STUDY ON THE RELATIONSHIP BETWEEN THE TOE-OUT GAIT AND FOOT HALLUX VALGUS IN THE ELDERLY CHINESE

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ABSTRACT. The study selects 50 senior people at the age of more than 60 and 30 young people at the age of 18-26 as test group and control group respectively, including people with mild foot disease, such as flat feet, pes cavus and hallux valgus. Questionnaire survey of effective data volume and observation are used to understand common problems of the foot in the elderly, collect shape photos of the foot in senior people, and subjectively analyze their foot shape and gait characteristics. Footscan plate plantar pressure test system and Kistler 3D force platform are used to objectively analyze plantar pressure distribution and gait characteristics of subjects. According to study results: Toe-out gait causes the plantar pressure to move to the forefoot, therefore, the forefoot is the part with the highest risk of injury of foot in toe-out gait, especially the first toe, causing hallux valgus and various foot problems. The toe-out gait causes increase of gait cycle, slow walking speed, poor buffer effect, and may bring pain in feet and lower extremities, thus affecting the dynamic characteristics of the entire lower limb.

KEY WORDS: the elderly, toe-out gait, foot hallux valgus

STUDIU PRIVIND RELAȚIA DINTRE MERSUL CU PICIOARELE ÎN EVERSIE ȘI HALLUX VALGUS LA POPULAȚIA CHINEZĂ VÂRSTNICĂ

REZUMAT. Studiul selectează 50 de persoane cu vârsta de peste 60 de ani și 30 de tineri cu vârsta cuprinsă între 18 și 26 de ani ca grup de testare, respectiv, grup martor, incluzând persoanele cu afecțiuni ușoare ale piciorului, cum ar fi piciorul plat, pes cavus și hallux valgus. Chestionarul privind volumul efectiv de date și observarea sunt utilizate pentru a înțelege problemele comune ale piciorului la vârstnici, pentru a colecta fotografii ale formei piciorului la persoanele în vârstă și pentru a analiza subiectiv forma piciorului și caracteristicile mersului. Sistemul de testare a presiunii plantare Footscan și platforma de forță Kistler 3D sunt utilizate pentru a analiza obiectiv distribuția presiunii plantare și caracteristicile mersului subiecților. Conform rezultatelor studiului, mersul cu picioarele în eversie determină deplasarea presiunii plantare către antepicior, prin urmare, antepiciorul este partea cu cel mai mare risc de rănire în mersul cu picioarele în eversie, în special degetul mare, provocând hallux valgus și diverse probleme la picioare. Mersul cu picioarele în eversie determină creșterea ciclului de mers, conduce la o viteză de mers lentă, are un efect slab de absorbție a șocului și poate cauza dureri ale labei piciorului și ale extremităților inferioare, afectând astfel caracteristicile dinamice ale întregului membru inferior.

CUVINTE CHEIE: vârstnici, mers cu picioarele în eversie, hallux valgus

ÉTUDE SUR LA RELATION ENTRE LA DÉMARCHE EN ROTATION EXTERNE ET L'HALLUX VALGUS DU PIED CHEZ LES PERSONNES ÂGÉES CHINOISES

RÉSUMÉ. L'étude sélectionne 50 personnes âgées de plus de 60 ans et 30 jeunes âgés de 18 à 26 ans comme groupe test et groupe témoin respectivement, y compris des personnes atteintes d'une maladie du pied bénigne, comme les pieds plats, le pied creux et l'hallux valgus. L'enquête par questionnaire sur le volume de données et l'observation sont utilisées pour comprendre les problèmes courants du pied chez les personnes âgées, collecter des photos de la forme du pied chez les personnes âgées et analyser subjectivement la forme du pied et les caractéristiques de la démarche. Le système de test de pression plantaire Footscan et la plate-forme de force Kistler 3D sont utilisés pour analyser objectivement la distribution de la pression plantaire et les caractéristiques de la marche des sujets. D'après les résultats de l'étude, la démarche en rotation externe provoque un déplacement de la pression plantaire vers l'avant-pied, par conséquent, l'avant-pied est la partie présentant le plus grand risque de blessure lors de la démarche en rotation externe, en particulier le gros orteil, provoquant un hallux valgus et divers problèmes pour le pied. La démarche en rotation externe augmente le cycle de marche, conduit à une vitesse de marche lente, a un faible effet d'absorption des chocs et peut provoquer des douleurs au pied et aux extrémités inférieurs, affectant ainsi les caractéristiques dynamiques de l'ensemble entier du membre inférieur.

MOTS CLÉS : personnes âgées, démarche en rotation externe, hallux valgus du pied

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INTRODUCTION

With aging of the world, problems of the elderly are increasing. The elderly are more susceptible to fracture during fall due to osteoporosis and brittleness increase. Statistically, more than 40% of the elderly easily fall with age [1]. Foot problems are related to the balance and stability of the elderly, playing an important role in preventing falling injury and improving living quality of the elderly [2]. Foot problems of the elderly are diverse and complex, and it is difficult to find the root cause, therefore, the study on the foot of the elderly lacks theoretical support.

Toe-out gait is one of the more common gait abnormalities [3]. Toe-out gait not only slows down the step, but also causes injury after long-term accumulation in the case that instep and forefoot are vulnerable to fatigue for larger impact on tibia when amount and intensity of exercise are greater [4]. Foot hallux valgus is a common morphological lesion, and foot hallux valgus malformation or pain manifests itself [5]. The incidence rate is high in the elderly, and normal walking is affected in severe cases. Li Fengling [6] selected 10 subjects with normal feet and 10 subjects with slight hallux valgus feet as control group and hallux valgus group. According to results, the lateral side of the forefoot becomes the main support mode, causing that ankle joint extends in case of touchdown, knee joint retracts, and hip joint turns outward. Su Honglun [7] *et al*. introduce the concept of transverse arch and hallux valgus, analyze biomechanical change, and obtain the relationship between hallux valgus and collapse of transverse arch. Wei Mengtian [8] *et al*. study the young men with toe-out gait. According to results, both the peak value and pressure time of toe-out gait in medial side and lateral side as well the third toe increase, and the time to reach the peak value in each area of the foot increases. According to some studies [9], foot impulse of toe-out gait decreases compared with the normal gait in forefoot and arch of foot. Gestel L.V. [10] *et al*. make a study on whether to change the foot load of toe-out gait through the plate pressure system. According to results, conscious change of gait can reduce the load of the foot area.

At present, neither domestic nor overseas studies draw a consistent conclusion in terms of plantar pressure distribution characteristics. In addition, studies on toe-out gait and hallux valgus make an analysis on mechanical changes based on focus on mechanics and morphological characteristics, but do not explore relevance. Therefore, causes of results are unknown, which is adverse to drawing a systematic conclusion. Therefore, the exploration on morphological and mechanical changes of toe-out gait and hallux valgus of the elderly and the analysis on its relevance are of great significance. Meanwhile, it provides data support for the study on the foot function, guarantee for the improvement of living quality of the elderly, and better theoretical research support for the development of shoes for the elderly.

EXPERIMENTAL

Experiment Equipment

Plate Plantar Pressure Test

The study adopts Belgian plate plantar pressure test system Footscan, with measurement frequency of 125 - 300 Hz, with 4,096 sensors with specification of 0.5 cm*0.7 cm.

3D Force Platform

In this study, Switzerland Kistler 3D force platform is used. 12 physical sensors of quartz crystal are placed on the four corners of the 3D force platform. 3 sensors for each corner are sensitive to the z, x and y-axis forces respectively. By combining the 3D force of four corners, the total 3D force and direction, as well as acting point and torque can be calculated. The plantar pressure test plate and 3D force platform are shown in Figure 1 from left to right.

Figure 1. Experimental equipment

Experimental Objects and Plans

Questionnaire Survey

Xi'an was selected as the study site for the questionnaire survey, 1,000 (500 male and 500 female) senior people at the age of 60 - 95 in Henan, Hebei, Jiangsu, Sichuan and other places were selected. The questionnaires were about the shoes and boots for the elderly. 1,000 questionnaires were distributed and 800 valid questionnaires were recovered. Seven views of the feet of the elderly were collected and the gait of the elderly was captured on video by digital high-definition cameras.

Mechanical Test

50 (25 male and 25 female) senior people at the age of more than 60 and 30 (15 male and 15 female) young people at the age of 18-26 were selected as test and control group, respectively, including people with mild foot disease, such as flat feet, pes cavus and hallux valgus. The subjects were healthy, with regular exercise habits; there had been no operation on foot and no other injury on lower limb in half a year; before the test, the subjects were informed of the test process, and all the subjects signed the informed consent form. During the test, the subjects were required to walk barefoot naturally with their normal gait [11], and the whole process was repeated three times. In order to ensure that the independent test is not affected by many factors, the interval of each test shall not be less than 1 min.

The plantar is divided into 10 regions according to the analysis process, as shown in Figure 2: Different zones are distinguished by different color blocks and acronyms. T1 represents the first toe, T2-5 represents the second to fifth toes, M1-M5 represents the first to the fifth metatarsophalangeal joints, MF represents the midfoot, HM represents the medial part of the heel, and HL represents the lateral part of the heel.

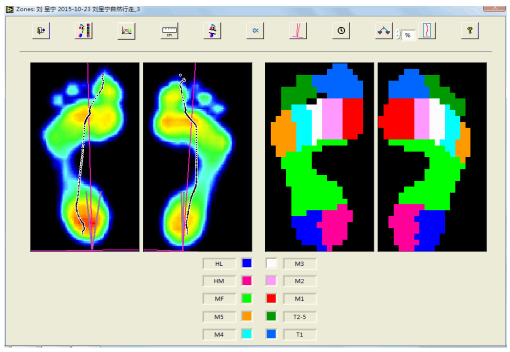

Figure 2. Regional distribution of plantar pressure

Methods

The study is mainly divided into two parts: survey and experiment. The survey study is mainly to obtain the proportion of common foot problems of the elderly through questionnaire survey and collection of foot shape and gait information. The experiment study mainly carries out biomechanical measurement of exercise [12]. Through the plate plantar pressure test and 3D force platform, parameter data of plantar pressure distribution and foot stability of the elderly is obtained, and data results are processed and analyzed to draw a condition of relevance between toe-out gait and foot hallux valgus of the elderly. The technical route of study is shown in Figure 3.

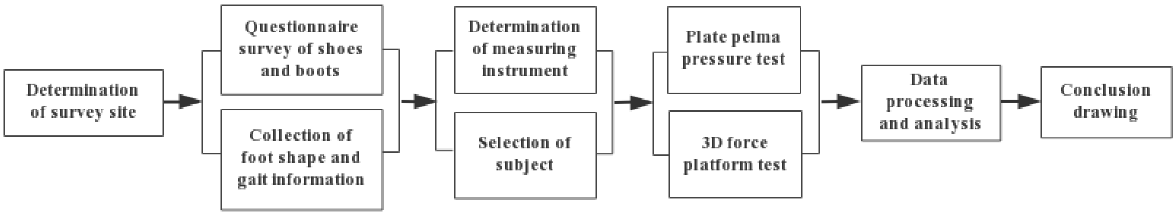

Figure 3. Research Technology Roadmap

RESULTS AND DISCUSSIONS

Survey Results of Common Foot Problems in the Elderly

The foot deformation of the elderly mainly includes the changes of forefoot, such as hallux valgus, claw toe, overlapping toe, and arch of foot. The survey results show that 15% of the elderly have claw toe, 19% of the elderly have overlapping toe, 14% of the elderly have toe adhesion, and 47% of the elderly have hallux valgus; the gait results show that 18% of the elderly shamble from side to side while walking, 20% of the elderly walk with weak legs and slow gait; 5% of the elderly have foot pain or numbness while walking, and 36% of the elderly walk in toe-out gait. Resurvey of the elderly with toe-out gait shows that 80% of the elderly have hallux valgus from the 36% of the people with toe-out gait. The summarized results are shown in Figure 4.

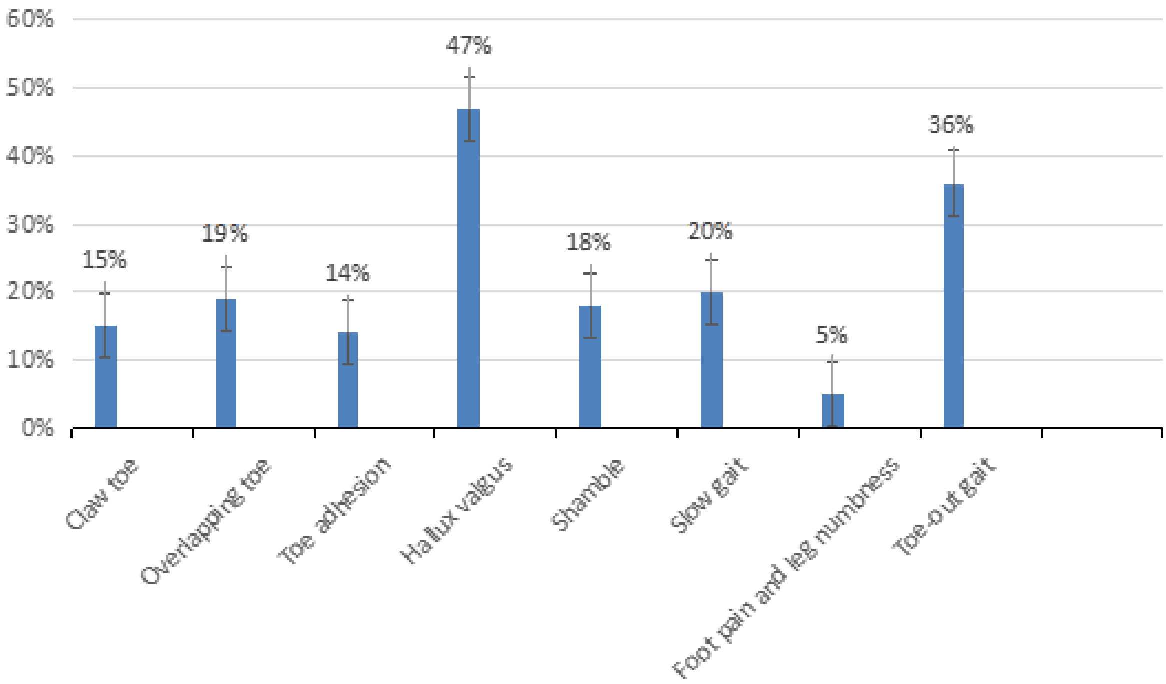

Figure 4. Survey results of common foot problems in the elderly

Plantar Mechanical Results of the Elderly

Results of Pressure Distribution in Each Plantar Zone through Plate Plantar Pressure Test

Data of peak pressure in each plantar zone in the elderly group and the young group is shown in Table 1.

Table 1: Peak pressure in each plantar zone (x±s)

Zone	Elderly male	Young male	Elderly female
T1	8.86 (±4.65)	8.93 (±4.32)	7.82 (±4.59)
T2-5	3.29 (±2.41)	3.01 (±2.63)	3.51 (±2.98)
M1	7.81 (±4.23)	10.34 (±4.3)	7.46 (±3.97)
M2	14.63 (±6.10)	16.92 (±4.15)	17.58 (±6.19)
M3	16.92 (±7.56)	18.03 (±5.34)	18.57 (±6.53)
M4	11.45 (±6.08)	10.79 (±5.68)	12.94 (±6.15)
M5	6.87 (±3.54)	5.04 (±3.17)	8.07 (±5.94)
MF	4.55 (±1.96)	3.16 (±2.12)	4.23 (±2.21)
HM	12.19 (±5.13)	14.29 (±5.01)	11.86 (±5.02)
HL	11.63 (±4.29)	14.17 (±3.95)	12.23 (±3.79)

According to the results of peak pressure in each plantar zone, in T1 zone, the peak pressure of plantar in the elderly group is lower than that of the young group, while in T2-5 zone, the peak pressure of plantar in the elderly group is significantly higher than that of the young group, which may be related to the big toe of the elderly. In the elderly group, the maximum zone of peak pressure of plantar is M2 and M3, showing that the plantar pressure of the elderly shifts to lateral forefoot.

Results of Touchdown Area in Each Plantar Zone through Plate Plantar Pressure Test

Data of plantar touchdown area of each zone in the elderly group and the young group is shown in Table 2. As for the touchdown area of the midfoot, if it is 21%-28%, it is the normal arch of foot; if it is more than 28%, it is flat feet; if it is less than 21%, it is pes cavus.

Table 2: Plantar touchdown area of each zone (x±s)

Zone	Elderly male	Young male	Elderly female
T1	15.14 (±4.82)	16.40 (±4.18)	13.24 (±4.73)
T2-5	11.7 (±6.93)	15.73 (±7.75)	11.32 (±7.89)
M1	15.83 (±4.56)	15.42 (±3.34)	12.94 (±3.34)
M2	12.47 (±2.03)	12.67 (±1.89)	10.36 (±2.58)
M3	10.01 (±1.43)	10.35 (±1.36)	8.47 (±1.73)
M4	10.43 (±1.11)	10.54 (±1.23)	8.52 (±1.74)
M5	10.70 (±2.32)	11.07 (±2.14)	9.74 (±2.85)
MF	40.01 (±9.09)	38.71 (±7.55)	37.22 (±8.72)
HM	19.76 (±1.80)	19.43 (±1.58)	16.67 (±3.46)
HL	17.25 (±1.78)	16.72 (±1.71)	13.56 (±3.31)

According to the results of touchdown area in each plantar zone, in T1 zone, the male in the elderly group is less than that in the young group by 1.26 cm^2, and the female in the elderly group is less than that in the young group by 1.84 cm^2. The touchdown area of the first toe decreases, objectively showing that the proportion of hallux valgus in the elderly is relatively high. The MF touchdown area in the elderly group is larger than that in the young group, the male in the elderly group is less than that in the young group by 1.30 cm^2, and the female in the elderly group is less than that in the young group by 1.05 cm^2.

Classification Results of Foot Axis Angles through Plate Plantar Pressure Test

As for the foot axis angles, if it is 5-12°, it is normal walking gait; if it is less than 5°, it is toe-in foot; if it is greater than 12°, it is toe-out foot [13]. Data of classification of foot axis angles is shown in Table 3.

Table 3: Classification of foot axis angles

Angle	Number of feet in elderly male	Number of feet in young male	Number of feet in elderly female	Number of feet in young female
＜5°	2	3	3	4
5°-12°	8	7	10	8
＞12°	15	5	12	3

According to the classification results of foot axis angles, the number with foot axis angles more than 12° is the majority in elderly group, showing that the elderly mostly walk in toe-out foot.

Time Phase Characteristics of Each Phase of Touchdown through Plate Plantar Pressure Test

The results of time phase show that except for the phase of heel touchdown, the time phases of other phases of gait cycle in the elderly group are significantly greater than that in the young group, as shown in Table 4.

Table 4: Data of single step timing ($\bar{X}$ ±s)

Time phase	Female			Male		
	Elderly female/ ms	Young female/ms	Sig. both sides	Elderly male/ms	Young male/ms	Sig. both sides
Heel touchdown	45.72 (±15.34)	55.46 (±23.20)	.002**	46.50 (±17.97)	53.15 (±16.17)	.014*
Forefoot touchdown	61.53 (±35.5)	52.42 (±25.04)	.020*	51.54 (±36.52)	35.28 (±21.78)	.000**
Whole foot touchdown	349.80 (±70.11)	274.46 (±75.11)	.000**	92.34 (±80.00)	293.62 (±63.70)	.004**
Forefoot off the ground	308.35 (±74.86)	273.79 (±47.79)	.000**	298.23 (±61.47)	279.97 (±46.93)	.040*
Whole gait cycle	767.02 (±65.56)	655.19 (±56.26)	.000**	787.53 (±50.49)	662.02 (±57.18)	.000*

Note: "*" and "**" refer to that they are significant in 0.05 level (both sides) and 0.01 level (both sides) respectively.

Time Phase Results of 3D Force Platform

Ts is the time of support phase before touchdown, Tb is the time of swing phase by single foot, and Tp is the time of the phase of kicking ground for pushing off. During movement, for each phase in single support gait cycle, the time phase of the elderly group is greater than that of the young group, as shown in Table 5.

Table 5: Single step timing and difference level ($\bar{X}$ ±s)

Time phase	Female			Male		
	Elderly female	Young female	Sig. both sides	Elderly male	Young male	Sig. both sides
Ts	0.72 (±0.21)	0.65 (±0.05)	.000**	0.8 (±0.14)	0.65 (±0.06)	.000**
Tb	0.35 (±0.11)	0.32 (±0.06)	.011*	0.4 (±0.09)	0.32 (±0.06)	.000**
Tp	0.37 (±0.13)	0.33 (±0.06)	.000**	0.4 (±0.08)	0.34 (±0.05)	.000**

Note: "*" and "**" refer to that they are significant in 0.05 level (both sides) and 0.01 level (both sides) respectively.

Study Results for Force Value in Z Direction of 3D Force Platform

Z direction refers to the direction that is perpendicular to the horizontal plane, and the T-test results of its mechanical indicators and independent samples of young people are shown in Table 6.

Table 6: T-test of each indicator in Z direction ($\bar{X}$ ±s)

Indicator	Female			Male		
	Elderly female	Young female	Sig. both sides	Elderly male	Young male	Sig. both sides
Fmax/N	544.83 (±211.26)	598.99 (±86.93)	.006**	719.86 (±109.29)	743.97 (±10.85)	.076
Tv/%ST	55.17 (±27.56)	69.28 (±16.18)	.000**	51.82 (±26.89)	52.61 (±5.24)	.073
Fsz/N	396.01 (±158.63)	414.46 (±52.72)	.189	518.09 (±76.13)	519.26 (±63.13)	.054
Vv/m/s	5.14 (±3.32)	5.05 (±0.31)	.641	6.36 (±1.11)	5.16 (±0.51)	.006**
Fbz/N	393.79 (±158.66)	415.49 (±60.49)	.134	521.69 (±82.94)	524.11 (±68.15)	.010*
Fpz/N	397.04 (±163.39)	411.41 (±58.43)	.327	516.23 (±80.95)	517.91 (±70.12)	.007**

Note: "*" and "**" refer to that they are significant in 0.05 level (both sides) and 0.01 level (both sides) respectively.

According to the results of force value in Z direction, the maximum force value Fmax in vertical direction, the average force value Fsz in support phase before touchdown, the average force value Fbz in vertical direction in swing phase and the average force value Fpz in vertical direction in the phase of kicking ground for pushing off of the elderly group are significantly reduced, especially in the elderly female.

Study Results for Force Value in Y Direction of 3D Force Platform

Y direction refers to the direction that is parallel to the walking direction, and the T-test results of its mechanical indicators and independent samples of young people are shown in Table 7.

Table 7: T-test of each indicator in Y direction ($\bar{X}$ ±s)

Indicator	Female			Male		
	Elderly female	Young female	Sig. both sides	Elderly male	Young male	Sig. both sides
Ta-pb/%ST	50.30 (±38.46)	51.55 (±35.48)	.807	47.38 (±36.58)	51.86 (±36.73)	.385
Va-pb/m/s	0.26 (±0.10)	0.25 (±0.74)	.752	0.33 (±0.10)	0.28 (±0.07)	.000**
Ta-pp/%ST	56.36 (±37.54)	47.06 (±35.32)	.073	49.67 (±36.17)	46.66 (±36.17)	.557
Va-pp/m/s	0.28 (±0.10)	0.248 (±0.06)	.002**	0.33 (±0.09)	0.30 (±0.07)	.009**

Note: "**" refers to that it is significant in 0.01 level (both sides)

According to the force value in Y direction, the time percentage for the occurrence of maximum force value Ta-pb in the elderly group is less than that in the young group, while the speed change in Y direction in swing phase Va-pb is large. It proves that the time of swing phase in the elderly group is short, and the stability of contralateral lower limb for supporting is poor, which makes the swing accelerate. In the phase of kicking ground for pushing off, the time percentage for the occurrence of maximum force value Ta-pp in Y direction in the elderly group increases, and the speed change Va-pp increases.

Study Results for Force Value in X Direction of 3D Force Platform

X direction refers to the direction that is perpendicular to the walking direction, and the T-test results of its mechanical indicators and independent samples of young people are shown in Table 8.

Table 8: T-test of each indicator in X direction ($\bar{X}$ ±s)

Indicator	Female			Male		
	Elderly female	Young female	Sig. both sides	Elderly male	Young male	Sig. both sides
Fmax(m-lm) /N	27.81 (±12.93)	21.81 (±10.65)	.001**	39.33 (±23.58)	39.06 (±17.0)	.919
Tm-lm/%ST	24.51 (±29.28)	28.27 (±25.33)	.342	26.71 (±30.15)	27.04 (±30.40)	.939
Fmax(m-ll) /N	30.80 (±15.49)	24.81 (±11.04)	.001**	41.86 (±28.13)	39.54 (±16.56)	.422
Tm-ll/%ST	33.96 (±32.49)	27.62 (±28.09)	.128	28.43 (±31.74)	27.76 (±30.47)	.879

Note: "*" and "**" refer to that they are significant in 0.05 level (both sides) and 0.01 level (both sides) respectively.

According to the force value results in X direction, the maximum force value Fmax (m-1m) in medial side of foot is significantly less than the maximum force value Fmax (m-11) in lateral side of foot, and the time Tm-1m for the occurrence of maximum force value in medial side of foot is less than the time Tm-11 for the occurrence of maximum force value in lateral side of foot.

Path of Center of Pressure (COP) of 3D Force Platform

The T-test results for path of COP in the elderly group and the young group as well as the independent samples are shown in Table 9.

Table 9: T-test of the data of COP ($\bar{X}$ ±s)

	Female			Male		
	Elderly female	Young female	Sig. both sides	Elderly male	Young male	Sig. both sides
Y/mm	62.35 (±24.64)	53.94 (±27.81)	.021**	77.53 (±30.98)	56.27 (±30.30)	.000**
X/mm	195.14 (±43.13)	187.57 (±49.02)	.236	246.00 (±52.19)	237.51 (±57.12)	.433

Note: "**" refers to that it is significant in 0.01 level (both sides)

According to the results for the path of COP, in Y direction, the crossing amplitude for the path of COP in the elderly group is greater than that in the young group, which is significantly different, indicating that the forward amplitude of the elderly is large, and the gait is unbalanced.

Experimental Analysis

Analysis I

The touchdown area and the peak plantar pressure of the elderly group in T1 zone reduces, while the plantar pressure in T2-T5 zones increases, causing the increase of pressure time integral in M2-M4 zones of the forefoot of the elderly group. Due to the hallux valgus caused by its bone deformity, the time phase in each phase increases, and the foot axis angles significantly increase. It can be concluded that the foot deformation directly affects the size change of each part of the foot, which causes the differences in its mechanical characteristics compared to young people. The force value of plantar pressure of the elderly is towards the outside, it may increase the feeling of fatigue in walking, and cause the flat feet in severe cases.

Analysis II

Due to the uneven plantar stress in walking caused by foot deformation, the time phase of each phase in walking in the elderly group is greater than that in the young group, and the foot axis angles significantly increase, which causes the toe-out gait. The survey results show that the toe-out gait in the elderly accounts for 36% of the respondents, which has also been indicated in the test indicators of 3D force platform, the value in X direction of the elderly group is greater than that of the young group. Because the foot of toe out is towards the outside when touching the ground during movement, the stride of each step will reduce compared to the normal touchdown stride when the step speed is certain, its force is not completely forward, while the foot moves forward in the form of half of “X”, “A” and “V”, the strength of the person moving is broken down in this way, which slows down the step speed.

Analysis III

The time phase of each phase in the whole gait cycle of the elderly group increases, the other phases of the single support gait cycle of the 3D force platform significantly increase except that the time Ts of support phase before touchdown in the elderly group is significantly less than that in the young group, the maximum force value in medial side of foot is significantly less than the maximum force value in lateral side of foot, and the increase of gait cycle indicates that the walking speed of the elderly becomes slow, which indicates the gait characteristics of drag, weakness and slowness of the elderly. And the center of gravity of the foot of the elderly is towards the outside, Fmax, Fsz, Fbz and Fpz reduce, which proves that the elderly have difficulty in lifting foot, and the gait characteristic of foot weakness is directly connected with the foot deformation caused by hallux valgus indeed.

CONCLUSIONS

(1) Toe-out gait causes the plantar pressure to move to the forefoot, therefore, the forefoot is the part with the highest risk of injury of foot in toe-out gait, especially the first toe, causing hallux valgus and various foot problems.

(2) The toe-out gait causes increase of gait cycle, slow walking speed, poor buffer effect, and may bring pain in feet and lower extremities, thus affecting the dynamic characteristics of the entire lower limb.

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