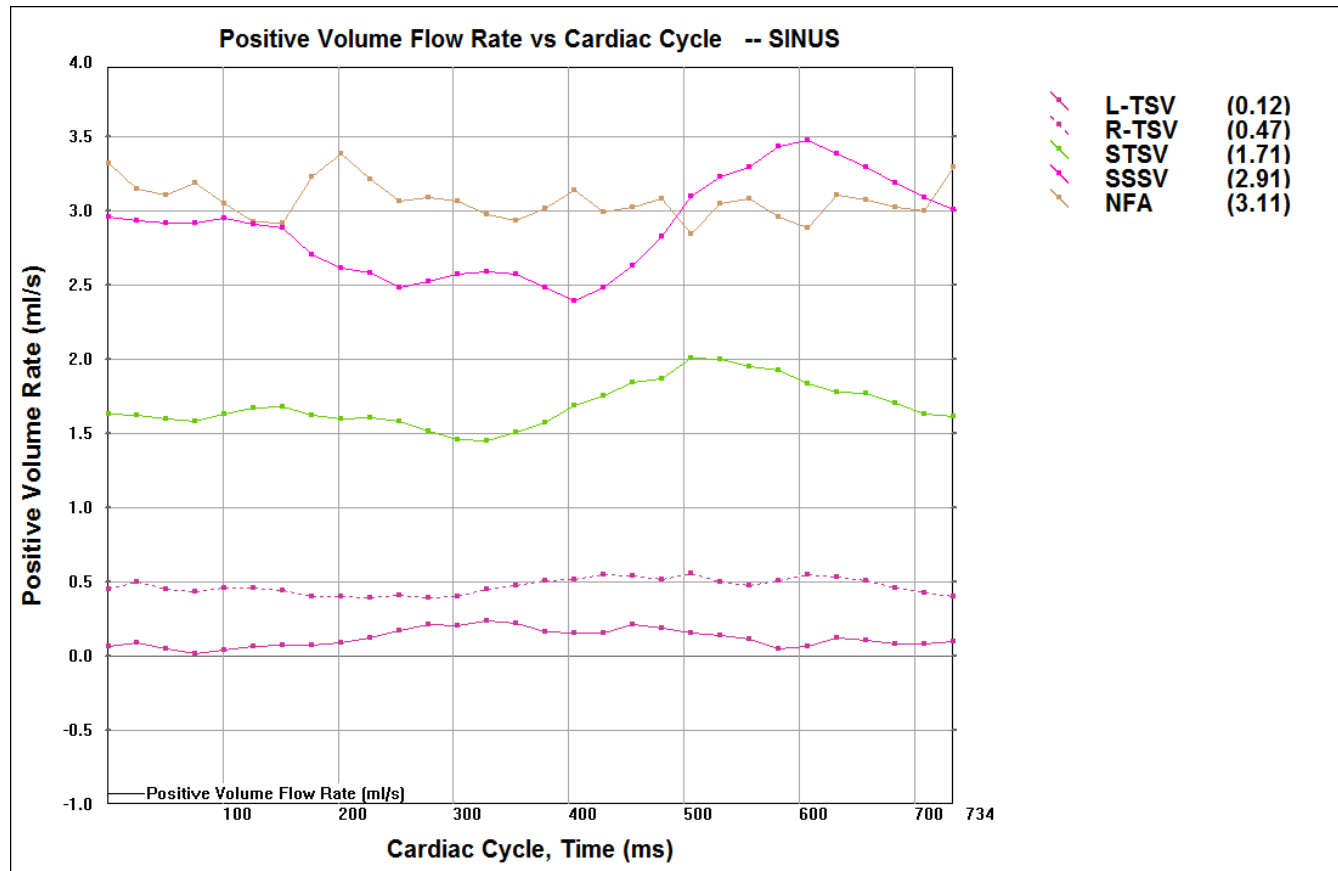
Discussion

Positive Volume Flow Rate vs. Time

Dural Sinuses

8.1.6.

Positive volume flow rate (ml/sec): the blood volume flow rate that is in the positive direction through the vessel over time (In some situations, the blood flow has reflux, which means that some of the blood is flowing in the wrong direction).



Discussion

Circulatory flow is seen for right transverse sinus vein (RTSV) and left transverse sinus vein (LTSV).

8.2. Flow Quantification Findings

CSF

8.2.1.

Description: Flow quantification is performed using a special MRI sequence to encode the blood flowing inside the blood vessels. This sequence generates two sets of images: a magnitude image, and a phase image. The magnitude image shows the vessel anatomy while the phase image can be used to quantitatively measure the velocity and direction of the blood flow. For a Siemens MRI scanner, dark areas on a phase image indicate flow towards the heart. The darker the area, the more quickly the blood is moving toward the heart. Inversely, bright areas indicate blood flow toward the brain, the brighter the area, the faster the flow. (Additional explanation is provided at the end of this report).

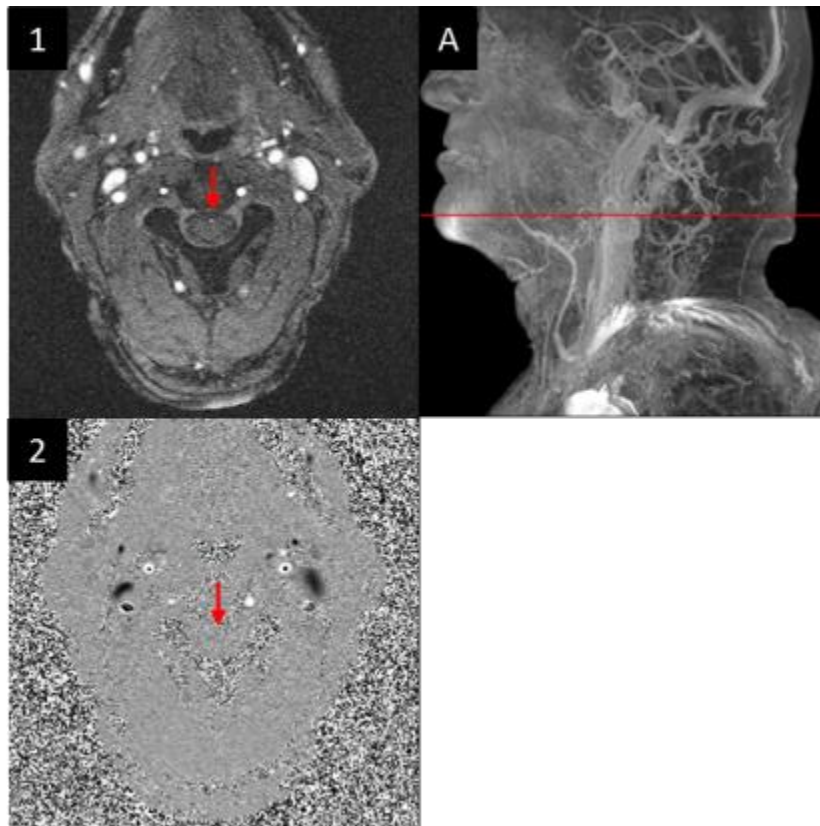


Figure Legend

1: Magnitude image.

2: Phase image.

CSF: Red arrows.

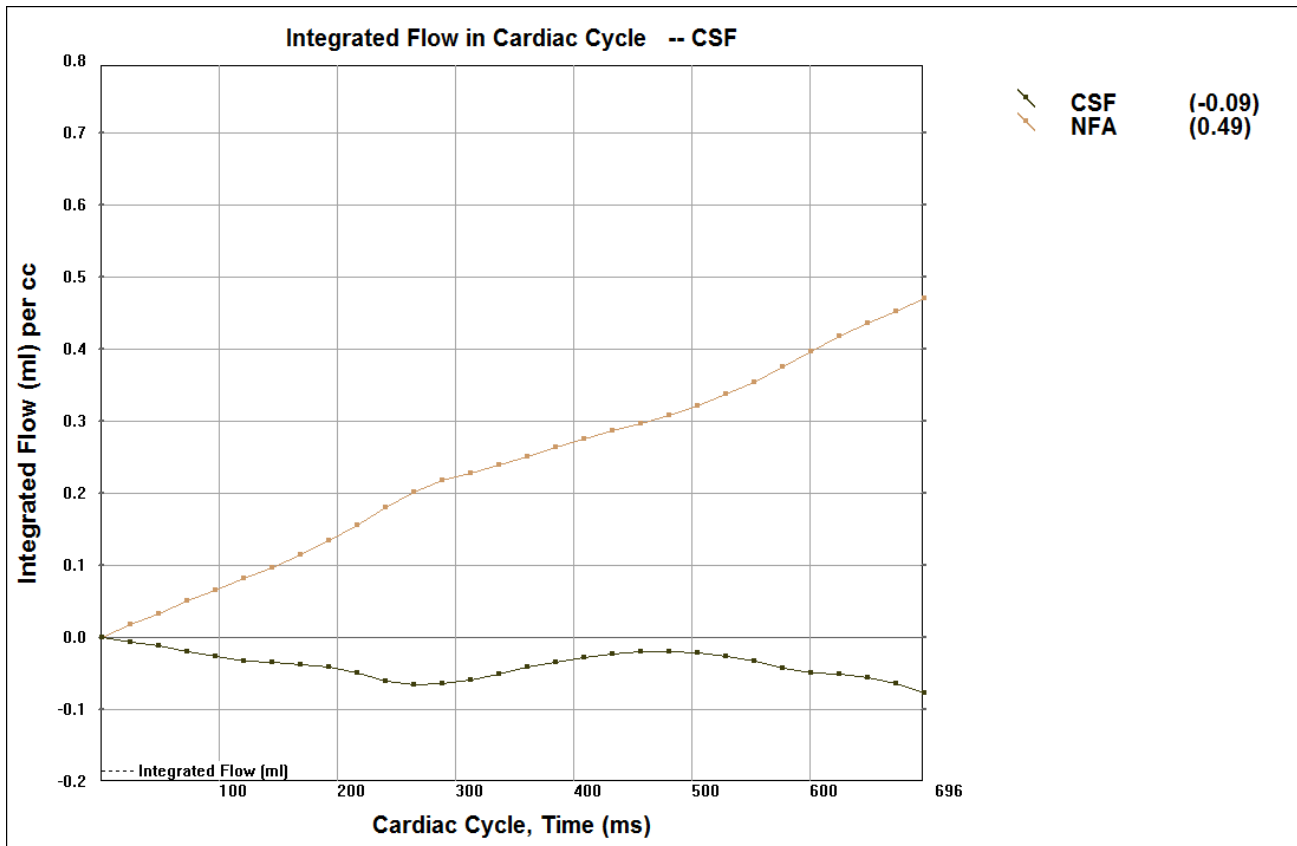
A: Sagittal view. Red line acts as localization of 1-2.

Integrated Volume Flow

CSF

8.2.2.

Integrated volume flow (ml): the blood volume that has flowed through the vessel over time.



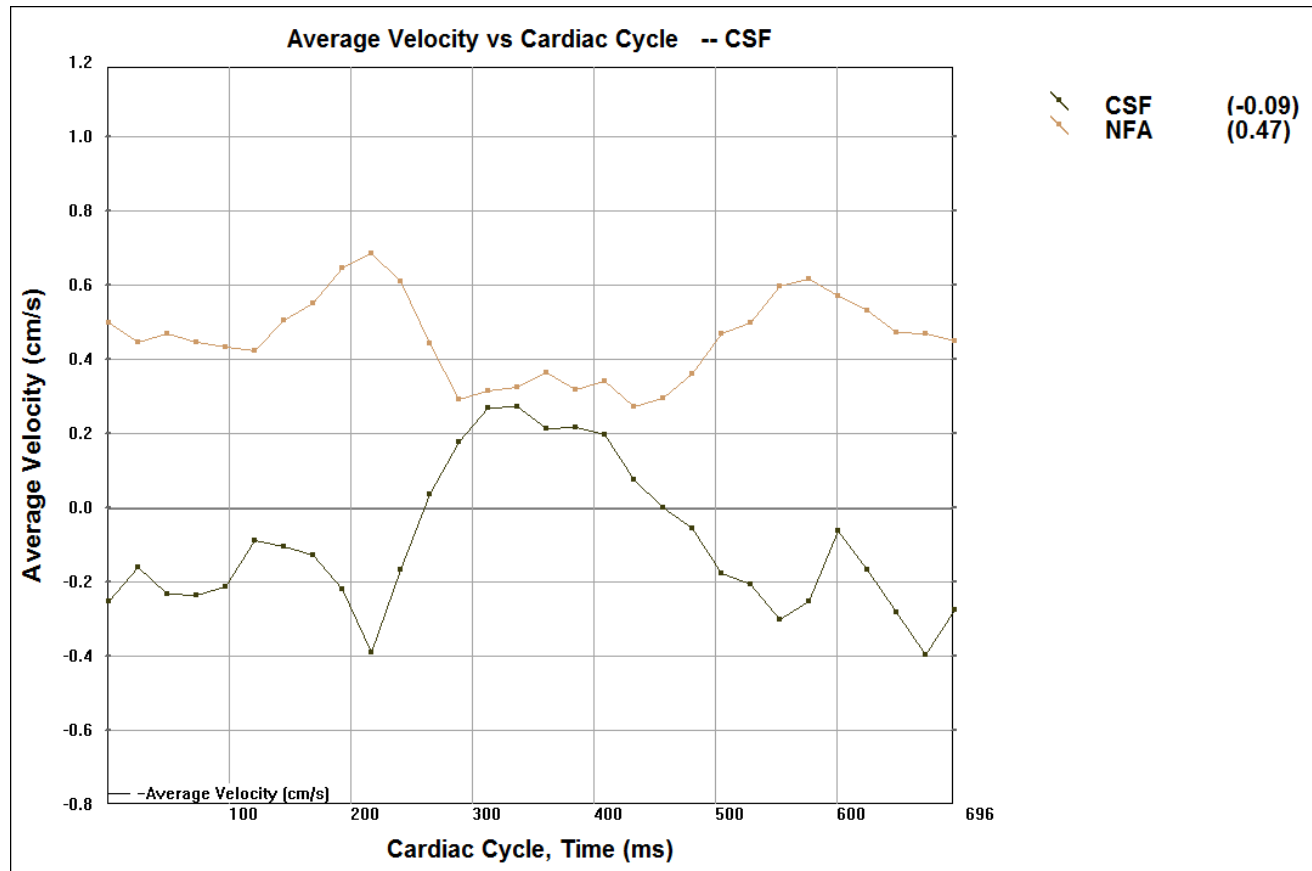
Discussion

Average Velocity

CSF

8.2.3.

Average velocity (cm/sec): the average flow velocity for all the voxels inside the vessel over time.



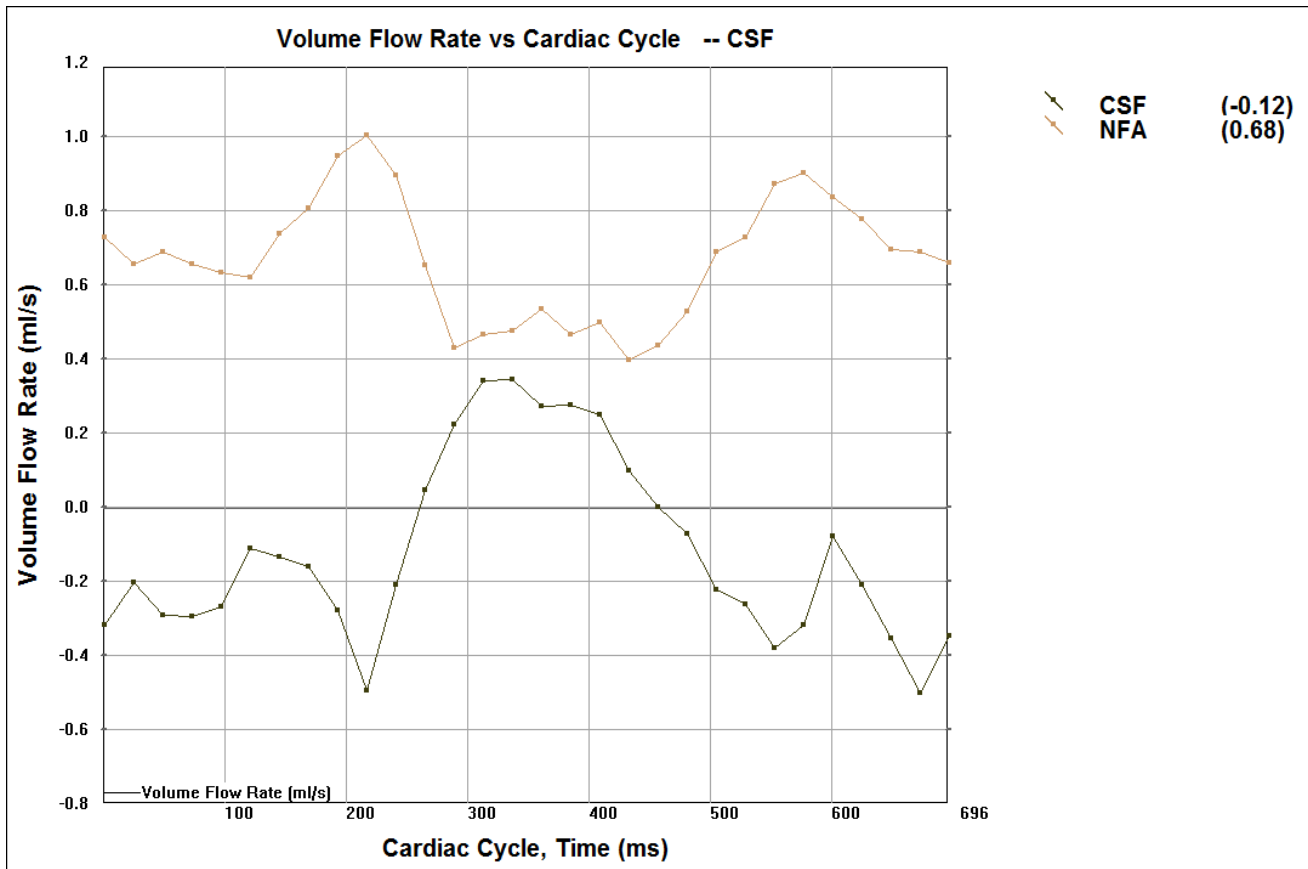
Discussion

Volume Flow Rate vs. Time

CSF

8.2.4.

Volume flow rate (ml/sec): the blood volume flow rate through the vessel over time.



Discussion

Peak CSF cranial flow is 0.38 ml/s and peak CSF caudal flow is -0.5 ml/s.



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8.3. Quantitative Flow Results

Table 6.

Structure	Flow Rate	Net Reflux	Circulatory Flow
Right Transverse Sinus	-3.3 ml/s	<input type="checkbox"/>	X
Left Transverse Sinus	-2.9 ml/s	<input type="checkbox"/>	X
Superior Sagittal Sinus	2.8 ml/s	<input type="checkbox"/>	<input type="checkbox"/>
Straight Sinus	1.7 ml/s	<input type="checkbox"/>	<input type="checkbox"/>
CSF	-0.12 ml/s	N/A	N/A

Discussion

Flow rates for dural sinuses and CSF.

8.4. Flow Quantification Findings

C7-T1 Neck Region

8.4.1.

Description: Flow quantification is performed using a special MRI sequence to encode the blood flowing inside the blood vessels. This sequence generates two sets of images: a magnitude image, and a phase image. The magnitude image shows the vessel anatomy while the phase image can be used to quantitatively measure the velocity and direction of the blood flow. For a Siemens MRI scanner, dark areas on a phase image indicate flow towards the heart. The darker the area, the more quickly the blood is moving toward the heart. Inversely, bright areas indicate blood flow toward the brain, the brighter the area, the faster the flow. (Additional explanation is provided at the end of this report).

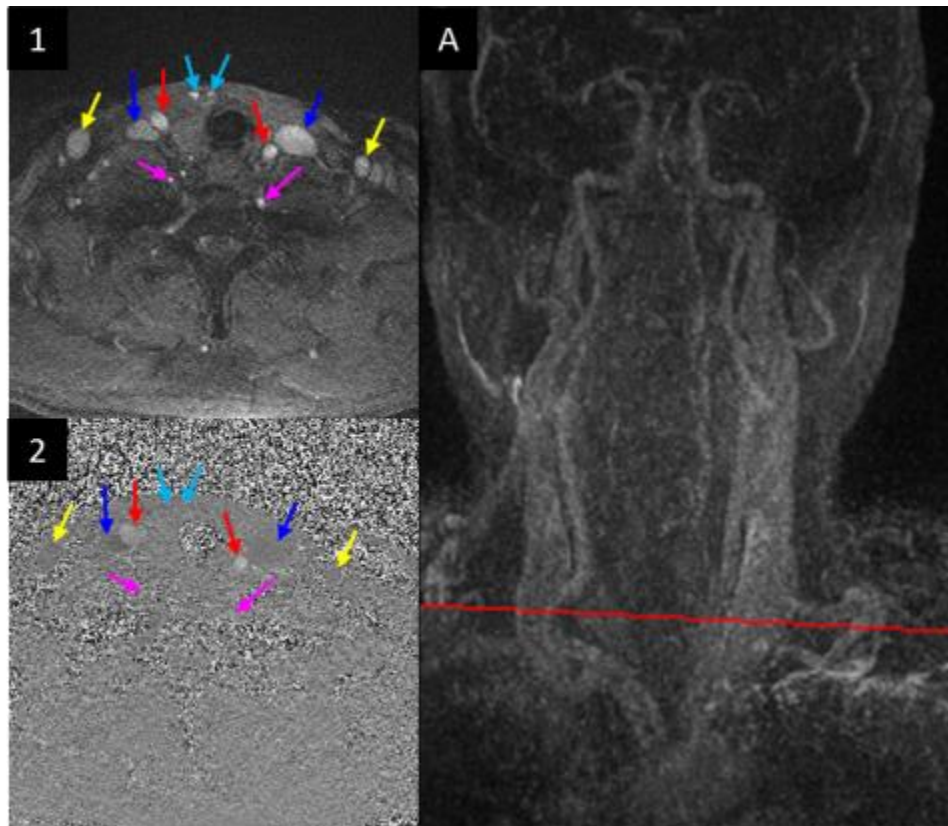


Figure Legend

1: Magnitude image. **2:** Phase image. **A:** Localization of 1-2.

1-2: Structure: Arrow Color

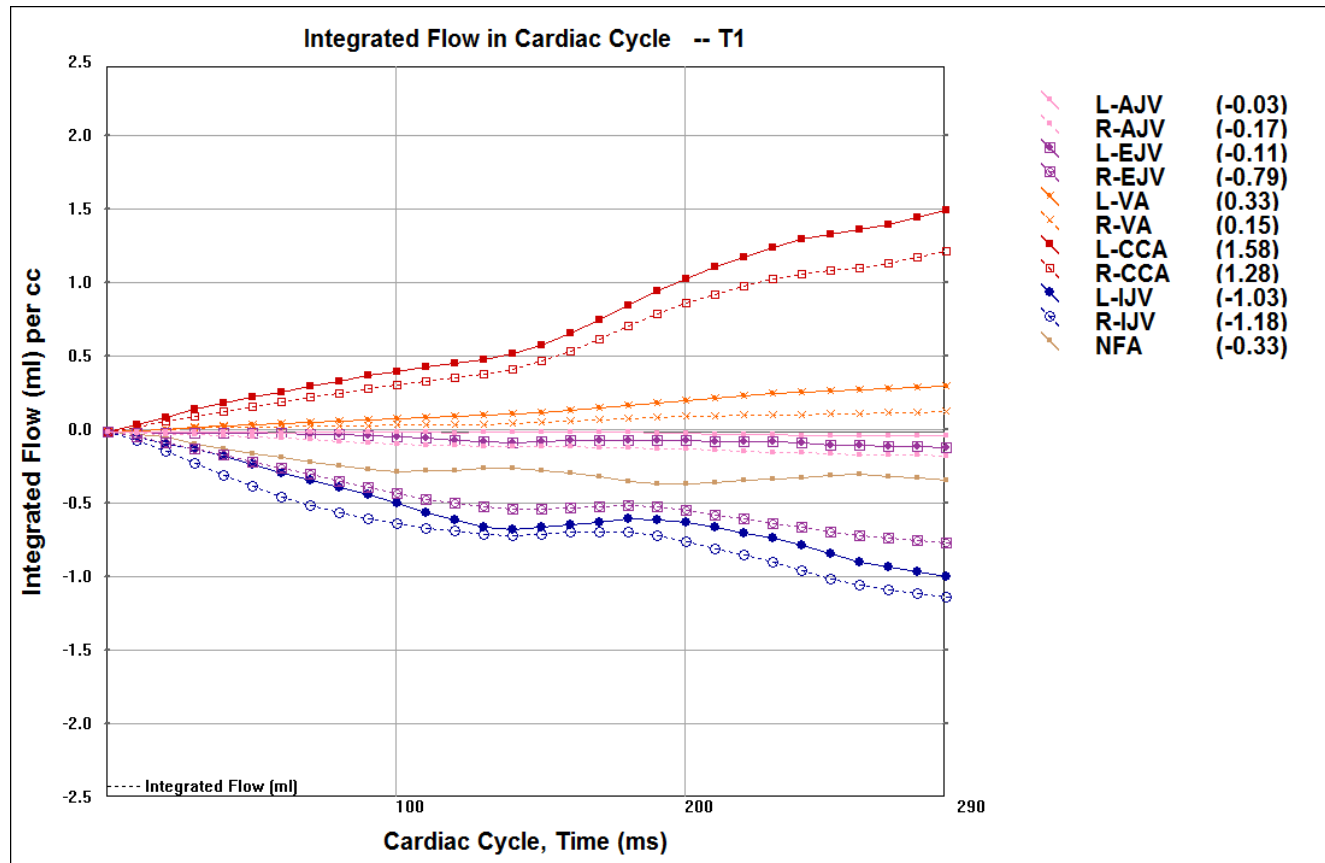
- Internal jugular vein (IJV): Dark blue.
- Common carotid artery (CCA): Red.
- Anterior jugular vein (AJV): Light blue.
- External jugular vein (EJV): Yellow.
- Vertebral artery (VA): Pink.

Integrated Volume Flow

C7-T1 Neck Region

8.4.2.

Integrated volume flow (ml): the blood volume that has flowed through the vessel over time.



Discussion

Dominant vessel:

- Right internal jugular vein (RIJV).

Subdominant vessel:

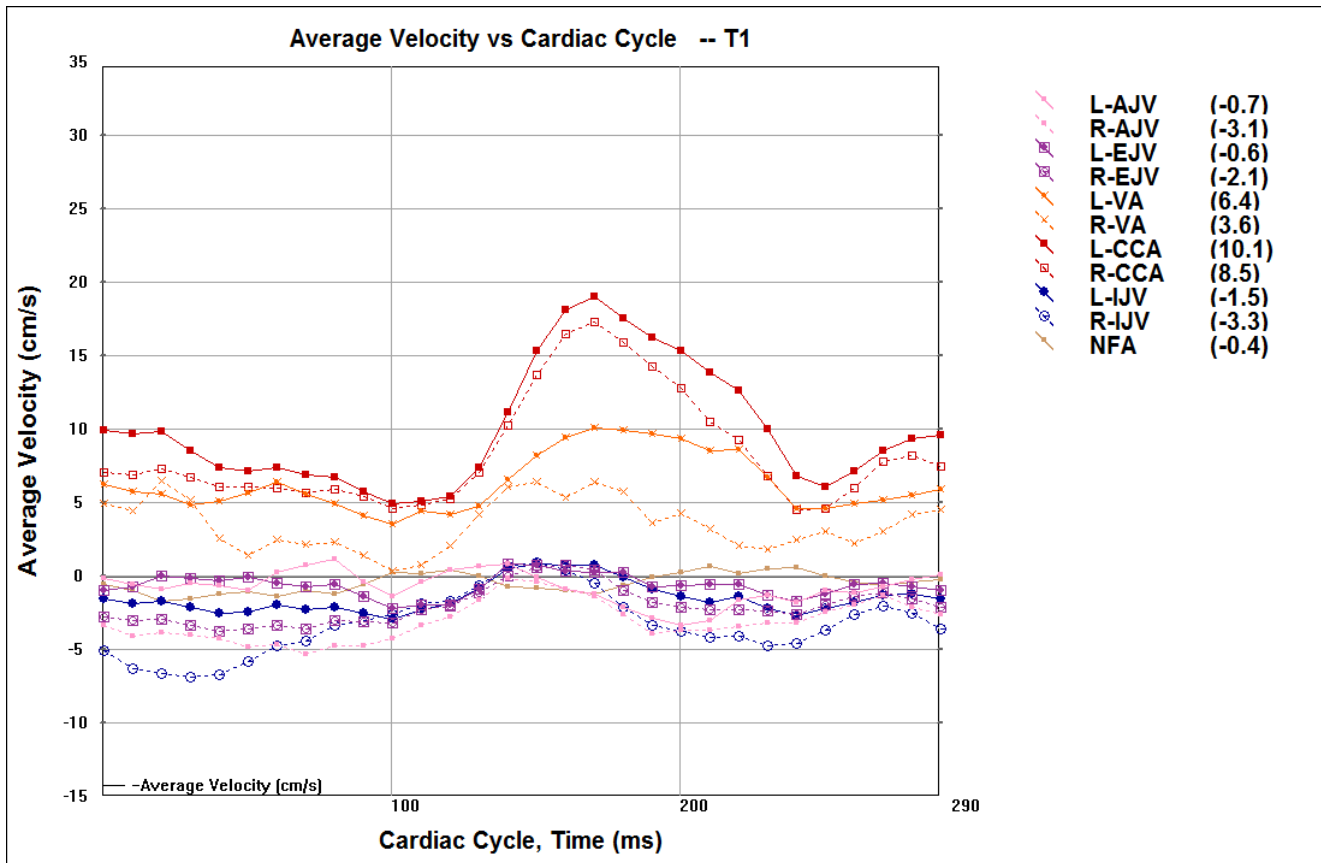
- Left internal jugular vein (LIJV).

Average Velocity

C7-T1 Neck Region

8.4.3.

Average velocity (cm/sec): the average flow velocity for all the voxels inside the vessel over time.



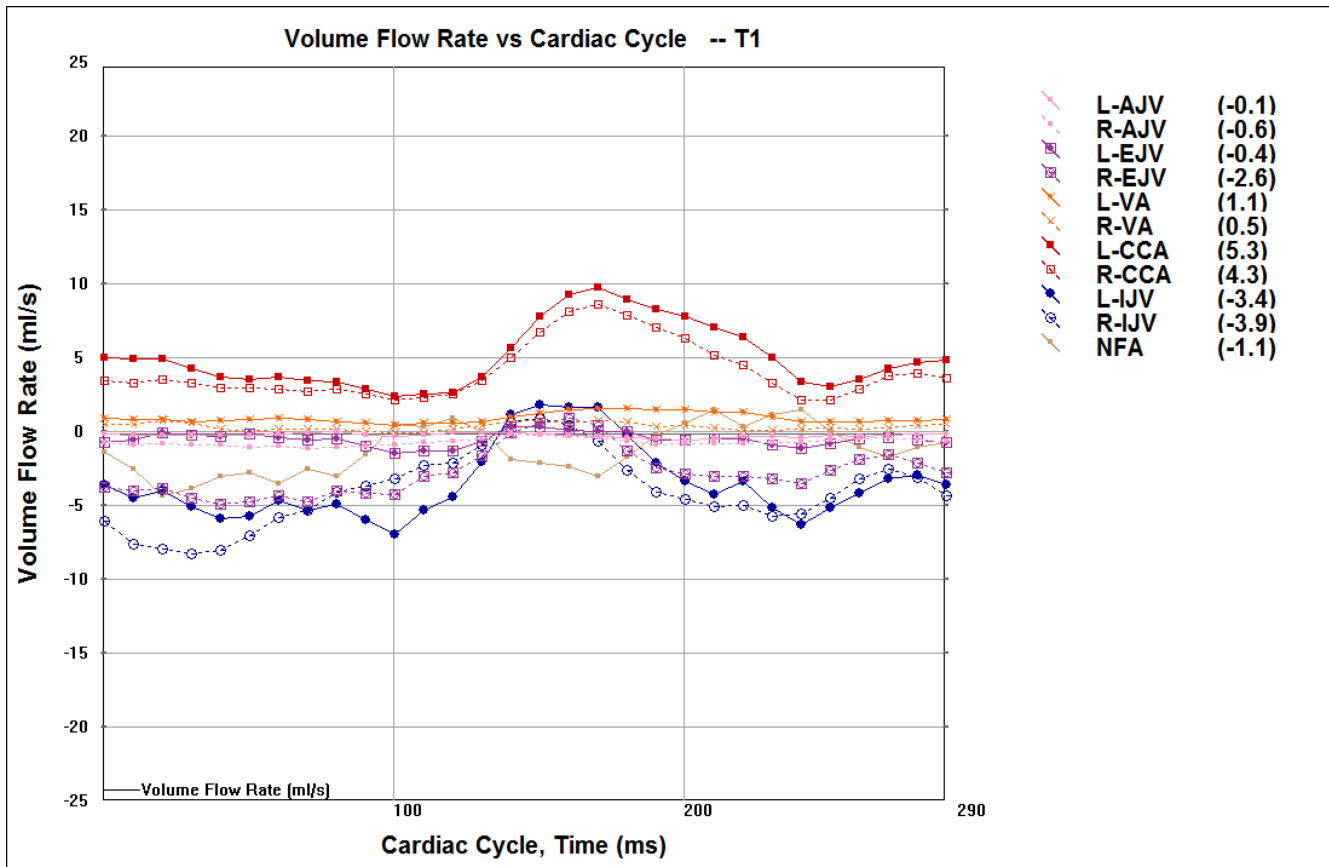
Discussion

Volume Flow Rate vs. Time

C7-T1 Neck Region

8.4.4.

Volume flow rate (ml/sec): the blood volume flow rate through the vessel over time.



Discussion

Net reflux in the:

- Right internal jugular vein (RIJV) from 130 to 170ms.
- Left internal jugular vein (LIJV) from 140 to 180ms.

Right internal jugular (RIJV) is dominant to the left internal jugular (LIJV) with a flow rate ratio of 1.1:1.

Total internal jugular vein (IJV) flow rate as a percentage of arterial flow rate (AFR) is 66%.

Arterial flow rate (AFR) rate is calculated as the sum of the:

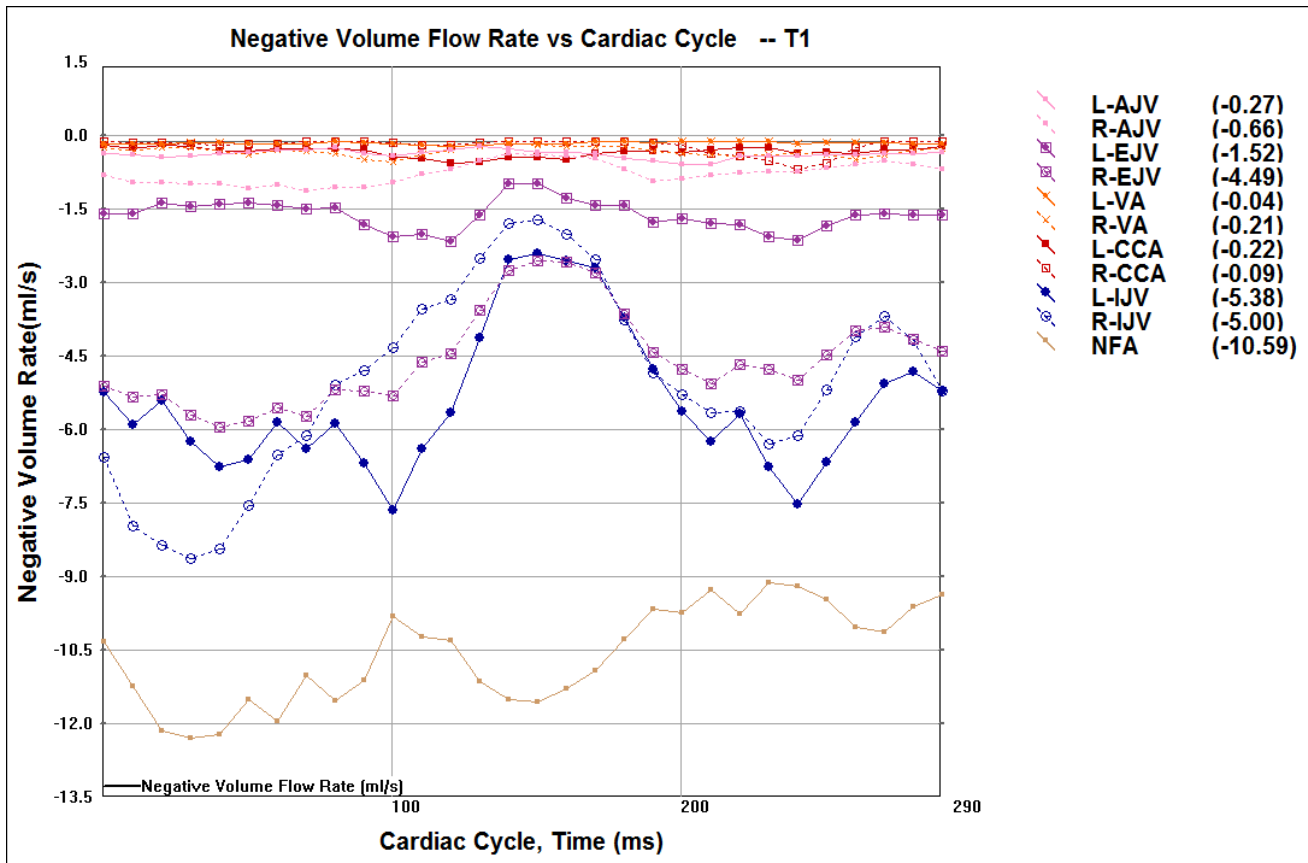
- Total common carotid artery (CCA) flow rate and the total vertebral artery (VA) flow rate.

Negative Volume Flow Rate vs. Time

C7-T1 Neck Region

8.4.5.

Negative volume flow rate (ml/sec): the blood volume flow rate that is in the negative direction through the vessel over time (In some situations, the blood flow has reflux, which means that some of the blood is flowing in the wrong direction).



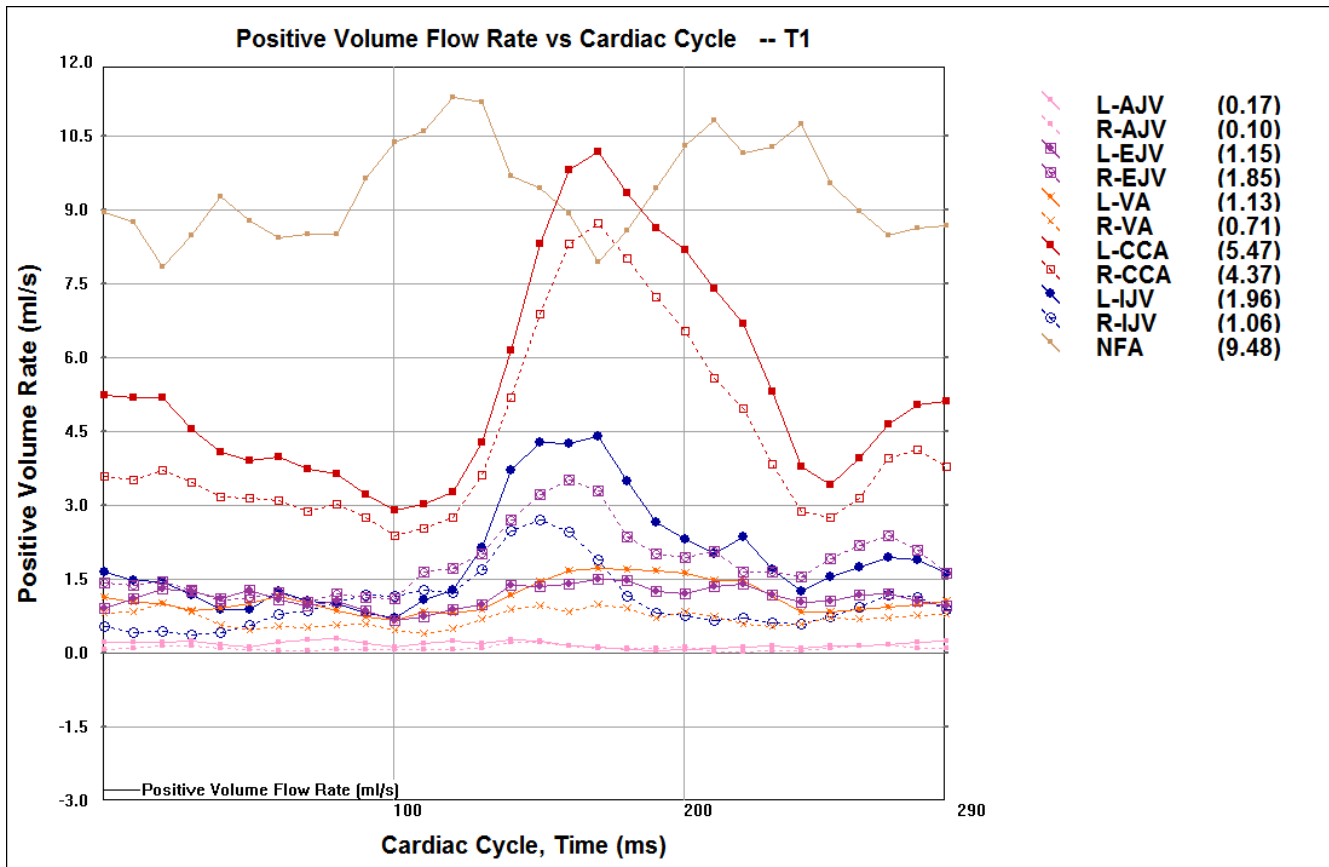
Discussion

Positive Volume Flow Rate vs. Time

C7-T1 Neck Region

8.4.6.

Positive volume flow rate (ml/sec): the blood volume flow rate that is in the positive direction through the vessel over time (In some situations, the blood flow has reflux, which means that some of the blood is flowing in the wrong direction).



Discussion

Net reflux in the:

- Right internal jugular vein (RIJV) from 130 to 170ms.
- Left internal jugular vein (LIJV) from 140 to 180ms.

Circulatory flow in the:

- Right internal jugular vein (RIJV).
- Left internal jugular vein (LIJV).
- Right external jugular vein (REJV).
- Left external jugular vein (LEJV).

8.5. Flow Quantification Findings

C5-6 Neck Region

8.5.1.

Description: Flow quantification is performed using a special MRI sequence to encode the blood flowing inside the blood vessels. This sequence generates two sets of images: a magnitude image, and a phase image. The magnitude image shows the vessel anatomy while the phase image can be used to quantitatively measure the velocity and direction of the blood flow. For a Siemens MRI scanner, dark areas on a phase image indicate flow towards the heart. The darker the area, the more quickly the blood is moving toward the heart. Inversely, bright areas indicate blood flow toward the brain, the brighter the area, the faster the flow. (Additional explanation is provided at the end of this report).

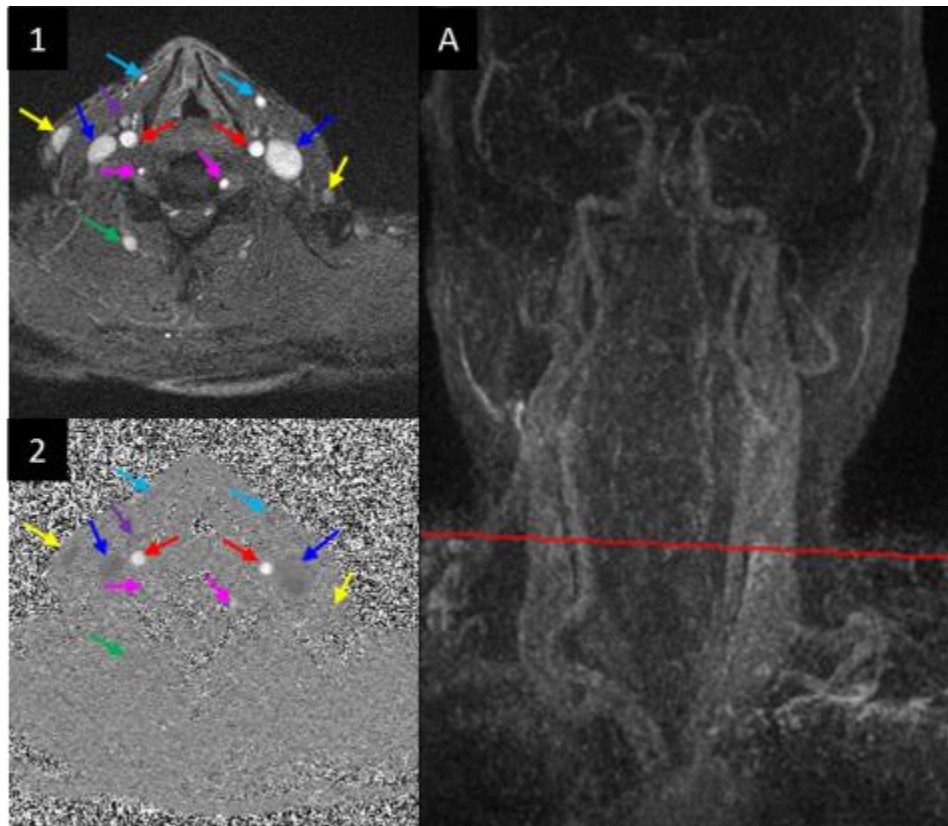


Figure Legend

1: Magnitude image. **2:** Phase image. **A:** Localization of 1-2.

1-2: Structure: Arrow Color.

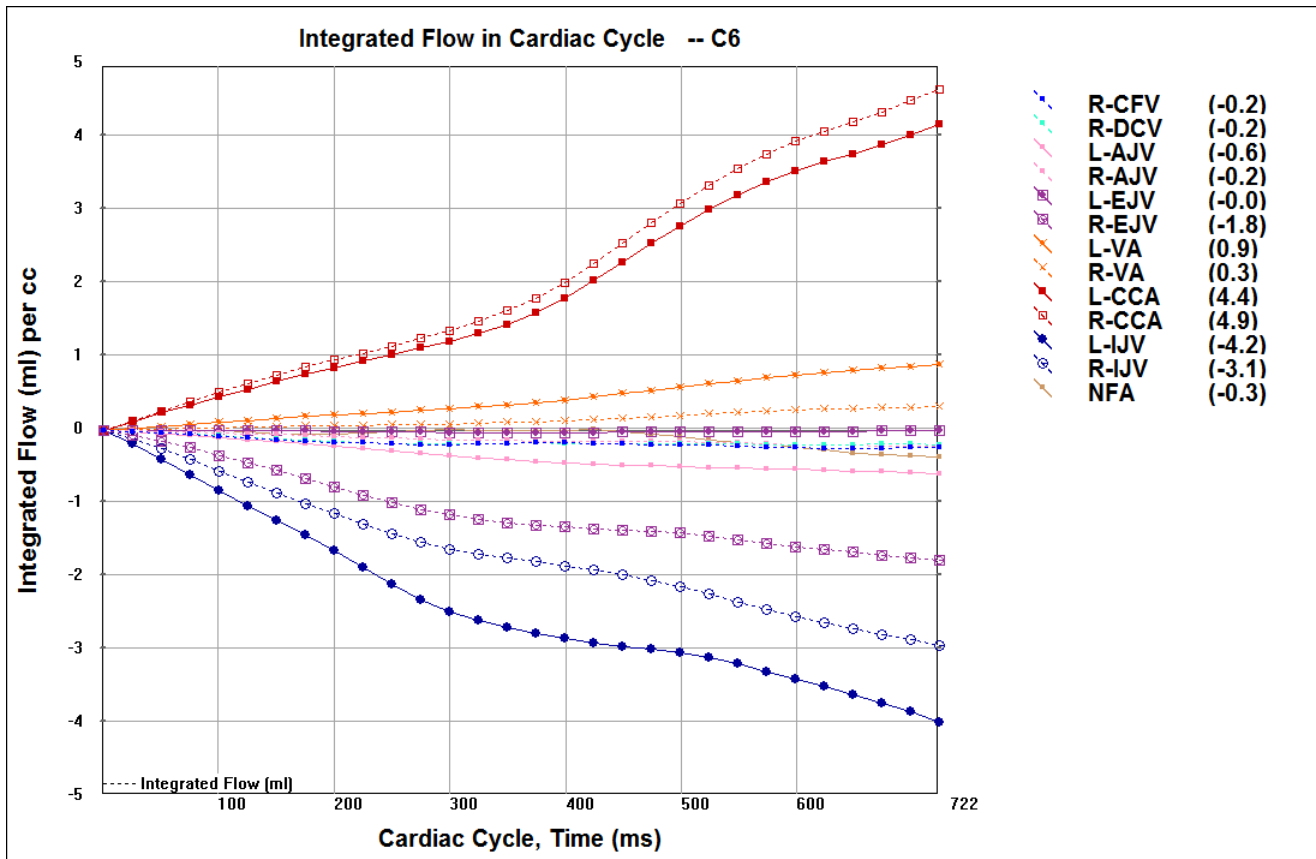
- | | |
|---|--|
| • Internal jugular vein (IJV): Dark blue. | Anterior jugular vein (AJV): Light blue. |
| • Common carotid artery (CCA): Red. | Common facial vein (CFV): Purple. |
| • Vertebral artery (VA): Pink. | |
| • External jugular vein (EJV): Yellow. | |
| • Deep cervical vein (DCV): Dark green. | |

Integrated Volume Flow

C5-6 Neck Region

8.5.2.

Integrated volume flow (ml): the blood volume that has flowed through the vessel over time.



Discussion

Dominant vessel:

- Left internal jugular vein (LIJV).

Subdominant vessel:

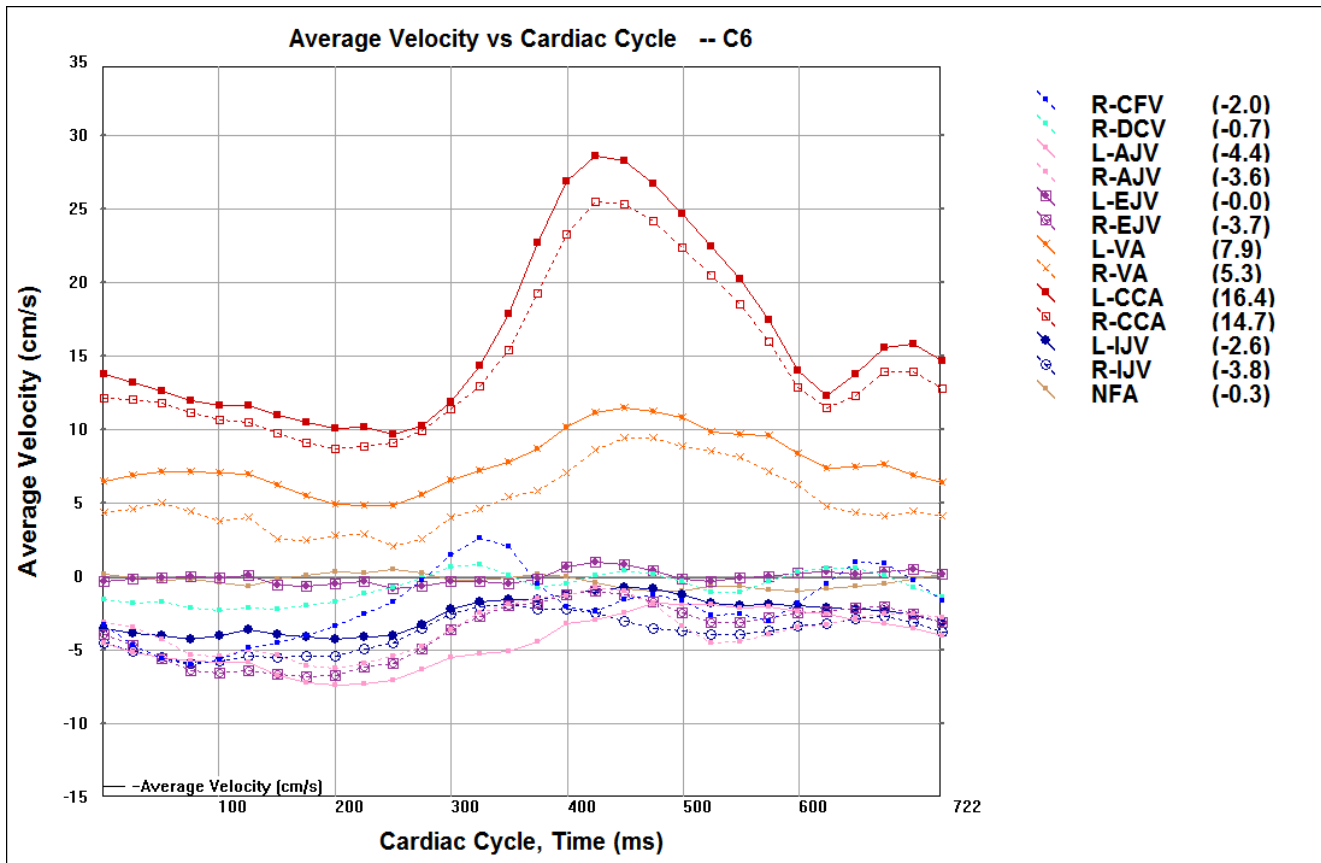
- Right internal jugular vein (RIJV).

Average Velocity

C5-6 Neck Region

8.5.3.

Average velocity (cm/sec): the average flow velocity for all the voxels inside the vessel over time.



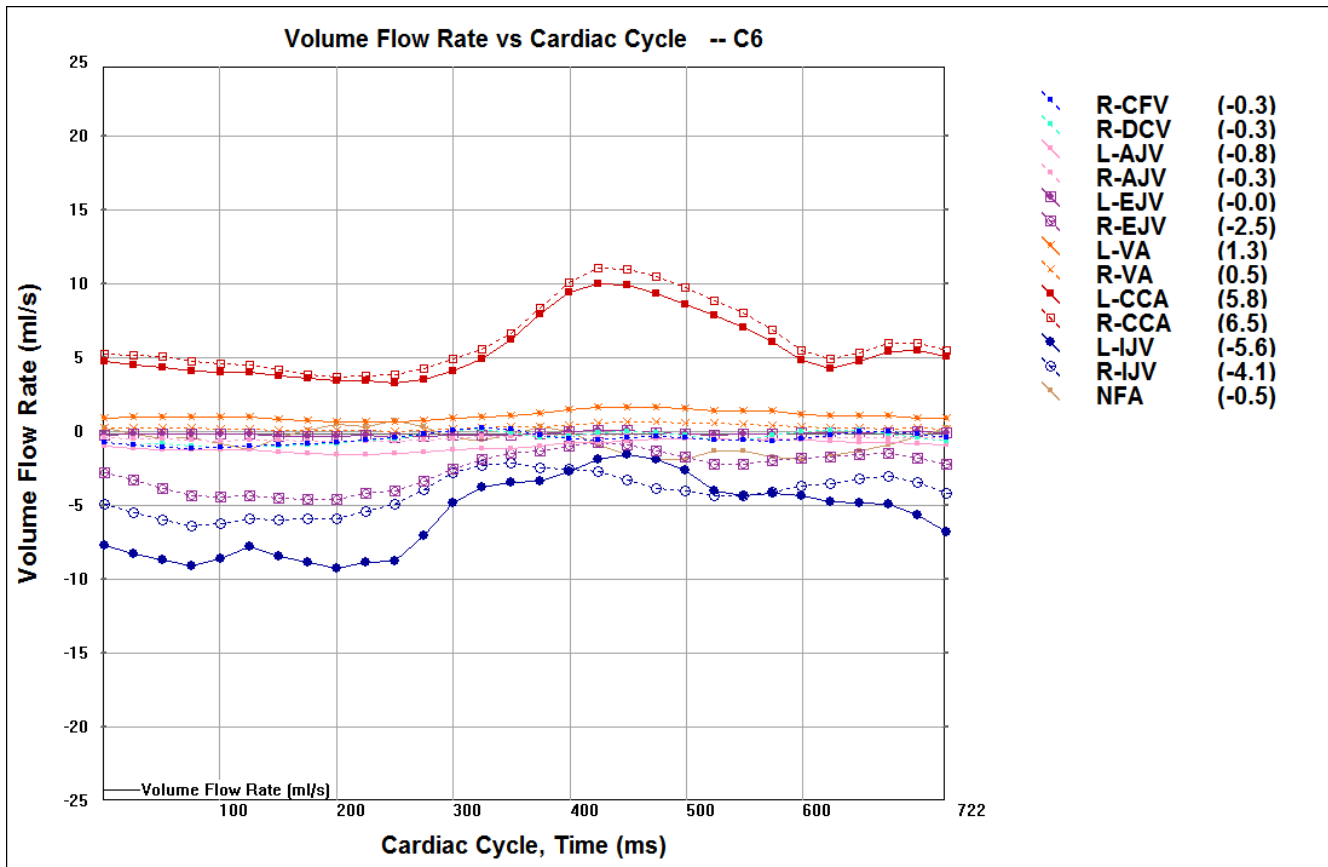
Discussion

Volume Flow Rate vs. Time

C5-6 Neck Region

8.5.4.

Volume flow rate (ml/sec): the blood volume flow rate through the vessel over time.



Discussion

Left internal jugular vein (LIJV) is dominant to the right internal jugular vein (RIJV) with a flow rate ratio of 1.3:1.

Total internal jugular vein (IJV) flow rate as a percentage of arterial flow rate (AFR) is 69%.

Arterial flow rate (AFR) rate is calculated as the sum of the:

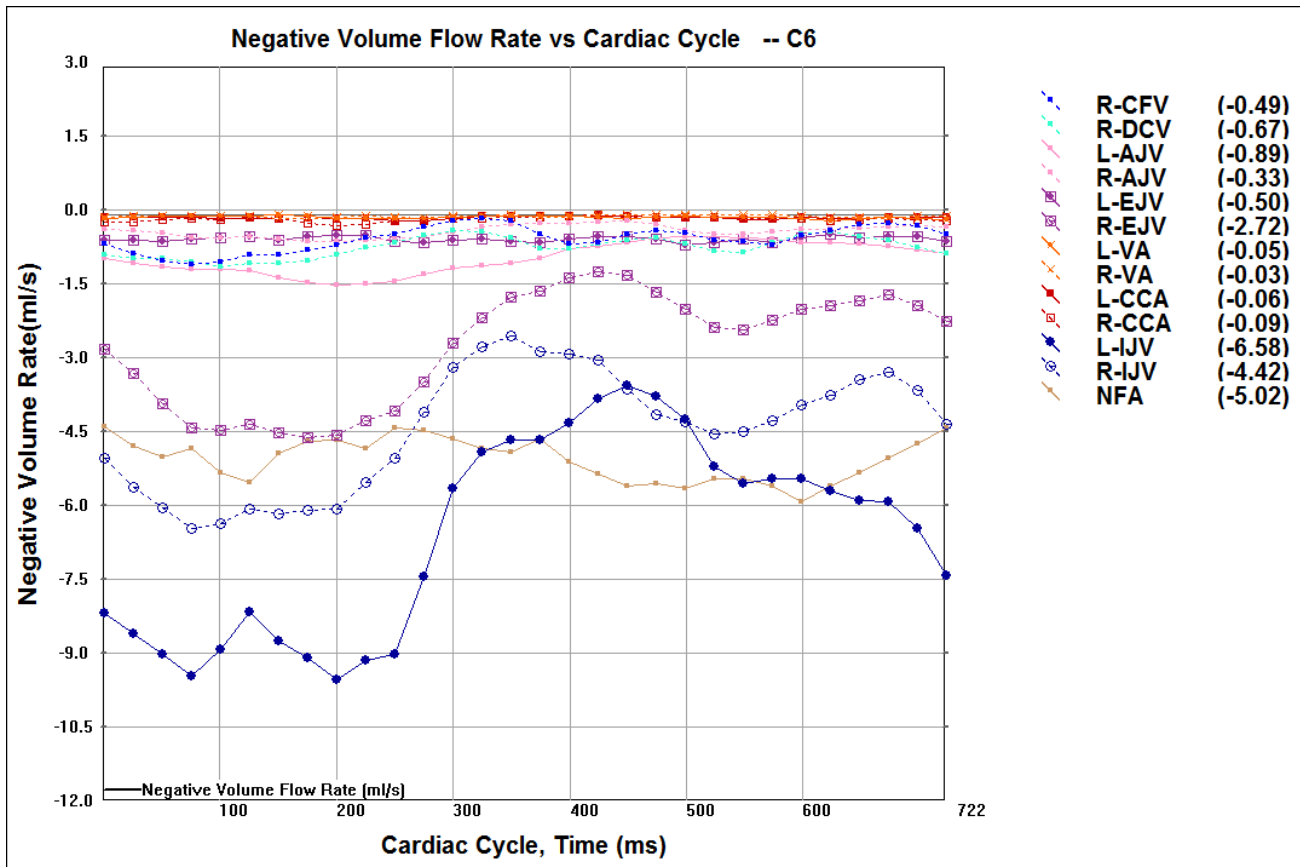
- Total common carotid artery (CCA) flow rate and the total vertebral artery (VA) flow rate.

Negative Volume Flow Rate vs. Time

C5-6 Neck Region

8.5.5.

Negative volume flow rate (ml/sec): the blood volume flow rate that is in the negative direction through the vessel over time (In some situations, the blood flow has reflux, which means that some of the blood is flowing in the wrong direction).



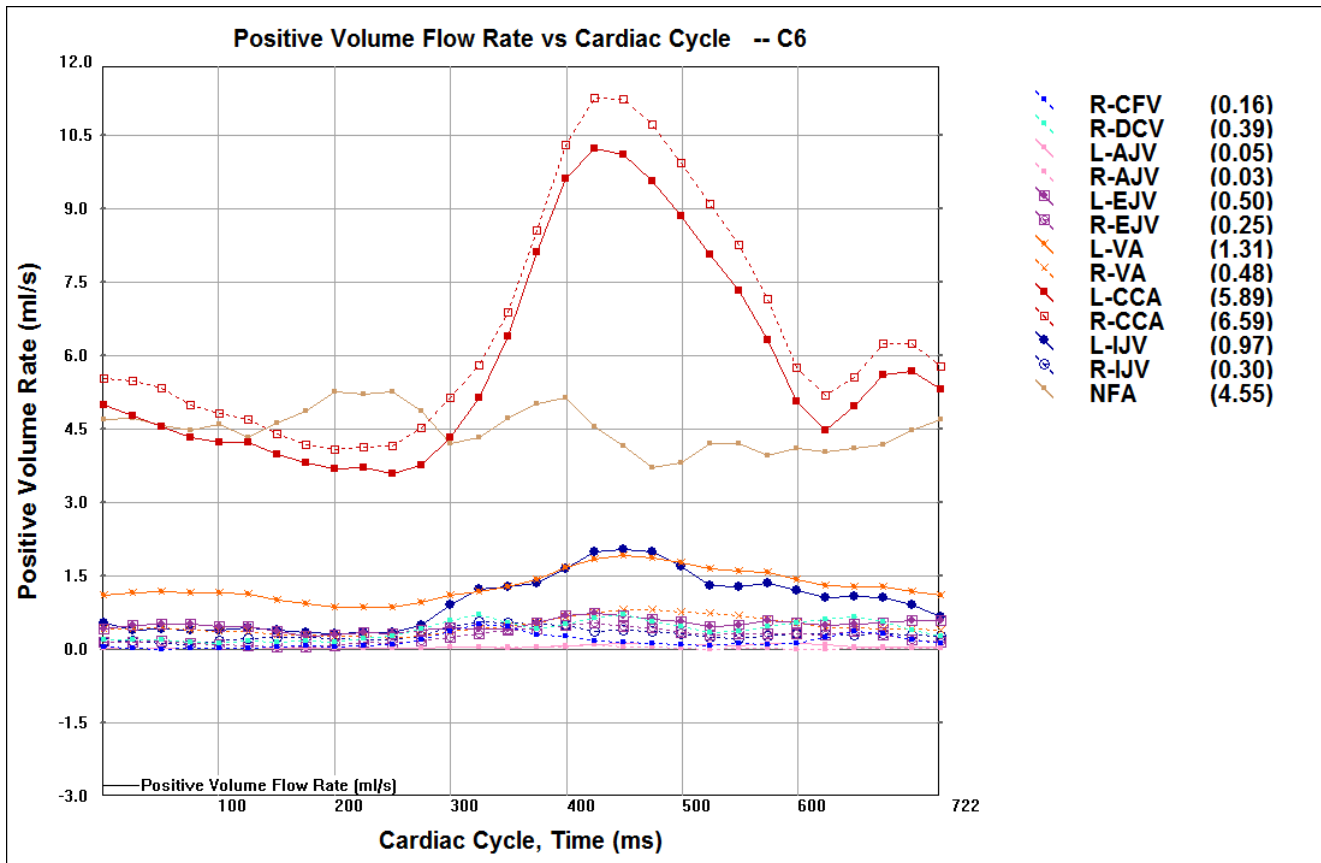
Discussion

Positive Volume Flow Rate vs. Time

C5-6 Neck Region

8.5.6.

Positive volume flow rate (ml/sec): the blood volume flow rate that is in the positive direction through the vessel over time (In some situations, the blood flow has reflux, which means that some of the blood is flowing in the wrong direction).



Discussion

Circulatory flow in the:

- Left internal jugular vein (LIJV).
- Right internal jugular vein (RIJV).
- Right external jugular vein (REJV).
- Left external jugular vein (LEJV).
- Right deep cervical vein (RDCV).

8.6. Flow Quantification Findings

C2-3 Neck Region

8.6.1.

Description: Flow quantification is performed using a special MRI sequence to encode the blood flowing inside the blood vessels. This sequence generates two sets of images: a magnitude image, and a phase image. The magnitude image shows the vessel anatomy while the phase image can be used to quantitatively measure the velocity and direction of the blood flow. For a Siemens MRI scanner, dark areas on a phase image indicate flow towards the heart. The darker the area, the more quickly the blood is moving toward the heart. Inversely, bright areas indicate blood flow toward the brain, the brighter the area, the faster the flow. (Additional explanation is provided at the end of this report).

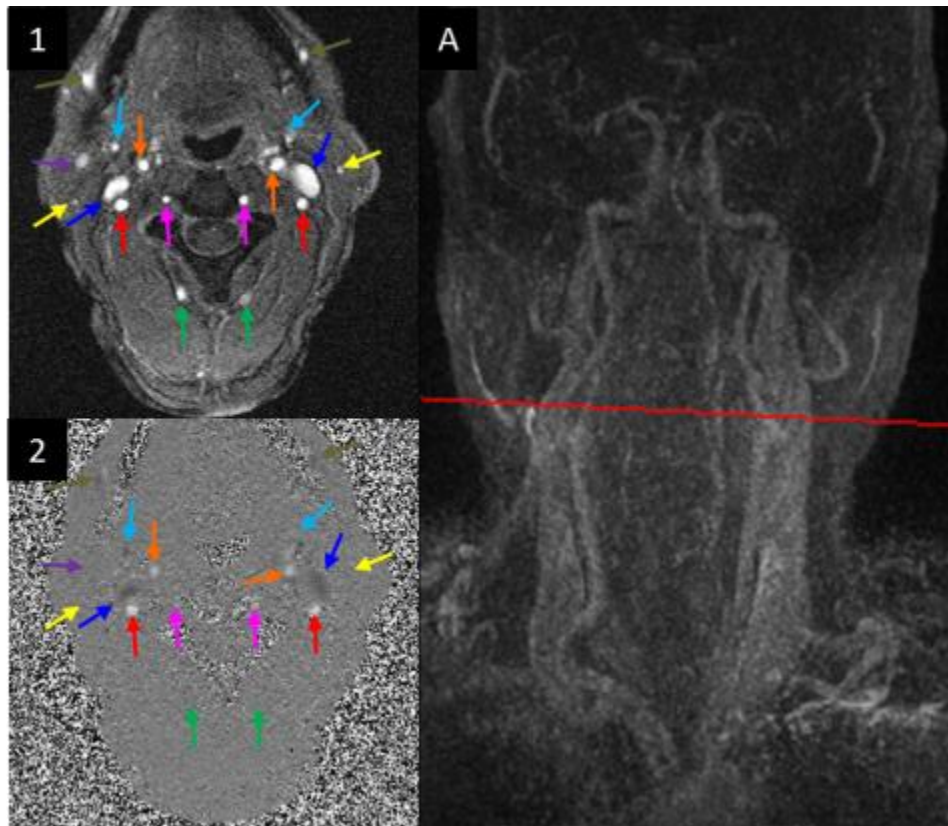


Figure Legend

1: Magnitude image. **2:** Phase image. **A:** Localization of 1-2.

1-2: Arrow Color: Structure

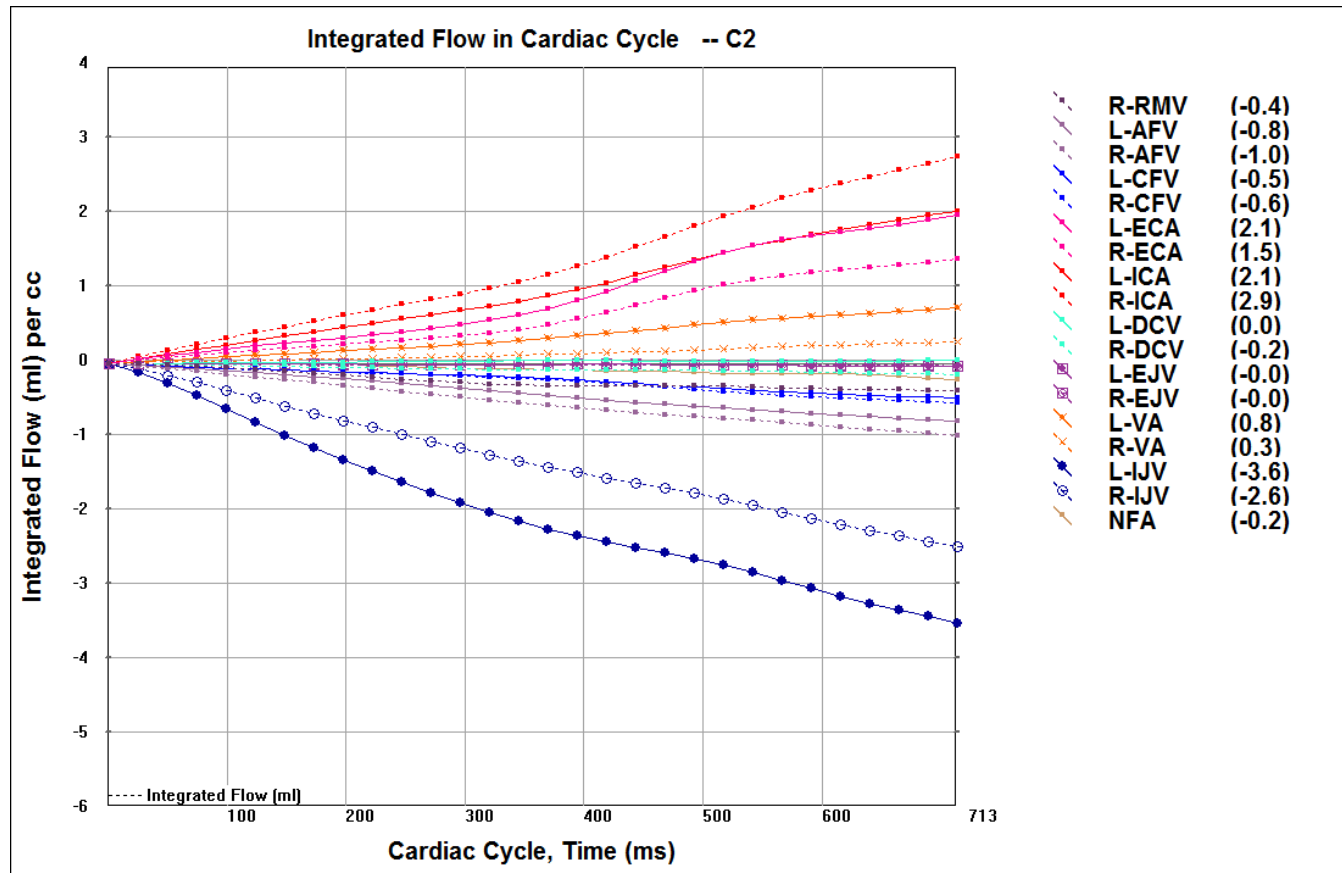
- | | |
|---|---------------------------------------|
| • Internal jugular vein (IJV): Dark blue. | Deep cervical vein (DCV): Green. |
| • Internal carotid artery (ICA): Red. | Retromandibular vein (RMV): Purple. |
| • External carotid artery (ECA): Orange. | Anterior facial vein (AFV): Tan. |
| • Vertebral artery (VA): Pink. | Common facial vein (CFV): Light Blue. |
| • External jugular vein (EJV): Yellow. | |

Integrated Volume Flow

C2-3 Neck Region

8.6.2.

Integrated volume flow (ml): the blood volume that has flowed through the vessel over time.



Discussion

Dominant vessel:

- Left internal jugular vein (LIJV).

Subdominant vessel:

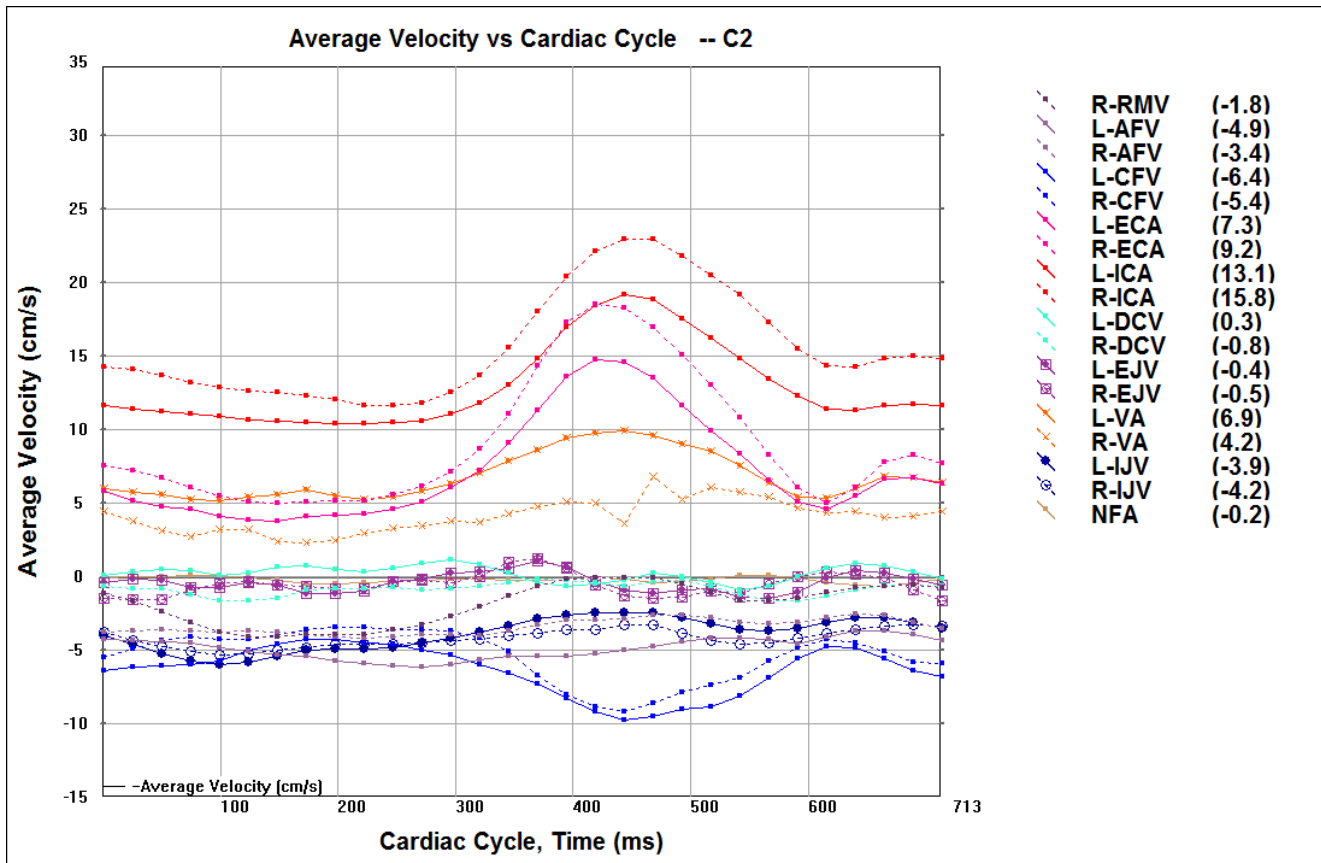
- Right internal jugular vein (RIJV).

Average Velocity

C2-3 Neck Region

8.6.3.

Average velocity (cm/sec): the average flow velocity for all the voxels inside the vessel over time.



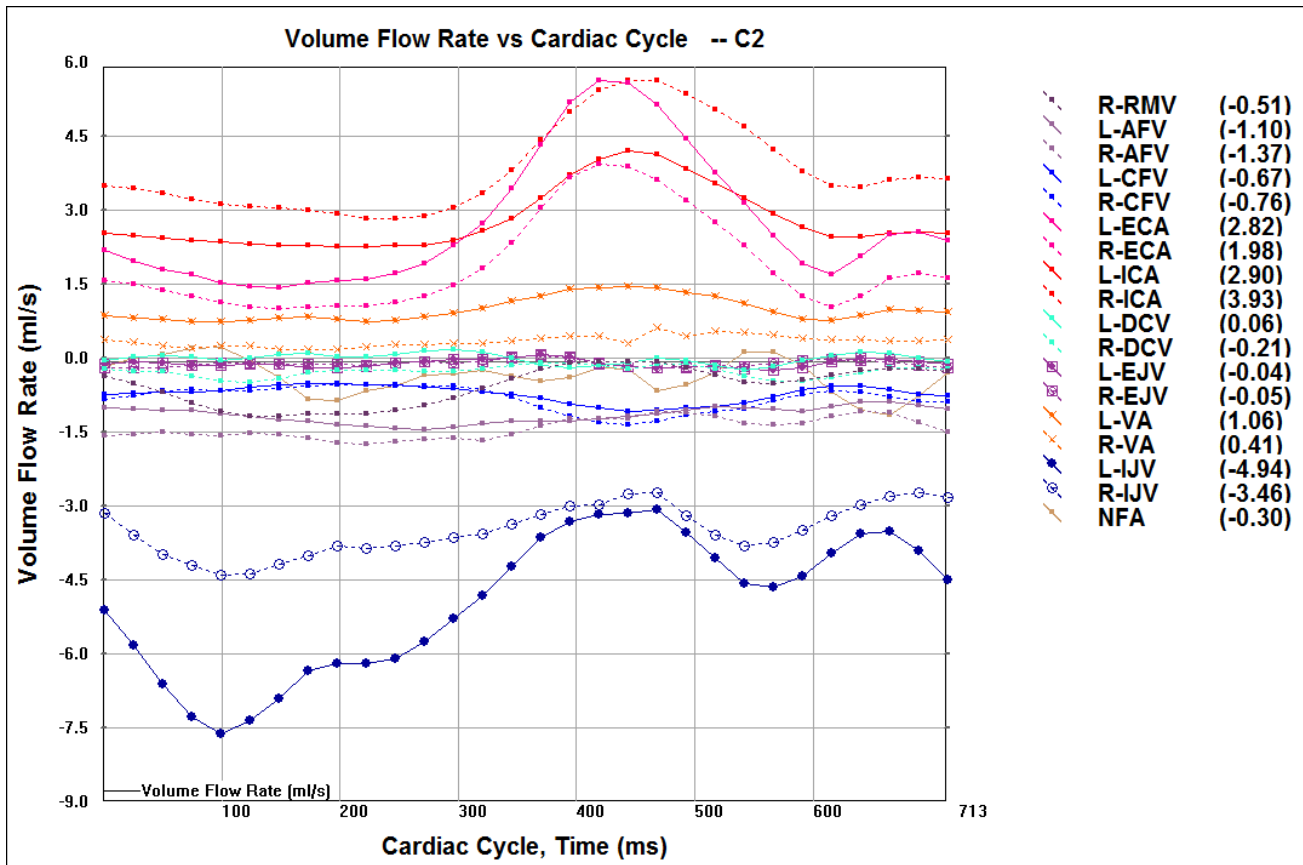
Discussion

Volume Flow Rate vs. Time

C2-3 Neck Region

8.6.4.

Volume flow rate (ml/sec): the blood volume flow rate through the vessel over time.



Discussion

Right internal jugular vein (RIJV) is dominant to the left internal jugular vein (LIJV) with a flow rate ratio of 1.4:1.

Total internal jugular vein (IJV) flow rate as a percentage of arterial cerebral blood flow rate (ACBFR) is 100%.

Arterial cerebral blood flow (ACBFR) rate is calculated as the sum of the:

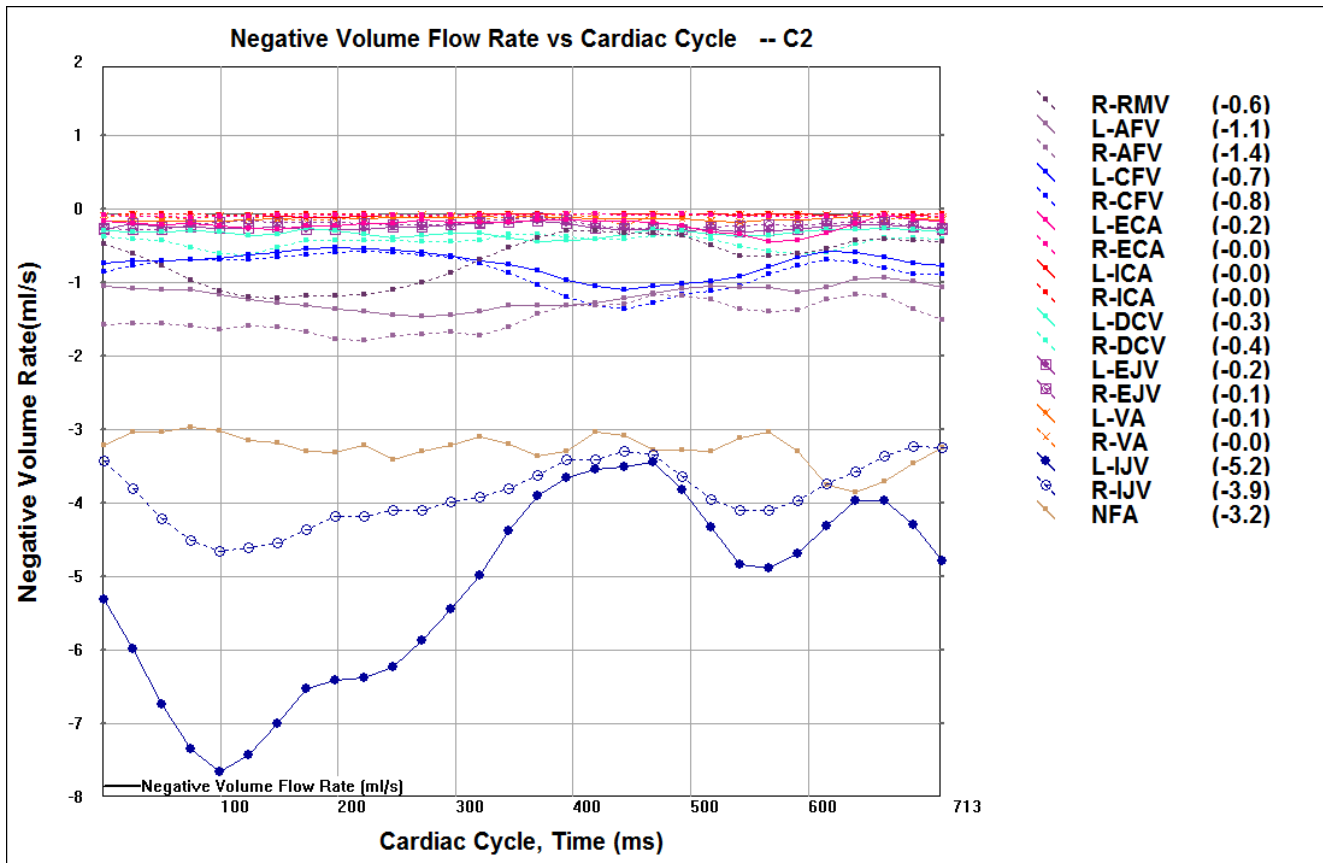
- Total internal carotid artery (ICA) flow rate and the total vertebral artery (VA) flow rate.

Negative Volume Flow Rate vs. Time

C2-3 Neck Region

8.6.5.

Negative volume flow rate (ml/sec): the blood volume flow rate that is in the negative direction through the vessel over time (In some situations, the blood flow has reflux, which means that some of the blood is flowing in the wrong direction).



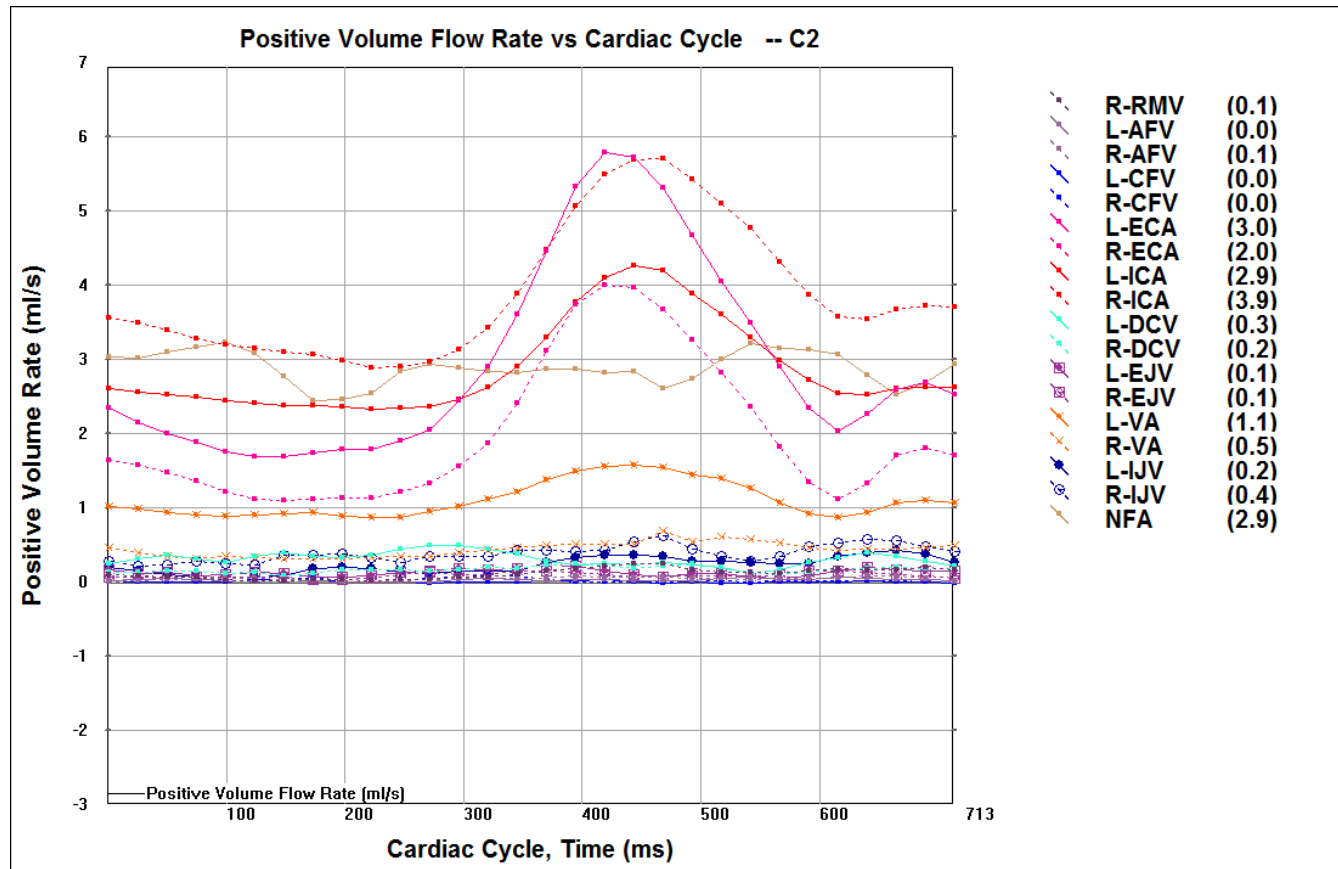
Discussion

Positive Volume Flow Rate vs. Time

C2-3 Neck Region

8.6.6.

Positive volume flow rate (ml/sec): the blood volume flow rate that is in the positive direction through the vessel over time (In some situations, the blood flow has reflux, which means that some of the blood is flowing in the wrong direction).



Discussion

Circulatory flow in the:

- Right internal jugular vein (RIJV).
- Left internal jugular vein (LIJV).
- Left deep cervical vein (LDCV).
- Right deep cervical vein (RDCV).

8.7.1. Quantitative Flow Summary Table

Blood flow in the major neck vessels of the venous system (internal jugular veins, external jugular veins and vertebral veins) has been measured at different regions as shown previously. The total flow for each side of the neck can be calculated by adding the flow of these vessels together. A dramatic difference between the right and left side indicates that the vessels on one side of the neck carry the majority of flow from the brain.

Table 7.

C7-T1 Region	Right		Left		Total
Flow Volume (ml/cardiac cycle)	RIJV	sub total	LIJV	sub total	Vein
	-1.18	-2.14	-1.03	-1.16	-3.31
	RCCA	sub total	LCCA	sub total	Artery
	1.28	1.43	1.58	1.90	3.33
Flow Rate (ml/s)	RIJV	sub total	LIJV	sub total	Vein
	-3.94	-7.15	-3.42	-3.88	-11.03
	RCCA	sub total	LCCA	sub total	Artery
	4.27	4.77	5.25	6.34	11.10
C5-6 Region	Right		Left		Total
Flow Volume (ml/cardiac cycle)	RIJV	sub total	LIJV	sub total	Vein
	-3.08	-5.60	-4.19	-4.81	-10.41
	RCCA	sub total	LCCA	sub total	Artery
	4.85	5.19	4.36	5.30	10.49
Flow Rate (ml/s)	RIJV	sub total	LIJV	sub total	Vein
	-4.12	-7.50	-5.61	-6.44	-13.94
	RCCA	sub total	LCCA	sub total	Artery
	6.50	6.95	5.84	7.09	14.04
C2-C3 Region	Right		Left		Total
Flow Volume (ml/cardiac cycle)	RIJV	sub total	LIJV	sub total	Vein
	-2.55	-4.69	-3.65	-4.95	-9.63
	RICA	sub total	LICA	sub total	Artery
	2.90	4.66	2.14	5.00	9.67
Flow Rate (ml/s)	RIJV	sub total	LIJV	sub total	Vein
	-3.46	-6.35	-4.94	-6.70	-13.05
	RICA	sub total	LICA	sub total	Artery
	3.93	6.32	2.90	6.78	13.10

Discussion

C7-T1: A/V mismatch for the lower neck region is 0.66%.

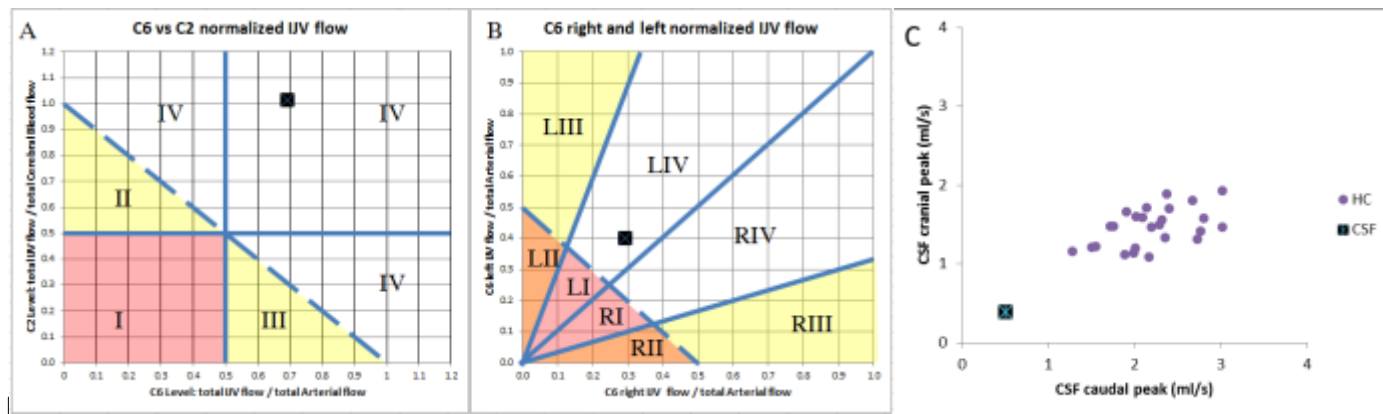
C5-6: A/V mismatch for the lower neck region is 0.73%.

C2-3: A/V mismatch for the upper neck region is 0.35%.

A/V Mismatch:

- Calculated by = (Total Arterial Flow – Total Venous Flow) / Total Arterial Flow x 100%.

8.7.2. Quantitative Flow Region Summary



A: Percentage of total arterial flow drained by the internal jugular veins (IJVs).

- Region I – IJVs drain < 50% of total arterial flow at both the C2-3 and C5-6 neck regions.
- Region II - IJVs drain > 50% of total arterial flow at the C2-3 neck region and < 50% of total arterial flow at the C5-6 neck region.
- Region III – IJVs drain < 50% of total arterial flow at the C2-3 neck region and >50% of total arterial flow at the C5-6 neck region.
- Region IV – IJVs drain > 50% of total arterial flow at both the C2-3 and C5-6 neck regions.

There is evidence that normal control subjects have flow at both C2-3 and C5-6 greater than 50%.

B: Percentage of total arterial flow drained by the internal jugular veins (IJVs) at C5-6 neck region.

Ratio of RIJV flow: LIJV flow

"R" regions have right IJV dominance. "L" regions have left IJV dominance.

- Region RI – IJVs carry < 50% of total arterial flow and the ratio of right to left IJV flow < 3: 1.
- Region RII – IJVs drain < 50% of total arterial flow and the ratio of right to left IJV flow > 3: 1.
- Region RIII – IJVs drain > 50% of total arterial flow and the ratio of the right to left IJV > 3: 1.
- Region RIV – IJVs drain > 50% of total arterial flow and the ratio of the right to left IJV < 3: 1.

There is evidence that normal control subjects lie in Region IV in Figure A and Region LIV and RIV in Figure B.

Figure C: The subject's caudal and cranial CSF flow peaks are plotted. The subject is denoted as square.

Discussion

Internal jugular flow lies within Region III of Figure A and within Region LIV in Figure B.

The IJVs drain:

- ❖ 69% of total arterial flow (AF) at the C5-6 region.
- ❖ 100% of total arterial cerebral blood flow (ACBF) at the C2-3 region.

At the C5-6 region the left IJV is dominant to the right IJV with a flow ratio of 1.3: 1.



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Technical Description of Flow Measurements

In MRI flow quantification, a complex series of images is acquired, generally during the length of a cardiac cycle. In a typical cardiac cycle of about 800 milliseconds, a series of approximately 30 measurements can be collected at different time points. For each measurement, a complex image (consisting of a magnitude and a phase image) is generated. The magnitude image contains anatomical contrast and is used to identify the vessel boundaries. The phase image contains the phase value of each voxel, which is proportional to the velocity of the blood flow at that voxel location (assuming no phase aliasing as explained below). For Siemens data, blood flowing from the heart to the brain (typically arterial flow) is defined as moving in the positive direction; these vessels appear bright in the phase image. The brighter the vessel, the higher the flow velocity. The flow toward the heart (typically venous flow) is in the negative direction; these vessels appear dark in the phase image. The darker the vessel, the higher the flow velocity toward the heart.

An important parameter for flow quantification imaging is the Velocity ENCoding (VENC) value, measured in cm/sec. The VENC value is the maximum velocity that can be accurately represented during a flow sequence. For example, if VENC=50, the maximum velocity that the flow quantification can encode is 50 cm/sec, which is mapped to π (positive flow) or $-\pi$ (negative flow). If the flow velocity at a voxel exceeds the VENC value, say 60cm/sec, then it will be encoded as -40cm/sec due to phase wrapping (aliasing). Aliasing can be eliminated with appropriately selected VENC values.

Processing of flow quantification images with the use of FlowQ software is as follows: The user segments the vessels by drawing the contours of the vessel boundaries. The software then reads the phase values inside of each vessel contour. Utilizing the VENC value, FlowQ software can decode the phase values to obtain the velocity of the blood flow through each voxel. Once flow velocities have been established, the following parameters can be calculated: integrated flow, volume flow rate, positive volume flow rate, negative volume flow rate, positive flow volume, average velocity, peak positive velocity, peak negative velocity, peak to average velocity ratio, average positive velocity and average negative velocity. Some of these parameters are included in the attached report.



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Technical Report Glossary

Abbreviations

Veins:

AFV: Anterior Facial Vein
AHAZGV: Accessory Hemiazygos Vein
AJV: Anterior Jugular Vein
AVPV: Anterior Vertebral Venous Plexus
AZGV: Azygos Vein
CFV: Common Facial Vein
DCV: Deep Cervical Vein
EPDV: Epidural Vein
EJV: External Jugular Vein
HAZGV: Hemiazygos Vein
IJV: Internal Jugular Vein
PEJV: Posterior External Jugular Vein
PVPV: Posterior Vertebral Venous Plexus
RMV: Retromandibular Vein
THYV: Thyroid Vein
VV: Vertebral Vein

Dural Venous Sinuses:

TSV: Transverse Sinus
SSSV: Superior Sagittal Sinus
STSV: Straight Sinus

Arteries:

CCA: Common Carotid Artery
DCA: Deep Cervical Artery
ECA: External Carotid Artery
ICA: Internal Carotid Artery
THYA: Thyroid Artery
VA: Vertebral Artery

Other:

C1-C7: 1-7 Cervical Vertebrae
CBF: Cerebral Blood Flow
CBV: Cerebral Blood Volume
CDC: Cardiac Cycle
CSA: Cross Sectional Area
CSF: Cerebrospinal Fluid
MTT: Mean Transit Time
T1-T12: 1-12 Thoracic Vertebrae
WM: White Matter

Imaging Terms:

ADC: Apparent Diffusion Coefficient
CE: Contrast Enhanced
DWI: Diffusion Weighted Imaging
DTI: Diffusion Tensor Imaging
FA: Fractional Anisotropy
MRA: Magnetic Resonance Angiography
MRI: Magnetic Resonance Imaging
MRV: Magnetic Resonance Venography
PWI: Perfusion Weighted Imaging
SWI: Susceptibility Weighted Imaging
TOF: Time of Flight
WI: Weighted-Imaging (i.e. T1WI)

Additional:

ACBFR: Arterial Cerebral Blood Flow Rate
AFR: Arterial Flow Rate
CMBs: Cerebro Microbleed
MVD: Medullary Vein Damage
PVD: Pial Vein Damage



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Anatomic Definitions

Agenesis: Imperfect development of a structure or non-development of a structure.

Anastomosis: The joining of two tubes; typically seen as the connection between two peripheral vessels without an intervening capillary bed.

Aplasia: Missing vessel; for example, the IJV is not visible through the length of the anatomically defined IJV (from distal end of the sigmoid sinus to its confluence with the subclavian vein). If any signal is shown for the IJV the vessel is not considered missing (see TVM).

Atresia: Condition in which a body orifice or passage in the body is abnormally closed or absent.

Atrophy: Partial or complete wasting away of tissue due to lack of use; can be caused by ischemia (restriction or poor blood circulation) or other causes.

Collateral: Circulation of blood flow through a secondary pathway after obstruction of principal pathway.

Contrast Enhancement: In MRI, the increase in signal caused by the use of a T1 reducing contrast agent (CA, i.e. gadolinium based agent) after intravenous injection into patient.

Cross-Sectional Area (CSA): Size of the vessel lumen as viewed from slice perpendicular to the path of the vessel (typically an axial view for vessels of the neck). The contour of the vessel is drawn and area is determined based on the pixel spacing of the acquired sequence. An approximate CSA is provided.

Ectasia: Dilation or distention of a tubular structure; typically observed in arterial structures near the carotid bifurcation between the C3-C5 regions. May pinch or compress surrounding structures (IJV).

Inhomogeneous: Signal is not uniform within a vessel or region of interest (i.e., demonstrates spatial variation).

Lesion: Abnormal signal (possible pathological tissue).

Narrowing: The reduction of CSA to a non-stenotic level (see stenosis).

Stenosis:

- At the lower and middle neck regions IJV stenosis is present if the CSA is equal to or less than 25mm² (assuming that the average diameter in this region is 1cm).
- At the upper neck region, IJV stenosis is present if the CSA is equal to or less than 12.5mm² (assuming that the average diameter in this region is 7mm).
- Unilateral: appearing on one IJV.
- Bilateral: appearing on both right and left IJVs.
- Diffuse/string-like: appearing through a substantial length of the IJV.

Truncular Venous Malformation (TVM): Abnormal congenital development of a vessel. For example; a discontinuous IJV at some point between the distal end of the sigmoid sinus and the confluence with the subclavian vein could be a TVM. Superior and inferior TVM form a clear stump with no connection (or a very thin connection between stumps. Septal flaps, dilation, and intra-membranous webs have also been considered TVM. (See also atresia, agenesis, and aplasia.)



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Flow Quantification Definitions

Absolute Flow: Total blood volume which has passed through the vessel in a given amount of time regardless of direction (Integral of both positive and negative volume flow rate plots).

A/V Mismatch: Calculated by $= (\text{Total Arterial Flow} - \text{Total Venous Flow}) / \text{Total Arterial Flow} \times 100\%$

Biphasic Flow Pattern: Flow profile in which a vein demonstrates two clear drops and two clear peaks during one cardiac cycle.

Circulatory Flow: Flow profile containing both positive and negative flow components during the same cardiac cycle indicating bidirectional flow within the vessel.

Dominant IJV: Subdominant IJV: Ratio of flow between the IJV which carries the most flow (dominant) and the other IJV (subdominant).

IJV Low Flow: Flow is considered low when the volume flow rate falls below 1ml/s.

Jetting Effect: Signal in a narrowed region, oftentimes near the center or edge, is much stronger than in the rest of the lumen.

Percentage Reflux: Ratio of the retrograde flow to the total absolute flow in the vein.

Reflux: Retrograde flow opposite to the expected direction (retrograde venous flow moves from the heart toward the brain). For the purposes of this report, the flow in the vein must drop to zero and continuously cross over into a retrograde flow pattern and then continuously return to zero and a normal flow toward the heart to be defined as reflux. This is to differentiate between circulatory flow and reflux.

Speed: Magnitude of flow through the acquired slice (oriented perpendicular to the vessel) in cm/sec.

Volume: Quantity of blood in ml.

Volume Flow Rate: Rate of blood flow in ml/sec.