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Application to Quantify Ulcer Areas and Track Their Progress

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Summary: Chronic ulcer treatments, such as those for diabetic foot ulcers and pressure sores, require prolonged treatment periods. Availability of effective objective indicators to determine treatment method efficacy is limited. Ulcer area is the agreed-upon indicator for ulcer healing because it contracts and/or undergoes epithelialization as healing occurs. Ulcer surface properties such as healthy or infected granulation and slough or necrotic tissue are also used. This study aimed to develop a user-friendly application automating the ulcer area measurement process and included a graphical time-series display of ulcer components manually classified by users. Images of ulcers photographed with adjacent circular 1.5-cm diameter stickers were prepared. In the application, users manually categorized and color-coded each image into five component types based on different ulcer characteristics. The application calculated the area of each component in pixels and then estimated the actual area using the sticker area as a reference. It also collated color-coded images and presented graphical illustrations of changes in area over time. The results indicated the application successfully automated area measurements of each ulcer component and graphical displays of changes in ulcer component areas over time. It enabled users to visually track quality changes and the chronic ulcer healing process. Historically, ulcer assessments are subjectively conducted via visual examination by physicians, creating less reproducible, objective data. Although ulcer properties still required manual entry by users, our application streamlined ulcer area measurement and time-course visualization and sets the groundwork for a fully automated artificial-intelligence–driven ulcer diagnosis system. *(Plast Reconstr Surg Glob Open 2024; 12:e5922; doi: 10.1097/GOX.0000000000005922; Published online 19 June 2024.)*

INTRODUCTION

In recent years, the prevalence of treatment for chronic ulcers (eg, diabetic foot ulcers and pressure sores) has increased in the field of plastic surgery in Japan. Treatment of these ulcers generally requires prolonged periods, and it is based on a limited number of indicators that may reflect the pathophysiology of the ulcer. When evaluating ulcer condition, physicians typically place the most importance on visual examination rather than general blood tests or radiographic examination, and two types of visual information are crucial to qualitatively as well as quantitatively characterize their condition. The first is the components constituting the ulcer, such as necrotic tissue, slough, and infected or healthy granulation. The second is the total area of the ulcer and the area of each component. Additionally, tracking the changes in each ulcer component over time leads to a more comprehensive and nuanced assessment of the ulcer's progression.

To make the ulcer evaluation procedure more convenient, we developed an application that analyzes ulcer photographs taken in routine clinical practice. This application prompts users to classify and color-code different ulcer components on the photographs. It measures the area of each component and the total ulcer area. Furthermore, it provides time-series graphs of the temporal changes in each component, offering a comprehensive view of the ulcer's evolution over time.

METHODS

A digital image of an ulcer was photographed with a circular sticker with a diameter of 1.5 cm (scale for area

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measurement) attached adjacent to the ulcer. We developed an application with the following functions: Users categorized the image into five types [sticker, healthy granulation, marbled granulation (less healthy edematous granulation appearing whiter on the surface), slough, and necrosis] and filled in corresponding areas with different colors on the application window. This step was completed manually by users. Using the 1.5-cm diameter circular sticker as a size reference ($\pi r^2 = \pi(1.5 \div 2)^2 \approx 1.77\,cm^2$), the application then calculated the actual area of each ulcer type that had been determined in pixels. The accuracy of the application was checked by comparing the actual values (the area of the ulcer transferred onto a transparent film, photographed, and then measured using ImageJ 1.54g) and the estimated values (area measured by the application) across 15 instances (seven patients, 15 images; each photograph was taken on a different day). As color-coded images were collected over time, the application displayed the results for area in a time-series graph. The color-coded ulcer image data were saved as image files, and the time-series graphs for each patient were saved as ".CSV" or image files. Time-series graphs were created for three patients. Accordingly, area measurements were conducted on 10 patients, including seven for verification of accuracy of application-based measurement and three for the creation of time-series graphs. We excluded small or inconsistently photographed ulcers.

RESULTS

The application successfully automated area measurement of each ulcer component that users manually annotated on the application window and graphically displayed changes in ulcer areas over time. This result enabled users to visually track ulcer quality changes and the healing process (Figs. 1 and 2). In comparing actual and application-based measurements of ulcer area in each of 15 instances, the correlation coefficient (r) was 0.993 and the mean absolute error (MAE) was 2.17 cm^2, indicating that the estimated values were accurate. In the 11 instances involving flat surfaces, r was 0.995 and the MAE was 0.65 cm^2. Meanwhile, in the four cases involving curved surfaces, r was 0.959 and the MAE was 6.34 cm^2. This suggests that measurements on curved surfaces were slightly less precise compared with flat surfaces. [**See Video (online),** which demonstrates the usage and features of this application.]

Takeaways

Question: How can we make the process of measuring and tracking the healing of chronic ulcers more objective, accurate, and user-friendly?

Findings: We developed an application that automates the ulcer area measurement process and provides a time-series display of ulcer components. This user-friendly tool leverages 2D imaging for ease of use and allows for real-time quantification and visualization of changes in ulcer size and quality.

Meaning: Our application streamlines the chronic ulcer assessment process, helping clinicians make more timely and informed decisions. It partially fills the gap between subjective visual inspection and objective data-based assessment.

DISCUSSION

This study was derived from an ongoing long-term project to develop a fully automated artificial intelligence (AI)–driven ulcer visual diagnosis system. The AI project required copious amounts of training data from patients for AI deep learning. In our opinion, the training data should include the following properties of the ulcer: the components of the ulcer, the total area of the ulcer, and the area of each ulcer component. This information represents qualitative and quantitative aspects of the specific ulcer. During the development phase of the software for automatically analyzing these ulcer properties, it became apparent that training data from a specific patient could be used in daily clinical practice to guide the treatment of that same patient. Therefore, we temporarily changed our research direction and decided to first create a partially-automated ulcer diagnosis application that included area measurements of ulcer components and graphical display of changes over time.

Figure 2 is a graph depicting the area changes of various components of a pressure ulcer (located in the ischial region) over time, as analyzed by our application. Initially, during the first 2.5 months, there was a linear decrease in granulation areas (healthy and marbled granulation), indicating progressive contraction and epithelialization. This period was followed by a plateau phase that suggested stagnation of the healing process. The nearly concordant trends of marbled granulation and well-perfused areas

Fig. 1. An example of the color-coding using this application. A, An ulcer image including a circular sticker with a diameter of 1.5 cm for reference. B, A color-coded image illustrating different ulcer components (sticker in green, healthy granulation in red, marbled granulation in magenta, slough in wheat, and necrosis in blue). C, An ulcer image featuring color-coded overlays to highlight different characteristics.

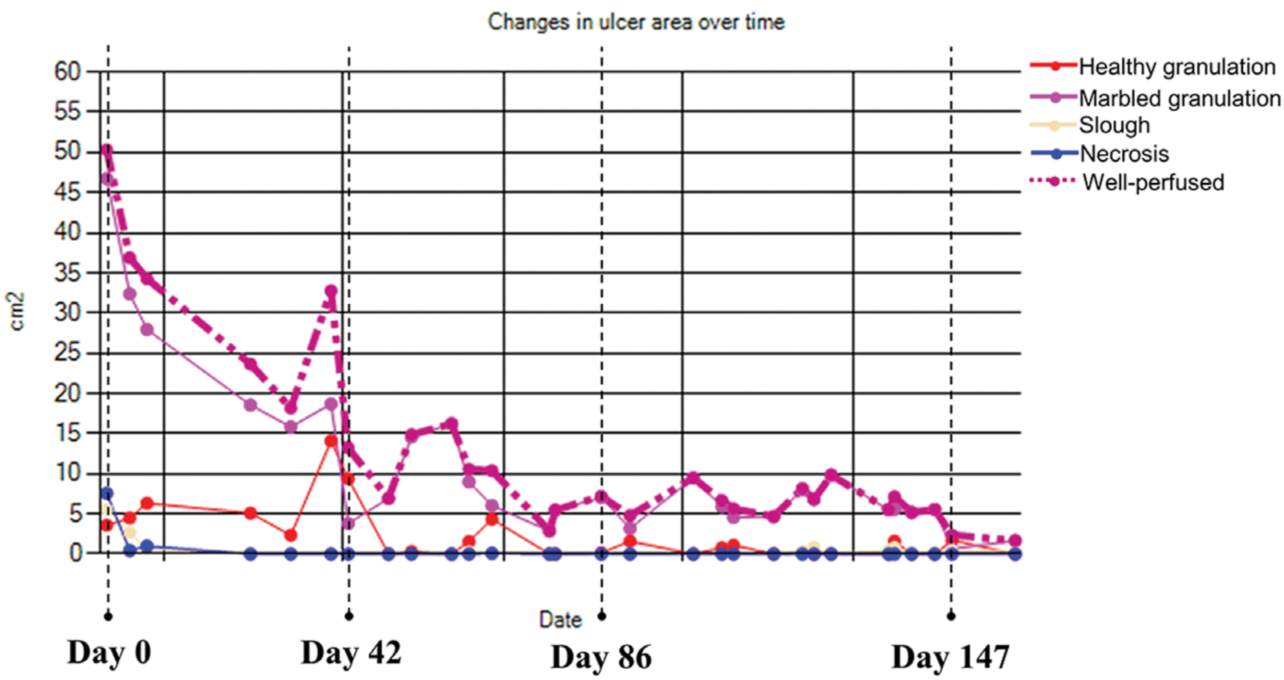

Fig. 2. Graph of an ulcer (ischial decubitus) displaying the areas [healthy granulation, marbled granulation, slough, necrosis, well-perfused (healthy granulation + marbled granulation)] over time.

(sum of healthy/marbled granulation areas) suggested a lack of healthy granulation and widespread bacterial contamination on almost the entire surface of the granulation tissue. Visualizing both qualitative and quantitative changes in the ulcer over time with the graphs allowed accurate assessment of healing phases, including progressive repair and stagnation, with minimal effort and thus could aid decision-making about treatment.

Our application focuses on two-dimensional ulcer measurement and does not measure three-dimensional shapes. Although some applications measure in three dimensions,[1] ours is less suitable for deep fistulae or ulcers with overhanging edges, or those with curved surfaces, where accuracy of area measurement based on two-dimensional photographs may be reduced. Fully automated visual diagnostic systems for lesions on the body surface should include accurate three-dimensional measurement functions. However, it is currently difficult to obtain accurate three-dimensional data for ulcers. We believe this two-dimensional ulcer analytical system will serve as a foundation for a future three-dimensional analytical system.

We reviewed the literature and found other applications for measuring ulcer area from two-dimensional photographs,[2–5] some of which are designed for smartphones.[2–4] Wang et al developed an application that not only measures ulcer area from images but also graphs changes over time.[2] However, these studies lack a key aspect of ulcers: the components of the ulcer that indicate ulcer quality.

To aid plastic surgeons in ulcer analysis, it is important to integrate their visual examination skills, honed in clinical practice, into an automated system. A promising approach involves developing AI specialized in ulcer analysis, which requires high-quality, AI-oriented training data. Our application not only enables automated measurement of ulcer component areas and the creation of a graphical view of their healing process, but also generates ulcer component identification data, which will be valuable for training a fully automated AI-driven ulcer diagnosis system.

CONCLUSIONS

We developed an application for automated ulcer area measurement and visual display of changes over time. It allowed users to effortlessly monitor ulcer areas and their quality changes and will contribute to the development of a fully automated AI-driven ulcer diagnosis system.

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DISCLOSURE

The authors have no financial interest to declare in relation to the content of this article.

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