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# Does weight loss affect the center of pressure of children with obesity: a follow-up study

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## Abstract

**Background:** Children with obesity were found to show the greater postural instability compared to the normal-weighted children. However, it's still unclear if their altered postural control ability would recover towards normal pattern after weight loss. The purpose of this study was to investigate the effect of weight loss on the center of pressure (COP) for obese children.

**Method:** Totally 147 children were conducted a follow-up study in three years. A total number of 22 participants aged 7–13 years were recruited for their remission of obesity problem after 36 months. Their dynamic plantar pressure data were collected by Footscan pressure plate. The normalized time of four sub-phases, displacements and velocities of COP in anterior–posterior (AP) and medial–lateral (ML) directions were calculated to perform the Kolmogorov–Smirnov test and paired sample t test for statistical analyses.

**Results:** After weight loss, children's normalized time of forefoot contact phase (FFCP) increased significantly, and their duration of flat foot phase (FFP) decreased significantly. They also exhibited the more medial and posterior orientated COP path after weight loss. In ML-direction, the COP displacement during FFP and FFPOP increased, and the COP velocity during FFPOP increased. In AP-direction, COP velocity during FFP and FFPOP increased.

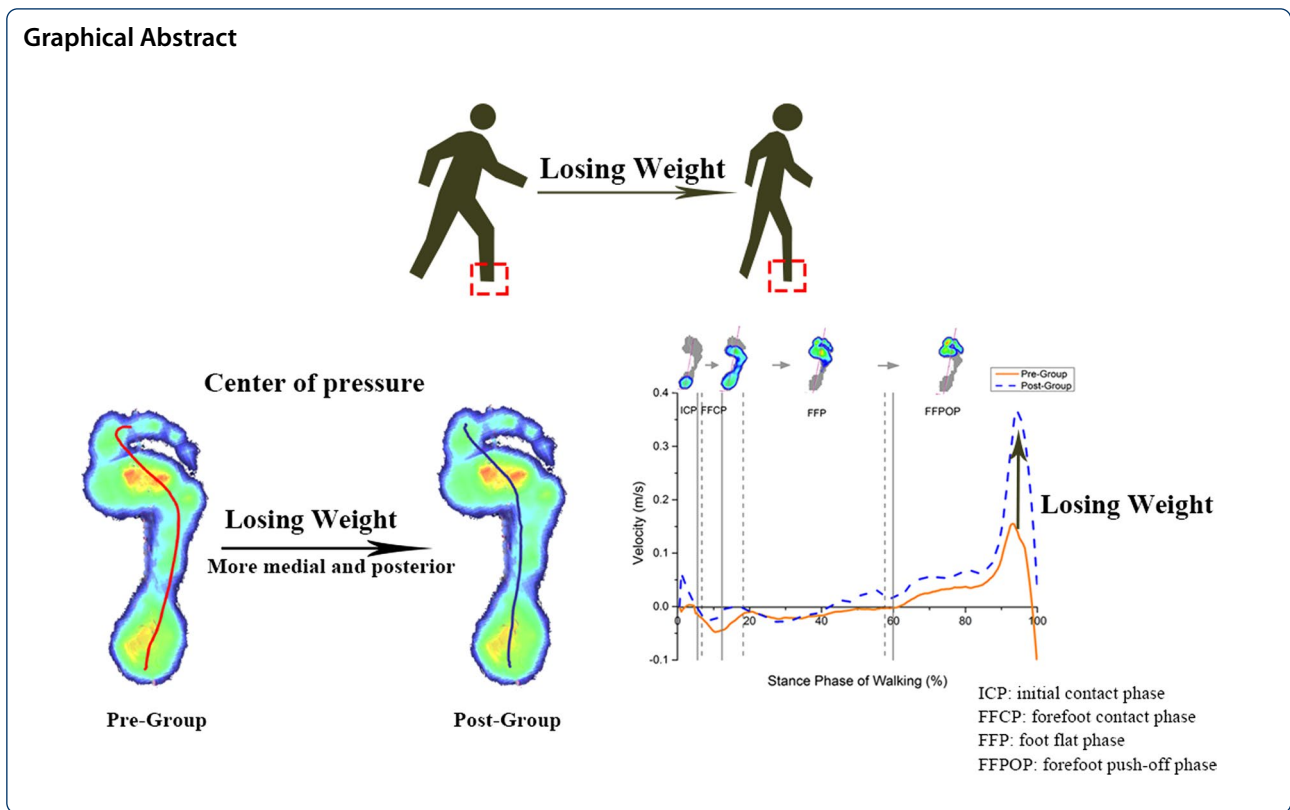
**Conclusions:** The findings indicated that weight loss would have effects on the COP characteristics and postural stability for obese children. COP trajectory can provide essential information for evaluating foot function. The findings may be useful for obese children, medical staff, and healthcare physician.

**Keywords:** Weight loss, Obesity, Children, Center of pressure, Postural stability

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### 1 Introduction

Due to the excess weight-bearing, obese children are easy to get damaged on the soft tissue and the bone structure [1, 2] and display postural instability in the course of physical exercise [3]. During continuous movements, the capacity of an individual's mobility is determined by postural stability [4]. Especially for children, maintaining static and dynamic balance is the foundation of their motor development. Given the negative effects of obesity, children with excessive body mass were clinically advised to lose weight to decrease the incidence of obesity-associated diseases. But it is wondering whether the altered postural control ability would improve or not after weight loss for children.

Postural control is a complex process that relies on the coordination of sensory and musculoskeletal system [5]. Postural stability is commonly evaluated by the center of pressure (COP) trajectory which is formed by coordinate series as it passes from the heel of the foot to the forefoot [5]. It is also identified as the centroid of all the external forces acting on the plantar surface [6]. Plantar pressure which is commonly used to evaluate the foot loading is confined to discrete regions, while COP can show the spatial relationship between the pressure distribution and the entire plantar surface [7]. It can provide greater insight into the gait efficiency than the measures that are

restricted to discrete region, such as peak pressure, pressure–time integral, or max force.

Several studies focused on the relationship between obesity and postural control, and found that obesity was related to a decreased efficiency of mechanisms responsible for postural and movement control [6, 7]. For example, obese children displayed a longer cycle duration, lower cadence, lower velocity, and longer stance period than normal-weight children during walking [8, 9]. Researchers also found that the maximum displacement of COP and the root mean square of COP displacement in the anterior–posterior and medial–lateral directions tended to be larger for obese boys [10]. The difference in the measurements in the medial–lateral direction between obese and normal-weight children was most

**Table 1** Chinese adolescent BMI reference (7–11 years)

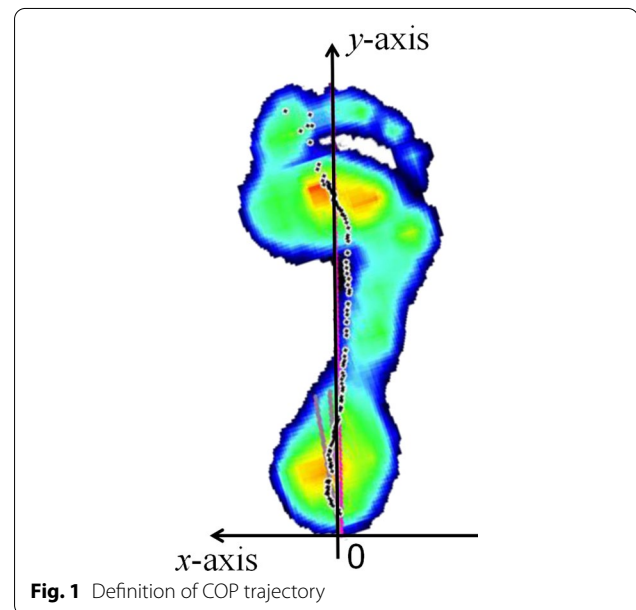
Age	Male		Female	
	Overweight	Obese	Overweight	Obese
7	17.4	19.2	17.2	18.9
8	18.1	20.3	18.1	19.9
9	18.9	21.4	19.0	21.0
10	19.6	22.5	20.0	22.1
11	20.3	23.6	21.1	23.3

**Table 2** Baseline data (Mean + S.D.) of participants in weight-loss group

	Pre-			Post-		
	Group 1	Group 2	Group 3	Group 1	Group 2	Group 3
number	11	1	10	11	1	10
age	8.0±0.8	7.0	7.8±0.8	11.0±0.8	10.0	10.8±0.8
Height (cm)	137.3±6.1	136.0	132.4±4.8	159.8±7.8	150.0	154.7±7.1
Weight (kg)	41.1±5.1	37.0	33.4±2.9	59.5±7.2	44.8	47.6±4.6
BMI (kg/m <sup>2</sup> )	21.7±1.3	20.0	19.0±0.5	22.8±1.0	19.9	19.8±0.8

significant [10]. Moreover, a study indicated that obese children and normal-weighted children adopt different walking strategies to maintain balance, avoiding an increase in the metabolic cost and the mechanical work required to move their excess body mass [11]. The obese children had a slower walking speed, shorter cadence, and longer double-support phase compared with the normal-weight children [12]. As mentioned above, obese children had poor performance in postural control and stability. Maintaining postural stability is essential for most daily activities and injury prevention. For obese children, poor postural stability may lead the higher risks of falling [10]. In addition, childhood is the most important period for the growth and development of humans. If weight loss can increase obese children's postural stability, it would benefit children's daily activities and help to prevent injuries. Therefore, this study aimed to investigate the effect of weight loss on children's postural control, which is of vital importance.

Previous studies investigated the postural control of the adults who lost weight in a short time by measuring postural sway ranges and foot progression angle, and the results indicated that even a slight weight loss would cause the changes of those variables [13, 14]. Additionally, the weight loss appeared to have few effects on the stride length and stance phases in a three-month follow-up study [15]. In a word, the available literature mostly focused on the postural stability in a very short time, ranging from three weeks to six months [16]. However, the changes of postural control in the ontogenetic development probably occur in a prolonged process rather than an immediate transformation. Children's foot structure and gait patterns continue to develop until the age of 12–13 years [17], which is a persistent and slow process. It is doubtful that the short-term follow-up study could draw a reasonable conclusion about the alteration in the postural stability and further limits the clinical utility on rehabilitation. In addition, proper postural stability is a prerequisite for improving children's motor skills to ensure a healthy and mature gait mechanism. Eva D' Hondt et al. revealed that when postural balance



was simultaneously challenged, overweight and obese children were easy to have adverse performance on fine motor skill [7]. Hence it is necessary to conduct a long-term follow-up study to determine the effect of weight loss on the postural stability of obese children.

The purpose of this study was to investigate the effect of weight loss on postural stability of obese children after three years by COP. It will be discussed if the altered COP pattern, in obese condition, would recover to a normal pattern after the weight loss. The results can be useful for the obese children, medical staff and healthcare physician.

## 2 Materials and methods

### 2.1 Participants

A total of 437 children were randomly selected from a primary school participated in this study, and 147 children of them have conducted a follow-up study after three years excluding missing samples. All the participants were free from any neurologic or lower-extremity

orthopedic pathology which could affect their walking ability. Participants were classified into types of normal-weighted, overweight and obese according to the recommendation of body mass index (BMI) established by the Group of China Obesity Task Force (Table 1). Twenty-two children aged 7–13 years were selected to perform the statistical analyses, for they lost weight in three years. The participants characteristics are shown in Table 2. The participants at first and follow-up measurements were perceived as pre- and post-group, respectively. Three types of weight loss patterns were observed in this work. After three years, there were eleven children changed from obese to overweight (group 1), one child changed

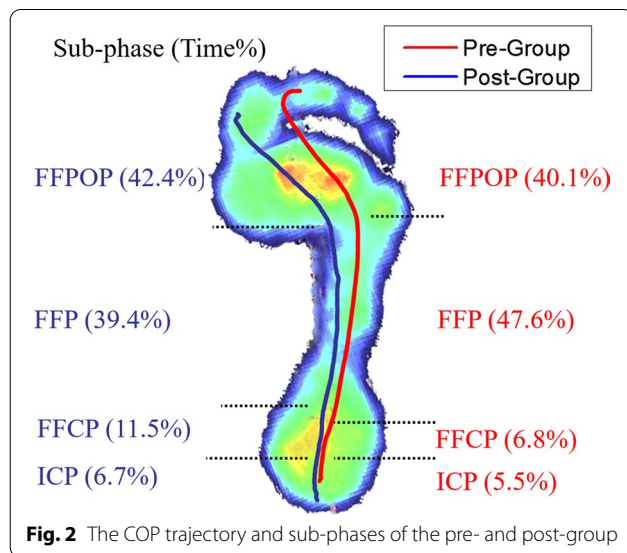
from obese to normal-weighted (group 2), and ten children changed from overweight to normal-weighted (group 3). Researchers obtained the written informed consent from at least one of the guardians of each child.

### 2.2 Experimental procedures

Dynamic plantar pressure data and other related pressure variables were collected by Footscan® plate system (RSscan International, Belgium) at a frequency of 250 Hz. The platform was mounted in the middle of a 5-m long rubber walkway. After the acclimatization, participants were instructed to walk along the walkway barefoot from one end to the other at their self-selected speed. “Two-step” initiation protocol method was used [18]. Besides, participants were asked to look straightly when walking through the plate, and make sure that both the feet were fully measured by the plate. At least three valid trials were collected to calculate the average value of the data afterward.

The COP data was exported from the Footscan® software. The COP trajectory was expressed in the form of *x*- and *y*-coordinate. The anterior–posterior (AP) direction which was defined as *y*-axis was described as the line from middle heel to forefoot, over the second metatarsal. The medial–lateral (ML) direction which was defined as *x*-axis is perpendicular to the *y*-axis, over the middle heel (Fig. 1). The COP data was characterized by spatial–temporal parameters and velocities of each sub-phase.

The stance phase was composed of four sub-phases [19]. The first sub-phase referred to the initial contact phase (ICP), which was identified as the amount of time in % to the complete stance phase that only the



**Table 3** Comparison of ML-COP displacement and velocity between the pre- and post-group. (Mean (SD))

		Displacement (mm)			Velocity (cm/s)		
		Pre-	Post-	Mean difference (95% CI) ES <sup>a</sup>	Pre-	Post-	Mean difference (95% CI) ES <sup>a</sup>
ML-COP mean	ICP	1.66 (2.12)	3.04 (2.26)	1.38 (−2.92 to 0.15)	1.2 (09.2)	6.1 (22.0)	4.9 (−0.108 to 0.008)
	FFCP	−0.26 (2.94)	1.82 (3.14)	2.08 (−4.20 to 0.04)	−3.0 (03.4)	−1.8 (4.8)	1.2 (−0.040 to 0.017)
	FFP	−4.48 (3.68)	0.10 (6.31)	4.58 (−8.16 to −0.99) 0.89 <sup>b</sup>	−1.5 (1.2)	−0.5 (2.7)	1.0 (−0.024 to 0.004)
	FFPOP	−0.31 (4.95)	9.41 (6.87)	9.72 (−13.87 to −5.56) 1.60 <sup>b</sup>	5.4 (3.9)	11.7 (4.0)	6.3 (−0.092 to −0.036) 1.59 <sup>b</sup>
ML-COP max	ICP	2.90 (1.82)	4.17 (2.20)	1.27 (−2.69 to 0.15)	14.5 (13.4)	28.9 (31.1)	14.4 (−0.315 to 0.027)
	FFCP	0.86 (2.77)	3.02 (3.19)	2.16 (−4.26 to −0.06) 0.72 <sup>b</sup>	2.6 (4.5)	7.0 (7.7)	4.4 (−0.078 to −0.009) 0.70 <sup>b</sup>
	FFP	−0.17 (3.65)	4.25 (6.11)	4.42 (−7.91 to −0.93) 0.88 <sup>b</sup>	4.9 (3.4)	17.2 (9.7)	12.3 (−0.177 to −0.069) 1.69 <sup>b</sup>
	FFPOP	10.72 (9.23)	31.23(6.49)	20.51 (−26.19 to −14.84) 2.57 <sup>b</sup>	28.3 (19.4)	118.1 (43.5)	89.8 (−1.133 to −0.661) 2.67 <sup>b</sup>
ML-COP min	ICP	0.09 (2.59)	1.35 (2.32)	1.26 (−2.97 to 0.46)	−23.2 (41.5)	−22.3 (22.9)	0.9 (−0.234 to 0.217)
	FFCP	−1.26 (2.99)	0.71 (3.19)	1.97 (−4.14 to 0.19)	−9.6 (5.7)	−11.6 (6.9)	−2.0 (−0.024 to 0.064)
	FFP	−8.47 (4.37)	−3.34(6.02)	5.31 (−8.86 to −1.42) 0.98 <sup>b</sup>	−8.6 (3.1)	−18.9 (17.8)	−10.3 (0.017 to 0.191) 0.81 <sup>b</sup>
	FFPOP	−6.53 (5.56)	0.41 (7.95)	6.94 (−11.70 to −2.18) 1.01 <sup>b</sup>	−28.3 (51.5)	−51.2 (59.4)	−22.9 (−0.157 to 0.616)

<sup>a</sup> ES: Effect size (Cohen’s d) only reported for statistically significant comparisons. CI: confidence interval

<sup>b</sup> Significant difference between groups, *p* < 0.05

heel region is supporting the body weight until one of the metatarsal heads is taking the support. The second sub-phase referred to the forefoot contact phase (FFCP), which started when one of the metatarsal heads was loaded and ending when all metatarsal areas contacted the ground. The third sub-phase referred to the foot flat phase (FFP), which started from the moment that all the metatarsal heads were supporting the body weight and stops when the heel was pushing off. The last sub-phase referred to the forefoot push-off phase (FFPOP), which started when the heel was leaving the ground and ended when the whole plantar was pushing off. The normalized time was obtained from the amount of time of each sub-phase divided by the complete stance phase.

Since the coordinate distributions of COP varied with the participants' foot sizes, the absolute values of x- and y-coordinate series were normalized to the foot length and foot width of each participant, respectively. The mean displacement of COP trajectories was plotted on the standard foot with foot length ( $222.1 \pm 12.3$  cm) and foot width ( $84.4 \pm 4.2$  cm), which was obtained from the average foot length and foot width of all the participants involved. The mean curves of each participant were computed by MATLAB software (Version 2017b, Mathworks, Natick/MA, USA), which were applied to interpolate the COP data to coordinates of 200 points. The displacements and velocities of COP in ML- and AP-direction of each sub-phase were calculated for the pre- and post-group.

The right foot was chosen to perform the statistical analyses [20]. As the partial correlation analysis results showed, the ages of participants had no significant correlation to the COP data, therefore the effect of age was

taken out of consideration in the following analyses. The normality of the durations in % of four sub-phases and COP velocities were tested by the Kolmogorov–Smirnov test, which presented normal distributions ( $p > 0.05$ ). A paired sample t test was used to compare the differences between COP data of pre- and post-group. All the statistical analyses were conducted by the SPSS software package version 26.0 (IBM, USA). The significance was set as the level of  $p < 0.05$ . Effect size using Cohen's value for t-test was calculated for all significant mean differences as a tool of consistent measure. The following interpretation of ES was used: trivial (0–0.2), small (0.2–0.6), moderate (0.6–1.2) and large ( $> 1.2$ ) [21].

### 3 Results

The COP trajectories normalized to the percentages of sub-phases respectively for the pre- and post-group of weight-loss children are shown in Fig. 2. It shows that COP has a more medially oriented shift for post-group, which implies greater pronation during FFP and FFPOP. The y coordinate series in y-axis of the starting and ending point of the COP trajectory decreased, which means that the overall COP trajectory shows a backward move compared to the pre-group. The COP trajectories of both groups showed some similar characteristics that a slight and short medial shift during ICP. Then the COP trajectories of the two groups of participants both shifted laterally during FFCP and FFP, and ends with a sharp medial shift during FFPOP.

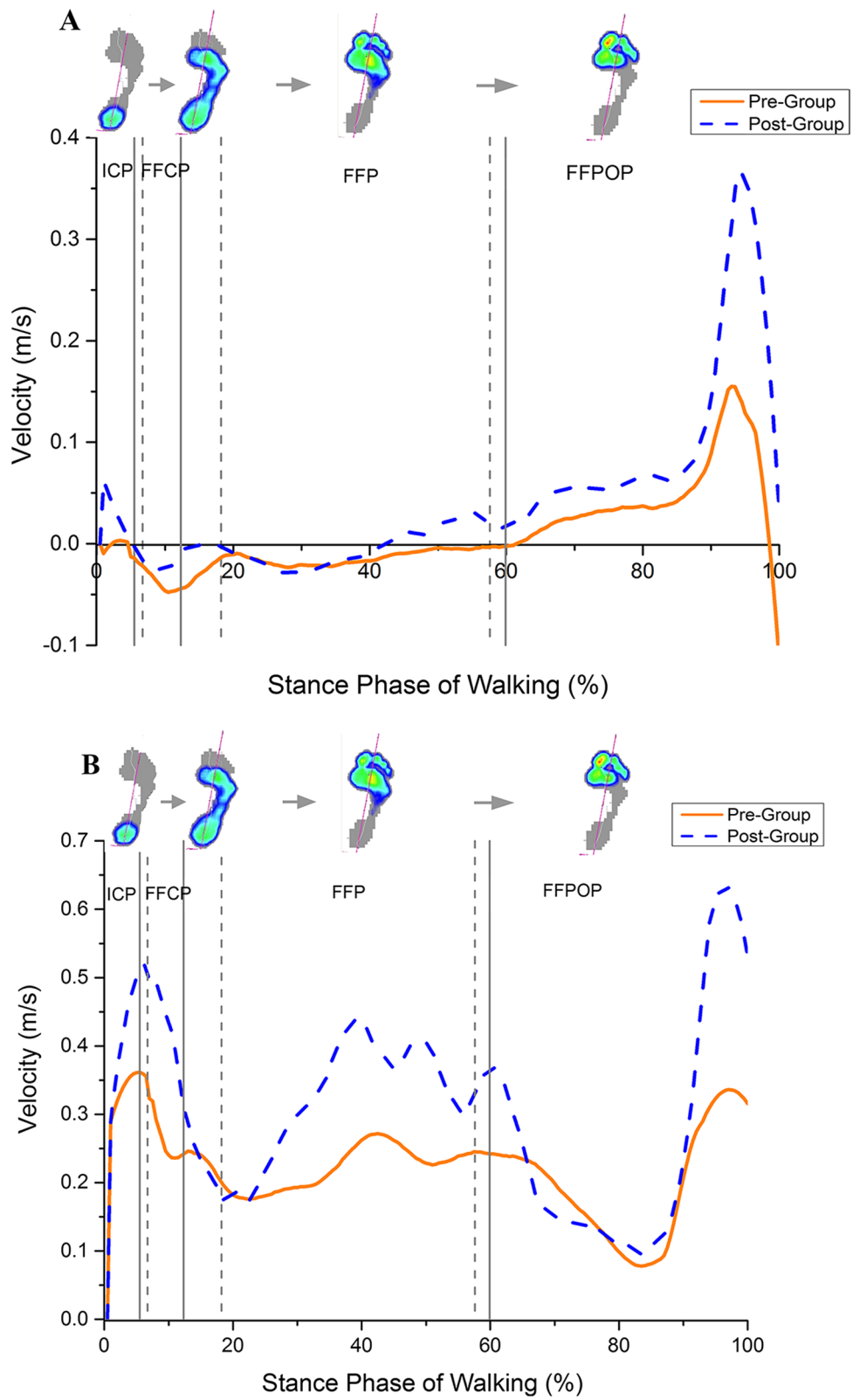
As shown in Fig. 2, the weight-loss affects the normalized time of sub-phase during FFCP and FFP. For the weight-loss post group, longer normalized time was spent on FFCP and significantly shorter normalized time

**Table 4** Comparison of AP-COP displacement and velocity between the pre- and post-group (mean (SD))

		Displacement (mm)			Velocity (cm/s)		
		Pre-group	Post-group	Mean difference (95% CI) ES <sup>a</sup>	Pre-group	Post-group	Mean difference (95% CI) ES <sup>a</sup>
AP-COP mean	ICP	36.29 (5.38)	33.13 (6.75)	-3.16 (-1.14 to 7.46)	126.0 (88.3)	109.0 (45.0)	-17.0 (-0.336 to 0.676)
	FFCP	56.84 (10.78)	59.07 (19.11)	2.23 (-13.26 to 8.80)	40.0 (17.7)	41.1 (29.0)	1.1 (-0.175 to 0.151)
	FFP	105.97 (11.90)	113.55 (23.90)	7.58 (-21.05 to 5.87)	24.5 (9.1)	38.5 (10.9)	14.0 (-0.209 to -0.071) 1.39 <sup>b</sup>
	FFPOP	175.58 (18.46)	169.00 (43.01)	-6.58 (-17.08 to 30.24)	17.6 (8.2)	24.5 (6.4)	6.9 (-0.119 to -0.019) 0.94 <sup>b</sup>
AP-COP max	ICP	44.91 (7.01)	43.46 (11.47)	-1.45 (-5.29 to 8.19)	95.2 (102.5)	115.9 (91.8)	20.7 (-0.875 to 0.462)
	FFCP	65.21 (14.02)	72.81 (30.86)	7.6 (-24.71 to 9.52)	70.4 (35.6)	94.6 (55.9)	24.2 (-0.561 to 0.076)
	FFP	155.31 (13.23)	161.65 (19.86)	6.34 (-18.29 to 5.60)	53.5 (13.5)	132.1 (69.1)	78.6 (-1.125 to -0.448) 1.58 <sup>b</sup>
	FFPOP	203.27 (33.40)	205.44 (46.79)	2.17 (-30.91 to 26.56)	66.8 (34.2)	174.1 (59.7)	107.3 (-1.402 to -0.743) 2.21 <sup>b</sup>
AP-COP min	ICP	28.74 (4.51)	25.08 (5.72)	-3.66 (0.04 to 7.29) 0.71 <sup>b</sup>	-10.1 (20.8)	-11.2 (22.6)	-1.1 (-0.138 to 0.160)
	FFCP	46.26 (6.98)	45.34 (11.61)	-0.92 (-5.88 to 7.72)	17.5 (14.9)	3.7 (15.1)	-13.8 (0.035 to 0.242) 0.92 <sup>b</sup>
	FFP	66.00 (13.69)	73.85 (30.75)	7.85 (-24.85 to 9.15)	4.0 (10.5)	-2.7 (15.5)	-6.7 (-0.025 to 0.160)
	FFPOP	155.77 (13.89)	159.70 (12.46)	3.93 (-13.14 to 5.27)	4.2 (5.8)	-6.0 (8.1)	-10.2 (0.053 to 0.152) 1.45 <sup>b</sup>

<sup>a</sup> ES: Effect size (Cohen's d) only reported for statistically significant comparisons

<sup>b</sup> Significant difference between groups,  $p < 0.05$



**Fig. 3** The velocities of COP in ML- (a) and AP-direction (b) for the pre- and post-group

was spent on FFP than the pre-group. The longest duration of the sub-phase was found in FFP for the pre-group. While after three years, the longest duration turned to be FFPOP for the post-group. This result indicates that, with weight loss, the normalized time for participants increased during FFCP and decreased during FFP.

A comparison of the displacements and velocities in ML-direction between the pre- and post-group are shown in Table 3. The mean, maximum and minimum displacements of COP in ML-direction for post-group were increased by 4.6 mm ( $p=0.014$ ), 4.4 mm ( $p=0.015$ ), 5.3 mm ( $p=0.008$ ) respectively during FFP, and increased by 9.7 mm ( $p<0.001$ ), 20.5 mm ( $p<0.001$ ), 6.9 mm ( $p=0.006$ ) respectively during FFPOP compared to the pre-group. The maximum displacement of COP in ML-direction increased by 2.2 mm ( $p=0.044$ ) during FFCP for the post-group.

Compared to the pre-group, the maximum velocity of the post-group in ML-direction increased by 4.4 cm/s ( $p=0.014$ ), 12.3 cm/s ( $p<0.001$ ), 89.8 cm/s ( $p<0.001$ ) respectively during FFCP, FFP and FFPOP. The mean velocity in ML-direction increased by 6.3 cm/s ( $p<0.001$ ) during FFPOP, and the minimum velocity decreased by 10.3 cm/s ( $p=0.022$ ) during FFP for the post-group.

A comparison of the displacements and velocities in AP-direction between two groups is shown in Table 4. The minimum displacement of COP in AP-direction for post-group decreased by 3.66 mm ( $p=0.048$ ) during ICP compared to the pre-group. The mean and maximum velocity of COP in AP-direction for post-group increased by 14.0 cm/s ( $p=0.000$ ) and 78.6 cm/s ( $p=0.000$ ) respectively during FFP, and increased by 6.9 cm/s ( $p=0.008$ ) and 107.3 cm/s ( $p=0.000$ ) respectively during FFPOP. The minimum velocity of COP in AP direction decreased by 13.8 cm/s ( $p=0.010$ ) during FFCP and decreased by 10.2 cm/s ( $p=0.000$ ) during FFPOP for the post-group. The velocities of COP in both directions for the two groups are shown in Fig. 3.

#### 4 Discussion

The study aimed to investigate the effect of weight loss on postural stability for children by evaluating COP parameters. Overall, many differences in COP characteristics (i.e., COP position, displacement, and velocity) were observed between the two groups. The level of effect sizes for these significant differences was from medium to large, ranging between 0.70 and 1.69, which is clinically meaningful. However, after weight loss, not all the COP parameters exhibited a more stable postural control, which is diverse from the previous research [15] indicating smaller COP displacements and velocities.

Previous studies have demonstrated that the COP trajectory parameters could be served as a reference to

evaluate foot function and balance control [22]. In this study, children generally showed an increased COP displacement in ML-direction and a decreased COP displacement in AP-direction after weight loss. Besides, children tend to have a more medial and posterior oriented COP path when they lost weight. For children who had lost weight, the contact area in the midfoot was supposed to decrease on account of the loss of fat [23], and the flexibility of the foot may get improved [24]. During walking, the feet would display greater frontal and transverse plane motion of the rearfoot and midfoot. Such motion is associated with subtalar joint pronation, which can result in the load being distributed to the medial forefoot [25]. Also, as the main load-bearing part of human, obese children's lateral longitudinal arch would bear excessive force. Therefore, as the representation of the trajectory of pressure, obese children's COP would exhibit a more lateral orientation. As their obese problems got relieved, the COP shifted to a more medial orientation. The second possible explanation for the result could be similar to the participants with exclusively chronic ankle instability who had a laterally oriented COP [26]. Children with obesity are characterized by reduced ankle plantar flexor moment and increased inversion moment, which may be related to the possible weakness of plantar flexor muscles for obese children [27, 28]. Unver et al. have reported that obese individuals had reduced relative muscle strength of plantar flexors, dorsiflexor and invertors [29], which may lead to a lateral situated COP and postural instability. A more anterior COP trajectory was found in obese children, and this result was presumably attributed to the high concentration of the abdominal adipose tissue in obese children causing the center of mass to shift toward the front of the ankle joint [13], which was derived from the previous modeling work for obese subjects of M. S. Philippe Corbeil et al. [30] According to the previous study, body weight distribution was considered to be an important factor which may affect the postural stability [31]. In this study, participants with abdominal obesity showed a larger sway range in anterior–posterior plane. Greater COP anterior movement would disturb the balance significantly [32]. Obese children were supposed to exert a compensation mechanism that the COP trajectory moves forward to stabilize the body during walking. In turn, when they are losing weight, this mechanism gradually disappears accompanying the abdominal adipose tissue reduced. Children with obesity are easily concentrated on the adipose of the abdomen. After weight loss, the posterior COP could be assumed to the decreased concentration of abdominal adipose, and the center of mass shifted posteriorly during walking.

Remarkable differences were found in COP displacements and velocities of four sub-phases in both directions. A previous study has reported the improved (reduced) postural sway indices, COP ranges, and velocities in both directions for males who lost their weight, which concluded that weight loss improved the balance control of the obese adults [14]. However, inconsistent results were found in our study, which were generally exhibited as the increased mean COP displacement and velocity in ML-direction, and increased COP velocity in AP-direction for children with weight reduction for obese children.

COP displacements in ML-direction reflect the inverted and everted movements of the foot. A previous study has found an increase in the displacement of COP related to falls [33]. In this study, children with weight reduction got the increased COP displacement during FFP and FFPOP, and the increased COP velocity during FFPOP in ML-direction, which described the functional ankle rocker characteristics [34]. In AP-direction, children after weight loss got increased COP velocity during FFP and FFPOP. The faster COP velocity during FFP indicated a faster forward weight shift. A possible explanation could be that weight loss promoted the flexibility of the foot, which leads to a more efficient load transference from the lateral part to the medial. Moreover, another study has found that greater sway ranges in both directions existed in males who had a lower score in the balance ability assessment [35]. During FFP, the forefoot is the only structure in contact with the ground and supporting the loads yielded by the locomotion, with the heel lifting and the subtalar joint turning inward [36, 37]. Besides, the foot changes from a flexible to a semi-rigid structure to adapt to the changes in external conditions, during which the body weight continuously pass over the foot [38]. The foot acts as a spring and lever arm to push-off during walking and ensures the loads pass over the foot, which was mediated by the mechanical constraints of the foot configuration [39]. It suggested that it was easier for children to change the foot from a flexible to a rigid structure after weight loss. When the COP crossed the metatarsophalangeal joint, the force required to push off the bodyweight is associated with a decreased COP velocity. The differences in COP velocity between the two groups indicated the variations of the mechanism for generating the required force for weight shifting. The differences in bone orientation or joint characteristics may affect the direction of the force vector applied to the forefoot [5]. For example, the foot of children after weight loss, bearing less fat, would show greater comparative plantarflexion of the forefoot compared to the children before weight loss. In this study, the velocity and displacement of COP do not simply decrease after weight

loss for obese children. For children after weight loss, it may display a larger vertical component for force vector. It should be noted that, as shown in Table 3, as they were growing up, the height of them increased. Even though their body type changed from obese to normal or overweight, the absolute weight of participants got increased, which may lead to the greater force in both vertical and horizontal directions, resulting the faster movement of COP.

There are several limitations in this study. COP was the only parameter used to investigate the postural stability for children after weight loss in this study. More parameters can be taken into the evaluation on the influence of weight loss on the postural control of obese children in further study, such as ankle joint and sway ranges of the body. Besides, there are only 22 participants participant in this follow-up study, which may influence the accuracy of the study. Further study can get more participants involved.

## 5 Conclusions

This study discussed the differences in postural stability of obese children who had lost weight through COP characteristics. As the COP trajectory can provide essential information for the evaluation of foot function and postural control. The most notable difference is that children tend to have a more medial and posterior orientation for the COP path after weight loss. For children after weight loss, in ML-direction, the COP displacement during FFP and FFPOP increased, and the COP velocity during FFPOP increased. In AP-direction, COP velocity during FFP and FFPOP increased. Weight loss would affect the COP characteristics greatly and could also help to improve children's postural stability. The findings of the study may be useful for obese children, medical staff, and healthcare physician.

### Abbreviations

COP: Center of pressure; BMI: Body mass index; ICP: Initial contact phase; FFCP: Forefoot contact phase; FFP: Flat foot phase; FFPOP: Forefoot push-off phase; ML: Medial-lateral; AP: Anterior-posterior.

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Not applicable.

### Authors' contributions

L.Z., L.Y. and W.D. designed the experiment; L.Z., S.Y. and R.L. carried out the experiment; L.Z. and R.L. analyzed experimental data; L.Z. and S.Y. wrote the manuscript; L.Y., J.B. and W.D. reviewed and improved the manuscript. All authors read and approved the final manuscript.

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**Availability of data and materials**

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

**Declarations****Competing interests**

The authors declare that they have no competing interests.

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