Susceptibility-Weighted Angiography of Intracranial Blood Products and Calcifications Compared to Gradient Echo Sequence

JORGE DOCAMPO, NADIA GONZALEZ, FERNANDO BRAVO, DANIEL SARROCA, CARLOS MORALES, CLAUDIO BRUNO

Fundación Científica del Sur; Lomas de Zamora, Argentina

Key words: MRI scans, brain imaging, intracerebral haemorrhage, cerebral calcification, cerebral cavernous malformations

SUMMARY – *This study evaluated the sensitivity of susceptibility-weighted angiography (SWAN) compared with gradient echo (GRE) sequence in the depiction of haemorrhagic and calcium lesions by virtue of correlation analysis between the number, area and contrast index. The study included 21 patients (15 women, 6 men; age range 18 to 80 years) in whom intracranial haemorrhage or calcifications were previously diagnosed with CT and/or MR. GRE and SWAN sequences were performed as part of a conventional Brain MR study using a 3T scanner. Pathologic findings were: cavernoma (n=8), chronic intraparenchymal haemorrhage (n=5), petechial bleeding (n=3), parenchymal calcifications (n=2), sequelae of haemorrhagic contusion focus (n=1), post-surgical glioma (n=1) and venous angioma (n=1). In eight patients, more lesions were found in the SWAN sequence than in GRE. In the measurement of the largest area, in all cases the measured area was larger in the SWAN sequence than in GRE. The SWAN sequence was reported to have shown higher contrast between the lesion and the healthy white matter than in GRE. The SWAN sequence is more sensitive than GRE in the identification of cerebral haemorrhage and calcifications. The SWAN sequence also obtained significantly larger images than with GRE, and a higher contrast difference between the lesion and the healthy parenchyma.*

Introduction

The presence of haemorrhage or blood breakdown products is a common finding in several pathologic conditions such as cerebral haemorrhage, vascular malformations, trauma, brain tumours or metastasis, and cerebral microbleeds¹⁻⁵. The T2 weighted gradient recalled echo (GRE) sequence is a well-recognized method for the detection of intracranial paramagnetic blood breakdown products, which cause marked signal intensity loss because of magnetic susceptibility effect^{1,5-7}. Because of its sensitivity to susceptibility changes, the GRE sequence is used to depict paramagnetic deoxyhaemoglobin, methaemoglobin or haemosiderin in lesions and brain parenchyma, as well as iron deposition and calcifications⁷⁻¹⁰.

T2 star-weighted angiography (SWAN), or

susceptibility-weighted angiography is a new, high-resolution 3D multi-echo gradient echo sequence that produces weighted averaging across images with different echo times (TEs) to achieve higher susceptibility weighting. Short TEs provide a time-of-flight (TOF) effect, allowing high-resolution visualization of cerebral arteries and veins, whereas long TEs provide the magnetic susceptibility effect with minimum intensity projections over neighbouring slices, enhancing contrast for certain substances with susceptibilities that differ from the background tissues such as extravascular blood products and calcification and iron deposition^{11,12}.

The aim of our study was to evaluate the sensitivity of SWAN compared with GRE sequence in the depiction of haemorrhagic and calcium lesions by virtue of correlation analysis between the number, area and contrast index.

Figure 1 Cavernoma. GRE sequence (A) and SWAN (B). Note that the SWAN sequence shows higher magnetic susceptibility than GRE (white arrows) to the presence of haemosiderin surrounding the cavernoma located in the left frontal lobe. The SWAN sequence also disclosed a microbleed focus located in the left corona radiata (white circle).

Materials and Methods

Patients

This prospective study included 21 patients (15 women, 6 men; age range 18 to 80 years); in whom intracranial haemorrhage or calcifications were previously diagnosed with CT and/or MR, and referred to our institution by their neurologist or neurosurgeon. GRE and SWAN sequences were performed as part of a conventional Brain MR study. The study was approved by our institutional review board. Patients with acute haemorrhage were excluded from this study.

MR Imaging

MR Imaging was performed on a 3T unit (GE 3,0T HDxt) with a 12-channel head coil. Imaging parameters for GRE were: TR, 425 ms; TE,

15 ms; flip angle, 25°; matrix, 320×224, FOV, 240 mm; section thickness, 2 mm; intersection gap, 0; bandwidth, 31.25 kHz and acquisition time, 3 minutes 40 seconds. Imaging parameters for SWAN were: TR, 42.3 ms; TE, 26 ms; flip angle, 15°; matrix, 256×256; FOV, 240 mm; section thickness, 2 mm; intersection gap, 0; bandwidth, 62.5 kHz and acquisition time, 2 minutes 50 seconds.

Image Analysis

Haemorrhagic lesions and calcifications were defined as areas of low signal intensity on GRE and SWAN images. Calcifications were confirmed with CT scans.

Three parameters were evaluated in both GRE and SWAN sequences: number of lesions, lesion area and contrast index (CI). Images

Figure 2 Cavernoma: iron and calcium deposit in the globus pallidus. GRE (A) sequence and SWAN (B). This sequence shows with higher susceptibility than GRE a cavernoma surrounded by haemosiderin, involving the head of the left caudate nucleus (white arrow); the same occurs with the findings in the globus pallidus (blue arrow). The magnetic susceptibility images are larger in the SWAN sequence than in GRE.

were independently reviewed by two trained neuroradiologists (MA and ME) on a computer using OsiriX v.4.0 to identify and count the number of hypointense lesions in each sequence, and final results were reached by consensus.

A third neuroradiologist (D.N.) simultaneously compared GRE and SWAN sequences at equivalent sections using a 20-inch monitor divided into two windows, to determine lesion area and CI. Lesion area was obtained by measuring anteroposterior and transversal diameter of lesions in a single section. In the cases where more than one lesion was identified, lesion area was calculated in the larger lesion. To determine CI, the signal intensity (SI) was measured with a circular region of interest (ROI) located over the larger lesion in a single section, and a ROI of the same diameter was placed over the adjacent normal white matter

in each case. ROIs of identical diameter were used in both GRE and SWAN sequences in each pair of lesions. In every case, lesions were magnified to facilitate the ROI location. CI was determined using the following formula: $CI = (SI_{WM} - SI_L) / SI_{WM}$, where SI_L is the mean signal intensity of the ROI placed over the lesion and SI_{WM} is the mean signal intensity of the adjacent white matter.

Statistical Analysis

Lesion area and CI of the lesions were compared using paired t tests. Differences were considered statistically significant if the P value was less than .01. The statistical analysis was performed with the Statistical Package for Social Sciences software (SPSS, Chicago, ILL, USA), Version 11.0.

← Figure 3 Bi-occipital calcifications in a coeliac patient. GRE sequence (A) and SWAN (B). A subtle difference in susceptibility is identified in both sequences, these differences being more hypointense on SWAN images (white arrow).

Results

Pathologic findings in the patients studied were: cavernoma (n=8), chronic intraparenchymal haemorrhage (n=5), petechial bleeding (n=3), parenchymal calcifications (n=2), sequel of haemorrhagic contusion focus (n=1), post-surgical glioma (n=1) and venous angioma (n=1).

In eight patients, more lesions were found in the SWAN sequence than in GRE, the largest difference of images found was ten, but the mean was 2.1 (Table 1). The type of lesion in which SWAN was the most sensitive was petechial bleeding.

Regarding evaluation of the basal ganglia, the SWAN sequence identified lesions in 14 patients, and the GRE sequence in 12 patients (Table 1).

In measurement of the largest area, in all cases the measured area was larger in the SWAN sequence than in GRE (Table 1). T-test result for paired or correlated samples shows that the SWAN sequence obtained, on average, significantly larger sizes of lesions compared with GRE: $t(20)=3.88$, $p < 0.01$, $d = 40.47$. The

mean difference in the area measured between SWAN and GRE was 17.42% higher for SWAN (range 4.3%-36.22%).

Upon CI evaluation between both sequences, the SWAN sequence was reported to have shown higher contrast between the lesion and the healthy white matter than in GRE, that is, it is more sensitive to detect haemosiderin and calcifications (Table 2). T-test result for paired or correlated samples indicates that the SWAN sequence presents higher contrast between lesion and normal white matter than GRE, with significant results: $t(20) = 5.943$, $p < 0.01$, $d = 0.125$. We also show a case of a patient who presented with an anomaly of venous drainage in the left cerebellar hemisphere, better shown applying the SWAN sequence than GRE, where the presence of hypointense small calibre vessels can be identified, draining a higher calibre venous vessel. In a patient with a haemorrhagic CVA sequel, we identified superficial haemosiderosis, which was better shown in the SWAN sequence than in GRE, and which presented the characteristic gyriform-type hypointensity signal, due to the deposit of haemo-

Table 1 Comparison between SWAN and GRE comparing the number of lesions, lesions in basal ganglia and lesion area.

Patient	Number of Lesions		Basal Ganglia		Area	
	GRE	SWAN	GRE	SWAN	GRE	SWAN
1	1	1	NO	NO	285.15	349.35
2	2	3	YES	YES	327.50	456.44
3	1	1	YES	YES	40.32	45.83
4	1	2	NO	YES	422.16	481.89
5	1	1	NO	NO	20.27	25.14
6	1	1	NO	NO	187.91	215.43
7	6	6	YES	YES	2863.31	3046.05
8	2	2	YES	YES	605.55	676.26
9	2	2	YES	YES	304.85	318.56
10	3	8	YES	YES	228.03	248.59
11	1	1	YES	YES	214.43	272.35
12	1	4	YES	YES	1045.68	1143.62
13	4	9	NO	NO	11.36	13.29
14	2	3	YES	YES	683.35	711.35
15	1	1	NO	NO	16.16	20.73
16	22	32	YES	YES	7.69	9.63
17	1	1	YES	YES	14.55	21.94
18	1	2	NO	YES	72.24	94.06
19	1	1	YES	YES	12.08	17.56
20	3	4	NO	NO	68.59	107.54
21	2	2	NO	NO	23.34	28.78

← Figure 4 Venous angioma. GRE sequence (A) and SWAN (B). The venous angioma located in the left cerebellar hemisphere (white arrow) is better delimited in the SWAN sequence than in GRE.

Figure 5 Sequelae of microangiopathic bleeding. GRE sequence (A) and SWAN (B). A noticeably higher number of petechial images of haemosiderin remains are shown in the SWAN sequence than in GRE.

siderin along the leptomeninges and cerebral cortical surface.

Discussion

There are few published articles on the SWAN sequence; most published works on susceptibility sequences concern GRE sequences and, recently, the susceptibility-weighted imaging (SWI) sequence. The SWAN sequence belongs to General Electric resonators; it would be equivalent to SWI, used in Siemens resonators.

In the present study, we found statistically significant results comparing the SWAN sequence with GRE, both regarding the evaluation of the lesion area as CI evaluation.

In order to make a comparison with SWAN sequence, we applied a GRE sequence with parameters we do not frequently use in daily practice, thus giving a sort of advantage to GRE over SWAN. We used the same FOV,

thickness and number of slices. The resolution matrix was higher in GRE (320×224) than the one applied with SWAN (256×256). However, we found significant differences in favour of the SWAN sequence.

Recent studies compared SWI and GRE sequences in 1.5 and 3T resonators, measuring lesion area and calculating CI, and obtained significant differences on the SWI sequence with respect to GRE¹³.

Numerous studies show a relation between iron deposits in the basal ganglia and patients' age¹⁴, as well as with the degree of cognitive decline, and this may be better assessed with susceptibility sequences. Some publications mention the sensitivity of the new susceptibility sequences (SWI and SWAN) regarding the detection of iron deposits in the basal ganglia¹⁵. We have findings in the basal ganglia in 14 patients on whom the SWAN sequence was applied, and in 12 patients studied with GRE, the basal ganglia being better shown in the SWAN sequence.

Regarding the detection of the intracranial

Figure 6 Superficial haemosiderosis. GRE sequence (A) and SWAN (B). A sequel of haemorrhagic CVA is observed, located in the left occipital lobe, cortical-subcortical, associated with superficial haemosiderosis, shown by the pial-cortical hypointensity at ipsilateral parieto-occipital level. This finding is better observed in the SWAN sequence.

vessels, the SWAN sequence shows as hypointense the small calibre venous vessels, and as hyperintense the arterial vessels. In addition, the SWAN sequence makes it possible to better observe the small calibre vessels, compared with GRE^{16,17}. The SWAN sequence can be used for the diagnosis of low and high-flow venous malformations, the low-flow vessels being shown as hypointense, and the high-flow vessels as hyperintense¹⁷.

We also found differences in the lesion count in both sequences, more lesions being shown in SWAN. The most identified type of finding was microbleeds. There is increasing evidence of the importance of diagnosing microbleeds, and how these are related to vascular disease. There is a direct relation between the presence of microbleeds and the existence of vascular pathology with a probable haemorrhagic CVA evolution^{13,18}. As a disadvantage of the SWAN sequence, we found that, compared with the modified GRE sequence applied, it presents lower anatomic resolution. Even though the

SWAN sequence provides lower anatomic detail, it presents higher sensitivity in the detection of small vascular structures, blood degradation products with paramagnetic features, and calcium and iron deposits, compared with GRE. However, the objective of the susceptibility sequences is not the quality of the anatomic image, but the sensitivity in the detection of haematic remains and calcium.

Conclusions

The SWAN sequence is more sensitive than GRE in the identification of cerebral haemorrhage and calcifications. The T-test result for paired or correlated samples indicates that the SWAN sequence obtained, on average, significantly larger images compared with GRE: $t(20) = 3.88$, $p < 0.01$, $d = 40.47$, and a higher contrast difference between the lesion and the healthy parenchyma: $t(20) = 5.943$, $p < 0.01$, $d = 0.125$.

Table 2 Contrast index (CI) between SWAN and GRE. To determine CI, the signal intensity was measured with a circular region of interest (ROI) located over the larger lesion (I) in a single section, and a ROI of the same diameter was placed over the adjacent normal white matter (WM) in each case.

Patient	Diagnosis	SWAN			GRE		
		I	WM	CI SWAN	I	WN	CI GRE
1	Cavernoma	240.57	2853.91	0.92	232.48	1675.39	0.86
2	Chronic Intraparenchymal Haemorrhage	1606.18	2846.14	0.44	1097.79	1607.56	0.32
3	Cavernoma	398.6	2340.58	0.83	476.45	1478.21	0.68
4	Cavernoma	320.64	2871.62	0.89	288.04	1805.57	0.84
5	Cavernoma	531.69	1985.78	0.73	634.33	1535.51	0.59
6	Venous Angioma	1489.45	2422.29	0.39	1305.25	1526.34	0.14
7	Chronic Intraparenchymal Haemorrhage	700.68	2121.28	0.67	793.34	1480.9	0.46
8	Chronic Intraparenchymal Haemorrhage	407.73	2375.96	0.83	336.18	1497.31	0.78
9	Chronic Intraparenchymal Haemorrhage	305.51	2382.6	0.87	338.18	1557.4	0.78
10	Cavernoma	376.6	1736.3	0.78	342.59	903.27	0.62
11	Cavernoma	482.87	2663.26	0.82	365.56	2001.8	0.82
12	Post-Surgical Glioma	174.43	2379.01	0.93	190.03	1545.85	0.88
13	Petechial Bleeding	600.46	2005.54	0.70	444.08	1360.08	0.67
14	Cavernoma	246.61	1712.63	0.86	236.96	1486.42	0.84
15	Cavernoma	397.5	1510.47	0.74	339.62	1128.5	0.70
16	Petechial Bleeding	571.13	2350.64	0.76	660.53	1569.37	0.58
17	Contusion Focus	711.71	3030.97	0.77	520.43	1773.97	0.71
18	Chronic Intraparenchymal Haemorrhage	444.19	2256.17	0.80	511.73	1710.34	0.70
19	Petechial Bleeding	815.41	3162.12	0.74	1089.12	1795.87	0.39
20	Calcifications	1673.87	3244.32	0.48	1600.66	2015.42	0.21
21	Calcifications	1107.12	2317.18	0.52	1118.67	1505.51	0.26

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Jorge Docampo, MD
Fundación Científica del Sur
Lomas de Zamora, Argentina
E-mail: docampojorge@hotmail.com