The American Journal of Medicine (2007) 120, 1042-1046

ELSEVIER

THE AMERICAN JOURNAL *of* MEDICINE®

CLINICAL RESEARCH STUDY

Skin Temperature Monitoring Reduces the Risk for Diabetic Foot Ulceration in High-risk Patients

David G. Armstrong, DPM, PhD,[a] Katherine Holtz-Neiderer, DPM,[b] Christopher Wendel, MS,[b] M. Jane Mohler, PhD,[b,c] Heather R. Kimbriel,[b] Lawrence A. Lavery, DPM, MPH[d]

[a]Scholl's Center for Lower Extremity Ambulatory Research (CLEAR), Rosalind Franklin University of Medicine and Science, North Chicago, Ill; [b]Southern Arizona Veterans Affairs Medical Center, Tucson; [c]Department of Epidemiology and Biostatistics, College of Public Health, University of Arizona, Tucson; [d]Department of Surgery, Texas A&M College of Medicine at Scott & White Memorial Hospital, Temple.

ABSTRACT

PURPOSE: To evaluate the effectiveness of home temperature monitoring to reduce the incidence of foot ulcers in high-risk patients with diabetes.

METHODS: In this physician-blinded, 18-month randomized controlled trial, 225 subjects with diabetes at high risk for ulceration were assigned to standard therapy (Standard Therapy Group) or dermal thermometry (Dermal Thermometry Group) groups. Both groups received therapeutic footwear, diabetic foot education, regular foot care, and performed a structured foot inspection daily. Dermal Thermometry Group subjects used an infrared skin thermometer to measure temperatures on 6 foot sites twice daily. Temperature differences >4°F between left and right corresponding sites triggered patients to contact the study nurse and reduce activity until temperatures normalized.

RESULTS: A total of 8.4% (n = 19) subjects ulcerated over the study period. Subjects were one third as likely to ulcerate in the Dermal Thermometry Group compared with the Standard Therapy Group (12.2% vs 4.7%, odds ratio 3.0, 95% confidence interval, 1.0 to 8.5, $P = .038$). Proportional hazards regression analysis suggested that thermometry intervention was associated with a significantly longer time to ulceration ($P = .04$), adjusted for elevated foot ulcer classification (International Working Group Risk Factor 3), age, and minority status. Patients that ulcerated had a temperature difference that was 4.8 times greater at the site of ulceration in the week before ulceration than did a random 7 consecutive-day sample of 50 other subjects that did not ulcerate (3.50 ± 1.0 vs 0.74 ± 0.05, $P = .001$).

CONCLUSIONS: High temperature gradients between feet may predict the onset of neuropathic ulceration and self-monitoring may reduce the risk of ulceration. © 2007 Elsevier Inc. All rights reserved.

KEYWORDS: Diabetes; Foot; Thermometry; Ulcer; Wound

In diabetes, as in other chronic diseases, self-care is an essential element of disease management and prevention. Most diabetic lower extremity complications involve sensory neuropathy; patients do not recognize that their feet are being injured until a wound develops.[1,2] Wounds are invariably preceded by inflammation.[3-6] Therefore, it would stand to reason that identifying preulcerative inflammation might predict foot ulceration. Temperature assessment seems to be a likely surrogate to measure inflammation.

Studies of dermal thermometry have suggested that variations in temperature >4°F (2.2°C) could be helpful in skin

This study was supported by VA HSR&D Merit Award 20-059. The views expressed in this article are those of the authors and do not necessarily reflect the position or policy of the Department of Veterans Affairs. All authors had full access to all of the data in the study and all take responsibility for the integrity of the data and the accuracy of the data analysis. This protocol has been registered with Clintrials.gov (NCT00105755).

Requests for reprints should be addressed to David G. Armstrong, CLEAR, Rosalind Franklin University of Medicine and Science, 3333 Green Bay Road, North Chicago, IL 60064.

E-mail address: armstrong@usa.net

0002-9343/$ -see front matter © 2007 Elsevier Inc. All rights reserved.
doi:10.1016/j.amjmed.2007.06.028

surveillance.[7-12] More recently, 2 randomized trials appeared to confirm that dispensing simple "personal thermometers" to neuropathic patients might serve as useful prevention tools.[13,14] The second of these studies appeared to suggest that this preventative effect is independent of simply increasing visual surveillance of the foot.[14] Previous studies using temperature as a self-assessment and monitoring tool appear promising; however, they were either conducted over rather short time frames (6 months)[13] or they studied very specific patient populations.[14] Therefore, the purpose of this study was to evaluate the effectiveness of an infrared home temperature monitoring instrument to reduce the incidence of foot complications in patients at high risk for diabetic foot ulceration.

CLINICAL SIGNIFICANCE

- Diabetic foot wounds are common, complex and costly. They are frequently caused by repetitive stress to the foot, causing inflammation and skin breakdown.
- The results of this study suggest that a simple device used by the patient can identify potentially damaging inflammation and allow the patient to modify activity before ulceration.
- In this manner, patients may modify their activity by checking their skin temperatures much as they dose their insulin by checking their glucose.

METHODS

In this physician-blinded, 18-month randomized controlled trial, 225 United States veterans with diabetes at high risk for ulceration (neuropathy and deformity or previous history of ulceration) were assigned to standard therapy or dermal thermometry groups. Both groups received therapeutic footwear, diabetic foot education, and regular foot care. All subjects were instructed to perform a structured foot inspection daily and record their findings in a logbook. If Standard Therapy Group subjects identified any foot abnormalities, they were to contact the study coordinator immediately. Dermal Thermometry Group subjects used an infrared skin thermometer (TempTouch, Xilas Medical, San Antonio, Tex) to measure temperatures on 6 sites on the foot twice a day. Temperature differences >4°F (>2.2°C) between left and right corresponding sites triggered patients to contact the study coordinator and reduce activity until their temperatures normalized. As a practical measure, the opposite extremity was used as a control because both feet are exposed to the same repetitive stresses during walking and therefore represented a built-in comparison source. Because the disease processes of neuropathic ulceration involves multiple factors that affect lower extremity perfusion and temperature regulation, we felt that it would be difficult to identify an absolute skin temperature level that could be considered normal or one that could be used as a universal reference.

Participants

All patients with type 2 diabetes receiving foot care at the Southern Arizona VA Health Care System, aged 18-80 years, who fit category 2 or 3 of the International Diabetic Foot Risk Classification System,[15] were candidates for inclusion in the study. Risk Group 3 included patients with a history of either a foot ulcer or of a partial foot amputation. Risk Group 2 included patients with neuropathy and structural foot deformity or limited joint mobility.[15] There were approximately 4800 patients with type 2 diabetes receiving care at the Southern Arizona VA Health Care System. Of these, 1942 were identified as high risk for development of foot ulcers (neuropathy and deformity), and at least 300 had been treated for a foot ulcer or a partial foot amputation in 1999.

Candidates were not admitted to the study if any of the following criteria were present: active open ulcers, amputation sites, or foot infections; active Charcot arthropathy; severe peripheral vascular disease, as evidenced by nonpalpable foot pulses or an ankle-brachial index <0.8 on either extremity; dementia or impaired cognitive function; active drug abuse or history of drug or alcohol abuse within 1 year of the study; sight impaired (ie, unable to read the large (2.5 cm) digital display characters on the dermal thermometer); or unable to walk without the assistance of a wheelchair or crutches.

Interventions

The TempTouch thermometer (Xilas Medical) is equipped with a "touch sensor" that detects tip contact with skin, which allows the user to just simply touch the end of the probe to the skin to take a measurement. To operate the device, the user would place the tip of the device on the skin, which would then automatically trigger a temperature measurement and display it on an LCD (liquid crystal display) screen. The thermometer utilized incorporates a gooseneck design, which allows the user to reach any point on the bottom or sides of the foot.

Objectives

We evaluated the effectiveness of self-administered in-home infrared temperature probe monitoring to reduce the incidence of diabetic foot ulcers in high-risk veterans with type 2 diabetes. Secondary objectives were to measure the effect of the intervention on type of ulcer, health-related quality of life, self-efficacy, satisfaction with care, and modulation of activity. We tested the hypothesis that self-monitored temperatures would: reduce the rate of foot ulcers and positively influence health-related quality of life, self-efficacy and satisfaction with care, and modulation of activity. This article addresses the primary outcome of foot ulcer

incidence; subsequent articles will present secondary outcomes.

Outcomes

Primary measures were collected at baseline and every 3 months thereafter (months 0, 3, 6, 9, 12, and 15), with a final visit at month 18. The primary endpoint (and focus of this article) with respect to effectiveness in reducing the incidence of diabetic foot ulcers, was the proportion of patients in each group developing a foot ulcer of any type. An ulceration was defined as the full thickness loss of epidermis and dermis or involvement of deeper structures. Additional outcomes, to be reported in future articles, included health-related quality of life, self-efficacy, and satisfaction with care, activity titration, and program costs.

Sample Size

Up to 70% of patients with a history of foot ulcers experience recurrence within 1 year. We believed that the incidence of ulceration would be 70% in the usual care group and from 30% to 45% in the thermometry self-monitoring group based on the work of Uccioli and coworkers and Walker and coworkers.[16,17] For a sample size of 70 per group, a log-rank test (2-sided $\alpha = .05$) for equality of survival curves would have 99% power to detect a 40% difference, 93% power to detect a 30% difference, and 83% power to detect a 25% difference. Interim analyses were not performed. There was no evidence that enhanced monitoring would result in worsened outcomes, thus, stopping rules were not established.

Randomization: Allocation Concealment and Implementation

Our study biostatistician generated a randomized assignment list. Once potential subjects were screened and consented, the coordinator used this list to sequentially assign patients to the intervention or usual care group; no exceptions were made.

Blinding (Masking)

The attending physician was blinded to the use of the TempTouch thermometer throughout the entire course of the study. When evaluating study patients, the subjects were instructed not to discuss their treatment group assignment. The treating physician did not use temperature assessment as part of their diagnostic examination.

Statistical Methods

The Cox proportional hazard model was used to evaluate the dependent outcome differences between groups (time to incident foot ulcers), producing a relative risk controlling for covariates such as history of amputation, diabetes complications index, and glucose control (HbA1c). Selection of covariates was performed using stepwise modeling procedures, supplemented by evidence from pilot studies and the literature. We used a chi-squared test with Yates correction to evaluate potential univariate dichotomous associations. We used a Mann-Whitney *U* test to evaluate skin temperature differences (compared with the contralateral foot) at the site of ulceration in the week preceding the reulceration and compared that with a 1-week sample of 50 randomly sampled subjects that did not ulcerate. For all evaluations, we used an alpha of 5%.

Table Descriptive Characteristics

	Thermometry	Control	*P*-value
Age (years)	68.2 (9.6)	69.7 (10.4)	.26
Sex %	98.2	94.7	.16
Duration diabetes	13.6 (11.6)	12.6 (9.1)	.47
Hemoglobin A1c	8.1 (1.9)	7.4 (1.4)	.29
Non-Hispanic white	72.97	71.05	
African American	4.50	8.77	
Hispanic	20.72	17.54	
Asian	0.00	1.75	
Native American	1.80	0.88	.383
Retinopathy (%)	23.4	34.2	.074
Diabetic foot risk classification			
Risk 2	84.7%	82.5%	
Risk 3	15.3%	17.5%	
VPT (volts)	42.6 (21.0)	50.1 (85.4)	.39
Neuropathy with loss of protective sensation	100%	100%	

All values are mean (SD) unless stated otherwise.

RESULTS

Descriptive characteristics of this population are illustrated in the Table. There was not a significant difference in characteristics based on treatment group assignment ($P > .05$ for all).

A total of 8.4% (n = 19) of all subjects ulcerated over the 18-month follow-up period. In the Standard Therapy Group, 12.2% (n = 14) of patients ulcerated compared with 4.7% (n = 5) of those in the Dermal Thermometry Group (OR 3.0, CI, 1.0 to 8.5, $P = .038$).

Proportional hazards regression analysis suggested that Standard Therapy Treatment, elevated foot ulcer classification (International Working Group Risk Factor 3), age, and minority status were significantly associated with a shorter time to ulceration. Standard Therapy Treatment (adjusted hazard ratio [HR] 2.9; 95% CI, 1.03 to 8.4; $P = .04$), Risk Group 3 status (adjusted HR 16.5; 95% CI, 4.5 to 31.7; $P = .001$), age (adjusted HR 0.93; 95% CI, 0.89 to 0.98; $P = .02$), and minority status (adjusted HR 0.40; 95% CI, 0.12 to 1.3; $P = .1$) were associated with ulceration. The cumulative survival curve comparing Dermal Thermometry Group treatment with standard therapy is illustrated in Figure 1.

Patients that ulcerated had a temperature difference (between the affected foot and the same site contralaterally) that was 4.8 times greater in the region of ulceration in the

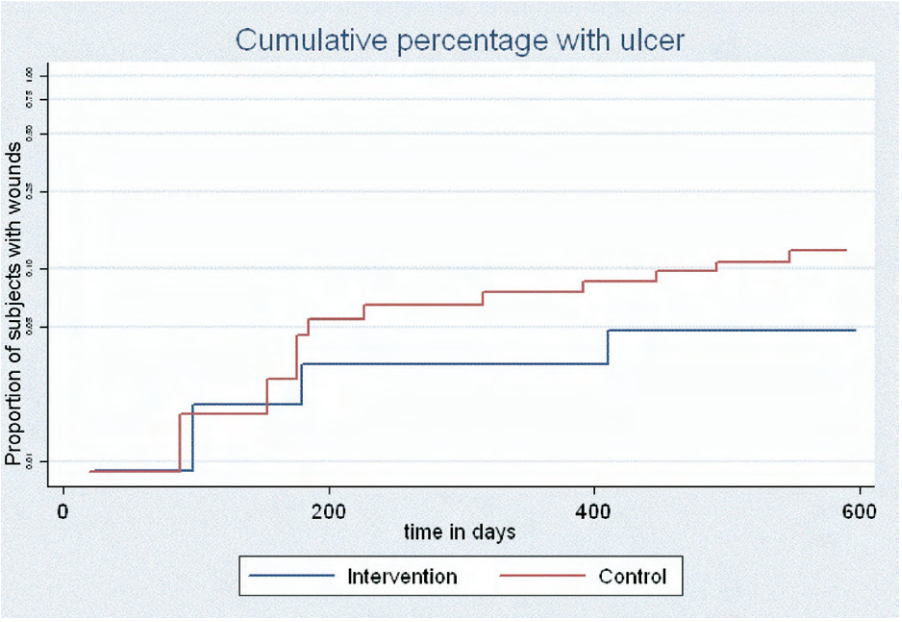

Figure 1 Prevention of ulceration: dermal thermometry vs. standard therapy. There were 12.2% patients ulcerated in the Standard Therapy Group compared with 4.7% in the Dermal Thermometry Group (OR 3.0; 95% CI, 1.0 to 8.5; $P = .038$). Additionally, thermometry was associated with a longer time to ulceration than control ($P = .04$).

week before the event than did a random 7-consecutive-day sample of 50 subjects that did not ulcerate (3.50 ± 1.0 vs 0.74 ± 0.05, $P = .001$). These data are illustrated in Figure 2.

DISCUSSION

There are few effective therapies to help high-risk patients with diabetes prevent foot ulcerations. Under the best circumstances, high-risk patients will receive a few hours of education a year concerning the complications of diabetes, regular foot evaluation by their primary care physician or specialty care by a podiatrist, and protective shoes and insoles. Unfortunately, standard prevention therapies usually are not provided. And, even when patients are treated in centers of excellence with aggressive medical and surgical intervention, between one third and two thirds of subjects with a prior history of diabetic foot ulcers will reulcerate in 12-24 months.[2,16,18] Lavery and coworkers have reported 2 randomized clinical trials using a temperature home monitoring device with similar results to this study.[13,19] This study substantively augments those previous studies in a larger, potentially higher-risk population and is the first, to our knowledge, to suggest that thermometry used by patients themselves can identify areas of inflammation before skin breakdown.

Self-monitoring is necessary to identify early warning signs to reduce the incidence of diabetic foot complications and the associated decrements in quality of life and high resource costs. Sadly, the ability of the most motivated patients with diabetes, their family members, and even health care professionals to identify "early warning signs" is limited. The precursors to ulceration are subtle, especially in a neuropathic foot. Self-evaluation of temperature seems to offer a mechanism to identify an early sign of injury, when there is still time to avert a wound. The results of this study suggest that a simple, inexpensive temperature device can be used effectively by high-risk patients to reduce foot ulceration. This offers a significant advantage over traditional prevention practices and therapies.

The concept of measuring skin temperature as a marker for tissue inflammation and injury in the insensate foot has been addressed by several authors. As early as 1971, Goller et al reported an association between increased local temperature and localized pressure leading to tissue injury.[7]

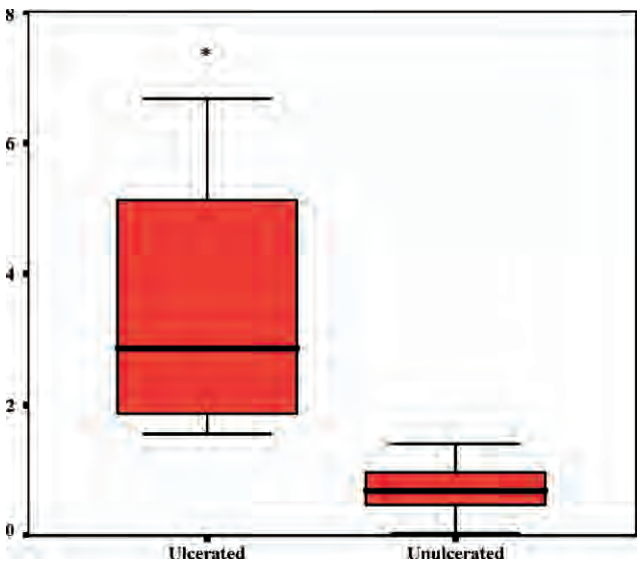

Figure 2 Temperature difference at 1 week before ulceration. *$P = .001$.

Sandrow and coworkers subsequently used thermometry as a tool to diagnosis occult neuropathic fractures in patients with diabetes in 1972.[20] Stess and colleagues described the use of infrared thermography to assess skin temperatures in patients with diabetes, patients with diabetes with neuropathic fractures, patients with diabetes with ulcers, patients with leprosy, and controls.[21] They found that neuropathic foot ulcers frequently had increased skin temperatures surrounding a central necrotic area, and suggested that temperature assessment may be a useful technique to identify patients at risk for ulceration. Similar findings were revealed in a larger study by Armstrong et al using standard thermometers.[22] The concept is elegant in its simplicity, and even challenging patient populations appear to have been able to successfully use the device.

Veterans treated in the Department of Veterans Affairs are older, poorer, and have more comorbidities than general community dwellers. However, they are not appreciably different from the disproportionately low income and minority population with diabetes in regards to ulcer outcomes.[23,24] Therefore, the results of this study should be applicable to both veteran and nonveteran populations alike. In fact, a less challenged population might realize better preventative outcomes.

In this study we evaluated 2 risk groups: patients with a history of previous diabetic foot ulceration or amputation (Risk Group 3) and those with sensory neuropathy and loss of protective sensation with structural foot deformities (Risk Group 2). The majority of subjects enrolled were in the latter group, and this group had a lower incidence of ulceration than expected. Our sample size estimate was based on published outcomes using "standard prevention" in diabetics with a history of pathology (Risk Group 3). Therefore, we underestimated the sample size needed to evaluate Diabetic Foot Risk Group 2 subjects, and we disproportionably enrolled fewer Diabetic Foot Risk Group 3 subjects. Despite these errors, the smaller patient sample was sufficient to show a significant impact when home temperature monitoring was used.

Quality of life, functional status, self-efficacy, satisfaction with care, and cost outcomes from this study will be addressed in future articles. While smaller studies in this area have mirrored the current project,[13,19] it is unknown if the same outcomes and compliance would be observed in a multicenter clinical trial over an extended period of evaluation. We look forward to work that might continue to refine this method's usefulness in a variety of settings.

References

1. Pecoraro RE, Reiber GE, Burgess EM. Pathways to diabetic limb amputation: basis for prevention. *Diabetes Care*. 1990;13:513-521.
2. Singh N, Armstrong DG, Lipsky BA. Preventing foot ulcers in patients with diabetes. *JAMA*. 2005;293(2):217-228.
3. Armstrong DG, Abu-Rumman PL, Nixon BP, Boulton AJ. Continuous activity monitoring in persons at high risk for diabetes-related lower-extremity amputation. *J Am Podiatr Med Assoc*. 2001;91(9):451-455.
4. Armstrong DG, Lavery LA, Holtz-Neiderer K, et al. Variability in activity may precede diabetic foot ulceration. *Diabetes Care*. 2004; 27(8):1980-1984.
5. Maluf KS, Morley RE, Richter EJ, et al. Foot pressures during level walking are strongly associated with pressures during other ambulatory activities in subjects with diabetic neuropathy. *Arch Phys Med Rehabil*. 2004;85(2):253-260.
6. Maluf KS, Mueller MJ. Novel Award 2002. Comparison of physical activity and cumulative plantar tissue stress among subjects with and without diabetes mellitus and a history of recurrent plantar ulcers. *Clin Biomech (Bristol, Avon)*. 2003;18(7):567-575.
7. Goller H, Lewis DW, McLaughlin RE. Thermographic studies of human skin subjected to localized pressure. *Am J Roentgenol Radium Ther Nucl Med*. 1971;113(4):749-754.
8. Stess RM, Sisney PC, Moss KM, et al. Use of liquid crystal thermography in the evaluation of the diabetic foot. *Diabetes Care*. 1986;9(3): 267-272.
9. Armstrong DG, Lavery LA, Liswood PJ, et al. Infrared dermal thermometry for the high-risk diabetic foot. *Phys Ther*. 1997;77(2):169-175.
10. Benbow SJ, Chan AW, Bowsher DR, et al. The prediction of diabetic neuropathic plantar foot ulceration by liquid-crystal contact thermography. *Diabetes Care*. 1994;17(8):835-839.
11. Bergtholdt HT, Brand PW. Thermography: an aid in the management of insensitive feet and stumps. *Arch Phys Med Rehabil*. 1975;56(5): 205-209.
12. Clark RP, Goff MR, Hughes J, Klenerman L. Thermography and pedobarography in the assessment of tissue damage in neuropathic and atherosclerotic feet. *Thermology*. 1988;3:15-20.
13. Lavery LA, Higgins KR, Lanctot DR, et al. Home monitoring of foot skin temperatures to prevent ulceration. *Diabetes Care*. 2004;27(11): 2642-2647.
14. Lavery LA, Higgins KR, Lanctot D, et al. Preventing diabetic foot ulcer recurrence in high-risk patients: the use of temperature monitoring as a self-assessment tool. *Diabetes Care*. 2007;30(1):14-20.
15. Peters EJ, Lavery LA. International Working Group on the Diabetic Foot. Effectiveness of the diabetic foot risk classification system of the International Working Group on the Diabetic Foot. *Diabetes Care*. 2001;24(8):1442-1447.
16. Uccioli L, Faglia E, Monticone G, et al. Manufactured shoes in the prevention of diabetic foot ulcers. *Diabetes Care*. 1995;18(10):1376-1378.
17. Walker SC, Helm PA, Pulliam G. Total contact casting and chronic diabetic neuropathic foot ulcerations: healing rates by wound location. *Arch Phys Med Rehabil.* 1987;68:217-221.
18. Mueller MJ, Sinacore DR, Hastings MK, et al. Effect of achilles tendon lengthening on neuropathic plantar ulcers. A randomized clinical trial. *J Bone Joint Surg Am*. 2003;85-A(8):1436-1445.
19. Lavery LA, Higgins KR, Armstrong DG, et al. Randomized clinical trial to evaluate a novel home temperature monitoring device to reduce the incidence of diabetic foot complications (Abstract). *Diabetologia*. 2002;45(Suppl 2):A342.
20. Sandrow RE, Torg JS, Lapayowker MS, Resnick EJ. The use of thermography in the early diagnosis of neuropathic arthropathy in the feet of diabetics. *Clin Orthop*. 1972;88:31-33.
21. Stess RM, Sisney PC, Koss KM, et al. Use of liquid crystal thermography in the evaluation of the diabetic foot. *Diabetes Care*. 1986;9: 267-272.
22. Armstrong DG, Lavery LA, Liswood PJ, et al. Infrared dermal thermometry for the high-risk diabetic foot. *Phys Ther*. 1997;77(2):169-175; discussion 176-177.
23. Reiber GE, Koepsell TD, Maynard C, et al. Diabetes in nonveterans, veterans, and veterans receiving Department of Veterans Affairs health care. *Diabetes Care*. 2004;27(Suppl 2):B3-B9.
24. Reiber GE, Boyko EJ. Diabetes research in the Department of Veterans Affairs. *Diabetes Care*. 2004;27(Suppl 2):B95-B98.