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Distance from Dura Mater to Spinal Cord at Thoracic Vertebral Level: Implications for Safe Thoracic Epidural Analgesia

흉부 척추에서 경막-척수 사이 거리에 관한 고찰

2013년 2월

서울대학교 대학원
의학과 마취통증의학 전공
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2013

Park Jin Woo

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Distance from Dura Mater to Spinal Cord at Thoracic Vertebral Level: Implications for Safe Thoracic Epidural Analagesia

지도 교수 허 진

이 논문을 의학석사 학위논문으로 제출함
2012년 10월

서울대학교 대학원
의학과 마취통증의학전공
박 진 우

박진우의 의학석사 학위논문을 인준함
2012년 12월

위 원 장 ______________________ (인)
부위원장 ______________________ (인)
위 원 ______________________ (인)

Distance from Dura Mater to Spinal Cord at Thoracic Vertebral Level: Implications for Safe Thoracic Epidural Analagesia

by
Park Jin Woo

A thesis submitted to the Department of Medicine in partial fulfillment of the requirements for the Degree of Master of Science in Meidicine (Anesthesiology and Pain Medicine) at Seoul National University College of Medicine

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Approved by Thesis Committee:

Professor ____________________Chairman
Professor ____________________Vice chairman
Professor ____________________

Abstract

Distance from Dura Mater to Spinal Cord at Thoracic Vertebral Level: Implications for Safe Thoracic Epidural Analgesia

Introduction: Neurologic complications related to thoracic epidural analgesia are rare but devastating. It is important to understand the anatomy of the spinal canal to minimize the risk of needle-related neurologic injury.

Methods: We retrospectively investigated T2-weighted spine magnetic resonance images of 346 patients. The vertical distance from the dura mater to the spinal cord (DTC) at all thoracic intervertebral levels was examined. The DTC and distance from the skin to the dura mater (STD) were evaluated at three different thoracic intervertebral levels (T1/2, T5/6, and T10/11) using three different pathways: the "U," "L," and "M" lines. The "U" and "L" lines contacted the upper and lower borders of the interspinous space, respectively. The line "M" represented a blind approach, passing the midpoint of two spinous process tips and the point bisecting the ligamentum flavum at each interspinous space.

Results: The vertical DTC was longest at the T5/6 intervertebral level and shortest at the T11/12 level. The vertical DTC was positively correlated with height ($p = 0.013$) and negatively correlated with age ($p < 0.001$). The "U" line was more horizontal than the "L" line at the upper and middle thoracic regions, but the relationship was reversed at the lower thoracic level. Among the three lines, the STD and DTC were longest on the “L” line at the T1/2 and T5/6 intervertebral levels. The distances were the longest on the “U” line at the T10/11 level. The angle between the “U” and “L” lines was largest at the T1/2 level and the difference in DTC between the “U” and “L” lines was greatest at T5/6. The STD on the “M” line was longer in males than in females ($p < 0.001$) and was positively correlated with height ($p = 0.016$) and weight ($p < 0.001$). The DTC on the “M” line was also longer in males than in females ($p = 0.037$) and shortened with age ($p = 0.001$).

Conclusions: Differences in the DTC were observed among thoracic intervertebral levels, mainly due to cervical and lumbar enlargement of the spinal cord. Among the three approaching lines, the dimensions implying a safety margin were longest on the “L” line at T1/2 and T5/6, and longest on the “U” line at T10/11. The variability of the safety margin according to the angle of needle insertion was largest at T5/6, and the angle between the upper and lower borders of the interspinous space was largest in the upper thoracic region.

Key words: thoracic epidural analgesia, distance from the dura mater to the spinal cord, interspinous space
Student Number: 2011-21841

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1. Introduction

Thoracic epidural analgesia (TEA) has been used to treat acute pain after thoracic and abdominal surgery.(1, 2) Although rare, neurological complications related to epidural analgesia can be devastating.(3) Thus, it is important to understand the anatomy of the spinal canal to prevent needle-related neurological injury to the spinal cord.

The most common method used to identify the epidural space is “loss of resistance” (LOR) to either air or fluid technique.(4) However, LOR is a blind technique, so the distance from the dura mater to the spinal cord (DTC) is a critical factor in neurological injury caused by needle trauma when a dura puncture occurs.(5, 6) The longer the DTC, the larger the safety margin.

The anatomical dimensions related to TEA, including the DTC, are not uniform at different vertebral levels; thus, it is necessary to investigate the difference in distance according to vertebral level to determine the target level and to choose a safe method of approach.

Several studies have investigated the DTC in the thoracic region and reported that the vertical distance was significantly greater in the middle thoracic region than at the upper and lower thoracic levels. However, these studies examined a relatively small number of patients and did not consider the angle at which the needle approached. Safety margins can change at the same vertical DTC by using different approach angles. Previous studies investigated the DTC at just three regions, not at all thoracic intervertebral levels.(7, 8)

In the present study, we retrospectively investigated the DTC at all thoracic segments by analyzing magnetic resonance images of 346 patients. The length from the skin to the dura mater (STD) and DTC at various approach angles from three different thoracic vertebral levels were also examined to understand the shape of the interspinous space and to develop safe approach strategies.

2. Methods

This retrospective study was performed after obtaining approval from the Institutional Review Board of Seoul National University Hospital (Seoul, Korea). A total of 870 patients underwent magnetic resonance imaging (MRI) of the thoracic vertebral segments from January to December 2010.

Patient selection

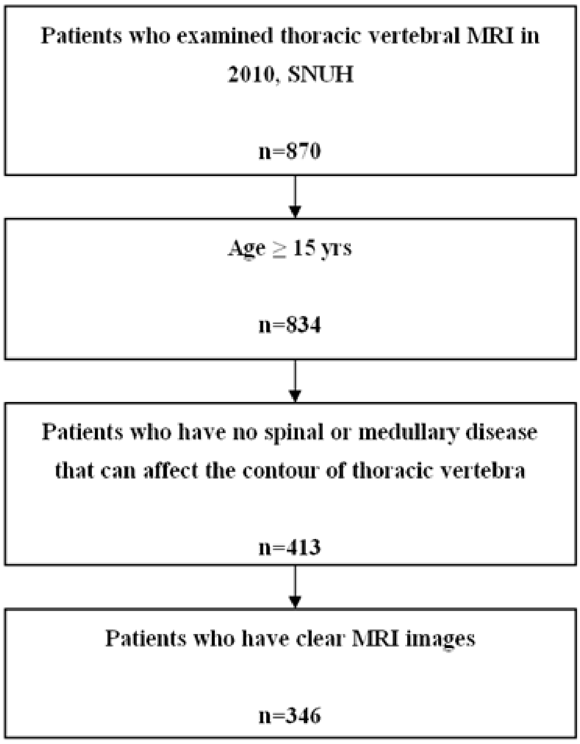

Fig 2.1. Flow chart of patient selection for image analysis

Based on an evaluation of magnetic resonance images by radiologists, patients who were diagnosed with thoracic spinal or medullary disease that could affect the contour of the spinal cord and epidural space (e.g., severe compression fracture, spinal cord tumor, or cerebrospinal fluid [CSF] seeding) were excluded. Patients whose anatomical dimensions were unclear due to poor-quality magnetic resonance images were also excluded. Patients < 15 years of age were also excluded; thus, 346 patients were enrolled (Fig. 2.1).

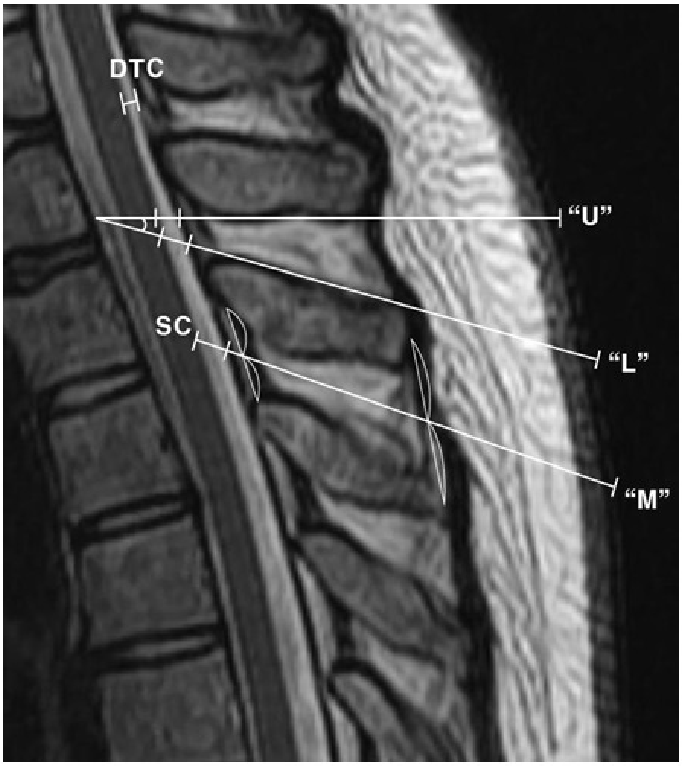

Fig 2.2. Dimensions on three approaching lines and the angle between the "U" and "L" lines on MRI
The line on the vertical DTC was estimated to be perpendicular to the spinal cord and dura mater at each level and started from the midpoint between two adjacent vertebral bodies. "U" line was the line contacting the upper border of the interspinous space and "L" line contacted the lower border of the interspinous space. "M" line passed the midpoint of two spinous process tips and the point that bisected the ligament flavum between the two spinous processes. SC = spinal cord, DTC = The Distance from dura mater to spincal cord

Study protocol and data collection

T2-weighted magnetic resonance spine images were acquired in the sagittal plane closest to the midline of the vertebral column using Picture Archiving and Communication System (PACS). The most appropriate plane was evaluated at each level and all dimensions are measured with Preview program (INFINITT, Seoul, South Korea).

The vertical DTC was measured at each thoracic intervertebral level. The line on the vertical DTC was estimated to be perpendicular to the spinal cord and dura mater at each level and started from the midpoint between two adjacent vertebral bodies (Fig. 2.2).

The STD and DTC were measured on three different approach pathways at upper (T1/2), middle (T5/6), and lower (T10/11) thoracic intervertebral levels. The first approach pathway was the “U” line. We defined the “U” line as the line contacting the lower border of the spinous process of the adjacent upper vertebra at the thoracic intervertebral level. The second was the “L” line, which contacted the upper border of the spinous process of the lower vertebra at the thoracic intervertebral space. Therefore, the “U” and “L” lines were the upper and lower borders of the interspinous space and were selected to evaluate the distinct outlines of the interspinous space at different thoracic regions and to demonstrate differences in the safety margin according to various approach angles.

The third was the “M” line, which passed the midpoint of two spinous process tips and the point that bisected the ligament flavum between the two spinous processes. The “M” line was supposed to represent a blind approach using the LOR technique. When performing epidural analgesia, a physician touches two tips of adjacent spinous processes over the skin and searches for the interspinous space. We selected the midpoint of two adjacent tips as a point on the “M” line. Using the blind technique, a needle can pass several courses in the interspinous space. We assumed that the point bisecting the ligamentum flavum between the two processes suggested the average of many possible courses, and chose that point as another mark on the “M” line.

We examined the angles between the “U” and “L” lines at the T1/2, T5/6, and T10/11 intervertebral levels to analyze the trend in the borders of the interspinous spaces and to evaluate variability in the approach angle at each intervertebral level (Fig. 2.2).

Statistical analysis

Data were analyzed using the SPSS software package (version 19.0; SPSS Inc., Chicago, IL, USA). Continuous variables are expressed as the mean ± standard deviation (SD) and were compared using paired *t*-tests. Multiple pairwise comparisons were made using the Bonferroni correction. A bivariate correlational analysis was performed to identify the relationship between the continuous variables and age, height, and weight. Student’s *t*-test was used to evaluate the differences in dimensions between males and females; $p < 0.05$ was considered significant.

3. Results

We analyzed the magnetic resonance images of 346 patients. Table 3.1 shows the demographic data. The intraclass correlation coefficient was calculated (> 0.9) to assess the reliability of all measurements.

Table 3.1. Patients Characteristics (n=346)

Characteristics	Value
Age	51.0 ± 17.2
Male : Female	177:169
Height (cm)	163.4 ± 8.9
Weight (kg)	59.9 ± 11.9
BMI	22.4 ± 3.7

Data are presented as either number of patients or as mean ± SD
BMI : body mass index (calculated as weight in kilograms divided by the square of height in meters)

The vertical DTC was longest at the T5/6 level and shortest at the T11/12 level (4.1 ± 1.4 and 2.5 ± 0.8 mm, respectively) (Fig. 3.1 and Table 3.2).

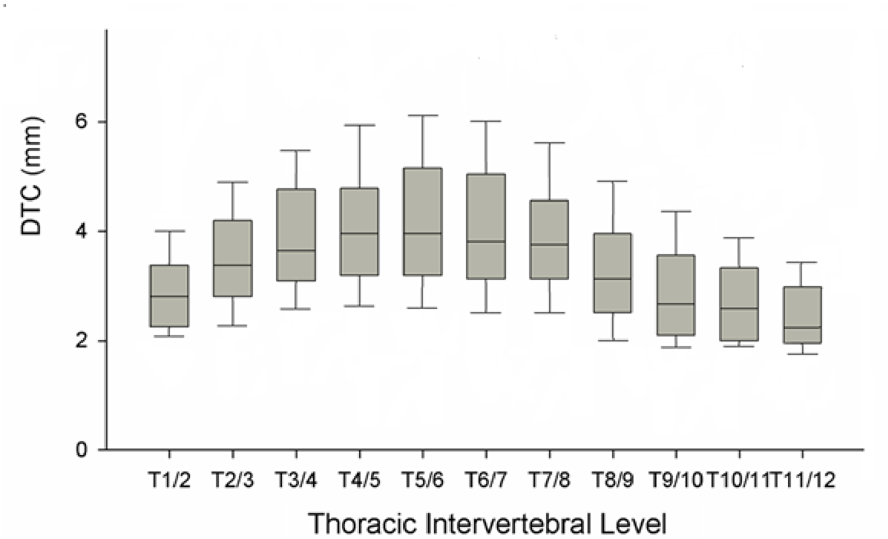

Fig 3.1. The vertical distance from the dura mater to the spinal cord (DTC) at each thoracic intervertebral level
Data are expressed as median (horizontal bar) with 25 to 75 percentiles (box) and 10 to 90 percentiles (whiskers) for each vertebral level.

A significant difference was observed for the DTC at all intervertebral levels compared with adjacent levels, indicating a significant difference in safety margin between adjacent thoracic levels. The vertical DTC at the T5/6 intervertebral level was positively correlated with height (r = 0.152, p = 0.013) and negatively correlated with age (r = -0.245, p = 0.000).

Table 3.2. Vertical DTC at Various Thoracic Intervertebral Levels†

Intervertebral level	DTC (mm)*
T1/2	2.9 ± 0.9
T2/3	3.5 ± 1.1
T3/4	3.8 ± 1.2
T4/5	4.1 ± 1.4
T5/6	4.2 ± 1.4
T6/7	4.1 ± 1.4
T7/8	3.8 ± 1.2
T8/9	3.3 ± 1.1
T9/10	2.9 ± 1.0
T10/11	2.8 ± 0.9
T11/12	2.5 ± 0.8

The data are presented as either number of patients or the mean ± SD
* There was a significant difference in DTC between adjacent levels (p<0.01)
† DTC : distance from the dura mater to the spinal cord

The STD and DTC on the “U,” “L,” and “M” lines were also the longest at T5/6. We assumed that the “M” line represented a blind approach, so the effects of patient characteristics on the “M” line dimensions were analyzed. The STD on the “M” line (STD [M]) was longer in males than in females (p < 0.001) and was correlated with height (r = 0.147, p = 0.016) and weight (r = 0.422, p < 0.001). The DTC on the “M” line (DTC [M]) was also longer in males than in females (p = 0.037) and was correlated only with age (r = -0.171, p = 0.001).

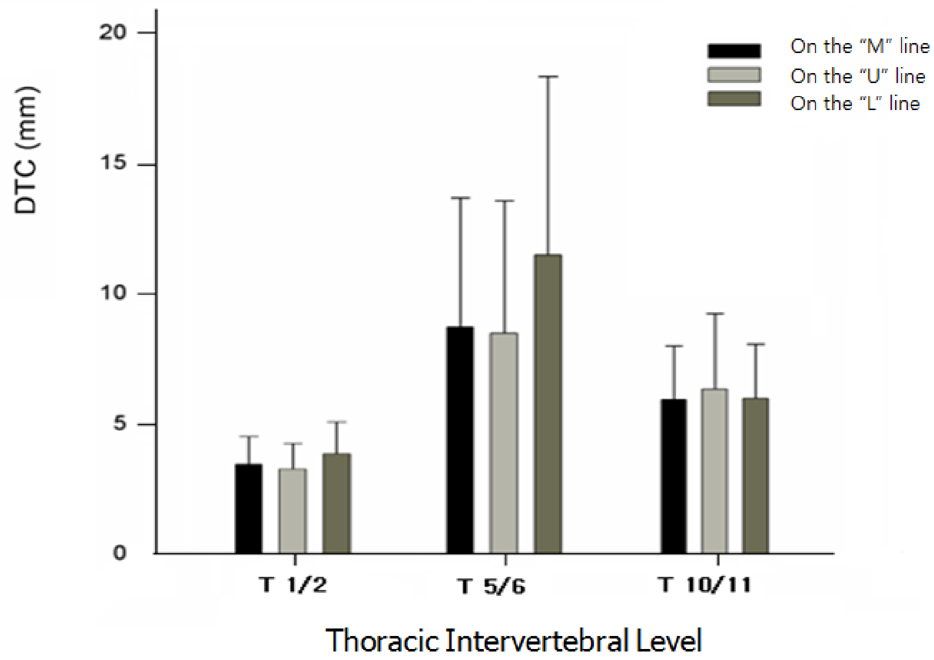

Fig 3.2. Distance from the dura mater to the spinal cord(DTC) on each approaching line
DTC was longest on the "L" line at the T1/2 and T5/6 intervertebral levels and on the "U" line at the T10/11 level. Data are expressed as mean (horizontal bar) with and standard deviation (whiskers) for each intervertebral level.

A significant difference in the safety margin was observed at each thoracic region among the three approaching lines. The STD and DTC were longest on the "L" line at the T1/2 and T5/6 intervertebral levels. The distance was longest on the "U" line at the T10/11 level (Fig. 3.2 and Table 3.3).

The insertion angle of the epidural needle is a critical factor in determining the safety margin at the same thoracic intervertebral level, and the difference in safety according to the approach angle at each thoracic region was verified. The "U" line was more horizontal than the "L" line at the T1/2 and T5/6 intervertebral levels. The angle between the "U" and "L" lines was largest at the T1/2 level, and narrowed from the upper to the middle region and was negative in the lower region (Table 3.4).

Table 3.3. Differences among the "U," "M," and "L" Lines at the T1/2, T5/6, and T10/11 Levels

	Approaching line	Distance from the skin to the dura mater (mm)	Distance from the dura mater to the spinal cord (mm)
T1/2	"U"	55.1 ± 9.6	3.1 ± 0.9
	"M"	56.7 ± 9.4	3.3 ± 1.1
	"L"	60.2 ± 9.8*	3.7 ± 1.2*
T5/6	"U"	68.2 ± 15.1	8.6 ± 5.3
	"M"	69.5 ± 15.1	8.8 ± 5.2
	"L"	80.0 ± 16.4*	11.6 ± 7.2*
T10/11	"U"	51.6 ± 10.7†	3.5 ± 1.6†
	"M"	49.5 ± 9.3	3.2 ± 1.1
	"L"	49.6 ± 9.4	3.2 ± 1.1

* Significant difference with corresponding values on the "U" and the "M" lines at the same level ($p<0.01$)
† Significant difference with corresponding values on the "M" and the "L" lines at T10/11 level ($p<0.05$)

Table 3.4. Angles and Differences between the "U" and "L" lines, at the T1/2, T5/6, and T10/11 Levels

	Angle between "U" and "L" (degree) *	DTC (L) – DTC (U) *†
T1/2	14.6 ± 8.1	0.6 ± 0.3
T5/6	9.1 ± 6.1	3.0 ± 3.8
T10/11	-2.2 ± 11.1	-1.9 ± 1.1

* A significant difference was observed between adjacent levels ($p<0.01$)
† DTC : distance from the dura mater to the spinal cord

As the "U" and "L" lines were two borders of the interspinous space, we determined the outline of the interspinous space at different thoracic vertebral levels (Fig. 3.3).

Fig 3.3. Outlines of the interspinous space at upper, middle and lower regions
The "U" lines and the "L" lines at upper, middle, lower thoracic region are showed on MRI images. The "U" line is more horizontal than the "L" line at T1/2, T5/6 intervertebral levels. And the "L" line is more horizontal than the "U" line at T10/11 level.

The larger the angle between the "U" and "L" lines, the higher the flexibility with regard to the angle of needle insertion at the interspinous space. However, the objective difference in DTC between the "U" and "L" lines was greatest at the T5/6 intervertebral level, where the vertical DTC was longest (Table 3.4).

4. Discussion

The course of needle insertion when performing epidural analgesia using the midline approach with the LOR technique is from skin to ligamentum flavum, and the needle should stop before piercing the dura mater for correct epidural needle placement. However, accidental dura puncture during epidural analgesia occurs in 0.4-6.0% of patients.(9) Dura puncture can be detected from associated CSF leakage, and the epidural catheter should not be inserted any further. Because LOR is a blind technique, there is no way to determine the needle position accurately other than by CSF leakage, which means the needle tip is in the subarachnoid space. Therefore, the DTC is a critical factor in neurological injury when a dura puncture occurs.

Our results revealed that the vertical DTC was longer in the middle thoracic region than at the upper or lower thoracic levels. This result is in good agreement with prior studies of the thoracic spinal canal.(8, 10) The spinal cord in the middle thoracic area is situated more ventrally, but the spinal cord occupies more space at the upper and lower thoracic levels because of cervical and lumbar enlargement. We investigated the vertical DTC at all thoracic levels. Our results will be helpful to determine the level at which epidural catheterization should be performed. Because a comparable effect of TEA can be expected from different thoracic levels by adjusting the drug dose or extent of catheter insertion, there are several possible target levels for needle insertion for an intended level of segmental block. Therefore, the significant difference in vertical DTC between adjacent thoracic intervertebral levels is valuable for selecting an insertion point with a larger safety margin. Ensuring a larger distance is one strategy for increasing the safety margin during TEA and, of course, during spinal anesthesia. A recent report presented a case of segmental spinal anesthesia for cholecystectomy in a patient with severe lung disease.(11)

The “U” line was more horizontal than the “L” line at the upper and middle thoracic intervertebral levels. Thus, the STD and DTC on the “L” line were longer than those on the “U” line or on the “M” line at the T1/2 and T5/6 levels. In contrast, the STD and DTC were longest on the “U” line at the lower thoracic region. Therefore, we speculate that TEA can be managed more safely by inserting a needle through a pathway near the lower border of the interspinous space at the upper or middle thoracic region and near the upper border at lower levels than by approaching from a random direction, as represented by the “M” line. The difference in DTC between the “U” and “L” lines was greatest at the T5/6 level, indicating that variability in the safety margin according to the needle insertion angle was largest at T5/6 and that the increase in safety margin was most significant at the mid-thoracic region.

The “U” line at the upper or middle thoracic region and the “L” line at lower levels might not be the longest pathway possible in the intervertebral space. For example, a line that starts from the posterior part of the lower border to the upper end of the ligamentum flavum suggests the greater safety margin than the “L” line. Therefore, the “U” and “L” lines are not absolute clinical guides for safety but references that can be used to understand the anatomy of the thoracic vertebral spine.

DTC (M), representing the clinical safety margin with a blind technique, was longer in males than females and correlated with age. It is uncertain whether differences in CSF volume or degenerative bony changes may affect the discrepancy in DTC (M).(12)

A number of limitations should be mentioned. First, about 9% of all cases had “M” lines at the T10/11 intervertebral level that did not pass through the interspinous space on the magnetic resonance images. This is because the lower thoracic spinous processes have more variable shapes and the midpoint of two adjacent tips can be far apart from the center of the posterior interspinous space. In those patients, the “M’ line does not represent a blind approach and is just an imaginary line.

Second, all data in this study were measured using supine magnetic resonance images. However, most neuraxial blockades are done with patients in the lateral decubitus position with or without leg flexion. Previous studies have demonstrated that the spinal cord and cauda eqiuna move with gravity and also ventrally with leg flexion.(7, 13, 14) Consequently, it is expected that the safety margin would be greater in a lateral than a supine position. However, whether the correlation between spinal structure and vertebral level would be maintained using a lateral posture is uncertain. A supplementary study was designed to evaluate the relationship between posture and spinal contour. We recruited volunteers for supine and decubitus magnetic resonance images to examine the effect of posture on the spinal canal. However, the MRI coil space was too small to get a lateral decubitus posture within the instrument, so we did not conduct the supplementary study. And another study was also planned to evaluate the changes in angle between the “U” and “L” lines on plain films taken from supine and lateral position. However, owing to the overlapping of the vertebral shadow with other bony structures, we could not get the precise values of angles. Therefore, additional studies are needed to elucidate the effect of various postures on the thoracic vertebral canal.

In conclusion, we investigated the vertical DTC at various thoracic intervertebral levels in an attempt to determine the outline of the intervertebral space. We found differences in the DTC among thoracic intervertebral levels, mainly due to cervical and lumbar enlargement. By comparing different approach angles, the safety margin was found to be the longest on the “L” line at the T1/2 and T5/6 levels and longest on the “U” line at lower thoracic regions. The DTC (M) in the thoracic vertebral region was longer in males than in females and decreased with age. The variability of the safety margin according to the angle of needle insertion was largest at T5/6. These differences merit consideration to prevent serious cord damage in association with TEA.

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초 록

흉부 척추 수준에서의 경막-척수 사이 거리에 관한 고찰

서론: 흉부 경막외 마취와 관련된 신경학적 부작용은 드물지만 매우 치명적일 수 있다. 따라서 경막외 바늘과 관련된 신경학적 손상을 방지하기 위해서는 척수관에 대한 해부학적 이해가 매우 중요하다.

방법: 우리는 총 346명의 환자들을 대상으로 T2 척추MRI 영상을 후향적으로 조사하였다. 경막-척수 사이 거리를 모든 흉추 분절에서 측정하였으며, “U”, “L”, “M” 선들로 구분되는 세가지 각도 상에서의 거리관계들을 3가지 다른 수준의 흉추 부위에서 측정하였다. “U” 선은 극돌기 사이 공간의 상부 경계선을 의미하며 “L” 선은 공간의 하부 경계선을, “M” 선은 임상에서의 맹목적인 접근경로를 의미한다.

결과: 경막-척수 사이 거리는 흉추 5/6 분절에서 가장 크게 측정되었고 흉추 11/12 분절에서 가장 작은 값을 보였으며, 키(유의수준 = 0.013) 그리고 연령(유의수준 < 0.001)과 상관관계를 보였다. ‘M’ 선상에서 측정한 피부-경막 거리는 여성에 비해 남성에서 더 길었으며(유의수준 < 0.001), 키(유의수준 = 0.016), 그리고 몸무

계(유의수준 < 0.001)와 상관관계를 보였다. ‘M’ 선상에서의 경막-척수 사이 거리 역시 여성에 비해 남성에서 길게 나타났으며(유의수준 = 0.037), 연령과 상관관계가 있다(유의수준 = 0.001). 세가지 선들을 비교해보면, 흉추 1/2 분절과 5/6 분절에서는 선상 피부-경막 거리와 경막-척수 거리가 ‘L’ 선에서 가장 길었으며 흉추 10/11 분절에서는 ‘U’ 선 위에서 가장 큰 값을 보였다. ‘U’ 선과 ‘L’ 선 사이의 각도는 흉추 1/2 분절에서 가장 크게 나타났고, 흉추 5/6 분절에서는 더 작은 값을, 흉추 10/11 분절에서는 음의 값을 보였다.

결론: 흉추분절에 따라 경막-척수 거리는 유의한 차이를 보이며 이는 경부 그리고 요부에서의 척수 팽창과 관련이 있을 수 있다. 세가지 접근선들을 비교할 때 흉추 1/2 분절과 5/6 에서는 ‘L’ 선에서, 흉추 10/11 분절에서는 ‘U’선상에서 보다 큰 안전역을 보인다. ‘접근경로에 따른 안전역의 차이는 흉추 5/6 분절에서 가장 크게 나타났으며 접근경로간 각도의 차이는 흉추 1/2 분절에서 가장 크게 보였다.

주요어: 흉부 경막외 마취, 경막-척수 사이 거리, 극돌기 사이 공간
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