Journal of Anesthesia (2024) 38:674–680
https://doi.org/10.1007/s00540-024-03374-w

ORIGINAL ARTICLE

Relationship between epidural catheter migration beneath the skin and subcutaneous fat thickness assessed using postoperative CT imaging: a retrospective cross-sectional study

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Received: 15 February 2024 / Accepted: 27 June 2024 / Published online: 11 July 2024

Abstract

Purpose The causes of epidural catheter migration beneath the skin have not been previously investigated. We hypothesized that greater subcutaneous fat thickness might be associated with increased catheter migration beneath the skin.

Methods We conducted a retrospective cross-sectional study of patients who had undergone combined general and epidural anesthesia, selecting individuals who received thoracic and abdominal CT scans within the first 5 postoperative days. Needle depth was defined as the distance from the needle tip to the skin surface when the anesthesiologist determined that the needle tip had reached the epidural space. We measured the length of the epidural catheter from the skin surface to the epidural space (catheter length), and subcutaneous fat thickness (fat thickness) using CT imaging. Migration distance was calculated by subtracting needle depth from catheter length.

Results We analyzed 127 patients (72 males), all undergoing epidural catheter insertion in the left lateral decubitus position via a paramedian approach. The median age of the patients was 71 years. Epidural catheters were postoperatively found to substantially curve beneath the skin. Regression analysis revealed no significant influence of fat thickness on catheter length (regression coefficient 0.10, 95% confidence interval [CI]: −0.17, 0.38). However, it indicated a positive correlation between fat thickness and needle depth (regression coefficient 0.50, 95% CI: 0.30, 0.70), and a negative correlation between fat thickness and migration distance (regression coefficient −0.40, 95% CI: −0.65, −0.14).

Conclusion We found a negative correlation between epidural catheter migration beneath the skin and subcutaneous fat thickness. Anesthesiologists should be aware of the possibility of substantial subcutaneous curving of the catheter, especially in patients with scant subcutaneous fat.

Keywords Epidural anesthesia · Epidural space · Neuraxial anesthesia · Paramedian approach · Synapse vincent

Introduction

Epidural anesthesia is effective for pain management following major surgical procedures, facilitating early ambulation and physical therapy [1, 2]. However, the catheter tip must remain in the epidural space even with patient movement for adequate analgesic effect [3, 4]. Previous studies have explored strategies to prevent catheter migration, emphasizing the importance of secure catheter fixation to the skin [5, 6]. However, secure skin fixation of the catheter only ensures that it does not get dislodged, and does not protect against catheter migration beneath the skin. In addition, the impact of catheter migration beneath the skin has not been previously evaluated. We hypothesized that greater subcutaneous fat thickness might be associated with increased catheter migration beneath the skin.

Recent advances in medical imaging have highlighted the potential of high-resolution computed tomography (CT) as a valuable tool for visualizing the trajectory of epidural catheters [7]. Here, we aimed to investigate the relationship between catheter migration beneath the skin and subcutaneous fat thickness using postoperative high-resolution CT images and the Synapse Vincent image analysis system (Fujifilm Medical, Tokyo, Japan).

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Methods

Study design and settings

This retrospective, cross-sectional study was performed at Toyama University Hospital, an academic, teaching, and tertiary care institution in Japan. This study was approved by the ethics committee of our hospital (Approval No. R2022221) on March 27, 2023, and adhered to the principles of the Declaration of Helsinki. The requirement for written informed consent was waived because of the retrospective nature of the study. Instead, opt-out consent documents were presented on our hospital website for patients who did not wish to participate. We followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement [8].

Patient selection and data collection

We retrospectively included all patients who underwent combined general and epidural anesthesia at our institution between January 1, 2005, and December 31, 2022, referencing our anesthesia records. Among them, we extracted patients who had received thoracic and/or abdominal CT examinations within the first five postoperative days, including the day of surgery. Subsequently, we thoroughly reviewed each CT image to verify the presence and placement of the epidural catheter. We excluded cases in which high-resolution CT was not performed, the tip of the catheter was not in the epidural space, the entire length of the catheter was not visualized, or data on needle length was missing from the patients' records. None of the patients declined study participation.

We retrieved patient demographic data, including age, sex, height and weight, from their electronic medical records. Details of the epidural anesthesia technique, such as patient positioning, were extracted from their anesthesia records. Data on needle depth, the distance from the needle tip to the skin surface, measured using the surface markings at 1 cm intervals on 18-gauge Tuohy needles (B Braun, Tokyo), when the anesthesiologist judged that the needle tip had reached the epidural space was also obtained from the anesthesia records. Our hospital used X-ray permeable nylon epidural catheters (Smiths Medical Japan, Tokyo) before 2012, and radiopaque Perifix® catheters (B Braun, Tokyo) after 2012. Adhesive tapes were used to secure the catheter to the skin.

Measurements

CT images were obtained using one of the following CT scanners: SOMATOM Force, SOMATOM Definition AS+, SOMATOM Sensation Cardiac 64, or SOMATOM Sensation 16 (Siemens Medical Solutions, Forchheim, Germany). The high-resolution images had a slice thickness of either 0.75 mm or 1.0 mm.

The length of the epidural catheter from the skin surface to its tip in the epidural space, referred to as catheter length, was measured utilizing the Synapse Vincent medical imaging system. This system employs the principles of curved planar reformations to aid in precisely measuring distances along curved anatomic paths.

The length of epidural catheter migration beneath the skin, referred to as the migration distance, was calculated by subtracting needle depth from the inserted catheter length.

We measured subcutaneous fat thickness using the CT images. The CT value of fat has a negative value because fat is X-ray permeable, i.e., it has low absorption. Tissues with a CT value of less than zero were defined as fat, and their thickness was measured as follows (Fig. 1). A line was drawn along the midline from the center of the spinal canal to the tip of the spinous process on the Synapse Vincent medical imaging system. Fat thickness was measured along the midline at three vertebral levels (T10 to T12). We defined the average value of the three levels as the subcutaneous fat thickness for each patient. In addition, we determined whether the skin entry point of the epidural catheter was to the left or right of the line.

Statistical analysis

Utilizing a 4-group analysis of variance with an alpha error of 0.05, a power of 0.8, and an effect size of 0.3, we calculated the required sample size as 32 per group. Descriptive

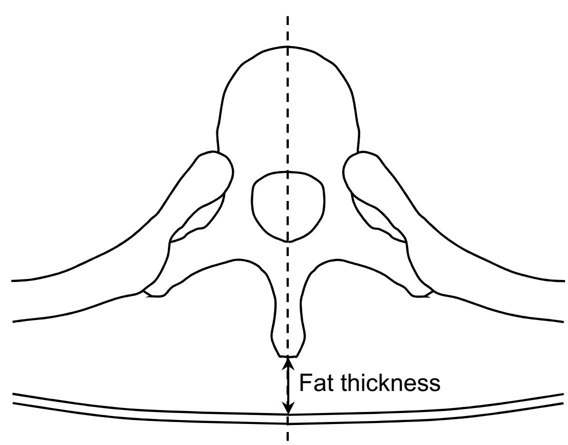

Fig. 1 Measurement of subcutaneous fat thickness A line was drawn along the midline from the center of the spinal canal to the tip of the spinous process on the Synapse Vincent medical imaging system (dashed line). Subcutaneous fat thickness (double-ended arrow) along the midline was measured at three vertebral levels (T10 to T12), and the mean of these measurements was defined as the subcutaneous fat thickness in each patient

statistics were presented as frequencies (%) and continuous values were presented as the median [range]. Comparisons across multiple groups were performed using Fisher's exact and Kruskal–Wallis tests. Bonferroni correction was used for post hoc analysis. Univariate regression analysis was used to examine the relationships between fat thickness and catheter length, needle depth and migration distance, respectively. For sensitivity analysis, we conducted multivariate regression analysis adjusted for patient characteristics, including age and sex. Regression coefficients are presented with 95% confidence intervals (CI). A two-sided p value of < 0.05 was considered statistically significant. Analyses were conducted using EZR software, which is a graphical user interface for R (The R Foundation for Statistical Computing, Vienna, Austria) [9].

Results

Between January 1, 2005, and December 31, 2022, a total of 11,559 patients received combined epidural and general anesthesia at our institution. Of them, we analyzed 127 patients who underwent high-resolution postoperative CT scans that revealed a visible epidural catheter (Fig. 2). All epidural catheters identified by CT scans were radiopaque Perifix® catheters.

Patient demographic and technical epidural anesthesia parameters are summarized in Table 1. Median patient age was 71 years [range, 15 to 89], with 72 males (56.7%). Median body mass index was 23.3 kg/m^2 [range, 16.7 to 35.2]. As documented in their anesthesia records, all epidural catheter insertions were performed with patients in the left lateral position using a paramedian approach. Most of the available data pertained to catheters positioned at the lower thoracic vertebral level, as all the high-resolution CT scans were taken after abdominal surgeries (Supplementary Table 1). The median values of the measured dimensions were as follows: catheter length: 7.4 cm [range, 5.0 to 10.6], needle depth: 5.0 cm [range, 3.0 to 7.5], and fat thickness 1.0 cm [range, 0.2 to 3.3] The median-migration distance, calculated by subtracting needle depth from catheter length, was 2.4 cm [range, −0.4 to 5.6].

To examine the effect of fat thickness on migration distance, we divided our patients into four groups according to fat thickness quartiles in increasing order of thickness as: Group A ($n = 32$): median thickness of 0.5 cm [range, 0.2 to 0.7 cm), Group B ($n = 32$): median thickness of 0.9 cm [0.7 to 1.0 cm], Group C ($n = 32$): median thickness of 1.2 cm [1.0, to 1.5 cm], and group D ($n = 31$): median-fat thickness of 2.1 cm [1.5 to 3.3 cm] (Table 2). Figures 3 and 4 display the trajectory of the epidural catheter as observed on high-resolution CT images, superimposed on schematic CT images. Notably, the catheter frequently exhibited a substantial subcutaneous curve in all groups. Despite all insertions intended to be made by the paramedian approach in the left lateral decubitus position, we found that the catheter entry point at the skin surface was to the right of the midline on CT images in 59 of the 127 cases: Group A: 19 cases, Group B: 14 cases, Group C: 14 cases, and Group D: 12 cases (dotted lines in Fig. 3) ($p = 0.377$ between these groups).

Table 2 summarizes the data on catheter length, needle depth and migration distance across quartiles of fat thickness. No differences in catheter length were observed between fat thickness groups. Regression analysis also showed no influence of fat thickness on catheter length (regression coefficient 0.10, 95%CI: − 0.17 to 0.38). In

Fig. 2 Flow diagram of study enrollment

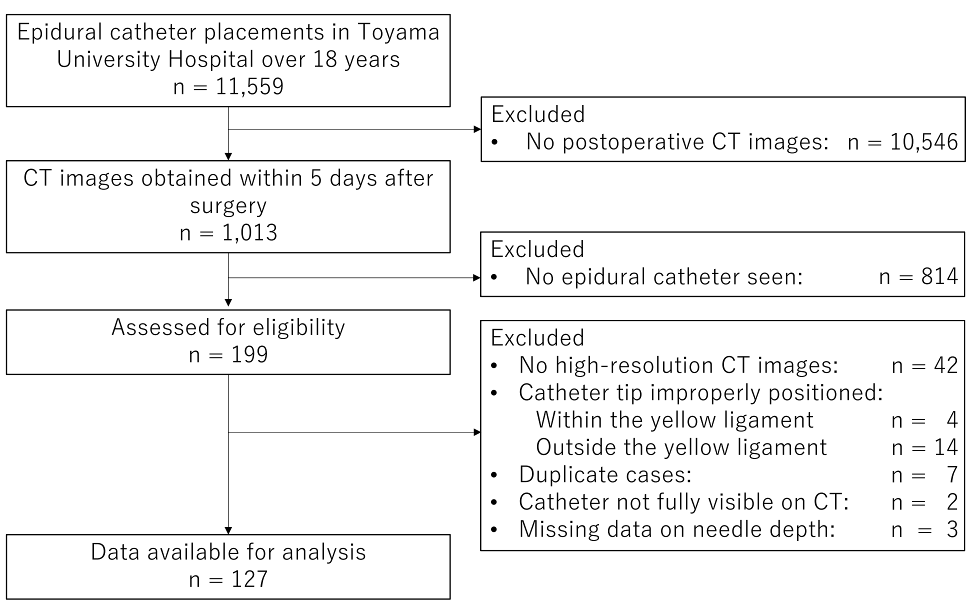

Table 1 Patient demographics and epidural anesthesia-related parameters

Variable	Value
Age, years	71 [15, 89]
Sex, male	72 (56.7)
Height, cm	160 [133.8, 183.0]
Weight, kg	58 [39, 98]
Body mass index, kg/m^2	23.3 [16.7, 35.2]
Postoperative day (0/1/2/3/4/5)	0/13/23/54/35/2
Insertion timing; before/after induction	Before: 107 (84.3) / After: 20 (15.7)
Insertion position	Left lateral decubitus: 127 (100)
Insertion technique	Paramedian approach: 127 (100)
Technique for identifying epidural space	LOR: 127 (100)
Length of the epidural catheter advanced after LOR, cm	5 [3, 7]
Insertion site (T6-7/T7-8/T8-9/T9-10/T10-11/T11-12/T12-L1/L1-L2)	3/22/36/31/15/12/6/2

The data are presented as frequencies (%) and medians [range]. Postoperative day indicates the day the CT image was taken. The length of epidural catheter advancement after loss of resistance (LOR) was decided by the anesthesiologist performing the epidural anesthesia. Insertion sites were precisely identified through high-resolution CT images

Table 2 Patient characteristics and procedural parameters in patients divided into four groups based on fat thickness

Group	A ($n=32$)	B ($n=32$)	C ($n=32$)	D ($n=31$)	p value
Fat thickness, cm	0.5 [0.2, 0.7]	0.9 [0.7, 1.0]	1.2 [1.0, 1.5]	2.1 [1.5, 3.3]	
Body mass index, kg/m^2	20.2 [16.7, 27.1]	22.3 [17.9, 27.9]	23.5 [18.2, 29.8]	26.7 [21.7, 35.2]	< 0.001
Catheter length, cm	7.5 [6.0, 9.3]	7.4 [5.0, 10.6]	7.4 [5.0, 9.2]	7.6 [5.6, 9.3]	0.805
Needle depth, cm	4.8 [3.0, 6.0]	5.0 [4.0, 7.0]	5.0 [4.0, 7.0]	6.0 [4.5, 7.5]	< 0.001
Migration distance, cm	2.8 [1.0, 5.6]	2.3 [−0.3, 3.0]	2.3 [0.5, 3.9]	2.0 [−0.4, 3.6]	0.012

Data are shown as the median [range]. Analysis was conducted by dividing the patients into four groups based on quartiles of fat thickness. Using postoperative CT images, catheter length was determined using the Synapse Vincent image analysis system. Needle depth was defined as the distance of the needle tip from the skin surface when the anesthesiologist felt a loss of resistance when inserting an 18-gauge Tuohy needle. Migration distance was calculated by subtracting needle depth from catheter length. Statistical analysis was performed using the Kruskal–Wallis test

contrast, significant differences were noted in needle depth and migration distance across fat thickness groups. In the post hoc analysis using Bonferroni correction, significant differences were observed between groups A and D, and C and D in terms of needle depth, and between groups A and D in terms of migration distance. Regression analysis revealed a positive correlation between fat thickness and needle depth (regression coefficient 0.50, 95%CI: 0.30 to 0.70), and a negative correlation between fat thickness and migration distance (regression coefficient − 0.40, 95%CI: − 0.65 to − 0.14). We also conducted analyses dividing patients into two and three groups based on subcutaneous fat thickness (Supplementary Tables 2 and 3). When divided into two groups, Group A ($n=64$) had a median-fat thickness of 0.7 cm [range, 0.2 to 1.0 cm], and Group B ($n=63$) had a median thickness of 1.5 cm [1.0 to 3.3 cm] (Supplementary Table 2). When divided into three groups, Group A ($n=42$) had a median-fat thickness of 0.5 cm [range, 0.2 to 0.8 cm], Group B ($n=42$) had a median thickness of 1.0 cm [0.8 to 1.3 cm], and Group C ($n=43$) had a median thickness of 1.9 cm [1.3 to 3.3 cm] (Supplementary Table 3). Similar results for catheter length, needle depth and migration distance were obtained regardless of how the groups were divided. No significant differences in catheter length were observed between the groups, and migration distance was the longest in the group with the thinnest subcutaneous fat.

Sensitivity analysis, which included adjustments for patients' age and sex, also showed consistent results. A significant positive correlation was observed between fat thickness and needle depth (regression coefficient 0.61, 95% CI: 0.41 to 0.80); the correlation between fat thickness and catheter length remained insignificant (regression coefficient 0.27, 95% CI: − 0.01 to 0.54); a negative correlation was observed between fat thickness and migration distance (regression coefficient − 0.34, 95% CI: − 0.61 to − 0.07). Patients' age and sex were not significant explanatory variables in the regression analysis for migration distance.

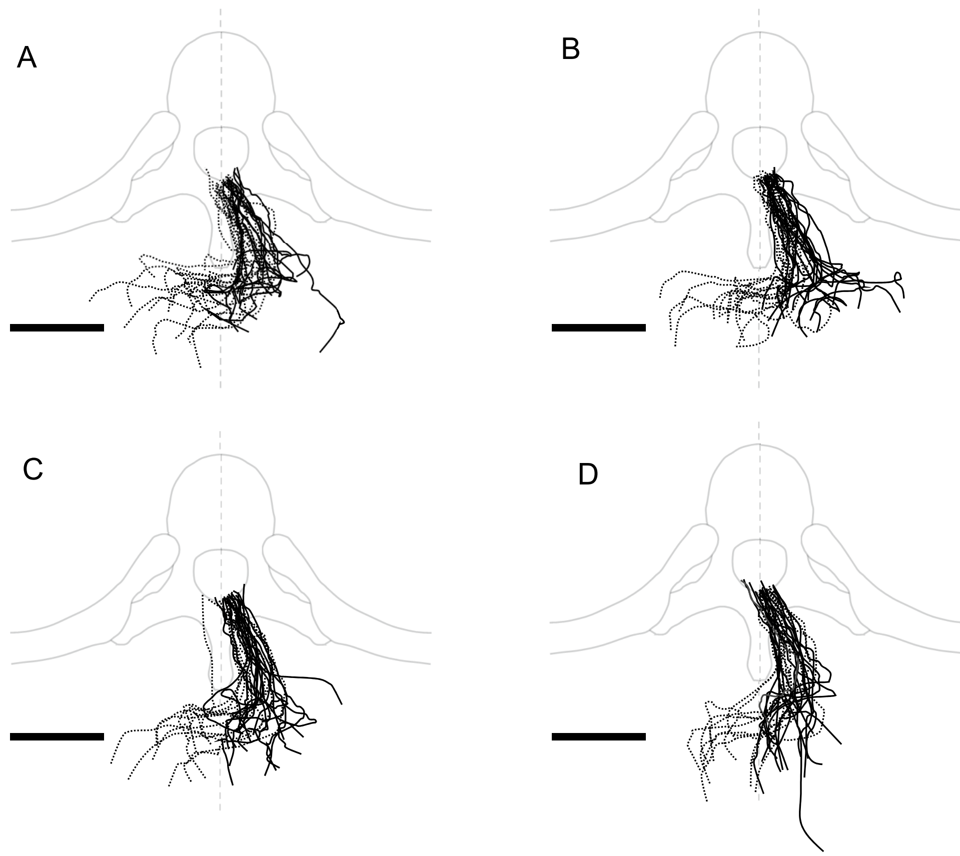

Fig. 3 Overlay of the epidural catheters on a schematic horizontal CT image Based on quartiles of fat thickness, the patients were divided into four groups: A, B, C, and D, in increasing order of thickness. We overlaid the trajectories of the epidural catheters in the horizontal plane for each group on a schematic CT image. In this study, for all cases, the patient's position during epidural anesthesia puncture was the left lateral decubitus position, with the catheters inserted using a left paramedian approach. The epidural catheters found by CT imaging to have been inserted to the left and right of the midline via the skin surface are indicated by solid and dotted lines, respectively. The midline is represented by the line drawn between the center of the spinal canal and the tip of the spinous process (dashed line). Bars, 2.5 cm

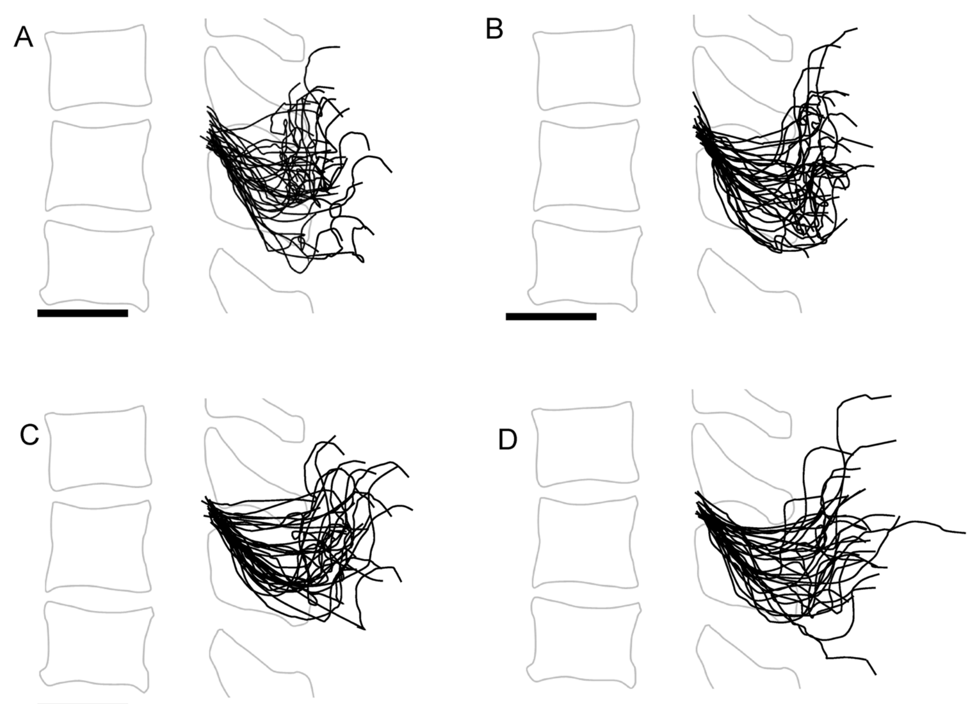

Fig. 4 Overlay of the epidural catheters on a schematic sagittal CT image The patients were divided into four groups based on quartiles of fat thickness, A, B, C and D, in increasing order of thickness. We overlaid the trajectories of the epidural catheters in the sagittal plane for each group on a schematic CT image. In this study, for all cases, the epidural anesthesia puncture was made with the patient in the left lateral decubitus position, using a left paramedian approach. Bars, 2.5 cm

Discussion

This study used high-resolution CT images and the Synapse Vincent image analysis system to investigate the relationship between epidural catheter migration beneath the skin and subcutaneous fat thickness. Unexpectedly, we found a negative correlation between epidural catheter migration beneath the skin and subcutaneous fat thickness.

The patient's position during the epidural anesthesia procedure might influence the subcutaneous curve of the epidural catheter. In this study, all patients were placed in the left lateral decubitus position during catheter insertion. Interestingly, as demonstrated by the dotted lines in Fig. 3, the entry point of the epidural catheter at the skin surface was located to the right of the midline in approximately half of the cases. This could be attributed to leftward sagging of the skin on the right side resulting from left lateral decubitus positioning. Such leftward sagging of the skin could strongly impact subcutaneous curving of the catheter, suggesting that adoption of the sitting position during the procedure might mitigate this effect. Nonetheless, the sitting position has potential disadvantages. It might cause vertical subcutaneous deviation and is associated with a higher incidence of vasovagal reflexes [10] and an increased risk of intravascular catheter entry [11]. Moreover, the position during insertion and postoperative positional changes can influence the risk of epidural catheter dislodgement [12]. Thus, further studies are warranted to elucidate the extent to which insertion position influences subcutaneous curving of the catheter.

A possible explanation for the epidural catheter's subcutaneous migration is the increased adipose tissue plasticity in patients with less subcutaneous fat. Histologic analysis of subcutaneous adipose tissue revealed significantly less fibrosis surrounding adipocytes in patients with a normal body mass index than those with severe obesity [13]. Malnutrition also decreases subcutaneous fat thickness and induces a catabolic state. Pathologic conditions, such as chronic inflammation and cancer, increase circulating levels of matrix metalloproteinases, which degrade the extracellular matrix [14].

Based on the results of the present study, we propose that the epidural catheter should be advanced for at least 5.6 cm following the loss of resistance. Using the paramedian approach with the patient in the lateral decubitus position, we found that migration length reached a maximum of 5.6 cm in groups with a fat thickness of 1.0 cm or less. Previous reports have also concluded that the optimal distance to which the epidural catheter should be advanced into the epidural space is 5 to 6 cm [15–17], supporting our findings.

This study has several limitations. First, we did not know when the subcutaneous migration occurred. Catheter migration is frequently observed subsequent to alterations in the patient's position [12]. Another plausible assumption is immediate subcutaneous migration of the catheter following withdrawal of the epidural needle. Second, only cases with postoperative high-resolution CTs showing the epidural catheter tip within the epidural space were included in this study. Excluding cases where the epidural catheter tip was not in the epidural space might have biased the discussion of how far the catheter should be advanced. Third, since this study aimed to measure catheter length from the skin to the epidural space, the analgesic effect in relation to epidural catheter placement was not evaluated. Fourth, since the CT images focused on the abdominal area, catheter entry points were in the lower thoracic spine in most cases (Table 1). Thus, extrapolating our results to the upper thoracic or lumbar spine would be challenging. Fifth, since measurement of catheter distance from the skin to the epidural space used a Tuohy needle with 1-cm interval surface markings, lengths less than 1 cm were dependent on the anesthesiologists' subjective assessment. Finally, we did not qualitatively evaluate the anesthesiologist's subjective impressions during catheter insertion. If data had been collected on the anesthesiologists' subjective ratings of ease or difficulty of catheter advancement during catheter insertion, this variable might have been found to be a predictor of catheter migration.

Conclusion

This study used high-resolution CT images with the Synapse Vincent image analysis system to investigate the relationship between epidural catheter migration beneath the skin and subcutaneous fat thickness. We found that catheters are more prone to deviation in patients with thinner subcutaneous fat. Anesthesiologists should be aware that lean patients are particularly susceptible to epidural catheter displacement.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s00540-024-03374-w.

Acknowledgements We thank Dr. Kazuma Nishikawa and Mr. Kazuaki Arai for their assistance with CT data acquisition, and Mr. Toshio Fujimori for analyzing the epidural catheter data. We also extend our appreciation to Dr. Yu Matsui for his valuable discussions. The authors thank FORTE Science Communications (https://www.forte-science.co.jp/) for English language editing.

Author contributions Conception and design of the study: MM. Analysis and interpretation of data: all authors. Drafting the article or revising it critically for important intellectual content: all authors. Final approval of the version to be submitted: all authors.

Funding This work was supported by JSPS KAKENHI Grant Number JP21K08918.

Data availability The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of interest The authors declare that they have no conflicts of interest.

Ethical approval This retrospective, cross-sectional study was approved by the ethics committee of Toyama University Hospital (Approval No. R2022221). The requirement for written informed consent was waived because of the retrospective nature of the study. Instead, opt-out consent documents were presented on our hospital website for patients who did not wish to participate.

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