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Investigating the Relationship Between Glycemic Control and Diabetic Foot Ulcer Healing Rates

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Abstract: Diabetic foot ulcers (DFUs) are amongst the most critical diabetes mellitus complications and commonly result in infection, hospitalization, and amputation. Glycaemic control, whose degree is commonly assayed by HbA1c at regular intervals, has been considered as a wound healing factor of prime significance, although with a direct effect on ulcer healing being questioned. Objective: The aim of the study was to investigate the relationship between glycaemic control and healing rate of patients' diabetic foot ulcers. Methods: Prospective observational study among diabetic patients hospitalized with foot ulcer. Baseline demographic data, glycaemic control parameters (e.g., HbA1c and fasting blood sugar), and characteristics of the ulcers were noted. Rate of healing of ulcer was monitored during a given follow-up period, and statistical correlation between glycaemic parameters and healing outcome was analysed. Results: The research proved a strong inverse correlation between ulcer healing rates and HbA1c levels. Patients with improved glycaemic control (HbA1c < 7.5%) exhibited quicker and more successful healing than those with poor control. Furthermore, other variables like the duration of diabetes, peripheral neuropathy, and infection status also affected the healing rates. Conclusion: Glycaemic control is a significant predictor of diabetic foot ulcer healing. Monitoring and optimisation of blood glucose on a regular basis is likely to promote wound healing and decrease complications, once again showing the significance of well-coordinated diabetic care.

Keywords: *Diabetic Foot Ulcer, HbA1c, Glycaemic Control, Ulcer Healing, Diabetes Mellitus, Wound Healing, Chronic Wounds, Healing Outcomes.*

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I. INTRODUCTION

Diabetes mellitus (DM) is a chronic, progressive, and systemic metabolic disorder characterized by elevated blood glucose levels, resulting from defects in insulin secretion, insulin action, or both. It has become an epidemic in magnitude worldwide, with the International Diabetes Federation estimating more than 537 million adults with diabetes in 2021, a number that is expected to increase substantially in the next few decades. The impact of diabetes goes beyond hyperglycemia to include a broad array of vascular and neuropathic complications, one of the most difficult and disabling of which is diabetic foot ulcers (DFUs). DFUs contribute to significant morbidity, decreased quality of life, increased hospitalization, and a significant risk of lower-limb amputation.

The pathogenesis of DFU is multifactorial and complex. Its pathogenesis is caused by chronic hyperglycemia, which results in peripheral neuropathy involving sensory, motor, and autonomic nerve damage. Sensory neuropathy causes a loss of protective sensation, making the foot vulnerable to repeated trauma and injury without awareness. Motor neuropathy results in intrinsic muscle weakness and foot deformities, changing the pressure distribution while walking, whereas autonomic neuropathy results in dryness and fissures because of loss of sweating, predisposing to skin breakdown. Apart from neuropathy, peripheral arterial disease (PAD), which is common in patients with diabetes, impairs tissue perfusion and delays wound healing. When combined with an impaired immune system, these conditions provide an ideal setting for infection and non-healing of chronic wounds.

DFUs are a significant health issue with more hospitalizations than other diabetes-related complications. As many as 25% of patients with diabetes are estimated to develop foot ulcers in their lifetime. Shockingly, DFUs lead to more than 80% of diabetes-related lower limb amputations. Despite improvements in wound management, offloading protocols, and infection control, healing rates remain below expectations in most environments. One modifiable variable that continues to receive increasing attention owing to its possible role in wound healing is

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glycemic control, which is usually quantified through glycated hemoglobin (HbA1c) levels.

HbA1c is a known marker of the mean blood glucose level over the previous two–three months. It is commonly used in clinical practice and research as a marker of long-term glycemic control. Increasing evidence indicates that poor glycemic control is not only a risk factor for developing DFUs, but also significantly hinders wound healing. Hyperglycemia negatively affects a variety of physiological mechanisms that are important for tissue repair. It is detrimental to neutrophil function, decreases chemotaxis and phagocytosis, and decreases the bactericidal capacity of immune cells, resulting in enhanced susceptibility to infection. In addition, chronic hyperglycemia inhibits fibroblast growth, collagen deposition, angiogenesis, and re-epithelialization, all of which are critical elements of the wound healing process.

Research has shown that patients with increased HbA1c levels have slower healing rates, higher rates of infection, and worse outcomes of ulcers than patients with more stringent glycemic control. However, the literature is not uniformly convincing. Clinical research indicates that, although glycemic control could be a factor in wound healing, it is not the only determining factor. Considerations, including wound depth and diameter, presence of osteomyelitis, vascular insufficiency, infection, and patient compliance with offloading and wound care, will significantly influence outcomes. Thus, as a firm theoretical and clinical foundation supports the role of glycemic control in healing in DFUs, evidence in hospital-based populations examining this relationship is scarce, and this is even more true in resource-limited environments.

The clinical utility of examining this association stems from its implications. If it is determined that there is a strong association between glycemic control and rates of healing, then it would reinforce the need for strict blood glucose control as a component of comprehensive diabetic foot management. In addition, recognizing those with inadequate glycemic control as high-risk individuals can lead to early interventions, such as more stringent glucose monitoring, adjustment of insulin, patient education, and multidisciplinary intervention. This proactive management can potentially shorten the healing time, avoid complications, shorten hospital stay, and minimize the risk of amputation.

The purpose of this study was to investigate the correlation between glycemic control, as indicated by HbA1c, and the healing rate of diabetic foot ulcers in patients undergoing treatment in a tertiary care center. By examining healing outcomes within different types of glycemic control: good (HbA1c < 7%), moderate (7–8.5%), and poor (>8.5%), the study will offer a better insight into the way in which chronic blood glucose levels affect wound resolution over time. We will also investigate the duration of ulcer healing, considering other possible confounding factors, such as age, diabetes duration, presence of infection, neuropathy, PAD, and ulcer grade or size.

To confirm the strength of the results, this study used both univariate and multivariate statistical tests. Logistic regression equations will be used to establish whether poor glycemic control is an independent predictor of non-healing ulcers. Correlation analysis will establish the strength and direction of the association between HbA1c levels and time to healing. Additionally, Kaplan-Meier survival analysis and Cox proportional hazards models were used to evaluate the time-to-healing outcomes in different glycemic control groups.

In addition to its scientific importance, this study is timely and clinically relevant. The increasing incidence of diabetes in India and other developing countries has resulted in a parallel increase in the incidence of foot complications. Most patients present late with advanced ulcers that necessitate complex interventions or amputations. In these situations, the early detection of modifiable risk factors, such as glycemic control, can have a significant impact on patient care. In addition, as the focus on the cost-effective delivery of healthcare increases, interventions that improve healing and minimize complications are of the highest value.

In conclusion, foot ulcers are a severe and often avoidable diabetes complication associated with high morbidity and mortality. Glycemic control, reflected by HbA1c, is a potentially amendable variable that can affect the direction of wound healing in patients with DFUs. Through a systematic analysis of the interaction between glycemic control and healing rates in a natural clinical environment, this study aimed to provide insightful contributions to diabetic wound care and assist evidence-based clinical decision-making. The results could assist clinicians in prioritizing glycemic control not only for long-term vascular outcomes but also for direct benefits in wound healing, ultimately enhancing the quality of life and prognosis of patients with diabetic foot ulcers.

II. MATERIALS AND METHODS

- *Study Design*

This prospective observational cohort study examined the correlation between glycemic control, as indicated by glycated hemoglobin (HbA1c), and diabetic foot ulcer (DFU) healing in patients with type 2 diabetes mellitus.

- *Study Setting*

This study was conducted in the Department of General Surgery, Government Cuddalore Medical College and Hospital, Chidambaram, Tamil Nadu, a tertiary care referral centre catering to a vast rural and semi-urban population in and around the Cuddalore district.

- *Study Duration*

The duration of the study was six months, from October 2024 to March 2025.

- *Sample Size*

Fifty diabetic foot ulcer patients were enrolled in the study through convenience sampling after applying predefined inclusion and exclusion criteria.

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➢ *Inclusion Criteria*
- Age ≥18 years.
- diagnosed with type 2 diabetes mellitus.
- History of diabetic foot ulcers (Wagner Grade I to III).
- Will provide informed consent and be willing to follow up

➢ *Exclusion Criteria*
- Patients with critical limb ischemia require urgent surgery or amputation.
- Ulcers of non-diabetic etiology (e.g., traumatic, venous, or malignant ulcers).
- Patients undergoing long-term immunosuppressive therapy, chemotherapy, or malignancy.
- Pregnant and lactating females.
- Patients with end-stage renal failure (eGFR <30 ml/min/1.73m²) or severe hepatic dysfunction.

➢ *Data Collection Procedure*

A structured case record form (CRF) was employed to capture data on demographic information, clinical profile, characteristics of the ulcer, laboratory parameters, treatment regimens, and outcome of ulcer healing.

➢ *Data recorded at baseline*
- Age, sex
- Duration of diabetes
- Level of HbA1c (assessed using high-performance liquid chromatography [HPLC])
- Random blood sugar and fasting plasma glucose
- Characteristics of the ulcer: size (cm²), depth, site, Wagner classification
- Infection (clinically evaluated ± wound culture if indicated)
- Peripheral neuropathy (evaluated by 10g monofilament and vibration perception threshold)
- Peripheral arterial disease (PAD) (clinically and Doppler study assessed)
- Presence of osteomyelitis (if suspected, diagnosed by X-ray or MRI)
- Other comorbidities: hypertension, dyslipidaemia, chronic kidney disease, smoking

➢ *Wound Assessment and Follow-up*
- Ulcer size and healing progress were recorded every week for 12 weeks.
- Healing was measured using the following equation:
✓ Reduction in ulcer area (using a sterile ruler or acetate tracing)
✓ Complete epithelialization
✓ Time to complete healing (in weeks)

- Patients were classified according to ulcer outcome at 12 weeks.
✓ Healed
✓ Not healed

- According to HbA1c, patients were divided into:
✓ Good control: HbA1c < 7%
✓ Moderate control: HbA1c 7–8.5%
✓ Poor control: HbA1c > 8.5%

III. STATISTICAL ANALYSIS

All the quantitative variables in the present study were analysed using MS Excel, SPSS, JSAP, MS Word.

A. Source of data
- Patients case sheets
- Interact with patients
- Prescription with orders

B. Result

This study examines the outcome of diabetic foot ulcer healing using a variety of statistical analysis to identify patterns, association and causal factors. The results include descriptive statistics, inferential statistics, correlation testing and survival analysis to assess the impact of glycemic control and ulcer type on the wound healing systemically.

➢ *Descriptive Statistics*

Table 1: Descriptive Statistics of Patients Receiving Iron Sucrose Injection

	Age	Duration of Diabetes (years)	HbA1c (%)	Ulcer size (cm^2)	Healing Time (weeks)
Valid	50	50	50	50	50
Mean	59.040	10.180	7.888	4.422	6.586
Median	60	9	7.550	4.2	6
Standard Deviation	11.348	7.073	1.356	2.059	2.044
Interquartile Range	16.750	9.750	1.900	3.250	4.000

The study group was of average age 59 years and average duration of diabetes 10.18 years. The majority of the patients had poor glycemic control (average HbA1c 7.89%), moderate size of ulcer, and average time to heal 6.59 weeks. Variation in time to heal indicates the role of factors at the level of individual patient such as glycemic control and type of ulcer.

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➢ *Inferential Statistics:*

Table 2: Contingency Tables

HbA1c Group	Healing Outcome		Total
	Healed	Not Healed	
Good	15	1	16
Moderate	8	6	14
Poor	6	14	20
Total	29	21	50

Table 3: Chi-Square Tests for Healing outcomes (vs) HbA1c Group

	Value	df	P
X^2	14.836	2	<.001
N	50		

The Chi-square test showed that there was statistically significant association between HbA1c level and ulcer healing process ($\chi^2 = 14.836$, $p < 0.001$). There was excellent healing rate in those with goo control since 15 of the 16 healed. On the other hand, most of the poorly controlled patients did not heal. This supports the strong association of HbA1c with healing of wounds.

➢ *Correlation Analysis:*

- *Pearson's Correlation:*

Table 4: Pearson's Correlations of HbA1c vs Healing Time

Variable Pair	Pearson's rho	p-value
HbA1c (%) vs Healing Time (weeks)	-0.117	0.416

Pearson's correlation of HbA1c with healing time was nonsignificant and weak ($r = -0.117$, $p = 0.416$). That is, mildly elevated HbA1c was correlated with longer healing times but that the correlation was too weak to be of value. No linear correlation, strong or weak, thus existed between glycemic control and healing time.

- *Spearman's Correlation:*

Table 5: Spearman's Correlation of HbA1c vs Healing Time

Variable Pair	Spearman's rho	p-value
HbA1c (%) vs Healing Time (weeks)	-0.247	0.083

The relationship between HbA1c and healing time, as found by Spearman's correlation, was a nearly significant, moderate negative relationship ($rho = -0.247$, $p = 0.083$), meaning that this was not significant but almost significant. What this implies is that there was a trend where higher HbA1c correlated with longer healing times. Although nonsignificant, it implies there could be some impact of compromised glycemia on delayed wound healing.

➢ *Regression Analysis:*

Table 6: Model Fit Summary for Logistic Regression Predicting Ulcer Healing

Model	Deviance	AIC	BIC	df	ΔX^2	p-value	McFadden R^2	Nagelkerke R^2	Tjur R^2	Cox & Snell R^2
M_0	68.029	70.029	71.941	49	—	—	0.000	0.000	—	—
M_1	51.026	57.026	62.762	47	17.003	<0.001	0.250	0.388	0.303	0.288

Table 7: Logistic Regression Analysis for Prediction of Ulcer Healing Based on HbA1c and Ulcer Size

Predictor	Estimate (β)	Std. Error	Z	Wald χ^2	df	p-value	95% CI (Lower–Upper)
M_0 (Null model)							
Intercept	0.323	0.287	1.126	1.269	1	0.260	-0.239 – 0.884
M_1 (Fitted model)							
Intercept	9.565	3.051	3.135	9.830	1	0.002	3.586 – 15.545
HbA1c (%)	-1.132	0.346	-3.267	10.671	1	0.001	-1.811 – -0.453
Ulcer Size (cm^2)	-0.058	0.166	-0.347	0.121	1	0.728	-0.383 – 0.268

df- Degrees of Freedom; CI – Confidence Interval

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The logistic regression model demonstrated that elevated HbA1c levels significantly decreased the chance of healing of the ulcer ($p = 0.001$), whereas size of the ulcer was not a significant predictor. The model demonstrated a highly significant improvement in fit ($p < 0.001$) with a moderate explanatory power (Nagelkerke $R^2 = 0.388$). These findings suggest that uncontrolled glycemia is an important factor influencing healing negatively.

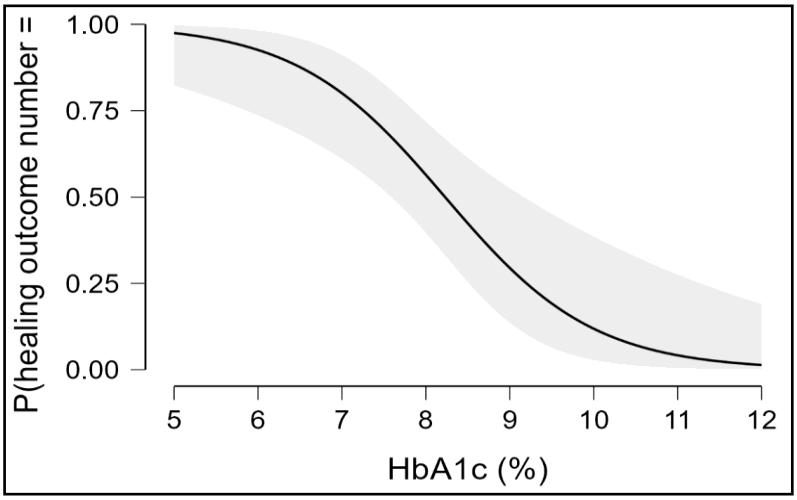

Fig 1: Probability of Ulcer Healing in relation to HbA1c (%)

This graph demonstrates a sharp inverse relationship between the degree of HbA1c and probability of healing, and the degree of HbA1c significantly reduces the probability of healing.

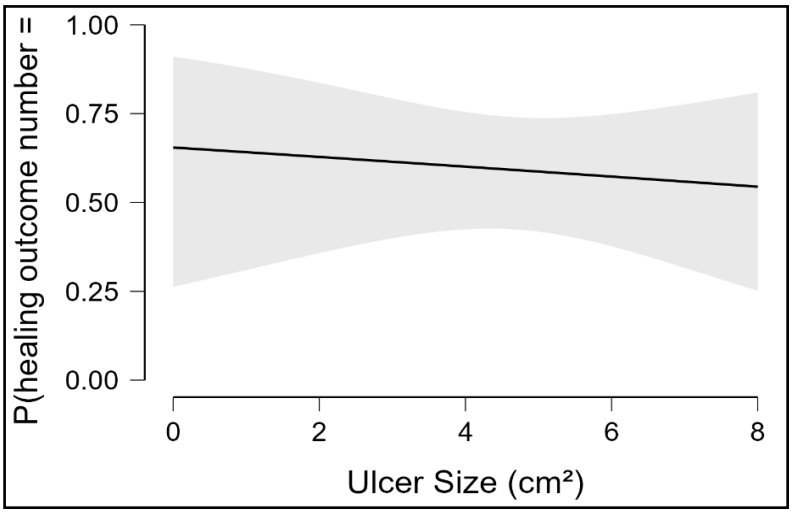

Fig 2: Predicted Probability of Ulcer Healing as a Function of Ulcer Size (cm²)

This graph shows a weak and nearly flat correlation, which suggests that ulcer size has very little effect on the outcomes of healing

- *Survival Analysis:*

Table 8: Kaplan -Meier Survival Analysis for Ulcer Healing Time

N	Events	Restricted Mean (weeks)	Std. Error	Median Survival (weeks)	95% CI for Median Survival	
					Lower	Upper
50	29	6.586	0.373	6.000	5.000	8.000

The median survival time to healing was 6 weeks with a 95% confidence interval of 5 to 8 weeks. The restricted mean survival time was 6.59 weeks, and it is the mean time to healing in the study population.

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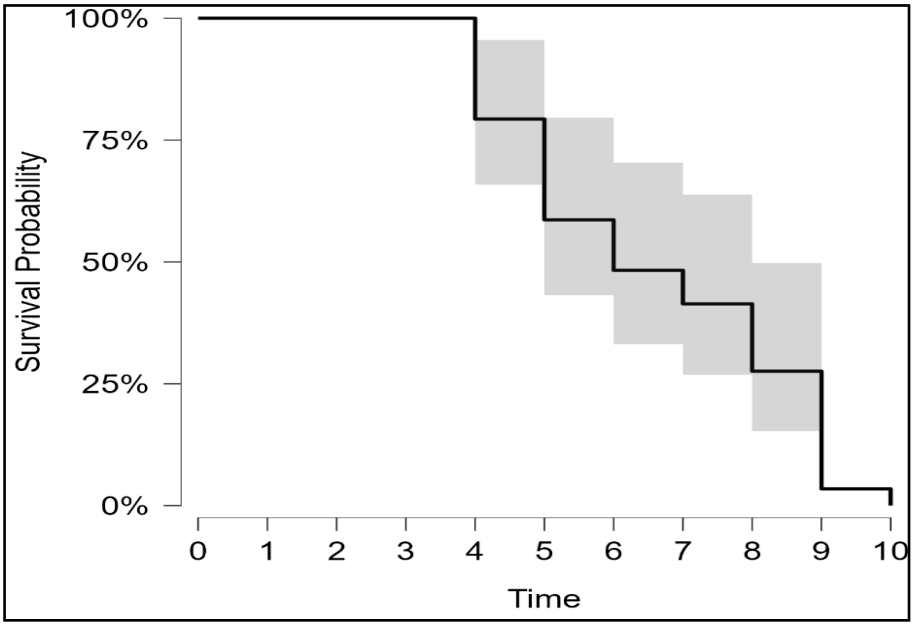

Fig 3: Kaplan-Meier Curve Illustrating Time to Healing of Ulcers

The survival plot shows that the chance of healing of the ulcer decreases progressively over a period of time, and 50% of the patients heal by the 6th week. Filled area represents the 05% confidence interval around the survival estimate.

IV. DISCUSSION

In this research, we assessed the association of glycaemic control (as indicated by HbA1c) with the healing rate of diabetic foot ulcers (DFUs) in an inpatient population. Most individuals with superior glycaemic control demonstrated that the rate of ulcer healing was faster, supporting the established association between hyperglycaemia and disruption of wound healing through several mechanisms such as oxidative stress, impairment of angiogenesis, and inflammatory cytokine expression. These findings are consistent with the results of Lavery et al. (2014), who recognized that patients with poor glycaemic control (HbA1c > 8%) had much slower diabetic foot ulcer healing compared to patients with improved glycaemic control. With respect to the duration of diabetes, subjects who had diabetes for a longer period of time had a slower healing rate than participants who had diabetes for a shorter duration. Similar results were reported by Zubair et al. (2015), who outlined a strong correlation between diabetes duration and poor DFU healing due to increased microvascular injury. Lastly, we observed that infected diabetic foot ulcers took longer to heal than those that were not infected. Game et al. (2016) reported similar findings, and noted that an infection impaired healing, which was associated with higher amputation rates. Although not statistically significant, there was a very small trend emerging among the female participants in our study with slightly better healing outcomes. Although not a universally accepted finding, Margolis et al. (2002) report female patients may have better healing outcomes than male patients based on the differences in compliance and hormonal factors that have an impact on the healing process. Members of our cohort who smoked had delayed healing outcomes. This finding is consistent with those of Smith et al. (2013) who found smoking delays wound repair processes in diabetic participants by impairing the microvascular system.

V. CONCLUSION

This study highlights the powerful impact of glycaemic control, in terms of HbA1c levels, on the healing of diabetic foot ulcers (DFUs). The patients with better glycaemic control (HbA1c < 7.5%) showed faster and more effective healing of ulcers compared with those with poor control who showed delayed or non-healing ulcers. Logistic regression analysis also confirmed HbA1c as an independent predictor of healing, whereas ulcer size did not show any significant relationship with healing. Additionally, Kaplan-Meier survival analysis also confirmed the findings, where the median time to healing was 6 weeks with faster recovery in patients with controlled blood glucose levels.

While correlation analyses between healing time and HbA1c were weak to moderate but not statistically significant, they did show a trend towards delayed healing with rising HbA1c. This implies that systemic factors like glycaemic control might have a greater influence on wound healing than local ulcer features.

In general, the study emphasizes the need for optimal glycaemic control of DFU patients. Monitoring of HbA1c and early medical treatment can promote healing and minimize complications. A combination of glycaemic control, wound therapy, and patient education is needed to enhance outcomes and quality of life of diabetic patients.

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