Comparison of Smartphone Application Utilization for Diabetic Foot Ulcer Assessment as an Alternative Telemedicine Approach at Adam Malik General Hospital Medan

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Abstract- Diabetic foot ulcer (DFU) is one of the most debilitating complications of diabetes mellitus, leading to high morbidity, prolonged hospitalization, and increased risk of amputation. Accurate wound assessment is essential for optimal management; however, conventional manual measurement is often inaccurate and lacks standardization. Smartphone-based applications have emerged as a potential alternative within telemedicine, especially in resource-limited settings. This diagnostic study compared the performance of the ImitoMeasure smartphone application with manual ruler-based measurements in 76 type 2 diabetes patients with DFU at Adam Malik General Hospital, Medan (April–May 2025). Ulcer length, width, and area were measured manually and digitally using standardized imaging, with diagnostic accuracy assessed by ROC curves and AUC analysis. The participants' mean age was 54.8 ± 10.5 years, with a slight male predominance (53.1%). Manual measurements showed a mean length of 5.94 ± 2.87 cm and width of 3.61 ± 1.74 cm, while ImitoMeasure reported higher values (length 7.49 ± 3.75 cm; width 4.33 ± 1.70 cm) and additionally calculated wound surface area (26.14 ± 19.47 cm²) and perimeter (19.09 ± 8.62 cm). ROC analysis revealed poor diagnostic agreement, with AUC values of 0.375 for length and 0.376 for area. Although ImitoMeasure facilitates digital documentation and remote monitoring, its limited accuracy compared to manual methods indicates it is not yet suitable as a replacement. Further calibration and algorithm refinement are needed to enhance reliability, but it holds promise as a supportive telemedicine tool for DFU assessment in the future.

***Index Terms*-:** diabetic foot ulcer, smartphone application, wound measurement, telemedicine, ImitoMeasure.

I. INTRODUCTION

Diabetes mellitus (DM) represents a heterogeneous group of metabolic disorders characterized by chronic *hyperglycemia* due to defects in insulin secretion, insulin action, or both (American Diabetes Association, 2014). As part of the spectrum of non-communicable diseases (NCDs), DM constitutes one of the leading causes of morbidity and mortality globally. According to the World Health Organization (WHO), NCDs are the predominant contributors to global mortality, and diabetes has been consistently identified as a condition of increasing prevalence and clinical significance. The rising prevalence of DM in Indonesia parallels global trends, representing an escalating public health challenge with substantial implications for healthcare systems.[1-3]

Among the numerous complications of DM, peripheral neuropathy represents a major determinant of foot-related morbidity. Diabetic peripheral neuropathy, particularly chronic sensory-motor neuropathy, contributes to impaired protective sensation in the distal extremities. This renders the plantar surface of the foot highly susceptible to trauma and ulcer formation, especially in weight-bearing regions such as the *caput metatarsale*. Progressive neuropathic injury, compounded by *microangiopathy*, predisposes patients to the development of diabetic foot ulcers (DFUs), deformities, and ultimately, limb amputation.[4-7]

DFUs are associated with considerable morbidity, mortality, and socioeconomic burden. They frequently require prolonged hospitalization, surgical interventions such as debridement, and in severe cases, major amputation. Surgical debridement remains the most efficient method for removing necrotic tissue, yet its success relies on meticulous separation of viable from non-viable tissue, coupled with vigilant postoperative monitoring and patient education. In Indonesia, the magnitude of this problem is illustrated by data from

RSUD Dr. Soetomo (2020), which reported that 60.5% of patients with DFUs sought treatment under internal medicine, whereas 39.5% were referred to surgical specialists for ulcer management. Such figures highlight the high clinical demand for comprehensive wound care in tertiary settings.[8]

Delayed presentation and diagnosis of DFUs further exacerbate disease outcomes. Several studies have identified a lack of patient awareness, underestimation of ulcer significance, and limited access to professional wound care as major determinants of delayed healthcare-seeking behavior. In many settings, these barriers perpetuate advanced disease progression at the time of hospital presentation, limiting therapeutic success and increasing the likelihood of poor outcomes.[9,10]

Conventional wound assessment methods, such as manual planimetry and simple ruler measurement, have been widely used in clinical practice. The ruler method, in which the maximum length and width of a wound are multiplied, offers a low-cost and easily applicable technique. However, its accuracy is limited to rectangular wounds and it frequently overestimates ulcer size, neglecting irregular wound margins. Such limitations underscore the need for more precise and standardized approaches to wound measurement in DFUs.[11]

Technological advances have facilitated the integration of digital tools into clinical wound assessment. High-resolution smartphone cameras, widely available at low cost, provide a highly mobile platform for clinical applications. Specialized applications such as ImitoMeasure offer non-contact digital planimetry, enabling more accurate wound measurement and documentation compared to conventional methods. Evidence suggests that with appropriate calibration and photographic alignment, smartphone-based wound assessment can minimize measurement errors caused by angular deviation or improper positioning.[11,12]

Beyond its role in measurement, smartphone-based wound documentation aligns with the broader concept of telemedicine. Defined as the delivery of healthcare services at a distance using electronic means, telemedicine offers cost-effectiveness, improved clinical outcomes, and enhanced patient satisfaction, particularly for chronic diseases such as type 2 DM and cancer. In resource-limited settings or for patients with restricted mobility, telemedicine presents an opportunity to optimize continuity of care and facilitate timely follow-up.[12]

Despite the growing interest in digital wound assessment, gaps remain regarding the diagnostic accuracy and reliability of smartphone applications compared to conventional measurement methods. In particular, studies evaluating ImitoMeasure as a telemedicine tool for DFU monitoring are limited, especially within the Indonesian healthcare context. Evaluating its sensitivity and specificity in comparison to manual ruler-based methods may provide critical evidence for its clinical utility in tertiary care hospitals such as Adam Malik General Hospital Medan.

The present study aims to assess the diagnostic performance of the ImitoMeasure smartphone application in DFU assessment. Specifically, it seeks to determine the sensitivity and specificity of the application in comparison with traditional methods, thereby evaluating its potential role as an alternative telemedicine approach for DFU monitoring at Adam Malik General Hospital Medan.

II. Methodology

This study employed an analytic observational design with a diagnostic test approach. Primary data were collected to evaluate the diagnostic performance of the ImitoMeasure smartphone application in assessing *diabetic foot ulcers*(DFUs) as an alternative telemedicine tool. The study specifically aimed to analyze the sensitivity and specificity of the application compared with conventional manual measurement techniques.

The research was conducted at Haji Adam Malik General Hospital Medan following approval by the Health Research Ethics Committee of the Faculty of Medicine, Universitas Sumatera Utara. Data collection was carried out over a two-month period, from April to May 2025. All eligible patients were recruited consecutively until the minimum sample size requirement was fulfilled. Based on prior sample size calculations using both mean difference and diagnostic test formulas, a total of approximately 77 participants with type 2 diabetes and clinically diagnosed DFUs were required for inclusion.

The study population comprised patients aged 18–70 years with a clinical and laboratory-confirmed diagnosis of DFU, treated either conservatively or surgically at the outpatient clinic and inpatient wards. Inclusion criteria were patients with measurable DFUs in two dimensions and who provided informed consent. Exclusion criteria included ulcers with indistinct wound margins precluding measurement, DFUs complicated by traumatic injuries, or wounds that could not be adequately documented using digital imaging. All participants provided signed informed consent prior to enrollment.

Variables measured included demographic characteristics (age, sex, education level), as well as wound parameters (maximum length, maximum width, surface area, and perimeter). Wounds were first measured manually using a sterile transparent ruler. The surface area was calculated by multiplying the longest length and width, acknowledging its limitation to rectangular assumptions. Subsequently, each wound was photographed using a high-resolution smartphone camera with the ImitoMeasure application installed. A standardized imaging protocol was applied: photographs were taken perpendicular to the wound surface, with a calibration marker (QR code scale) placed at the same level as the wound to minimize parallax error. Deviation from the optical axis greater than 20° was avoided to reduce measurement inaccuracy, as prior studies have demonstrated underestimation of wound surface area by up to 10% with misaligned imaging.

Data analysis was performed using SPSS statistical software. Descriptive statistics were used to summarize baseline demographic and clinical characteristics. Agreement between manual and digital measurements was initially assessed using Cohen's Kappa coefficient, with values above 0.8 considered strong. Comparative analysis between manual and smartphone-based measurements was conducted using independent t-tests for normally distributed data or the Mann–Whitney U test otherwise. To evaluate the diagnostic performance of ImitoMeasure, receiver operating characteristic (ROC) curves were generated and the area under the curve (AUC) was calculated. Sensitivity, specificity, and optimal cut-off points were determined using 2×2 contingency tables.

The study protocol was reviewed and approved by the Health Research Ethics Committee of the Faculty of Medicine, Universitas

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Sumatera Utara. All participants provided written informed consent, and ethical principles were observed throughout the study, including confidentiality and the right to withdraw at any time without affecting their standard medical care.

III. RESULTS

A total of 76 patients diagnosed with *diabetic foot ulcer* (DFU) were included in this study. The mean age of participants was 54.84 ± 10.53 years, ranging from 36 to 80 years. The majority of patients were male (n = 40; 53.1%), while females comprised 46.9% (n = 36). In terms of educational background, most patients had attained university-level education, with 30 participants (39.5%) holding a bachelor's degree and 16 (21.1%) a master's degree. Senior high school graduates represented 27.6%, while those with only elementary or junior high education were less common at 6.5% and 5.3%, respectively. These demographic characteristics are summarized in Table 1.

Table 1. Frequency Distribution of Patients with Diabetic Foot Ulcers Based on Demographic Characteristics

Variable	Frequency (n)	Percentage (%)
Age	54.84 ± 10.531 (36–80) years	
Gender		
Male	40	53.1%
Female	36	46.9%
Educational Level		
Primary School	5	6.5%
Junior High School	4	5.3%
Senior High School	21	27.6%
Bachelor's Degree	30	39.5%
Master's Degree	16	21.1%

Wound measurements obtained through manual assessment demonstrated a mean ulcer length of 5.94 ± 2.87 cm (range 1.42–11.24 cm) and a mean width of 3.61 ± 1.74 cm (range 1.20–8.50 cm). In comparison, measurements taken using the ImitoMeasure application revealed longer and wider estimates, with mean ulcer length recorded as 7.49 ± 3.75 cm (range 1.64–18.28 cm) and mean width as 4.33 ± 1.70 cm (range 1.30–7.61 cm). Beyond simple dimensions, the application enabled automated calculation of surface area and perimeter, yielding mean values of 26.14 ± 19.47 cm² (range 1.41–78.78 cm²) and 19.09 ± 8.62 cm (range 4.56–38.81 cm), respectively. These findings are detailed in Table 2.

Table 2. Frequency Distribution of Patients with Diabetic Foot Ulcers Based on Length, Width, Depth, and Area of Ulcer

Variable	Mean ± SD (Min–Max)
Manual Measurement	
Length	5.942 ± 2.874 (1.415–11.243) cm
Width	3.606 ± 1.743 (1.199–8.504) cm
ImitoMeasure	
Length	7.492 ± 3.745 (1.640–18.28) cm
Width	4.334 ± 1.697 (1.30–7.61) cm
Area	26.1368 ± 19.466 (1.41–78.78) cm²
Perimeter	19.085 ± 8.6203 (4.56–38.81) cm

When assessing the diagnostic validity of the smartphone application, ROC curve analysis revealed relatively low discriminative ability. The area under the curve (AUC) for ulcer length was 0.375, suggesting poor agreement between manual and digital length assessments. Similarly, the AUC for ulcer surface area was 0.376, also indicating suboptimal diagnostic performance. These findings are summarized in Table 3, while Figures 1 and 2 present the ROC curves for length and surface area measurements, respectively.

Table 3. Sensitivity and Specificity Values of the Imitomeasure Application in Wound Assessment of Diabetic Foot Ulcer Patients

Variable	AUC
Length	0.375
Area	0.376

Figure 1. ROC Curve of Manual and Imito Length Measurement

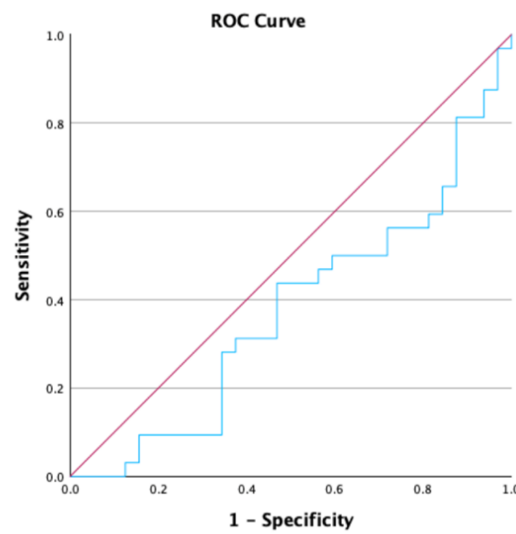
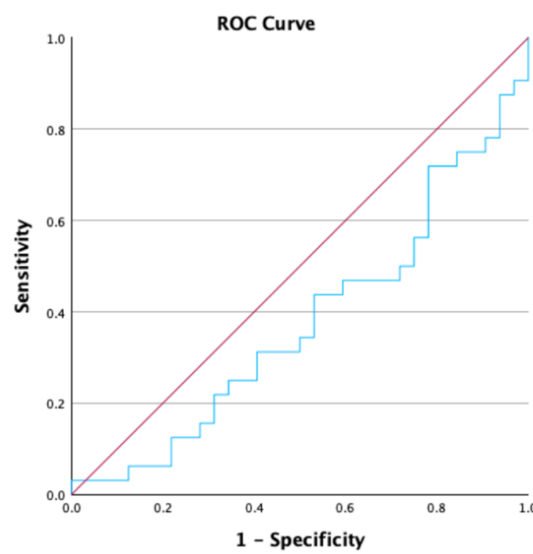


Figure 2. ROC Curve of Manual and Imito Area Measurement



The sensitivity and specificity analysis demonstrated that ImitoMeasure was limited in replicating manual measurements for both ulcer length and ulcer surface area. The low AUC values indicated that the application was unable to achieve clinically acceptable diagnostic thresholds when compared to conventional ruler-based assessments. This finding suggests potential measurement bias related to imaging technique, calibration errors, or wound morphology affecting automated edge detection.

Despite these limitations, the use of ImitoMeasure provided advantages in terms of practicality, rapid digital documentation, and the ability to quantify parameters beyond manual measurement, such as perimeter and exact surface area. These features are potentially valuable in telemedicine settings, particularly for longitudinal monitoring of wound progression where trends may be more clinically relevant than absolute agreement with manual methods.

While manual measurement remains the reference standard, the digital approach using the ImitoMeasure application demonstrated feasibility and practicality but lacked sufficient diagnostic accuracy in length and area measurements. Further refinement of calibration protocols, imaging standardization, and algorithm optimization may be necessary to enhance its sensitivity and specificity before widespread clinical implementation as a telemedicine tool in DFU assessment.

IV. DISCUSSION

Diabetic foot ulcer (DFU) is a serious complication of *Diabetes mellitus* that requires accurate assessment to support effective management and prevent limb-threatening outcomes. This study aimed to evaluate the diagnostic performance of the smartphone-based wound measurement application ImitoMeasure as an alternative telemedicine approach by comparing its measurements with manual methods, considered the reference standard. The discussion below interprets the findings on demographic distribution, wound measurements, diagnostic validity, and their implications in clinical practice.

The mean age of patients in this study was 54.8 years, consistent with the typical age distribution of DFU patients as reported, found the highest prevalence among middle-aged to elderly populations (50–60 years). The near-equal gender distribution (53.1% male vs. 46.9% female) also mirrors prior epidemiological data, highlighting that DFU is not strongly sex-dependent. However, our study population showed a relatively high proportion of patients with tertiary education (40.6% bachelor's degree), which contrasts with Najihah (2021), who reported predominantly lower educational attainment among DFU patients. This discrepancy may reflect the referral pattern to Adam Malik General Hospital, a tertiary care center serving socioeconomically and educationally diverse populations.[13]

Socio-demographic factors are relevant to DFU severity and management. Older age is associated with impaired wound healing due to vascular compromise and neuropathy, while lower educational attainment is often linked to reduced health literacy, delayed care-seeking, and poor self-care practices. Interestingly, the relatively high education level in our cohort may suggest greater awareness and health-seeking behavior, yet the persistence of advanced DFU presentation indicates that sociodemographic advantages alone do not prevent disease progression, likely due to systemic factors such as healthcare access and comorbid burden.[14]

Comparison of ulcer length revealed that ImitoMeasure produced larger mean values than manual measurements (7.49 cm vs. 5.94 cm). This tendency of digital measurement to overestimate length may be explained by the application's edge detection algorithm, which is designed to capture irregular wound borders that manual ruler-based techniques may underestimate. Wang et al. (2017) similarly reported that smartphone-based wound assessment tools demonstrated heightened sensitivity in delineating wound margins, particularly in ulcers with irregular or undermined edges.[11]

Conversely, ulcer width showed the opposite trend, with ImitoMeasure reporting smaller values (4.33 cm) compared to manual measurement (7.49 cm). This discrepancy may reflect technical limitations such as calibration errors, camera resolution, or suboptimal photographic angles, which could distort the horizontal dimension of the wound. Foltynski et al. (2019) emphasized that lack of standardization in image capture can significantly impact the reproducibility of digital wound measurements. Thus, variability in training and technique among users may explain the inconsistency across dimensions in this study.[15]

Beyond length and width, ImitoMeasure also provided automated calculation of wound surface area and perimeter, with mean values of 26.1 cm² and 19.1 cm, respectively. These features are advantageous, as manual calculation of area and perimeter is time-consuming and subject to greater observer variability DFU area may range widely (<5 cm² to >50 cm²) depending on severity, which is consistent with the variability observed in our study population. Although the absolute values diverged from manual measures, the ability to generate reproducible digital area estimates may still be clinically useful for monitoring healing trends over time.[13]

Diagnostic validity analysis revealed low AUC values for both ulcer length (0.375) and area (0.376). Since an AUC of 0.5 indicates random performance, these findings suggest poor discriminatory capacity of ImitoMeasure relative to manual measurements. This result diverges markedly from prior studies. Wang et al. (2017) reported high diagnostic accuracy (AUC 0.85–0.90) for wound measurement applications, while Howell et al. (2021) demonstrated strong correlation coefficients (>0.9) between digital and manual wound measurements.[11,16]

Several factors may account for the low AUC values in this study. First, the imaging algorithm employed by ImitoMeasure may be less advanced compared to other applications such as WoundVision, limiting its sensitivity in detecting irregular wound edges. Second, technical factors such as lighting, smartphone resolution, and calibration protocols likely affected image accuracy. Third, user-related factors, including lack of standardized training, may have contributed to errors in image capture. Widianawati et al. (2023) emphasized that technology literacy, education level, and prior experience significantly influence adoption and accuracy of digital health applications.[14]

Wound characteristics also likely influenced results. DFUs often present with necrosis, slough, and irregular edges, complicating digital boundary detection. Singh et al. (2022) reported that necrotic tissue and poor lighting conditions hinder edge recognition in smartphone-based wound assessments. These morphological complexities may explain why ImitoMeasure underperformed in this cohort despite its theoretical algorithmic capacity.[17]

It is important to note that manual measurement, while considered the gold standard, also has inherent limitations. Inter-rater variability, challenges in measuring irregular wounds with a straight ruler, and reliance on two-dimensional approximations contribute to inaccuracy. Toma et al. (2022) highlighted that even manual methods may not provide true wound area, suggesting that low AUC values may partly reflect imperfections in the reference standard itself.[18]

When compared to global studies, the present findings highlight significant divergence. Wang et al. (2017) and Howell et al. (2021) demonstrated robust diagnostic agreement between smartphone-based wound applications and manual measurement, supporting their use in clinical practice. In contrast, our findings suggest that ImitoMeasure requires further refinement to achieve similar reliability. These differences may stem from disparities in technology, training, and study design across settings.[11,16]

Despite these limitations, the potential of smartphone applications for DFU assessment in Indonesia remains considerable. In a country with wide geographic disparities in healthcare access, telemedicine can reduce travel burden, improve follow-up adherence, and facilitate earlier detection of complications. Nejati et al. (2016) reported that mobile health applications enhanced chronic disease management by enabling remote monitoring and patient engagement, which is highly relevant for DFU care.[19]

For clinical implementation, structured recommendations include standardized training for healthcare providers, development of hospital-level SOPs for wound imaging, and algorithmic refinement of applications to improve boundary detection. Barakat-Johnson et al. (2022) emphasized the importance of integrating artificial intelligence and machine learning (AI/ML) to enhance diagnostic performance, particularly for automated wound edge detection and healing prediction.[20]

Looking ahead, AI-powered wound assessment holds promise for addressing the limitations of current applications. Machine learning algorithms trained on large datasets of DFU images could improve accuracy in detecting wound boundaries and tissue types, even in complex ulcers with necrosis or infection. Such innovations may enable fully automated, reliable telemedicine-based wound monitoring systems in tertiary hospitals like Adam Malik General Hospital.

This study demonstrates that while ImitoMeasure offers practical advantages in wound documentation and telemedicine potential, its current diagnostic accuracy is limited. The low AUC values indicate that it cannot yet replace manual methods as a standalone tool. Nevertheless, with algorithmic improvement, standardized user training, and integration into telemedicine systems, smartphone applications could play a transformative role in DFU management in Indonesia, particularly in tertiary referral settings.

V. CONCLUSION

This study demonstrated that the use of the ImitoMeasure smartphone application in the assessment of *diabetic foot ulcer*(DFU) at Adam Malik General Hospital Medan holds promise as a telemedicine tool, but its diagnostic accuracy remains limited. The mean wound dimensions obtained using ImitoMeasure showed significant variability when compared to manual measurement, and the calculated Area Under the Curve (AUC) values were notably low (~0.37 for length and area), suggesting suboptimal sensitivity and specificity. These findings indicate that while ImitoMeasure can complement clinical practice, it cannot yet replace manual measurement as the gold standard in DFU assessment.

Nevertheless, the potential utility of smartphone-based wound assessment in telemedicine should not be overlooked. With appropriate enhancements in image processing algorithms, standardized operating procedures for image acquisition, higher quality device specifications, and structured user training, applications such as ImitoMeasure may contribute to improved accessibility, cost-effectiveness, and continuity of care for DFU patients, especially in resource-limited settings. Further development and validation studies are required before such applications can be reliably integrated into clinical workflows at tertiary referral hospitals.

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