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Original Article

# Contrast Enhanced Cerebral MR Venography: Comparison between Arterial and Venous Triggering Methods

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**Purpose :** To compare the arterial and venous detection sites of triggering methods in contrast-enhanced-MR-venography (CE-MRV) for the evaluation of intracranial venous system.

**Materials and Methods:** 41 healthy patients underwent CE-MRV with autotriggering at either the cavernous segment of internal carotid artery with an inserted time-delay of 6 seconds (n = 20) or the superior sagittal sinus without any time-delay (n = 21). 0.1 mmol/kg gadolinium-based contrast material (Magnevist®, Schering, Germany) was intravenously injected by hand injection. A sagittal fast-spoiled-gradient-echo-sequence ranging from one ear to the other was performed (TR/TE5.2/1.5, Matrix 310×310, 124 sections in the 15-cm-thick volume). 17 predefined venous structures were evaluated on all venograms by two neuroradiologists and defined as completely visible, partially visible, or none visible.

**Results:** The rate of completely visible structures were 272 out of 323 (84%) in the arterial triggering CE-MRV and 310 out of 340 (91%) in the venous triggering CE-MRV. The venous triggering CE-MRV demonstrated an overall superior visualization of the cerebral veins than the arterial triggering CE-MRV (Fisher exact test, $p < 0.006$).

**Conclusion:** CE-MRV using venous autotriggering method provides higher-quality images of the intracranial venous structures compared to that of arterial.

**Index words :** Contrast-enhanced MR angiography · Cerebral Vein · Contrast enhanced cerebral MR venography · Comparison between arterial and venous triggering methods

## INTRODUCTION

Contrast enhanced MR venography (CE-MRV) is known to be useful in evaluating the normal venous anatomy (1–9), assessing the intracranial venous lesions including cerebral venous thrombosis (5, 10, 11), and preoperative imaging of brain tumors (12).

Although CE-MRV can be obtained after a standard delay time of 20–60 seconds after intravenous infusion of contrast media (3, 7, 9, 11), optimized triggering methods can be more beneficial. A triggering method is a concept of determining the appropriate time to collect the raw data corresponding to the k-space center in each patient, by measuring the maximal concentration of contrast media in the vessels. Because the transit time of the contrast material varies with the patient's heart rate, cardiac output, age, and severity of the vascular abnormality, using triggering methods in each patient may lead to better imaging of the venous structures.

CE-MRV using automated or fluoroscopic triggering devices, which measure the contrast media at the intracranial dural sinuses (8, 10) or the cavernous carotid arteries (2) are being used to determine the appropriate delayed timing of CE-MRV sequence. However, studies on the image quality and visibility of

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venous structures between different detection sites have not been reported, to our knowledge.

The purpose of this study was to compare the arterial and venous detection sites of venous triggering methods in CE-MRV for the evaluation of intracranial venous system.

## MATERIALS AND METHODS

This retrospective study was approved by our Institutional Review Board for Health Insurance Portability and Accountability Act-compliant study and the need of consent was waivered.

### Patient population

Our study population consisted of 41 consecutive patients (22 men and 19 women, 29 to 86 years old, mean age 54 years), who underwent brain MR imaging for health checkup. None of the patients had signs or symptoms suggesting pathologic changes of the cerebral veins or dural sinuses. The CE-MRV were taken by either arterial triggering (n=20) or venous triggering (n=21). Exclusion criterias included nondiagnostic CR-MRV due to severe motion artifact (n=1) and pathological conditions which could alter venous imaging (n=1, incidentally detected parasagittal meningioma). A total of 39 patients (19 arterial triggering and 20 venous triggering CE-MRV) were evaluated.

### MRV protocol

All contrast-enhanced-MR-venography (CE-MRV) were performed using a 1.5T MR system (SignaTwinspeed®, GE Medical Systems, Milwaukee, WI, U.S.A.) with a standard head-coil. The sequence of the CE-MRV included the following four integral parts as described by Farb et al. (2): (a) Initiation of two-dimensional (2D) single-section bolus-detection sequence; (b) Intravenous bolus injection of contrast media; (c) Automated detection of the arrival of intravascular contrast material, resulting in automatic termination of the detection sequence; and trigerring of (d) a fast 3-dimensional gradient-echo MR angiography sequence with elliptic centric-ordered phase encoding.

The 2D real-time fluoroscopic bolus-detection sequence was used to trigger 2D MR venography (2, 13), which was performed with TR / TE, 11.5 / 9.5; flip angle, 30degree; field of view, 22 × 22 cm; matrix, 320 × 128; bandwidth, 62.5 kHz; and section thickness 10 mm. 2D bolus-detection sequence was oriented in the transverse plane and located at the level of cavernous carotid arteries for the arterial triggering method, and in the sagittal plane, at the superior sagittal sinus for venous triggering method. For bolus detection method, data from the region of interest were collected and evaluated in an automated fashion so that the mean signal intensity of the brightest 20% of pixels in the region of interest was averaged for 10 consecutive images. These protocols were provided by our MR vendor. A triggering threshold was then set at 5 SDs higher than the mean of the averaged data. After the operator was notified that the triggering threshold had been determined, subsequent intravenous injection of a bolus of contrast material resulted in a rapid increase in signal intensity in the region of interest that exceeded the set threshold. After an additional preprogrammed delay of 6 seconds, the detection sequence was terminated automatically and, simultaneously, the 3D centric MR angiographic sequence was initiated. The 6-second delay was determined empirically to ensure sufficient perfusion of contrast material through the circle of Willis, the physiologic cerebral circuit, and well into the intracranial venous system before initiation of the centric filling of k space. With imaging and processing delays, triggering occurred 6–7 seconds after arrival of the leading edge of the bolus of contrast material. Bolus of 0.1 mmol/kg of gadolinium-based contrast material (Magnevist®, Schering, Germany) was intravenous injected by hand injection at the rate of 2 cc/sec, followed by injection of 20 cc of saline at the same rate. This injection protocol was followed for all patients. A sagittal fast-spoiled-gradient-echo-sequence ranging from one ear to the other ear was performed using the following parameters: TR/TE, 5.2/1.5; flip angle, 30°; fractional echo acquisition; field of view, 25 cm; matrix, 320 × 320; bandwidth, 62.5 kHz; section thickness, 1.2 mm; 124 partitions, resulting voxel dimensions were 0.78 × 0.78 × 1.2 mm.

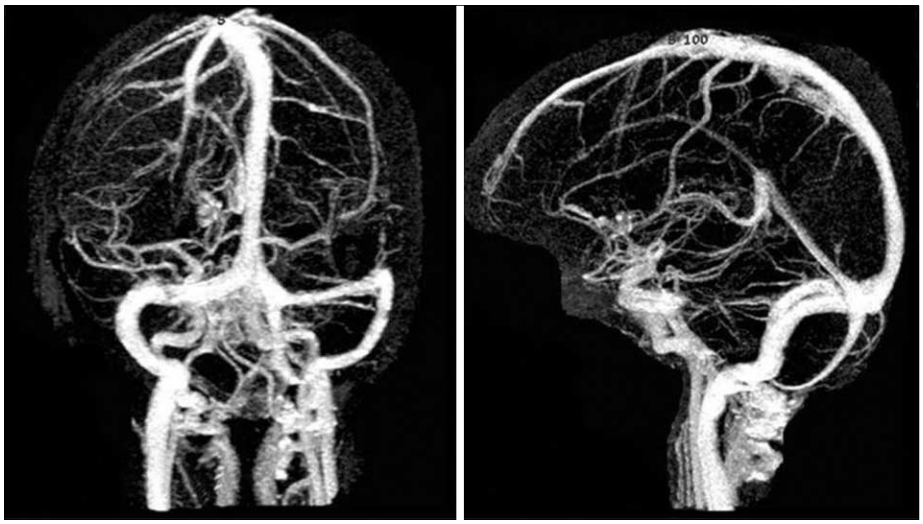
### Image analysis

Two radiologists (K.B.S. and J.S.L., each with over 10 years of experience) interpreted the MIP images of arterial triggering CE-MRV and venous triggering CE-MRV studies, in random order, on a dedicated PACS

station (Marosis m-view®; Infinitt, Seoul, Korea), blinded of patient history and identity. Readers were blinded to the different MRV techniques. Separate image reading sessions were organized for both readers by the study coordinator (C.H.S.), who attended all reading sessions. The readers were instructed to use the only coronal and sagittal MIP postprocessed data. Both the arterial triggering CE-MRV and venous triggering CE-MRV were evaluated qualitatively for image quality. Each MRV data set was divided into 17 predefined intracranial venous structures: the superior, inferior sagittal sinus, right and left transverse sinus, transverse sigmoid sinus junction, sigmoid sinus, thalamostriate veins, internal cerebral veins, vein of Galen, basal veins of Rosenthal, and the straight sinus. A total of 663 venous structures were analyzed during both arterial triggering CE-MRV and venous triggering CE-MRV.

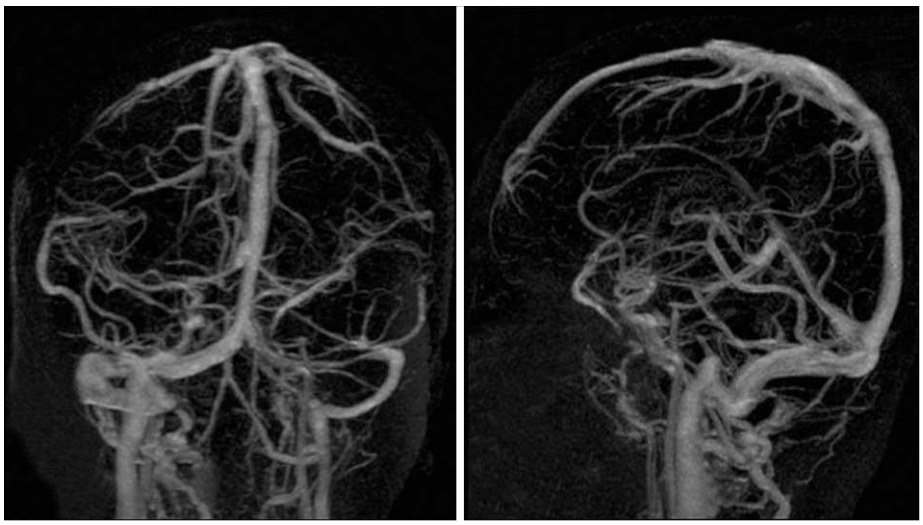
Overall image quality was rated using a three - point scale: 1 = not visible, 2 = partially visible, 3 = completely visible. A completely visible structure implied that the reader was highly confident that he/she was able to visualize the lumen of the venous structure in its entirety, whether it was truly hypoplastic or clearly normal. With these criteria, the readers were not permitted to designate a dural venous sinus as simply hypoplastic as a justification for a report of partially visible or not visible. The readers were also asked to assess the overall quality of the MR venograms as diagnostic or nondiagnostic.

When two radiologists rated image quality differently, the final score of image quality was made with



a b

**Fig. 1.** Coronal (a) and sagittal (b) MIP images of contrast enhanced MR venography obtained with arterial triggering and 6 seconds of inserted time-delay.



a b

**Fig. 2.** MIP images obtainedwith (a) coronal and (b) sagittal MR venography with venous triggering at superior sagittal sinus without time-delay.

consensus.

### Statistics

The Student's *t* test or Mann-Whitney *U* test, depending on the results of a normality (Kolmogorov-Smirnov) test, was used to compare the patient's sex, age, past medical history between the two groups.

The image quality scores between the arterial triggering CE-MRV and venous triggering CE-MRV were compared with the Fisher exact test.

For interobserver agreement, the kappa value was calculated. Interobserver agreement for the image quality on each dataset, and for detection of findings on each dataset between the two readers, were determined by calculating the k values, using a weighted kappa test (poor agreement k = 0; slight agreement k = 0.01–0.2, fair agreement k = 0.21–0.4; moderate agreement k = 0.41–0.6; good agreement k =0.61–0.8; excellent agreement k = 0.81–1). $P < 0.05$ were regarded as statistically significant.

**Table 1. Image Quality Scores of the Arterial Triggering and Venous Triggering CE-MRV**

| Venous structures | Arterial triggering | | | Venous triggering | | |
|---|---|---|---|---|---|---|
| | NV | PV | CV | NV | PV | CV |
| Superior sagittal sinus | 0 | 3 | 16 | 0 | 0 | 20 |
| Inferior sagittal sinus | 1 | 9 | 9 | 2 | 7 | 11 |
| Torcula herophili | 0 | 1 | 18 | 0 | 0 | 20 |
| Transverse sinuses | | | | | | |
| Right | 0 | 1 | 18 | 0 | 0 | 20 |
| Left | 0 | 2 | 17 | 0 | 1 | 19 |
| Transverse-sigmoid sinus junction | | | | | | |
| Right | 0 | 2 | 17 | 0 | 1 | 19 |
| Left | 0 | 3 | 16 | 0 | 1 | 19 |
| Sigmoid sinuses | | | | | | |
| Right | 0 | 2 | 17 | 0 | 1 | 19 |
| Left | 0 | 2 | 17 | 0 | 0 | 20 |
| Thalamostriate veins | | | | | | |
| Right | 1 | 3 | 15 | 1 | 3 | 16 |
| Left | 1 | 4 | 14 | 1 | 2 | 17 |
| Internal cerebral veins | | | | | | |
| Right | 0 | 2 | 17 | 0 | 1 | 19 |
| Left | 0 | 3 | 16 | 0 | 2 | 18 |
| Vein of galen | 0 | 3 | 16 | 0 | 1 | 19 |
| Basal veins of rosenthal | | | | | | |
| Right | 0 | 3 | 16 | 1 | 2 | 17 |
| Left | 0 | 4 | 15 | 1 | 2 | 17 |
| Straight sinus | 0 | 1 | 18 | 0 | 0 | 20 |
| Total | 3 (1% /) | 48 (14% /) | 272 (84% /) | 6 (2% /) | 24 (7% /) | 310 (91% /) |

Footnote- Figures represent number of MRV which revealed the above scores (reviewer 1 / reviewer 2)
NV (Not visible), PV (Partially visible), CV (Completely visible)

## RESULTS

There was no significant difference in the patient's sex, age, past medical history between the arterial triggering CE-MRV group (n=19) and venous triggering CE-MRV group (n=20).

The overall image quality scores rated by both readers for the arterial triggering CE-MRV and venous triggering CE-MRV were all in the visibility range, with the mean image quality scores as 2.83 (CI = 2.78–2.87) for the arterial triggering CE-MRV and 2.89 (CI = 2.86–2.93) for the venous triggering CE-MRV. The rate of completely visible venous structures were 272 out of 323 (84%) in the arterial triggering CE-MRV (Fig. 1) and 310 out of 340 (91%) in the venous triggering CE-MRV (Fig. 2) (Table 1). The overall score was significantly higher in the venous CE-MRV group compared to the arterial triggering CE-MRV group ($p < 0.006$).

Interobserver agreements was good for both for arterial triggering CE-MRV ($k = 0.76$) and venous triggering CE-MRV ($k = 0.72$).

The mean triggering time (time taken for the contrast media to exceed the level of triggering concentration at the detected site) was measured 19.4 sec (13–28 sec) in arterial triggering CE-MRV and 21.0 sec (17–36 sec) in venous triggering CE-MRV (Table 2).

## DISCUSSION

MR venography is regarded as the best noninvasive method for evaluating the cerebral venous system (13). The two most common techniques are time-of-flight effects of moving spins and motion-induced phase shifts (the 3D phase-contrast technique). Phase-contrast MRV uses velocity-induced phase shifts, which are proportional to the velocity of flow, to depict flowing blood. Phase-contrast MRV has the ability to quantify flow and determine flow direction. CE-MR angiography technique benefits from a triggering mechanism to optimize capture of vascular contrast with the acquisition of raw data corresponding to the center of the k-space collected during the contrast material in the vessel of interest. Accurate timing of the arrival of the contrast material bolus to the acquisition of the central k-space lines is critical to the success of this technique (14, 15). The transit time of a contrast material bolus from the infusion site to the imaged region of the body varies with heart rate, cardiac output, age, and severity of the vascular abnormality, which are parameters difficult to predict accurately. Liauw et al. conducted a study in 12 healthy volunteers using time-of-flight and phase-contrast techniques in the transverse, sagittal, and coronal planes. They found that visualization of a normal intracranial venous system was better with 3D phase-contrast and 2D time-of-flight MR angiographic techniques in the coronal plane than with transverse or sagittal 2D time-of-flight MR angiography (16). CE-MRV with the paramagnetic effect of gadolinium shortens the intravascular T1 relaxation time, thus increasing the signal intensity of blood, with no saturation effects. For optimal image quality, the injection profile must be set when the contrast bolus is maximally present within the vessels of interest during image acquisition. Too early or too late acquisition might miss the peak passage of contrast bolus and produce inadequate visualization of the vessels. The major advantages of 3D CE-MRV are the superior visualization of intracranial venous morphology, and a faster acquisition time which reduces patient-related

**Table 2. The Mean Image Quality Scores and Trigger Time of Venous Triggering CE-MRV and Arterial Triggering CE-MRV**

| | Arterial triggering | | | Venous triggering | | |
|---|---|---|---|---|---|---|
| | NV (1 point) | PV (2 points) | CV (3 points) | NV (1 point) | PV (2 points) | CV (3 points) |
| Numbers | 3 / (1% /) | 48 / (14% /) | 272 / (84% /) | 6 /(2% /) | 24 / (7% /) | 310 / (91% /) |
| Score (mean) | 2.83 (CI=2.78–2.87) | | | 2.89 (CI=2.86–2.93) | | |
| Trigger time* | 19.4 sec (13–28 sec) | | | 21.0 sec (17–36 sec) | | |

Footnote- Figures represent number of MRV which revealed the above scores. (reviewer 1 / reviewer 2)
NV (Not visible), PV (Partially visible), CV (Completely visible)
* Trigger time : duration between the injection of contrast media and bolus detection at artery or vein, respectively

motion artifacts on the images (17).

There are several methods to detect and trigger the optimal timing for contrast injection during image acquisition of 3D CE-MRV. There have also been many reports comparing 3D CE-MRV with time-of-flight or phase-contrast MRV (5–7, 10). Fu et al have successfully used a real-time triggering method, in which the 3D CE MR angiographic sequence was initiated precisely when contrast medium was filling in the superior sagittal sinus (18). Farb et al compared Auto-triggered elliptic centric ordered sequence (ATECO) MR venography with inserted time-delay after arterial triggering and time-of-flight MR venography techniques in 23 patients and observed rates of complete visibility of the venous structure of 99% and 72%, respectively (17).

Our study revealed a significantly higher image quality of the intracranial venous structures in the MR venography conducted with venous triggering method compared to the arterial triggering method. The difference between the triggering time of the arterial and venous CE-MRV was about two seconds (ranging from four to eight seconds). We suggest this difference may have arised from the circulation time between the carotid artery and internal jugular vein, and is somewhat similar to the reported cerebral circulation time, which is 5.54 seconds when measured by sonogram (19). Our results also demonstrated the triggering time also varied between the same methods (13–28 sec in arterial triggering CE-MRV and 17–36 sec in venous triggering CE-MRV), even though all the included patients had no pathologic conditions. The circulation time may probably vary even more in pathologic conditions, again suggesting the benefit of individualized triggering methods compared to the standard delayed method. However caution in using venous triggering method in patients with venous thrombosis is needed because the contrast media may have a very long triggering time or even never exceed the triggering point due to complete obstruction.

The followings are some limitations of our study. The major limitation of our study lies in its small size and retrospective nature. The study population was not constant because of continuous influx and efflux of patient. To overcome this as much as possible, we used consecutive normal patients. Also, the intra individual comparison of arterial triggering and venous triggering MR venography could not be done for the same patients due to obvious ethical reasons. However, we believe that this shortcoming has been overcome, because the patient's sex, age, past medical history were compared and were not significantly different between the two groups. Furthermore, the study was based on nonpathological patients only. Thus, one must be careful to applicate these results on patients with pathological conditions of the venous system. Future studies on the triggering detection site and time of venous pathology, such as venous thrombosis should be done.

## CONCLUSION

In conclusion, venous triggering contrast enhanced MR venography provides high-quality images of the intracranial venous structures superior to that of arterial triggering contrast-enhanced MR venography. Further studies are required to determine the utility of the technique in neurovascular diseases such as dural venous sinus thrombosis.

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# 조영 증강 자기공명정맥 촬영술에서의 동맥과 정맥 triggering 방법의 비교

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**장민지 · 최현석 · 정소령 · 안국진 · 김범수**

**목적**: 뇌내 정맥혈관을 평가하기 위한 조영 증강 자기공명 정맥촬영술의 arterial trigger 와 venous trigger 방법으로 시행한 영상의 차이점을 비교 분석하고자 한다.

**대상과 방법**: 건강검진을 목적으로 자기공명정맥촬영술을 시행한 41명의 환자들을 대상으로 해면부위의 내경 동맥에서 arterial triggering하여 6초 후에 얻은 영상 (n = 20) 과 상시상 정맥동에서 venous triggering (n = 21) 방법으로 시행한 영상을 후향적으로 분석하였다. 영상은 가돌리늄 조영제 (Magnevist®, Schering, Germany) 를 0.1 mmol/kg 정맥주입하여 시행하였고, 두개강 전반에 대하여 시상영상을 fast spoiled gradiend echo sequence로 시행하였다 (TR/TE 5.2/1.5, matrix 310×310, 절편수 124 절편, 두께 15 cm). 두 그룹의 영상을 해부학적 정맥 혈관 구조에 따라 17 정맥구역에 대하여 평가하였고, 정맥의 영상품질은 세 단계 (안보임, 일부 보임, 완전히 보임)로 나눠서 평가하였다.

**결과**: 정맥이 완전히 보인 구역은 arterial triggering 자기공명 정맥 촬영술에서 84% (272/323), venous triggering 자기 공명 정맥촬영술에서 91% (310/340) 이다. Venous triggering 자기공명촬영술과 arterial 자기 공명 정맥촬영술을 비교하였을 때 뇌내 정맥 구조를 평가하는데 있어 venous triggering 방법이 통계적으로 유의하게 높았다 (Fisher exact test, $p<0.006$).

**결론**: 조영 증강 자기공명 정맥 촬영술은 정맥 혈관 구조에 대한 고화질의 이미지를 제공하였고 arterial triggering 방법보다 venous triggering 방법이 뇌내 정맥 구조 평가에 우월한 것으로 나타났다.

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