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Objectively-assessed foot and ankle characteristics in people with systemic lupus erythematosus: a comparison with age- and sex-matched controls

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ABSTRACT

Objective. To objectively identify foot and ankle characteristics in people with SLE compared to age- and sex-matched controls.

Methods. 54 SLE and 56 control participants attended a study visit designed to comprehensively assess the foot and ankle. Objectively-assessed foot characteristics included muscle strength, joint motion, foot posture, foot problems, protective sensation, vibratory perception (VPT), ankle brachial index (ABI), plantar pressure and spatiotemporal gait characteristics. Self-reported measure of foot pain and impairment were also assessed including a 100mm foot pain visual analogue scale. Data were analysed using regression models. Plantar pressure and gait models were adjusted for walking velocity, body mass index and foot pain.

Results. Compared to controls, participants with SLE had lower muscle force for plantarflexion, dorsiflexion, inversion and eversion (all $P<0.001$), higher foot posture indices ($P=0.007$), higher foot problem scores ($P=0.001$), higher VPT ($P=0.001$) and more frequent abnormal ABI ($OR=3.13$, $P=0.044$). Participants with SLE also had lower peak pressure and higher pressure time integrals for all foot regions (all $P<0.001$), lower step and stride length, velocity and cadence and higher step, swing, stance and single and double support times compared to controls (all $P<0.001$). Compared to controls, participants with SLE also reported greater foot pain ($P<0.001$).

Conclusion. People with SLE experience a wide-range of foot complaints. This study has shown objective evidence of foot and ankle disease in people with SLE, including reduced muscle strength and altered gait patterns when compared to controls. This highlights the importance of foot health assessments as part of SLE management.

SIGNIFICANCE AND INNOVATION

- This was the first study to comprehensively assess objective foot and ankle characteristics in people with SLE.
- People with SLE exhibit structural and functional evidence of foot disease including reduced muscle strength, when compared to controls.
- People with SLE demonstrated altered gait patterns, including reduced gait velocity even after adjusting for foot pain.

Systemic lupus erythematosus (SLE) is an autoimmune rheumatic disease characterised by multi-organ involvement [1]. The clinical presentation of SLE is diverse, with manifestations in the cutaneous, musculoskeletal, cardiovascular and neurological systems [1]. People with SLE report a decreased health-related quality of life with associated chronic fatigue, activity limitation and reduced functional capacity [2, 3].

The feet have been identified as an under-appreciated area of involvement in people with SLE [4]. A greater prevalence of sonographically-evident inflammatory joint abnormalities have been reported in the feet compared to the hands and wrists [5]. The degree of foot complaints reported by people with SLE have been highlighted in survey studies [6, 7], and include joint pain and swelling, impaired circulation, compromised skin and nail health, and foot deformity. People with SLE also report foot- and lower limb-related functional impairment and activity limitation [6-8]. More than one-third of people with SLE report either difficulty or a complete inability to walk [7]. However, objectively-assessed measures of foot function, including muscle strength and gait characteristics have not been previously

evaluated in people with SLE. Objective podiatric assessments can be undertaken efficiently and quickly in clinical practice to determine the foot health status of patients. Such assessments are central in identifying the needs of the patient and informing treatment strategies to prevent and manage foot problems.

Further research, which assesses objective foot and ankle characteristics, is warranted to quantify the extent and nature of foot problems experienced by people with SLE. This study aimed to identify foot and ankle characteristics in people with SLE compared to age- and sex-matched control participants.

METHODS

Participants

A cross-sectional observational study was undertaken. All participants were recruited from Auckland, New Zealand. Participants with SLE were recruited from secondary-care rheumatology clinics from Auckland, Counties Manukau and Waitemata District Health Boards in Auckland and had a physician diagnosis of SLE according to the 2012 SLICC criteria [9]. Participants with SLE were excluded if they had cutaneous lupus without systemic involvement. Age- (within 5 years) and sex-matched control participants were recruited from Auckland University of Technology (AUT) staff through poster and newsletter advertising. Participants in both groups were excluded if they were younger than 20 years of age (legal minors), required an interpreter, had recent foot surgery or trauma, or had neuromuscular or other arthritic inflammatory conditions. All participants provided written informed consent

prior to data collection. Ethical approval was obtained from AUT Ethics Committee (AUTEC 16/209).

Demographic and clinical assessment

Participants attended a single clinical visit at AUT, New Zealand. Demographic data were obtained and the 68/66 tender/swollen joint count [10] was completed on all participants. Disease characteristics were recorded for participants with SLE, including disease duration, disease activity (SLEDAI-2K [11]), medication, comorbidities and, if available, recent laboratory results within 4 months before the study visit (creatinine, erythrocyte sedimentation rate (ESR), and C-reactive protein (CRP)).

Assessment of musculoskeletal foot characteristics

A single experienced podiatric researcher, who was not blinded to the participant's group allocation, undertook all objective assessments. Isometric muscle force for ankle plantarflexion, dorsiflexion, inversion and eversion was measured using a CITEC hand-held dynamometer (CIT Technics, Haren, Netherlands) [12]. Participants were seated during testing with hips flexed and knees extended. The examiner stabilised the lower leg and foot in a neutral position. Three consecutive contractions of three to five seconds were recorded for each muscle group using the 'make' technique in which the examiner held the dynamometer stationary while the participant exerted maximal external force against it. The dynamometer was positioned proximal to the metatarsophalangeal joints on the plantar aspect of the foot for plantarflexion, or on the dorsum of the foot for dorsiflexion; on the

medial aspect of the first metatarsal shaft for inversion; and on the lateral aspect of the fifth metatarsal shaft for eversion. The maximum of the three measurements for each foot were used in the analysis.

Range of motion for 1MTPJ dorsiflexion was assessed using a hand-held goniometer [13]. Participants were positioned seated with knees extended and the shafts of the first metatarsal and proximal phalanx were marked. The goniometer was aligned with the centre of the joint and a passive dorsiflexion force was applied to the hallux until its end range of motion. Ankle inversion and eversion were assessed with participants seated and knees extended [14]. The examiner located and marked the midline of the anterior lower leg and the longitudinal midline of the second metatarsal with the centre of the goniometer positioned at the anterior ankle. With the ankle in a relaxed position, the examiner guided the participant to their end range for eversion and inversion. Ankle dorsiflexion was assessed using the weight-bearing lunge test [15]. Participants were positioned with their tested foot over a line drawn perpendicular to a wall, with the centre of their heel and second toe positioned over the line. They were instructed to lunge forward so their knee touched a vertical line drawn on the wall, while ensuring their heel remained in contact with the floor. The examiner measured the angle between the anterior tibia and the wall. The averages of three measurements for each foot were used for analysis.

Foot type was assessed using the Foot Posture Index (FPI) [16], which has demonstrated moderate intra-rater reliability for the assessment of foot posture in adults [17]. During assessment participants were instructed to stand in a relaxed weight-bearing position while the examiner assessed six-criterion-based observations of the rearfoot and forefoot. Each FPI criterion was scored on a five-point scale (-2 to +2). The scores for the six criteria are

summated to give an overall score for each foot ranging from -12 (highly supinated) to +12 (highly pronated).

The presence of foot problems were determined using the Foot Problem Score [18] which covers foot pain, foot deformity and skin lesions. Foot pain was dichotomised as yes (scored 5 points) or no (0 points); hallux valgus was graded as mild (1 point), moderate (2 points) or severe (3 points); lesser toe deformities, including hammer and claw toes, hyperkeratotic lesions, including corn sand calluses and other bony prominences, including tailors bunions and exostoses were each scored one point [18]. Points for each foot were summated to give a total score for each participant.

Assessment of plantar pressure and spatiotemporal gait parameters

Dynamic plantar pressure was captured during barefoot walking using the TekScan MatScan® system (Boston, MA, USA) and a two-step gait initiation protocol which required the participant to step on the platform on their second step and to continue walking past the platform for at least two more steps. The Research Foot® Version 6.61 was used to mask the plantar foot into: the heel, midfoot, first metatarsal, second metatarsal, metatarsals three to five, the hallux and the lesser toes [19] and peak plantar pressure (kPa) and pressure time integrals (kPa*s) were computed for each region. Means were computed from three repeated trials for each foot.

Spatial and temporal parameters during barefoot walking were collected using a 4.88 x 0.61m electronic GAITRite walkway system (CIR Systems, Inc., New Jersey, US). Participants were instructed to walk at a comfortable walking speed [20]. Prior to calculation of the gait

parameters, the data were reviewed on the monitor screen to ensure that footfalls had been correctly identified.. The GAITRite software (GAITRite® gold, Version 3.2b) was used to compute the following parameters: velocity, cadence, step and stride length, support base, and step, swing, stance, and single and double support times. Means were computed from the three repeated walking trials for each parameter.

Assessment of neurovascular foot characteristics

Protective sensation of the plantar foot was assessed using a 10g Semmes-Weinstein monofilament using a three-site testing protocol (hallux, third metatarsal head, fifth metatarsal head) [21]. Each site was assessed once and loss of sensation for each foot was defined as an inability to detect the monofilament at $\geq$1 sites [21]. Vibration perception was assessed using a biothesiometer placed on the dorsal hallux, proximal to the nail fold. The amplitude was increased at an even rate from 0mV and the participant was asked to indicate when they felt the vibratory stimuli. The average of three measurements for each foot were used for the analysis. A loss of vibratory perception was defined as a threshold of >25mV [22].

Skin temperature was assessed using an infrared thermometer (DermaTemp). The average temperature from the plantar first, third and fifth metatarsal heads were recorded. The average of three repetitions were taken for each foot were used for the analysis.

Ankle Brachial Index (ABI) was used to determine the presence of peripheral arterial disease. Participants rested for $\geq$5minutes in a supine position before testing. Systolic pressure of the dorsalis pedis, posterior tibial and brachial arteries were determined bilaterally using an

8MHz Doppler probe and sphygmomanometer. The higher of the two brachial arteries was divided by the highest ankle pressure for each side. The lower of the two values was used for analysis. An ABI value of ≤1.00 was considered abnormal and indicative of occlusive disease [23].

Assessment of patient-reported pain and disability

Right and left foot pain over the past week were assessed using 100mm visual analogue scales (VAS) anchored with 'no pain' at the left and 'extreme pain' at the right. Region-specific foot pain was also assessed in which participants indicated the areas of pain experienced on each foot by shading in areas of pain on validated diagrams [24]. The diagrams were divided into 10 regions (1MTP, hallux, great toe, lesser toes, plantar forefoot, midfoot, medial arch, ankle, plantar heel, posterior heel). The presence of pain was recorded for each region as 'present' (scored 1) or 'absent' (scored 0). The 10 regions were further stratified into: toes, forefoot, midfoot and rearfoot.

Disabling foot pain was assessed using the Manchester Foot Pain and Disability Index (MFPDI) [25] which is a 19-item index measuring foot-related functional limitation, pain, and physical appearance. Statements relating to each item were answered 'none of the time' (scored 0), 'on some days' (scored 1) or 'on most/everyday(s)' (scored 2) in the past month. A total score of 38 was calculated for each participant. The Lower Limb Task Questionnaire (LLTQ) [26] was used to measure lower limb function. The LLTQ consists of two sections, one related to activities of daily living and the other to recreational activities. Each section includes 10 activities for which participants are asked to rate the difficulty they have had with each in the

past 24 hours (unable =0, severe difficulty =1, moderate difficulty =2, mild difficulty =3, and no difficulty =4).

Statistical analysis

A total sample size of 112 participants was computed for this study with 56 participants with SLE and 56 age- and sex-matched controls. This sample size was calculated based on previous literature measuring foot pain using 100mm VAS in people with other autoimmune rheumatic disease (rheumatoid arthritis) [27]. This assumes the mean (SD) values for foot pain as 35.3 (22.9) mm for participants with autoimmune disease and 20.5 (24.9) mm in controls. The power was set to 0.90 and level of significance 0.05. Due to time constraints within the project 54 participants with SLE and 56 controls were ultimately recruited.

All raw data were described separately for each group as n (%) for categorical data and mean (SD) for continuous data. Continuous outcomes were reviewed for normality using visual inspections (histograms, Q-Q plots, and scatterplots) and formal tests (Kolmogorov-Smirnov and Shapiro-Wilk). Linear regression (continuous outcome measures), multinomial logistic regression (ordinal data), and binary logistic regression (dichotomous data) were used to determine the difference in outcome measures between the two groups. Where appropriate, the models accounted for repeated measures taken from right and left feet through a mixed-modelling approach in which a participant-specific random effect and participant-nested random effect for foot-side were included [28]. This analysis produces results identical to an analysis of measures averaged for each foot-side that would allow for a between-foot-side correlation [28]. Due to the potential influence of foot pain on objective measures of

structure and function, the regression models for muscle force, joint motion, FPI, plantar pressure and gait characteristics were adjusted for foot pain VAS. In addition, plantar pressure was adjusted for BMI and gait velocity, and spatiotemporal parameters were adjusted for BMI (due to the linear relationship between increased plantar pressure and increases in BMI and gait velocity). All hypothesis tests (excluding covariate testing) were carried out at a 5% level of significance against two-sided alternatives. No adjustment for multiplicity was used, but all test-statistics, their null distributions and their observed significance levels were reported. Data were analysed using IBM SPSS Statistics v24.

RESULTS

Participants

Invitation letters were posted to 448 patients with SLE. Of these, 65 registered interest in the study. Eleven did not fulfil the inclusion criteria, leaving 54 participants with SLE completing the study. Fifty-six age- and sex-matched controls also completed the study. The majority of participants were middle-aged females of European ethnicity (Table 1). Compared to controls, participants with SLE had a significantly higher BMI (P=0.004), were more likely to have a history of smoking (P=0.046) or be unemployed (P=0.006) and had higher tender (P<0.001) and swollen (P=0.025) joint counts. Disease characteristics for participants with SLE are presented in Table 2. Participants with SLE had a mean (SD) SLEDAI-2K score of 13.3 (9.7) and disease duration of 15 (12) years.

Musculoskeletal foot characteristics

Differences in musculoskeletal foot characteristics between groups are presented in Table 3. Compared to controls, participants with SLE had significantly lower muscle force for plantarflexion, dorsiflexion, inversion and eversion of the ankle (all $P<0.001$). Participants with SLE also had a significantly higher FPI indicative of a more pronated foot posture ($P=0.007$) and a greater foot problem score ($P=0.001$). There were no differences between groups for joint motion, hallux valgus, or other deformities (all $P>0.05$).

Plantar pressure and spatiotemporal gait parameters

Table 4 presents the between-group differences for plantar pressure, pressure time integrals and spatiotemporal parameters. After adjusting for BMI and gait velocity, participants with SLE had significantly lower peak pressure and significantly higher pressure-time integrals at all seven regions of the plantar foot (all $P<0.001$). After adjusting for BMI, participants with SLE had significantly lower step and stride length and higher step, swing, stance and single and double support times compared to controls (all $P<0.001$). Participants with SLE also had a significantly lower velocity and cadence compared to controls (all $P<0.001$).

Neurovascular foot characteristics

Table 5 presents the differences between groups for the neurovascular characteristics. Participants with SLE had significantly higher VPTs indicative of reduced vibratory perception (*P*=0.001) and were more likely to have abnormal ABI (*OR*=3.13, *P*=0.044). No differences were observed between groups for the remaining neurovascular measures (all *P*>0.05).

Patient-reported pain and disability

Table 6 presents the differences in patient-reported outcomes between groups. Compared to controls, participants with SLE reported significantly worse foot pain VAS scores (*P*<0.001), MFPDI (*P*<0.001), and LLTQ (*P*<0.001). Participants with SLE were more likely to have foot pain compared to controls (62% vs. 29%, *OR*=4.31, *P*<0.001). The most common individual sites for foot pain in SLE were the lesser toes (n=41 feet, 38%), dorsal midfoot (n=40 feet, 37%) and ankle (n=34 feet, 32%). The rearfoot was the most common overall region for foot pain in people with SLE (n=47 feet, 44%). Forty-six feet (43%) of participants with SLE had pain in ≥2 regions.

DISCUSSION

The multi-system heterogenic nature of SLE is reflected in the diversity of structural, functional and neurovascular foot problems observed in the current study, including impaired foot and ankle muscle function and gait changes, which have not been assessed

previously in this population. People with SLE also report a range of foot- and ankle-related problems, including wide-spread pain, functional disability and activity limitations.

The reductions in plantarflexion, dorsiflexion, inversion and eversion muscle force observed in the current study are similar to previous studies when assessing function of major lower limb muscle groups in people with SLE, including quadriceps and hamstrings [3, 29, 30]. Foot and ankle muscle strength is important in performing daily functional activities, including walking, which requires adequate sagittal plane motion for forward progression and frontal plane motion for stability and shock absorption [31]. Muscle weakness in SLE may be due to a reduction in physical fitness as a consequence of fatigue; a symptom experienced by 80% of people with SLE [2].

Results from the current study showed reduced peak pressures and increased pressure time integrals in all areas of the plantar foot in people with SLE. These results suggest that even though maximal load at each area under the foot in people with SLE is low, relative to that of control participants, the cumulative effect of pressure over time is very high. High pressure time integrals are associated with underlying tissue damage and pain in other populations, including diabetes [32] and rheumatoid arthritis [33]. Although this is most commonly considered a result of a slow walking speed or the presence of foot pain [34, 35], the current analysis adjusted for gait velocity and foot pain, meaning that the findings may be attributed to factors beyond these factors. It is possible that alterations in foot structure and posture,

as well as changes to foot function resulting from muscle strength deficits and reduced sensation, may contribute to these altered gait patterns in people with SLE.

Limitations to foot joint motion were not a characteristic feature in people with SLE in the current study. This may reflect the infrequency of sonographic and radiographic foot joint and bone lesions in people with SLE [36, 37] and the non-erosive nature of SLE arthritis [38]. Similar rates of bony deformities, including hallux valgus and clawed digits, as well as skin lesions and hyperkeratosis were also observed between people with SLE and controls. This is consistent with a previous study which found the prevalence of hallux valgus in SLE was not different from controls [37].

Consistent with previous research [39], the current study found greater vibration perception thresholds in people with SLE in comparison to controls, indicating impaired large peripheral nerve fibre function. Nerve conduction studies have also shown significant deterioration of lower limb motor and sensory nerves in people with SLE [39, 40]. Finally, almost one quarter of participants in the current study had abnormal ABI values. Peripheral vascular disease is fairly prevalent in people with SLE [41-43] resulting in decreased blood flow to the extremities and accounting for the high occurrence of chilblains and Raynaud's phenomenon in this population [46].

The current results highlighted the extent and magnitude of self-reported foot pain and disability experienced by people with SLE. Previous research has reported a prevalence of current self-reported foot pain in people with SLE ranging from 33% to 66% [6, 7, 37]. Consistent with this, 62% of participants with SLE in the current study reported foot pain. Although foot pain was wide-spread and often affecting multiple locations, the most common area for pain in people with SLE was the rearfoot; also consistent with previous postal survey data [6, 7]. Although the exact cause of this pattern of pain is unclear, joints of the rearfoot have been reported to have more frequent synovitis on ultrasound imaging in people with SLE compared to controls [37].

Findings from this study should be considered in light of some limitations. Firstly, the participants with SLE in the current study were recruited from secondary care clinics in Auckland, NZ and may not represent SLE in rural communities or globally. Although control participants and participants with SLE were recruited from the same city (Auckland, New Zealand), they may not have come from the same source population which may have increased the risk for selection bias. In addition, gait characteristics were assessed during barefoot walking which may not reflect patterns typically exhibited in daily activity with the use of everyday footwear. Furthermore, potential for outcome ascertainment bias may have been introduced as the podiatric researcher was not blinded to the group allocation of the participants, and therefore may have influenced the strength of between group differences. Finally, people with foot problems may have been more interested in a study of foot disease, which may lead to over-estimation of the prevalence of foot problems in people with SLE.

These results highlight the importance of foot health assessments as part of the management of patients with SLE. Existing studies have shown that podiatric services, including nail and skin care, clinical padding, foot orthoses and footwear advice for patients suffering from rheumatological foot conditions, such as rheumatoid arthritis, gout and other connective tissues diseases are effective in reducing foot pain, impairment and disability [44]. Furthermore, previous work has shown that people with SLE wear shoes which are inappropriate for their level of pain and disability [45]. Along with the results from the current study, these findings warrant the need for further research that assesses the role of foot-specific interventions, including general podiatric care and footwear.

CONCLUSION

In summary, people with SLE exhibit objective evidence of foot and ankle disease, including reduced foot and ankle muscle strength and altered plantar pressure and gait patterns when compared to matched controls. People with SLE also report a wide-range of foot complaints related to pain, disability and activity limitation.

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Table 1. Demographic and clinical characteristics

	Control	SLE	*P*
N	56	54	-
Age, years	48 (14)	52 (14)	0.21
Gender, female, n (%)	52 (93%)	50 (93%)	0.97
Ethnicity, n (%)	European 41 (73%)	European 31 (57%)	0.08
	Māori 3 (5%)	Māori 3 (6%)	
	Pacific 0 (0%)	Pacific 5 (9%)	
	Asian 12 (21%)	Asian 13 (24%)	
	Other 0 (0%)	Other 2 (4%)	
Weight, kg	67.3 (12.1)	74.6 (19.5)	**0.020**
Height, m	1.64 (0.07)	1.63 (0.08)	0.30
Body mass index, kg/m^2	24.87 (4.11)	28.10 (7.19)	**0.004**
Systolic blood pressure, mmHg	115 (14)	120 (19)	0.11
Diastolic blood pressure, mmHg	74 (10)	76 (9)	0.31
Smoker, n (%)	Never 45 (80%)	Never 33 (61%)	**0.046**
	History 9 (16%)	History 13 (24%)	
	Current 2 (4%)	Current 8 (15%)	
Employment, n (%)	Employed 39 (70%)	Employed 32 (59%)	**0.006**
	Not working 3 (5%)	Not working 14 (26%)	
	Retired 5 (9%)		

	Education 9 (16%)	Retired 6 (11%) Education 2 (4%)	
Tender joint count	0.7 (1.8)	8.2 (9.5)	**< 0.001**
Swollen joint count	0.3 (1.1)	2.8 (8.1)	**0.025**

Values are presented as mean (SD) unless otherwise indicated. Bolded *P* values indicate significant difference at $P < 0.05$.

Table 2. SLE disease characteristics (n = 54)

SLEDAI-2K	13.3 (9.7)
SLE disease duration, years	15 (12)
Laboratory tests	
CRP, mg/L	6.8 (10.7)
ESR, mm/hr	35.4 (41.1)
Creatinine, µmol/L	76.8 (25.8)
Medications, n (%)	
Hydroxychloroquine	32 (59%)
Immunosuppressive	21 (39%)
Prednisone	19 (35%)
NSAID	16 (30%)
Analgesic	17 (31%)
Anticoagulant	5 (9%)
Statin	8 (15%)
Anti-hypertensive	13 (24%)
Comorbidities and complications of disease, n (%)	
Lupus nephritis	8 (15%)
Chronic kidney disease	2 (4%)
Raynaud's syndrome	21 (39%); involving feet 14 (26%)
Fibromyalgia	4 (7%)
Sjögren syndrome	6 (11%)
Chilblains	24 (44%); involving feet 19 (35%)

Osteoporosis	7 (13%)
Depression	3 (6%)
Dyslipidaemia	6 (6%)
Cardiovascular diseases	6 (6%)
Hypertension	17 (31%)
Diabetes	1 (2%)

Values are presented as mean (SD) unless otherwise indicated. SLEDAI-2K = systemic lupus erythematosus disease activity index 2000; CRP = c-reactive protein; ESR = erythrocyte sedimentation rate; e-GFR = estimated glomerular filtration rate; NSAID = non-steroidal anti-inflammatory drug.

Table 3. Differences in musculoskeletal foot characteristics between controls and SLE

	Mean (SD)		Diff.	95% CI for Diff.	*P*
	Control	SLE			
Plantarflexion force[b], N	232.0 (79.7)	188.9 (70.9)	-43.1	-63.2, -23.1	**<0.001**
Dorsiflexion force[b], N	177.0 (60.4)	145.1 (53.2)	-32.0	-47.1, -16.8	**<0.001**
Inversion force[b], N	103.1 (44.7)	78.1 (40.7)	-25.0	-36.4, -13.6	**<0.001**
Eversion force[b], N	90.0 (34.9)	66.6 (31.9)	-23.4	-32.3, -14.5	**<0.001**
1MTP dorsiflexion ROM[b], °	79.7 (25.7)	80.6 (22.7)	0.9	-5.5, 7.4	0.77
STJ inversion ROM[b], °	36.0 (17.4)	35.1 (13.3)	-0.9	-5.0, 3.2	0.67
STJ eversion ROM[b], °	13.8 (9.5)	14.0 (8.2)	0.2	-2.2, 2.6	0.87
Ankle lunge[b], °	43.3 (10.5)	40.9 (9.8)	-2.3	-5.0, 0.4	0.09
Foot posture index[b]	3.8 (5.3)	5.6 (5.1)	1.8	0.5, 3.2	**0.009**
Foot problem score	11.3 (7.3)	16.3 (8.6)	5.0	2.0, 8.0	**0.001**
	N (%)[a]		*OR*	95% CI for *OR*	*P*
	Control	SLE			
Foot tenderness present	14 (13%)	67 (62%)	14.32	6.41, 32.00	**<0.001**
Foot swelling present	9 (8%)	30 (28%)	4.58	1.78, 11.76	**0.002**
Hallux valgus grade	None 60 (54%) Mild 30 (27%) Moderate 15 (13%)	None 78 (72%) Mild 18 (17%) Moderate 8	0.95	0.57, 1.57	0.84

	Severe 7 (6%)	(7%) Severe 2 (2%)			
Tinea	4 (4%)	5 (5%)	1.16	0.36, 3.78	0.81
Verruca	0 (0%)	3 (3%)	1.58	0.37, 6.69	0.53
Digital amputation	0 (0%)	2 (2%)	1.37	0.31, 6.04	0.68
Bony prominence(s)	35 (31%)	27 (25%)	0.72	0.36, 1.46	0.36
Hammer toes	9 (8%)	6 (6%)	0.74	0.27, 2.07	0.57
Claw toes	14 (13%)	14 (13%)	1.04	0.39, 2.77	0.93
Hyperkeratotic lesions	98 (88%)	91 (84%)	0.75	0.30, 1.86	0.53

1MTP = first metatarsophalangeal joint; STJ = subtalar joint; ROM = range of motion; Diff. = difference between controls and SLE; CI = Confidence Interval; OR = odds ratio. Bolded *P* values indicate significant difference at $P < 0.05$. [a]Calculated from number of feet (control = 112 feet, SLE = 108). [b]Adjusted for foot pain VAS.

Table 4. Difference in plantar pressure and spatiotemporal gait parameters between controls and SLE

	Mean (SD)		Diff.	95% CI for Diff.	*P*
	Control	SLE			
Peak plantar pressure, kPa[a]					
Heel	244.0 (111.0)	155.4 (87.4)	-88.6	-115.2, 62.0	**<0.001**
Midfoot	116.1 (68.6)	68.3 (55.3)	-47.8	-64.4, -31.3	**<0.001**
First metatarsal	209.3 (90.6)	119.0 (70.9)	-90.3	-112.0, -68.7	**<0.001**
Second metatarsal	278.8 (104.1)	174.0 (80.7)	-104.7	-129.5, -79.9	**<0.001**
Third to fifth metatarsals	235.3 (88.8)	149.4 (66.9)	-86.0	-106.9, 65.0	**<0.001**
Hallux	189.0 (100.2)	127.2 (79.6)	-61.8	-85.9, -37.8	**<0.001**
Toes	124.1 (82.6)	63.6 (89.3)	-60.5	-80.8, -40.1	**<0.001**
Pressure time integral, kPa*s[a]					
Heel	46.4 (61.2)	154.5 (45.3)	108.1	93.8, 122.4	**<0.001**
Midfoot	25.3 (34.9)	64.5 (26.0)	39.3	31.1, 47.4	**<0.001**
First metatarsal	50.6 (66.7)	120.4 (51.4)	69.8	53.9, 85.6	**<0.001**
Second metatarsal	73.6 (64.2)	176.2 (47.8)	102.6	87.5, 117.7	**<0.001**
Third to fifth metatarsals	56.6 (58.4)	146.1 (43.6)	89.5	75.8, 103.2	**<0.001**
Hallux	36.1 (56.2)	128.6 (42.0)	92.5	79.3, 105.7	**<0.001**
Toes	26.1 (35.7)	60.9 (28.0)	34.8	26.3, 43.4	**<0.001**
Spatiotemporal gait parameters[b]					
Step length, cm	63.7 (102)	57.2 (9.5)	-6.5	-9.1, -3.9	**<0.001**
Stride length, cm	127.6 (20.0)	114.7 (19.1)	-12.9	-18.1, -7.7	**<0.001**

Support base, cm	9.8 (4.0)	10.3 (3.7)	0.5	-0.6, 1.5	0.37
Step time, s	0.52 (0.08)	0.58 (0.08)	0.06	0.04, 0.08	**<0.001**
Swing time, s	0.39 (0.04)	0.41 (0.04)	0.02	0.01,0.03	**<0.001**
Stance time, s	0.64 (0.13)	0.73 (0.12)	0.10	0.06, 0.13	**<0.001**
Single support time, s	0.39 (0.05)	0.42 (0.04)	0.02	0.01, 0.04	**<0.001**
Double support time, s	0.24 (0.10)	0.31 (0.09)	0.07	0.05, 0.10	**<0.001**
Velocity, cm/s	125.1 (24.5)	102.1 (19.8)	-23.0	-31.4, -14.6	**<0.001**
Cadence, steps/min	117.9 (13.5)	105.7 (10.9)	-12.2	-16.9, -7.6	**<0.001**

Diff. = difference between controls and SLE; CI = Confidence Interval. Bolded *P* values indicate significant difference at $P < 0.05$. [a]Adjusted for BMI, gait velocity and foot pain VAS. [b]Adjusted for BMI and foot pain VAS.

Table 5. Differences in neurovascular foot characteristics between controls and SLE

	Mean (SD)		Diff.	95% CI for Diff.	*P*
	Control	SLE			
VPT, mV	8.9 (9.4)	13.2 (9.5)	4.3	1.8, 6.8	**0.001**
Temperature, °C	24.9 (3.0)	25.2 (2.9)	0.5	-0.5, 1.1	0.44
ABI	1.03 (0.06)	1.02 (0.14)	-0.01	-0.05, 0.03	0.61
	N (%)		*OR*	95% CI for *OR*	*P*
	Control	SLE			
Loss of protective sensation[a]	3 (3%)	10 (9%)	2.89	0.75, 6.97	0.11
Abnormal VPT (< 25mV)[a]	0 (0%)	10 (9%)	3.56	0.98, 12.91	0.05
Intermittent claudication	0 (0%)	1 (2%)	1.37	0.17, 11.30	0.77
Abnormal ABI	5 (9%)	13 (24%)	3.13	1.03, 9.49	**0.044**

VPT = vibration perception threshold; ABI = ankle brachial index; Diff. = difference between controls and SLE; CI = Confidence Interval; OR = odds ratio. Bolded *P* values indicate significant difference at $P < 0.05$. [a]Calculated from number of feet (control = 112 feet, SLE = 108).

Table 6. Difference in self-reported pain and disability between controls and SLE

	Mean (SD)		Diff.	95% CI for Diff.	*P*
	Control	SLE			
Foot pain VAS, mm	4.5 (24.3)	25.7 (23.9)	21.2	14.6, 27.7	**<0.001**
MFPDI, total	1.3 (2.6)	11.6 (8.4)	10.31	8, 12.6	**<0.001**
LLTQ activities of daily living	39.2 (1.4)	34.7 (5.6)	-4.57	-6.1, -3	**<0.001**
LLTQ recreational activities	35.7 (11.0)	24.9 (6.2)	-10.79	-14.1, -7.4	**<0.001**
	N (%)[a]		*OR*	95% CI for *OR*	*P*
	Control	SLE			
Any foot pain present	32 (29%)	67 (62%)	4.31	2.24, 8.29	**<0.001**
First MTP pain	12 (11%)	25(23%)	2.51	1.08, 5.88	**0.034**
Hallux pain	9 (8%)	22 (20%)	2.93	1.13, 7.61	**0.027**
Great toe pain	17 (15%)	32 (30%)	2.39	1.10, 5.26	**0.028**
Lesser toe pain	13 (12%)	41 (38%)	4.85	2.17, 10.84	**<0.001**
Plantar forefoot pain	9 (8%)	24 (22%)	3.29	1.29, 8.38	**0.013**
Dorsal midfoot pain	7 (6%)	40 (37%)	9.03	3.52, 23.12	**<0.001**
Medial arch pain	3 (3%)	19 (18%)	4.64	1.65, 13.06	**0.004**
Ankle pain	9 (8%)	34 (32%)	5.46	2.23, 13.40	**<0.001**
Plantar heel pain	1 (1%)	16 (15%)	5.03	1.57, 16.14	**0.007**
Posterior heel pain	5 (5%)	20 (19%)	4.84	1.58, 14.81	**0.006**
Any toe pain	17 (15%)	43 (40%)	3.85	1.82, 8.15	**<0.001**

Any forefoot pain	15 (13%)	32 (30%)	2.76	1.27, 6.01	**0.011**
Any midfoot pain	7 (6%)	39 (36%)	8.67	3.37, 22.32	**<0.001**
Any rearfoot pain	9 (8%)	47 (44%)	9.56	3.89, 23.50	**<0.001**
Pain ≥ 2 locations[b]	12 (11%)	46 (43%)	6.11	2.79, 13.42	**<0.001**
Pain ≥ 3 locations[b]	3 (3%)	32 (30%)	15.18	4.11, 46.04	**<0.001**

VAS = Visual Analogue Scale; MFPDI = Manchester Foot Pain and Disability Index; LLTQ = Lower Limb Task Questionnaire; HAQ-DI = Health Assessment Questionnaire - Disability Index; EQ 5D 5L = EuroQol 5 Dimensions 5 Levels. Diff. = difference between controls and SLE; CI = Confidence Interval. MTP = metatarsophalangeal joint; OR = Odds Ratio. Bolded *P* values indicate significant difference at $P < 0.05$. [a]Calculated from number of feet (control = 112 feet, SLE = 108). [b]From either toes, forefoot, midfoot, and/or rearfoot.