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Evaluation of CSF Motion in Syringomyelia with Spatial Modulation of Magnetization (SPAMM)

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CSF flow dynamics has been known to have a key role the pathogenesis of syringomyelia. Our purpose was to evaluate the CSF flow pattern in syringomyelia with spatial modulation of magnetization (SPAMM) that can depict directional flow, and to determine the relationship between flow dynamics and clinical outcome after decompress surgery. We performed pre- and post-operative MRI in 9 patients with syringomyelia with SPAMM technique. They showed caudal shift of tagging bands in the syrinx cavity in systolic phase while stagnation of CSF flow was seen in diastolic phase. The degree of band shift in syrinx was well correlated with the degree of shrinkage in size of syrinx after operation. Evaluation of syringomyelia by SPAMM technique can predict postsurgical outcome after decompress surgery.

Key Words: Spinal cord, MR, spinal cord, abnormalities, magnetic resonance (MR), technology

INTRODUCTION

Syringomyelia is a clinical result from various etiologies including Chiari I malformation, post-traumatic and post-meningitic sequalae. It had been proposed that discrepancy between intracranial and spinal canal pressure contribute in developing syringomyelia.[1,2] Obstruction of CSF pathway in any portion may result in formation of syrinx cavity regardless of the causes.[3] There are various maneuvers in treatment of syringomyelia. They include foramen magnum decompression in Chiari malformation, and syringo-subarachnoid or syringo-peritoneal shunt for other causes of syringomyelia. Recent study showed that the measurement of CSF flow might assist in the evaluation of the efficacy of surgery.[4]

In disease process of altered CSF hydrodynamics, such as outflow obstruction of CSF pathway or spinal canal stenosis, understanding of CSF flow is important in the diagnosis and treatment plan.[5,6] Although cisternography and ventriculography using radioisotopes or radiopaque contrasts have played important roles in the evaluation of CSF flow, they had some limitations in quantification of CSF flow. Spatial modulation of magnetization (SPAMM) technique has been widely applied in evaluation of motion structures such as moving blood or cardiac motion.[7,8] SPAMM technique has advantages in evaluating exact flow velocity as well as anatomical landmarks. In the case of bi-directional movement such as spinal canal, SPAMM may be more powerful in quantification of the flow than other techniques. The purpose of our study was to evaluate the flow pattern in syringomyelia cavity using SPAMM technique and tried to establish the relationship between the motion of CSF in syrinx and causes of syringomyelia.

MATERIALS AND METHODS

From November 1996 to May 2000, we studied nine patients referred to our institute diagnosed as syringomyelia. Materials included 5 patients with Chiari malformation and two post-meningitis syringomyelia and two post-traumatic syringo-

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hydromyelia. They were five males and four female patients with mean age of 31.4 (range 23 - 47 years). Patients with Chiari malformation underwent posterior fossa decompress surgery and the other 4 patients underwent shunt operation. All procedures were performed under the guidance of the institutional board for clinical studies. All patients were aware of the risk of their examination and we got informed consent from all participants.

Preoperative and 2 month postoperative MRI were taken and all patients were followed up on out patient department at least 1 year. SPAMM study was performed with 1.5T superconducting unit (Vision, Siemens Medical Systems, Erlangen, Germany) with CP-spine-array coil. ECG triggered multiphase images were obtained with parameters of TR/TE/TD/FA=42 ms/7.2 ms/0-600 ms/20°. 128 × 256 matrix size, 6 mm slice thickness, 250 mm FOV and 10 mm saturation thickness were used. A tagging RF pulse was applied after the trigger pulse to produce a stripe pattern in the object. A series of fast gradient echoes followed. The number of gradient echo measurements could be adjusted by the number of phases similar to a standard cine type technique. The application of the subsequent gradient echoes was defined by the pulse repetition time (TR) as shown in the diagram (Fig. 1). Sixteen phase images were obtained between every R-R interval. Conventional MR images were used for evaluation of change in size and characters of primary lesion. Two radiologists (S-K. L., T-S. C.) analyzed the existence and direction of band shift in each of pre- and post-operative images. Relationship between syrinx fluid movement and change in size or symptom improvement was analyzed.

RESULTS

Case summary of 9 patients with syringomyelia is described in Table 1. Two types of surgical intervention were done. CSF in subarachnoid space showed to and fro movement according to the cardiac cycle in normal volunteer (Fig. 2). All patients with Chiari I malformation showed band shift of various degrees in syrinx fluid as well as CSF space of which syrinx size decreased and symptom improvement was accomplished after decompression surgery. T2 weighted sagittal images of spine showed decrease in width and extent of syrinx. The degree of band shift also decreased as the size diminished while movement of CSF in subarachnoid space remained as same as initial study (Fig. 3).

Post-meningitic (Case 6, 7) and post-traumatic patients (Case 8, 9) did not present pulsatile movement of syrinx. They also showed decreased CSF movement in subarachnoid space (Fig. 4). One of 2 patients with post-traumatic syringomyelia showed minimal decrease in syrinx size but all of them did not show relief of their symptoms. Two post-meningitic patients (Case 6, 7) showed no interval change of syrinx size and symptoms.

DISCUSSION

The pathophysiology of syringomyelia is still unclear but two different mechanisms are proposed. Briefly, one theory suggests impaired outflow of spinal fluid to CSF space at the level of 4th ventricle and the role of systolic pulsation that transmitted to syrinx cavity as a generation

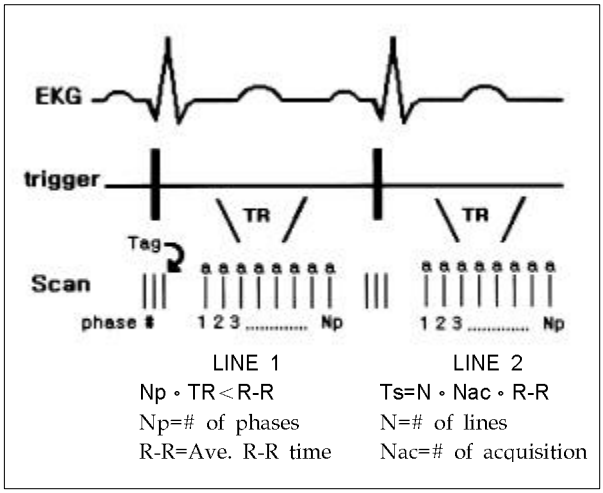

Fig. 1. Pulse diagram of spatial modulation of magnetization. A tagging RF pulse is used immediately after the trigger pulse, and this pattern was followed by a series of fast gradient echo sequences. The number of gradient echo measurements is adjusted according to the number of phases.

Table 1. Case Summary of 9 Patients with Syringomyeli

	Sex/Age	Preop Sx	Diagnosis	Location	Surgery	Fluid motion in Preoperative MRI		Postop Sx	Postoperative MRI
						Subarachnoid space	Syrinx Cavity		
1	F/47	Both arm weakness, sensory change	Chiari I malformation	Cervicothoracic	FMD*	To and fro movement,,	Caudal movement	Improved	Decreased syrinx cavity
2	F/25	Quadriparesis, sensory change	Chiari I malformation	Cervicothoracic, multiseptated	FMD	To and fro movement	Caudal movement in each syringes	Improved	Decreased syrinx cavity
3	M/23	Both arm weakness	Chiari I malformation	Cervicothoracic	FMD	To and fro movement	Caudal movement	Improved	Complete resolution of syringomyelia
4	F/28	Right side sensory change, dullness	Chiari I malformation	Holocord	FMD	To and fro movement	Caudal movement	Improved	Decreased syrinx cavity
5	F/33	Quadriparesis, sensory change	Chiari I malformation	Holocord, multiseptated	FMD	To and fro movement	Caudal movement	Improved	Decreased syrinx cavity
6	M/35	Posterior neck pain, weakness of both lower extremities	Thoracic spine fracture (T12)	Thoracic	Syringo-peritoneal shunt	Minimal movement	None	Not improved	No change of syrinx
7	M/36	Quadriplegia	Thoracic spine fracture (T4 and T4)	Cervicothoracic	Syringo-peritoneal shunt	None	None	Not improved	Minimal decrease in size of syrinx
8	M/23	Quadriparesis	Meningitis, 8 years ago	Cervicothoracic	Syringo-peritoneal shunt	None	None	Not improved	No change of syrinx
9	M/33	Both lower extrimities weakness, left arm dullness	Meningitis, 12 years ago	Cervicothoracic	Syringo-peritoneal shunt	To and fro movement	None	Not improved	No change of syrinx

*Foramen magnum decompression.

Pulsatile movement of CSF in subarachnoid space, cranial direction in diastole and caudal direction in systole.

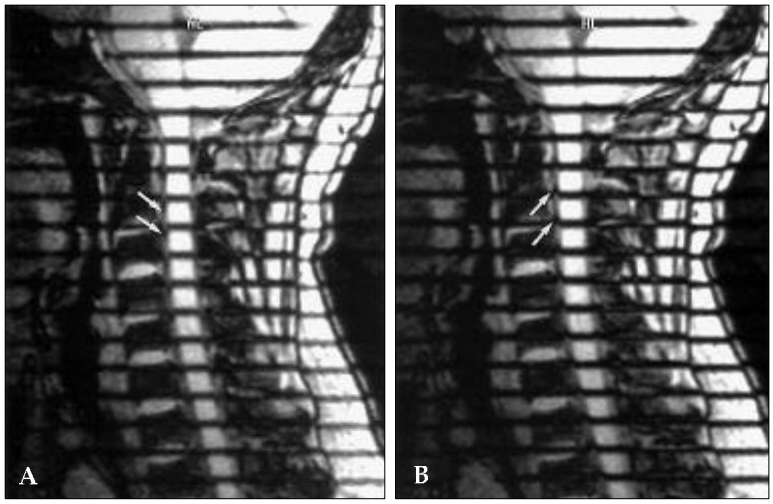

Fig. 2. Normal CSF motion in healthy volunteer. To-and-fro motion of CSF is demonstrated according to systolic (A) and diastolic (B) phases.

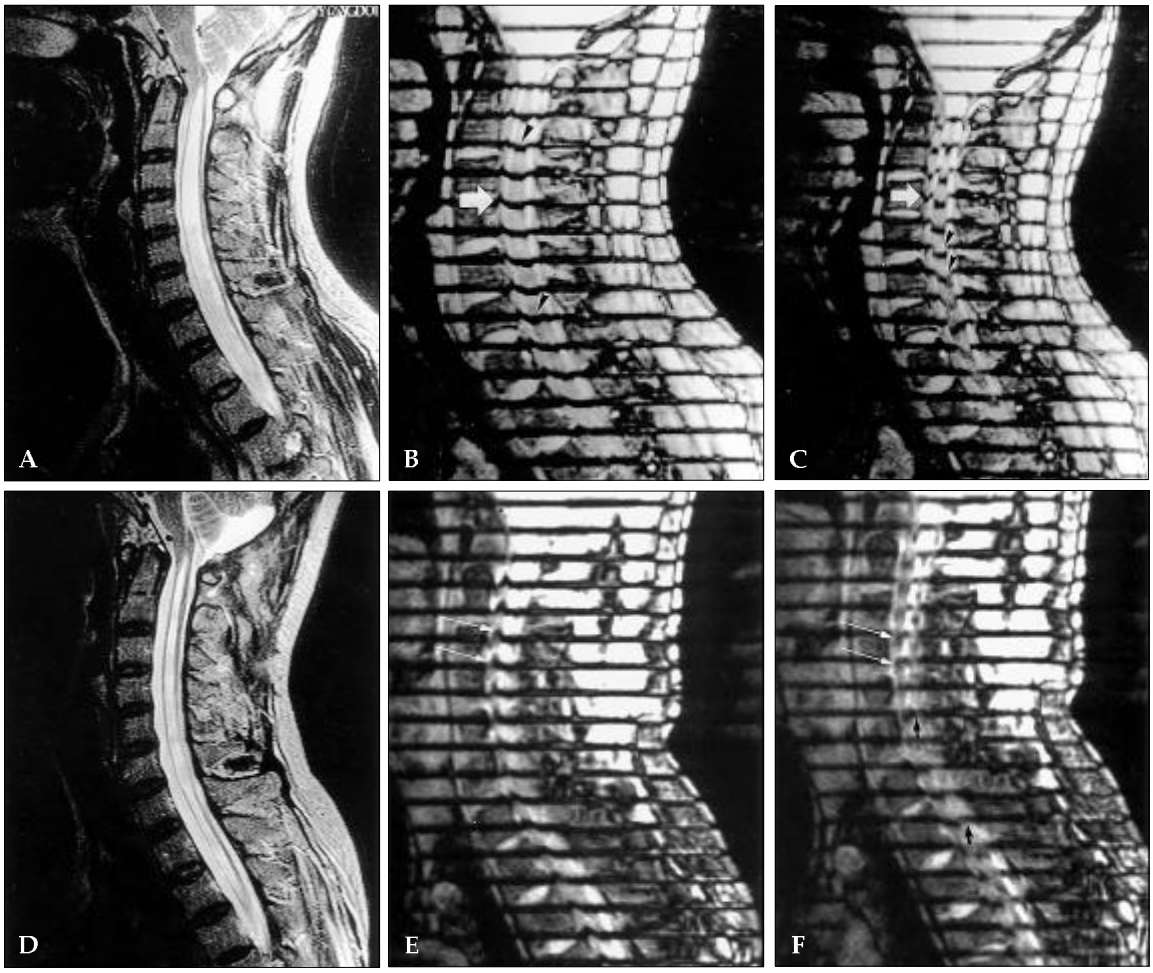

Fig. 3. Syringomyelia associated with Chiari malformation. Preoperative T2 weighted image shows syrinx in cervicothoracic level (A). Preoperative SPAMM images in diastole (B) and systole (C) depict pulsatile to-and-fro movement of CSF in subarachnoid space (thick arrow) with continuous caudal band shift of syrinx (arrowheads). Postoperative images show decrease in size of syrinx (D). Postoperative SPAMM images in diastole (E) and systole (F) demonstrate to-and-fro movement of CSF in subarachnoid space as well syrinx fluid (thin arrows). Note lesser degree band shift of syrinx fluid

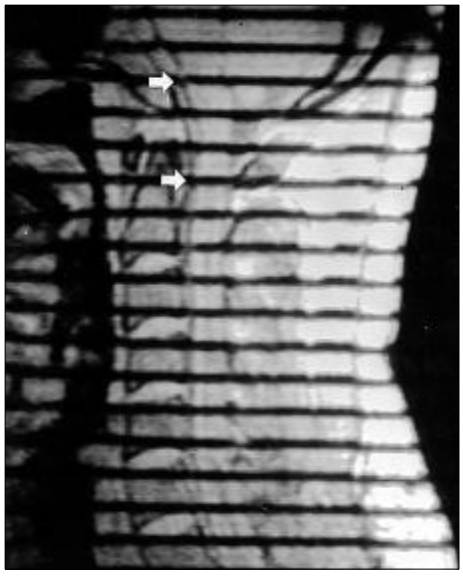

Fig. 4. Syringomyelia developed 12 years after meningitis. Note pulsatile motion of CSF in subarachnoid space without evidence of intrasyrinx fluid motion (arrows). This patient showed no improvement after shunt surgery.

factor for syringomyelia (water hammer effect).[1] Another theory proposes that increased intracranial venous pressure, as during coughing or other valsalva like maneuvers, cause cranio-spinal dissociation of pressure. As a result, together with partial obstruction at the level of foramen magnum, syringomyelia develops (sloshing mechanism).[2] Furthermore, in this situation, hindbrain anomalies encourage the movement of CSF into the spinal cord, which is another driving force to generate syringomyelia.

Various surgical approaches are used, such as direct drainage of syrinx fluid or decompression of outflow tract according to the type of syringomyelia. Recent strategy for surgical treatment of the syrinx cavity is well documented by some authors, although still controversial.[9] However, there has not been any available method to predict post-surgical outcome in syringomyelia.

Magnetic resonance imaging has been the most effective diagnostic approach in patients with syringomyelia because of its non-invasiveness and conspicuous ability to describe soft tissue structures. Imaging findings were well documented through various literatures. [10,11] With development of advanced MR technique, more detailed analysis of CSF flow became possible including pulsatile movement of CSF in spinal canal.[12] SPAMM technique was developed for evaluation of cardiac wall motion, moving blood or cerebrospinal fluid.[7,8] Pulsatile movement of hindbrain and motion of intra-syrinx fluid in syringomyelia patients associated with Chiari malformation was discussed by Terae and coworkers.[13] They found downward displacement of band stripe on cine-MRI of spinal canal with presaturation bolus tracking. They postulated that increased pulsatile movements of the spinal cord, together with the one-way valve mechanism at the level of CSF outflow obstruction, act as a "vacuum-pump" to extend the syrinx.

On present study, somewhat different characters of CSF flow were observed. Five patients with Arnold-Chiari malformation in our series showed similar pulsatile movement of CSF in subarachnoid space in the spinal canal, representing as band shift on SPAMM images. In diastolic phase, shift of band stripes was observed along cranial direction, while caudal direction band shift was seen in systolic phase, e.g. to-and-fro movement. But, in the syrinx cavity, intra-syrinx fluid showed continuous motion toward caudal direction during cardiac cycles. In diastole, lesser degree band shift was observed as compared with bigger one in systolic phase, all of which are downward displacement. To-and-fro movement, as known to be intra-syrinx pulsation, was not demonstrated as shown in Fig. 4.

As considered with these results and previous reports about one way valve mechanism, continuous unidirectional movement of intra-syrinx fluid does exist and play an important role in the pathogenesis and extension of syringomyelia.

In this study, four cases of post-traumatic and post-meningitic syringomyelia were included and three of them had no fluid motions and one had weak fluid motion within syrinx cavity. Generally, post-traumatic or post-meningitic syringomyelia does not communicate with 4th ventricle. If there exists fluid motion in the syrinx, we can suggest that pressure is transmitted from subarachnoid space via wall of spinal cord, especially upper portion of the spinal canal. Tobimatsu and colleagues[14] found that fluid motion also existed in post-traumatic syringomyelia and CSF flow had

relationship with severity of clinical symptom by use of cardiac-triggered phase images. Most patients of our series without hindbrain anomaly also complained various degree motor neuron symptoms but they did not show prominent intra-syrinx fluid movement as Chiari malformation. As compared with syrinx related with hindbrain anomaly, symptom improvement and shrinkage in size also did not occur. It means that the syrinx has no connection with CSF space as well as reduced wall capacity to remodeling after surgery. As a result, decompression maneuver has little role in shrinkage of the syrinx. Moreover, adhesion or decreased CSF movement of spinal CSF space seems to have another role that leads reduced ability to shrinkage of syrinx. In other words, the presence of pulsatile motion in syrinx suggests transmission of intracranial pressure not only through channel between 4^{th} ventricle and syrinx but also via the wall of spinal cord. Spinal cord wall with a capacity to transmit pressure gradient to syrinx is an indirect evidence of wall redundancy and capability of shrinkage or remodeling after decompression. Recently, many techniques including phase contrast velocity imaging and bolus tracking method were used in evaluation of syringomyelia.[15,16] SPAMM, in contrast to other techniques, can provide more detailed and apparent visual data of CSF motion and direction of the flow within spinal canal.

In conclusion, preoperative evaluation of syringomyelia with SPAMM technique can distinguish syrinx type and provide prognostic value. Band shift of syrinx fluid on SPAMM images can be a direct sign of syringomyelia with hindbrain anomaly and favorable prognosis. We also speculate that continuous movement of intra-syrinx fluid during cardiac cycle can be considered as another factors for developing and extending syringomyelia.

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