Seasonality in Foot Inflammation Detected by a Telemedicine Once-Daily Temperature Monitoring Mat

Brian J. Petersen, MBA, MS[1]; Katherine A. Wood, BS[1]; Min Zhou, MSE[1]; Jonathan D. Bloom, MD[1]
[1] Podimetrics, Inc.

Purpose

Seasonal variation in the incidence of diabetic foot wounds is an understudied factor. The existing literature on the topic is outdated, scarce, and limited to retrospective studies of amputations rates in temperate northern hemisphere climates [1,2]. Leung et al suggested that patients should be scheduled for clinical appointments in late winter and early spring in order to proactively remind patients to perform daily foot checks before a season of increased activity. Researchers also suggested that in future studies, average temperature should be analyzed daily in order to observe the acute effects of temperature on the progression of diabetic foot ulcers (DFU). Armstrong et al concluded that cold weather can act as a preventative factor through limiting patient activity, and thus injury. Though these conclusions are of value, they have a narrow scope, applying only to a specific geographic area, and need further validation.

We aimed to characterize the pattern of foot inflammation in an arid climate to provide insight into the cause of previously observed seasonality and to inform future directions in clinical research. Rather than using amputation and hospitalization rates as main outcomes, we investigated daily foot temperature. Foot temperature is an indicator for inflammation and can be used to predict foot complications, such as DFU [3-5].

Methods

We analyzed three years of daily foot temperature data generated from a telemedicine remote temperature monitoring mat, pictured in Image 1 (Podimetrics RTM System; Podimetrics Inc., Somerville MA). Patients used the Podimetrics mat once-daily indoors, and the ambient temperature in patients' homes during the period studied was 75.3 +/- 3.3 degF. It is a Class 1 FDA cleared device and is calibrated to accurately assess dermal foot temperatures over a range of 59 degF to 104 degF. Our cohort consisted of 542 high-risk patients living in the American southwest (Image 2). More than 400,000 foot temperature readings, or "scans", were collected from these patients during this period. We assessed the percentage of scans on any given day that showed signs of inflammation, which we defined as a temperature difference exceeding 4 degF between a patient's left and right feet.

Image 1: Podimetrics, Inc RTM mat

We qualitatively evaluated the trends in inflammation over the three-year period. Finally, we evaluated historical daily weather data in the geography of our cohort using the National Oceanic and Atmospheric Administration (NOAA) records and overlaid the number of inflammatory foot scans with the corresponding weather data for that day.

Image 2: Locations of American southwest patients

In Phoenix, Arizona, USA during the past 20 years the outdoor average high temperature June through September (Summer months) was 104.6 degF, whereas December through March (Winter months) it was 71.2 degF (Table 1) [6]. Thus, the Winter months in this geographic location tend to have the most comfortable ambient temperature when patients may likely be more active outside of their homes.

Summer Temperatures	Winter Temperatures
105.4 degF	66.6 degF
106.9 degF	68.2 degF
105.1 degF	71.1 degF
100.9 degF	79.1 degF

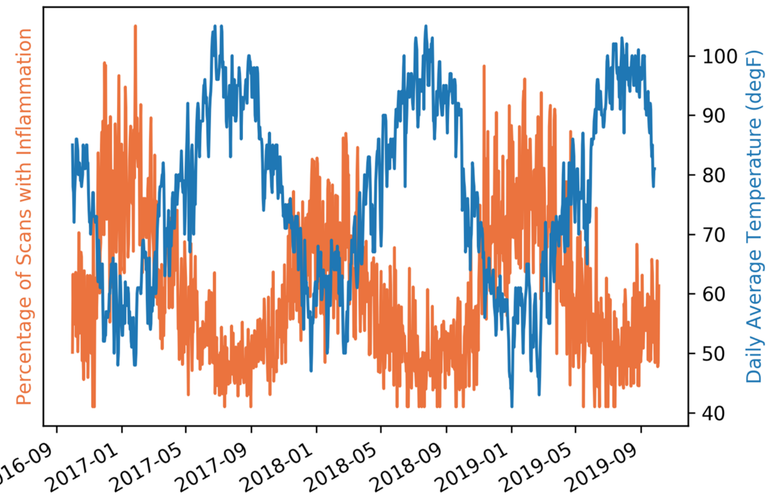
Table 1: Average maximum temperature in Phoenix, AZ during Jun-Sept and Dec-Mar

Aims: We hypothesize that patients are more active during these Winter months, going for more walks and outings compared to other seasons where environmental factors cause discomfort and are avoided. This presumed increase in activity results in more frequently detected inflammation. Furthermore, we predict a higher percentage of inflammation can be seen occurring around holidays specific to the US, such as Thanksgiving in November, religious holidays in December and, or acute injuries around Independence Day.

Results

Our data demonstrate that over three years of observation, higher foot inflammation occurs in months when the weather is more conducive to outdoor activity. In our American southwest cohort, the average inflammation (characterized as the percentage of patients who exceed a 4 degF temperature difference between the left and right feet) was greatest during the Winter months and lowest during the Summer months, shown in orange in Figure 1. By comparing inflammation data to environmental temperatures in that area, shown in blue in Figure 1, we gain insight into this seasonal pattern. Figure 1 also demonstrates increased inflammation around the American holidays in November and December. Figure 2 shows the decrease in inflammation as environmental temperatures increase to uncomfortable heat, such as 90 degF to over 100 degF.

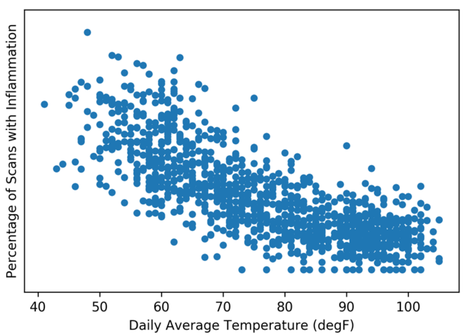
Figure 1: Percentage of scans with inflammation on each date plotted against daily average temperature during those dates



Limited current literature studied injury outcomes of two isolated populations in northern climates, concluding that an increase in activity during warmer weather months correlates to an increase in foot wound occurrence [1,2]. Our analysis is consistent with these findings in the sense that all three studies report poorer outcomes (or more inflammation, presumably associated with poorer outcomes) during comfortable environmental conditions, such as favorable weather for activity.

One benefit of this study is that markers of ongoing inflammation are reported instead of an outcome. This discovery leads to speculation that the wounds observed in the two prior publications, Armstrong 1997 and Leung 2007, were likely the result of repetitive microtrauma through increased or variable activity, as opposed to acute injury.

Figure 2: Percentage of scans showing inflammation gathered during different average environmental temperatures



Conclusions

The seasonal increase of a patient's daily foot temperature asymmetry from July to January can be seen in Figure 3, as well as the spikes in inflammation during the American holidays in late November and December. The thermogram which brought attention to an ulcer on this patient's hallux is seen in Figure 4. This case study comes from Killeen et al [10], where a subset of our cohort in Arizona was investigated. The case series identified the limitations of daily foot checks due to vision impairment and the importance of once-daily remote temperature monitoring for these patients [10]. This 71-year-old male patient with visual impairment was contacted via phone due to three consecutive scans which showed inflammation. The patient reported no visual changes to his foot and the following day he had his caregiver complete a visual foot exam, upon which a superficial ulcer on the right hallux was found. The patient was seen in clinic that day for debridement and wound care and the wound healed within 19 days due to the early discovery and treatment.

Figure 3: Arizona patient's daily asymmetry scans

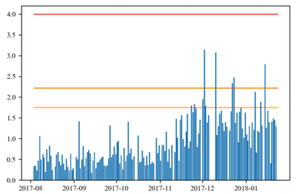
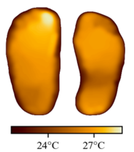


Figure 4: Arizona patient's foot temperature scan, showing inflammation to the hallux



Once-daily foot temperature monitoring is an evidence based practice for detecting and monitoring foot inflammation. Supported by three randomized control trials [3-5] and recommended by three clinical practice guidelines [7-9], once-daily thermometry allows for remote monitoring of ongoing foot inflammation. In our study, using a remote temperature monitoring mat to detect foot inflammation and hots spots, innovative data were collected and aligned with seasonal variations. Our approach differs from the existing literature, which utilized retrospective ulcer and hospitalization outcomes data in primarily northern climates. Our data show ongoing inflammation in an arid climate, confirming the conclusions made by these previous studies as well as holding high clinical implications for affecting the approaches toward diabetic foot complication risks and injury prevention per the season.

Changes in climate can alter a patient's lifestyle, which in turn can cause activity driven injury to the diabetic foot. Thus, seasonality may need to be accounted for when assessing the risk of foot health. For example, frequent clinic visits can be scheduled preceding the months with climate conducive to activity in order to check for proper fitting footwear and encourage regimented preventative habits regarding foot health. Foot complications such as callus that are found in clinic may be taken more seriously when considered in the context of time of year. Additionally, the emergence of new telemedicine monitoring will create an increase in notifications based on seasonal variations. Inflammation which is consistently driven by preferable weather is likely due to increased activity; though, quantitative activity monitoring paired with once-daily foot temperature scans would be a valuable contributor to future research. Increased activity may also occur during American holidays, as patients travel to see family or celebrate the holidays. Ultimately, these seasonal patterns support the need for once-daily inflammation monitoring via telemedicine during these high-risk times of year.

References and Acknowledgements

[1] Leung, H. B., Ho, Y. C., Wong, W. C. & Guerin, J. Seasonal variations in non-traumatic major lower limb amputation in Hong Kong Chinese diabetic patients. Hong Kong Med. J. 2007;13, 379–381.
[2] Armstrong, D. G., Lavery, L. A., van Houtum, W. H. & Harkless, L. B. Seasonal variations in lower extremity amputation. J. Foot Ankle Surg. 1997;36, 146–150.
[3] Lavery LA, Higgins KR, Lanctot DR, Constantinides GP, Zamorano RG, Armstrong DG, et al. Home monitoring of foot skin temperatures to prevent ulceration. Diabetes Care. 2004 Nov;27(11):2642–7.
[4] Lavery LA, Higgins KR, Lanctot DR, Constantinides GP, Zamorano RG, Athanasiou KA, et al. Preventing diabetic foot ulcer recurrence in high-risk patients: use of temperature monitoring as a self-assessment tool. Diabetes Care. 2007 Jan;30(1):14–20.
[5] Armstrong DG, Holtz-Neiderer K, Wendel C, Mohler MJ, Kimbriel HR, Lavery LA. Skin temperature monitoring reduces the risk for diabetic foot ulceration in high-risk patients. Am J Med. 2007 Dec;120(12):1042–6.
[6] National Weather Service, National Oceanic and Atmospheric Administration
[7] Lavery LA, Davis KE, Berriman SJ, Braun L, Nichols A, Kim PJ, et al. WHS guidelines update: Diabetic foot ulcer treatment guidelines. Wound Repair Regen. 2016 Jan;24(1):112–26.
[8] Bus SA, van Netten JJ, Lavery LA, Monteiro-Soares M, Rasmussen A, Jubiz Y, et al. IWGDF guidance on the prevention of foot ulcers in at-risk patients with diabetes. Diabetes Metab Res Rev. 2016 Jan;32 Suppl 1:16–24.
[9] Frykberg RG, Armstrong DG, Giurini J, Edwards A, Kravette M, Kravitz S, et al. Diabetic foot disorders. A clinical practice guideline. For the American College of Foot and Ankle Surgeons and the American College of Foot and Ankle Orthopedics and Medicine. J Foot Ankle Surg. 2000;Suppl:1–60.
[10] Killeen, A. L., Brock, K. M., Dancho, J. F. & Walters, J. L. Remote Temperature Monitoring in Patients With Visual Impairment Due to Diabetes Mellitus: A Proposed Improvement to Current Standard of Care for Prevention of Diabetic Foot Ulcers. J. Diabetes Sci. Technol. 2019.

Acknowledgements: Priti Lakhani; Nicole Neff