

# How to equalize the leg length in total hip arthroplasty for patients with unilateral Crowe type IV developmental dysplasia of the hip

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## Research article

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# Abstract

**Background:** The purpose of this study was to explore that how to equalize the leg length in total hip arthroplasty (THA) with shortening subtrochanteric osteotomy (SSTO) or not for unilateral Crowe type IV developmental dysplasia of the hip (DDH) through the evaluation of the postoperative full-length anteroposterior radiographs.

**Methods:** The postoperative radiographs of 60 patients with unilateral Crowe type IV DDH from July 2012 to May 2019 were retrospectively reviewed. These data included leg length, femoral length, height of center of rotation (COR) of hip, height of greater trochanter, and depth of the sleeve or cone. Patients with leg length discrepancy (LLD) < 10 mm were defined as the non-LLD group.

**Results:** In the non LLD group (26 patients of SSTO and 22 of non-SSTO), the femoral length both SSTO and non-SSTO groups were significantly shorter on operated side, compared with the contralateral side, and the mean discrepancy in SSTO group was approximately equal to the mean length of SSTO. The mean height of COR of hip on operated sides both SSTO and non-SSTO groups were 13.2 mm, and the contralateral sides were 15.2 mm and 15.5 mm, respectively. The depth of the sleeve or cone between SSTO and non-SSTO groups were 21.7 mm and 30.6 mm, respectively. The depth of the sleeve or cone in SSTO group was negatively correlated with the length of SSTO. The height of the greater trochanter of the operated and contralateral sides were 5.3 mm and 16.6 mm in SSTO group, and those in the non-SSTO group were 13.2 mm and 17.2 mm.

**Conclusions:** SSTO led to femoral shortening on the operated side for patients with unilateral Crowe type IV DDH. The position of sleeve or cone should be close to the apex of greater trochanter to compensate the length of SSTO.

## Background

Unilateral Crowe type IV developmental dysplasia of the hip (DDH) is one of the most severe femur and acetabulum morphologic deformities, which results in pain of hip and low-back, limp, compensatory scoliosis of spine and leg length discrepancy (LLD) [1, 2]. Total hip arthroplasty (THA) is one of the most effective operation to alleviate pain, improve function and rectify compensatory scoliosis of spine and LLD [1, 3, 4]. The anatomical abnormalities in Crowe type IV DDH, including the small shallow acetabulum, the narrow and stovepipe-shaped proximal femur and excessive femoral anteversion, make THA more technical challenges[5–8]. Although careful preoperative planning and surgical techniques were used by the surgeon, the complications after THA can also occur. A frequently postoperative complication is LLD. LLD not only leads to gait asymmetry but also results in the increasing risk of prosthesis failure [9, 10], then may have negative effect on postoperative recovery and patient satisfaction.

In the setting of Crowe type IV DDH, femoral shortening osteotomy may be necessary to safely reduce the hip to the true acetabulum, mitigate hip soft-tissue contractions and protect the neurovascular structures

[5]. The most commonly used method is shortening subtrochanteric osteotomy (SSTO) [11, 12]. Although all the surgical techniques also may be needed to acquire appropriate leg length. Unfortunately, it is difficult to achieve the equal leg length due to the variation of femur, acetabulum and tibia, and there are no guidelines that enable the surgeon to achieve the equal leg length.

The purpose of the present study was to explore that how to equalize the leg length in THA with SSTO or not for unilateral Crowe type IV DDH through the evaluation of the postoperative full-length standing anteroposterior radiographs.

## Methods

We retrospectively reviewed the radiographic data of all patients with unilateral Crowe type IV DDH. The contralateral hips of all patients were normal (the Shenton line was intact, the acetabular index was normal or nearly normal and there was no osteoarthritis) [1]. A total of 87 patients were admitted to our hospital for THA as candidates for THA from July 2012 to May 2019. 27 patients were excluded for the following reasons: ten for prior hip or pelvic surgery, eight for residual DDH (infection and trauma), nine for no postoperatively full standing anteroposterior radiographs. There was no surgery on the tibia, no flexion contracture of hip, no knee flexion deformity and no history of cerebral palsy and poliomyelitis in the remaining 60 patients. The retrospective study was approved by our hospital ethics committee review board.

All patients underwent cementless ceramic-on-ceramic (CoC) bearing THA by a single surgeon (YGZ) using the Pinnacle acetabular shell, Biolox delta ceramic liner and femoral head, a S-ROM titanium alloy femoral stem with titanium sintered proximal sleeve or cone (DePuy, Warsaw, Indiana, USA). The acetabular shell was fixed by two screws. The SSTO was performed when the hip was hard reduction. The position of osteotomy was located at the distal end of sleeve or cone. Encirclage wiring (two or three steel wire) was done around the location of the osteotomy to prevent fractures.

### Groups according to LLD and SSTO

All patients were classified based on LLD after THA. Patients with LLD < 10 mm [9] (either shorter or longer) were defined as the non-LLD group, whereas patients with LLD  $\geq$  10 mm were defined as the LLD group. To identify differences associated with SSTO, each group was further divided into two groups based on whether SSTO or not.

### Radiographic measurements

The postoperative full-length standing anteroposterior radiographs were acquired at the follow-up period (at least 3 months). A Revolution XR/d digital imaging system (GE Healthcare, Milwaukee, WI) with the standard radiographic procedure was used [13]. We followed the methods of Zhang et al. [1]. The patient stood facing the X-ray tube, and film-focus distance was 200 cm. The system could be set at 70 to 90 kVp and 100 to 200 mA according to the height and weight of the patient. Each leg was internally rotated

(15 degree) to ensure that the patella located anteriorly. The beam was parallel to the ground when moving from the pelvis to the ankles, enabling the system to acquire 6 overlapping radiographs [1]. Then the system combined all radiographs into one full-length standing anteroposterior radiograph. All the radiographs were viewed and measured on a picture archiving and communication system (PACS, UniWeb Viewer, version 4.0, EBM technologies) [1].

Four measurements were made bilaterally on the full-length standing anteroposterior radiographs of each patient (**Fig.1**): (1) leg length, which was the distance from the teardrop to the center of the ankle joint (when the teardrop on operated side was covered after THA, which would be confirmed through the preoperative radiograph). (2) femoral length, which was the distance from the apex of greater trochanter to the articular surface of lateral femoral condyle. (3). the height of center of rotation (COR) of hip, which was the vertical distance from the COR of hip to the interteardrop line [14]. (4) the height of greater trochanter, which was the vertical distance from the apex of greater trochanter to the interteardrop line. One measurement was made on the operated side (**Fig.1**): the depth of the sleeve or cone in the femoral medullary canal, which was the vertical distance from the apex of greater trochanter to the proximal end of sleeve or cone.

The actual values for each measurement were obtained by calibration using the known diameter of the ceramic femoral head for references. Two independence investigators (YQD and JYS), who were familiar with digital measurement, performed the radiographic measurements. All of the measurements were repeated four weeks later to assess the intra-observer reliability. All radiographs on the blinded images for measurement were presented in random order to ensure that the investigator was blind to the patient's data. These intraclass correlation coefficients (ICCs) for inter-observer ( $> 0.92$ ) and intra-observer ( $> 0.90$ ) reliability indicated high reproducibility.

## Statistical analysis

Categorical data were compared using a chi-squared test. A paired samples t test or Wilcoxon test was used to compare continuous data between the operated and contralateral sides. An independent-samples t test or Mann-Whitney U test was used to compare continuous data between the SSTO and non-SSTO groups.

The correlation analysis was tested using Pearson's correlation coefficients. All tests were performed using SPSS version 25 (IBM Corp., Armonk, NY). Continuous data were given as the mean and standard deviation. A p-value  $< 0.05$  was considered significant in all analysis.

## Results

Of the 60 patients, the mean LLD was  $3.0 \pm 9.7$  mm. In SSTO group (36 patients), the operated side was shorter than the contralateral side in 32 patients (88.9%), and 4 patients (11.1%) had longer operated sides. In non-SSTO group (24 patients), the operated side was shorter than the contralateral side in 10 patients (41.7%), and fourteen patients (58.3%) had longer operated sides (Fig. 2). 48 patients (26 for

SSTO and 22 for non-SSTO) were in the non-LLD group and 12 (10 for SSTO and 2 for non-SSTO) were in the LLD group.

Patient the demographic characteristics in the non-LLD group was shown in Table I. There were no significant differences between SSTO and non-SSTO groups in gender, age, height, weight, BMI, side and sleeve or cone. The parameters of measurements on the full-length standing anteroposterior radiographs was showed in Table II.

In the non-LLD group, 26 patients were performed the SSTO, the mean length of SSTO was 29.0 mm (range from 15 mm to 45 mm). The leg length on the operated side was shorter, by an averaged of 4.2 mm, than that on the contralateral side. The mean leg length of the operated and contralateral sides were 680.6 mm and 684.9 mm, respectively ( $p < 0.001$ ). Compared that with contralateral side, the femoral length of operated side was significantly shorter, by a mean of 30.0 mm. The mean femoral length of the operated and contralateral sides were 358.6 mm and 388.6 mm, respectively ( $p < 0.001$ ). The discrepancy of the femoral length on contralateral and operated sides was positively correlated with the length of SSTO ( $r = 0.683$ ,  $p < 0.001$ ) (Fig. 3). The height of COR of hip on the operated side (13.2 mm) was lower, by an averaged of 2.0 mm, than that on the contralateral side (15.2 mm) ( $p = 0.046$ ). The mean height of the greater trochanter of the operated and contralateral sides were 5.3 mm and 16.6 mm ( $p < 0.001$ ).

22 patients were in non-SSTO group. the leg length on the operated side was longer, by an averaged of 1.6 mm, than that on the contralateral side. The mean leg length of the operated and contralateral sides were 698.8 mm and 697.1 mm, respectively ( $p = 0.226$ ). The mean femoral length of the operated and contralateral sides were 387.5 mm and 391.2 mm, respectively ( $p = 0.022$ ). The height of COR of hip on the operated side (13.2 mm) was lower, by an averaged of 2.3 mm, than that on the contralateral side (15.5 mm) ( $p = 0.157$ ). The mean height of the greater trochanter of the operated and contralateral sides were 13.2 mm and 17.2 mm ( $p = 0.077$ ).

The mean depth of the sleeve or cone between SSTO and non-SSTO groups were 21.7 mm and 30.6 mm, respectively ( $p < 0.001$ ). The depth of the sleeve or cone in SSTO group was negatively correlated with the length of SSTO ( $r = -0.632$ ,  $p = 0.001$ ) (Fig. 4).

The causes of LLD were analyzed in the LLD group. In SSTO group, five patients for the length of SSTO  $> 35$  mm, three for the depth of sleeve or cone  $> 25$  mm, two for the length of SSTO  $> 35$  mm and the depth of sleeve or cone  $> 25$  mm. In non-SSTO group, the length of tibia of two patients in operated side was longer than that in contralateral side (the discrepancy of the length of tibia were 12.0 mm and 18.0 mm, respectively).

## Discussion

LLD after THA with Crowe type IV DDH remains a major problem. Park et al. [15] reported the mean LLD after THA was 36 mm in 25 Crowe type IV DDHs. Wang et al. [16] also found the postoperative LLD

between 10 mm and 20 mm were presented in 39% of patients. How to equalize the leg length in THA for patients with unilateral Crowe type IV DDH remains a major problem. During THA, the height of COR of hip, the length of SSTO and the depth of sleeve or cone could affect the operated leg length. How to balance the relationship of the above factors to get a perfect THA is challenging for surgeon. In this study, we retrospectively reviewed the radiographic data of all patients with unilateral Crowe type IV DDH and explored that how to equalize the leg length through adjusting the relationship of the three factors in THA.

In Crowe type IV DDH, THA with placement of an acetabular cup in the false acetabulum or high hip center is an easier procedure, but cannot equalize the leg length and lead to problems with fixation, stability and the restoration of appropriate hip biomechanics [5, 17]. The placement of cup in the true acetabulum is imperative [2, 7, 15, 16]. In the past, an extra-small acetabular cup combined with a thin polyethylene liner was used to reconstruct in the true acetabulum. However, the high wear rate of polyethylene resulted in the high failure rate of component [2, 18]. As most of Crowe type IV DDH are quite young and more active, the CoC bearing may be the ideal option. Zhou et al. [2] found it was entirely feasible to make a 46 mm acetabular cup combined with CoC bearing in the true acetabulum by reaming acetabulum posteriorly and inferiorly by the finite element analysis and clinical results. All cups were stable at a mean duration of 3.7 years follow-up. Erdem et al. [19] in a study of 26 hips with Crowe type IV DDH, which were reconstructed in the true acetabulum (the height of COR of hip: 15 mm), found all the cups were stable at a mean follow-up of 7.1 years. In our study, the procedure of reconstructing the acetabular cup was followed the methods of Zhou et al. [2]. The placement of the acetabular cup was located in the posterior and inferior position of true acetabular region. The mean height of COR of hip on operated sides both SSTO and non-SSTO groups were 13.2 mm, and the contralateral sides were 15.2 mm and 15.5 mm, respectively.

However, the effective method that safely reduce the cup to the true acetabulum may be femoral shortening osteotomy, which also could protect the neurovascular tissues. The most commonly used method of osteotomy is SSTO [7, 8, 16]. The SSTO can be performed by using several techniques, including transverse, oblique, z-shaped and the v-shaped osteotomy. Muratli et al. found no difference with regard to stability of the four techniques during loading testing in a biomechanical laboratory setting [20]. In our study, 26 patients were performed the transverse SSTO in the non-LLD group, and the mean length of SSTO was 29.0 mm. The mean femoral length on operated side was significantly shorter compared with that on the contralateral side, and the mean discrepancy was approximately equal to the mean length of SSTO. The mean height of greater trochanter was also lower than that on the contralateral side after SSTO.

However, not all the Crowe type IV DDHs need the SSTO. Some factors or methods were reported to be able to achieve hip reduction without SSTO, such as the false acetabulum before THA, muscle release or tenotomy and injection of muscle relaxant [11, 12, 21, 22]. In our study, 22 patients were not performed the SSTO in the non-LLD group. The false acetabula were presented in 21 patients. The false acetabulum may be an important factor determining SSTO application. According to the measurement results after

THA, the height of greater trochanter on operated side was close to that on the contralateral side, which could be adjusted by the depth of sleeve or cone.

The depth of sleeve or cone in the femoral medullary canal was an important method to adjust the LLD after the cup was reconstructed in the true acetabulum. In SSTO group, the SSTO led to the femoral shortening on the operated side. The position of sleeve or cone should be close to the greater trochanter to compensate the length of SSTO. In non-SSTO group, the depth of sleeve or cone should be adjusted to make that the height of greater trochanter on the operated side was close to that on the contralateral side. The depth of sleeve or cone in non-SSTO group was deeper than that in SSTO group.

To the best of our knowledge, this is the first compared study regarding LLD after THA with SSTO or not. The strength of this study explored that how to equalize the leg length in THA with SSTO or not for unilateral Crowe type IV DDH. However, there are also several limitations in the study. First, this is a retrospective study with a relatively small patients for each group. The second limitation of our study is the lack of measurements of preoperative full-length standing anteroposterior radiographs, such as the height of dislocation and the length of femur and tibia on the operated side, which may be influence factors for SSTO and the leg length. Finally, all surgeries were performed in the single institution by a single surgeon, which could have affected the results of this study.

## Conclusions

According to our study, the placement of the acetabular cup was located in the posterior and inferior position of true acetabular region for unilateral Crowe type IV DDH. SSTO led to the femoral shortening on the operated side. The position of sleeve or cone should be close to the apex of greater trochanter to compensate the length of SSTO. The position of sleeve or cone without SSTO should be adjusted to make sure that the height of greater trochanter on the operated side was close to that on the contralateral side.

## Abbreviations

THA: Total hip arthroplasty; SSTO: Subtrochanteric shortening osteotomy; DDH: Developmental dislocation of the hip; COR: center of rotation; LLD: leg length discrepancy. CoC: ceramic-on-ceramic; ICCs: intraclass correlation coefficients.

## Declarations

### Ethics approval and consent to participate

The Ethics Committee of our hospital, General Hospital of Chinese People's Liberation Army, approved the study protocol. All the study participants provided written informed consent for the study.

### Consent for publication

Written informed consent was obtained from all patients for publication of this study and any accompanying images.

### **Availability of date and materials**

The data will be made available from the authors upon reasonable request.

### **Competing interests**

The authors declare that they have no competing interests.

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### **Authors' contributions**

YGZ and MN conceptualized and designed the study, YQD drafted the initial manuscript, analyzed and interpreted the data and revised the manuscript for important intellectual content. JYS, HYM and SW were involved in the data collection and analysis. NM and YGZ coordinated and supervised data collection, critically reviewed. All authors have read and approved the final manuscript.

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Not applicable.

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## Tables

**Table I.** Patient Demographic and clinical characteristics in non-LLD group.

Variable	SSTO	Non-SSTO	P values
Patients (n)	26	22	
Gender (n)			0.654
Male	2 (8%)	1 (5%)	
Female	24 (92%)	21 (95%)	
Age (yrs) *	39.9 ± 12.2	38.1 ± 10.7	0.555
Height (cm) *	158.4 ± 6.2	160.0 ± 5.6	0.325
Weight (kg) *	56.7 ± 9.7	58.5 ± 10.9	0.547
BMI (kg/m <sup>2</sup> ) *	22.5 ± 3.0	22.8 ± 3.9	0.791
Side (n)			0.371
Right	14 (54%)	9 (41%)	
Left	12 (46%)	13 (59%)	
Sleeve or Cone (n)			0.164
Sleeve	23 (88%)	16 (73%)	
Cone	3 (12%)	6 (27%)	

The values are given as the mean and standard deviation.

LLD, leg length discrepancy; SSTO, shortening subtrochanteric osteotomy; BMI, body mass index.

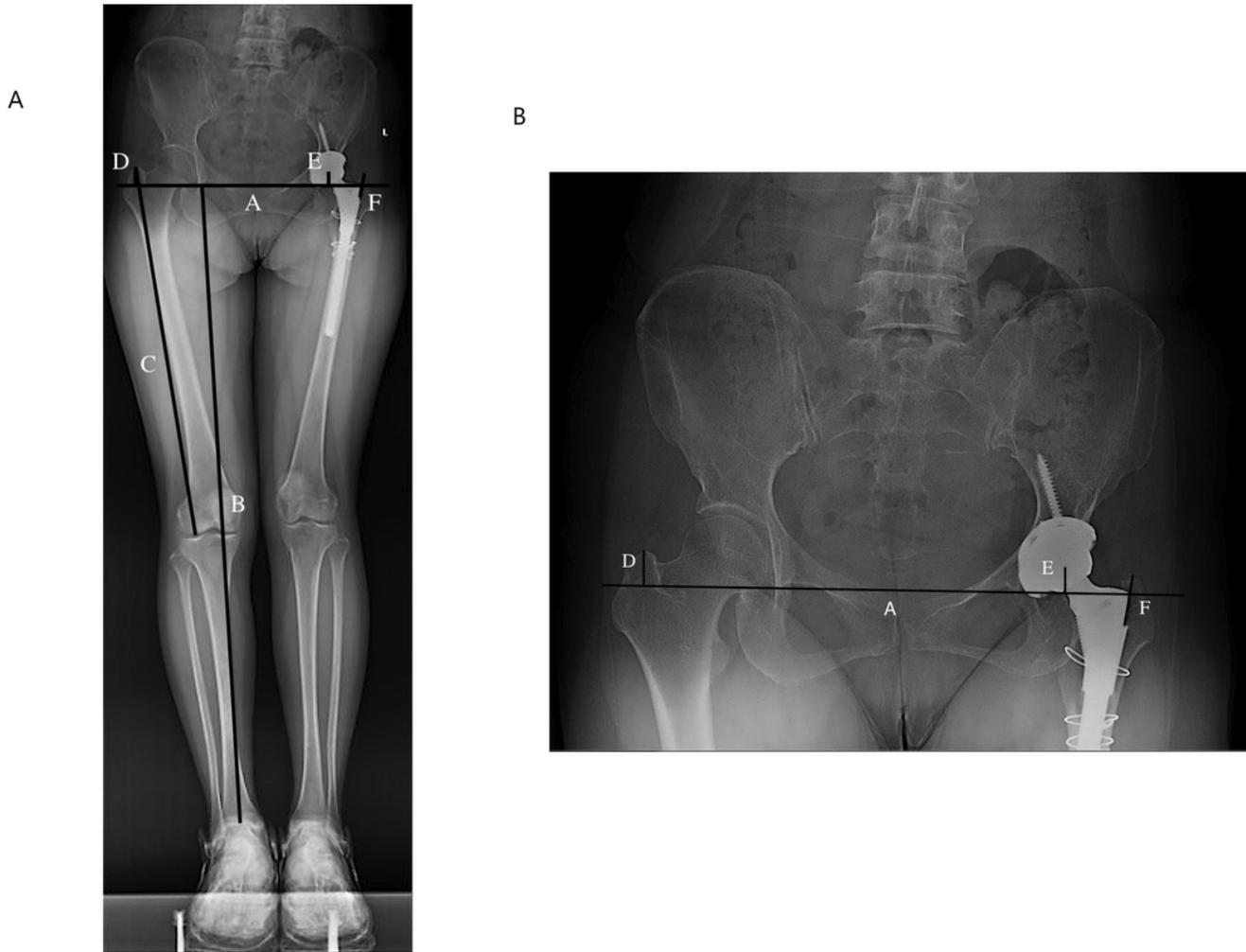
**Table II.** Parameters of measurements on the full-length standing anteroposterior radiographs in non-LLD group.

Parameter (mm)	SSTO (n=26)			Non-SSTO (n=22)			P values *
	Operated side	Contra-side	P values	Operated side	Contra-side	P values	
Leg length	680.6 ± 38.1	684.9 ± 40.0	<0.001	698.8 ± 41.2	697.1 ± 43.1	0.226	0.120
Femoral length	358.6 ± 23.1	388.6 ± 21.0	<0.001	387.5 ± 23.5	391.2 ± 27.1	0.022	<0.001
Height of center of rotation of hip	13.2 ± 4.0	15.2 ± 2.2	0.046	13.2 ± 6.3	15.5 ± 3.3	0.157	0.980
Height of the greater trochanter	5.3 ± 9.3	16.6 ± 5.9	<0.001	13.2 ± 7.5	17.2 ± 6.6	0.077	0.003
Depth of the sleeve or cone	21.7 ± 7.0	-	-	30.6 ± 7.0	-	-	<0.001

The values are given as the mean and standard deviation. If the value is negative, the height of rotational center of hip is below the greater trochanter. SSTO, shortening subtrochanteric osteotomy.

\* P values means the differences between the operated side of SSTO and Non-SSTO groups.

## Figures



**Figure 1**

The measurements determined on the full-length standing anteroposterior (a) and the partial enlarged radiographs (b). (A) Teardrop line. (B) Leg length. (C) Femoral length. (D) Height of greater trochanter. (E) Height of rotational center of hip. (F) Depth of the sleeve or cone.

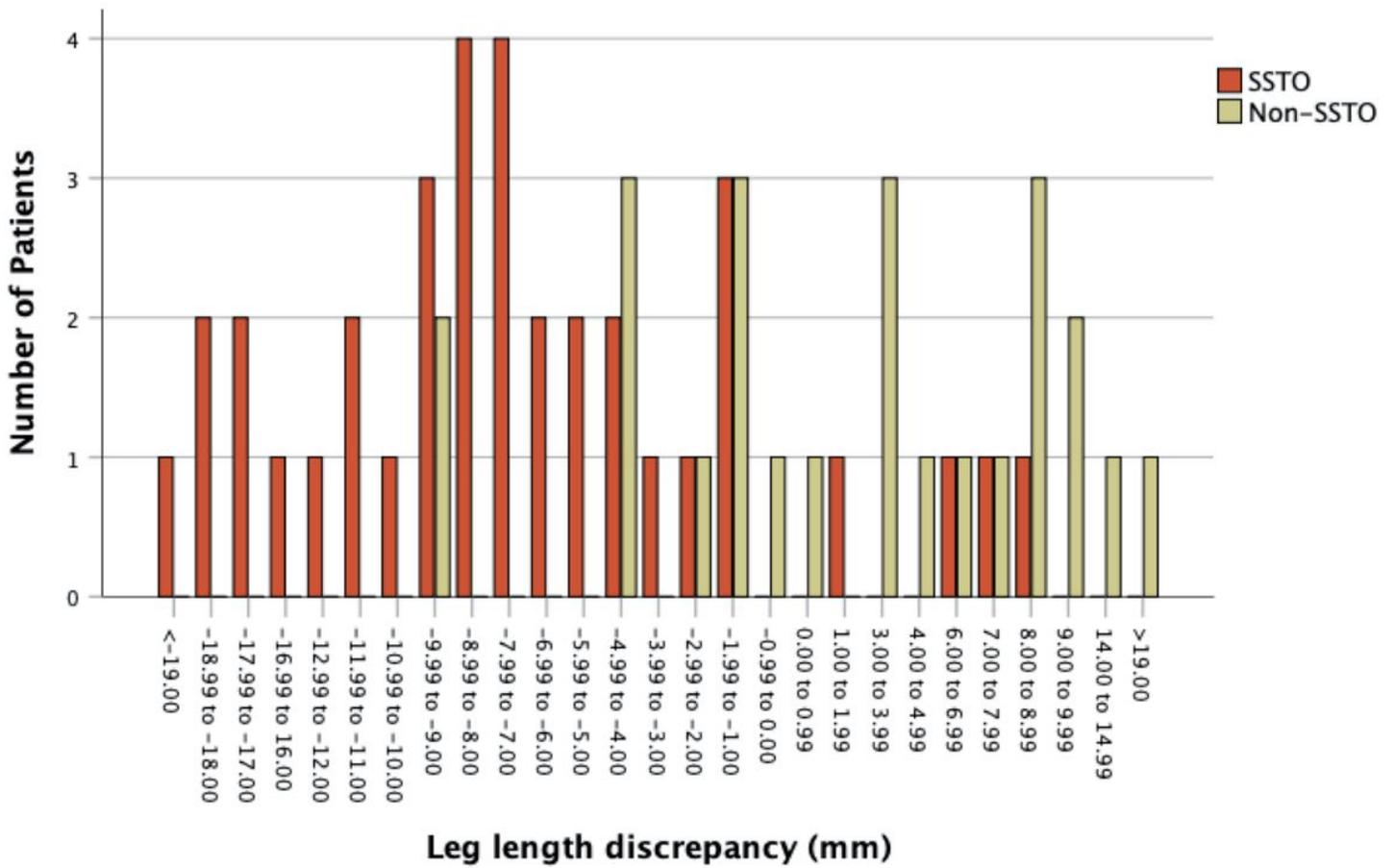
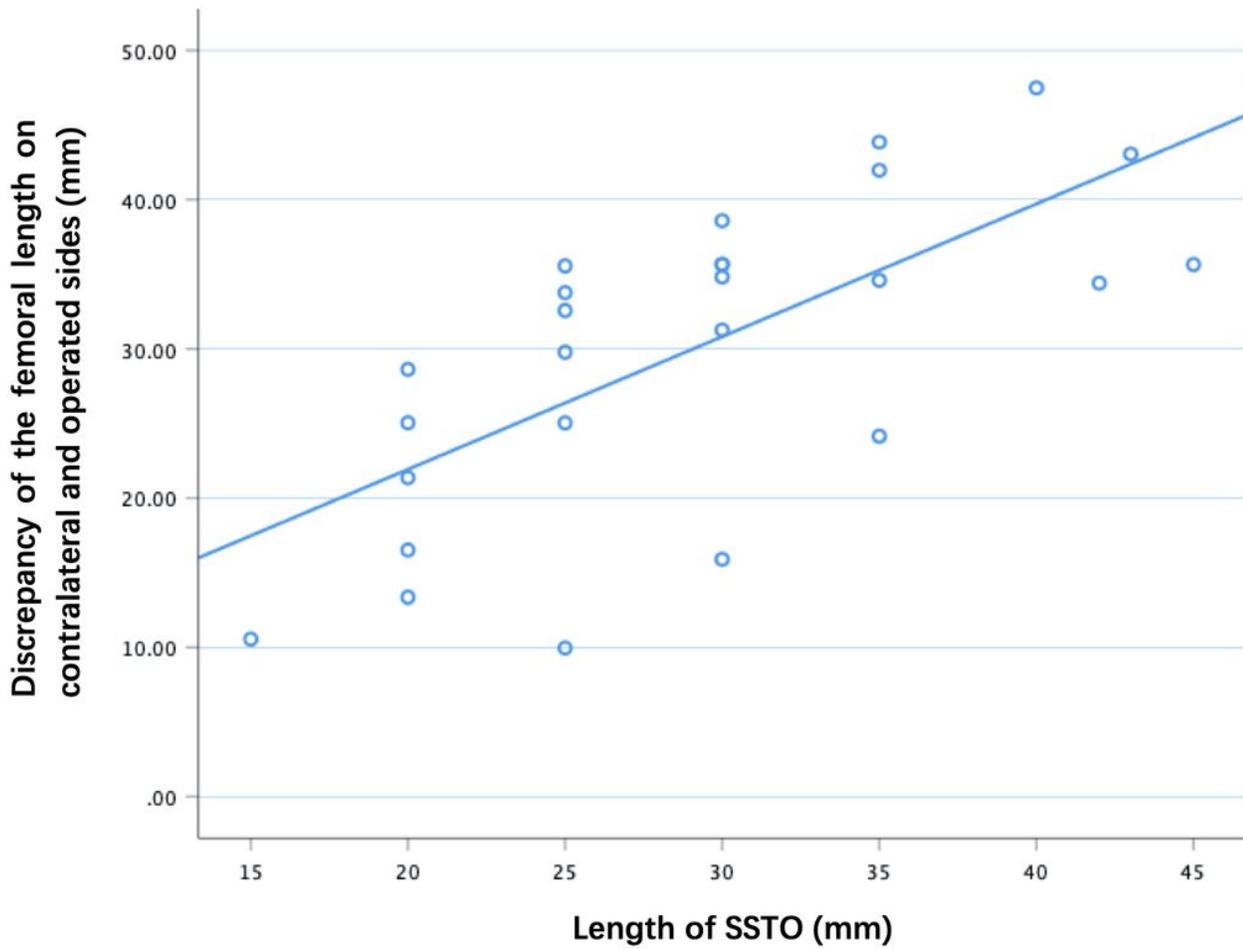


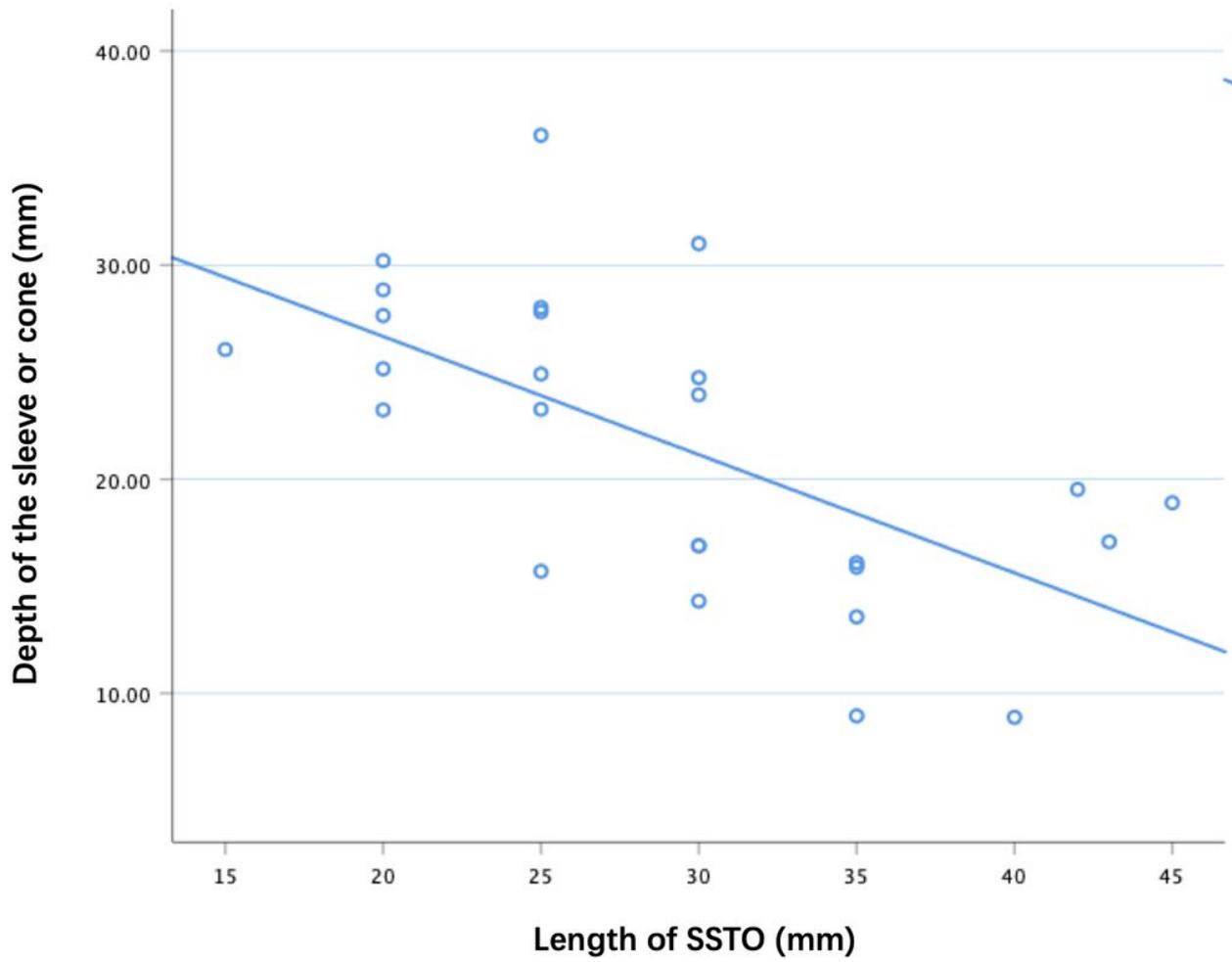
Figure 2

The figure demonstrates the leg length discrepancy (LLD) of all the patients for this study.



**Figure 3**

Correlation between the discrepancy of the femoral length on contralateral and operated sides and the length of SSTO in the non-LLD group.



**Figure 4**

Correlation between the depth of the sleeve or cone and the length of SSTO in the non-LLD group.