GHM Open. 2025; 5(1):52-57.

DOI: 10.35772/ghmo.2023.01024

From prototype to implementation: Development of the DMIST scoring system for monitoring diabetic foot ulcers

Rie R. Yotsu[1,2,§,*], Makoto Oe[3,§], Hiromi Sanada[4], Takeshi Tamaki[1]

[1] Department of Dermatology, National Center for Global Health and Medicine, Tokyo, Japan;
[2] Department of Tropical Medicine and Infectious Disease, Tulane School of Public Health and Tropical Medicine, New Orleans, USA;
[3] Department of Clinical Nursing, Faculty of Health Sciences, Institute of Medical, Pharmaceutical and Health Sciences, Kanazawa University, Ishikawa, Japan;
[4] Ishikawa Prefectural Nursing University, Ishikawa, Japan.

Abstract: Diabetic foot ulcers (DFUs) pose a significant health challenge, marked by high morbidity, mortality, and healthcare costs. Effective evaluation of the DFU healing process is crucial to prevent delays and enhance patient outcomes. Traditional wound healing scales like PUSH and DESIGN have proven suboptimal for DFUs, necessitating a disease-specific approach. This communication introduces a qualitative study, which served as the first step in developing the DMIST scale, a tool to monitor and assess DFUs over time. Using a morpho-qualitative analysis method, we examined 50 DFUs in 42 patients from a hospital in Tokyo, classifying ulcers by primary pathogenic factors and healing periods. Our analysis identified 8 categories and 33 sub-categories of morphological characteristics. Key findings included identification of features such as the "red ring", "hyperkeratosis", and "rolled wound edges", each affecting healing times. The DMIST scale integrates these visual signs, offering a practical tool for DFU management, particularly valuable in low-resource settings. This scale has undergone validation and refinement through international collaboration, with the aim to improve DFU patient outcomes globally. We hope the DMIST scale to be widely adapted and that our experience in its development will aid future development of wound assessment tools from various causes.

***Keywords*:** assessment, management, wound, neuropathy, peripheral arterial disease, infection

Introduction

Diabetic foot ulcers (DFUs) are a major complication of diabetes, with their incidence rising substantially alongside the global diabetic population. DFUs can severely impact quality of life of those affected, limiting daily activities and potentially leading to amputation. They are associated with significant morbidity, mortality, and high healthcare costs. The protracted nature of DFUs is partly due to delayed diagnosis and inadequate care, making early diagnosis and treatment crucial. Effective evaluation of the wound healing process is essential to identify deviations from normal healing and to adjust management accordingly to avoid delayed healing.

Existing wound healing scales like the Pressure Ulcer Scale for Healing (PUSH) (*1*) and the DESIGN (*2*) for pressure ulcers, and the Southampton Wound Scoring System (*3*) and ASEPSIS (*4*) for surgical wounds, have proven valuable. However, their application to DFUs has been suboptimal. With this background, we have developed the DMIST scale, which is a disease-specific scale for monitoring and assessing the clinical course of DFUs.

The wound healing process primarily depends on the depth of the wound. Wounds that affect only the superficial dermis are healed by regeneration, while wounds that extend deeper into the dermis need to go through repair, typically involving four stages: inflammatory, proliferation, maturation, and epithelialization (healed). DFU pathogenesis involves a complex interplay between three main underlying pathogenic factors: neuropathy, angiopathy, and infection. Despite empirical knowledge of their effects on the repair process (*5*), the distinct impacts of these factors remain underexplored. Moreover, signs of deviation from the normal healing process by primary pathogenic factors, and their relation to healing time, are still poorly understood.

Therefore, in order to develop the DMIST scale, we first needed to identify the morphological characteristics of the healing process of DFUs by different primary

pathogenic factors and at various stages of healing. This identification allowed us to select signs that are suggestive of deviation from the normal wound healing process to be included in our prototype DMIST scale. The aim of this short communication is to share this first stage of the DMIST scale development.

Research design for developing the prototype DMIST scale

Morpho-qualitative analysis method

We employed a morpho-qualitative analysis method developed by our research team (*6*). This method uses clinical photos of lesions to create drawings, followed by providing verbal descriptions to each photo. Creating drawings helps capture small, subtle signs that may be overlooked when directly verbalizing from photos. The verbal data are subsequently analyzed using a qualitative descriptive study method.

Subjects and data collection process

Study subjects were recruited from patients with DFUs who visited the Dermatology Department of a tertiary hospital in Tokyo, Japan between August 2010 and January 2014. Photos of DFUs were taken during outpatient visits, with the healing period defined as number days from first confirmed visit to wound closure. DFUs were classified following the Kobe classification based on their primary pathogenic factor: Type I (peripheral neuropathy), Type II (PAD), Type III (infection), and Type IV (combination of factors) (*7*). Peripheral neuropathy was assessed using a Semmes-Weinstein 5.07/10 g monofilament, 128-Hz tuning fork, Achilles tendon reflexes, coefficient of variation for the R–R intervals in electrocardiogram, and nerve conduction velocity exams. Neuropathic symptoms such as pain, paresthesia, tingling, discomfort, and numbness were also recorded. PAD was assessed using ankle–brachial index (ABI), skin perfusion pressure (SPP), transcutaneous oxygen pressure ($tcpO_2$), and enhanced computed tomography (CT) scan. Infection was assessed by clinical and laboratory (elevated white blood cell count and C-reactive protein) findings, and when in need, image exams (X-ray, CT, or magnetic resonance imaging) were performed.

Data analysis

The verbal data obtained through the morpho-qualitative analysis method were analyzed for similarities and aggregated into sub-categories and broader categories. Extracted categories and subcategories were then organized into spreadsheets based on three healing periods (≤ 30 days, 31-90 days, ≥ 91 days) and by Kobe classification. These characteristics were examined within and across these groups.

Ethical considerations

This study was conducted in accordance with the principles of the Declaration of Helsinki, with approval by the Ethical Committee of the National Center for Global Health and Medicine, Tokyo, Japan (approval number: 727). All participants provided consent for use of their clinical data and photographs for scientific purposes.

Key results

Overview of study subjects

A total of 50 DFUs in 42 diabetic patients were recruited and evaluated. Their average age was 65.9 ± 14.1 years, with 76.1% male. The most common ulcer site was the toes (25/50, 50%), and the most common trigger was vasculopathy (9/50, 18%) followed by shoe sore (7/50, 14%).

The average follow-up time was 77.4 ± 90.5 days, ranging from 1 to 377 days, with a mean interval between observations of 24.1 ± 38.5 days. A total of 227 photographs were taken throughout the healing process and were included in the analysis. DFUs were classified by the Kobe classification, and there were 14 Type I, 15 Type II, 12 Type III and 9 Type IV. Twenty-two DFUs achieved complete healing, 22 were in advanced healing stages, 2 wounds progressed to gangrene, and 2 required amputation. Two participants died during the course of the study.

Overview of extracted morphological characteristics

Our analysis resulted in 8 categories and 33 subcategories of morphological characteristics. Table 1 presents these findings together with their definitions. Figure 1 and Supplemental Table S1 (*https://www.ghmopen.com/site/supplementaldata.html?ID=93*) present these characteristics for the three healing periods (≤ 30 days, 31-90 days, ≥ 91 days) and for the four Kobe classification types. For the healing periods, those that reached complete healing (22 DFUs) were included in the analysis.

This study identified the different morphological characteristics of DFU healing. While some characteristics were shared, there were notable differences during the inflammatory and proliferation phases based on healing times and by primary pathogenic factors or the Kobe classification. Maturation phase characteristics were more similar across groups. Furthermore, we were able to improve the understanding of some characteristics, which have been empirically known, but have been poorly studied or documented previously, such as "red ring",

Table 1. Morphological characteristics of the healing process of diabetic foot ulcers extracted from our analysis and their definitions

Category	Subcategory	Definitions
Depth	Dermal level	Tissue loss/damage extending to the dermis
	Tendon level	Tissue loss/damage extending to the tendon
	Bone/joint level	Tissue loss/damage involving the bone or joint
Size	Enlargement	Increase in wound size
	Decrease	Decrease in wound size
Granulation tissue	Red granulation tissue	New connective tissue with red color, featuring proliferation of microscopic blood vessels
	Granulation tissue with swelling	New connective tissue with swelling due to inflammation or excessive exudate
	Bright red granulation tissue	New connective tissue with bright red color, featuring excessive proliferation of microscopic blood vessels
	Granulation tissue with bumpy surface	New connective tissue with a papular to nodular surface in appearance
	Excessive granulation tissue: Excessive granulation tissue	Excessive growth of new connective tissue, oftentimes protruding the level of the surrounding skin
Necrotic tissue	Eschar	Thick dry/dead black necrotic tissue
	Hard slough	Hard yellow fibrinous tissue consisting of fibrin, pus, and proteinaceous material
	Soft slough	Soft yellow fibrinous tissue consisting of fibrin, pus, and proteinaceous material
	Oatmeal/porridge-like necrotic tissue	Dead tissue with oatmeal/porridge-like appearance and texture; whitish to yellowish in color, mushy in texture
Translucent film	Translucent film	Jelly-like translucent thin film covering the wound surface
Wound edge	Maceration	Softening and whitening of skin due to constantly wet environment
	Red ring	Wound edge that is rimmed by a thin red line /Red-rimmed wound edge
	Hyperkeratosis	Excessive keratinous proliferation on the wound edge/ layers of keratinization on the wound edge
	Rolled	Extension of the surrounding skin covering the wound edge
	Petechiae	Signs of petechiae (subcutaneous purple dots) on the wound edge
	Pink ring	New skin formation (pinkish in color) from the wound edge
	Bridging	Bridging between two points of the wound edge with new skin formation
Tunnel/ Undermining	Tunnel	Narrow passageway inside the wound resulting in dead space, occurs in one direction
	Undermining	Erosion under the wound edge, occurs in one or more directions
Surrounding skin	Pink-purple-red change in skin color (non-infection):	Pinkish, purplish, to reddish color change of the surrounding skin from pressure, ischemia, *etc.* but not from infection
	Pink-purple change in skin color (post-infection):	Pinkish to purplish color change of the surrounding skin after infection; no three cardial signs of infection, *i.e.*, redness, swelling, and warmth
	Redness and swelling	Reddish color change and swelling also often associated with warmth of the surrounding skin as signs of infection
	Hyperpigmentation	Darkening of skin color
	Keratin flakes	Shedding of the upper keratin layer during or after inflammation
	Natural redness	Sign of inflammation due to accelerating wound healing process; natural redness as a result of dilation of blood vessels to allow circulating cells, nutrients, enzymes, antibodies, and other beneficial elements reach the wound; no signs of infection
	Hypopigmentation	Lightening of skin color
	Purpura/old bleeding	Purpura or old bleeding (still reddish in color, bleeding in the shallower level of the dermis compared to purpura) of the surrounding skin
	Fine lines	Lines observed in the surrounding skin during wound contraction

"hyperkeratosis", and "rolled wound edges".

Red ring sign

We initially hypothesized that the red ring sign is unique to wounds with underlying PAD. It was interesting however, that through our analysis, it was a shared feature across all Types of DFUs during the inflammatory phase, irrespective of the presence of PAD. Thus, this study's findings indicate that both micro-vasculopathy from peripheral neuropathy and macro-vasculopathy from PAD can lead to the presentation of the red ring sign. The red ring may be a sign that there is an imbalance in circulation, which can lead to ischemia inside the wound and delay wound healing. Abnormalities of the blood vessels in

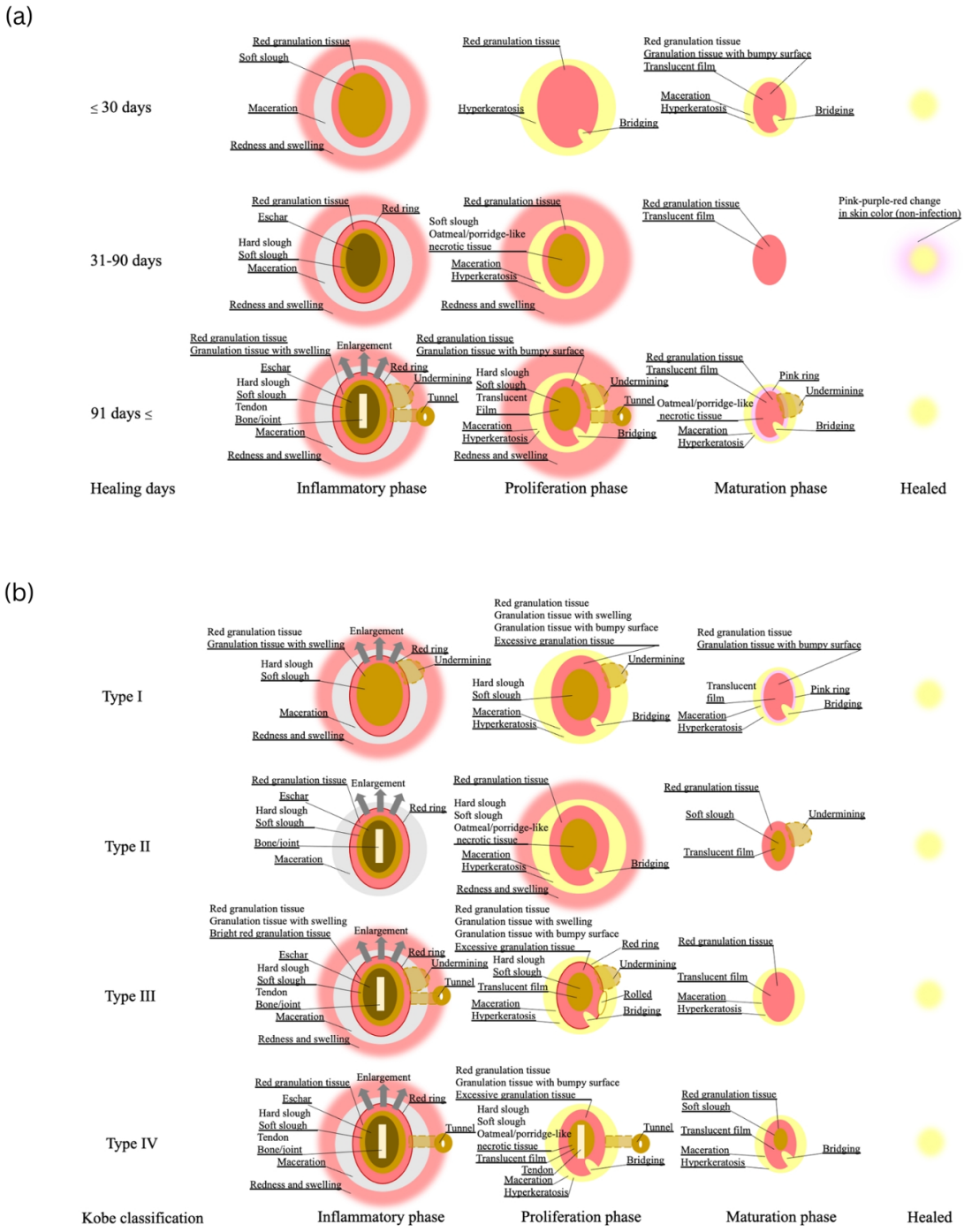

Figure 1. Pattern diagram of morphological characteristics of the healing process of diabetic foot ulcers. (a) Based on healing duration, **(b)** Based on the Kobe classification.

the wound bed and wound edges of DFUs have been observed histopathologically (*8*).

Hyperkeratosis

Hyperkeratosis on the wound edges, a common feature across all groups, started from the proliferative phase until the mature phase. The mechanism of this hyperkeratosis is not well understood. There has been a report suggesting that suppression of desmocollin 1 degradation in diabetic callus may be contributing in its development (*9*). In a study using rat models, hyperkeratosis of wound edges was observed histologically and was considered to be one of the major causes of delayed healing (*10*). It is also known that excessive hyperkeratosis of wound edges needs to be treated in order to accelerate wound healing (*11-13*). In this study, we treated hyperkeratosis by excision, which may have resulted in shortening of healing times of some wounds. The wounds that showed slower

recurrence of hyperkeratosis tended to heal quicker.

Infection-related characteristics, including rolled wound edges

Infection-related characteristics were identified in the study. Tunnels only appeared during the inflammatory and proliferation phases of Kobe classification Types III and IV. Tunnelling is likely linked to infection, serving as a good cultivating space for bacteria (*14*). A rolled wound edge was found to only appear during the proliferation phase of Type III. The condition we observed is also defined as epibole in some literature, and is commonly known to be associated with infection (*15*). It is a condition when the upper epidermal cells roll down over the lower epidermal cells, inhibiting side-ways migration of cells (*15*). In a recent study by Armstrong *et al*., they showed a high bacterial load on wound edges and periwound (2 cm radius around the wound edge) using fluorescence-imaging (*16*). It may be possible that these bacteria are playing some role in altering migration of the epidermal cells. Tunnelling and rolled wound edges were linked to specific DFU types, highlighting the importance of managing infection to improve DFU healing outcomes.

Morphological characteristics related to healing time

Predicting healing time can aid treatment decisions. DFUs healing within 30 days were typically shallow, without severe tissue involvement or significant necrosis such as eschar and hard slough. In contrast, DFUs taking over 91 days showed deeper tissue involvement, tunneling or undermining, and unique characteristics such as petechiae during the inflammatory phase, appearance of translucent film during the proliferative phase, and a pink ring during the maturation phase. Appearance of petechiae in the periwound region can be a sign of abnormal blood vessels.

Limitations

In this study, the observations were made while the patients were receiving treatment accordingly to the latest standard of care, and some of these treatment methods could have affected the morphological characteristics of their ulcers. We documented treatment methods but did not reflect this in our analysis due to its complexity. Patients' follow-up intervals were not uniform, *i.e*., it was made at the convenience of our patients, which could have led to missing some morphological characteristics.

Development of the prototype DMIST scale

Building on these findings, we developed the prototype DMIST scale, a disease-specific scale for monitoring and assessing clinical course of DFUs. We included morphological characteristics such as "red ring", "hyperkeratosis", and "rolled wound edges", which were identified during the aforementioned study. These characteristics are simple to observe, and the DMIST scale is based solely on visual signs. As the global prevalence of diabetes continues to be on the rise, with projections indicating that over 90% of the increase in the diabetic population by 2045 will occur in low- and middle-income countries (*17*), our aim for the DMIST scale is to be particularly valuable for follow-up of DFU patients, especially in low-resourced settings with limited healthcare access.

Current status of the DMIST scale

Following this morphological study, we conducted validation studies (*18*), and after multiple refinements, we now have an established tool. The DMIST scale was validated and refined through international collaborations. Further studies were undertaken and it was used to test the relationship between items of DMIST and healing of DFUs after 4 weeks (*19*) and the quality of life of patients living with DFUs (*20*). We have presented the tool at several conferences, and it is now beginning to be adopted by footcare clinics across Japan and other countries.

In conclusion, the steps to develop a disease assessment tool require verification of reliability and validity. While research has explored the pathophysiology of DFU chronicity, a substantial gap remains in translating this knowledge into real-world clinical practice. This study provides valuable insights into the morphological characteristics of DFU healing, identifying indicators that supported development of the DMIST scale for better DFU management. The prototype DMIST has since undergone rigorous validation of its reliability and validity in its current form. Our hope for the DMIST scale is that it will be widely adopted to improve patient outcomes and well-being for those with DFUs. Additionally, we believe our experience in its development will aid future development of wound assessment tools for various etiologies.

Funding: This study was funded through the National Center for Global Health and Medicine (NCGM) Intramural Research Fund (22-120).

Conflict of Interest: The authors have no conflicts of interest to disclose.

References

1. Stotts NA, Rodeheaver GT, Thomas DR, Frantz RA, Bartolucci AA, Sussman C, Ferrell BA, Cuddigan J, Maklebust J. An instrument to measure healing in pressure ulcers: Development and validation of the pressure ulcer scale for healing (PUSH). J Gerontol A Biol Sci Med Sci. 2001; 56:M795-M799.

2. Sanada H, Moriguchi T, Miyachi Y, Ohura T, Nakajo T, Tokunaga K, Fukui M, Sugama J, Kitagawa A. Reliability and validity of DESIGN, a tool that classifies pressure ulcer severity and monitors healing. J Wound Care. 2004; 13:13-18.
3. Bailey IS, Karran SE, Toyn K, Brough P, Ranaboldo C, Karran SJ. Community surveillance of complications after hernia surgery. BMJ. 1992; 304:469-471.
4. Wilson AP, Treasure T, Sturridge MF, Gruneberg RN. A scoring method (ASEPSIS) for postoperative wound infections for use in clinical trials of antibiotic prophylaxis. Lancet. 1986; 1:311-313.
5. Yotsu RR, Pham NM, Oe M, Nagase T, Sanada H, Hara H, Fukuda S, Fujitani J, Yamamoto-Honda R, Kajio H, Noda M, Tamaki T. Comparison of characteristics and healing course of diabetic foot ulcers by etiological classification: Neuropathic, ischemic, and neuro-ischemic type. J Diabetes Complications. 2014; 28:528-535.
6. Nanjo Y, Nakagami G, Kaitani T, Naito A, Takehara K, Lijuan J, Yahagi N, Sanada H. Relationship between morphological characteristics and etiology of pressure ulcers in intensive care unit patients. J Wound Ostomy Continence Nurs. 2011; 38:404-412.
7. Terashi H, Kitano I, Tsuji Y. Total management of diabetic foot ulcerations--Kobe classification as a new classification of diabetic foot wounds. Keio J Med. 2011; 60:17-21.
8. Ferguson MW, Herrick SE, Spencer MJ, Shaw JE, Boulton AJ, Sloan P. The histology of diabetic foot ulcers. Diabet Med. 1996; 13 Suppl 1:S30-S33.
9. Tsuruoka K, Oe M, Minematsu T, Tomida S, Ohashi Y, Shimojima Y, Mori Y, Nitta S, Qin Q, Abe M, Yamauchi T, Sanada H. Skin characteristics associated with foot callus in people with diabetes: A cross-sectional study focused on desmocollin1 in corneocytes. J Tissue Viability. 2020; 29:291-296.
10. Huang L, Minematsu T, Kitamura A, Quinetti PC, Nakagami G, Mugita Y, Oe M, Noguchi H, Mori T, Sanada H. Topical administration of acylated homoserine lactone improves epithelialization of cutaneous wounds in hyperglycaemic rats. PLoS One. 2016; 11:e0158647.
11. Murphy C, Atkin L, Dissemond J, Hurlow J, Tan YK, Apelqvist J, James G, Salles N, Wu J, Tachi M, Wolcott R. Defying hard-to-heal wounds with an early antibiofilm intervention strategy: Wound hygiene. J Wound Care. 2019; 28:818-822.
12. Leaper DJ, Schultz G, Carville K, Fletcher J, Swanson T, Drake R. Extending the TIME concept: What have we learned in the past 10 years? (*). Int Wound J. 2012; 9 Suppl 2:1-19.
13. Sibbald RG, Elliott JA, Persaud-Jaimangal R, *et al.* Wound bed preparation 2021. Adv Skin Wound Care. 2021; 34:183-195.
14. Sibbald RG, Woo K, Ayello EA. Increased bacterial burden and infection: The story of NERDS and STONES. Adv Skin Wound Care. 2006; 19:447-461; quiz 461-463.
15. Wound Care Advisor. Causes, prevention, and treatment of epibole. *https://woundcareadvisor.com/causes-prevention-treatment-epibole/* (accessed July 29, 2024).
16. Armstrong DG, Edmonds ME, Serena TE. Point-of-care fluorescence imaging reveals extent of bacterial load in diabetic foot ulcers. Int Wound J. 2023; 20:554-566.
17. IDF Diabetes Atlas. IDF Diabetes Atlas 2021. *https://diabetesatlas.org/atlas/tenth-edition/* (accessed July 29, 2024).
18. Oe M, Yotsu RR, Arisandi D, Suriadi, Sakai Y, Imran, Takehara K, Nakagami G, Tamaki T, Sugama J, Sanada H. Validity of DMIST for monitoring healing of diabetic foot ulcers. Wound Repair Regen. 2020; 28:539-546.
19. Tsuchiya S, Suriadi, Sanada H, Sugama J, Oe M. Relationship between items of DMIST and healing of diabetic foot ulcers. Int Wound J. 2023; 20:345-350.
20. Oe M, Saad SS, Jais S, Sugama J. Impact of foot ulcer-related factors on quality of life in patients with diabetes: Prospective observational study. Int Wound J. 2024; 21:e14895.

Received November 28, 2023; Revised July 30, 2024; Accepted August 16, 2024.

Released online in J-STAGE as advance publication September 13, 2024.

[§]*These authors contributed equally to this work.*
**Address correspondence to*:
Rie R. Yotsu, Department of Dermatology, National Center for Global Health and Medicine, National Center for Global Health and Medicine, 1-21-1 Toyama, Shinjuku-ku, Tokyo 162-8655, Japan.
E-mail: rieyotsu@hosp.ncgm.go.jp