Determination of the Thecal Sac Ending Using Magnetic Resonance Imaging: Clinical Applications in Craniospinal Irradiation

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Purpose : *To determine level of the thecal sac ending in unaffected individuals of young age-group and in patients with cerebrospinal fluid (CSF) seeding tumor using Magnetic Resonance Imaging (MRI).*
Material and Method : *MRI of the lumbosacral spine of 253 cases (age range 1-40 years) had been reviewed. Of these, 20 cases were known having CSF seeding tumors. Two hundred and thirty-three cases of unaffected individuals were used as control group. Sagittal MR images were used to determine the level of thecal sac ending by referencing on the corresponding vertebral body and intervertebral disc.*
Results : *The range of the thecal sac ending level in unaffected population varied from the lower one-third of L5 to the middle one-third of S3. About 97% of cases, the distal end of thecal sac terminated at the S2-3 intervertebral disc space or higher. In patients with CSF seeding tumor, the range of thecal sac ending was from the middle one-third of L5 to the S2-3 intervertebral disc space. There was no statistically significant difference of thecal ending level between unaffected group and patients with CSF seeding tumors (p=0.19).*
Conclusion : *Placing inferior border of radiation field at the middle one-third of S3 vertebra would help to cover the entire subarachnoid space in all cases. Without MR machine, this study may be used as a general guideline for placing the inferior border for spinal irradiation.*

Keywords : *Thecal sac, Magnetic resonance imaging, Craniospinal irradiation*

J Med Assoc Thai 2004; 87(11): 1368-73
Full text. e-Journal: *http://www.medassocthai.org/journal*

Generally, the mean level of ending or termination of the thecal sac, which has been described in the standard textbook and some cadaveric studies, locates at the second sacral vertebral level[1-3]. However, there are variations of the level of the thecal sac ending i.e. it may extend caudally than the S2 level[3,4]. The radiotherapists who have to place the portal fields for craniospinal irradiation (CSI) need to know the level of the thecal sac ending to cover the entire subarachnoid space for treatment of cerebrospinal fluid (CSF) seeding or leptomeningeal metastases.

Myelography, which is an invasive technique, has been used to determine the distal extent of the thecal sac in the past[5]. Recently developed Magnetic Resonance Imaging (MRI), which is non-invasive, becomes the study of choice for spine and spinal cord studies [6]. Unfortunately, the MRI machine is not widely available and has not been used to define the caudal end of the thecal sac in patients who undergo CSI. The present study aimed to determine the thecal sac ending level in unaffected individuals of a young age-group and in patients with CSF seeding tumor using MRI, which would be helpful for estimating the proper inferior border of the spinal irradiation filed.

Material and Method

Three hundred and seventy-one consecutive patients whose age ranged from 1 to 40 years, underwent MRI studies of the whole spine or lumbosacral region from January 1994 to December 1998 at Ramathibodi Hospital. One hundred and eighteen patients

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were excluded due to abnormalities detected which affected the thecal sac besides from CSF seeding tumor; or incomplete medical records. There were 253 patients evaluated in this study, 233 patients were classified as an unaffected population, and 20 patients were a group of patient who had CSF seeding tumor. The unaffected population included 115 male and 118 female with median age of 32 years old. In group of CSF seeding tumor, the median age was 14 years old.

All MR studies were performed using the GE Signa 1.5 Tesla MR machine (General Electric Medical System [GEMS]; Milwaukee, WI, USA). Sagittal spin echo T1-weighted images were acquired at a repetition time (TR) of 400-600 ms and an echo time (TE) of 17 ms with an imaging matrix of 512 x 256, four excitations per acquisition (NEX), and a field of view (FOV) of 32 cm. Each image was scanned with 4 mm slice thickness and 1 mm slice gap. The authors used the image that showed the most inferior convergence point of the thecal sac for measurement. Additional image planes with or without gadolinium enhancement were reviewed when needed for clarification[7]. All images were reviewed from magnet tapes at the MR imaging console in a low-light environment.

The thecal sac ending was accepted as the most caudal point of the thecal sac that could be visualized on the sagittal images. A horizontal line was drawn from the point of the convergence of dural margin to the posterior margin of the corresponding vertebrae in three separated segments i.e. upper, middle, and lower one-third segments; and intervertebral space was considered as a separate segment (Fig. 1). The lowest vertebral body above the sacrum separated with a complete lower intervertebral disc space was designated as the fifth lumbar vertebra. These measurements were performed under consensus of two radiologists. The study was approved by the institutional ethical committee.

The mean $\pm$ SD and median value of the caudal level for each sex and group of patients were obtained. The statistical analysis was performed using a personal computer with STATA 8.0 (StataCorp, College Station, TX, USA). The Fisher's exact test was performed. The p-value for significance was set at 0.05.

Results

Level of thecal sac ending in unaffected population

The levels of termination of the unaffected thecal sacs are shown in Table 1. The range of the thecal sac ending level varied from the lower one-third of L5 to the middle one-third of S3. The median level

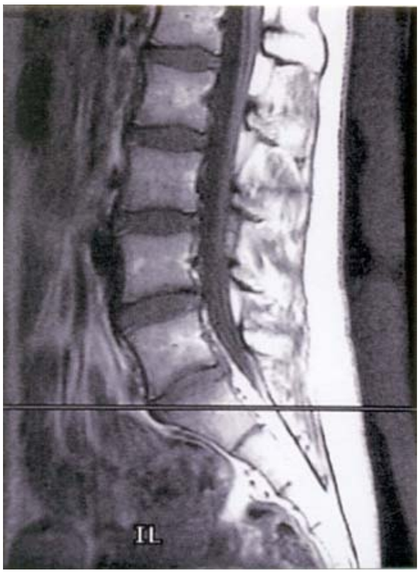

Fig. 1 Sagittal T1W image zoom at thecal sac ending level demonstrated measurement technique by drawing a perpendicular line from point of dural convergence to the corresponding vertebra

for thecal sac ending was at the S1-2 interspace. The most frequent level of thecal sac ending was at the middle one-third of S2. In about 97% of cases, the thecal sac terminated at the S2-3 interspace or higher. There was no termination below the S3 vertebra. The median level of the thecal sac ending was also at the S1-2 interspace in both males and females. The median level and lowest level for thecal sac ending in each age group are shown in Table 2.

Table 1. Frequency distribution of the level of thecal sac ending as determined by MR imaging

Thecal sac ending levels	Number	%
L5		
Lower	2	0.86
L5-S1	13	5.58
S1		
Upper	23	9.87
Middle	19	8.15
Lower	22	9.44
S1-2	43	18.45
S2		
Upper	27	11.59
Middle	46	19.74
Lower	21	9.01
S2-3	10	4.29
S3		
Upper	3	1.29
Middle	4	1.72
Total	233	100

Table 2. Level of thecal sac ending in each age group

Age (year)	Thecal sac ending level	
	Lowest	Median
1 - 10	Middle S3	Middle S2
11 - 20	Upper S3	Upper S2
21 - 30	S2-3	Upper S2
31 - 40	Middle S3	S1-2

Table 3. Level of thecal sac ending in each patient with CSF seeding tumor (n = 20)

Primary tumor	Age (year)	Level	MRI	CSF cyto-logy	Radiation Portal (Inferior border)
Astrocytoma, malignant	20	L, S1	+	-	L, S2
Ependymoma	5	M, S2	-	-	-
Ependymoma, malignant	3	L, S1	-	-	-
Ependymoma, malignant	4	L, S2	+	-	-
Ependymoma	6	U, S2	-	-	-
Germinoma	15	M, S2	+	-	U, S3
Germinoma	18	S2-3	-	+	-
Leptomeningeal metastasis, undifferentiated carcinoma	36	U, S1	+	+	-
Leptomeningeal metastasis, adenocarcinoma	39	S1-2	+	+	-
Leptomeningeal metastasis, breast carcinoma	39	L, S2	+	-	-
Neuroblastoma	11	M, L5	-	+	-
PNET	11	L5-S1	-	-	-
PNET	11	M, S2	-	-	-
PNET	13	M, S2	+	-	S2
PNET	18	U, S2	+	-	S3
PNET	26	U, S2	-	-	-
Pinealoblastoma	11	L5-S1	-	-	S2
Pineal tumor	19	U, S1	-	-	-
Pineal tumor	14	M, S1	-	-	-
Schwannoma, malignant	23	L5-S1	+	+	-

U, M, and L: Upper, middle, and lower one-thirds of vertebra, respectively
PNET: Primitive neuroectodermal tumor

Level of thecal sac ending in cases with CSF seeding tumor (Table 3)

Twenty patients with known CSF seeding tumors, which included 5 medulloblastoma, 4 ependymoma, 3 pineal region tumor, 2 germinoma, and one each of malignant astrocytoma, malignant schwannoma, metastatic neuroblastoma, leptomeningeal metastatic breast carcinoma, undifferentiated carcinoma, and adenocarcinoma. Among these, 9 patients had evidence of CSF or drop metastases shown by MRI. Meanwhile, MRI showed negative results in 2 patients, but malignant cells were found in CSF cytology. The thecal sac ending ranged from the middle one-third of L5 to the S2-3 interspace and the median level was at the S1-2 interspace. There was no statistically significant difference of thecal ending level between unaffected group and patients with CSF seeding tumors ($p = 0.19$).

Discussion

Validity of the method

MRI was chosen to determine the level of the thecal sac ending in the present study because this modality demonstrates detailed anatomy and detects and characterizes abnormalities of the spine and spinal cord better than myelography, as well as being considered as a non-invasive technique[6-8]. There is also no radiation and almost no risk of contrast media reaction. The distal end of the thecal sac can easily be localized and determine which corresponded to the vertebral bony landmark. However, there is a limitation of sagittal MRI of the lumbosacral spine to determine the exact level of the vertebral column in cases in which a transitional lumbosacral vertebra presents. Using whole spine localizer scans, careful inspection for a well-formed disc extending for the whole AP diameter of the sacrum, and observation of an abnormal upper outline have been reported to be helpful to identify transitional lumbosacral vertebral variations and vertebral segments[9,10].

The present study limited the population age to not more than 40 years old, which was different from those cadaveric and myelographic studies. The reason was that a higher incidence of advanced degenerative disc and spine, and associated perithecal fibrosis may effect the thecal sac[3,5,11,12]. A study by Evison et al stated that osteoporosis of the surrounding bones and a loss of tension of elasticity in supporting ligaments with increasing age may affect the thecal sac[13]. However, the study from Scharf et al in a younger population age ranged from 31 months to 18 years found that there was no association between thecal sac termination and age, gender, or the disease affected[14]. This result was similar to findings in the present study. In addition, most of the CSF seeding tumors e.g. medulloblastoma, ependymoma, and germ cell tumor occur before the age of 40 and they are frequently treated with craniospinal irradiation, which was the most concerned issue in the present study[15].

Level of thecal sac ending

In the present study, the level of the thecal sac ending in unaffected subjects ranged from the lower one-third of L5 to the middle one-third of S3, which was relatively narrower in range than that previously reported(4,5,13). The lowest ending of the thecal sac found in the present study was higher than in previous studies, which reported it at the S3-4 interspace, S4 body, or S4-5 interspace. Importantly, there was no statistically significant difference of thecal ending level between the unaffected group and patients with CSF seeding tumors. This information might be applied for therapeutic portal field planning in craniospinal irradiation.

In cases of CSF seeding tumors such as medulloblastoma(15-17), the craniospinal irradiation was one of the treatments of choice to control the primary tumor and disseminated disease. Radiation technique, especially the placement of the caudal end of the CSI field has a significant impact on the treatment outcome and pattern of failure(18,19). Therefore, the defining level of the thecal sac ending in these cases is important. Generally, the inferior border of the spinal field has been placed at the inferior edge of the S2 vertebra, which could cover the subarachnoid space in most cases according to the present results. Previous studies, however, reported that 8.7-33.0% of cases have the thecal sac ending below the S2-3 interspaces(14,20). In comparison to the present study, the lowest level of the thecal sac ending was even lower at the middle segment of S3. The present results also showed that the uppermost ending of the thecal sac was at the middle one-third of L5. In this circumstance, one should be concerned in routinely placing the lower border of spinal irradiation at S2, in which unnecessary treatment may occur i.e. a scattered radiation dose to the surrounding organs especially the ovaries or testes(21-23). Individualized evaluation using the MRI will provide accurate treatment planning under the condition that an mr machine must be available. Contrary, if MR study of the spine particular lumbrosacral region is not available, placing the lower border of spinal irradiation at S2 might not be able to cover the whole thecal sac in some cases. According to the present result, placing the lower border of the radiation port at the middle one-third of S3 would cover the inferior margin of the thecal sac in all cases.

Even if there is no statistical significance, the difference of the thecal sac ending in patients with CSF seeding tumors compared to the unaffected population in the present study or previous reports may correlate with the presence of the disseminated disease or post radiation effect. The effect of the spinal irradiation to the thecal sac ending has been reported, which is minimally cranial or caudal relocated, in the scale less than 1 cm from the pre-treatment ending level(14). A study of five patients showed evidence of caudal extension of the thecal sac ending by one-third to one-half of a vertebral segment, possibly due to dural expansion by the intradural tumor, which usually shows a gross tumor mass(24). To confirm this issue, a higher number of CSF seeding tumor patients is needed.

There were major limitations in the present study. It was a retrospective study. The unaffected populations, represented as normal in the present study, were not truly “normal” individuals. There must be an indication for performing an mr study of the spine. However, the authors already excluded one-third of the cases that clearly showed an abnormality affecting the thecal sac. It was almost impossible to perform MR study in hundreds of a “normal” population with cost-effectiveness. The small number of CSF seeding tumor cases was also another limitation. Some also had not documented CSF metastasis. The present study did not reveal how far the lateral extension of the dural root sleeves was, which is also important for placing lateral margin of spinal irradiation. To answer this question, a specific plane of MR, i.e. oblique coronal, is needed, which could not be achieved by the present retrospective study. Although there were limitations, the authors believed that the present results could be used as a general guideline for placing the inferior border for the spinal irradiation. The authors would recommend individualized evaluation by using MRI for a baseline study and treatment planning if an MR machine is available. If not, placing the inferior border of the radiation field at the middle one-third of S3 vertebra would help to cover the entire subarachnoid space in all cases.

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การศึกษาตำแหน่งต่ำสุดของถุงน้ำไขสันหลังจากภาพการตรวจคลื่นแม่เหล็กไฟฟ้าเพื่อประยุกต์ใช้ในการวางแผนการรักษาด้วยวิธี craniospinal irradiation

สิทธิ์ พงษ์กิจการุณ, สุภนีวรรณ เชาว์วิศิษฐ, มัณฑนา ธนะไชย

ได้รวบรวมภาพการตรวจคลื่นแม่เหล็กไฟฟ้าและข้อมูลทางคลินิกในกลุ่มผู้ป่วยในโรงพยาบาลรามาธิบดี จำนวนทั้งสิ้น 253 ราย โดยแบ่งเป็น 233 รายที่ไม่พบความผิดปกติของกระดูกสันหลังและ 20 รายที่มีโรคมะเร็งที่สามารถกระจายทางน้ำไขสันหลัง ซึ่งจุดต่ำสุดของถุงน้ำไขสันหลังหาได้จากภาพถ่ายระนาบแบ่งซ้ายขวา (Sagittal plane) โดยเปรียบเทียบกับระดับของกระดูกสันหลัง

ผลการศึกษาในกลุ่มไม่พบความผิดปกติของกระดูกสันหลัง พบว่าตำแหน่งต่ำสุดของถุงน้ำไขสันหลังอยู่ในช่วงกระดูกสันหลังส่วนเอวที่ 5 (L_5) ถึง กระดูกสันหลังส่วนก้นกบที่ 3 (S_3) โดยร้อยละ 97 พบจุดต่ำสุดอยู่ไม่ต่ำไปกว่าระดับหมอนรองกระดูกส่วนก้นกบที่ 2 และ 3 (S_{2-3}) สำหรับในกลุ่มที่มีโรคมะเร็งที่สามารถกระจายทางน้ำไขสันหลัง พบจุดต่ำสุดอยู่ในช่วงกระดูกสันหลังส่วนเอวที่ 5 (L_5) ถึง ระดับหมอนรองกระดูกส่วนก้นกบที่ 2 และ 3 (S_{2-3}) ผลวิเคราะห์เปรียบเทียบตำแหน่งต่ำสุดของถุงน้ำไขสันหลังระหว่างทั้งสองกลุ่ม ไม่พบความแตกต่างทางสถิติอย่างมีนัยสำคัญ โดยสรุป การกำหนดขอบล่างของการฉายรังสีวิธี craniospinal ไว้ที่ระดับกระดูกสันหลังส่วนก้นกบที่ 3 จะสามารถครอบคลุมตำแหน่งต่ำสุดของถุงน้ำไขสันหลังได้ทุกราย ซึ่งจะช่วยในการวางแผนการฉายรังสีในที่ที่ไม่มีเครื่องตรวจคลื่นแม่เหล็กไฟฟ้า