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Impact of lumbar spine pathology on asymmetrical hallux valgus in a population-based cohort study

Takumi Matsumoto[1✉], Ryutaro Takeda[1], Toshiko Iidaka[2], Chiaki Horii[1], Hiroyuki Oka[3], Shigeyuki Muraki[2], Suguru Inokuchi[4], Satoshi Arita[5], Yuyu Ishimoto[5], Hiroshi Hashizume[5,6], Hiroshi Yamada[5], Munehito Yoshida[5,7], Kozo Nakamura[8], Sakae Tanaka[1] & Noriko Yoshimura[2]

This study aims to investigate the influence of lumbar spine disorders on the development of asymmetric hallux valgus (HV). Data from the fifth survey of the Osteoarthritis/Osteoporosis Against Disability (ROAD) study, a nationwide prospective study in Japan, were analyzed. HV severity was categorized into 4 grades based on the radiographic HV angle, and asymmetric HV was defined as having at least one HV on either side, with a difference of two or more severity grades between the left and right. Controls were matched from both the Normal group (without HV on both sides) and the Symmetric group (HV on at least one side with a difference of one or less severity grades). Univariate analysis assessed lumbar conditions, and multinomial logistic regression analysis explored the association between lumbar spine disorders and asymmetric HV. Among 1997 participants, 27 had asymmetric HV. Univariate analysis revealed a higher incidence of L5 spondylolisthesis and scoliosis in the Asymmetric group. Multinomial logistic regression analysis revealed that scoliosis independently increased the likelihood of asymmetrical HV (Odds ratio [OR] = 3.586, 95% Confidence interval [CI] 1.111–11.582), but showed no significant impact on symmetrical HV (OR 0.910, 95% CI 0.355–2.334). Asymmetric HV is rare but may be associated with lumbar spine disorders, particularly scoliosis.

Hallux valgus (HV) is a common foot deformity worldwide, with an estimated pooled prevalence of 23% in adults aged between 18 and 65 years[1]. Several factors have been identified as contributing to the development of HV, including footwear, genetics, sex, age, structural factors such as metatarsal head shape or length, body mass index, and systemic joint laxity[2,3]. The presence of these risk factors theoretically influences both sides of the foot; in fact, the majority of HV are bilateral[4]. Thus, it is rare but not unheard of to encounter cases of unilateral HV or HV with significant asymmetry in severity between the left and right sides. These infrequent occurrences raise intriguing questions about the underlying mechanisms involved in the development and progression of HV. However, to the best of our knowledge, there has been no systematic investigation into the factors underlying such asymmetric HV cases.

Reports on cases of unilateral HV have been limited to those primarily attributed to traumatic causes such as injuries to the medial collateral ligament of the first metatarsophalangeal (MTP) joint, avulsion fractures at the insertion site of the adductor hallucis muscle, or acute tarsal tunnel syndrome following a fracture of the tibia[5–7]. However, it is worth noting that in clinical practice, there are instances where individuals present with asymmetrical HV without any history of trauma. In one case report, the development of ipsilateral HV was attributed to atrophy of the abductor hallucis muscle caused by unilateral S1 radiculopathy following surgery on the lumbar spine[8]. If lumbar nerve root issues are considered a potential cause of unilateral HV, this raises questions regarding the relationship between unilateral HV and degenerative lumbar conditions, such as scoliosis and spondylolisthesis, which are common degenerative disorders associated with age, along with HV itself.

[1]Department of Orthopaedic Surgery, Faculty of Medicine, The University of Tokyo, 7-3-1 Hongo, Bunkyo-Ku, Tokyo 113-8655, Japan. [2]Department of Preventive Medicine for Locomotive Organ Disorders, 22nd Century Medical & Research Center, Faculty of Medicine, University of Tokyo, Tokyo, Japan. [3]Department of Medical Research and Management for Musculoskeletal Pain, 22nd Century Medical & Research Center, Faculty of Medicine, University of Tokyo, Tokyo, Japan. [4]Inokuchi Clinic, Tokyo, Japan. [5]Department of Orthopaedic Surgery, Wakayama Medical University, Wakayama, Japan. [6]School of Health and Nursing Science, Wakayama Medical University, Wakayama, Japan. [7]Sumiya Orthopaedic Hospital, Wakayama, Japan. [8]Towa Hospital, Tokyo, Japan. ✉email: matumot-tky@umin.ac.jp

Nevertheless, no systematic investigation has been conducted to examine the association between lumbar spine disorders and asymmetric HV.

In the present study, we aimed to investigate the influence of lumbar spine disorders in patients with unilateral HV using a large population-based cohort.

Methods

Study design

The data utilized in the present study were derived from the fifth survey of the Osteoarthritis/Osteoporosis Against Disability (ROAD) study, an ongoing nationwide prospective study launched in 2005. The ROAD study aims to investigate the genetic and environmental factors underlying bone and joint diseases, particularly osteoporosis and osteoarthritis. It consists of population-based cohorts situated in three distinct communities in Japan: an urban area in Itabashi, Tokyo; a mountainous region in Hidakagawa, Wakayama; and a coastal region in Taiji, Wakayama. Participants were recruited from the resident registry data of each community. Further details regarding the ROAD study can be found in previous publications[9,10]. The fifth survey was conducted between 2018 and 2019, focusing on the mountainous and coastal regions, excluding the urban area.

Among the 2386 participants from these regions, we focused on the 828 from the mountainous region and 1169 from the coastal region who underwent bilateral foot and lumbar spine radiography for subsequent analysis, excluding those without complete imaging data. All the participants included in the ROAD study were Japanese.

Radiographic assessment of foot

Licensed radiography technicians obtained anteroposterior radiographs of both feet of each participant. The participants were positioned supine with the plantar aspects of their feet placed on the image receptor, and the X-ray beam was angled approximately 15 degrees posteriorly towards the calcaneus. To ensure consistency and minimize interobserver variability, all measurements were conducted by an independent board-certified foot and ankle surgeon affiliated with the Japanese Society for Surgery of the Foot.

The HV angle was calculated from the radiographs as the angle between the longitudinal axis of the first metatarsal and the proximal phalanx[11]. The accuracy and reliability of this measurement were previously assessed and documented[3]. We reported an intraclass correlation coefficient (ICC) of 0.99 for the HV angle, indicating excellent reliability, and a standard error of measurement (SEM) of 1.0°, confirming high precision. HV severity was categorized based on the HV angle using the following criteria established by the Japanese Orthopedic Society: < 20° (normal), 20°–29° (mild), 30°–39° (moderate), and ≥ 40° (severe)[12].

Cases in which there was a difference of two or more HV severity grades between the left and right sides were defined as asymmetric HV cases and formed the Asymmetric group. Symmetric cases were defined as those with at least unilateral HV, but with an HV severity grade difference of 1 or less between the left and right sides. The normal cases comprised individuals without HV on either side.

To minimize the potential confounding factors, a matched case–control design was employed, extracting controls at a 3:1 ratio from both symmetric and normal cases for the Symmetric and Normal groups, respectively, in comparison to the Asymmetric group. This design is particularly effective in controlling confounding variables and is well-suited for studies with rare outcomes or diseases[13]. Controls were selected to match the sex, age and BMI from both the symmetric HV cases and the normal cases, with a range of ± 1 year for age and ± 1.5 kg/m² for BMI. Matching was performed by extracting the participants and using the randomization function in Excel to select the top three matches.

Radiographic assessment of the lumbar spine

Anteroposterior and lateral radiographs of the lumbar spine were obtained with patients in an upright standing position. All radiographs were interpreted by a single experienced orthopedic surgeon who was blinded to the presence or severity of HV among the participants.

Consistent with the methodology employed in previous epidemiological studies on radiographic spondylolisthesis, the percentage of slip (%slip) was calculated by dividing the slip distance by the caudal body width. A subject was classified as having spondylolisthesis if they exhibited an anterior or posterior slip of ≥ 5% at any lumbar level as determined from the lateral views[14]. The degree of scoliosis was evaluated using the Cobb angle of the main lumbar curve on anteroposterior spine radiographs, which was determined by measuring the angle between the lines drawn parallel to the superior endplate of the most tilted vertebra above the deformity and the inferior endplate of the most tilted vertebra below the deformity[15]. Scoliosis was defined as a Cobb angle of 10 degrees or more. The intra-observer reliability of these measurements has been evaluated as high in our previous cohort studies, with a kappa value of 0.83 and 0.74 for grouping based on %slip and the Cobb angle, respectively[16,17].

A full spinal MRI was conducted on all participants using a mobile MRI unit (Excelart 1.5T; Toshiba, Tokyo, Japan) housed in a truck, except for those with a heart pacemaker, claustrophobia, or other contraindications. For individuals in the Asymmetric group, lumbar spine MRI findings were examined for stenosis and its causes, including herniation, flavum thickening, and other relevant observations[16,18].

Statistics

Continuous variables were reported as mean ± standard deviation, while categorical variables were presented as counts and percentages. Comparisons of the participants' backgrounds and radiographic parameters between groups (Normal vs. Symmetric HV vs. Asymmetric HV) were performed using appropriate statistical methods, as described below. One-way ANOVA followed by the Tukey–Kramer test, was used to compare all continuous variables among the groups. The chi-square test or Fisher's exact test was used to compare the proportions

between groups. When these tests showed significant differences, an adjusted residual analysis was performed to identify the responsible categories. Multinomial logistic regression analysis was used to investigate the contribution of lumbar spine disorders to asymmetric HV deformities. Multinomial logistic regression is one of the multiple logistic regression analyses typically employed when the dependent variable is categorical and consists of more than two categories.

A significance level of 0.05 was used to determine statistical significance for each analysis. All statistical analyses were conducted using the IBM SPSS Statistics 29.0.0.0 software (IBM Corp., Armonk, NY, USA).

Results

The severity grades of HV assessed separately for the left and right feet are presented in a 4×4 table format in Table 1. A total of 1231 participants without HV in either foot were categorized as normal. Of the remaining 766 individuals, 315 had no difference in HV severity grade between the left and right feet, 424 had a 1-grade difference, 24 had a 2-grade difference, and 3 had a 3-grade difference in HV severity between the left and right feet. Thus, there were 27 cases classified as asymmetric HV cases, and 739 cases classified as symmetric HV cases according to the definition we established.

Of the 27 cases classified as asymmetric HV, an 84-year-old woman had a severe lumbar flexion deformity and difficulty in assessing scoliosis on plain radiographs. After excluding this patient, the remaining 26 were included in the Asymmetric group. From the 1231 individuals classified as normal, we extracted 77 individuals for the Normal group, matching them with the Asymmetric group. Similarly, from the 739 individuals classified as symmetric cases, we extracted 75 individuals as the Symmetric group. While the ideal matching ratio would have been 1:3, in a few cases, only two individuals could be successfully matched, resulting in the number of individuals being 1–3 fewer than the expected target of 78.

In the comparison among the three groups, the overall prevalence of spondylolisthesis from the third to fifth lumbar vertebrae was 31% in the Asymmetric group, 40% in the Symmetric group, and 30% in the Normal group, with no statistically significant difference (p = 0.3890) (Table 2). When analyzing each lumbar level separately using the chi-square analysis, no significant differences were observed at L3 (p = 0.3675) or L4 (p = 0.4368) among the three groups (Asymmetric, Symmetric, Normal). However, at L5, there was a statistically significant

Left	Right			
	Normal	**Mild**	**Moderate**	**Severe**
Normal	1231 (normal)	**149 (symmetric)**	9 (asymmetric)	1 (asymmetric)
Mild	**176 (symmetric)**	**254 (symmetric)**	**43 (symmetric)**	3 (asymmetric)
Moderate	6 (asymmetric)	**43 (symmetric)**	**54 (symmetric)**	**8 (symmetric)**
Severe	2 (asymmetric)	6 (asymmetric)	**5 (symmetric)**	**7 (symmetric)**

Table 1. Severity grades of hallux valgus for the left and right feet. The number within each cell represents the number of feet corresponding to the severity level. The characters within parentheses indicate the groups to which each severity level belongs. The cells in bold indicate individuals belonging to the symmetric cases.

	Asymmetric group (N = 26)	Symmetric group (N = 75)	Normal group (N = 77)	P value
Age (years)	73.9 ± 6.6	73.9 ± 6.5	73.6 ± 6.1	0.9512
Sex (F:M)	23:3	66:9	69:8	0.9503
BMI (kg/m^2)	22.7 ± 4.0	22.4 ± 3.4	22.7 ± 3.6	0.9180
HVA right (degree)	27.4 ± 12.3[a,b]	24.0 ± 6.4[b,c]	12.2 ± 4.1[a,c]	< 0.0001
HVA left (degree)	27.3 ± 10.1[a,b]	24.2 ± 7.2[b,c]	12.3 ± 4.3[a,c]	< 0.0001
Spondylolisthesis				
L3-5	8 (31%)	30 (40%)	23 (30%)	0.3890
L3	1 (4%)	7 (9%)	10 (13%)	0.3675
L4	6 (23%)	24 (32%)	18 (23%)	0.4368
L5	4 (15%)*	4 (5%)	1 (1%)**	0.0169
Scoliosis	11 (42%)*	15 (20%)	11 (14%)	0.0095

Table 2. Comparison of participants' demographic data and radiographical measurements among the Asymmetric, Symmetric, and Normal groups. *Significant increase after residual analysis, indicated by an adjusted standardized residual exceeding an absolute value of 1.96, corresponding to a significance level of p < 0.05. **Significant decrease after residual analysis, indicated by an adjusted standardized residual exceeding an absolute value of 1.96, corresponding to a significance level of p < 0.05. [a]p < 0.05, between Asymmetric and Normal groups after post-hoc test. [b]p < 0.05, between Asymmetric and Symmetric groups after post-hoc test. [c]p < 0.05, between Symmetric and Normal groups after post-hoc test.

difference in the prevalence of spondylolisthesis among the groups, with rates of 15% in the Asymmetric group, 5% in the Symmetric group, and 1% in the Normal group (p = 0.0169). Residual analysis further showed that the prevalence was significantly higher in the Asymmetric group and significantly lower in the Normal group at the L5 level (Table 2).

A comparison of scoliosis revealed significant differences among the groups, with 42% in the Asymmetric group, 20% in the Symmetric group, and 14% in the Normal group (p = 0.0095). Residual analysis further confirmed the significantly higher prevalence of scoliosis in the Asymmetric group (Table 2).

Among the 26 participants in the Asymmetric group, only six exhibited no significant findings in their lumbar spine MRI examinations, while the remaining 20 showed abnormalities, such as stenosis, intervertebral disc herniation, and flavum thickening, as detailed in Supplementary Table 1.

The aim of the present study was to determine whether the presence of lumbar spine disorders influence the asymmetric HV; therefore, the multinomial logistic regression analysis was performed firstly with the reference category being set to "the Normal group" (Table 3). After this Model 1 was evaluated, the reference category was then set to "the Symmetric group," thus constituting Model 2 (Table 4). In Model 1, compared to the normal foot, the presence of scoliosis increased the likelihood of asymmetric HV (B = 1.277, OR 3.586 [95% CI 1.111–11.582], p = 0.033). Residing in coastal regions increased the likelihood of symmetric HV (B = 0.830, OR 2.293 [95% CI 1.151–4.572], p = 0.018) but had no significant influence on asymmetric HV. In model 2, compared to symmetric HV, the presence of scoliosis increased the likelihood of asymmetric HV (B = 1.371, OR 3.940 [95% CI 1.239–12.531], p = 0.020).

Among the 11 participants with scoliosis in the Asymmetric group, the convex side was on the left in 6 cases and on the right in 5 cases (Supplementary Table 1). Regarding the HV severity, 5 cases had more severe HV on the left side, and 6 cases on the right. Concordance between the convex side of the scoliosis and the HV severity side was observed in 55% of cases and discordance in 45% of cases. Fisher's exact test indicated no significant relationship between the convex side of scoliosis and the HV severity side (p > 0.99).

A representative case of asymmetric HV was presented in Fig. 1.

Discussion

Using a large-scale cohort of nearly 2,000 general population participants, the present study not only revealed the frequency of asymmetric HV with significant severity differences between the left and right feet, but also unveiled the potential role of lumbar spine disorders as underlying factors. Asymmetric HV cases were relatively rare in the study cohort, and multinomial logistic regression analysis revealed the contribution of scoliosis to asymmetric HV.

	B	SE	Wald	df	P value	Exp (B)	95% CI Lower	Upper
Symmetric hallux valgus								
Resident area (ref. coastal region)	0.830	0.352	5.563	1	0.018	2.293	1.151	4.572
L5 spondylolisthesis	1.539	1.166	1.742	1	0.187	4.661	0.474	45.843
Scoliosis	− 0.094	0.480	0.038	1	0.845	0.910	0.355	2.334
Asymmetric hallux valgus								
Resident area (ref. coastal region)	− 0.163	0.532	0.094	1	0.759	0.849	0.299	2.409
L5 spondylolisthesis	1.943	1.195	2.646	1	0.104	6.982	0.671	72.603
Scoliosis	1.277	0.598	4.559	1	0.033	3.586	1.111	11.582

Table 3. Logistic regression model I: reference category was set to the Normal group. *B* logistic coefficient, *SE* standard error, *df* degrees of freedom, *Exp(B)* odds ratio, *CI* confidence interval.

	B	SE	Wald	df	P value	Exp (B)	95% CI Lower	Upper
Normal								
Resident area (ref. coastal region)	− 0.830	0.352	5.563	1	0.018	0.436	0.219	0.869
L5 spondylolisthesis	− 1.539	1.166	1.742	1	0.187	0.215	0.022	2.110
Scoliosis	0.094	0.480	0.038	1	0.845	1.099	0.428	2.817
Asymmetric hallux valgus								
Resident area (ref. coastal region)	− 0.993	0.528	3.539	1	0.060	0.370	0.132	1.042
L5 spondylolisthesis	0.404	0.827	0.239	1	0.625	1.498	0.296	7.571
Scoliosis	1.371	0.590	5.393	1	0.020	3.940	1.239	12.531

Table 4. Logistic Regression Model II: Reference Category was set to the Symmetric group. *B* logistic coefficient, *SE* standard error, *df* degrees of freedom, *Exp(B)* odds ratio, *CI* confidence interval.
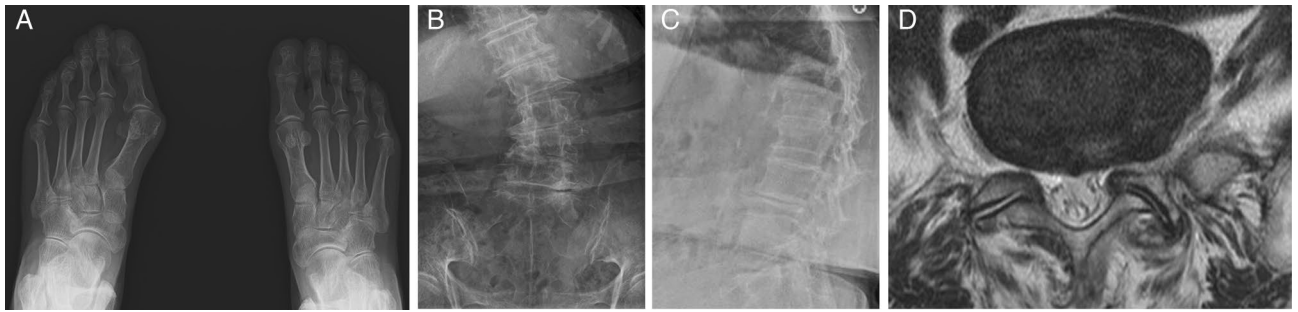
Fig. 1. Images representing a case of asymmetric hallux valgus in an 83-year-old woman. Anteroposterior bilateral foot radiograph (**A**) demonstrates asymmetric hallux valgus on the left foot. Anteroposterior (**B**) and lateral (**C**) radiographs of the lumbar spine demonstrates scoliosis with convexity to the left and loss of lordosis accompanied by degenerative changes. MRI at the L5/S1 level (**D**) reveals no central stenosis, but degeneration of the lumbar spine has led to narrowing of the left lateral recess.

In the present study, we categorized the severity of HV into four stages, defining individuals with at least one HV on either side and a difference of two or more stages between the left and right as having asymmetric HV, and those with a difference of one stage or less as having symmetric HV. Among the participants, 27 were classified as having asymmetric HV, while 739 were classified as having symmetric HV. Remarkably, 96% of the HV cases exhibited symmetric deformities, indicating that asymmetric HV is rare, accounting for only 4% of HV cases. Reports evaluating the HV symmetry based on severity categorization are scarce in the available literatures. While not specifically focused on assessing symmetry, Coughlin et al. investigated 108 cases with HVA of 20° or more requiring surgery at a single institution. Their findings indicated that 84% of the patients had bilateral HV, providing some insight into the prevalence of bilateral deformities in severe cases requiring surgeries[19]. In another retrospective study focusing on surgical cases of HV, 33 patients with unilateral HV at the time of surgery were followed-up for an average of 4.7 years[4]. The study revealed that among these patients, 14 developed HV on the non-operated side, resulting in a final bilateral involvement rate of 97.3%, indicating that the condition was predominantly bilateral. Another study examining the severity of HV deformities in patients with bilateral symptomatic deformities seeking surgical correction found no statistically significant difference in the deformity severity between the left and right feet[20]. However, this study only compared the average values of the left and right HV angles in the subjects and did not explore whether individual cases might exhibit notable disparities in severity grades between the left and right sides. Many known risk factors for HV affect both feet; therefore, it is logical to expect that bilateral occurrence would be common. However, to the best of our knowledge, no comprehensive reports have investigated the underlying factors in the rare cases of unilateral or asymmetric HV.

In the pathophysiology of HV, the significant role of the abductor hallucis muscle is well recognized and supported by various factors, such as the reduction in abductor hallucis strength in HV cases[21,22], the effectiveness of toe spread out exercises in preventing HV progression[23], and the contribution of abductor hallucis muscle dysfunction due to trauma to the development of HV[5]. The abductor hallucis is an intrinsic muscle that plays a role in abduction and flexion of the hallux. It originates from the medial process of the calcaneal tuberosity and is inserted into the medial aspect of the first proximal phalanx of the hallux. It is innervated by the medial plantar nerve, which is a branch of the tibial nerve derived from the nerve roots, predominantly S1[24]. In HV deformities, it is believed that as the hallux undergoes progressive medial deviation, the abductor hallucis muscle becomes displaced to the plantar side, leading to the loss of its intended function and contributing to the progression of the deformity[22]. However, some reports have also indicated a reduction in abductor hallucis muscle strength even in mild deformities, with no observed correlation between decreased muscle strength and the severity of HV[21,25]. This suggests that a decrease in the abductor hallucis muscle strength might serve as a potential trigger for HV. As evidence of the association between abductor hallucis muscle weakness and the occurrence of HV, there is a case report demonstrating the development of HV due to medial plantar nerve paralysis following tarsal tunnel syndrome after a tibial fracture[6]. In another case report, a 73-year-old woman presented with a severe unilateral HV deformity and metatarsophalangeal joint dislocation after undergoing lumbar spine surgery six years earlier[8]. These examinations indicated that the deformity was likely caused by abductor hallucis muscle wasting due to S1 nerve root injury as a complication of lumbar spine surgery. These case reports suggest that HV can result from the wasting of the abductor hallucis muscle due to neurological disorders.

In the present study, the univariate analysis showed a higher incidence of L5 spondylolisthesis in the Asymmetric group. In cases of L5 spondylolisthesis, it has been reported that the L5 root is primarily affected, and in severe cases, the S1 root may also be involved[26]. Considering that the abductor hallucis muscle is innervated by S1 in 80% of cases, while both L5 and S1 contributed equally in 10%, and L5 alone in 10%[24], L5 spondylolisthesis can lead to muscle weakness. Conversely, L4 spondylolisthesis typically affects the L5 root through central and lateral recess stenosis, while foraminal stenosis affects the L4 root, thereby reducing the likelihood of abductor hallucis muscle weakness. Additionally, not all spondylolisthesis cases result in nerve root impairment, which may explain the lack of a significant association between L4 spondylolisthesis and asymmetric hallux valgus observed in our study.

Univariate and multivariate analyses revealed an association between unilateral HV and scoliosis. Degenerative lumbar scoliosis is a common spinal deformity in the elderly, and its prevalence has been reported to be 3%

in the same cohort as in the present study[17]. It can cause low back pain, radicular pain, and neurogenic claudication. In a radiographic study of patients with degenerative lumbar spinal stenosis and scoliosis presenting with radiculopathy, S1 root radiculopathy occurred in 18% of patients and was predominantly influenced by lateral recess stenosis on the convex side[27]. In the present study, we found no prominent relationship between the convex side of scoliosis and the side with more severe HV. However, given the small number of cases, further investigations with larger sample sizes are necessary to explore the relationship between the convex side of scoliosis and HV severity. Furthermore, in patients with scoliosis, factors such as pelvic tilt, weight distribution, and altered walking patterns may contribute to the development of asymmetric HV[28].

The present study has some limitations. The primary limitation is its limited geographical scope, which focuses exclusively on a specific region in Japan. This regional focus may raise questions regarding the generalizability of the findings to broader populations. Another limitation was the absence of detailed neurological assessments. The lack of comprehensive neurological examinations makes it challenging to definitively conclude whether asymmetric HV is solely attributable to abductor hallucis muscle neuropathy. Additionally, this study did not investigate the potential influence of lower limb balance, hip and knee joint alignment, or center of gravity on the asymmetry of HV. Future research should consider these factors for a more comprehensive understanding. Despite these limitations, the strength of this study lies in its evaluation of both lumbar spine and foot conditions in a large cohort of nearly 2,000 individuals from the general population, enabling the investigation of the underlying factors associated with rare pathologies.

In conclusion, although the occurrence of an asymmetric HV is uncommon, it is potentially associated with lumbar spine deformities. The results of the present study do not suggest that all cases of asymmetric HV are due to lumbar spine deformities. However, it is important to assess paralysis and lumbar deformities as a potential factor in patients with asymmetric HV, as this information is vital for surgical decision-making and for providing comprehensive explanations to patients regarding the possibility of recurrence.

Data availability
The data that support the findings of this study will not be shared, because the data were collected on the agreement from participants that the individual-level data will not be released, and only aggregated data must be publicized.

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Author contributions

Conception and design: TM, SI, ST, NY; Analysis and interpretation of the data: TM, RT; Drafting of the article: TM; Final approval of the article: All authors; Provision of study materials or patients: TI, CH, HO, SM, NY; Statistical expertise: HO; Obtaining of funding: TI, HO, ST, NY; Administrative, technical, or logistic support: TI, CH, YI, HH, HY, MY, KN, ST, NY; Collection and assembly of data: TM, RT, SA, TI, CH, YI, HH, HY, NY.

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Competing interests

The authors declare no competing interests.

Ethics consideration

Ethical approval for the study was obtained from the ethics committee of the University of Tokyo (Approval No. 1264). This study was conducted in accordance with the principles of the Declaration of Helsinki, and written informed consent was obtained from all participants.

Additional information

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Correspondence and requests for materials should be addressed to T.M.

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