# Comparison of Plantar Pressure Between Patients With Severe Chronic Lateral Ankle Instability and Healthy Subjects

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**Research**

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# Abstract

**Background:** The biomechanical pathophysiology of chronic lateral ankle instability (CLAI) is not fully understood. Planter pressure is susceptible to subtle changes in foot and ankle movement and could be used to detect CLAI. Therefore, this study aimed to compare plantar pressure between patients with CLAI and healthy subjects.

**Methods:** Eighteen patients with CLAI who were scheduled for anterolateral ligament repair (9 women and 9 men) and 100 healthy subjects (50 women and 50 men) were included. Using an in-shoe pressure sensor system with ten plantar pressure sensors, the plantar pressure was recorded at a sampling rate of 200 Hz while walking. Analyses were adjusted for body mass index and gait speed.

**Results:** Patients with CLAI had a significantly lower peak pressure on the hallux and toes than did healthy subjects. However, patients with CLAI had a significantly higher peak pressure on the medial aspect of the foot than did healthy subjects.

**Conclusions:** The planter pressure distribution significantly differed between patients with CLAI and healthy subjects. The difference could have been due to a compensatory mechanism to prevent ankle instability. These findings could be used to elucidate the biomechanical pathophysiology of CLAI.


# Introduction

Lateral ankle sprains are the most common injuries sustained during sports activities. Most patients with ankle sprains recover fully with conservative treatment, but 20–40% develop chronic lateral ankle instability (CLAI) [1–3]. CLAI leads to the ankle giving way [4] and reduced quality of life [5] and is associated with the risk of post-traumatic ankle osteoarthritis [6]. Further, individuals with CLAI reportedly lack both static postural control [7] and dynamic postural control [8]. Some studies also reported that individuals with CLAI had higher peak pressure on the lateral aspect of the foot than did healthy subjects [9–11] but that the hallux peak pressure did not differ [11]. However, most previous studies used CLAI copers who did not necessarily require surgical treatment. Thus, the biomechanical pathophysiology of CLAI is not fully understood. Therefore, the purpose of this study was to compare plantar pressure during walking between healthy subjects and patients with severe CLAI who required surgical treatment. The hypothesis was that the peak pressure of the foot would be higher in the lateral aspect in patients with severe CLAI than in healthy subjects and the peak pressure of the hallux would be similar between patients with severe CLAI and healthy subjects.

# Materials And Methods

# Subjects

Eighteen patients with CLAI who were scheduled for anterolateral ligament repair (9 women and 9 men) and 100 healthy subjects (50 women and 50 men) were included. Patients with CLAI were diagnosed with

grade III ligament injuries, resistant to conservative treatment, and clinically indicated for surgical treatment. The specific inclusion criteria were as follows: a history of at least one significant ankle sprain, postinjury duration of > 6 months, recurrent sprain and/or the ankle giving way [4], and grade III ligament [12] lesion confirmed by both magnetic resonance imaging and a positive anterior drawer test [13]. Patients with CLAI and healthy subjects were excluded if they had previously undergone foot surgery or presented with congenital or acquired foot deformities on clinical examination. Demographics including age, sex, height, weight, and body mass index (BMI) were recorded and the demographic data are shown in Table 1. The study protocol was approved by the Institutional Review Board of our institution and written informed consent was obtained from all subjects before enrollment.

Table 1
Demographic data

| | **Normal** | **CLAI** | ***P* Value** |
|---|---|---|---|
| Number (Women, Men) | 100 (50, 50) | 18 (9, 9) | |
| age * | 32 ± 8 | 28 ± 12 | 0.02 |
| Height (m) | 1.65 ± 0.09 | 1.68 ± 0.09 | 0.12 |
| Weight (kg) * | 60 ± 12 | 67 ± 18 | 0.02 |
| BMI ($kg/m^2$) * | 21.7 ± 2.7 | 23.3 ± 4.0 | 0.02 |
| CLAI: chronic lateral ankle instability | | | |
| Comparison of demographic data, *$p < .05$ significantly higher, Paired t-test. Values are given as mean ± SD. | | | |

# Measurement devices

The plantar pressure sensor (University of Fukui Graduate School of Engineering, Japan) has ten sensors of 1 mm thickness and 12 g weight [14]. They are connected to a measuring unit of 17 g in weight with a 200 Hz sampling rate (Fig. 1). Three sensors were placed on the toes, four on the forefoot, two on the midfoot, and one on the hindfoot. Four sizes (23–28 cm) of sports shoes and corresponding sizes of plantar pressure sensors were prepared to provide the best fit shoes for each subject.

# Measurement and evaluation

Subjects were instructed to walk at least ten steps at a comfortable speed while the plantar pressure was recorded. The maximum loading point while walking was measured in the hallux (sensor a) and the movement of the maximum loading point while walking was analyzed by evaluating different areas in the antero-posterior (AP) direction and medio-lateral (ML) direction (Fig. 2). Results were compared by

converting the BMI to 22 and gait speed to 118 steps/min (Microsoft Excel 2016 and COP graph creator, University of Fukui Graduate School of Engineering, Japan). The gait speed was 120 ± 9 steps/min for women and 116 ± 11 steps/min for men and there was no significant difference between men and women. Since the overall average was 118 steps/min, this value was used for the adjustment.

# Statistical analysis

A two-sample t-test was used for data comparison (Microsoft Excel 2016). For all analyses, statistical significance was set at $P < .05$. All analyses with the exception of demographic data were subjected to Bonferroni's correction for multiple comparisons. All data are reported as the mean ± standard deviation.

# Results

The mean age of the cohort was 32 ± 8 years (Table 1). Patients with CLAI had a significantly lower peak pressure on the hallux and toes and higher peak pressure on the medial aspect of the foot than did healthy subjects (CLAI/Normal: Hallux 408.5/559.6 kPa, Toes 271.7/383.6 kPa, Medial 531.1/408.9 kPa). These significant differences remained in the comparisons among women and among men (Table 2, all $P < .05$).

Table 2
Peak plantar pressure (kPa) in healthy subjects and patients with CLAI

| **Women** | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Hallux * | toes * | forefoot | midfoot | hindfoot | medial * | lateral |
| Normal | 619 ± 105 | 452 ± 102 | 570 ± 71 | 121 ± 53 | 522 ± 130 | 453 ± 57 | 318 ± 59 |
| CLAI | 495 ± 207 | 320 ± 167 | 611 ± 26 | 129 ± 56 | 544 ± 120 | 645 ± 125 | 343 ± 35 |
| *P* Value | < .05 | < .05 | 0.11 | 0.34 | 0.37 | < .05 | 0.14 |
| Men | | | | | | | |
| | Hallux * | toes * | forefoot | midfoot | hindfoot | medial * | lateral |
| Normal | 499 ± 134 | 316 ± 91 | 491 ± 98 | 136 ± 78 | 593 ± 143 | 365 ± 86 | 349 ± 73 |
| CLAI | 311 ± 61 | 223 ± 49 | 459 ± 77 | 147 ± 48 | 468 ± 212 | 418 ± 117 | 290 ± 62 |
| *P* Value | < .05 | < .05 | 0.37 | 0.21 | 0.33 | < .05 | 0.05 |
| All subjects | | | | | | | |
| | Hallux * | toes * | forefoot | midfoot | hindfoot | medial * | lateral |
| Normal | 560 ± 134 | 384 ± 118 | 531 ± 94 | 128 ± 67 | 556 ± 141 | 409 ± 85 | 333 ± 68 |
| CLAI | 409 ± 181 | 272 ± 132 | 513 ± 97 | 138 ± 53 | 494 ± 190 | 531 ± 166 | 315 ± 57 |
| *P* Value | < .05 | < .05 | 0.26 | 0.28 | 0.08 | < .05 | 0.16 |

Comparison of peak plantar pressure in healthy subjects and patients with CLAI, *$p < .05$ significantly higher, Paired t-test. Values are given as mean ± SD (kPa).

# Discussion

This study aimed to compare plantar pressure during walking between healthy subjects and patients with severe CLAI who required surgical treatment. The main findings were that patients with severe CLAI applied a significantly higher peak pressure on the medial aspect of the foot and lower peak pressure on the hallux and toes while walking than did healthy subjects. Interestingly, these findings were not consistent with those of previous studies involving participants with CLAI [9–11]. However, the participants with CLAI in previous studies did not require ankle stability surgery (i.e., their condition was less severe), which may explain why the plantar pressure differed from that in this study.

We observed higher pressure distribution in the medial aspect of the foot in patients with CLAI, which could have stemmed from a compensatory mechanism to avoid lateral ankle instability. This finding was also inconsistent with those of previous studies [9–11]. Feger et al. reported that the percentage of activation time of the peroneus longus muscle was greater in the CLAI group than in the control group [15]. Moisan et al. reported that the muscle that seemed the most affected among participants with CLAI

was the peroneus longus while walking [16]. Due to the influence of the peroneus longus muscle, the peak pressure on the medial aspect of the foot is be higher, which contributes to the prevention of lateral ankle sprains.

Lower pressure in the toes and the hallux in patients with severe CLAI was observed in the current study, but Koldenhoven et al. did not report a significant difference in the pressure on the hallux between patients and controls [11]. This contrasting finding could be explained by the avoidance mechanism of lateral ankle instability. The moment arm of the inversion force on the ankle joint that is generated by lateral thrust increases as the body weight shifts forward. Patients with CLAI may have unconsciously attempted to minimize the moment arm of the inversion torque on the ankle joint by reducing the peak pressure on the hallux and toes.

The limitations of this study should be considered. First, the plantar pressure was measured only once, the day before surgery, but the planter pressure pattern may change with time. However, because the evaluation was conducted immediately before surgery, the data could presumably be taken under the worst condition of CLAI. Second, patients with CLAI were slightly younger and slightly heavier than the control group. However, the activity level was similar, and all pressure data were normalized as their BMI was 22. Therefore, the statistical comparisons were scarcely affected. Lastly, although statistical significance was achieved in the comparisons, the current study participants might have been too homogeneous to apply the results to the other cultural and racial backgrounds. Thus, the generalizability of the results is limited. It should be noted that the current results were collected from subjects who were relatively older than most active sport athletes. Regardless, the current findings could be used to elucidate the biomechanical pathophysiology of CLAI. In addition, evaluating the plantar pressure after arthroscopic lateral ligament repair may contribute to the improvement of gait balance and gait posture, which may help to prevent the ankle from giving way.

# Conclusions

Patients with CLAI had a different peak pressure of the foot (higher on the medial side and lower on the toes and the hallux) than healthy subjects. The difference could have been induced by a compensatory mechanism to prevent ankle instability.

# Abbreviations

CLAI: chronic lateral ankle instability

# Declarations

### Ethics approval and consent to participate

The study protocol was approved by the institutional review board of Kobe University Graduate School of Medicine (No. B190150). Written informed consent was obtained from each subject.

### Consent for publication

Not applicable.

### Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding authors on reasonable request. Please contact authors for data requests (MD, PhD. Yuichi Hoshino – email address: yuichi-h@mta.biglobe.ne.jp).

### Competing interests

The authors declare that they have no competing interests.


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### Authors' contributions

TY, YH and NK were involved in study conception and design, data collection, data analysis and interpretation, and drafting the manuscript. KK, KN and KN were involved in data interpretation and contributed to drafting the manuscript. DA, TM and RK was involved in study design, data interpretation, and contributed to drafting the manuscript. All authors have read and approved the final manuscript.


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# Figures

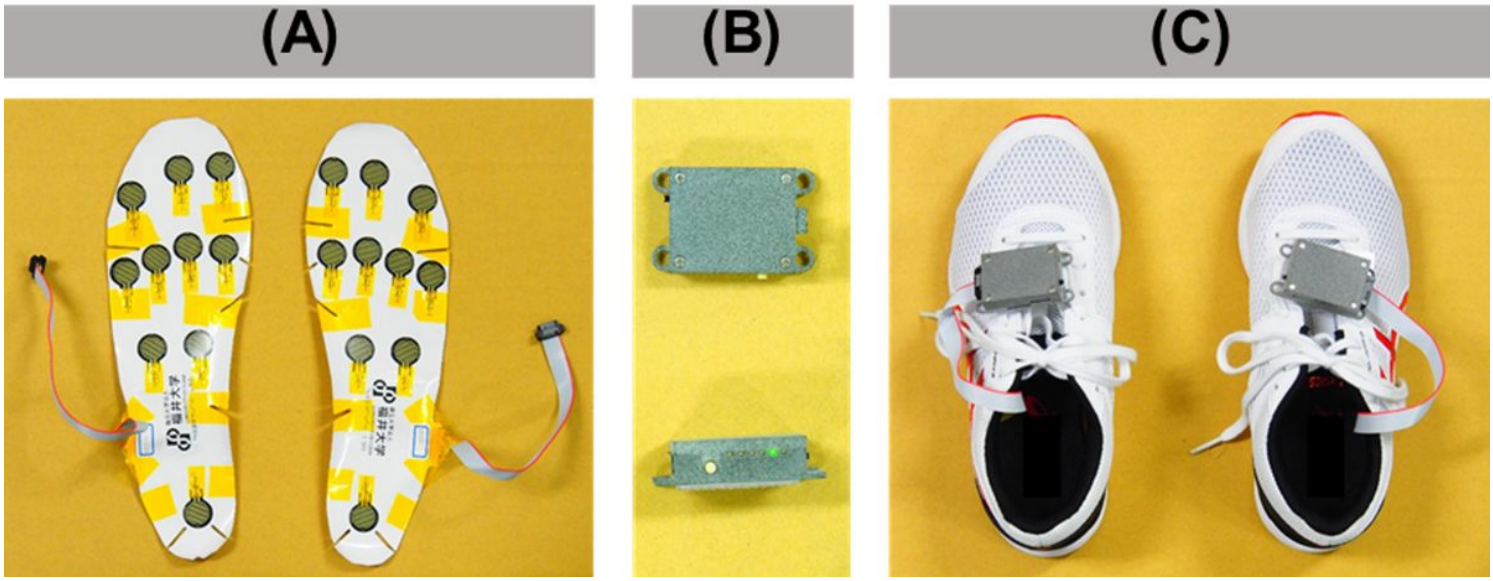


**Figure 1**

Plantar pressure measurements (A) Ten of the sensors are attached underneath the insole and connected to the measuring unit. The sensors are only 1mm in thickness and total 12g in weight. (B) The measuring unit is only 17g in weight and collects data at 200Hz. (C) The sensor is placed underneath the insole and connected to the measuring unit on the top of the foot.

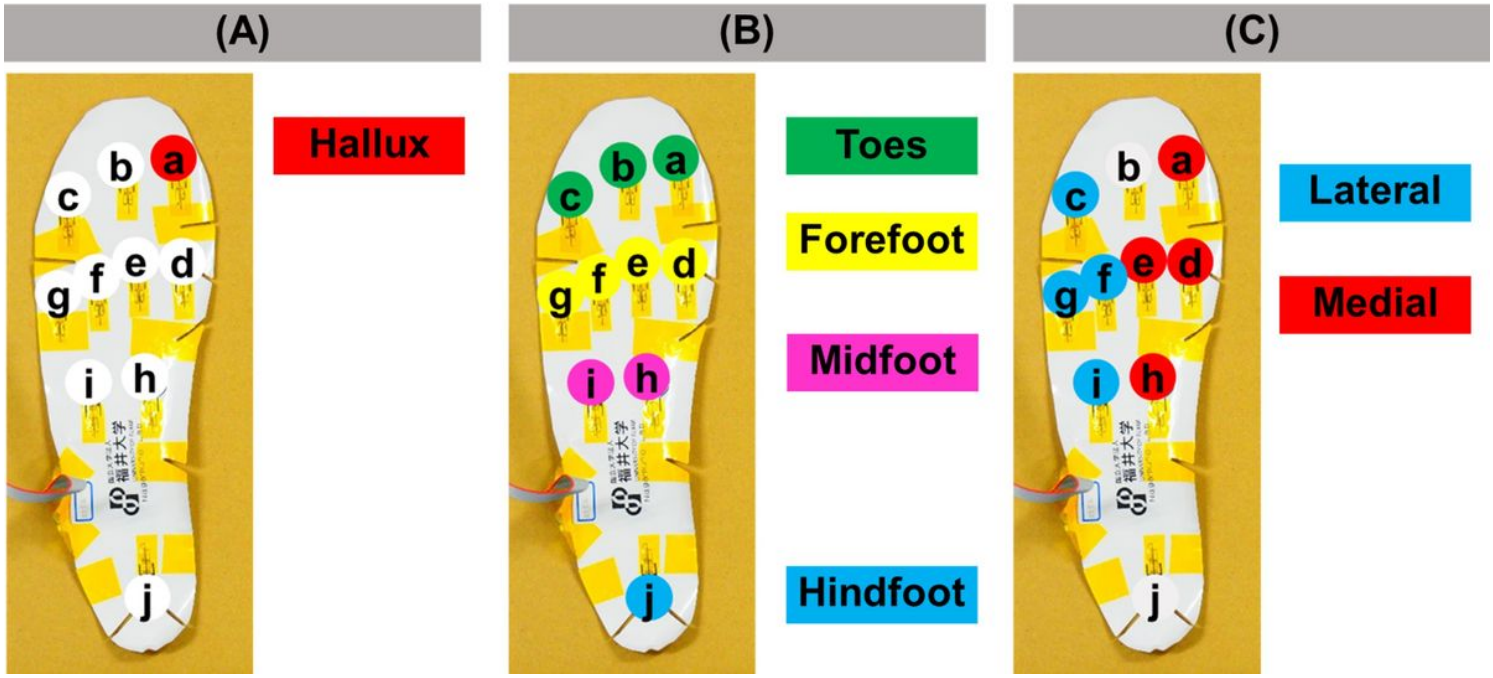


**Figure 2**

The evaluation of plantar pressure (A) The value of the sensor a in the figure was defined as Hallux. (B) Areas for analyzing weight-bearing point in anteroposterior direction. The evaluation was divided into four parts: toes, forefoot, midfoot, and hindfoot, and the average value was calculated. (C) Areas for

analyzing weight-bearing point in medio-lateral direction. The average value was calculated separately for the medial and lateral.