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Relationship between leg length discrepancy and functional scoliosis in children and adolescents

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Abstract

Purpose As the relationship between leg-length discrepancy (LLD) and scoliosis has not been clearly defined, the purpose of this study was to explore the impact and severity of LLD in children and adolescents with scoliosis and the consistency between lower limb length discrepancy and pelvic height difference.

Methods This retrospective study was conducted using prospectively collected data from 63 patients with functional scoliosis-associated LLD who received treatment at our hospital from March 2021 to July 2024. The inclusion criteria included: ①Children or adolescents with functional scoliosis complicated with LLD; ②Scoliosis classified as thoracolumbar or lumbar curve; ③A bilateral acetabular dome line parallel to the superior sacral endplate. The patients' whole-spine posteroanterior and full lower limb radiographs were obtained to collect data on age, sex, LLD, Cobb angle, and pelvic height difference. Correlation analysis evaluated the relationship between LLD, leg-length discrepancy ratio (LLDR), Cobb angle, and the pelvic height difference. Univariate regression analysis was used to analyze the data using the SPSS software.

Results In all cases, the convex side of the scoliosis corresponded to the shorter leg side. Female patients constituted 67% of the cohort. The patients' mean age was 11.79 ± 3.52 years (range: 4 to 19 years). The average Cobb angle was 14.78 ± 4.99°, the average LLD was 11.22 ± 12.74 mm, and the mean pelvic height difference was 12.41 ± 10.32 mm. Significant correlations were observed when the bilateral acetabular dome line was parallel to the superior sacral endplate, and the scoliosis was thoracolumbar or lumbar, indicating associations between LLD and the Cobb angle ($R = 0.440$, $P < 0.05$) and between LLDR and the Cobb angle ($R = 0.445$, $P < 0.05$). Additionally, a strong positive correlation was identified between LLD and pelvic height difference ($R = 0.874$, $P < 0.05$), indicating a high level of concordance between pelvic height difference and LLD.

Conclusions In children and adolescents with functional scoliosis complicated by LLD, the Cobb angle significantly correlated with LLD. Additionally, LLDR also showed a significant correlation with the Cobb angle. A concordance was also observed between the pelvic height difference and LLD.

Clinical trial number Not applicable.

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Keywords Children and adolescents, Functional scoliosis, Cobb angle, Leg length discrepancy, Pelvic height difference

Introduction

Leg-length discrepancy (LLD) is a common orthopedic condition characterized by a length difference between the left and right lower limbs. In most cases, the discrepancy is minor, with approximately 90% of the population having a limb length discrepancy < 10 mm, while only 10% have perfectly equal lower limb lengths [1]. LLD is primarily attributed to excessive growth, growth disorders, and dysplasia of the lower limbs, all of which contribute to the discrepancy [2]. Severe LLD can lead to a range of complications. Current research and surveys have confirmed that LLD is linked to various diseases, including lower back pain, discopathy, hip and knee osteoarthritis, stress fracture, standing imbalance, and running injuries [3–8]. Although these diseases are relatively rare in children and adolescents, they can occur in adulthood as people age.

The primary skeletal adaptations to LLD include pelvic obliquity, rotation, and scoliosis [9]. When LLD is present, pelvic obliquity may develop. To maintain shoulder balance, the trunk may compensate by forming scoliosis. This type of scoliosis, commonly called functional scoliosis, typically resolves completely or partially when the LLD is corrected [10]. However, prolonged LLD can permanently alter spinal biomechanics, potentially converting functional scoliosis into structural scoliosis [11]. Furthermore, LLD may develop secondary to scoliosis due to asymmetric loading on the lower extremities [12, 13]. Therefore, early LLD identification and management is crucial. However, there is currently no widely accepted consensus on LLD treatment strategies. An LLD of less than 20 mm is generally common and typically does not result in significant clinical issues. In contrast, an LLD of 20 mm or greater is regarded as clinically significant and requires appropriate treatment.

However, our observations suggest that in children and adolescents with functional scoliosis who also have LLD, addressing discrepancies of less than 20 mm can significantly reduce or even completely correct the Cobb angle of scoliosis. Furthermore, there is a notable lack of research providing clinical guidance on treatment principles for children and adolescents with functional scoliosis complicated by mild LLD (less than 20 mm). This study explored the impact and severity of LLD on functional scoliosis in children and adolescents without other spinal disorders, as well as the consistency between lower limb length discrepancy and pelvic height difference.

Materials and methods

This is a study integrating prospective data collection and retrospective case analysis. The study population consisted of patients with scoliosis and LLD who attended outpatient clinics at the Second Hospital of Shanxi Medical University between March 2021 and July 2024. A total of 250 cases were initially collected. After applying strict inclusion and exclusion criteria, 63 patients were ultimately included in the study. This study has been approved by the Ethics Committee of the Second Hospital of Shanxi Medical University ([2025] YX No. 003). Patients who met the following criteria were included in the study: ① Children or adolescents with functional scoliosis complicated with LLD; ② Scoliosis classified as thoracolumbar or lumbar curve; ③ A bilateral acetabular dome line parallel to the superior sacral endplate (Fig. 1D). The exclusion criteria included: ① Scoliosis other than functional; ② Patients with a history of spinal or lower limb surgery; ③ Patients on orthopedic treatment with spinal braces; ④ Patients with other spinal or lower limb disorders; ⑤Other factors that cause pelvic obliquity, such as pelvic hypoplasia and rotation, abduction or flexion contracture hip, knee flexion contracture, Knee varus or valgus etc.; ⑥Those incomplete data, including incomplete radiographs.

All patients underwent anteroposterior full-spine and full-length lower extremity radiographs in an upright position. During the imaging procedure, patients stood on a horizontal platform facing the radiograph scanner. The examiner ensured patients fully extended their hip and knee joints and maintained a neutral pelvic position without rotation. Patients were instructed to support their body weight evenly on both legs without using auxiliary tools, such as wooden blocks or other height-enhancing objects, to balance LLDs. Two radiological technicians supervised the entire process to minimize variability and ensure consistency in the results.

The following data were collected: age, sex, LLD, Cobb angle, and pelvic height difference. Leg length was measured from the center of the femoral head to the midpoint of the line connecting the medial and lateral malleoli and converted to millimeters using the radiological scale in the imaging software. LLD was defined as the absolute difference in bilateral leg length (mm; Fig. 1B). However, as the absolute leg lengths varied across individuals, the same LLD could affect patients differently. To account for this variability, we introduced the leg length discrepancy ratio (LLDR), calculated as the LLD divided by the length of the unaffected (longer) leg and multiplied by 100 (%) [14]. Scoliosis was defined as a coronal Cobb angle ≥ 10°

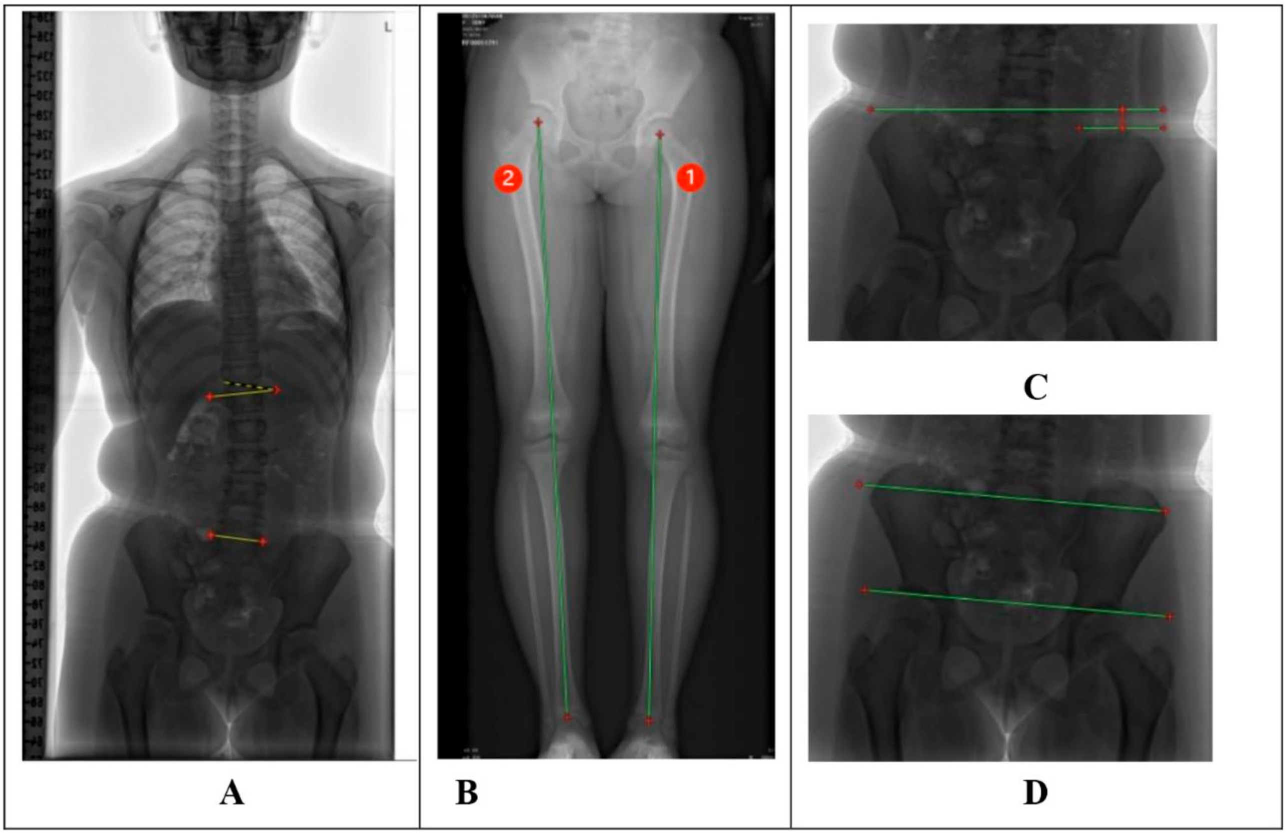

Fig. 1 **A**, **B**, **C**, and **D**: Radiographic measurements. (**A**) Cobb angle, The Cobb angle was measured as the angle between the upper and lower vertebrae angle; (**B**) Leg-length discrepancy(LLD) and leg-length discrepancy ratio (LLDR), Leg length was measured from the center of the femoral head to the midpoint of the line connecting the medial and lateral malleoli. LLD=①-②, LLDR=①-②/②*100%; (**C**) Pelvic Height Difference, Horizontal lines were drawn through the highest points of the bilateral iliac crests and the vertical distance between the two lines was measured; (**D**) The bilateral acetabular dome line is parallel to the superior sacral endplate

[15]. The Cobb angle was measured as the angle between the upper endplate of the superior vertebra and the lower endplate of the inferior vertebra (Fig. 1A) [16]. To determine the pelvic height difference, horizontal lines were drawn through the highest points of the bilateral iliac crests, and the vertical distance between these lines was measured in millimeters (Fig. 1C).

The absolute value was taken for LLD when analyzing the correlation between LLD and the Cobb angle. However, for the correlation between LLD and pelvic height difference, the difference was calculated by subtracting the height of the right side from that of the left. A positive value was recorded if the left side was higher than the right, while a negative value indicated that the left side was lower. Furthermore, patients were stratified into four LLD groups based on the degree of discrepancy: 0–5 mm, 5–10 mm, 10–20 mm, and > 20 mm.

Two spinal surgery residents independently extracted and measured radiological parameters using the Start WebClient system. The average of the two measurements was used as the final value. All data were presented as mean ± standard deviation. Since the sample size of the research object is > 50, the Kolmogorov-Smirnov test was used to examine the sample size. It was found that all variables did not conform to a normal distribution. As none of the variables were normally distributed, the Kruskal-Wallis test was employed to evaluate differences in pelvic height difference and Cobb angle across various LLD groups. The correlation between LLD and the Cobb angle of the main curve was assessed using Spearman's rank correlation coefficient. Univariable linear regression analysis was used to derive the regression equations, coefficients, and equations for the correlations between LLDR and Cobb angle, as well as between LLD and pelvic height difference. Statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS) Version 27.0. A p-value < 0.05 was considered statistically significant in all analyses. Correlations were categorized based on the absolute value of the corresponding coefficient (|r|) as weak (0.10–0.29), moderate (0.30–0.49), strong (0.5–0.99), or perfect (1.0) [17, 18].

Table 1 Demographic and clinical data for patients

Characteristic	Number of Patients	Percentage/ mean ± standard deviation
Gender		
Male	21	33
Female	42	67
Age(years)		
4–10	23	37
11–18	40	63
Average		11.79 ± 3.52
LLD(mm)		
≤ 5	15	21
5–10(>5)	32	54
10–20(>10)	11	17
>20	5	8
Average		11.22 ± 12.74
Cobb angle (°)		
≤ 20	57	91
20–30(>20)	4	6
>30	2	3
Average		14.78 ± 4.99
Curve of scoliosis		
Thoracolumbar	19	30
lumbar	44	70
pelvic height difference(mm)		
Average		12.41 ± 10.32

Results

The demographic data of all patients are shown in Table 1. The patients had a mean age of 11.79 ± 3.52 years (range: 4 to 19 years), with the majority being female patients, accounting for 67%. The mean Cobb angle was 14.78 ± 4.99°, the mean LLD was 11.22 ± 12.74 mm, and the mean pelvic height difference was 12.41 ± 10.32 mm (Table 1). In all cases, the convex side of the scoliosis corresponded to the shorter leg side, and the bilateral acetabular dome line was parallel to the superior sacral endplate. Figure 2A illustrates the relationship between LLD and Cobb angle, revealing a moderate and statistically significant correlation [correlation coefficient (R) = 0.440, $P<0.05$]. Figure 2B depicts the relationship between LLDR and Cobb angle, demonstrating a stronger correlation than that between LLD and Cobb angle [$R=0.445$, $P<0.05$]. The corresponding regression equations are as follows: Cobb angle = 11.06 + 0.33×LLD and Cobb angle = 11.21 + 2.25×LLDR. Figure 2C shows the relationship between LLD and pelvic height difference, with a strong correlation observed [$R=0.874$, $P<0.05$], indicating a high level of consistency between these parameters. LLD was further categorized into the 0–5 mm, 5–10 mm, 10–20 mm, and > 20 mm groups. Results of the Kruskal-Wallis test indicated significant differences in both the Cobb angle and pelvic height

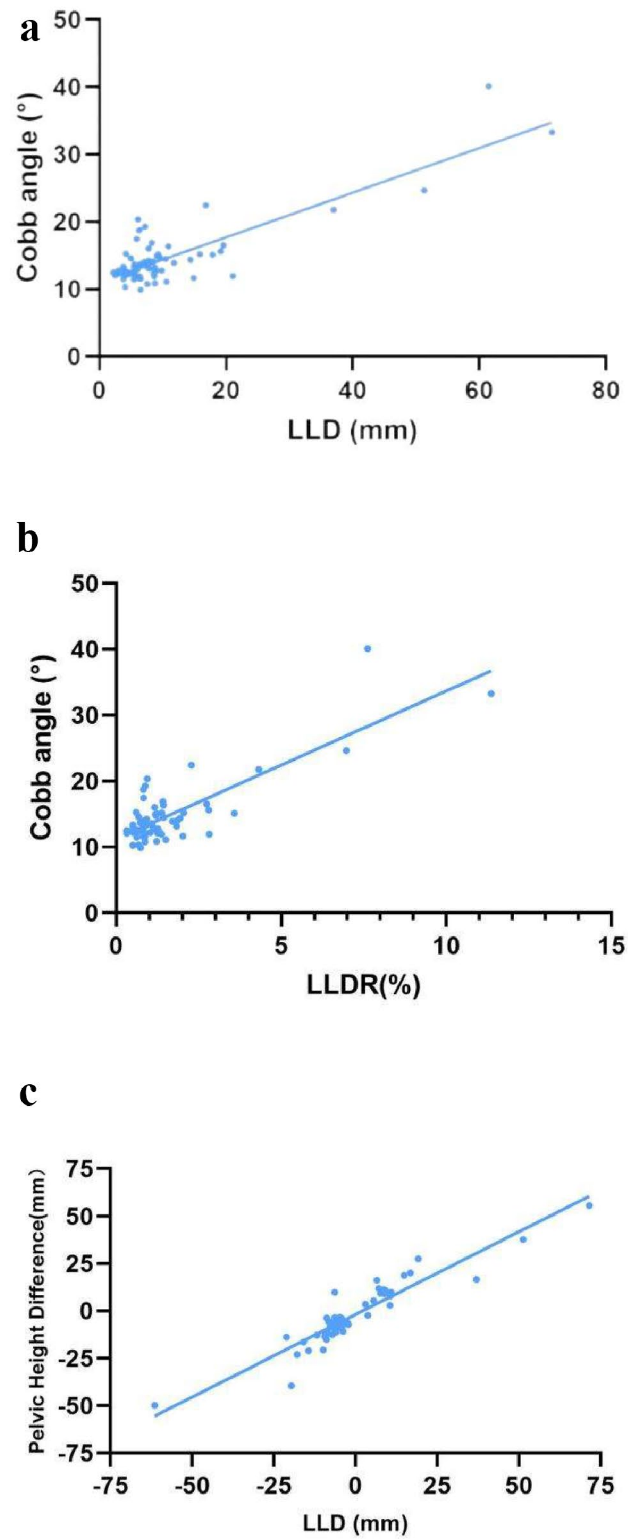

Fig. 2 **A**. The Cobb angle had a significant positive correlation with the LLD severity ($R=0.440$, $p<0.05$). LLD, leg-length discrepancy. **B**. The Cobb angle had a significant positive correlation with the LLDR severity ($R=0.445$, $p<0.05$). LLDR, leg-length discrepancy ratio. **C**. The LLD had a significant positive correlation with pelvic height difference ($R=0.874$, $p<0.05$)

Table 2 Details of the Cobb angle and pelvic height difference classified by LLD

Variable	LLD				H-value of Kruskal-Wallis	*p*
	0–5 mm($n=15$)	5–10 mm($n=32$)	10–20 mm($n=11$)	>20 mm($n=5$)		
Cobb angle (°)	12.460	13.330	15.090	24.650	12.254	0.007**
Absolute value of the pelvic height difference	6.300	9.450	18.700	37.700	28.211	0.000**

* $p<0.05$ ** $p<0.01$

Values are presented as mean ± standard deviation

difference among the groups ($p<0.05$). Detailed results are presented in Table 2.

Discussion

LLD is a common orthopedic condition observed in approximately 10% of primary school children [10]. Most studies suggest that an LLD < 20 mm is typically asymptomatic; however, discrepancies of 20 mm or greater are known to cause noticeable gait and/or posture disorders. As the degree of LLD increases, the severity of associated symptoms becomes more pronounced. Clinical observations, however, indicate that even mild LLD (< 20 mm) can significantly impact scoliosis. Correcting the LLD has been shown to significantly improve the Cobb angle of scoliosis. Jan Raczkowski reported similar findings showing that even mild primary LLD during growth and development may contribute to functional scoliosis [10]. Our results further demonstrated a significant correlation between mild LLD and scoliosis when the bilateral acetabular dome line was parallel to the superior sacral endplate, suggesting that mild LLD contributes to functional scoliosis. This type of scoliosis induced by lower limb discrepancy improves upon correction of the LLD. However, achieving bilateral limb length equalization is challenging, when the LLD is less than 20 mm, it can be managed by heel lifts or shoe lifts; when the LLD is greater than or equal to 20 mm, it requires meticulous planning and an appropriate management strategy. Before the intervention, precise measurement of the length discrepancy and consideration of the patient's age are critical factors in ensuring optimal outcomes [19–22].

Although LLD can impact the development and improvement of scoliosis, previous research reported no statistically significant correlation between LLD and scoliosis when no restriction was applied to the alignment of the bilateral acetabular dome line with the superior sacral endplate. To further investigate this phenomenon, we analyzed functional scoliosis in children and adolescents with LLD, particularly cases where LLD was ≤ 20 mm. Our findings suggest that the body compensates for the scoliosis induced by LLD through various regulatory mechanisms, including hip abduction, flexion and extension of the knee joints, and tilting or rotation of the pelvis and sacrum. These compensatory mechanisms may explain the absence of a significant correlation between mild LLD and scoliosis. However, when the bilateral acetabular dome line is parallel to the superior sacral endplate, the pelvis and sacrum can be regarded as a relatively large lumbar vertebral body, which eliminates the compensatory effects of pelvic and sacral tilting. Under these conditions, LLD exerts a direct effect on the spine, resulting in a significant correlation between LLD and scoliosis. These findings suggest the importance of early detection and intervention for LLD in children and adolescents with functional scoliosis, as timely treatment can help to partially alleviate scoliosis progression. Building on this analysis, future studies will investigate the impact of LLD on scoliosis when the bilateral acetabular dome line is not parallel to the superior sacral endplate.

Many other investigations have defined LLD based on the differences in femoral head position on anteroposterior full-spine radiographs [3, 11, 23, 24]. The primary advantage of this approach is that it allows simultaneous evaluation of the lower limbs and scoliosis on a single anteroposterior full-spine radiograph. However, anteroposterior full-spine radiographs cannot fully capture the entire length of the lower limbs; thus, defining LLD based solely on femoral head height differences is prone to inaccuracies. Additionally, If the hip joint is slightly abducted during imaging, the ipsilateral leg will appear shorter than its actual length. We measured radiological parameters using anteroposterior full-spine and full-length lower extremity radiographs and conducted a correlation analysis between LLD and the Cobb angle of scoliosis. We believe this approach provides the most objective and accurate results. Additionally, we utilized the calculation method proposed by Tomo Hamada [14], which determines the LLDR by dividing the LLD value by the length of the longer leg and multiplying by 100%. This method eliminates the confounding effect of different leg lengths for the same LLD. Our results were consistent with those reported by Tomo Hamada [14]. In patients with scoliosis whose bilateral acetabular dome line is parallel to the superior sacral endplate, we observed concordance between LLD and pelvic height difference. This finding suggests that a small difference in the structural length of the lower limbs can cause the development of pelvic asymmetry, an anteroposterior full-spine radiograph alone can effectively evaluate the relationship between the lower limbs and the spine, which reduces the patient's radiation exposure and financial burden.

This study has some limitations. First, the sample size needs to be expanded, particularly for cases of LLD > 20 mm, where the current number of samples is relatively small. Second, although clinical observations and previous reports, such as those by Giles and Taylor [3], indicate that internal or external heel lifts can correct scoliosis, with cases of LLD > 5 mm benefitting from heel elevation, we have not yet employed statistical methods to quantify the precise impact of LLD correction or improvement on scoliosis outcomes. Third, scoliosis is a complex deformity involving the coronal, sagittal, and transverse planes; however, this study only evaluated the relationship between LLD and the spine in the coronal plane. The impact of LLD on spinal alignment in the sagittal and transverse planes remains unexplored.

Conclusions

LLD is a common orthopedic condition that can contribute to spinal scoliosis. In children and adolescents with functional scoliosis complicated by LLD, a significant correlation between the Cobb angle and LLD was observed when the bilateral acetabular dome line was parallel to the superior sacral endplate, particularly for cases with LLD ≤ 20 mm. Furthermore, LLDR also exhibited a significant correlation with the Cobb angle. A marked concordance was also identified between pelvic height difference and LLD.

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Author contributions
XFH participated in study design, analyzed data and wrote the manuscript; XXH participated in study design, guided the research, supported the funds and revised the draft manuscript; JEZ participated in study design, prepared figures, sorted the image data and other data; ZQ participated in study design, prepared figures, sorted the image data and other data; ZS participated in study design, guided the research and reviewed the thesis; LK participated in study design, guided the research and reviewed the thesis; LYW participated in study design, prepared figures, sorted the image data and other data; All authors reviewed the manuscript.

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

Declarations

Ethics approval and consent to participate
This study was approved by the ethics committee of the Second Hospital of Shanxi Medical University([2025]YX No.003). All procedures performed on this study were in accordance with the ethical standards of the 1964 Helsinki declaration. Informed consent was obtained from all individual participants included in the study. For participants under the age of 16, written informed consent was obtained from the participants' parents or guardians.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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