Clinical Trial/Experimental Study

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Evaluation of the position of the needle tip during thoracentesis

Experimental study

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Abstract

Introduction: Thoracentesis is performed to both diagnose and/or treat pleural effusion, and several important complications of thoracentesis are occasionally observed. To assess precise thoracentesis procedures, we evaluated the position of the needle tip during thoracentesis by using a thoracentesis unit, comparing experienced and inexperienced groups.

Methods: Twenty eight physicians (19 board-certified pulmonologists as an experienced group and the remaining 9 as an inexperienced group) participated at Fukujuji Hospital in January 2021. All participants performed 2 punctures with a handmade thoracentesis unit and measured the needle's angle to the midline.

Results: The median distance from the needle tip to the midline when the needle was inserted 5 cm (D5) was 0.47 cm (range 0.06–1.05), and the median difference between D5 on the 1st puncture ($D5_{1st}$) and D5 on the 2nd puncture ($D5_{2nd}$) was 0.22 cm (range 0.00–0.69). D5 was shorter in the experienced group than in the inexperienced group (median 0.40 cm (range 0.06–0.66) vs 0.58 cm (range 0.44–1.05), $P < .001$). There were no significant differences in the $D5_{1st}$ and $D5_{2nd}$ distances between the experienced and inexperienced groups (median 0.22 cm (range 0.00–0.40) vs 0.41 cm (range 0.04–0.69), $P = .094$). When 4 areas were divided by the x-axis and y-axis, 32 punctures (55.2%) deviated to the right-upper quadrant, and 25 (86.2%) of participants made the 1st puncture and 2nd puncture in the same direction.

Conclusions: All doctors should know that the needle direction might shift by approximately 1 cm, and more than half of the practitioners punctured towards the upper right.

Abbreviations: θx = the angle of the needle and the midline on the x-axis, θy = the angle of the needle and the midline on the y-axis, D5 = the distance from the needle tip to the midline when the needle was inserted 5 cm, D5(x) = D5 on the x-axis, D5(y) = D5 on the y-axis, $D5_{1st}$ = the distance from the needle tip to the midline on the 1st puncture when the needle was inserted 5 cm, $D5_{2nd}$ = the distance from the needle tip to the midline on the 2nd puncture when the needle was inserted 5 cm, IQR = interquartile range.

Keywords: iatrogenic pneumothorax, puncture, safety, thoracentesis, training

1. Introduction

Thoracentesis is performed for both diagnosis and/or therapy for pleural effusion, and several important complications of thoracentesis are occasionally observed.[1] The most common complication after thoracentesis is iatrogenic pneumothorax, which occurs in 0.61% to 11% of cases.[2–4] Other serious complications after thoracentesis are solid organ puncture and haemothorax.[5] To reduce the risk of these complications, especially iatrogenic pneumothorax, which has an incidence of 1.0% to 4.9%, ultrasound guidance is used.[5–10] Thoracentesis procedural practice (experiential training) may reduce the iatrogenic risk to patients,[6] and experienced doctors may have lower pneumothorax rates than inexperienced practitioners.[5] The guidelines for the management of empyema have suggested that thoracentesis should be performed when the pleural fluid thickness is 2 cm or more on computed tomography scans.[11] However, there is no report demonstrating the safety of a needle technique for thoracentesis procedures. Considering that pneumothorax rates relate to a physician's experience, the position of the needle tip in thoracentesis might be dependent on individual physician differences. Accordingly, this study aimed to assess the needle tip position during thoracentesis for a safer procedure with a thoracentesis unit.

Editor: Maya Saranathan.

The study was approved by the Institutional Review Board of Fukujuji Hospital. It was determined that patient consent was not required. The decisions made by this board are based on and in accordance with the Declaration of Helsinki.

The authors have no funding and conflicts of interests to disclose.

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

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How to cite this article: Shimoda M, Morimoto K, Tanaka Y, Yoshimori K, Ohta K. Evaluation of the position of the needle tip during thoracentesis: experimental study. Medicine 2021;100:28(e26600).

Received: 9 March 2021 / Received in final form: 29 April 2021 / Accepted: 22 June 2021

http://dx.doi.org/10.1097/MD.0000000000026600

2. Materials and methods

2.1. Study design and setting

This study was conducted with 28 volunteer physicians at Fukujuji Hospital, the Japan Anti-Tuberculosis Association (JATA), in January 2021. Fifteen board-certified respiratory physicians and 4 board-certified respiratory surgeons were allocated to an experienced group. Nine practitioners, including 3 internal medicine residents, 2 diabetologists, 2 doctors in the medical examination centre, and 2 dermatologists, were allocated to an inexperienced group. All internal medicine residents have performed thoracentesis fewer than 5 times per year, and the other practitioners in the inexperienced group have not performed any in the past year. The median number of experience years among the experienced group was 16 (interquartile range (IQR) 13–22), and that of the inexperienced group was 10 (IQR 5–18) ($P = .043$).

This study was approved by the Institutional Review Board of Fukujuji Hospital (Study number: 20056).

2.2. Measuring device and formula

The thoracentesis unit (Sensi-kun 2 go) was comprised of a wooden board (DAISO INDUSTRIES Co., Ltd., Hiroshima, Japan; 0.95 dollars), a rubber stopper (HIKARI Co., Ltd., Osaka, Japan; 1.79 dollars), a laptop stand (EIOKIT Co., Ltd., Jiangsu, China; 28.49 dollars), and 2 protractors (DAISO INDUSTRIES Co., Ltd.; 0.95 dollars) (Fig. 1A, B). A rubber stopper was fitted at the centre of the wooden board for a puncture target, and protractors were set on the top and side edges of the wooden board. A sheet of blue paper (DAISO INDUSTRIES Co., Ltd.; 0.95 dollars) with a central hole covered the wooden board like a surgical drape. The wooden board was fixed on a laptop stand. The angle of the wooden board with the laptop stand and the floor was 60 degrees. All practitioners performed 2 punctures (1st puncture and 2nd puncture) aiming vertically towards the wooden board surface. Every practitioner was right-handed and performed punctures with their right hands with a 23-gauge 60 mm needle and a 10 mL syringe. When the midline was drawn vertically towards the wooden board surface through the

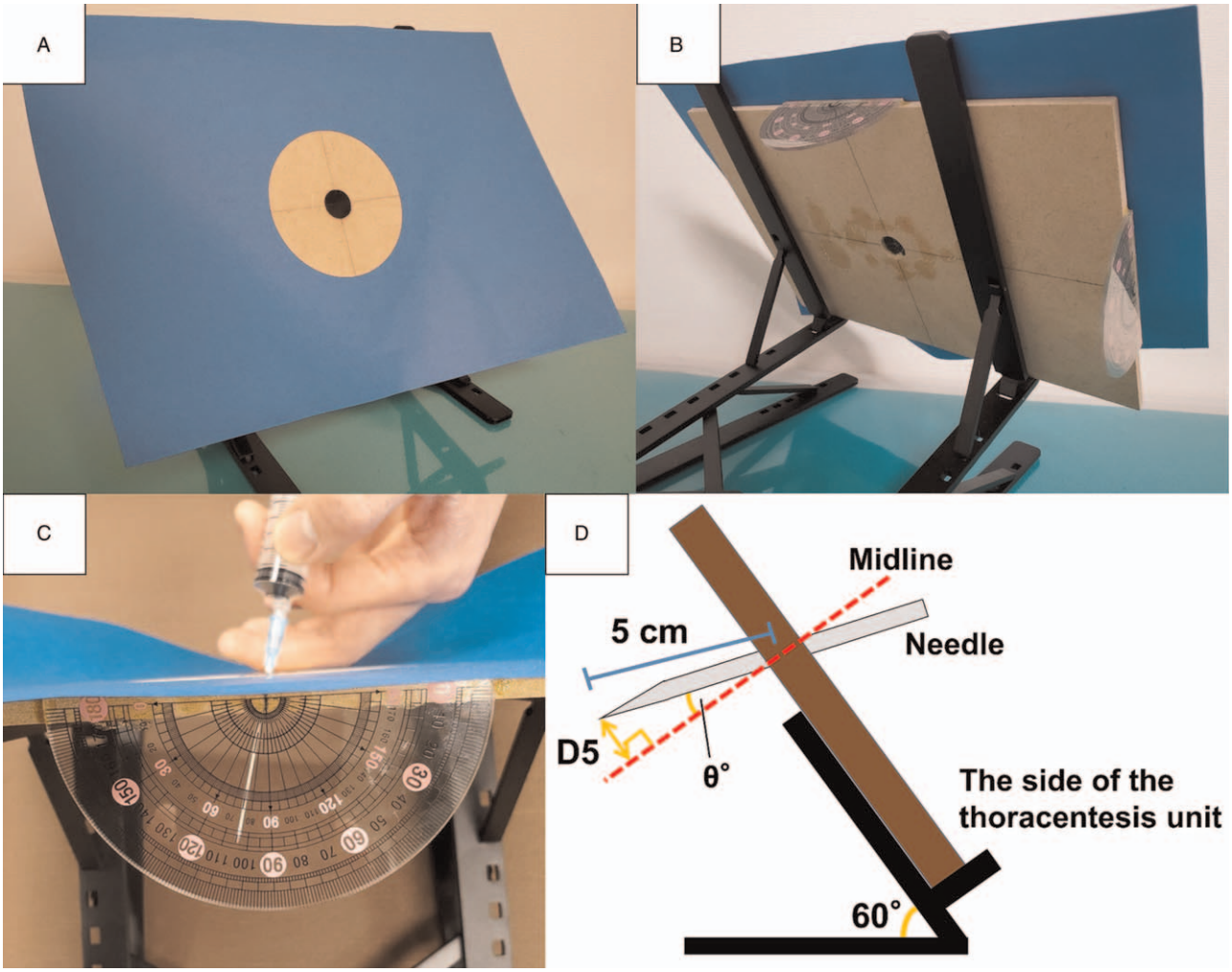

Figure 1. The thoracentesis unit (Sensi-kun 2 go) used in this study. The wooden board was fixed on a laptop stand. A rubber stopper was fitted at the centre of the wooden board for a target of puncture, and protractors were set on the top and side edges of the wooden board. A blue sheet of paper with a central hole covered the wooden board like a surgical drape. (A): The front of the thoracentesis unit. (B): The back of the thoracentesis unit. (C): The angle of the needle to the midline was measured with a protractor. (D): Schematic diagram of the thoracentesis unit used in this study. The distance from the midline to the position of the needle tip was calculated when the depth of the inserted needle was 5 cm. D5 = the distance from the needle tip to the midline. θ = the angle of the needle and midline.

puncture point, the angle of the needle to the midline was measured by protractors divided into the x-axis direction (parallel to the ground) and y-axis direction (vertically to the ground) (Fig. 1C). The angle of the needle was measured with a protractor to utilize lines passed through the centre on the wooden board to overlap the 90-degree line of a protractor. The distance from the midline to the position of the needle tip was calculated when the needle was inserted 5 cm (D5) (Fig. 1D). D5 was calculated according to the formula below.

$D5 = \sqrt{(D5(x)^2 + D5(y)^2)}$

$D5(x) = 5\,cm * \sin(\theta x)$, $D5(y) = 5\,cm * \sin(\theta y)$

D5(x): D5 on the x-axis, D5(y): D5 on the y-axis, θx: the angle of the needle and the midline on the x-axis, θy: the angle of the needle and the midline on the y-axis

All D5 values were plotted in a rectangular coordinate system when the midline was regarded as the origin. Furthermore, D5 on the 1st puncture ($D5_{1st}$) was compared to D5 on the 2nd puncture ($D5_{2nd}$). All $D5_{2nd}$ values were plotted in a rectangular coordinate system in which $D5_{1st}$ was regarded as the origin.

2.3. Statistical methods

All data were analyzed and processed using EZR, version 1.53.[12] Student *t* test, the Mann–Whitney *U* test, and Fisher exact test were used to compare differences between groups. The Wilcoxon signed-rank test was used to compare data between D5 (x) and D5(y). The level of statistical significance was set at $P = .05$ (2-tailed).

3. Results

Fifty eight puncture data points were obtained from 29 practitioners. The median θx was 0.8 degrees (IQR −1.0–3.0), and the median θy was 3.0 degrees (IQR −1.0–5.0). Figure 2 shows the locations of the needle tip when the depth of the inserted needle was 5 cm. The median D5 was 0.47 cm (range 0.06–1.05), and all locations were within 1.10 cm of the origin. D5(y) was significantly longer than D5(x) (median (range) 0.26 cm (range −0.60–0.95) vs 0.07 cm (range −0.52–0.48), $P = .003$). The plot of $D5_{2nd}$ when $D5_{1st}$ was defined as the origin is shown in Figure 3. All locations were within 0.70 cm of the origin, and the median difference between $D5_{1st}$ and $D5_{2nd}$ was 0.22 cm (range 0.00–0.69). When the area was divided into 4 quadrants by the x-axis and y-axis, 32 of 58 punctures (55.2%) occurred in the right-upper quadrant, and 25 practitioners (86.2%) placed the 1st and 2nd punctures in the same quadrant. We compared the experienced group (n = 19) and inexperienced group (n = 9). Figure 3 shows the locations of the needle tip at a depth of 5 cm by the experienced and inexperienced groups. The median D5 of the experienced group was shorter than that of the inexperienced group (median 0.40 cm (range 0.06–0.66) vs 0.58 cm (range 0.44–1.05), $P < .001$), while the difference between $D5_{1st}$ and $D5_{2nd}$ was not significant between the experienced and inexperienced groups (Fig. 5) (median 0.22 cm (range 0.00–0.40) vs 0.41 cm (range 0.04–0.69), $P = .094$). In the experienced group, 17 of 38 punctures (44.7%) occurred in the right-upper quadrant, and there was no significant difference between D5(x) and D5(y) (median (range) 0.00 (−0.52–0.48) vs 0.17 (−0.61–0.61), $P = .076$).

4. Discussion

This study aimed to evaluate the position of the needle tip for a safer thoracentesis procedure by using a thoracentesis unit. All D5 values showed a narrow range within 1.1 cm, and the difference between $D5_{1st}$ and $D5_{2nd}$ was short (within 0.7 cm). Many practitioners punctured in the same quadrant for both punctures. Interestingly, punctures tended to shift in the y-axis direction, and more than half of practitioners punctured in the right-upper quadrant. Therefore, each practitioner might have his/her own preferences when performing punctures. Furthermore, D5 was shorter when measured in the experienced group

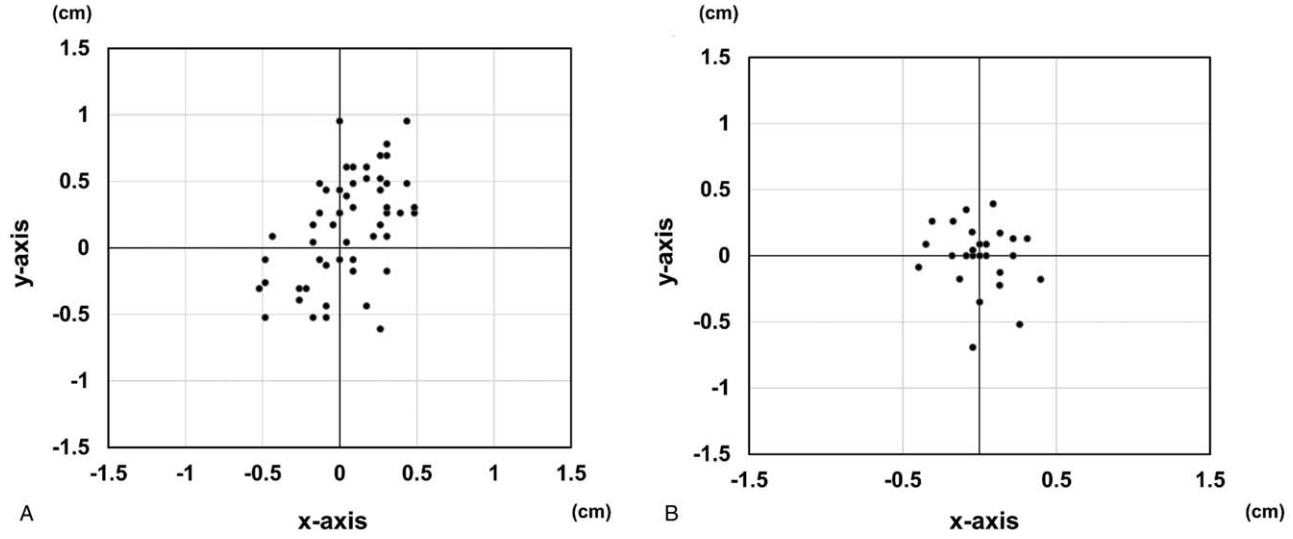

Figure 2. Locations of the needle tip when the depth of the inserted needle was 5 cm. (A): All puncture data. The median D5 was 0.47 cm (range 0.06–1.05). (B): Data for the 2nd puncture when the 1st puncture was defined as the origin. The median difference between $D5_{1st}$ and $D5_{2nd}$ was 0.22 cm (range 0.00–0.69). D5: The distance from the needle tip to the midline when the depth of the inserted needle was 5 cm. $D5_{1st}$: The distance from the needle tip to the midline on the 1st puncture when the depth of the inserted needle was 5 cm. $D5_{2nd}$: The distance from the needle tip to the midline on the 2nd puncture when the depth of the inserted needle was 5 cm.

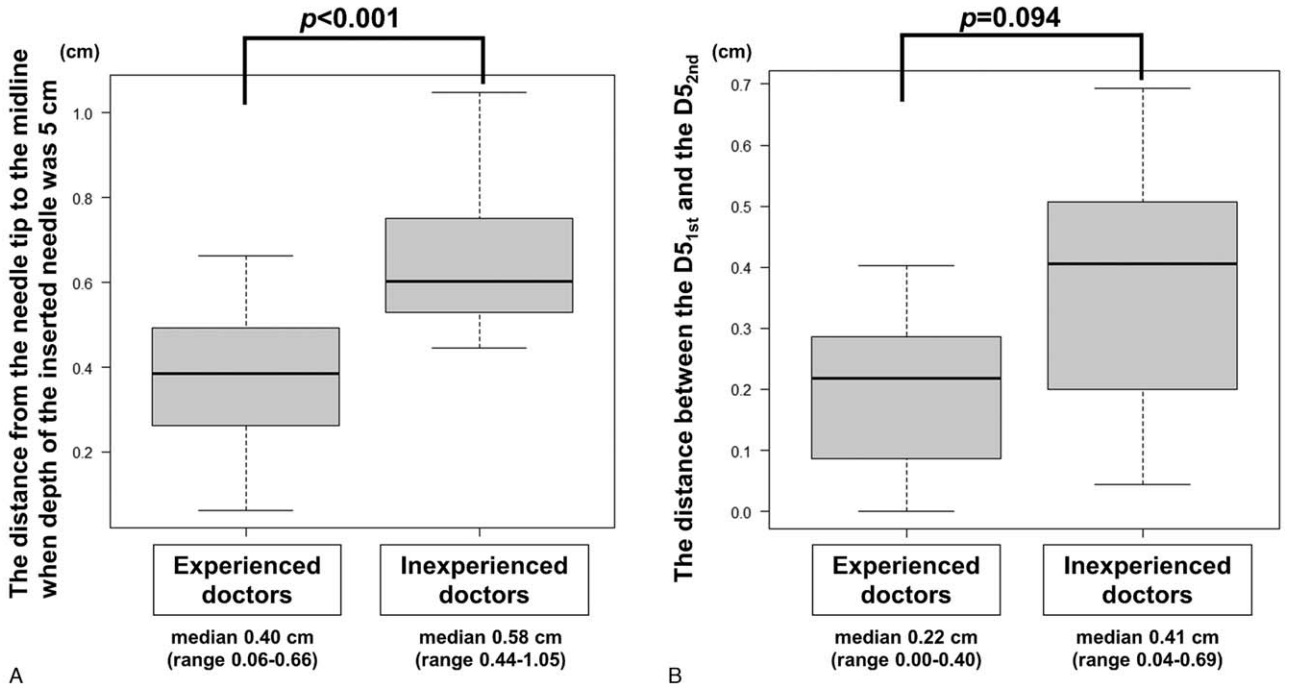

Figure 3. Comparisons between experienced doctors and inexperienced doctors. D5 measured for experienced doctors was less than that measured for inexperienced doctors (median 0.40 cm (range 0.06-0.66) vs 0.58 cm (range 0.44–1.05), $P < .001$). The difference between $D5_{1st}$ and $D5_{2nd}$ was not significant between experienced and inexperienced doctors (median 0.22 cm (range 0.00–0.40) vs 0.41 cm (range 0.04–0.69), $P = .094$). D5: The distance from the needle tip to the midline when the depth of the inserted needle was 5 cm. $D5_{1st}$: The distance from the needle tip to the midline on the 1st puncture when the depth of the inserted needle was 5 cm. $D5_{2nd}$: The distance from the needle tip to the midline on the 2nd puncture when the depth of the inserted needle was 5 cm.

than that in the inexperienced group. From the above results, understanding individual data, such as the position of the needle tip, could be useful for the evaluation of safety techniques and training methods.

This study evaluated the position of the needle tip when the depth of the inserted needle was 5 cm, using a chest wall reference thickness of 47.29 mm at the 2nd intercostal space on the mid axillary line and 34.33 mm at the 4th/5th intercostal space on the anterior axillary line.[13] Generally, a 60 mm 16-G catheter or a 40 mm 21-G needle in slim subjects, whose distance from skin to parietal pleura is less than 40 mm, are used for thoracentesis.[14] Our results suggest that extra space in all directions over a range of at least 1.8 cm (maximum D5 and maximum difference between $D5_{1st}$ and $D5_{2nd}$) under preprocedural ultrasonography is required for thoracentesis. A previous report demonstrated that the incidence of pneumothorax following preprocedural ultrasonography was relatively high (12%);[15] therefore, doctors should know that the direction of actual puncture might be shifted a maximum of more than 1 cm from the direction evaluated by ultrasonography.

Risk factors for pneumothorax have been reported to decrease with ultrasonography-guided thoracentesis,[8] a small amount of aspirated pleural fluid,[8,15] and experienced operators.[5] Thoracentesis in our hospital is usually performed with 2 punctures, an exploratory puncture and an indwelling needle, under preprocedural ultrasonography without ultrasonography guidance. However, the incidence of complications in our hospital is relatively low, as the rate of iatrogenic pneumothorax was 1.89% (3 of 159 cases) and the rate of iatrogenic haemothorax was 0.63% (1 of 159 cases) from January to June 2020. These rates were as low as those of ultrasonography-guided thoracentesis in previous reports.[5–10] Respiratory doctors in our hospital, who constituted the experienced group in this study, had many years of experience (median 16 years (IQR 13–22)), and the experienced group could place punctures more accurately than the inexperienced group. Therefore, the low incidence of pneumothorax might be related to the level of experience.

The experiential training methodology in a previous prospective study was as follows: a half-day workshop using ultrasound imaging and cadaveric and inanimate models, direct supervision of an experienced proceduralist during the initial 10 thoracenteses on human subjects, and feedback.[5] Other previous reports also suggested introducing simulation-based education for thoracentesis skills.[9,16,17] The importance of thoracentesis education has been discussed, especially for residents.[5,17] Most resident physicians learn to perform invasive procedures in a manner that is neither standardized nor rigorous; therefore, they are uncomfortable performing thoracentesis procedures, as they are higher discomfort procedures than central line insertion, lumbar puncture, or paracentesis.[18] It may be helpful to measure the angle of puncture in practice using simulation models such as our thoracentesis unit to train for safer thoracentesis procedures. All doctors in our study received feedback on how far their needle tip was from the midline and were able to modify their procedure. This practice, which includes measurement of the angle of puncture without human subjects and receiving feedback, might be useful for other invasive procedures.

This investigation had several limitations. It was conducted in a single centre. The thoracentesis unit in the study was handmade, and the angle of the needle tip to the midline was measured with protractors and observed with the naked eye. However, the angle

of the needle was measured to utilize lines passed through the centre on the wooden board to overlap the 90-degree line of a protractor; therefore, we believe that the angle was measured accurately.

5. Conclusion

This study demonstrated that the distance from the needle tip to the midline was within 1.1 cm, and $D5_{2nd}$ showed a difference from $D5_{1st}$ of less than 0.7 cm. Interestingly, it was easy for punctures to shift in the y-axis direction, and more than half of practitioners tended to place punctures in the right-upper quadrant. Therefore, every doctor should know that the needle direction might be shifted approximately 1 cm even if they puncture straight towards the centre.

Author contributions

Conceptualization: Masafumi Shimoda, Kozo Morimoto.
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Formal analysis: Masafumi Shimoda.
Investigation: Masafumi Shimoda.
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Project administration: Masafumi Shimoda, Ken Ohta.
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Supervision: Masafumi Shimoda, Kozo Morimoto.
Validation: Masafumi Shimoda.
Visualization: Masafumi Shimoda.
Writing – original draft: Masafumi Shimoda.
Writing – review & editing: Masafumi Shimoda, Kozo Morimoto.

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