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# Using a Crossline Laser to Predict Peak Plantar Pressure During Walking

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***Context:*** Developing low-cost assessment tools to quantify ankle biomechanics in a clinical setting may improve rehabilitation for patients with chronic ankle instability (CAI).

***Objective:*** To determine whether a crossline laser can predict peak plantar pressure during walking.

***Design:*** Descriptive laboratory study.

***Setting:*** Laboratory.

***Patients or Other Participants:*** Twenty-five participants with CAI (9 men, 16 women; age = 20.8 ± 2.3 years, height = 170.4 ± 10.4 cm, mass = 78.9 ± 22.4 kg).

***Intervention(s):*** Participants completed 30 seconds of treadmill walking with a crossline laser fixed to their shoe while, simultaneously, a video camera recorded the laser projection on the wall and an in-shoe plantar-pressure system measured plantar pressure.

***Main Outcome Measure(s):*** Peak laser rotation and peak plantar pressure of the lateral midfoot and forefoot.

***Results:*** With respect to peak plantar pressure, peak rotation of the laser during walking explained 57% of the variance in the lateral midfoot and 64% in the lateral forefoot.

***Conclusions:*** The crossline laser may be a valuable clinical tool for predicting lateral peak plantar pressure in patients with CAI during walking.

***Key Words:*** biomechanics, chronic ankle instability, gait

**Key Points**

- A crossline laser pointer is a potentially valuable instrument for predicting peak plantar pressure in individuals with chronic ankle instability.
- Before implementing the tool in clinical practice, the agreement between instruments must be improved.
- In future studies, researchers should use a faster frame rate to record the laser output in order to determine whether the agreement between variables improves and then assess the regression equations for accuracy across a new dataset from a different group of affected participants.

Chronic ankle instability (CAI) is a common condition among physically active individuals and is associated with long-term consequences, including repetitive ankle sprains and an increased risk of ankle osteoarthritis.[1,2] An aberrant walking gait involving increased lateral midfoot and forefoot plantar pressure and a laterally deviated center of pressure is frequent among individuals with CAI[3] and theorized to contribute to the repetitive ankle sprains and the development of ankle osteoarthritis.[3,4] The increased lateral load and lateral center-of-pressure trajectory resemble the mechanism of injury and alter talar-joint loading and cartilage-contact strain, thereby perpetuating cyclic ankle sprains and degradation of cartilage.[3,4]

To mitigate the risk of repetitive ankle sprains and ankle osteoarthritis, gait impairments should be properly assessed and addressed during the rehabilitation process. Recently, a novel biofeedback tool via a crossline laser pointer was shown to reduce lateral plantar pressure and medially shift the center of pressure during walking in patients with CAI.[5] Although a tool to improve gait biomechanics has been identified, quantifying biomechanics is predominately limited to expensive 3-dimensional motion analysis or in-shoe plantar-pressure systems that are often not readily available in clinical settings. Therefore, clinicians are often unable to identify which patients may need gait retraining and whether gait retraining effectively improves patients' biomechanics. Considering that patients with CAI can alter their gait biomechanics in response to the novel crossline laser tool, perhaps the same tool can be used to predict biomechanics. Therefore, the purpose of this technical report was to determine the ability of a crossline laser to predict lateral midfoot and forefoot peak plantar pressure in individuals with CAI during treadmill walking.

## METHODS

### Participants

Twenty-five adults (9 men, 16 women; age = 20.8 ± 2.3 years, height = 170.4 ± 10.4 cm, mass = 78.9 ± 22.4 kg) with self-reported CAI (Identification of Functional Ankle Instability score = 21.1 ± 3.7, Foot and Ankle Ability Measure score = 81.3% ± 8.8%, and Foot and Ankle Ability Measure-Sport score = 67% ± 10.9%) participated. We used the inclusion and exclusion criteria established by the International Ankle Consortium for studies of participants with CAI.[1] If a participant reported a history of bilateral ankle sprains, the perceived worse ankle was

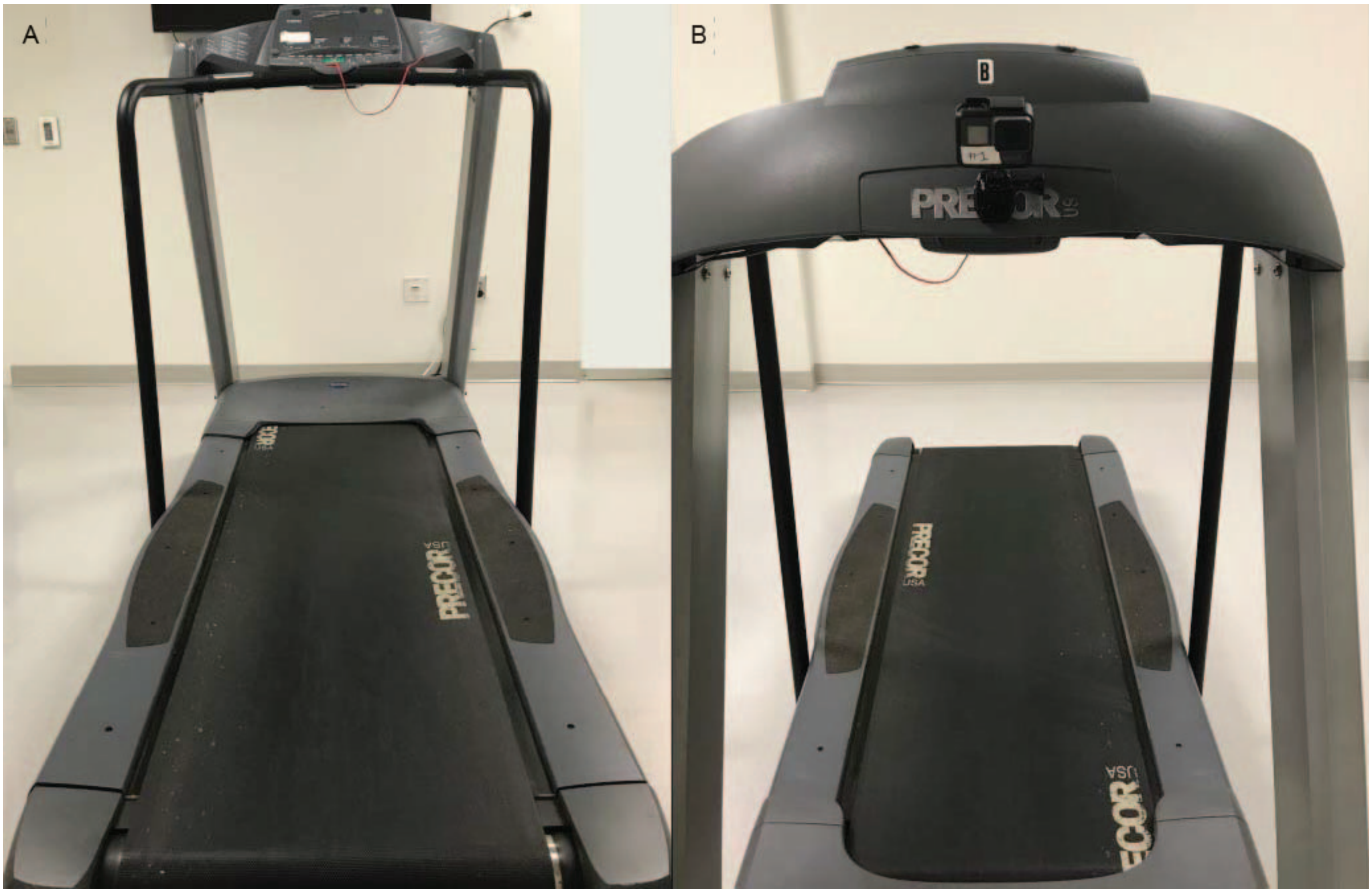


**Figure 1. A, Treadmill set-up and, B, with the mounted video camera.**

selected as the involved limb. All participants provided written informed consent, and this study was approved by our university's institutional review board.

## Instrumentation

All walking trials were completed on a treadmill (model C9561; Precor Inc, Woodinville, WA) placed perpendicular to and 1 m from the wall (Figure 1A). Plantar pressure was measured using an in-shoe plantar-pressure system (model Pedar-X; Novel Inc, St Paul, MN) consisting of an insole sampling at 100 Hz placed within a standardized athletic shoe (model GEL-Contend 4; ASICS Corp, Irvine, CA). Plantar-pressure data were recorded using the associated software (Database Pro; Novel Inc). The crossline laser consisted of a class IIIA diode battery pack (2 AA batteries) with an on-off switch and a mounting strap (Motion Guidance, Castle Rock, CO) used to attach the laser diode to the dorsum of the involved limb. A video camera (model Hero 5 Black; GoPro Inc, San Mateo, CA) recording at 60 frames per second was mounted to the front of the treadmill to capture the rotation of the laser projection on the wall (Figure 1B). Finally, a free virtual goniometer software program (version 0.8.15; Kinovea, Bordeaux, Nouvelle Aquitaine, France) was used to measure the laser's peak angle of rotation during the walking trials.

## Procedures

After the participant was fitted for the plantar-pressure insole and footwear and had the laser diode fixed to the dorsum of the involved limb, he or she stood on the treadmill with the feet positioned shoulder-width apart and in neutral position. The laser was powered on and positioned to project the crossline onto the wall directly in front of the treadmill such that (1) the horizontal laser line was visually parallel to the floor, (2) the vertical laser line was perpendicular to the floor, and (3) the axis of the 2 laser lines was aligned with the participant's foot (Figures 2A and B). Next, the recruit turned on the treadmill and increased the belt speed to reach a normal, comfortable walking pace while looking forward. Once the preferred pace (0.9 $\pm$ 0.2 m/s) was achieved, we recorded a 30-second trial, during which we measured plantar pressure via the in-shoe plantar-pressure system and simultaneously captured a video recording of the laser output on the wall.

## Data Processing

Peak plantar pressure (in kilopascals) in the lateral midfoot and lateral forefoot regions of the involved limb was identified across the middle 10 consecutive steps.[5] The average of those 10 values was calculated for both foot regions and used for analysis.[5]

Peak rotation (in degrees) of the laser crossline was measured by importing the 30-second video file into the virtual goniometer software. *Peak laser rotation* was operationally defined as the point at which the laser maximally rotated laterally (eg, toward the right if the involved limb was on the right) at any phase during the gait cycle. All participants displayed some level of laser rotation

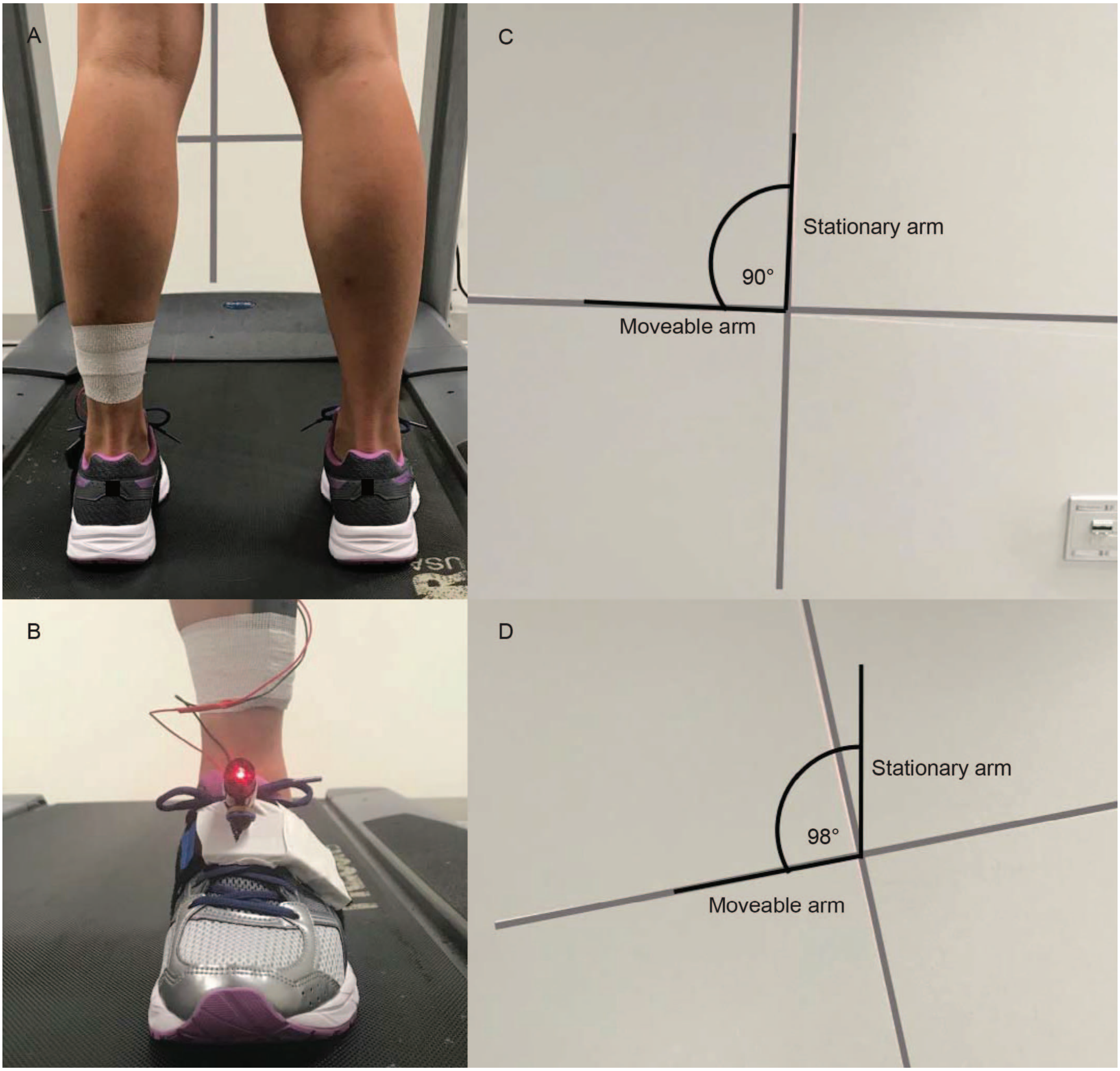


**Figure 2. The neutral starting position of the participant shown from the, A, posterior and, B, anterior directions. The video recording of the crossline laser for a participant in, C, neutral and, D, rotated positions with the virtual goniometer. The stationary arm of the virtual goniometer remained perpendicular to the floor, and the moveable arm was aligned with the horizontal laser line.**

away from the body's midline; therefore, all maximal laser angles were positive. After it was imported, the video file was advanced to allow us to analyze the 3 middle steps. Unlike the plantar-pressure data, we analyzed only 3 steps to mimic other common clinical practice assessment tools that average 3 trials. Including 10 steps would have threatened the clinical utility. For each step, the video was played frame by frame until peak rotation of the laser line was observed. At this time, the virtual goniometer axis was superimposed on the crossline laser axis. We positioned the stationary goniometer arm perpendicular to the floor and the moveable arm over the horizontal laser line. Based on the alignment of the virtual goniometer arms, a neutral (nonrotated) laser output would measure an angle of 90° (Figure 2C) and a rotated laser output would measure $>$90° (Figure 2D); therefore, the peak laser angle was the difference between the 2 values (peak laser angle = laser angle of rotation − 90°). After this process was completed across the 3 steps, an average of the peak laser angle was calculated and subjected to statistical analysis. If the laser captured on the still image of the video was blurred, the investigator (L.D.) placed the goniometer over the most defined portion of the laser lines. Using these instructions, we found that the interrater reliability between 2 investigators (L.D. and D.M.T.) from our laboratory was excellent (intraclass correlation coefficient [ICC] = 0.92).

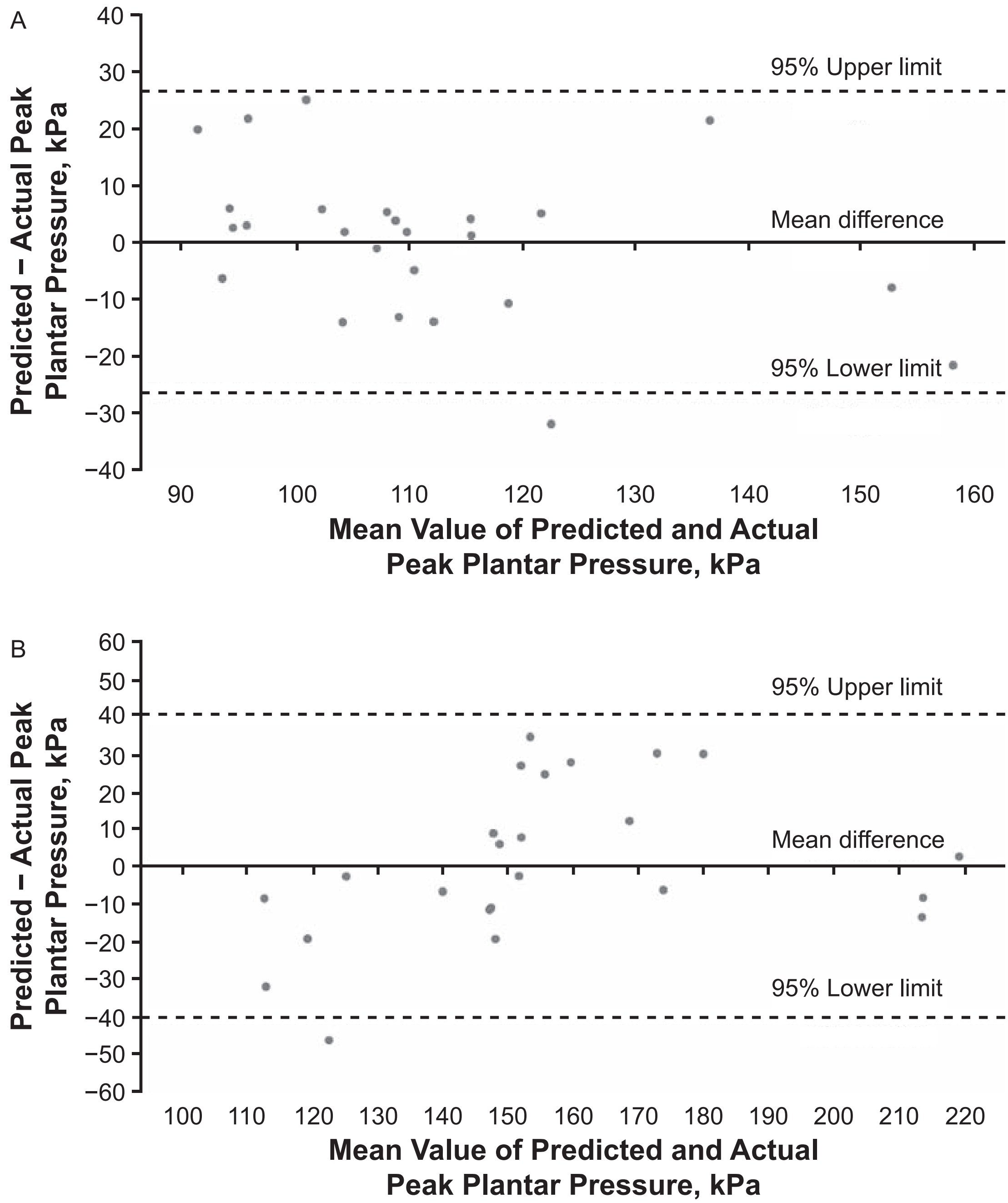


**Figure 3. Bland-Altman plots for the predicted and actual peak plantar-pressure values in the, A, lateral midfoot and, B, forefoot regions.**

### Statistical Analysis

Separate linear regression analyses using the enter method were conducted to predict peak lateral midfoot and lateral forefoot plantar-pressure values by using the peak laser angle. The peak laser angle was entered into the respective regression equation to calculate predicted peak plantar pressure in both regions of the foot. Calculating predicted peak plantar pressure allows for a better interpretation of the results by demonstrating how closely the laser angle can predict the actual peak pressure. To identify differences between the actual and predicted peak-pressure values for each region of the foot, separate paired *t* tests were performed. Two-way random-effects absolute-agreement ICCs were calculated to determine the reliability between the actual and predicted peak-pressure values for both the lateral midfoot and lateral forefoot regions.[6] The ICC values were interpreted as follows: *poor* (<0.50), *moderate* (0.50–0.749), *good* (0.75–0.899), and *excellent* ($\geq$0.90).[6] Finally, to further assess agreement between the actual and predicted peak-pressure values, separate Bland-Altman plots with 95% limits of agreement (LoAs) were created for both regions of the foot.[7] All data analysis was performed using SPSS (version 25; IBM Corp, Armonk, NY) with the $\alpha$ level set at $\leq$.05.

## RESULTS

The linear regression showed that peak laser angle explained a large amount of variance for both the lateral midfoot ($R^2 = 0.57$, $P < .001$; equation $= 82.2 + [4.1 \cdot x]$) and lateral forefoot ($R^2 = 0.64$, $P < .001$; equation $= 102.5 +$

[7.2·x]) peak plantar pressure. In addition, we observed no differences between the actual and predicted peak plantar pressures for the lateral midfoot (actual = 111.4 ± 20.7 kPa, predicted = 111.4 ± 15.7 kPa; $P > .99$) and lateral forefoot (actual = 154.2 ± 34.5 kPa, predicted = 154.1 ± 27.7 kPa; $P = .99$). Furthermore, moderate-to-good reliability existed between the actual peak-pressure value and the value predicted from the peak laser-angle value for both the lateral midfoot (ICC = 0.74, $P < .001$) and lateral forefoot (ICC = 0.79, $P < .001$). The mean differences between the actual and predicted values were 0.002 ± 13.6 kPa (95% LoA = –26.6 kPa, 26.6 kPa) for the lateral midfoot and 0.04 ± 20.8 kPa (95% LoA = –40.7 kPa, 40.8 kPa) for the lateral forefoot. Bland-Altman plots illustrate the agreement between the actual and predicted values for both the lateral midfoot (Figure 3A) and lateral forefoot (Figure 3B).

## DISCUSSION

The peak laser angle during treadmill walking predicted peak plantar pressure in the lateral midfoot and forefoot regions in participants with CAI. The predicted plantar-pressure values derived from the peak laser angle had moderate-to-good reliability versus the actual plantar-pressure values.

We are not the first to examine a clinical assessment for detecting altered biomechanics during gait. Donovan et al[8] found that a step-down task could be used to identify participants with increased inversion during walking, stepping down, and jump landing. Although the step-down task can be used to identify individuals with excessive frontal-plane motion, the scoring is dichotomous (*yes*/*no*), so the task is best suited as a screening tool. However, the laser angle provides a numeric value, which has the potential to detect changes in biomechanics as treatment progresses. In addition to the step-down task, Harradine et al,[9] in a systematic review, determined that real-time clinical gait assessment using noncomputerized and non-instrumented techniques did not have clinically acceptable reliability (ICCs <0.50) for detecting altered biomechanics. The authors indicated that the poor reliability may have stemmed from the lack of standard protocols across studies, unlike our investigation, in which we provided standard instructions for all components of the assessment.

Although the crossline laser tool predicted lateral plantar pressure, the relatively wide 95% LoAs depicted in the Bland-Altman plots captured the 43% and 36% of shared variance not explained by the regression model. Given this observation, the crossline laser tool has the potential to be a valid clinical instrument for estimating peak plantar pressure in patients with CAI, yet in the current form, the tool should not be implemented into clinical practice. The wide 95% LoAs and unexplained variance may reflect the limitations of our study. First, we restricted the video camera speed to 60 frames per second to best align with inexpensive video cameras. Considering that most smartphones can capture videos at a faster rate, we should have increased our frame rate, which would have provided more data points and increased our ability to measure the true peak laser angle. Furthermore, we only measured laser rotation, whereas other deviations of the laser, such as the distance from the midline within the transverse plane (abduction and adduction) or distance from the floor within the sagittal plane (dorsiflexion and plantar flexion),[10] could also be related to the lateral peak pressure of the foot. Finally, we did not evaluate structural characteristics, such as foot type and rearfoot alignment. Including these characteristics may strengthen the prediction model.

## CONCLUSIONS

A crossline laser pointer has the potential to be a valuable instrument for predicting peak plantar pressure in individuals with CAI. However, before the tool can be implemented in clinical practice, the agreement between instruments must be improved. The procedures from our study should be replicated using a faster frame rate for recording the laser output to determine whether the agreement between variables improves. The regression equations should then be assessed for accuracy across a new dataset from participants not involved in the original investigation.

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