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Original Article

Surgery Section

Static Foot Pressure and Percentage Contact Area of the Foot as an Assessment Tool for the Success of Anterior Cruciate Ligament Reconstruction: A Cross-sectional Study

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ABSTRACT

Introduction: Anterior Cruciate Ligament (ACL) plays a vital role in gait balancing and lower limb kinematics. Any injury to the ACL leads to gait imbalance and alterations in foot pressure distribution. The stability and biomechanics of the lower limb after ACL Reconstruction (ACLR) can be measured through foot pressure analysis, gait analysis, and percentage contact area of the foot, among others.

Aim: To evaluate the static foot pressure and percentage contact area of the foot in ACL deficient group, comparing it with the ACLR group and the normal healthy individual group.

Materials and Methods: An analytical cross-sectional study was conducted at the Department of Sports Medicine, King George Medical University, Lucknow, Uttar Pradesh, India from March 10, 2021 to March 15, 2023. A total of 15 patients in each group (ACL injury, ACLR patients, and normal healthy individuals) were included in this study. Foot pressures (static) were recorded in all three groups using the BTS P-WALK system with BTS Biomedical software, which included high-density sensors and a plate size of 700 × 500 × 5 mm. Statistical analysis was performed using Statistical Package for the Social Sciences (SPSS) software version 26.0. Chi-square and linear regression tests were used to analyse the differences between the groups.

Results: In the intragroup analysis, ACL deficient patients' ipsilateral limbs showed lower foot pressure in the mid-foot (7±3.4), hind-foot (40.33±10.08), and whole foot pressure (110.19±34.7 Pascal (N/M^2)) (p-value>0.05) compared to normal healthy individuals (126.06±19.4 Pascal (N/M^2) (p>0.05) and ACLR (125.06±14.3 Pascal (N/M^2)) (p-value>0.05) groups, which suggested insignificant differences. The percentage contact area of the foot was significantly lower (43.15±3.4) (p-value<0.001) compared to normal healthy individuals (49.82±0.84) and ACLR (49.02±0.91) groups. However, in intergroup comparisons, the differences in mid-foot, whole foot pressure, and percentage contact area of the foot were significant (p-value <0.001) within the groups.

Conclusion: Although there is a wide range of variation in the values of static foot pressure and percentage contact area of the foot in ACL deficient patients, after ACLR, these values become nearly similar to those of normal healthy individuals at around one year after ACLR.

Keywords: Foot pressure, Gait analysis, Kinematics, Pedobarography

INTRODUCTION

ACL tears are commonly observed in athletes and young adults during sports activities or road traffic accidents, resulting in functional instability [1,2]. Various methods, such as knee laxity evaluation and assessment of extensor muscle strength, are used to evaluate functional outcomes after ACLR. However, these methods primarily focus on static tests and may not adequately capture dynamic evaluation [3,4]. ACLR not only addresses knee laxity but also improves the biomechanics of the lower limb. Gait pattern analysis, using kinematic and mechanical methods, has been proposed as a valuable approach for evaluating functional outcomes [5,6]. Foot pressure distribution measurement, a tool commonly used in gait analysis, can assess the stability and kinematic function of the limb in such cases. Abnormalities in foot pressure distribution and decreased muscle strength around the ACL deficient knee may lead to differences compared to normal individuals or the non affected lower limb [7]. While foot pressure analysis has been extensively studied in conditions such as diabetic foot, rheumatoid arthritis, neuropathic foot, stroke, and various other disease-related gait analyses [8-10], its application in ACL injury and postoperative rehabilitation is relatively rare [11,12]. Notably, present study focuses on measuring static foot pressure and the percentage contact area of the foot, which is unique compared to previous research. Therefore, the aim of this study was to investigate foot pressure asymmetry and discrepancies in the percentage contact area of the foot among patients with ACL injuries, those who underwent ACLR, and normal healthy individuals.

MATERIALS AND METHODS

An analytical cross-sectional study was conducted at the Department of Sports Medicine, King George Medical University, Lucknow, Uttar Pradesh, India from March 10, 2021, to March 15, 2023. This study was planned after obtaining ethical approval from the local ethical committee of KGMU (Ref. code: 102nd ECM IIB/P114), and informed written consent was obtained from the patients for the publication of this article and for providing the scientific data for further research. A total of 15 patients were included in each group: ACL injury group, ACLR group, and normal healthy individual group.

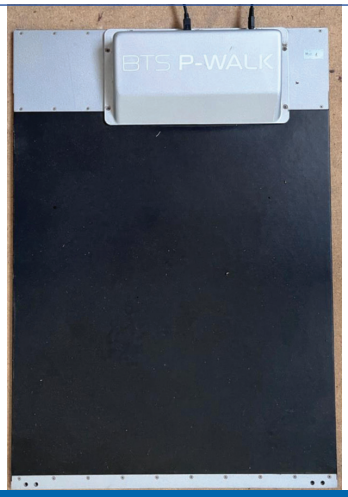
Inclusion criteria: ACL injury patients confirmed by physical examination and radiological findings (MRI) were included in the ACL deficient group. The ACLR group comprised previously operated patients for ACL injury in the same institute.

Exclusion criteria: Patients with neuropathic joints, multiligamentous injuries, high-grade meniscal tears, joint arthropathy, restricted joint range of motion, and any other limb pathology were excluded from the study.

Sample size: The minimum sample size required was determined based on a study conducted by Çetin E et al., [11]. Considering a 95% level of confidence, a 1.5 margin of error, and a standard deviation of 4.26, the minimal required sample size was 35. Taking into account the non response rate, a total sample size of 45 individuals was selected, with 15 patients in each group (ACL injury group, ACLR group, and normal healthy individual group).

Sampling: The patients were selected using systematic random sampling. The ACL injury group consisted of new patients randomly selected from a pool of ACL deficient patients, considering the inclusion and exclusion criteria. The ACLR group consisted of individuals who had previously undergone ACL reconstruction within the given study duration, not selected from the ACL deficient group. The normal healthy individual group consisted of healthy individuals from the general population without any knee injury or abnormality, who were requested to visit the centre for foot pressure analysis and percentage contact area of the foot. The leg included in the study was determined according to the ACL deficient and ACLR groups.

Pedobarographic evaluation, including static foot pressure and percentage contact area of the foot, was performed in the ACL deficient group, which was then compared with the pedobarographic values of the ACLR group (after one year of follow-up) and the normal healthy individual group. Foot pressures (static) were recorded in all three groups using the BTS P-WALK system with BTS Biomedical software, which included high-density sensors and a plate size of 700 × 500 × 5 mm [Table/Fig-1].



[Table/Fig-1]: BTS P-WALK foot pad, used for foot pressure analysis and percentage surface area of foot calculation in this study.

Subjects were asked to stand on a foot plate with their ACL deficient limb, ACLR limb, and a similar limb (right/left) for the control group. The values were recorded on the computer. Peak static foot pressure and percentage contact area of the foot were calculated by combining the forefoot, mid-foot, and hindfoot data from the mask data. The mean±Standard Deviation (SD) of two measurements from each foot (ACL injured, ACLR, and normal foot) were saved for analysis.

STATISTICAL ANALYSIS

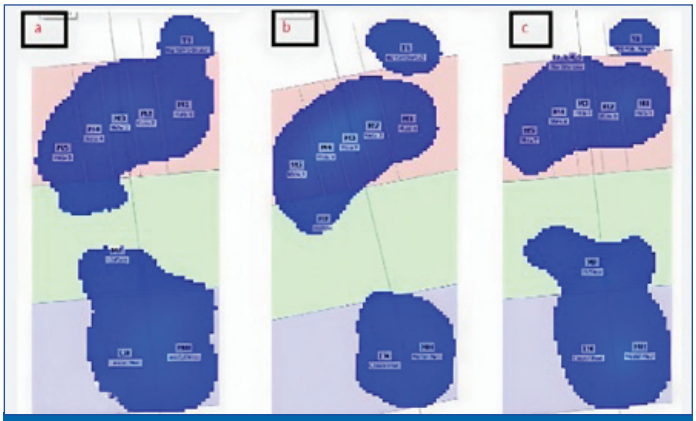
Statistical analysis was performed using SPSS 26.0 software. Chi-square and linear regression tests were used to calculate the mean±SD and analyse the differences between the ACL deficient, ACLR, and healthy normal individual groups. A p-value <0.05 was considered to be statistically significant.

RESULTS

A total of 15 patients were included in each group (13 males and 2 females) of ACL injury, ACLR (those who underwent ACL surgery one year ago in the same institute), and normal healthy controls. The average time between ACL injury and pedobarography was 3.1 months (ranging from two months to 11 months), and the surgeries were performed within one week. The age of the patients ranged from 21 to 46 years, with a mean age 24.26± 6.1 years. Demographic details are presented in [Table/Fig-2]. The BTS system divides the foot into various anatomical parts (forefoot- T1, T2, T3, T4, T5, M1, M2, M3, M4, M5, mid-foot, and hindfoot - MH, LH), and the pressure of different parts was calculated in Pascal (N/M^2) [Table/Fig-3].

Parameters	Normal healthy individual (12 right+3 left legs)	ACL deficient group (12 right+3 left legs)	ACLR group (12 right+3 left legs)	p-value (Linear regression analysis)
Age (years)	24.93±5.4	24.26±6.1	25.26±6.1	<0.001
Sex (M/F)	13 M/2 F	13 M/2 F	13 M/2 F	(string variable)
Height (m)	1.67±0.07	1.65±0.06	1.65±0.06	<0.001
Weight (Kg)	62.86±9.0	66±5.4	63.73±5.7	0.133
BMI (kg/m^2)	22.53±3.5	24.24±2.34	23.40±2.68	0.05

[Table/Fig-2]: Demographic data of subject of each group {mean (SD)}. Linear regression analysis; p-value <0.05 significant



[Table/Fig-3]: These are the pressure distribution (foot pressure), which is divided in the three parts-forefoot (T1, T2 T3 T4 T5, M1, M2, M3, M4, M5- all toes and metatarsal areas), mid-foot and hind-foot (MH,LH- medial heal and lateral heal) of: (a) Normal healthy individual limb; (b) ACL deficient limb; and (c) Anterior Cruciate Ligament Reconstruction (ACLR) limb at one year of follow-up. Obvious foot pressure distribution asymmetry among them but ACLR is grossly matching with normal healthy individual.

Intergroup comparison: There was a gross reduction in forefoot pressure (62.86±33.8 Pascal (N/M^2)) (p-value<0.242), mid-foot pressure (7±3.4 Pascal (N/M^2)) (p-value<0.175), hindfoot pressure (40.33±10.08 Pascal (N/M^2)) (p-value<0.259), and whole foot pressure (110.19±34.7 Pascal (N/M^2)) (p-value<0.328) [mean (SD)] in the ACL deficient limb group compared to the contralateral normal limb in the same patients. However, these differences were not statistically significant based on the p-values. When comparing the normal healthy individual group and the ACLR group, all forefoot, mid-foot, hindfoot, and whole foot pressures were almost equal to the contralateral limb of the same control and ACLR groups. However, all p-values were >0.05, indicating that these differences were not significant [Table/Fig-4].

Healthy individual group	Ipsilateral limb as ACL deficit and ACLR group Pascal (N/M^2)	Contralateral limb Pascal (N/M^2)	p-value (χ^2 test)
Fore foot pressure	67.93±16.2	67.8±17.02	0.078
Mid-foot pressure	13.13±6.1	12.86±4.7	0.158
Hind foot pressure	45±7.4	47.26±8.8	0.349
Whole foot pressure	126.06±19.4	127.93± 19.4	0.295
ACL deficient group	**Ipsilateral (ACL deficient limb)**	**Contralateral (Normal limb)**	
Fore foot pressure	62.86±33.8	75.2±18.3	0.242
Mid-foot pressure	7±3.4	8±4.3	0.175
Hind foot pressure	40.33±10.08	47.33±8.1	0.259
Whole foot pressure	110.19±34.7	130.53±21.3	0.328

ACLR group	Ipsilateral (ACLR limb)	Contralateral (Normal limb)	
Fore foot pressure	65.8±11.5	69.8±11.8	0.327
Mid-foot pressure	12.2±3.5	13.9±3.6	0.125
Hind foot pressure	47.06±8.2	46.26±9.8	0.328
Whole foot pressure	125.06±14.3	129.96±12.1	0.251

[Table/Fig-4]: Static foot pressure distribution {mean (SD)}, in normal healthy individual, ACL deficient group and ACLR group at one year follow-up (intragroup comparison).
Chi-square test; p-value <0.05 significant

However, when considering the percentage contact area of the foot, the mean±SD was found to be significantly reduced (43.15±3.4) in ACL deficient limbs compared to the contralateral limb in the same patients (57.18±4.0) (p-value <0.001). In contrast, in the normal healthy individuals (49.82±0.84) (p-value <0.001) and ACLR (49.02±0.91) (p-value <0.001) groups, the ipsilateral percentage contact area was almost similar to the contralateral limbs, showing significance in terms of p-values (p-value <0.001) [Table/Fig-5]. The difference in mid-foot, whole foot pressure, and percentage contact area of the foot was significant (p-value <0.001) within the groups [Table/Fig-6].

Groups	Ipsilateral limb as ACL deficit and ACLR group	Contralateral limb	p-value (Chi-square test)
% surface area of foot in normal healthy individual	49.82±0.84	50.13±0.84	<0.001
% surface area of foot in ACL deficient group	43.15±3.4	57.18±4.0	<0.001
% surface area of foot in ACLR group	49.02±0.91	51.10±0.74	<0.001

[Table/Fig-5]: Percentage contact area of foot {mean (SD)}, in normal healthy individual, ACL deficient group and ACLR group at one year follow-up.
Chi-square test; p-value <0.05 significant

Groups Parameters	Ipsilateral limb as ACL deficit and ACLR groups	Ipsilateral (ACL deficient limb)	Ipsilateral (ACLR limb)	p-value (Linear regression analysis)
Fore foot pressure Pascal (N/M^2)	67.93±16.2	62.86±33.8	65.8±11.5	0.355
Mid-foot pressure Pascal (N/M^2)	13.13±6.1	7±3.4	12.2±3.5	0.001
Hind foot pressure Pascal (N/M^2)	45±7.4	40.33±10.08	47.06±8.2	0.061
Whole foot pressure Pascal (N/M^2)	126.06±19.4	110.19±34.7	125.06±14.3	0.001
Surface area of foot (in percentage)	49.82±0.84	43.15±3.4	49.02±0.91	0.001

[Table/Fig-6]: Static foot pressure distribution and percentage contact area of foot {mean (SD)} in normal healthy individual, ACL deficient group and ACLR group at one year follow-up (intergroup comparison).
One-way ANOVA; p-value <0.05 significant

DISCUSSION

Previous studies have shown that lower extremity biomechanics in ACL deficient patients differ from postoperative ACL reconstructed patients and normal healthy individuals, particularly in knee movement during walking and other activities [13]. Several studies have investigated joint position sense, muscle activities during walking, and joint movement in ACL deficient patients [5,6,14,15]. It has been noted that ACL deficient knees have decreased kinesthesia and worse knee position sense compared to normal knees [14,15]. Patients with ACL deficiency tend to avoid quadriceps contraction during specific phases of walking [5]. Joint movement in ACL deficient knees is also decreased compared to non injured knees [6]. However, foot pressure analysis in such cases is rare.

In this study, wide range of variation in static foot pressure (with reduced mid-foot pressure in the ACL deficient group compared to the ACLR and normal healthy individual groups) and percentage contact area of the foot (reduced in ACL deficient limbs) compared to the normal healthy individual and postoperative ACLR groups were observed. The static foot pressure and percentage contact area of the foot in the postoperative ACLR group were nearly similar to those of the normal healthy individual group, indicating a restoration of lower limb biomechanics around one year after ACL reconstruction, which is close to normal compared to healthy individuals. This suggests that at this stage, patients can safely return to their normal athletic activities, as the objective assessment of ACL strength supports their readiness.

Authors did not found any studies that compared static foot pressure analysis and percentage contact area of the foot among healthy individuals, ACL deficient, and ACLR groups to assess the strength and stability of the ACL in postoperative ACLR patients. This is what makes present study unique.

Limitation(s)

The main limitation of this study was the small sample size in each group and the short duration of follow-up. These limitations can be addressed in future studies.

CONCLUSION(S)

There is a wide range of variation in the values of static foot pressure and percentage contact area of the foot in the ACL deficient group. After one year of follow-up, these values in the ACLR group are nearly similar to those of the normal healthy individual group. This assessment tool can be used to evaluate the biomechanics and stability of the ACLR limb and determine if patients can safely return to their previous level of physical activity.

Author's contributions: AA and AK conceived and designed the study and provided research material. SA and AS collected, organised, and interpreted the data, and SA wrote the draft and provided logistic support. PP is statistician who has been involved in the statistics part of this manuscript. All authors have critically reviewed and approved the final draft and are responsible for the content and similarity index of the manuscript.

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