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The Optimal Angles and Point of Needle Insertion in Paramedian Spinal Anesthesia: an Ultrasonographic Study

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Abstract

Background: Multiple attempts at needle placement in conventional paramedian spinal anesthesia are still often required to reach the subarachnoid space in some individuals. This study aims to assess the optimal angles and point of needle insertion for spinal anesthesia using neuraxial ultrasound scanning.

Method: Neuraxial ultrasound scanning of the L2-L5 intervertebral spaces in 120 volunteers aged 20-79 years was performed. The optimal vertical and horizontal angles were analyzed using the Arccosine function. The baseline characteristics, neuraxial structural depth, and optimal needle insertion point were evaluated in transverse midline (TM) and paramedian sagittal oblique (PSO) views from ultrasound scanning.

Results: At 1 cm caudal to spinous process, mean optimal needle-entry angle was 18.6±5.2°, 18.5±5°, and 18.7±4.9° in PSO view and 25±6.2°, 25.7±6.3°, and 28.1±6.9° in TM view at L2/3, L3/4 and L4/5 intervertebral space, respectively. The distance from midline to lateral for paramedian needle insertion was 1.7±0.4 cm at both L2/3 and L3/4, and 1.8±0.4 cm at L4/5 intervertebral space. There was significant inverse correlation between maximal vertical angle, age, and BMI at L2-5 ($P < 0.05$).

Conclusion: The optimal angles of needle trajectory range for paramedian spinal anesthesia were 13-25° vertically and 17-35° medially off the sagittal plane in L2-L5 levels, and optimal point for needle insertion was 1.7-1.8 cm lateral from midline. Increased age and high BMI were associated with unfavorable parameters which may result in difficult spinal anesthesia.

Keywords: geometrical model, paramedian approach, spinal anesthesia, ultrasonography

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Introduction

Conventional spinal anesthesia using the paramedian approach was described based on surface anatomical landmarks as 1 cm lateral-caudad needle insertion, with 10 to 15 degrees off the sagittal plane in the cephalomedial plane in general population.[1] However, multiple attempts at needle placement are still often required to reach the subarachnoid space, and this conventional procedure may be difficult and unsuccessful in some patients especially in obese and elderly people, which may have an abnormality of the spine or be unable to fully flex the lumbar.[2-4] Moreover, multiple puncture attempts and traumatic needle placement may result in numerous complications such as patient discomfort, post-dural puncture headache, paresthesia, and spinal hematoma.[5]

Nowadays, real-time and pre-procedural ultrasound-guided spinal anesthesia have been increasingly used not only to improve the success rate of spinal anesthesia but also to decrease the attempts in needle placement and redirection.[6-10] Ultrasound scan is advantageous in providing clear neuraxial structural image, ensuring radiation safety and lowering cost, as evidenced by many studies which support the use of pre-procedural ultrasound-guided spinal anesthesia over the conventional surface landmark-guided technique.[9,11] However, only a few studies described optimal angles and needle insertion point in the conventional paramedian approach by using ultrasound guidance at different intervertebral levels.[7,11] This study seeks to fill this gap by identifying the optimal angles, needle insertion point and correlation with patient characteristics using the Arccosine function from lumbar neuraxial ultrasound scanning in the parasagittal oblique (PSO) and transverse median (TM) views.

The primary outcome of this study was the identification of optimal vertical and horizontal angles for needle placement, using the paramedian approach on the L2-L5 intervertebral spaces and the optimal skin distance from the midline of neuraxial alignment to needle insertion point. The secondary outcome was the correlation of optimal angles and participants' characteristics at each intervertebral level.

Materials and methods

Following approval by the institutional review board at Faculty of Medicine, Chulalongkorn University, and registration in the Thai Clinical Trials Registry [TCTR20180818001], we recruited 121 volunteers aged 20-79 years at King Chulalongkorn Memorial Hospital. The exclusion criteria were spinal pathologies such as scoliosis, spondylolisthesis, spondylosis and history of spine surgery.

Arccosine function

A mathematical approach using the Arccosine function is determined by the needle insertion point-posterior dura distance (a) and the perpendicular distance (b). The optimal angles (θ) in each intervertebral level were calculated by inverse Cosine or Arccosine [Arccosine b/a][10] as shown in Figure 1.

First, after written informed consent was obtained, trialing the application of this model on one patient, we confirmed our hypothesis

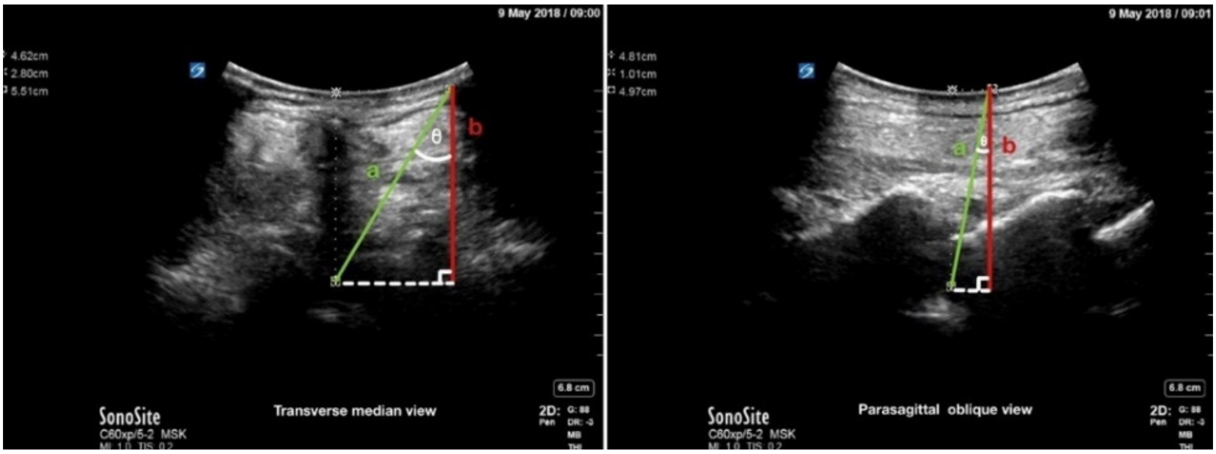

Figure 1 Cosine θ=b/a; Arccosine b/a=θ

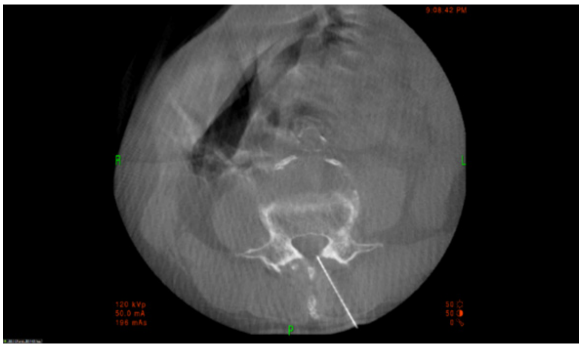

Figure 2 Needle position was confirmed using computed tomography (CT) image.

that the Arccosine calculation enables more precise calculation of optimal vertical and horizontal angles. Various parameters were measured from the preprocedural-ultrasound scan. After sterile preparation, the anesthesiologist (W.K.) performed spinal anesthesia with a 27-gauge Quincke spinal needle. The puncture site was marked during scanning. A sterile protractor was used to measure the calculated needle angles. A precise position of the needle was confirmed using a computed tomography (CT) image of the neuraxial structure under the mobile C-arm cone-beam computed tomography (CBCT), as shown in Figure 2.

Study procedure

One-hundred twenty participant was brought to the block room. Neuraxial ultrasound scanning was performed by an anesthesiologist with over five years of experience in the procedure (W.K., B.S.). All participants were positioned laterally on their left side in full flexion, as shown in Figure 3. Anatomical landmarks were subjectively graded as easy (iliac crest, spinous process and interspinous gaps are easily palpable), moderate (iliac crest, spinous process and interspinous gaps are less palpable), difficult (unable to palpate iliac crest or spinous process or interspinous gaps), and impossible (unable to palpate iliac crest, spinous process and interspinous gaps altogether).

Neuraxial ultrasound scanning was performed using a 2-5 MHz curvilinear transducer of SonoSite X-Porte, Bothell, Washington. The scanning was done in 2 ultrasound planes: midline approach resulting in the transverse median (TM) view and paramedian approach resulting in the parasagittal oblique (PSO) view. The ultrasound view quality was

Figure 3 Participants were positioned and held by an assistant.

determined via the visibility of the ligamentum flavum-dura mater complex (LF) and posterior longitudinal ligament (PLL). This was classified into 5 grades: excellent (both LF and PLL clearly visible), very good (either LF or PLL clearly visible), good (both LF and PLL not clearly visible), poor (either LF or PLL poorly visible) and very poor (both LF and PLL not visible).

Firstly, the ultrasound transducer was placed on the left parasagittal plane and tilted towards the midline for the PSO view of the L2-L5 intervertebral spaces (see Figure 4). The laminae and intervertebral spaces were identified. "A" refers to skin distance from the midline of the neuraxial alignment to the center of the ultrasound transducer in the best image of the PSO view. The transducer was stabilized, and the best image was captured for various measurements. The puncture site of the paramedian spinal approach was identified as 1 cm caudal from halfway of the ultrasound probe. The distances from the needle insertion point to the upper and lower borders of the posterior dura are defined as "Z" and "Y", consecutively. "X" represents the perpendicular distance from the needle insertion point to the posterior dura. The optimal vertical angle in the PSO view was then calculated from the difference between β and δ angles, derived from the Arccosine function in trigonometry:

$$\beta - \delta = \text{Arccosine } X/Z - \text{Arccosine } X/Y$$

Secondly, the ultrasound probe was rotated by 90° to the TM view, as shown in Figure 5. "A", the skin distance (cm) from the PSO view, is the left lateral distance of the needle insertion point from the midline of neuraxial alignment. The distance from the needle insertion point to right and left borders of the

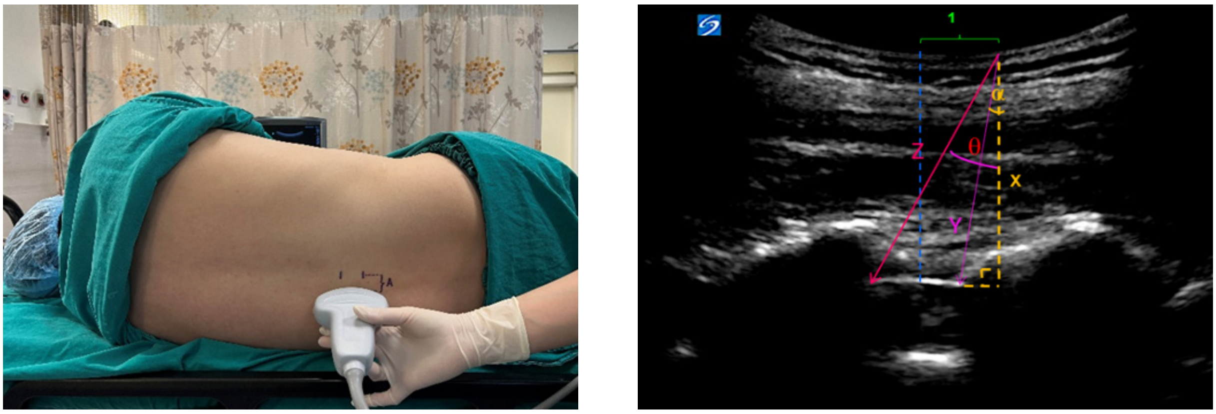

Figure 4 Paramedian sagittal oblique view (PSO view) of neuraxial ultrasound scanning.

posterior dura are defined as "D" and "C", consecutively. "B" is the perpendicular distance from the needle insertion point to the posterior dura. Similar to that in the PSO view, the optimal horizontal angle in the TM view was calculated from the difference of β and δ angles:

$$\beta - \delta = \text{Arccosine B/D} - \text{Arccosine B/C}$$

Sample size calculation

Since there had been no previous study of similar design, and as this research is a descriptive study, we used factorial design to calculate the sample size, with gender and age as subdivision factors. Participants of ages ranging from 20-79 years were divided into 6 groups of equal age ranges: 20-29, 30-39, 40-49, 50-59, 60-69 and 70-79. For each age group, 20 participants were recruited, consisting of 10 males and 10 females. In total, 120 participants were recruited for this study.

Data analysis and statistics

Data were analyzed using SPSS (version 25.0, Chicago, IL, USA). The categorical variable was shown in number and percentage. Chi-square test was used to calculate the difference. Data with normal distribution was summarized as mean (SD) and compared with independent T-test. Data with non-normal distribution was described in median (interquartile range) and compared with Mann-Whitney U test. We used Pearson's correlation coefficient to determine the correlation. $P < 0.05$ was deemed statistically significant.

Results

One hundred and twenty subjects were enrolled in this study. Table 1 summarizes the population characteristics. The mean age of population was 50.4±17.2 years, and the mean weight was 67.3±12.7 kg. Quality of ultrasound scan in the PSO and TM view at each lumbar intervertebral space was shown in Table 2. The ultrasound imaging in the PSO view was graded excellent in majority of population (42.5% at L2/3, 40% at L3/4, and 54% L4/5 intervertebral space), whereas in the TM view, the ultrasound visibility was graded excellent in smaller population (24.2% at L2/3, 23.3% at L3/4 and 31.7% L4/5 intervertebral space).

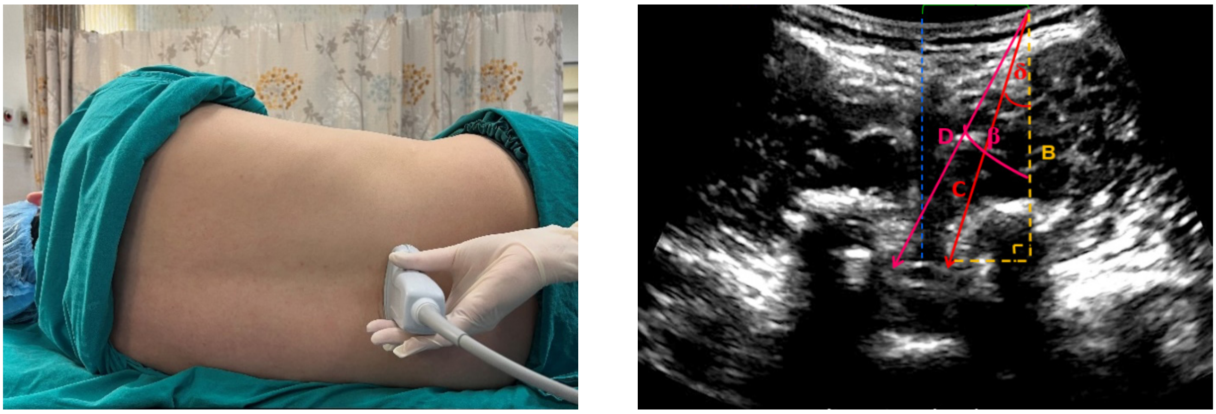

Figure 5 Transverse median view (TM view) of neuraxial ultrasound scanning.

Table 1 Demographic data

Variables	n=120
Age (yr), mean±SD	50.4±17.2
Gender, n (%)	
Female	60 (50.0)
Male	60 (50.0)
Weight (kg), mean±SD	67.3±12.7
Height (cm), mean±SD	163.9±9.2
BMI (kg/m^2), mean±SD	25.0±4.2
Back exam, n (%)	
Easy	80 (66.7)
Moderate	38 (31.7)
Difficult	2 (1.7)
Failed spinal anesthesia history, n (%)	120 (100.0)
Intercristal line, n (%)	
L2/3	4 (3.3)
L3/4	36 (30.0)
L4/5	80 (66.7)

Values are reported as mean±SD or number (%) of patients

Abbreviation: BMI, Body mass index; SD, standard deviation

The needle-entry angle in the PSO view and TM view, and midline-to-lateral distance for paramedian needle insertion at all levels are presented in Table 3. The optimal angle of needle trajectory range for paramedian spinal anesthesia was 13-25° vertically and 17-35° medially off the sagittal plane. In each lumbar intervertebral level, the mean needle-entry angle was 18.6±5.2° at L2/3, 18.5±5° at L3/4 and 18.7±4.9° at L4/5 intervertebral space in the PSO view. While in the TM view, mean needle-entry angle was 25±6.2° at L2/3, 25.7±6.3° at L3/4 and 28.1±6.9° at L4/5 intervertebral space. The distance from midline to lateral for paramedian needle insertion was 1.7±0.4 cm at both L2/3 and L3/4, and 1.8±0.4 cm at L4/5 intervertebral space.

Analysis of optimal angles and midline-to-lateral distance for paramedian needle insertion point at L2-5 with the independent predictive variables using Pearson's correlation revealed that the vertical angle θ (maximum cephalad angle) in the PSO view (explained in Figure 1) was significant inverse correlated with BMI ($r = -0.344$, $P < 0.001$ at L2/3; $r = -0.263$, $P = 0.004$ at L3/4; and $r = -0.445$, $P < 0.001$ at L4/5). In addition, the vertical angle θ significantly decreased with age ($r = -0.215$, $P = 0.019$ at L2/3; $r = -0.322$, $P < 0.001$ at L3/4; and $r= -0.322$, $P < 0.001$ at L4/5). The length of interspinous gap was also inversely correlated with age ($r = -0.236$, $P = 0.1$ at L2/3; $r = -0.524$, $P < 0.001$ at L3/4; and $r = -0.446$, $P < 0.001$ at L4/5). The distance from midline to lateral for paramedian needle insertion showed a significant positive correlation with weight ($r = 0.253$, $P = 0.005$ at L2/3; $r = 0.214$, $P = 0.019$ at L3/4; and $r = 0.239$, $P = 0.009$ at L4/5). However, no significant association between the independent predictive variables and lateromedial angle variables were observed in the TM view.

Discussion

In this study we have described the optimal angles and needle insertion point for paramedian spinal anesthesia at lumbar intervertebral levels using geometrical models. At 1 cm caudal to the spinous process, our findings showed that caudad angle ranged between 13-25° and medial angle ranged between 17-35° off the sagittal plane which are slightly inconsistent with suggested conventional paramedian technique; angle 10° to 15° off the sagittal plane in a cephalomedial

Table 2 Characteristics of the lower lumbar spine

	L2-3	L3-4	L4-5
Parasagittal oblique view, n (%)	51 (42.5)	48 (40.0)	54 (45.0)
Excellent	27 (22.5)	22 (18.3)	29 (24.2)
Very good	33 (27.5)	33 (27.5)	26 (21.7)
Good	9 (7.5)	17 (14.2)	8 (6.7)
Poor	0	0	3 (2.5)
Very poor			
Transverse median view, n (%)			
Excellent	29 (24.2)	28 (23.3)	38 (31.7)
Very good	29 (24.2)	22 (18.3)	31 (25.8)
Good	33 (27.5)	35 (29.2)	30 (25.0)
Poor	22 (18.3)	25 (20.8)	18 (15.0)
Very poor	7 (5.8)	10 (8.3)	3 (2.5)

Values are reported as number (%) of patients.

Table 3 Needle-entry angle (degree) in parasagittal oblique view and transverse median view, distance from midline to lateral for paramedian insertion

	L2-3	L3-4	L4-5
Parasagittal oblique, mean±SD			
Minimum needle-entry angle (degree)	13.4±5.3	13.1±4.8	13.0±4.5
Maximum needle-entry angle (degree)	24.0±5.3	24.0±5.0	24.4±5.5
Mean needle-entry angle (degree)	18.6±5.2	18.5±5.0	18.7±4.9
Transverse median, mean±SD			
Minimum needle-entry angle (degree)	17.7±6.6	18.4±6.5	21.1±7.0
Maximum needle-entry angle (degree)	32.3±5.8	33.1±5.8	35.2±6.5
Mean needle-entry angle (degree)	25.0±6.2	25.7±6.3	28.1±6.9
Distance from midline to lateral for paramedian approach (cm), mean±SD	1.7±0.4	1.7±0.4	1.8±0.4

Values are reported as mean±SD.
SD, standard deviation

plane. Whereas the needle insertion point is comparable to the classical recommendation; 1-2 cm lateral and caudad to midline.[1]

Even though spinal anesthesia is widely performed in median approach, some anesthesiologists prefer paramedian approach. As stated in previous studies, paramedian technique demonstrated some advantages in terms of larger intervertebral spaces, better sonographic window in both paramedian sagittal oblique and transverse median planes and higher first-pass success rate.[12,13] However, the most common mistake when using paramedian approach is to insert needle too lateral to the midline and too cephalad angle considering that it required three-dimensional perception and involve variability in optimal insertion point and angle. Together with advantage of ultrasound visualization, our study also integrated geometrical models to determine the angle of needle trajectory and optimal needle insertion point, which may help reduce number of needle insertion attempts and needle redirection thus improve success rate for dural puncture.

Previous studies applied geometrical models to demonstrate optimal angle and point of needle insertion in spinal anesthesia. Vogt et al.[14] demonstrated that optimal point of needle insertion was more cranial when spinous processes run steeper and optimal cephalad angle for needle insertion were 9° when using midline approach. Another study by Puigdellivol-Sanchez and coworkers used Pythagoras' theorem to analyze the optimal angles possible for dural puncture in paramedian approach at lumbar levels from MRI and ultrasound image, their results showed that mean optimal angle for needle entry at L3/4 level from ultrasonography were 15.9° and 30° at 1 and 2 cm paramedian, respectively.8 While in our results, we found a slightly larger needle-entry angle (25.7°) and the optimal needle insertion point (1.7 cm) at this lumbar intervertebral level, for which conventional angle of 10-15° that suggested in previous literatures may not be generally applicable as some individuals may have anatomical variations of the spine.

Notably, there are several factors found to be associated with optimal angle and needle insertion points including age and body habitus. Previous study by Shankar and colleagues reported that interspinous gap alone significantly predicted first-attempt success when performing spinal anesthesia.[15] According to our analysis, maximal cephalad angle for needle entry was decreased and interspinous gap was narrower with increasing age. These findings would account for difficulty performing spinal anesthesia in older patients because of narrower possible optimal angle for needle insertion. Moreover, there is significant evidence supporting role of ultrasound scanning in improving successful neuraxial block in such patients as shown in previous studies.[11,16-18]

In addition, considering that neuraxial anesthesia in patients with high BMI can be challenging due to poorly palpable pertinent landmarks, previous studies have shown that ultrasound imaging can facilitate neuraxial anesthesia in this population by accurately determining interspinous space and predicting the depth from skin to dura, and therefore improve first-pass success rate and number of needle passes.[4,19-23] However, to the best of our knowledge, there were no prior studies investigating optimal angle or needle insertion in patient with high BMI. Existing study by Salman A et al. have only focused on needle insertion depth, showing direct correlation between BMI and needle depth.[24] In the present study, we demonstrated that patients with increased BMI were correlated with less cephalad maximal vertical angle and more lateral points for paramedian needle entry. These findings have implicated that needle trajectory in patients with higher BMI may require less cephalad angulation and more lateral needle insertion from midline to maximize success rate of dural puncture.

The current study has several limitations. Firstly, our results were obtained in general population, hence the optimal angle in our study may not be applicable to certain population such as pregnancy, elderly (more than 80 years of age), and patients with spinal deformities. Study by Kim et al. showed that optimal needle insertion at level of spondylolisthesis was more caudad than levels without spondylolisthesis, for which ultrasonography would be helpful in such patients.[25] Future studies should consider including investigation in these population. Secondly, ultrasound scanning is operator dependent thus measurement error was inevitable with small angle and distance. Moreover, angle measurements by ultrasound may be inconsistent with measurements by other methods such as MRI and CT imaging. As found in previous study by Puigdellivol-Sanchez and coworkers, angles were slightly but significantly greater when measured by ultrasound than by MRI at 2 cm paramedian.[8] The possible explanation would be skin and subcutaneous fat compression during ultrasound procedures. However, the overall measurements were comparable. Lastly, we did not practically perform dural puncture in study participants. Further studies are needed to confirm the advantages of ultrasonography in guidance of optimal angle and point of needle insertion during spinal anesthesia.

In conclusion, we demonstrated that the optimal angle range for paramedian spinal anesthesia were 13-25° vertically and 17-35° medially off the sagittal plane, and optimal needle insertion points were 1.7-1.8 cm lateral from midline. We also found that age and BMI were significantly determined the optimal vertical angles and needle insertion point. Therefore, we believe that our results may facilitate better understanding about the optimal angles and needle insertion point and help improve success rate when performing lumbar neuraxial anesthesia. Regardless, this study provides good fundamental idea for future research in special population.

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