Measurement of foot plantar skin strain using Digital Image Correlation methods for diabetic foot assessment

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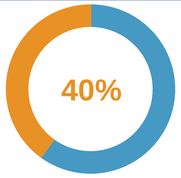
Background

Diabetic foot complications are a leading cause of non-traumatic lower limb amputations, with around 7000 recorded in England annually[1].

Current diabetic foot ulcer (DFU) risk is pressure derived. Shear is known to contribute to DFU risk, but is not quantified at present in risk assessment or treatment pathways.

Spent by NHS England goes to the treatment of the diabetic foot[2].



5 year mortality rate following diabetic ulceration[3].

5 year mortality rate following diabetic ulceration with amputation[4,5].

Aims and Objectives

Figure 1: Schematic of DFU risk assessment

- Analyse plantar foot surface strain during gait to work towards risk assessing the diabetic foot for DFU potential (Fig. 1)
- Develop shod and unshod methods of strain capture using digital image correlation
- Assess feasibility of these methods to track surface strain during stance phase

Method

Digital Image Correlation (DIC)

DIC tracks an applied stochastic speckle pattern to provide strain data. Applied to the plantar aspect, it allows for skin strain monitoring during stance.

Two methods were chosen - direct speckle application to the foot for unshod assessment [**P**lantar **L**oaded **O**bservation **D**IC - **PLOD**] and speckle application to a plastically deformable insole used whilst shod [**ST**rain **A**nalysis and **M**apping of the **P**lantar **S**urface - **STAMPS**] (Fig. 2).

A computer generated speckle pattern [Correlated Solutions Speckle Generator v1.0.5] was optimised for each method for reproducibility of pattern to ensure consistent tracking capabilities.

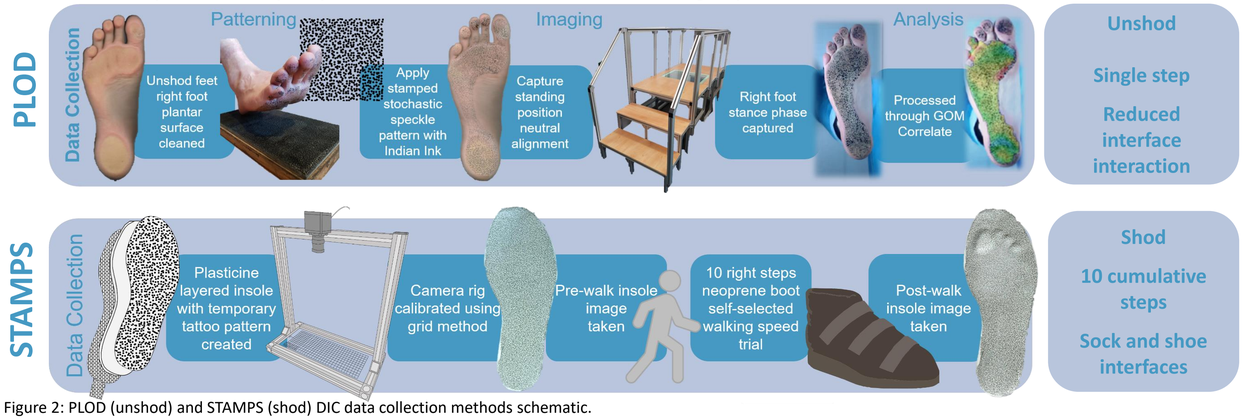


Figure 2: PLOD (unshod) and STAMPS (shod) DIC data collection methods schematic.

Feasibility Studies

Small cohort feasibility studies were conducted for both methods with a non-diabetic population, see Table 1. Studies were conducted at a normal self-selected walking pace, such as seen during activities of daily living.

PLOD		STAMPS	
3 Male	3 Female	2 Male	1 Female
61.6 – 96.9 kg		67.5 – 75.0 kg	
8-12 UK Male	5.5-7 UK Female	8-10 UK Male	8 UK Female

Table 1: Participant characteristics.

Data Analysis

A shared protocol for analysis was developed (Fig. 3). Strain 'heatmap' visualisations were generated [GOM Correlate 2020 v2.0.1], converted to quiver plots for analysis [MATLAB R2021a] with anatomical masking applied (as *per* Pedar™ the plantar pressure capture 'gold standard'), and segmented outputs analysed.

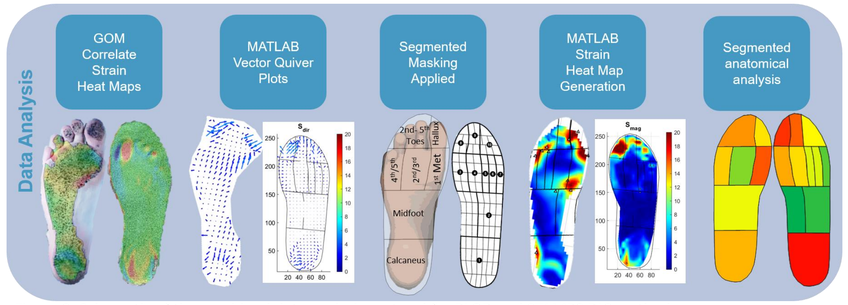


Figure 3: Schematic of the combined data analysis protocol for PLOD and STAMPS DIC methods.

Results and Discussion

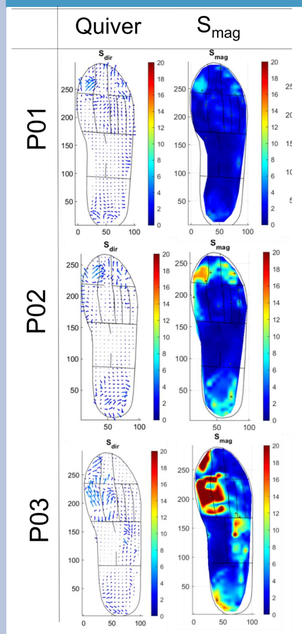


Figure 4: STAMPS cumulative steps quiver and magnitude strain outputs on a relative colour scale.

- PLOD and STAMPS methods showed participants displaying a varied strain pattern, both in terms of the strain values analysed, and anatomical location prevalence during gait (Figs. 4 and 5).
- Varied strain values were determined, derived from the nature of their measurement, with one recording direct surface strain measures of skin during the interaction, and one a measure of plasticine deformation from cumulative steps.
- Both methods present positives and negatives, but both are low-cost, quick to implement and provide opportunity for use in a clinical environment.
- Unshod provides phasic analysis of gait and a wealth of information for researchers.
- Tracking segments unshod is challenging due to relative movement of the applied mask and would be improved by being able to adapt the mask per output frame *as per* Pedar™.
- Insoles show good potential due to singular output providing ease of analysis for clinicians and can be pre-made to reduce error.

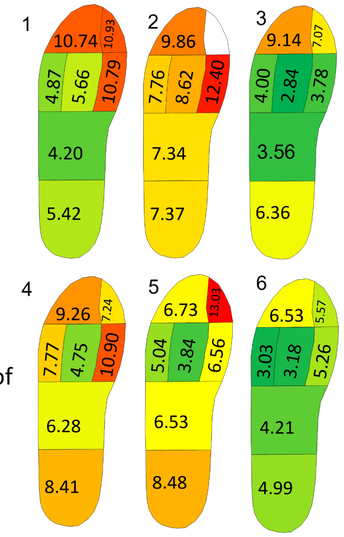


Figure 5: PLOD six participant study averaged mean strain per region across all frames of stance with relative colour scale (red = high strain, green = low strain).

Conclusions and Future Work

- Studies assessing surface strain response over varied controlled speeds and using existing DFU pressure distribution interventions.
- Tribological pin-on-plate study using a developed tissue holder to recreate plantar heel interaction under representative pressures and surface strains to assess deep tissue response and topographical changes regarding DFU risk.

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