Original Article

Establishing the Normal Reference Values of Plantar Pressure Metrics in South Asian Population and Evaluating the Impact of Increased Body Mass Index on Plantar Pressure Dynamics in Young Adults

Kamalraj Subramaniam[1,2], Bhuvaneswari Muruganesan[1,2], Girinivasan Chellamuthu[3,4], Sathish Muthu[4,5]

[1]Department of Biomedical Engineering, Faculty of Engineeing, Karpagam Academy of Higher Education, [2]Centre for Biophotonics and Technology, Karpagam Academy of Higher Education, [4]Department of Orthopaedics, Orthopaedic Research Group, Coimbatore, [3]Department of Shoulder and Elbow Surgery, MIOT International, Chennai, [5]Department of Orthopaedics, Government Medical College, Karur, Tamil Nadu, India

Abstract

Background: Plantar pressure metrics vary greatly based on the morphometry of the individual. Hence, estimating the normal values of plantar pressure specific to the race of the individual is essential to identify pathological variations. This study aims to establish the normal reference values of plantar pressure metrics in south Asian population and identify the role of obesity on the global parameter variations. **Methods:** Healthy young adult volunteers aged >18 years of both sexes were allotted into two groups based on their Body Mass Index (BMI). The plantar pressure parameters such as arch index; weight and corresponding weight distribution over different areas of the foot along with balance assessment using the Y-balance test were estimated for both the foot. Independent sample *t*-test was used to compare the assessment parameters between the two groups. **Results:** We enrolled 46 healthy individuals with mean of BMI 21.4 ± 2.1 in this study as reference population to define the normal plantar pressure metrics and compared them with 35 overweight individuals with BMI 27.9 ± 3. We noted a significant difference in the average ($P < 0.001$) and maximum pressure ($P < 0.001$) exerted on the foot between the two groups. However, it did not affect the overall weight distribution pattern ($P = 0.239$) or balance ($P = 0.810$) between them. Upon analyzing the regional weight distribution pattern, we noted a significant difference in the forefoot ($P = 0.031$) and hindfoot weight distribution ($P = 0.031$) between the two groups. We noted significant intra-group variations between the right and left foot in parameters such as arch index ($P < 0.001$, $P = 0.027$), weight distribution ($P < 0.001$, $P < 0.001$), and foot progression angle ($P = 0.038$, $P = 0.003$) among overweight and normal individuals, respectively, that correlated significantly with limb dominance profile of the individual ($r = 0.863$, $P < 0.001$). **Conclusion:** Normal reference podometric parameters for Asian population are established. There exists significant difference between the right and left feet of normal and overweight individuals in their arch index, weight distribution, and foot progression angle. However, overweight individuals had significant differences in the pressure and weight distribution pattern compared to normal individuals.

Keywords: Balance, biomechanics, body mass index, overweight, plantar pressure

Introduction

Plantar pressure measurement remains the key diagnostic modality for early identification of gait abnormalities and other foot pathologies.[1] Apart from these, other applications of plantar pressure estimation include foot wear design, sport performance analysis, balance estimation, and injury prevention mechanisms.[2,3] Body Mass Index (BMI) is a measure of body fat based on the individual's height and weight.[4] Increased BMI is associated with many medical

Access this article online

Quick Response Code:

Website: https://journals.lww.com/jajs

DOI: 10.4103/jajs.jajs_129_24

Address for correspondence: Dr. Sathish Muthu, Department of Orthopaedics, Government Medical College, Karur, Tamil Nadu, India.
E-mail: drsathishmuthu@gmail.com

Submitted: 19-Nov-2024 **Revised:** 30-Apr-2025
Accepted: 01-May-2025 **Published:** 26-Aug-2025

This is an open access article distributed under the terms of the Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 License (CC BY-NC-ND), where it is permissible to download and share the work provided it is properly cited. The work cannot be changed in any way or used commercially without permission from the journal.

For reprints contact: WKHLRPMedknow_reprints@wolterskluwer.com

How to cite this article: Subramaniam K, Muruganesan B, Chellamuthu G, Muthu S. Establishing the normal reference values of plantar pressure metrics in South Asian population and evaluating the impact of increased body mass index on plantar pressure dynamics in young adults. J Arthrosc Jt Surg 2026;13:21-5.

disorders including musculoskeletal disorders of the lower limb and noncommunicable diseases such as diabetes and hypertension.[5] When the BMI is >25, the individuals are considered overweight. When the BMI is >30, it is class 1 obesity. When BMI is >35, it is class 2 obesity and when BMI is >40, it is class 3 obesity.[5] Increased weight is known to cause mechanical strain to weightbearing with alteration in the normal gait. This leads to accelerated degenerative changes in the weight bearing joints such as hip, knee, and ankle.[6]

The mechanical changes in weight bearing pattern due to increased BMI are readily observed in the foot pressure distribution pattern.[7] Foot distribution pattern is altered with increased contact pressure in some areas of foot and morphological changes such as collapse of arches of foot with increase in BMI. These alterations can lead to changes in gait and mechanical axis. Addressing these changes with foot wear modifications and proactive steps to decrease BMI can prevent further degenerative disorders of weight-bearing joints in younger individuals.[8]

Foot pressure distribution also varies with race and ethnicity as does the foot morphology.[9,10] In this background, we aim establish the normal plantar pressure metrics specific for south Asian population and compare the pressure distribution pattern between individuals with normal and overweight BMI categories who are otherwise healthy.

Methods

This observational case-control study is conducted after obtaining approval from the institutional ethical committee. The study protocol was designed and conducted in the Center for Biophotonics and Technology. Each participant signed an informed consent comprising the protocol briefing before participating in the study. In order to improve the comprehension among the participants, an audiovisual demonstration has been presented to all participants before data acquisition. The study was conducted to obtain a normative reference podogram metrics among the South Asian population; hence, we set the minimum samples to be included per category of BMI to be 25 subjects based on the previous study by Jasiewicz *et al*.[11]

Healthy young adults over 18 years of age were recruited for the study and participants with BMI ≥20 and ≤25 were classified into the normal group and BMI ≥25 and ≤30 were categorized into the overweight group. We excluded participants with a history of diabetes, hypertension, heart diseases, cardiovascular or respiratory disorders, stroke, and lower extremity injuries. We also ensured that the participants did not suffer from any neurological disorder, plantar fasciitis, rheumatoid arthritis, or ligamentous injury of the lower extremities.

Each selected participant was requested to stand on the portable plantar pressure system (OHM 3000 plus, Kan Innovations, India) to carry out a bipedal stance pedogram. The test takes about 20 s measuring the parameters of both the right and left feet of the participants simultaneously. Three repetitive trials were conducted and corresponding readings were recorded for both the control (left and right) and overweight (left and right) groups and mean values were taken for analysis. The parameters analyzed in the pedogram include an arch index, average and maximum pressure, overall and regional weight distribution pattern, foot morphometry including area, forefoot width, and hindfoot width along with the medial and lateral plantar angle, long plantar angle, heel angle, subarch angle, hallux angle, foot progression angle, spread coefficient, forefoot coefficient, forefoot, and heel coefficient as shown in Figure 1.

We performed a Y-balance test to assess the balance of the individual foot as shown in Figure 2.[12] The test was repeated thrice and mean values were used to calculate the composite score for the individual foot. The test involves the measurement of the reaching distance of the suspended leg in the single-leg stance in all three axes. The composite score is calculated by the formula composite score = sum of reach distance in 3 axes/3 times limb length × 100.

All continuous variables are presented in mean and standard deviation. Categorical variables are presented as percentages. We used an independent sample *t*-test to compare the two groups. We used a paired *t*-test for intra-group comparisons between the two feet. A $P < 0.05$ was considered statistically significant. Statistical analysis was carried out in SPSS version 25 (IBM Corp, Armonk, NY, USA).

Results

One hundred participants were considered for eligibility and 81 participants were included in the study meeting the inclusion criteria of which 35 were in the overweight BMI (27.9 ± 3) category with a male: female ratio of 22:13 while the remaining 46 belonged to normal BMI (21.4 ± 2.1) with male: female ratio of 33:13 as shown in Figure 3. We did not note any significant difference between the two groups based on their demographic variables such as age, height, or sex as given in Table 1. The normal reference range of plantar pressure indices in the south Asian individuals with normal BMI are presented and compared with individuals of overweight BMI as shown in Table 1.

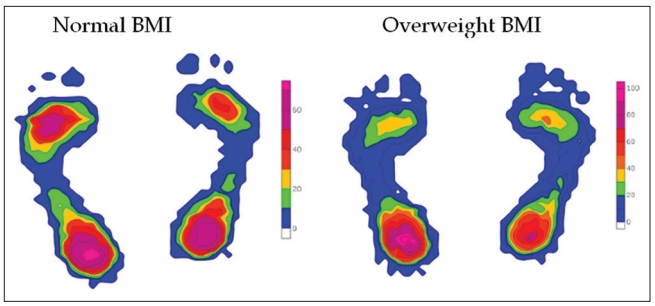

Figure 1: Illustrative podogram with pressure distribution pattern between normal Body Mass Index (BMI) and overweight BMI individuals

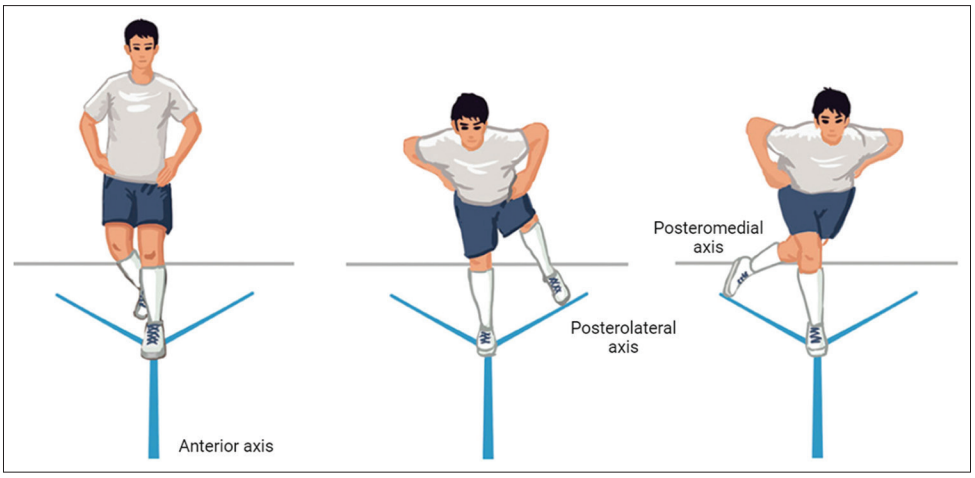

Figure 2: Y-balance test for individual leg. Adapted from Guo *et al.* (2022)[12]

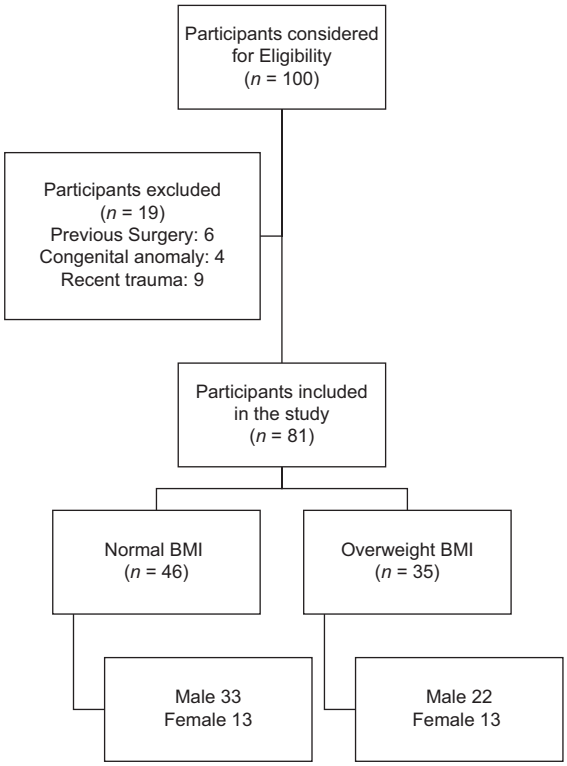

Figure 3: Flow diagram of participants enrolled in the study

Table 1: Comparison of baseline parameters between the overweight and control group

Parameters	Overweight group (mean±SD)	Normal group (mean±SD)	*P*
Age	19.22±1.37	19.26±1.21	0.911
Height	167.48±8.64	168.46±9.19	0.627
Weight	78.64±12.22	60.93±8.63	0.000
BMI	27.93±3.05	21.42±2.16	0.000
Arch index	0.22±0.04	0.19±0.06	0.015
Maximum pressure	113.69±53.33	79.59±33.54	0.001
Average pressure	25.45±5.91	19.37±3.33	0.000
Weight distribution	48.34±7.00	46.79±4.73	0.239
Foot area	134.12±17.45	122.00±18.02	0.003
Foot length	25.26±1.50	24.79±1.58	0.184
Forefoot width	9.71±0.65	9.30±0.79	0.013
Hindfoot width	7.08±0.63	6.73±0.71	0.025
Forefoot weight distribution	27.60±7.87	33.29±13.66	0.031
Hindfoot weight distribution	72.39±7.87	66.70±13.66	0.031
Long plantar angle	13.84±5.01	13.90±5.62	0.961
Lateral plantar angle	8.64±3.84	8.56±3.99	0.927
Medial plantar angle	5.19±1.36	5.33±1.86	0.709
Forefoot angle	116.64±9.97	115.33±8.83	0.533
Heel angle	20.59±6.99	18.66±8.27	0.271
Sub-arch angle	80.61±6.36	80.30±6.68	0.831
Foot progression angle	7.78±4.54	6.60±4.34	0.237
Coefficient of spreading	0.97±0.06	0.93±0.06	0.029
Forefoot and heel coefficient	0.73±0.06	0.73±0.10	0.972
Right navicular distance	5.62±1.41	5.47±1.51	0.651
Left navicular distance	5.85±1.53	5.71±1.50	0.682
Right composite balance score	90.25±11.63	89.63±11.20	0.809
Left composite balance score	90.52±12.59	89.62±12.07	0.745

BMI: Body mass index, SD: Standard deviation

We noted a significant difference in the average ($P < 0.001$) and maximum pressure ($P < 0.001$) exerted on the foot between the two groups. However, it did not affect the overall weight distribution pattern ($P = 0.239$) or balance ($P = 0.810$) between them. Upon analyzing the regional weight distribution pattern we noted a significant difference in the forefoot ($P = 0.031$) and hindfoot weight distribution ($P = 0.031$) between the two groups as noted in Table 1. We also noted significant differences in the foot morphometric data such as foot area ($P = 0.003$), forefoot width ($P = 0.013$), and hindfoot width (0.025). However, we did not note any differences between the two groups on their medial and lateral plantar angles, heel angle or subarch angle. Similarly, we did not note any significant differences between the groups on their balance composite scores based on the Y-balance test ($P = 0.810$).

We noted significant intra-group variations between the right and left foot in their arch index ($P < 0.001$, $P = 0.027$), weight distribution ($P < 0.001$, $P < 0.001$), and foot progression

angle (P = 0.038, P = 0.003) among overweight and normal individuals, respectively, as shown in Table 2 that correlated significantly with limb dominance profile of the individual (r = 0.863, P < 0.001).

Discussion

Plantar pressure measurement remains of the key evaluation parameters to diagnose various foot and lower extremity disorders.[13] Significant correlations have been noted in the variation in the distribution pattern and pressure pattern noted in the podogram with neuromuscular and cardiometabolic diseases.[14] While abnormal plantar pressure distribution combined with sensorimotor defects results in plantar calluses and when combined with neuropathic complications in diabetics results in diabetic foot syndrome.[15] Furthermore, variations in the plantar pressure measurements are seen in neuromuscular diseases such as Parkinsons disease, Hansen's disease, and rheumatoid arthritis.[16,17]

There were previous reports that plantar pressure increases during standing and walking.[8] Moreover, associations were derived between the BMI and the foot pressure metrics in adults,[8,18] adolescents and children.[19] This work is the first report in literature on the baseline podographic parameters in healthy young cohorts to be considered as a baseline reference value for future studies of Asian origin. Further, insights from the study corroborates with the findings in the literature that normal and overweight individuals differ significantly based on average (P < 0.001) and maximum pressure (P < 0.001) exerted.[8,18] However, our study established that despite the differences between the normal and overweight group on podogram, the overall weight distribution pattern (P = 0.239) or balance (P = 0.810) between them remained unaltered. The regional weight distribution pattern differed significantly between the two groups especially in the forefoot (P = 0.031) and hindfoot weight distribution (P = 0.031).

Apart from the weight distribution pattern changes noted between the normal and the overweight individuals, each group noted significant intra-group variations between the right and left foot in parameters such as arch index (P < 0.001, P = 0.027), weight distribution (P < 0.001, P < 0.001), and foot progression angle (P = 0.038, P = 0.003) among overweight and normal individuals, respectively. The dominant side of the individual had a significant correlation for higher weight distribution profile compared to the nondominant side (r = 0.863, P < 0.001).

Obesity in children and adolescents has been shown to increase the contact area and noticeably result in flat feet. In addition, it results in thicker midfoot fat pads and reduced sensitivity on the sole of the foot.[19] Despite the increased contact area on the foot surface in overweight and obese children, it is insufficient to offset the increased forces during walking, causing higher plantar pressures compared to children with normal body weight.[19] This increases the risk of ulcerations, pain with physical activity that hampers the growth of the child. The current adult offloading foot wear could also be made available for children with the use of arch supports, metatarsal additions with apertures to dissipate the peak pressure amplitude.[20]

The study is not without limitations. The sample size of individuals included in the study is limited. However, we

Table 2: Comparison of parameters between the right and left side in the overweight and control group

Parameters	Overweight group			Control group		
	Mean difference	SD	*P*	Mean difference	SD	*P*
Arch index	0.02	0.03	0.002	0.01	0.04	0.027
Maximum pressure	9.86	53.88	0.287	−4.83	34.74	0.351
Average pressure	−0.55	6.23	0.602	−1.49	3.10	0.002
Weight distribution	−3.31	14.01	0.171	−6.41	9.47	0.000
Foot area	−4.51	9.80	0.010	−6.90	10.19	0.000
Foot length	−0.26	0.78	0.053	−0.62	0.57	0.000
Forefoot width	−0.08	0.60	0.443	−0.26	0.74	0.022
Hindfoot width	0.35	0.82	0.016	0.34	1.08	0.037
Forefoot weight distribution	−4.14	8.23	0.005	−3.05	7.48	0.008
Hindfoot weight distribution	4.14	8.23	0.005	3.05	7.48	0.008
Long plantar angle	−0.33	5.50	0.723	0.75	5.08	0.320
Lateral plantar angle	−0.02	4.17	0.974	0.97	3.55	0.069
Medial plantar angle	−0.31	2.00	0.367	−0.22	2.01	0.461
Forefoot angle	−3.39	10.42	0.063	−3.20	13.26	0.109
Heel angle	−1.66	13.51	0.491	−9.86	20.34	0.006
Sub-arch angle	2.24	8.78	0.141	0.05	9.35	0.974
Foot progression angle	−1.57	4.30	0.038	−1.89	4.06	0.003
Coefficient of spreading	0.01	0.06	0.254	0.00	0.07	0.826
Forefoot and heel coefficient	0.04	0.09	0.019	0.06	0.13	0.003
Composite balance score	−0.27	4.75	0.736	0.16	5.20	0.838

SD: Standard deviation

ensured comparability of the individuals between the normal and overweight BMI to make meaningful comparisons and derive meaningful conclusions. Considering the study might suffer from measurement bias, all the parameters were made in triplicate and mean values were used for analysis. Gait and postural control require the integration of external sensory information, which involves processing by the cortical, subcortical, brainstem, and spinal cord structures in a feedback/feedforward mechanism. The interaction between these central nervous system structures, whether through sensory integration or motor control, results in greater variability in gait characteristics. The impact of this external sensory information on the balance and pressure patterns noted between normal and overweight individuals is not ascertained. Further, the plantar pressure parameters were monitored in static mode in bipedal stance phase; their dynamic pattern variations need further analysis. However, the established baseline plantar pressure metrics holds good for the real-life testing scenarios which involve static measurement without eliminating the external sensory information.

Conclusion

Normal reference podometric parameters for Asian population are established. There exists significant difference between the right and left feet of normal and overweight individuals in their arch index, weight distribution, and foot progression angle. However, overweight individuals had significant differences in the pressure and weight distribution pattern compared to normal individuals.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

References

1. Razak AH, Zayegh A, Begg RK, Wahab Y. Foot plantar pressure measurement system: A review. Sensors (Basel) 2012;12:9884-912.
2. Bonato P. Wearable sensors/systems and their impact on biomedical engineering. IEEE Eng Med Biol Mag 2003;22:18-20.
3. Rodgers MM. Dynamic biomechanics of the normal foot and ankle during walking and running. Phys Ther 1988;68:1822-30.
4. CDC. Centers for Disease Control and Prevention. Body Mass Index (BMI); 2024. Available from: https://www.cdc.gov/healthyweight/assessing/bmi/index.html. [Last accessed on 2024 Jun 11].
5. Purnell JQ. Definitions, classification, and epidemiology of obesity. In: Feingold KR, Anawalt B, Blackman MR, Boyce A, Chrousos G, Corpas E, *et al*., editors. Endotext. South Dartmouth (MA): MDText.com, Inc.; 2000. Available from: https://www.ncbi.nlm.nih.gov/books/NBK279167/. [Last accessed on 2024 Jun 11].
6. King LK, March L, Anandacoomarasamy A. Obesity and osteoarthritis. Indian J Med Res 2013;138:185-93.
7. Khalaf K, Mohan DM, Hindi MA, Khandoker AH, Jelinek HF. Plantar pressure alterations associated with increased BMI in young adults. Gait Posture 2022;98:255-60.
8. Hills AP, Hennig EM, McDonald M, Bar-Or O. Plantar pressure differences between obese and non-obese adults: A biomechanical analysis. Int J Obes Relat Metab Disord 2001;25:1674-9.
9. Brisbane JM, McCullough MB, Baker C, London JS, Queen RM. Impact of race, gait speed and arch height on plantar loading. J Biomech 2023;155:111648.
10. Mei Q, Gu Y, Xiang L, Yu P, Gao Z, Shim V, *et al*. Foot shape and plantar pressure relationships in shod and barefoot populations. Biomech Model Mechanobiol 2020;19:1211-24.
11. Jasiewicz B, Klimiec E, Młotek M, Guzdek P, Duda S, Adamczyk J, *et al*. Quantitative analysis of foot plantar pressure during walking. Med Sci Monit 2019;25:4916-22.
12. Guo Z, Huang Y, Zhou Z, Leng B, Gong W, Cui Y, *et al.* The effect of 6-week combined balance and plyometric training on change of direction performance of elite badminton players. Front Psychol 2021;12:684964.
13. Savelberg HH, Schaper NC, Willems PJ, de Lange TL, Meijer K. Redistribution of joint moments is associated with changed plantar pressure in diabetic polyneuropathy. BMC Musculoskelet Disord 2009;10:16.
14. Barn R, Waaijman R, Nollet F, Woodburn J, Bus SA. Predictors of barefoot plantar pressure during walking in patients with diabetes, peripheral neuropathy and a history of ulceration. PLoS One 2015;10:e0117443.
15. Fernando ME, Crowther RG, Pappas E, Lazzarini PA, Cunningham M, Sangla KS, *et al*. Plantar pressure in diabetic peripheral neuropathy patients with active foot ulceration, previous ulceration and no history of ulceration: A meta-analysis of observational studies. PLoS One 2014;9:e99050.
16. Lee H, Ishikawa H, Shibuya T, Takai C, Nemoto T, Nomura Y, *et al*. The combination of modified Mitchell's osteotomy and shortening oblique osteotomy for patients with rheumatoid arthritis: An analysis of changes in plantar pressure distribution. Int J Environ Res Public Health 2021;18:9948.
17. Shalin G, Pardoel S, Lemaire ED, Nantel J, Kofman J. Prediction and detection of freezing of gait in Parkinson's disease from plantar pressure data using long short-term memory neural-networks. J Neuroeng Rehabil 2021;18:167.
18. Birtane M, Tuna H. The evaluation of plantar pressure distribution in obese and non-obese adults. Clin Biomech (Bristol) 2004;19:1055-9.
19. Catan L, Amaricai E, Onofrei RR, Popoiu CM, Iacob ER, Stanciulescu CM, *et al*. The impact of overweight and obesity on plantar pressure in children and adolescents: A systematic review. Int J Environ Res Public Health 2020;17:6600.
20. Collings R, Freeman J, Latour JM, Paton J. Footwear and insole design features for offloading the diabetic at risk foot-a systematic review and meta-analyses. Endocrinol Diabetes Metab 2021;4:e00132.