Hallux valgus severity, great toe pain and plantar pressures during gait: a cross-sectional study of community-dwelling adults

**ABSTRACT**

**Background:** Hallux valgus (HV) is a common disabling condition affecting 36% of adults aged 65 years and over. Identifying whether the severity of the deformity alters weight-bearing patterns during walking may assist clinicians optimise offloading interventions. Therefore, we examined how plantar pressure distributions during walking are affected by HV severity.

**Methods:** Plantar pressures and maximum forces in ten regions of the foot were obtained from 120 participants (40 men, 80 women) aged ≥50 years using a pressure platform (RS Scan ® International, Olen, Belgium). HV severity was documented using a validated line-drawing instrument with participants separated into four groups: none (n=30), mild (n=30), moderate (n=30) and severe (n=30). Pressure and force values were compared across HV severity, stratified by presence or absence of great toe pain.

**Results:** Participants with severe HV were more likely to have great toe pain. More severe HV was associated with significant reductions in peak pressure and maximum force under the hallux but not at other sites of the foot. This association appeared strongest in those reporting great toe pain.

**Conclusions:** Greater HV severity is associated with great toe pain and reduced loading under the hallux when walking. These observed changes in plantar pressure and maximum force may reflect a pain avoidance mechanism.

**Keywords:** plantar foot pressure, force, hallux valgus, foot, biomechanics, deformity

**1. INTRODUCTION**

Hallux valgus (HV) is a common condition affecting the forefoot in which the first metatarsophalangeal joint (MTPJ) is progressively subluxed due to lateral deviation of the hallux and medial deviation of the first metatarsal. HV affects 23% of people aged 18 to 65 years and 36% of those over 65 years of age (Nix, Smith & Vicenzino, 2010). As the deformity progresses, the lateral displacement of the hallux interferes with the normal alignment and function of the lesser toes, resulting in hammer toe or claw toe deformities, altered weight bearing patterns and the development of plantar keratotic lesions (Spink, Menz & Lord, 2009).

Identifying areas of high pressure and force in people with HV deformity may assist clinicians to select offloading interventions such as padding, strapping and orthotic therapy (Hurn, Vicenzino & Smith, 2016). Previous studies evaluating plantar pressures in HV have reported inconsistent findings. This is partly explained by differences in the plantar pressure measurement systems and variations in masking techniques (Nix, Vicenzino, Collins & Smith, 2013). However, perhaps the most significant factor influencing these findings is the severity of HV, as it is likely that different plantar loading patterns develop as the condition progresses. A systematic review (Nix, Vincenzino, Collins, & Smith, 2013) found that only three studies reported a quantitative measurement method for HV (Bryant, Tinley & Singer, 1999; Kadono et al., 2003; Martinez-Nova, Sanchez-Rodruguez, Leal-Muro & Pedrera-Zamorano, 2011). Most studies used the well-recognised cut-point of a HV angle of 15 degrees to define HV (Martinez-Nova, Sanchez-Rodruguez, Leal-Muro & Pedrera-Zamorano, 2011; Jianmin et al., 2012), however there is likely to be considerable variation across studies in HV severity amongst those who fulfil this definition. Only one study has examined plantar pressures across differing levels of HV severity, however only standing observations of plantar pressure were performed (Iliou et al., 2015).

Therefore, the objective of this study was to evaluate dynamic plantar pressure distribution during walking using a high-resolution plantar pressure measurement system in participants with varying degrees of HV severity, documented using a validated line drawing instrument.

**2. METHODS**

**2.1 Study design**

This study uses cross-sectional, baseline data taken from a population-based prospective cohort study, the Clinical Assessment Study of the Foot (CASF) (Roddy et al., 2011). All adults aged 50 years and over registered with one of four participating general practices in North Staffordshire were invited to take part in the study, regardless of foot-related consultation.

**2.2 Health survey questionnaire**

Participants completed a health survey questionnaire, which provided information on aspects of general health, foot pain and demographic characteristics (age and sex). Specific foot pain-related questions informing the present analysis included pain in and around the foot in the past 12 months, and foot pain, aching or stiffness in the last month. The location of foot pain experienced in either foot during the past month was ascertained by shading on a foot manikin (© The University of Manchester 2000. All rights reserved) (Garrow, Silman & Macfarlane, 2004; Chatterton et al., 2013). Participants were defined as having great toe pain if they shaded the dorsal or plantar aspects of the hallux or first MTPJ as previously described (Chatterton et al., 2013). HV severity was ascertained using a validated line-drawing instrument consisting of five drawings for each foot, one depicting hallux valgus of 0º and the others sequentially increasing angulation in 15º increments (Roddy, Zhang & Doherty, 2007). Study participants ­selected one drawing for each foot which best represented the HV angle of that foot. ­This study used data from the right foot only. HV severity was graded, based on the following angles: 0º was classed as none, 15º as mild, 30º as moderate, and 45º and 60º HV angles were classed as severe.

Participants who reported pain in or around the foot in the past 12 months and provided consent to further contact were invited to attend a research clinic where radiographic, clinical and biomechanical assessments were undertaken.

**2.3 Radiographic assessment**

Weight-bearing dorso-plantar and lateral radiographs were taken of both feet. Plain radiographs were scored by a single reader (MM) blind to all other participant information. Osteophytes and joint space narrowing at the 1st MTPJ was scored (0–3) according to a validated atlas and classification system (Menz, Munteanu, Landorf, Zammit & Cicuttini, 2007). Radiographic 1st MTPJ OA was defined as grade 2 or more for either feature on either view. Participants were divided into four mutually exclusive radiographic severity groups using the following case definitions: (i) none = no radiographic evidence of OA; (ii) mild OA = a score of one for either osteophytes or joint space narrowing on either the dorso-plantar or lateral views (but no scores above one); (iii) moderate OA = a score of at least two for either osteophytes or joint space narrowing in either the dorso-plantar or lateral views (but no scores above two), and (iv) severe OA = a score of at least three for either osteophytes or joint space narrowing in either the dorsoplantar or lateral views. Intra-rater reliability for the presence of 1st MTPJ OA was excellent (mean quadratic weighted Kappa (ĸ) = 0.78; mean % exact agreement = 82.1%; mean % close agreement = 99.2%), and inter-rater reliability scored by a second blind assessor (HBM) was moderate (mean quadratic weighted ĸ = 0.54; mean % exact agreement = 60.6%; mean % close agreement = 96.1%) as previously described (Menz et al., 2015).

**2.4 Clinical and biomechanical assessment**

A research assessor blinded to postal questionnaire responses and radiographic findings carried out a standardised clinical interview, physical examination and biomechanical assessment of each participant. Anthropometric measurements (height and weight) were collected and body mass index (BMI) calculated, in addition to a detailed clinical foot and ankle examination. The present analysis used data documenting foot posture and range of motion. Foot posture was examined in a relaxed bi-pedal stance using the Foot Posture Index (FPI) (Redmond, Crosbie & Ouvrier, 2006). The FPI includes six criteria based on a multidimensional observation of the foot. Using a 5-point scale (range -2 to +2), a summative score is produced to represent the degree of foot pronation/supination, with a more pronated foot profile reflected by higher scores. The raw FPI scores were converted to Rasch-transformed logit values (Keenan, Redmond, Horton, Conaghan & Tennant, 2007). Dorsiflexion range of motion at the first MTPJ was measured as the end range of passive hallux extension achieved in a non-weight bearing position (Hopson, McPoll & Cornwall, 1995).

For the biomechanical assessment, plantar pressures for both feet were recorded using a pressure platform consisting of a 12mm thick floor mat (578mm x 418 mm) (RS Scan ® International, Olen, Belgium). The mat incorporated 4096 resistive sensors which sample at a rate of 300 Hz. Participants were required to perform a level barefoot walk across the mat, which was calibrated at the start of each clinic and then recalibrated for each participant’s weight and shoe size prior to their assessment. A two-step gait initiation protocol was used to ensure the participant’s test foot made contact with the sensor area of the mat with the second step (Bryant, Singer & Tinley, 1999). Participants completed several practice trials to familiarise themselves with the procedure and to facilitate optimisation of a normal walking pattern across the mat. This was followed by three recorded trials for each foot, capturing data on maximum force (N), peak pressure (N/cm2) and contact time (ms). Contact time was considered to be a proxy measure of walking velocity.

**2.5 Biomechanical data processing**

Data processing was performed using Scientific Footscan® software (RSscan International). Ten pre-set foot ‘masks’ generated by the software correspond to hallux, lesser toes, 1st MTPJ, 2nd MTPJ, 3rd MTPJ, 4th MTPJ, 5th MTPJ, midfoot, medial heel and lateral heel regions. Each mask region enables a comparative calculation of peak pressure and maximum force to be derived across all ten regions. Following visual inspection of the masked regions for all right feet in the sample, manual adjustments and corrections were made to set the mask into the most optimal position to represent the anatomical structure of the plantar surface of the foot (Figure 1). One trained clinician observer (GRC) performed all plantar pressure data processing in accordance with a standardised protocol, whilst remaining blinded to HV status. Once a masking template had been generated for each of the three recorded trials for each foot, the average peak pressure, maximum force and contact time was calculated, to produce one set of estimates for each participant.

Potential participants were excluded for the following reasons: previous HV surgery, missing/spoiled plantar pressure data, missing HV data or missing radiographic data. Participants were also excluded if inflammatory arthritis (non-specific inflammatory arthritis, rheumatoid arthritis or psoriatic arthritis) was identified in medical records or a clinical radiology report by a consultant musculoskeletal radiologist.

**2.6 Statistical analysis**

To construct the analyses for this study, we used stratified sampling. All right feet with self-reported severe HV were first identified. A random sample of equal size and same proportion of females was then obtained from each of the other three HV categories (none, mild and moderate HV). To examine differences in plantar pressure parameters between the four HV categories, one-way analyses of variance (ANOVA) was used. ANOVA assumptions of normality and homoscedasticity were met for all variables. Further stratified analyses were performed to compare the distributions of peak pressure and maximum force values between participants with and without great toe pain. The impact of contact time on peak pressure and maximum force values was also analysed. All analyses were performed using SPSS version 24 (IBM Corporation, Armonk, NY) and Excel for Microsoft (The Microsoft Corp., Redmond, WA). The level of statistical significance was defined as *p*<0.05.

**2.7 Ethical approval**

Ethical approval was obtained from Coventry Research Ethics Committee (reference number: 10/H1210/5).

**3. RESULTS**

**3.1 Study population**

There were 30 participants (67% female) available within the study cohort who had the most severe category of HV. Thirty eligible participants, with equal gender proportions, were then randomly sampled to derive 30 cases for each of the other three HV categories. This resulted in a study sample of 120 participants (mean [SD] age 65.6 [8.1] years; 67% female; mean BMI 30.9 [6.3]) (Table 1).

A dose-response trend was observed for great toe pain, with those in the severe group twice as likely to report great toe pain (63.3%) as those with no deformity (30%). Dose-response trends were also observed between hallux valgus severity and a more pronated foot profile, and symptomatic 1st MTPJ OA (Table 1).

**3.2 Peak pressure**

Peak pressure according to HV severity is shown in Table 2. Participants with more severe HV exhibited lower peak pressures under the hallux. There were no significant differences between HV severity subgroups for the other mask regions. Stratified analysis comparing those with (n=55) and without (n=65) great toe pain is shown in Table 3. There were no differences in the peak pressure according to HV severity in those without great toe pain. In participants with great toe pain, peak pressure under the hallux was significantly lower in those with more severe HV.

**3.3 Maximum force**

Participants with more severe HV exhibited significantly lower maximum force under the hallux (Table 2). There were no significant differences between HV severity subgroups for the other mask regions. There were no differences in maximum force according to HV severity in participants without great toe pain (Table 4). In those with great toe pain, maximum force under the hallux and lesser toes was significantly lower in those with more severe HV.

**3.4 Contact time**

There was no significant difference in total contact time between the HV severity subgroups across all participants (Table 5).

**4. DISCUSSION**

The objective of this study was to examine the relationship between plantar pressure distribution during walking and HV severity. We found that peak pressure and maximum force under the hallux were significantly reduced in feet with greater HV severity, but no effect was observed for other mask regions. When these analyses were stratified according to great toe pain, lower plantar pressures under the hallux and maximum force under the hallux and lesser toes, in those with more severe HV were observed only in the presence of great ­­toe pain. These findings are consistent with the view that plantar loadin­­g in HV may be driven by a pain avoidance mechanism (Jianmin et al., 2012).

There have been several plantar pressure studies comparing individuals with HV deformity with asymptomatic control participants, however most of these do not account for severity of HV, as highlighted in a systematic review (Nix, Vicenzino, Collins & Smith, 2013). Plantar pressure studies that do not account for the severity of HV deformity have produced inconsistent findings. For example, three studies have demonstrated increased pressure under the medial forefoot in those with HV (Bryant, Tinley & Singer 1999; Mickle, Munro, Lord, Menz & Steele, 2011, Jianmin et al., 2012), whilst others have reported significantly lower first metatarsal pressures (Kadono et al., 2003) or no difference between those with and without HV (Martinez-Nova, Sanchez-Rodriguez, Leal-Muro & Pedrera-Zamorano, 2011). Similarly, while two studies have reported greater pressure under the hallux in those with HV (Bryant, Tinley & Singer, 1999; Martinez-Nova, Sanchez-Rodriguez, Leal-Muro & Pedrera-Zamorano, 2011), others have shown a lower hallux pressure (Mueller et al., 2003; Menz & Morris, 2006; Gurney, Kersting & Rosenbaum, 2009) or no difference (Mickle, Munro, Lord, Menz & Steele, 2011). The considerable variation across studies may be due to a lack of HV severity subgrouping, as our study has shown a trend towards dose-response relationships between greater HV severity and reduced loading under the hallux.

Only one study has evaluated plantar pressures across differing degrees of HV severity. Iliou et al. (2015) reported a strong correlation between greater severity of HV and pressure under the hallux and first and second metatarsal heads, which was attributed to “hallux pronation” and “medial sesamoid subluxation”. However, in this study, plantar pressures were recorded with participants in barefoot static stance rather than during gait. To the best of our knowledge, our study is the first dynamic plantar pressure study which compares different severity subgroups of HV.

Key strengths of our study include the use of a population-based sample and a validated line-drawing instrument to classify HV severity (Roddy, Zhang & Doherty, 2007). However, our findings need to be interpreted in the context of several limitations. Firstly, the ‘masking’ performed using the RSScan software required manual adjustment for each participant. Although this was completed by one trained clinician, the inter-observer reliability of this approach is not known. Secondly, this data set included only right feet, and it has recently been highlighted that combining both right and left foot data through commonly used mixed linear regression models provide more power, efficiency, and clinically meaningful results (Stewart, Pearson, Rome, Dalbeth & Vandal, 2018). Finally, our data are cross-sectional, so we cannot confirm that the patterns observed across HV severity subgroups are indicative of the trajectory of disease progression over time.

**5. CONCLUSION**

Greater HV severity is associated with great toe pain and reduced loading under the hallux when walking. The observed changes in plantar pressure and maximum force identified in stratified analyses suggest that these changes are likely to reflect a pain avoidance mechanism. Future studies should explore the extent to which changes in hallux loading in response to mechanical interventions such as footwear and foot orthoses are influenced by changes in symptoms.

**REFERENCES**

Bryant, A., Singer, K., Tinley, P. (1999). Comparison of the reliability of plantar pressure measurements using the two-step and midgait methods of data collection. Foot and Ankle International, 20, 646-650. doi: 10.1177/107110079902001006

Bryant, A., Tinley, P., Singer, K. (1999) Plantar pressure distribution in normal, hallux valgus and hallux limitus feet. The Foot, 9, 115-119. doi:10.1054/foot.1999.0538

Chatterton, BD., Muller, S., Thomas, MJ., Menz, HB., Rome, K., Roddy, E. (2013). Inter and intra-rater repeatability of the scoring of foot pain drawings. Journal of Foot and Ankle Research, 6, 44. doi:10.1186/1757-1146-6-44

Garrow, AP., Silman, AJ., Macfarlane, GJ. (2004). The Cheshire Foot Pain and Disability Survey: a population survey assessing prevalence and associations. Pain, 110, 378-384. doi:10.1016/j.pain.2004.04.019

Gurney, JK., Kersting, UG., Rosenbaum, D. (2009). Dynamic foot function and morphology in elite rugby league athletes of different ethnicity. Applied Ergonomics, 40, 554-559. doi:.1016/j.apergo.2008.11.001

Hopson, MM., McPoll, TG., Cornwall, MW. (1995). Motion of the first metatarsophalangeal joint. Reliability and validity of four measurement techniques. Journal of the American Podiatric Medical Association, 85, 198-204. doi:10.7547/87507315-85-4-198

Hurn, SE., Vicenzino, BT., Smith, MD. (2016). Non-surgical treatment of hallux valgus: a current practice survey of Australian podiatrists. Journal of Foot and Ankle Research, 9, 16. doi:10.1186/s13047-016-0146-5

Iliou, K., Paraskevas, G., Kanavaros, P., Gekas, C., Barbouti, A., Kitsoulis, P. (2015). Relationship between pedographic analysis and the Manchester scale in hallux valgus. Acta Orthopaedica et Traumatologica Turcica, 49, 75-79. doi:10.3944/AOTT.2015.14.0012

Jianmin, W., Qicheng, D., Zhiyong, Y., Weidong, S., Qining, W., Kunlin, W. (2012). Adaptive changes of foot pressure in hallux valgus patients. Gait and Posture, 36, 344-349. doi:10.1016/j.gaitpost.2012.03.030

Kadono, K., Tanaka, Y., Sakamoto, T., Akiyama, K., Komeda, T., Taniguchi, A., Takakura, Y. (2003). Plantar pressure distribution under the forefeet with hallux valgus during walking. Journal of Nara Medical Association, 54, 273-281.

Keenan, AM., Redmond, AC., Horton, M., Conaghan, PG., Tennant, A. (2007). The Foot Posture Index: Rasch analysis of a novel, foot-specific outcome measure. Archives of Physical Medicine and Rehabilitation, 88, 88-93. doi:10.1016/j.apmr.2006.10.005

Martinez-Nova, A., Sanchez-Rodriguez, R., Leal-Muro, A., Pedrera-Zamorano, J. (2011). Dynamic plantar pressure analysis and midterm outcomes in percutaneous correction for mild hallux valgus. Journal of Orthopaedic Research, 29, 1700-1706. doi:10.1002/jor.21449

Menz, HB., Morris, ME. (2006). Clinical determinants of plantar forces and pressures during walking in older people. Gait and Posture, 24, 229-236. doi:10.1016/j.gaitpost.2005.09.002

Menz, HB., Munteanu, SE., Landorf, KB., Zammit, GV., Cicuttini, FM. (2007). Radiographic classification of osteoarthritis in commonly affected joint of the foot. Osteoarthritis and Cartilage, 15, 1333-1338. doi:10.1016/j.joca.2007.05.007

Menz, HB., Roddy, E., Marshall, M., Thomas, MJ, Rathod, T., Myers, H., Thomas, E., Peat, GM. (2015). Demographic and clinical factors associated with radiographic severity of first metatarsaophalangeal joint osteoarthritis: cross-sectional findings from the Clinical Assessment Study of the Foot. Osteoarthritis and Cartilage, 23, 77-82. doi: 10.1016/j.joca.2014.

Mickle, KJ., Munro, BJ., Lord, SR., Menz, HB., Steele, JR. (2011). Gait, balance, and plantar pressures in older people with toe deformities. Gait and Posture, 34, 347-351. doi:10.1016/j.gaitpost.2011.05.023

Mueller, MJ., Hastings, M., Commean, PK., Smith, KE., Pilgram, TK., Robertson, D., Johnson, J. (2003). Forefoot structural predictors of plantar pressures during walking in people with diabetes and peripheral neuropathy. Journal of Biomechanics, 36, 1009-1017. doi:10.1016/S0021-9290(03)00078-2

Nix, SE., Smith, M., Vicenzino, BT. (2010) Prevalence of hallux valgus in the general population: a systematic review and meta-analysis. Journal of Foot and Ankle Research, 3, 21. doi:10.1186/1757-1146-3-21

Nix, SE., Vicenzino, BT., Collins, NJ., Smith, MD. (2013). Gait parameters associated with hallux valgus: a systematic review. Journal of Foot and Ankle Research, 6, 9. doi: 10.1186/1757-1146-6-9

Redmond, AC., Crosbie, J., Ouvrier, RA. (2006). Development and validation of a novel rating system for scoring standing foot posture: The Foot Posture Index. Clinical Biomechanics, 21, 89-98. doi:10.1016/j.clinbiomech.2005.08.002

Roddy, E., Myers, H., Thomas, MJ., Marshall, M., D’Cruz, D., Menz, HB., Belcher, J., Muller, S., Peat, G. (2011). The clinical assessment study of the foot (CASF): study protocol for a prospective observational study of foot pain and foot osteoarthritis in the general population. Journal of Foot and Ankle Research, 4, 22. doi:10.1186/1757-1146-4-22

Roddy, E., Zhang, W., Doherty, M. (2007). Validation of a self-report instrument for assessment of hallux valgus. Osteoarthritis and Cartilage, 15, 1008-1012. doi:10.1016/j.joca.2007.02.016

Spink, MJ., Menz, HB., Lord, SR. (2009). Distribution and correlates of plantar hyperkeratotic lesions in older people. Journal of Foot and Ankle Research, 2, 8.doi:[10.1186/1757-1146-2-8](https://dx.doi.org/10.1186%2F1757-1146-2-8)

Stewart S, Pearson J, Rome K, Dalbeth N, Vandal A. (2018). Analysis of data collected from right and left limbs: Accounting for dependence and improving statistical efficiency in musculoskeletal research. Gait & Posture, 59, 182-187. doi:10.1016/j.gaitpost.2017.10.018

**TABLES**

**Table 1.** Participant characteristics stratified by hallux valgus severity. Values are mean (SD) unless otherwise noted.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | None  (n=30) | Mild  (n=30) | Moderate  (n=30) | Severe  (n=30) |
| Age – years | 64.3 (7.8) | 63.6 (7.9) | 66.4 (8.8) | 67.6 (8.1) |
| Females, n (%) | 20 (66.7) | 20 (66.7) | 20 (66.7) | 20 (66.7) |
| BMI – kg/m² | 31.7 (6.1) | 31.4 (5.4) | 28.5 (5.9) | 32.1 (7.7) |
| Great toe pain, n (%) | 9 (30.0) | 13 (43.3) | 14 (46.7) | 19 (63.3) |
| Foot Posture Index | 2.5 (1.4) | 2.5 (1.5) | 2.7 (1.5) | 3.2 (1.6) |
| 1st MTPJ dorsiflexion – degrees | 59.2 (21.5) | 69.6 (18.9) | 60.3 (16.5) | 59.8 (17.5) |
| Symptomatic radiographic 1st MTPJ OA | 0 (0) | 1 (3.3) | 6 (20.0) | 8 (26.7) |
| Notes: BMI: body mass index; MTPJ: metatarsophalangeal joint; SD: standard deviation | | | | |

**Table 2.** Peak pressure and maximum force in participants with varying severity of hallux valgus. Values are mean (SD).

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | None  (n=30) | Mild  (n=30) | Moderate  (n=30) | Severe  (n=30) | ANOVA  *p-value* |
| Peak pressure (N/cm2) |  |  |  |  |  |
| Hallux | 12.4 (7.0) | 9.9 (3.6) | 10.6 (5.6) | 7.4 (4.7) | 0.008 |
| Lesser toes | 4.4 (2.9) | 3.3 (1.7) | 4.2 (2.8) | 4.0 (2.1) | 0.418 |
| 1st MTPJ | 13.2 (5.4) | 12.1 (4.0) | 12.0 (6.1) | 13.9 (6.3) | 0.487 |
| 2nd MTPJ | 19.9 (6.9) | 21.2 (7.4) | 18.2 (8.4) | 18.0 (6.3) | 0.293 |
| 3rd MTPJ | 19.4 (6.8) | 20.1 (8.3) | 18.0 (8.0) | 17.5 (5.7) | 0.496 |
| 4th MTPJ | 15.1 (6.5) | 15.4 (6.6) | 14.5 (6.9) | 13.6 (5.6) | 0.693 |
| 5th MTPJ | 8.6 (6.1) | 8.5 (5.0) | 9.2 (3.9) | 10 (5.2) | 0.662 |
| Midfoot | 5.0 (4.1) | 4.2 (2.9) | 4.1 (4.0) | 4.4 (2.9) | 0.773 |
| Medial heel | 19.1 (6.6) | 17.6 (6.9) | 17.8 (6.2) | 17.6 (5.4) | 0.754 |
| Lateral heel | 16.7 (6.2) | 15.3 (5.6) | 15.2 (7.2) | 15.4 (6.0) | 0.539 |
| Maximum force (N) |  |  |  |  |  |
| Hallux | 198.4 (128.5) | 154.3 (67.2) | 167.6 (103.4) | 104.6 (76.5) | 0.003 |
| Lesser toes | 87.0 (71.6) | 59.3 (36.9) | 70.3 (50.2) | 69.2 (43.2) | 0.230 |
| 1st MTPJ | 270.7 (123.8) | 247.2 (92.6) | 247.1 (127.2) | 290.1 (149.8) | 0.481 |
| 2nd MTPJ | 260.1 (111.5) | 266.5 (98.4) | 220.6 (108.1) | 233.2 (91.8) | 0.263 |
| 3rd MTPJ | 210.0 (83.8) | 221.6 (105.3) | 189.1 (92.1) | 176.5 (66.4) | 0.195 |
| 4th MTPJ | 148.3 (70.0) | 152.4 (71.7) | 137.7 (73.0) | 125.9 (57.3) | 0.442 |
| 5th MTPJ | 91.6 (82.7) | 89.0 (56.0) | 88.5 (45.2) | 99.1 (60.7) | 0.908 |
| Midfoot | 142.5 (135.5) | 116.0 (98.5) | 127.8 (149.9) | 149.0 (127.3) | 0.757 |
| Medial heel | 487.4 (188.5) | 458.8 (208.7) | 447.2 (182.1) | 425.7 (151.3) | 0.625 |
| Lateral heel | 384.3 (166.4) | 350.5 (134.6) | 348.0 (177.4) | 319.3 (120.5) | 0.432 |
| Notes: MTPJ: metatarsophalangeal joint; SD: standard deviation | | | | | |

**Table 3.** Peak pressure (N/m2) in participants with varying severity of hallux valgus stratified by presence or absence of great toe pain. Values are mean (SD).

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| No great toe pain | None  (n=21) | Mild  (n=17) | Moderate  (n=16) | Severe  (n=11) | ANOVA  *p-value* |
| Hallux | 12.0 (7.9) | 9.7 (3.6) | 10.8 (3.6) | 9.2 (5.4) | 0.514 |
| Lesser toes | 3.7 (2.6) | 3.5 (1.8) | 4.1 (2.3) | 4.2 (1.9) | 0.791 |
| 1st MTPJ | 12.4 (4.8) | 11.2 (4.5) | 11.0 (5.8) | 14.0 (5.8) | 0.445 |
| 2nd MTPJ | 19.5 (6.0) | 19.6 (7.4) | 15.9 (7.1) | 18.3 (8.3) | 0.398 |
| 3rd MTPJ | 19.0 (7.0) | 19.2 (8.3) | 16.7 (7.9) | 17.9 (6.4) | 0.752 |
| 4th MTPJ | 14.5 (7.3) | 14.8 (6.3) | 14.9 (6.8) | 12.5 (5.2) | 0.792 |
| 5th MTPJ | 8.7 (7.0) | 7.9 (4.7) | 9.9 (3.9) | 9.4 (4.6) | 0.727 |
| Midfoot | 4.7 (4.4) | 3.7 (2.4) | 4.9 (3.6) | 4.5 (2.2) | 0.784 |
| Medial heel | 20.3 (7.3) | 15.5 (5.1) | 18.9 (6.2) | 18.8 (5.9) | 0.131 |
| Lateral heel | 17.8 (7.1) | 13.5 (3.6) | 16.8 (7.7) | 15.4 (5.0) | 0.203 |
| Great toe pain | None  (n=9) | Mild  (n=13) | Moderate  (n=14) | Severe  (n=19) | ANOVA  *p-value* |
| Hallux | 13.2 (4.8) | 10.2 (3.9) | 10.4 (7.5) | 6.4 (4.1) | 0.015 |
| Lesser toes | 5.8 (3.4) | 3.1 (1.8) | 4.2 (3.4) | 3.9 (2.3) | 0.172 |
| 1st MTPJ | 15.3 (6.6) | 13.1 (3.2) | 13.1 (6.5) | 13.8 (6.7) | 0.840 |
| 2nd MTPJ | 20.8 (9.1) | 23.3 (7.3) | 20.9 (9.3) | 17.9 (5.1) | 0.259 |
| 3rd MTPJ | 20.6 (6.5) | 21.3 (8.5) | 19.7 (8.2) | 17.4 (5.5) | 0.451 |
| 4th MTPJ | 16.9 (4.1) | 16.4 (7.1) | 14.1 (7.3) | 14.3 (5.9) | 0.605 |
| 5th MTPJ | 8.5 (3.9) | 9.3 (5.6) | 8.5 (4.1) | 10.3 (5.7) | 0.700 |
| Midfoot | 5.9 (3.3) | 4.8 (3.5) | 3.4 (4.6) | 4.5 (3.4) | 0.471 |
| Medial heel | 16.5 (4.1) | 20.5 (8.3) | 16.5 (6.2) | 17.1 (5.2) | 0.310 |
| Lateral heel | 14.5 (2.8) | 17.7 (7.0) | 13.5 (6.6) | 14.1 (4.3) | 0.206 |
| Notes: MTPJ: metatarsophalangeal joint; SD: standard deviation | | | | | |

**Table 4.** Maximum force (N) in participants with varying severity of hallux valgus stratified by presence or absence of great toe pain. Values are mean (SD).

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| No great toe pain | None  (n=21) | Mild  (n=17) | Moderate  (n=16) | Severe  (n=11) | ANOVA  *p-value* |
| Hallux | 195.9 (146.4) | 154.7 (73.2) | 155.0 (55.0) | 135.5 (91.4) | 0.379 |
| Lesser toes | 69.6 (54.8) | 64.3 (35.6) | 69.4 (40.9) | 72.6 (38.1) | 0.967 |
| 1st MTPJ | 250.5 (114.7) | 235.4 (105.8) | 225.8 (131.0) | 293.1 (141.9) | 0.529 |
| 2nd MTPJ | 252.9 (107.0) | 261.2 (102.8) | 195.5 (98.0) | 223.5 (123.4) | 0.279 |
| 3rd MTPJ | 202.9 (87.9) | 212.8 (104.6) | 181.0 (96.3) | 181.8 (81.9) | 0.723 |
| 4th MTPJ | 139.5 (77.7) | 148.2 (69.8) | 148.0 (77.4) | 116.6 (62.9) | 0.679 |
| 5th MTPJ | 92.3 (94.2) | 84.1 (53.1) | 99.4 (42.3) | 92.9 (54.4) | 0.934 |
| Midfoot | 136.2 (150.0) | 95.5 (69.8) | 145.6 (115.4) | 142.3 (99.4) | 0.585 |
| Medial heel | 507.9 (214.2) | 411.5 (151.6) | 487.4 (194.0) | 443.3 (176.7) | 0.425 |
| Lateral heel | 401.4 (194.6) | 319.9 (89.7) | 393.8 (199.8) | 332.1 (131.4) | 0.367 |
| Great toe pain | None  (n=9) | Mild  (n=13) | Moderate  (n=14) | Severe  (n=19) | ANOVA  *p-value* |
| Hallux | 204.3 (79.3) | 153.7 (61.4) | 182.1 (141.3) | 86.8 (62.4) | 0.006 |
| Lesser toes | 128.0 (91.6) | 52.8 (39.2) | 71.4 (60.8) | 67.3 (47.0) | 0.030 |
| 1st MTPJ | 318.1 (138.1) | 271.5 (123.0) | 271.5 (123.0) | 288.4 (158.0) | 0.774 |
| 2nd MTPJ | 277.1 (126.6) | 273.5 (96.2) | 249.4 (115.5) | 238.8 (71.0) | 0.699 |
| 3rd MTPJ | 226.7 (76.0) | 233.1 (109.5) | 198.5 (89.8) | 173.5 (57.9) | 0.199 |
| 4th MTPJ | 168.8 (44.5) | 158.0 (76.7) | 126.0 (68.6) | 131.4 (54.9) | 0.282 |
| 5th MTPJ | 90.1 (51.5) | 95.5 (61.2) | 76.2 (46.8) | 102.8, (65.3) | 0.628 |
| Midfoot | 157.6 (99.8) | 140.0 (124.9) | 107.7 (184.3) | 152.9 (143.5) | 0.806 |
| Medial heel | 439.6 (102.0) | 520.8 (259.5) | 401.3 (162.4) | 415.6 (138.9) | 0.298 |
| Lateral heel | 344.4 (56.7) | 390.7 (173.3) | 295.8 (136.7) | 311.9 (117.0) | 0.253 |
| Notes: MTPJ: metatarsophalangeal joint; SD: standard deviation | | | | | |

**Table 5.** Total contact time stratified by hallux valgus severity. Values are mean (SD).

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | None  (n=30) | Mild  (n=30) | Moderate  (n=30) | Severe  (n=30) | ANOVA  *p-value* |
| Total contact time (ms) | 1074.9 (383.7) | 1089.4 (309.6) | 1108.6 (511.8) | 1107.6 (255.6) | 0.983 |
| Notes: SD: standard deviation | | | | | |

**FIGURE LEGENDS**

**Figure 1.** Illustration of plantar pressure output from the RS Scan ® system together with the 10 mask regions applied in the analysis.