Sis-MF: A mobile application for monitoring wound healing

Sis-MF: um aplicativo móvel para monitorar a cicatrização de feridas

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ABSTRACT
The aim of this study was to develop a mobile application for monitoring wound healing. With recent advances in mobile technology, an easy-to-access tool becomes necessary to monitor the healing process by photographing the wounds and registering their progression. A Web platform was used for developing the wound monitoring system (Sis-MF) and data was processed by a cloud server. Twenty-seven geometric images were created and the edges of wounds from 27 images were outlined on paper. The geometric shapes and wound shapes were classified by size as small (1-8 cm²), medium (8-24 cm²), and large (> 24 cm²). Their areas were calculated using the Sis-MF mobile application and compared with measurements obtained using the open source ImageJ software. A usability test was performed through a questionnaire, which was completed by five health professionals. The Sis-MF mobile application was created. No significant differences between measurements obtained using Sis-MF and ImageJ were found, indicating that Sis-MF can be used to measure wound areas. The expert suggestions were evaluated and used to improve the mobile application regarding Android platform updates and quality,
usability, accessibility, and accuracy in the calculation of wound areas defined by the wound geometry. A freely-available, efficient mobile application for monitoring wound healing progress was developed for the use of health professionals.

**Keywords:** Webcasts, mobile applications, cell phone, computer storage devices, wounds and injuries, electronic health records.

**RESUMO**
O objetivo deste estudo foi desenvolver um aplicativo móvel para monitorar a cicatrização de feridas. Com os avanços recentes na tecnologia móvel, uma ferramenta de fácil acesso torna-se necessária para monitorar o processo de cicatrização, fotografando as feridas e registrando sua progressão. Foi utilizada uma plataforma web para o desenvolvimento do sistema de monitoramento de feridas (Sis-MF) e os dados foram processados por um servidor nuvem. Vinte e sete imagens geométricas foram criadas e as bordas das feridas de 27 imagens foram contornadas em papel. As formas geométricas e as formas da ferida foram classificadas por tamanho em pequeno (1-8 cm²), médio (8-24 cm²) e grande (> 24 cm²). Suas áreas foram calculadas usando o aplicativo móvel Sis-MF e comparadas com as medidas obtidas usando o software ImageJ de código aberto. Foi realizado teste de usabilidade por meio de questionário, respondido por cinco profissionais de saúde. O aplicativo móvel Sis-MF foi criado. Não foram encontradas diferenças significativas entre as medidas obtidas com o Sis-MF e o ImageJ, indicando que o Sis-MF pode ser usado para medir as áreas da ferida. As sugestões dos especialistas foram avaliadas e utilizadas para melhorar o aplicativo móvel em relação às atualizações da plataforma Android e qualidade, usabilidade, acessibilidade e precisão no cálculo das áreas da ferida definidas pela geometria da ferida. Um aplicativo móvel eficiente e disponível gratuitamente para monitorar o progresso da cicatrização de feridas foi desenvolvido para uso de profissionais de saúde.

**Palavras-chave:** Webcasts, aplicativos móveis, telefone celular, dispositivos de armazenamento em computador, ferimentos e lesões, registros eletrônicos de saúde.

**1 INTRODUCTION**

Technological advances in health care have increased longevity but also resulted in increased rates of age-related diseases and chronic conditions, including wounds. Wounds have been a major concern for health professionals because, in addition to patient morbidity and discomfort, they are associated with a prolonged hospital stay, prolonged treatment regimens, and increased hospital costs [1]. About 6.5 million people in the USA are affected by chronic wounds, resulting in an annual financial burden of about US$ 25 billion to the US healthcare system [2]. The most common chronic wounds are pressure injuries, venous ulcers, and diabetic ulcers [2]. Approximately 60,000 people die each year in the USA from complications resulting from hospital-acquired pressure injuries [1]. Wound treatment requires knowledge of the tissue repair process. Although most wound healing problems are related to local wound factors and surrounding tissue, systemic factors are often responsible for delayed healing [1,3-6].
The US Agency for Healthcare Research and Quality (AHRQ), formerly the Agency for Health Care Policy and Research (AHCPR), recommends debridement of any necrotic tissue found during a wound assessment if the clinical condition of the patient permits [1]. In some situations, such as ischemic wounds with dry necrosis, improvement of the vascular condition is required before debridement, or in cases of ulcers with eschar formation, the procedure may lead to unnecessary discomfort and pain [1,7,8].

Many studies have been conducted on the pathophysiological mechanisms and factors affecting wound healing. The knowledge of the healing process allows directing the treatment to accelerate the outcome and preventing or minimizing complications [9]. Wound assessment and regular standardized documentation are considered important steps in wound management, whereas challenges include non-compliance to protocol and inconsistency of documentation [10]. Detailed documentation is necessary to determine the degree of wound severity, monitor the healing progress, and evaluate the effectiveness of the treatment. However, the current practice of documenting wounds using digital photography is often time-consuming and labor-intensive [11].

Digital photography has been increasingly used in health care facilities, contributing to the assessment of patients and documentation [11]. Digital cameras have been replaced by smartphones, reducing the time between taking pictures and downloading the images to the patient's electronic medical record [12]. Advanced methods have been developed, but their use in clinical practice is limited because of the high cost of the equipment [13]. The success of a digital photo-based initiative that allows the storing of data in computer devices depends on the efforts of healthcare professionals and, especially, on an easily accessible mobile application that provides information on the progress of wound healing. Although electronic documentation is certainly not the only determinant of a good outcome, it may potentially contribute to more effective data collection and documentation, resulting in more effective care [14].

Due to advances in technological resources for wound assessment and documentation and the small number of studies on this topic, the purpose of this study was to develop a mobile application to monitor the healing of skin wounds.

2 METHODS

This was a comparative study on the application of mobile technology for monitoring wound healing. The study was approved by the Research Ethics Committee of the Federal University of São Paulo (UNIFESP), Brazil (approval no. 2.658.669), and
written informed consent was obtained from all participants prior to their inclusion in the study.

A Web platform was used for developing a wound monitoring system (Sis-MF) and data was processed by a cloud server. For the protection of patient records, the mobile application was designed with a sign-in screen that requires the user to provide his or her sign-in information (email address and password) to gain access to the system. A graphical user interface facilitates navigation and, after the assessment of the wound, shows a chart of wound area over time.

The shape and wound areas calculated using the Sis-MF mobile application were compared with measurements obtained using the open source ImageJ software (https://imagej.nih.gov/ij/; National Institutes of Health, Bethesda, MD, USA). For this purpose, the edges of 27 wounds of varying sizes from images selected from the authors’ personal collections were traced and their areas were measured using both the Sis-MF and ImageJ software, as well as the areas of 27 simple geometric shapes, such as circles, ellipses, squares, rectangles, and parallelograms. The shape and wound areas were divided by size into subgroups of 9 areas each, as follows: small (1-8 cm²), medium (8-24 cm²), or large (> 24 cm²) size areas. Each wound shape or geometric shape was printed on an A4-size paper and placed on a flat surface. A ruler ≥ 10 cm was placed adjacent to the shape and used as a reference, as required by the ImageJ software. The Sis-MF mobile application does not require the use of a ruler for calibration. Each printed shape was photographed three times using a smartphone (Motorola Moto G, 5th generation, Android 6.0) with a 13-megapixel camera. The camera in landscape mode was positioned perpendicular to the shape, approximately 15 cm from the sheet of paper, and the photograph was taken after focusing on the image. The photographs were then used for measuring the area of the shapes and wounds using both the Sis-MF and ImageJ software for comparison of results. All area measurements were performed by the same investigator.

The usability of the Sis-MF was evaluated by five specialist nurses with more than five years of experience in wound care. The health professionals were personally invited and signed the written informed consent after the objectives and purposes of the study had been fully explained. The experts had access to the Sis-MF, instructions for use, and completed a usability questionnaire with 11 items relevant for the evaluation of the mobile application, assessing content, presentation, ease of use, and practical value. The expert
responses were evaluated and the suggestions were discussed and used to improve the mobile application.

The accuracy of the measurement techniques was evaluated using GraphPad Prism 3.0 (GraphPad Software Inc., San Diego, CA). Descriptive analysis was conducted to determine the mean, median, standard deviation, and standard error of measurements. Analysis of variance (ANOVA) followed by the Newman-Keuls multiple comparison test, and an unpaired t-test were performed. All statistical tests were carried out at a significance level $\alpha$ of 0.05 ($p < 0.05$).

3 RESULTS

The wound monitoring system (Sis-MF) was developed as a mobile application, allowing users to photograph wounds and monitor the healing progress. The application is freely available in Brazilian Portuguese at “http://www.monitorandoferidas.com.br/”.

Examples of display screens showing the graphical user interface are shown in Figures 1 and 2.

Figure 1. Display screens showing the graphical user interface. (A) Sign-in screen; (B) user registration screen; and (C) patient registration screen.
Figure 2. Display screens showing the graphical user interface. (A) Wound registration screen; (B) wound area calculation screen; and (C) statistical chart screen.

The sign-in screen requires users to enter their email address and password. After signing into the system, the main screen appears. It contains navigation elements providing access to the various content sections, including information about registered patients. When accessed from a browser, the patient registration interface allows the user to select an image of a wound from a database or personal files, crop the image to remove as much of its background as possible and calculate its area. The user also has the option to use the camera of the mobile device to take a picture in real time. The system provides a statistical chart for monitoring the mean value of the wound area over time.

Wound areas calculated using Sis-MF were compared with measurements obtained using ImageJ. No significant differences were found between areas of geometric shapes calculated using basic area formulas, the Sis-MF mobile application, and ImageJ software for the three size subgroups as follows: small ($p = 0.9495$), medium ($p = 0.9829$), and large ($p = 0.9517$) size areas, as shown in Figure 3.
Figure 3. Bar chart with error bars comparing areas of geometric shapes calculated using basic area formulas (control), the Sis-MF mobile application, and ImageJ software for the three size subgroups: (A) small (range = 1-8 cm²; p = 0.9495); (B) medium (range = 8-24 cm²; p = 0.9829); and (C) large (range > 24 cm²; p = 0.9517) size areas. ANOVA and Newman-Keuls multiple comparison test (significance level, p < 0.05).

Also, no significant differences were observed between wound areas calculated using the Sis-MF mobile application and ImageJ software for the three size subgroups as follows: small (p = 0.2774), medium (p = 0.7208), and large (p = 2948) size areas, as shown in Figure 4.
Figure 4. Bar chart with error bars comparing wound areas calculated using the Sis-MF mobile application and ImageJ software for the three size subgroups: (A) small (range = 1-8 cm²; \( p = 0.2774 \)); (B) medium (range = 8-24 cm²; \( p = 0.7208 \)); and (C) large (range > 24 cm²; \( p = 0.2948 \)) size areas. Unpaired t-test test (significance level, \( p < 0.05 \)).

The experts (n = 5) who evaluated the usability of the Sis-MF mobile application were mostly female (3/5, 60%); the mean age was 39.8 years, mean number of years since graduation was 13.2, and mean years of experience in wound care, management, and teaching were 12.8, 3.2, and 2.4, respectively. One expert had a doctoral degree and 4 experts had a master’s degree or graduation specialization.

All experts perceived the Sis-MF mobile application as useful for their institution.
and 4 of them considered that it provides information to support decision-making in wound management. Three experts evaluated the time required to input data into the system as very good. In addition, three experts rated as good the design presentation, ease of use, and ease of access on a mobile device. The perceived accuracy of measurements was rated by the experts as excellent (n = 1), good (n = 1), regular (n = 2), and poor (n = 1).

4 DISCUSSION

The primary objective in wound management is to accelerate wound healing. Prolonged hospital stay is associated with an increased risk of complications and hospital costs [1-3]. As the length of hospital stay decreases, it becomes necessary for health care facilities to be creative in their methods of monitoring patients in an outpatient setting [15]. Proper wound healing is a factor of fundamental importance that affects patient recovery following hospital discharge.

The addition of a visual component in the monitoring of the healing process allows a more complete wound evaluation [15]. Health professionals often use digital cameras to photograph wounds [11-13,16-20]. A basic determination of wound improvement is the reduction of its size over time [21,22]. There are many techniques used to measure the area and volume of wounds [11-13,20]. The simplest and most standard technique calculates the wound area by multiplying the longest length by the largest width measured by a ruler or tape measure. This technique is limited by subjective interpretation and interobserver variability [23,24].

A surface area calculated by multiplying length and width measurements is mathematically accurate for a square or rectangle. Other geometric shapes (e.g., circles, ellipses, parallelograms, trapezoids, among others.) can also be calculated using basic area formulas. To test the accuracy of the Sis-MF mobile application, 27 simple geometric shapes were created, divided by size into subgroups (small, medium, and large size shapes), and the shape areas measured using both the Sis-MF and ImageJ software were compared with values obtained from area formulas. The open source ImageJ software has been widely used by several researchers throughout the world in the last 30 years [25,26]. No significant differences were found between areas calculated using basic area formulas, Sis-MF, and ImageJ, showing that the Sis-MF mobile application was able to accurately measure areas of geometric shapes.
In this study, the edges of 27 wounds images of varying sizes were traced on paper, printed, and photographed using the Sis-MF mobile application. Wound areas of small, medium and large sizes were estimated using both the Sis-MF and ImageJ software, and then compared. No significant differences were observed between areas calculated using the two software. A previous study compared measurements of wound areas using two different software, including ImageJ, and reported no significant differences between methods [27]. In other study, 25 digital photographs of foot and leg ulcers were taken placing a ruler next to the wound in parallel with the healthy skin; wound areas were measured by 4 evaluators using ImageJ, and the authors concluded that ImageJ shows excellent reliability in estimating wound areas [28]. In another study, two images of pressure injuries were used by 35 physical therapy students for measuring the wound areas using two software [29]. The results showed low inter-rater reliability, which may be attributed to the lack of experience of the students in defining the edges of pressure injuries and using the software [29]. In the present study, all area measurements were performed by the same investigator using two software different from those used in the aforementioned study [29], thus contributing to the consistency of results.

As the use of tablets and cell phones becomes more common, patients and caregivers are increasingly willing to use this technology to gain access to health information [12]. The increased use of smartphones by health professionals provides the opportunity to improve communication, access to information, and tools for use at the bedside or from anywhere at any time [30].

The Sis-MF mobile application was developed in Brazilian Portuguese for use by health professionals in Brazil to assist in wound monitoring, focusing on the measurement of wound areas. The ideal tool for measuring wound areas should be able to record uneven surfaces in a three-dimensional environment without manual contact with the wound. The Sis-MF mobile application is able to measure wound areas without the use of a ruler or tape measure as a reference for distance, and without contact with the wound surface to be photographed.

A user registration and sign-in system was created to provide a safe application environment and protect the stored data by restricting unauthorized access to member-only areas and tools on the application. The experts who participated in the study had little difficulty using the mobile application. The usability test provided valuable information, facilitating identification of targets for improvement. Expert suggestions contributed to improvements regarding Android platform updates, enhancing usability,
mobile application access, and accuracy in the calculation of geometric shape areas representing wound contours.

Although the perceived ease of use of Sis-MF was rated as good in the usability test, some suggestions revealed that a previous training in the use of the mobile application is necessary to improve the accuracy of wound area measurements. This highlights the importance of utility tests in the development of new applications and protocols for patient-centered care.

The use of the Sis-MF mobile application does not replace a medical consultation, but may guide and standardize wound assessment and monitoring procedures regarding changes in the wound surface area.

Sis-MF may contribute to improvements in the assessment and treatment of wounds, and support clinical decision making, providing a scientific approach to the monitoring of wounds, reducing risks of complications, enhancing quality of life, and reducing hospitalization costs and burdens to the healthcare system, which may result in cost savings to the public health sector and to patients and their families.

5 CONCLUSION

The freely-available Brazilian Portuguese Sis-MF system was developed as a mobile application for monitoring the healing progress of wounds by measuring wound areas without the use of a ruler or tape measure as a reference for distance, and without contact with the wound surface to be evaluated. Experts perceived the Sis-MF mobile application as useful and considered that it may provide information to support decision-making in wound management.
REFERENCES


