A low-cost telemedicine system (SISTINE) to analyze foot pressure dynamics in chronic venous disease: insights from a figure of 8 test

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Summary

This study evaluates curvilinear gait behavior in patients having chronic venous diseases (CVD), by investigating foot pressure asymmetries obtained from a low-cost telemonitoring system embedding smart socks (SISTINE).

Introduction

Chronic venous diseases (CVD) pose significant healthcare challenges, requiring monitoring to prevent complications. The SISTINE system, a telemedicine framework using sensorized sock technology, has shown promise in analyzing CVD patients' pathological gait [1]. During daily activities, 20-50% of steps involve rotations, demanding complex neuromuscular coordination [2]. This complexity underscores the need for advanced diagnostic approaches. This study extends the system's capabilities by leveraging embedded force and inertial sensors, to capture complex locomotor dynamics through a figure of 8 (Fo8) test. The analysis of variations in foot pressure and movement aims to reveal potential compensatory mechanisms in patients with different CVD severities, to facilitate early detection and longitudinal monitoring of vascular disease progression in CVD patients. The study specifically aims to address two research questions:
1. Can the SISTINE system discriminate between CVD severity levels by examining phase-dependent foot behavior?
2. Which specific test elements - including test phases, pressure parameters, and foot characteristics - can effectively differentiate phlebopathy severities from healthy controls?

Methods

A total of 21 patients (15F; 57±18y; 71±12kg; 1.69±0.06m; clustered by severity using Clinical Etiological Anatomical Pathological scale: low severity LS = C1 & C2: 9+2 patients, high severity HS = C3 & C4: 7+2 patients) and 11 healthy controls (4F; 33±16y; 68±9kg; 1.7±0.02m) each voluntarily participated to perform 3+3 Fo8 tests in clockwise and counter-clockwise direction, wearing 2 sensorized socks instrumented with force-sensitive pressure sensors under Vth and Ist metatarsal heads (@30 sample/s) and, on the ankles and pelvis, 3 inertial sensors (IMU, @35 sample/s) [1]. An index of medio-lateral intermetatarsal pressure gradient ($F_{V\text{-}I}$), normalized to the mean pressure value, was extracted for clockwise tests from two pressure sensors under the Vth and Ist metatarsal heads, using Matlab (v23). Four Fo8 phases were segmented using the pelvis IMU, while strides were detected from ankle IMUs. Average $F_{V\text{-}I}$ values were computed for each trial and phase for the inner and outer foot. Data normality was Kolmogorv-Smirnov tested. Differences in time-of-test completion were investigated amongst groups (Mann Whitney U test). Mid-lateral support ($F_{V\text{-}I}$) differences were investigated between inner and outer foot, for each phase and patient class separately (two-sided t-test for paired samples) and between severities, for each foot and phase separately (repeated measure ANOVA with factors between), to identify Fo8 elements responsive to disease progression.

Results and Discussion

The phlebopathic group was slightly slower than controls in test completion (14s median [3 IQR] vs 13s median [1 IQR]), in line with former results [1]. Low-severity patients presented a significant difference between inner and outer foot in phases 1 and 3, with a medial-outer and lateral-inner behavior opposite to healthy population [2]. In the starting and ending phases (ph1, ph4) controls and patients of different severity could be differentiated by $F_{V\text{-}I}$ values of the outer foot, while the inner foot contributed to the differentiation of controls and high-severity patients in ph1 and ph3. Phase-dependent differences in foot pressure suggest a compensatory mechanism, potentially indicating early adaptive changes in gait patterns associated with CVD.

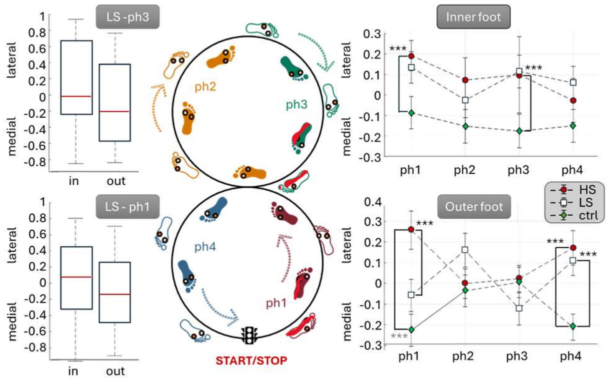

Figure 1: Significative results for inner-outer foot comparison across phases and phases comparisons across severity based on $F_{V\text{-}I}$

Conclusions

The analyzed low-cost technology opens to the possibility to monitor functional feet behavior in patients with CVD, potentially informative of the disease progression.

References

[1] D'Angelantonio et al. (2022). IEEE MetroInd4.0, 137-142.
[2] Turcato A et al. (2015). JNER, 12: 1-12.