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Original Article

Relationship between the thoracic asymmetry in standing position and the asymmetry of ankle moment in the frontal plane during gait

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Abstract. [Purpose] We aimed to investigate the relationship of thoracic asymmetry in standing position with asymmetry of the internal ankle moment in the frontal plane during gait. [Participants and Methods] The following measurements were recorded in 22 healthy adult males using a 3D motion analyzer and force plates: thoracic lateral deviation, asymmetrical ratios of the upper and lower thoracic shape, internal ankle moment in the frontal plane, mediolateral deviations of the center of mass and center of pressure. [Results] In the standing position, the thorax was deviated to the left relative to the pelvis, and the upper and lower thoracic shapes were asymmetrical. During gait, significant lateralities were observed in the internal ankle moment in the frontal plane, mediolateral deviations of the center of mass and the center of pressure. Significant positive correlations were observed between the asymmetrical ratio of the lower thoracic shape and both the asymmetry of the internal ankle moment in the frontal plane and the mediolateral deviation of the center of pressure. [Conclusion] These results suggest that thoracic asymmetry is associated with mediolateral control of the ankle during gait.
Key words: Thoracic asymmetry, Ankle moment, Gait asymmetry

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INTRODUCTION

Thoracic movement is composed of rib and the thoracic spine movements, which perform important roles in the respiration and postural stability. In recent years, several studies have focused on the thoracic lateral deviation (TLD) and asymmetry of the thoracic shape in the resting position and investigated their relationship with physical function[1–4]. Based on a significant correlation between the asymmetry of the thoracic shape and respiratory function, Hirayama et al.[1] suggested that the greater the asymmetry of the thoracic shape, the lower the respiratory function. Homma et al.[2] and Sano et al.[3] also found a significant correlation between the TLD and the asymmetry in the cross-sectional area of the quadratus lumborum and the psoas major. These previous studies suggested that thoracic asymmetry (the TLD and asymmetry of the thoracic shape) causes impaired respiration and motor function by causing asymmetry in the local muscle activity of the trunk. Although these studies[1–3] investigated static tasks such as forced breathing and supine motions, another study[4] that focused on gait and investigated the relationship between thoracic asymmetry and the asymmetry of lower extremity movements. We previously reported that the TLD and asymmetry of the thoracic shape in standing position were significantly correlated with the

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asymmetry of the lateral tilt angle of the shank during gait[4]. Although these results suggest that thoracic asymmetry affects the mediolateral control of the ankle during gait, these associations have not been clarified to date.

The kinematic response of the ankle frontal plane can be regarded as the internal ankle moment in the frontal plane (IAMF). IAMF is regarded as the activity of the ankle valgus/varus muscles, which contribute to the mediolateral stability of gait with the hip adduction/abduction muscles[5]. It is an important indicator that performs a proactive role in controlling the center of pressure (COP)[6, 7]. Thus, although the IAMF contributes to postural control, it is also considered a negative factor that impairs lower extremity alignment in orthopedic diseases. Choi et al.[8] claimed that the external ankle varus moment during gait in patients with medial ankle osteoarthritis is a mechanical factor that causes varus of the talus, and they reported that patients with a lower medial longitudinal arch had a greater varus moment. Furthermore, gait analysis in patients with knee osteoarthritis[9, 10] has revealed that the IAMF is associated with external knee adduction moment, and the IAMF is considered an important factor in the progression of knee osteoarthritis. Thus, IAMF imbalance is considered a factor that increases mechanical stress on the lower extremities and negatively affects the local alignment. Therefore, clarification of the factors associated with the IAMF is beneficial in physiotherapy for gait disorders.

Based on previous studies[1–4], we expect that thoracic asymmetry causes asymmetry of the IAMF during gait. Although it is necessary to collect data on the disease to apply this hypothesis to clinical practice, it is expected that many factors, such as pain and deformity, may affect the disease outcome. For this reason, we believe that basic research on able-bodied individuals is necessary at present, as the relationship between the thorax and the ankle remains unclear. Therefore, in this study, we analyzed thoracic asymmetry in the standing position and the asymmetry of the IAMF during gait in able-bodied individuals. In addition, we analyzed the center of mass (COM) and COP to identify background factors. By analyzing these parameters, we investigated the relationship between thoracic asymmetry and mediolateral control of the ankle during gait. The objective of this study was to understand this relationship in able-bodied individuals with the assumption that our findings could be applied to physiotherapy for gait disorders in the future.

PARTICIPANTS AND METHODS

The participants were 22 healthy males with no spinal or thoracic deformations (age: 27.3 ± 3.7 years, height: 170.2 ± 4.8 cm, body mass: 64.4 ± 8.7 kg, body mass index: 22.2 ± 2.5 kg/m^2; mean ± standard deviation [SD]). Before the commencement of the experiments, the participants were informed of and read the scientific purpose and significance of the research and signed a written consent form. This study was approved by the ethics committee of Tokyo Medical University in accordance with the Declaration of Helsinki revised October 2013 (approval no. T2020-0085).

In this study, we measured the TLD, the asymmetrical ratios of the upper thoracic shape (UTS) and the lower thoracic shape (LTS) in the standing position, the IAMF, the COM and COP mediolateral deviation during gait. A 3D motion analyzer (Vicon Nexus2; Vicon Motion Systems, Ltd., Oxford, UK) with eight infrared cameras and six force plates (Advanced Mechanical Technology, Inc., Watertown, MA, USA) was used for the measurements. The sampling frequency was set at 100 Hz.

A total of 21 reflective markers were placed (Figs. 1 and 2) on the sternal angle (A) to measure standing position: three equally spaced on each side at the same height as A (right; A1-3, left; A4-6), the spinous process with the same height as A (B), the xiphoid process (C), the spinous process with the same height as C (D), three equally spaced on each side with the same height as D (right; D1-3, left; D4-6), the T8 spinous process, the left and right anterior superior iliac spine (LASIS, RASIS), the left and right posterior superior iliac spine (LPSIS, RPSIS). The A1-6 and D1-6 markers were placed at a distance of 13% between the left and right acromions to fit within the thorax and were placed horizontally and equally spaced using a line laser and tape measure. To avoid changes in thoracic shape with breathing, a natural standing position in the resting expiratory position was measured for five seconds three times.

With reference to previous studies[1–4, 11], the TLD was calculated from the center of the thorax and pelvis. The midpoints of C and T8 were defined as the center of the thorax, and the midpoints of ASIS and PSIS on each side were calculated and their respective midpoints were defined as the center of the pelvis (Fig. 1). The mediolateral axial coordinates of the center of the thorax relative to the center of the pelvis were defined as the TLD. Positive values for the TLD indicate a right deviation of the thorax relative to the pelvis, whereas negative values indicate a left deviation.

The asymmetrical ratios of the UTS and LTS were calculated from the anteroposterior diameters of the thorax on each side[1, 4, 11]. The thoracic shape indicates the unevenness of the thoracic surface and reflects the rotational alignment of the ribs[1, 4, 11]. Thus, the anteroposterior diameter of the thorax at each level can be viewed as an uneven shape of the thoracic surface, reflecting the rotational alignment of the ribs. The measurement region for the UTS was the anteroposterior diameter from B marker to the anterior surface of the thorax at the same level. The distances from B to A1-6 (BA1, BA2, BA3, BA4, BA5, BA6) were calculated, and the right sum (BA1 + BA2 + BA3) was defined as the anteroposterior diameter of the right upper thorax and the left sum (BA4 + BA5 + BA6) was defined as the anteroposterior diameter of the left upper thorax, respectively (Fig. 2). The measurement region for the lower thorax shape was the anteroposterior diameter from the C marker to the dorsal surface of the thorax at the same level, in consideration of the bulge of the anterior chest. The distances from C to D1-6 (CD1, CD2, CD3, CD4, CD5, CD6) were calculated, and the anteroposterior diameters of the right lower thorax (CD1 + CD2 + CD3) and left lower thorax (CD4 + CD5 + CD6) were defined using the same method as the upper thorax (Fig. 2).

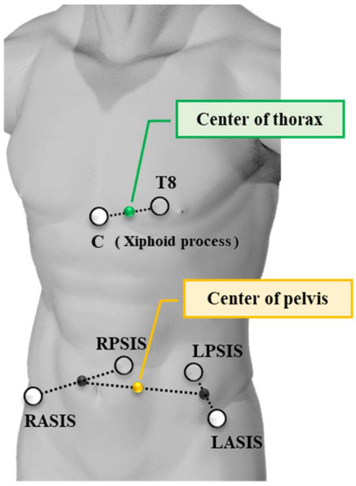

Fig. 1. Marker placements of thoracic lateral deviation (TLD).
RPSIS: right posterior superior iliac spine; RASIS: right anterior superior iliac spine; LPSIS: left posterior superior iliac spine; LASIS: right anterior superior iliac spine.

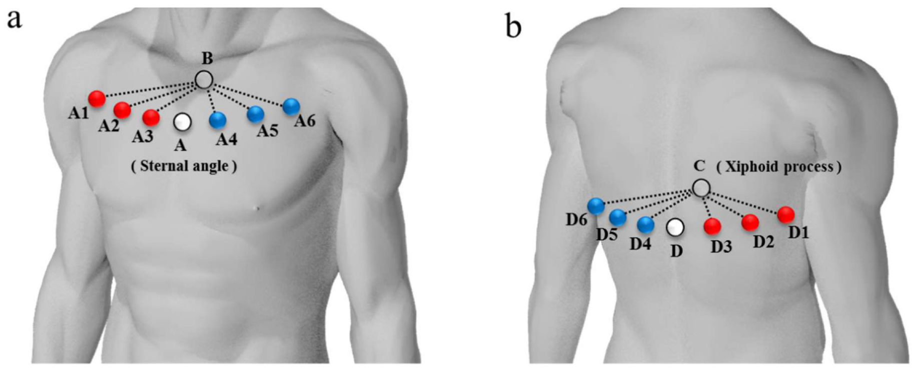

Fig. 2. Marker placements of thoracic shape.
a: Upper thoracic shape (UTS), b: Lower thoracic shape (LTS).

The right anteroposterior diameter divided by the left side was defined as the asymmetrical ratios of the UTS and LTS. If the asymmetrical ratio is 1, it indicates that the left and right anteroposterior diameters are symmetrical; if the ratio is greater than 1, it indicates that the right is greater than the left. The mean value of 3-s was calculated from the 5-s measurements, and the mean value of three trials was defined as the representative value for each participant.

A total of 39 infrared markers were placed on the bilateral anatomical landmarks (the ASIS, PSIS, lateral thighs, lateral femoral epicondyles, lateral shanks, lateral malleoli, calcanei, second metatarsal heads, front heads, back heads, C7 and T10 spinous process, jugular notch, xiphoid process, right scapula, acromio-clavicular joints, lateral humeri, lateral humerus epicondyles, lateral forearms, styloid processes of radius, styloid processes of ulna, and the second metacarpal heads) based on the Plug-in Gait Full Body Model[12)] to measure gait. Gait speed was defined as the comfortable speed of each participant, and the participants practiced sufficiently to avoid bias toward progress. The trials for which ground reaction force on the bilateral sides could be recorded were employed, and a total of three measurements were taken.

The IAMF, the COM and COP mediolateral deviations during the bilateral stance phase were calculated. The IAMF values were normalized to body weight. Positive values for the IAMF indicate that the ankle valgus moment is exerted, whereas negative values indicate that the ankle varus moment is exerted. The COM mediolateral deviation was defined as the mediolateral axis coordinates of the COM relative to the center of the foot, defined as the midpoint of the calcaneus and the second metatarsal head markers on the stance side. Measurements were normalized by height to account for differences in participants' heights. Because the COM in normal gait is positioned medially to the foot throughout the stance phase[13)], smaller values for the COM mediolateral deviation indicate lateralization, whereas greater values indicate medialization. The COP mediolateral deviation was defined as the mediolateral axial coordinates of the COP relative to a line connecting the calcaneus and the second metatarsal head markers. Positive values for the COP mediolateral deviation indicate medialization of the COP relative to the foot length axis, whereas negative values indicate lateralization.

Gait parameters in the stance phase were normalized to 100% and averaged over three trials. Loading response (16% of the stance: LR), midstance (50% of the stance: MS), and terminal stance (83% of the stance: TS) during the stance phase were the analysis points[10, 14]. The IAMF and COM coordinates were calculated based on the Plug-in Gait Full Body Model, and the TLD, the asymmetrical ratios of the UTS and LTS, the center of the foot coordinates, and the COP mediolateral deviation were calculated using analysis programming software (Body Builder; Vicon Motion Systems, Ltd., Oxford, UK).

The mean and SD of the TLD and the asymmetrical ratios of the UTS and LTS, the IAMF, the COM and COP mediolateral deviations for each side were calculated for each participant. A 95% confidence interval (95% CI) was calculated from the TLD and the asymmetrical ratios of the UTS and LTS. The normality of each parameter was confirmed by the Shapiro–Wilk test. The IAMF, the COM and COP mediolateral deviation were compared between left and right during each gait cycle (Paired t-test). Additionally, significant differences in gait parameter asymmetry (right-left) and correlation coefficients with thoracic parameters were calculated using Pearson's correlation coefficient or Spearman's rank correlation coefficient. Significant difference was defined as a p-value of <0.05. All data were analyzed and evaluated using SPSS Statistics, version 28.0, for Windows (IBM Corp., Armonk, NY, USA).

RESULTS

The average TLD was −7.2 ± 5.4 mm (95% CI: −9.6, −4.8 mm), with the thorax deviated to the left relative to the pelvis. The asymmetrical ratio of the UTS was 0.98 ± 0.01 (95% CI: 0.97, 0.98), with the anteroposterior diameter of the upper thorax greater on the left than on the right. The asymmetrical ratio of the LTS was 1.03 ± 0.02 (95% CI: 1.02, 1.04), with the anteroposterior diameter of the lower thorax greater on the right than on the left.

The IAMF and COM and COP mediolateral deviations for the left and right sides during each gait cycle are shown in Table 1. The IAMF was significantly greater on the right than on the left in each gait cycle. The COM mediolateral deviation was significantly greater on the right than on the left in each gait cycle. The COP mediolateral deviation was significantly greater on the right than on the left in each gait cycle.

Correlation coefficients between the thoracic parameters and asymmetry in gait parameters for significant lateralities are shown in Table 2. A significant positive correlation was found between the asymmetrical ratio of the LTS and the asymmetry of the IAMF, and between the asymmetry of the COP mediolateral deviation in MS and TS.

Table 1. Mean and standard deviation (SD) of internal ankle moment in the frontal plane (IAMF), center of mass (COM), and center of pressure (COP) mediolateral deviations

		LR (16% of stance)	MS (50% of stance)	TS (83% of stance)
IAMF (Nmm/kg)	R	77.8 ± 38.8**	57.6 ± 37.1**	161.4 ± 32.5**
	L	−29.6 ± 54.0	−33.4 ± 60.8	36.6 ± 62.9
COM mediolateral deviation (mm/m)	R	34.0 ± 5.9**	27.0 ± 5.0*	35.2 ± 7.3*
	L	32.1 ± 5.3	25.1 ± 4.1	32.8 ± 5.7
COP mediolateral deviation (mm)	R	5.7 ± 3.4**	6.3 ± 5.3**	16.6 ± 3.3**
	L	−6.7 ± 4.0	−7.5 ± 7.4	2.3 ± 6.5

LR: loading response; MS: midstance; TS: terminal stance.
Values are mean ± SD (n=22).
*Significantly different (p<0.05) from left.
**Significantly different (p<0.01) from left.

Table 2. Correlation coefficients between thoracic parameters and asymmetry of gait parameters

	Asymmetry of IAMF (R–L)			Asymmetry of COM mediolateral deviation (R–L)			Asymmetry of COP mediolateral deviation (R–L)		
	LR	MS	TS	LR	MS	TS	LR	MS	TS
TLD (mm)	−0.28	−0.06	−0.19	0.25	0.16	0.11	−0.09	0.05	−0.08
Asymmetrical ratio of UTS (R/L)	0.28	−0.15	−0.14	−0.08	−0.12	−0.16	0.09	−0.21	−0.15
Asymmetrical ratio of LTS (R/L)	0.11	0.66**	0.69**	−0.15	0.03	0.02	0.20	0.62**	0.61**

TLD: thoracic lateral deviation; UTS: upper thoracic shape; LTS: lower thoracic shape; IAMF: internal ankle moment of the frontal plane; COM: center of mass; COP: center of pressure; LR: loading response; MS: midstance; TS: terminal stance.
*Significant correlation (p<0.05).
**Significant correlation (p<0.01).

DISCUSSION

In this study, thoracic asymmetry in the standing position, asymmetry of the IAMF, the COM and COP mediolateral deviations during gait were analyzed. In addition, the relationship between thoracic and gait parameters was investigated.

The thorax of the participants in this study was deviated to the left relative to the pelvis in the standing position. Furthermore, the UTS had a greater anteroposterior diameter on the left relative to the right, and the LTS had a greater anteroposterior diameter on the right relative to the left. The expansion of the anterior-posterior diameter of the thoracic shape can be regarded as the backward rotation of the ribs, while the reduction can be regarded as the forward rotation of the ribs[1, 4, 11]. Thus, it is suggested that the right upper ribs in cases of leftward deviation of the thorax are in a forward rotational position and the left is in a backward rotational position relative to the contralateral side, while the lower ribs are in the opposite rotational position to the upper ribs. Several previous studies analyzing the thorax in able-bodied individuals have reported thoracic asymmetry, as shown by our results[1–4, 11]. We speculate that a possible reason for the similar thoracic asymmetry in many able-bodied individuals is the functional asymmetry of the lower limbs. Many studies[15–18] have reported that one lower limb contributes to support and control while the other contributes to propulsion during able-bodied gait. Hirasawa[19] reported that the left lower limb carries the support function and the right lower limb the propulsion function, based on the results of an investigation of functional asymmetry of the lower limbs in standing position and gait. Thus, we consider that the reason for many able-bodied individuals showing left deviation of the thorax and asymmetry in rib alignment is to position the trunk mass on the left lower limb to perform tasks such as support and control. Based on this hypothesis, we would expect thoracic asymmetry to be a factor in causing laterality in lower extremity kinetics. In fact, bilateral differences in ankle kinetics in the frontal plane were observed and related to thoracic parameters in this study.

Results of the left-right comparison in gait parameters showed that the IAMF, the COM and COP lateral deviations were significantly greater on the right than on the left through LR, MS, and TS. These findings mean that the internal ankle valgus moment is greater, and the COM and COP are deviated medially in the right stance phase relative to the left. The activity of ankle muscles, regarded as the internal ankle moment, contributes to the control of COP and the stability of COM[6, 7, 13]. Therefore, because the COM is deviated to the left during gait in cases of leftward deviation of the thorax, it is considered that the COP is medialized by increased activity of the ankle valgus muscles during the right stance phase, and these contrasting strategies are used on the left.

Correlation analysis of thoracic and gait parameters showed significant positive correlations between the asymmetrical ratio of the LTS and the asymmetry of the IAMF and the COP mediolateral deviation in MS and TS. However, there was no significant correlation between thoracic parameters, including the asymmetrical ratio of the LTS and the asymmetry of the COM mediolateral deviation. These results suggest that participants with greater asymmetry of the LTS also tend to have greater asymmetry of the IAMF and COP position, but not necessarily greater asymmetry of the COM position. The activity of not only the hip joint muscles, but also the ankle valgus/varus muscles, is important for mediolateral stability in MS and TS, which are categorized as the single stance phase[7, 20]. Thus, participants with greater asymmetry of the LTS are expected to have minimized COM deviation during the single stance phase due to increased asymmetry of activity of the ankle valgus/varus muscles. Despite these considerations, we cannot clearly state the detailed mechanism by which the asymmetry of the LTS is related to the asymmetry of the IAMF. We expect that further investigation of the effect of thoracic asymmetry on other segments will clarify the detailed mechanism that led to the present results.

This study showed that able-bodied individuals with thoracic asymmetry have laterality of the IAMF during gait, and that the laterality is related to the asymmetry of the lower thoracic shape. Choi et al.[8] have suggested that the lower the medial longitudinal arch of the foot, the greater the external ankle varus moment is in patients with medial ankle osteoarthritis. Therefore, it is necessary in the future to examine the possibility that worsening asymmetry of the LTS may cause overuse of the ankle valgus/varus muscles and worsening of the foot structure. In addition to the aforementioned effects of thoracic asymmetry on other segments, we believe that research on orthopedic diseases will lead to clinical applications.

This study has several methodological limitations. It is unclear whether the thoracic skeleton could be accurately assessed because thoracic shape measurements include soft tissue thickness in the anterior thoracic region and back. In addition, the IAMF, COM, and COP mediolateral deviations failed to consider the influence of the foot angle in the horizontal plane. Therefore, it is necessary in the future to investigate the reliability of the analysis method for the thorax, and the asymmetry of the foot angle in the horizontal plane in able-bodied gait.

In conclusion, this study investigated the thoracic asymmetry in the standing position and the asymmetry of the IAMF and the COM and COP mediolateral deviations during gait and analyzed the correlations between these values. The results showed that the thorax in the standing position deviated to the left, and asymmetry of the UTS and LTS was observed. Significant lateralities were observed in the IAMF and the amount of the COM and COP mediolateral deviation during gait. In addition, there were significant positive correlations between the asymmetry of the LTS and the asymmetry of the IAMF and the amount of the COP mediolateral deviation in the MS and TS. These results suggest that the thoracic asymmetry is associated with the mediolateral control of the ankle during gait.

Conflicts of interest

The authors declare the there is no conflict of interests regarding the publication of this article.

REFERENCES

1) Hirayama T, Homma Y, Mohara A, et al.: Effects of the features of thoracic shape at rest on thoracic mobility and respiratory function. Rigakuryoho Kagaku, 2018, 33: 513–518 (in Japanese with English abstract). [CrossRef]
2) Homma Y, Hirayama T, Mohara A, et al.: Relations of bilateral symmetry in the cross-sectional area of the quadratus lumborum muscles to posture in the frontal plane and respiratory function in forced breathing. Rigakuryoho Kagaku, 2018, 33: 501–506 (in Japanese with English abstract). [CrossRef]
3) Sano T, Komuro N, Homma Y, et al.: Relationship between lateral thoracic deviation and left-right ratio of psoas major cross-sectional area. Rigakuryoho Kagaku, 2022, 37: 297–301 (in Japanese with English abstract). [CrossRef]
4) Komuro N, Homma Y, Adachi R, et al.: Relationships among thoracic lateral deviation, thoracic shape, and lateral tilt angle of the shank in the stance phase of gait. Rigakuryoho Kagaku, 2020, 35: 187–191 (in Japanese with English abstract). [CrossRef]
5) Pandy MG, Andriacchi TP: Muscle and joint function in human locomotion. Annu Rev Biomed Eng, 2010, 12: 401–433. [Medline] [CrossRef]
6) Brough LG, Klute GK, Neptune RR: Biomechanical response to mediolateral foot-placement perturbations during walking. J Biomech, 2021, 116: 110213. [Medline] [CrossRef]
7) van Leeuwen AM, van Dieën JH, Daffertshofer A, et al.: Ankle muscles drive mediolateral center of pressure control to ensure stable steady state gait. Sci Rep, 2021, 11: 21481. [Medline] [CrossRef]
8) Choi JH, Han HS, Park YJ, et al.: Relationship between ankle varus moment during gait and radiographic measurements in patients with medial ankle osteoarthritis. PLoS One, 2021, 16: e0253570. [Medline] [CrossRef]
9) Ro DH, Lee J, Lee J, et al.: Effects of knee osteoarthritis on hip and ankle gait mechanics. Adv Orthop, 2019, 2019: 9757369. [Medline] [CrossRef]
10) Fukaya T, Mutsuzaki H, Nakano W, et al.: Characteristics of frontal plane lower limb movement during walking in patients with knee osteoarthritis of varying severity. J Orthop Surg (Hong Kong), 2019, 27: 2309499019848085. [Medline] [CrossRef]
11) Aramaki Y, Homma Y, Mamizu T, et al.: Analysis of the asymmetry of thoracic shape at rest: relationship with lateral thoracic deviation. J Phys Ther Sci, 2022, 34: 454–458. [Medline] [CrossRef]
12) Plug In Gait Model Details: http://www.idmil.org/mocap/Plug-in-Gait+Marker+Placement.pdf (Accessed May 16, 2022)
13) Winter DA: Biomechanics and motor control of human movement, 4th ed. Hoboken: John Wiley & Sons, 2009, pp 281–295.
14) Perry J, Burnfield J: Gait analysis: Normal and pathological function, 2nd ed. Thorofare: SLACK, 2010, pp 137–160.
15) Sadeghi H, Allard P, Prince F, et al.: Symmetry and limb dominance in able-bodied gait: a review. Gait Posture, 2000, 12: 34–45. [Medline] [CrossRef]
16) Gregg RD, Dhaher Y, Lynch KM: Functional asymmetry in a five-link 3D bipedal walker. Annu Int Conf IEEE Eng Med Biol Soc, 2011, 2011: 7820–7823. [Medline]
17) Gregg RD, Dhaher YY, Degani A, et al.: On the mechanics of functional asymmetry in bipedal walking. IEEE Trans Biomed Eng, 2012, 59: 1310–1318. [Medline] [CrossRef]
18) Polk JD, Stumpf RM, Rosengren KS: Limb dominance, foot orientation and functional asymmetry during walking gait. Gait Posture, 2017, 52: 140–146. [Medline] [CrossRef]
19) Hirasawa Y: Lateralization of a left human foot and a right from a viewpoint of stasiology. Shinkei Shinpo, 1980, 24: 623–633 (in Japanese).
20) Hof AL, Duysens J: Responses of human ankle muscles to mediolateral balance perturbations during walking. Hum Mov Sci, 2018, 57: 69–82. [Medline] [CrossRef]