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SfM-3DULC: Reliability of a new 3D wound measurement procedure and its accuracy in projected area

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Abstract

Three-dimensional (3D) wound measurement lacks a gold standard to test accuracy. It is useful to develop procedures to scan wounds and reconstruct their 3D model with low-cost techniques. We present a new procedure (Structure from Motion [SfM]-3DULC) that uses photographs for measuring nine wound variables. We also propose a new variant of ImageJ in which an orthophoto is used to measure the projected area (Ortho-ImageJ). In addition, we compare the wound measurements made by dermatologists and non-experts. A group of five experts in dermatology and five non-specialists measured 33 leg wounds five times per procedure. Intra-rater and inter-rater reliability scores of SfM-3DULC were evaluated with the intraclass correlation coefficient (ICC 2,1). The accuracy of the two new procedures (SfM-3DULC and Ortho-ImageJ) in the measurement of projected area was assessed by comparing their values with those obtained using ImageJ, with the Wilcoxon matched-pairs signed rank test ($\alpha = 0.05$). This test was also used to analyse the differences between the measurements made by dermatologists and non-experts. All the variables measured by dermatologists using SfM-3DULC showed excellent scores of intra-rater reliability (ICC > 0.99) and inter-rater reliability (ICC > 0.98). No significant differences between the three procedures were found when comparing their projected area values. Significant differences between the measurements of dermatologists and non-experts were found in most of the variables: circularity coefficient, perimeter, projected area, surface area, and reference surface area. The wound measurement procedure SfM-3DULC has an excellent reliability, is accurate for the measurement of projected area, and can be used by dermatologists for wound monitoring in everyday clinical practice.

KEYWORDS

3DULC, ImageJ, measurement, SfM, wound

1 | INTRODUCTION

Wounds are a problem that affects the quality of life of patients,[1] with a high prevalence[2,3] and a huge cost.[4,5] Wound measurement is useful for clinical monitoring, since it is an indicator of its progression to healing.[6-8]

Traditional measurement procedures are often invasive. Some two-dimensional (2D) measurement procedures, for example, graduated ruler and contact planimetry, are still used in clinical practice because of their simplicity and convenience. However, they have technical drawbacks including inaccuracy and imprecision.[9,10] Other three-dimensional (3D) measurement procedures such as saline solution and alginate casts may have, in addition, adverse events in patients such as pain, irritation, or allergic reaction.

Over the past decade, the use of non-contact techniques has spread. For 2D measurement, a frequently used procedure in clinical practice is the open-source digital image processing program ImageJ (National Institutes of Health, Rockville, MD). This software has been successfully used in wound measurement[11] and other medical applications, such as ovarian cancer[12] and microscopy.[13] ImageJ has demonstrated high accuracy, precision, and reliability.[11,14,15] It is also easy to use, quick, and requires only a digital camera and an object of known size, for example, a ruler.

A number of specific devices have been developed for 3D measurement.[16-20] Some of the photogrammetric techniques that these devices use to scan wounds and reconstruct their 3D model are stereophotogrammetry, structured light scanning, and laser scanning.[21,22] Manufacturers usually include their own software to measure the variables of the scanned 3D model.

The absence of a gold standard in clinical practice is a major obstacle to calibrate the accuracy of 3D wound measurement procedures. Some new procedures have the following disadvantages[10,23]: (a) need specific scanning devices; (b) not demonstrated usefulness in clinical practice; and (c) high cost.

Therefore, it is useful to develop procedures to scan wounds and reconstruct their 3D model with low-cost techniques that do not require specific scanning devices. One example is the Structure from Motion (SfM) technique, which uses the overlap of several photographs in different positions and orientations to reconstruct the 3D model. This technique has been used in many applications, including wound measurement.[24]

1.1 | Justification and objectives

In previous studies, we developed a wound measurement procedure (SfM-3DULC) that uses a digital camera to scan the wound. The scanning steps have been detailed,[25] including (a) camera positions and number of photographs required for the 3D model reconstruction using the SfM technique with Agisoft Photoscan Professional software (Agisoft LLC, St. Petersburg, Russia); (b) measurement of nine wound variables with 3DULC software,[26] developed by the authors in Python programming language. 3DULC software includes a workflow specifically created to measure wounds and can be used as a subsequent step after scanning the 3D model with SfM or other techniques (Figure 1). Its processing time is approximately 5 minutes.

Furthermore, photographs used in ImageJ should be exactly perpendicular to the wound, facing it in the frontal plane. Slight tilts affect the projected area, underestimating it more as the camera angle increases. It may be useful to try a new variant (Ortho-ImageJ) of this procedure in which an orthophoto is used in ImageJ, because it would not be affected by the camera angle and the lens distortions (radial and tangential). Therefore, inter-rater reliability of the procedure would depend only on the wound edge outlined by each rater, and not on the data source. This variant has not been published, to the best of our knowledge.

Based on the above, it is justified a project to compare in clinical practice the two new wound measurement procedures (SfM-3DULC and Ortho-ImageJ) with the standard procedure ImageJ. The primary objective of this pilot study is to evaluate the intra-rater and inter-rater reliability scores of SfM-3DULC in nine wound variables. The secondary objectives are to analyse the accuracy of the two new procedures in the measurement of projected area by comparing their values with those obtained using ImageJ, and to determine if there are differences between

Key messages

- it is useful to develop low-cost wound measurement procedures that do not require specific scanning devices
- five experts in dermatology and five non-specialists measured 33 leg wounds
- significant differences between the measurements of dermatologists and non-experts were found in most of the variables
- using orthophotos in the variant Ortho-ImageJ did not demonstrate an advantage over traditional ImageJ in shallow wounds
- SfM-3DULC has an excellent reliability and is accurate for the measurement of projected area

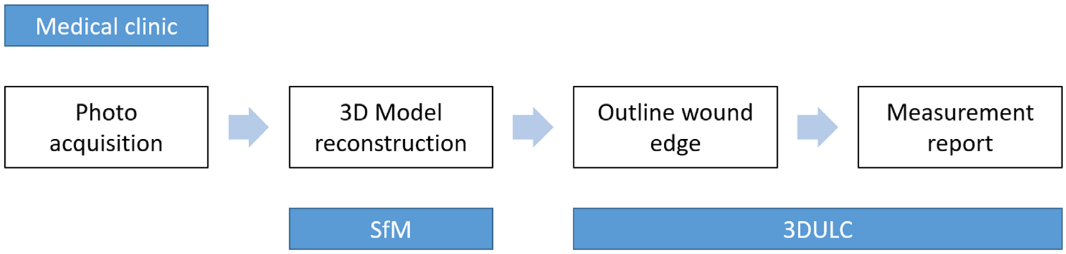

FIGURE 1 SfM-3DULC workflow chart showing the steps to follow from the photo acquisition to the measurement report

the measurements made by dermatologists and non-experts in the nine wound variables and the three wound measurement procedures.

2 | MATERIALS AND METHODS

2.1 | Ethical aspects

This project was approved by the Institutional Review Board of the Hospital Universitari i Politècnic La Fe de València in November 2018 (protocol number 2018/0527) and is in accordance with the Good Clinical Practice guidelines, the Declaration of Helsinki and the current legislation. The patients were previously informed of the objectives, procedures, and risks of the project and their written informed consent was obtained. Their personal data were anonymised.

2.2 | Patient population

The recruitment and follow-up of patients was performed in 5 days randomly selected in 2019. All patients were being treated at the Dermatology Department of the Hospital Universitari i Politècnic La Fe de València, and the Unidad de Enfermería, Úlceras y Heridas complejas La Fe. Fifteen patients were included according to the following inclusion criteria: (a) over 18 years of age; (b) diagnosed with open leg wound with tissue loss; (c) presence of two centimetres of healthy skin around the wound, visible from at least one perspective; (d) ability to keep the leg in a static position for 45 seconds. Two patients were excluded, as they did not meet inclusion criteria 3 and 4, respectively. In this pilot study, wounds of different aetiologies were measured in 33 medical visits, ranging from one to five medical visits per patient.

2.3 | Materials

The following materials were used: Canon EOS1DX MKIII camera (20.1 Megapixels), ImageJ version 1.53a, Agisoft Photoscan Professional version 1.4.5, 3DULC version 1.0, calibrated paper, and ruler.

2.4 | Statistical analysis

Statistical analysis was performed using IBM SPSS Statistics version 25. Five experts in dermatology and five non-specialists measured 33 leg wounds five times per procedure. Intra-rater and inter-rater reliability scores of SfM-3DULC were evaluated with the intraclass correlation coefficient (ICC 2,1). The Wilcoxon matched-pairs signed rank test ($\alpha = 0.05$) was used to (a) analyse the accuracy of SfM-3DULC and Ortho-ImageJ in the measurement of projected area by comparing their values with those obtained using ImageJ; (b) compare the wound measurements made by dermatologists and non-experts.

2.5 | ImageJ

A calibrated ruler was placed near the wound and a frontal photograph was taken. This photograph was scaled in ImageJ by selecting two marks from the calibrated ruler and the actual distance. The wound edge was outlined using the "freehand" tool and the projected area (2D) was measured.

2.6 | Ortho-ImageJ

The same steps as in the ImageJ procedure were performed, but using an orthophoto created from the Agisoft Photoscan Professional 3D model. The projected area (2D) was measured.

3 | SFM-3DULC

Calibrated paper was placed on a flat and firm surface. The leg was positioned on it, with the dry wound visible (Figure 2A). We took 15 photographs converging to the wound from successive positions in two perpendicular

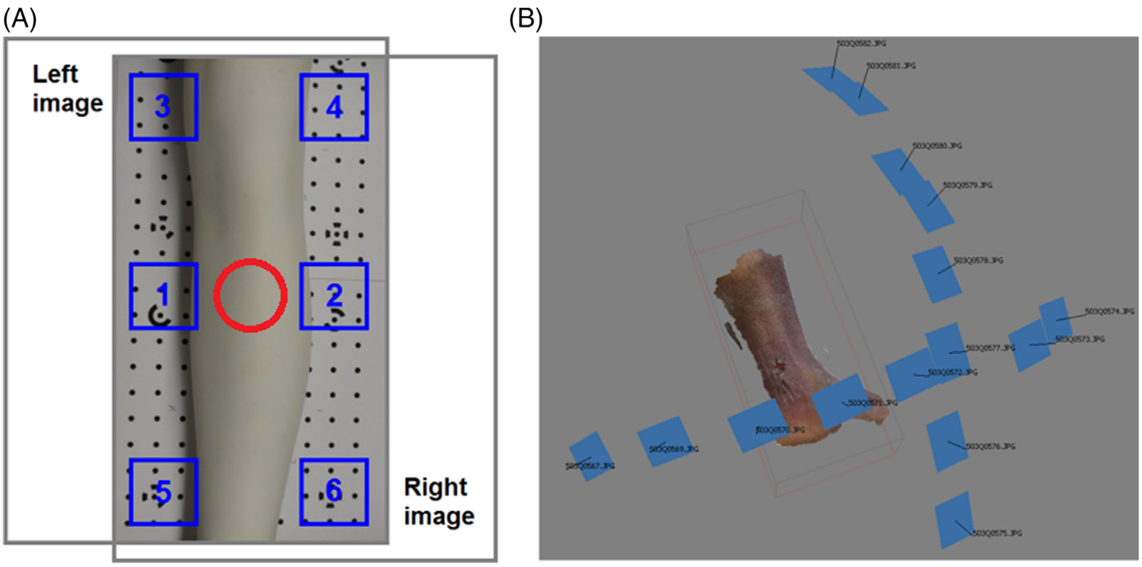

FIGURE 2 Photo acquisition in SfM-3DULC: A, Overlap of two photographs (grey rectangles). The wound (red circle) is in the centre, and ground control points are in the six von Gruber locations (blue squares). B, Camera arrangement in the 15 photographs (blue rectangles)

arcs of great circle. The arcs were centred in the wound and had a radius of 30–40 cm (Figure 2B). The 3D model was reconstructed using Agisoft Photoscan Professional software, whose workflow includes camera alignment, dense point cloud generation, mesh reconstruction, and texture building.

The 3D model was moved and rotated in 3DULC software until it was in the frontal plane. This software creates an orthophoto with a pixel size of 100 μm, and the user outlined the wound edge. The following wound variables were automatically measured: circularity coefficient (Equation (1)), evenness coefficient (Equation (2)) (0D), maximum length, maximum depth, perimeter (1D), projected area, surface area, reference surface area (2D), and volume (3D). An example of a measurement report obtained with 3DULC software can be found in Figure 3.

Circularity[27] and evenness coefficients estimate the planimetric and altimetric regularity of the wound, respectively. They are dimensionless and their range is the unit interval [0–1], obtaining higher values in more regular wounds.

$$\text{Circularity coefficient} = \frac{4*\pi*\text{Projected area}}{\text{Perimeter}^2}, \quad (1)$$

$$\text{Evenness coefficient} = \frac{\text{Reference surface area}}{\text{Surface area}}. \quad (2)$$

The projected area is the projection of the wound onto a plane. It was calculated by counting the number of pixels in the orthophoto that were classified as wound. The surface area is the unfolding of the wound bed. In order to calculate it, the 3D model was split into right triangles with a leg length of 100 μm, and the area of each triangle was measured. The reference surface area is the "wound ceiling" and approximates to the natural curvature that the healthy skin would have. 3DULC software interpolates 2 cm of the healthy skin around the wound, minimising the root-mean-square error (Equation (3)) using a second-order polynomial regression with two predictors (Equation (4)), in which the value of the *Z*-coordinate is predicted from the *X* and *Y* coordinates.

$$\text{RMSE} = \sqrt{\frac{1}{n}\sum_{j=1}^{n}\left(z_j - \hat{z}_j\right)^2}, \quad (3)$$

$$\hat{z} = a_1 + a_2 x + a_3 y + a_4 x^2 + a_5 y^2 + a_a xy. \quad (4)$$

4 | RESULTS

The descriptive statistics of central tendency and dispersion of the wound variables are shown in Table 1. Intra-rater and inter-rater reliability scores of SfM-3DULC are reported in Table 2. The comparison of the wound measurements made by dermatologists and non-experts appears in Table 3. Finally, we present the comparison between the new procedures and ImageJ in the measurement of projected area.

Intra-rater reliability scores of SfM-3DULC (Table 2) were greater than 0.99 in all the variables measured by

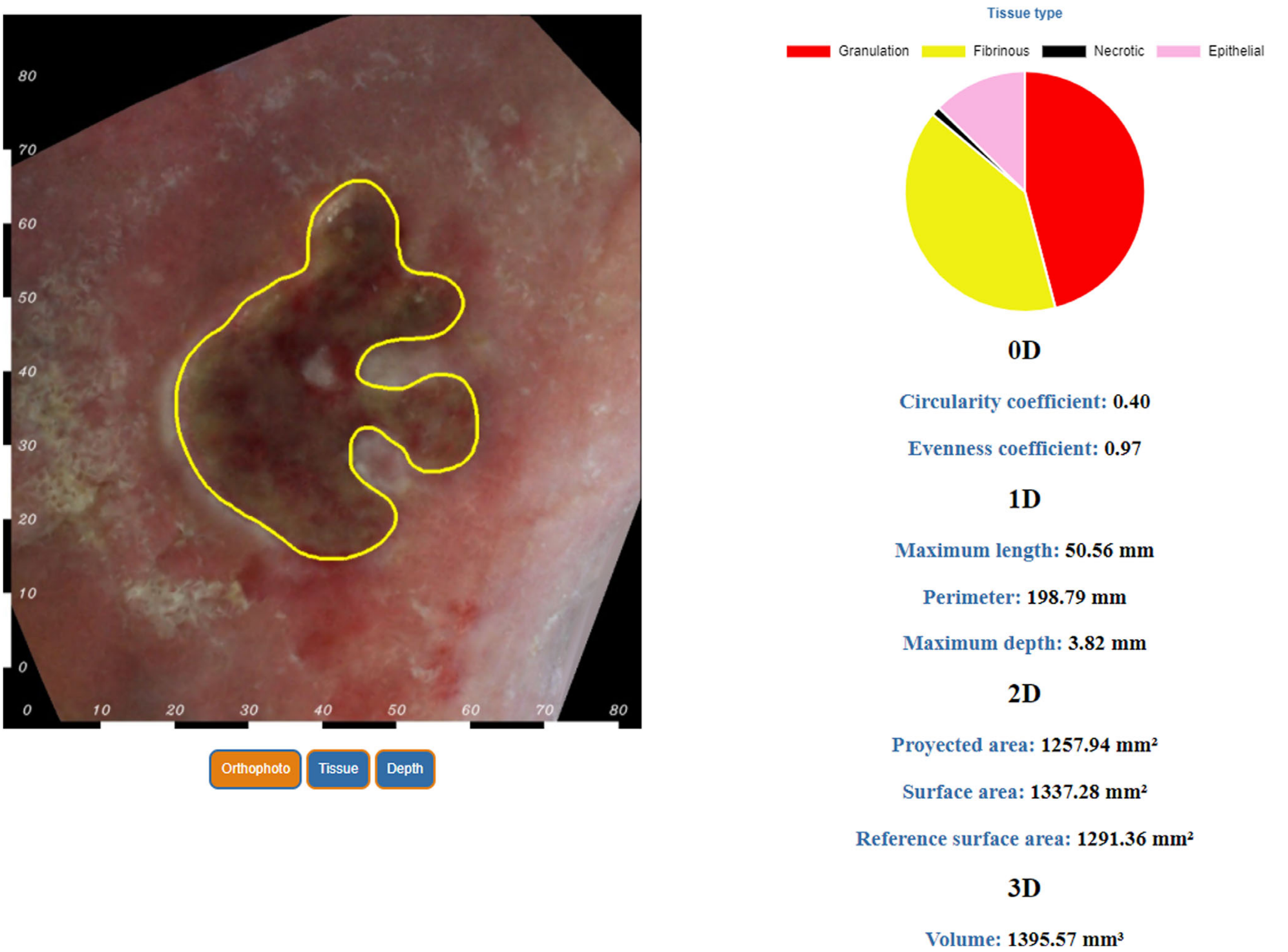

FIGURE 3 Example of a measurement report obtained with 3DULC software

TABLE 1 Values found in the nine wound variables using the wound measurement procedure SfM-3DULC (n = 33)

Variables	Units	Range	Mean ± SD
Circularity coefficient	Dimensionless	0.40–0.82	0.58 ± 0.12
Evenness coefficient	Dimensionless	0.77–0.97	0.91 ± 0.06
Maximum length	mm	11.7–94.1	39.3 ± 23.2
Perimeter	mm	32.6–303.5	121.1 ± 77.3
Maximum depth	mm	0.6–7.9	3.2 ± 1.6
Projected area	mm^2	48.9–3512.8	862.6 ± 902.1
Surface area	mm^2	51.5–3308.2	857.7 ± 883.1
Reference surface area	mm^2	49.6–2617.2	774.7 ± 755.7
Volume	mm^3	−0.8 to 2612.3	743.7 ± 876.8

Abbreviation: SfM, Structure from Motion.

dermatologists and greater than 0.98 in non-experts. Inter-rater reliability scores of SfM-3DULC were greater than 0.98 in all the variables measured by dermatologists and greater than 0.89 in non-experts.

When comparing the wound measurements made by dermatologists and non-experts (Table 3), significant differences were found in circularity coefficient, perimeter, projected area, surface area, and reference surface area. We did not find significant differences in evenness coefficient, maximum length, maximum depth, and volume.

When comparing the new procedures and ImageJ in the measurement of projected area, no significant

TABLE 2 Intra-rater and inter-rater reliability scores of the wound measurement procedure SfM-3DULC in the nine wound variables (n = 33)

	Intra-rater reliability[a]		Inter-rater reliability[a]	
Variables	**Dermatologists**	**Non-experts**	**Dermatologists**	**Non-experts**
Circularity coefficient	0.994	0.986	0.988	0.895
Evenness coefficient	0.999	0.999	0.989	0.958
Maximum length	1.000	1.000	1.000	0.999
Perimeter	1.000	0.999	1.000	0.995
Maximum depth	1.000	0.999	0.992	0.990
Projected area	1.000	0.999	1.000	0.999
Surface area	1.000	0.999	0.999	0.998
Reference surface area	1.000	0.999	0.999	0.998
Volume	1.000	0.999	0.997	0.988

[a]Intraclass correlation coefficient (ICC 2,1).
Abbreviation: SfM, Structure from Motion.

TABLE 3 Comparison of the wound measurements made by dermatologists and non-experts in the nine wound variables and the three wound measurement procedures (n = 33)

Procedure	Variables	*P*-value[a]
ImageJ	Projected area	.043
Ortho-ImageJ	Projected area	.001
SfM-3DULC	Circularity coefficient	.000
	Evenness coefficient	.053
	Maximum length	.406
	Perimeter	.014
	Maximum depth	.131
	Projected area	.001
	Surface area	.041
	Reference surface area	.001
	Volume	.118

[a]Wilcoxon matched-pairs signed rank test.

differences were found between SfM-3DULC and ImageJ (*P*-value = .598) nor Ortho-ImageJ and ImageJ (*P*-value = .675).

5 | DISCUSSION

Wound measurement procedures should be validated in wound models and patients.[21] This pilot study was performed in clinical practice, after the tests in artificial wound models.[25] As another step in the validation of SfM-3DULC, we evaluated its reliability in the measurement of nine wound variables (some not previously reported in the literature) and the accuracy in the measurement of one of them. In the following steps, we will compare the performance of SfM-3DULC in the measurement of other variables such as volume with other 3D measurement devices. We will also compare the influence of the image quality on the results obtained, using digital cameras or smartphones with different specifications.

Projected area, usually called area, is the most common variable to monitor wound progression to healing.[28] The projection of this area onto the plane of the photograph is affected by the following: (a) camera angle: more accurate (and higher) projected area values are obtained as the camera is more frontal to the wound; (b) complex topography: the cylindrical shape of the leg and the orography of the wound bed vary the distance from the tissue to the sensor. Elements located at different distances have different scales in the photograph, which is not considered when setting a single scale. (c) Radial and tangential lens distortions. These disadvantages of the photograph in the standard procedure ImageJ encouraged us to try using an orthophoto in the variant Ortho-ImageJ.

In previous works, different reliability scores were reported depending on the size and shape of the wound.[22,29] The irregularity of the wound complicates its scanning, since some regions may be hidden from various angles. An illustrative example would be undermining or tunnelling wounds, which are extremely irregular and impossible to measure using photogrammetric techniques based on the visible spectrum. For these wounds, it might be interesting to use other wavelengths capable of penetrating through the skin. To quantitatively assess this aspect, in this project we measured two variables that estimate the regularity of the wound edge (circularity coefficient) and the wound bed (evenness coefficient). It may be a plausible hypothesis that more accurate and precise results can be obtained in more regular wounds using the same measurement procedure. However, future studies are needed to confirm or reject this hypothesis.

Some parts of the wound bed may be above the reference surface. There are two criteria for calculating the volume when this occurs: not counting these parts or counting them as negative values. 3DULC software uses this second option, so these parts subtract volume from the total. One of the wounds obtained a negative volume (-0.8 mm^3) for this reason.

Intra-rater and inter-rater reliability scores of SfM-3DULC (Table 2) were excellent[30] in all the variables measured by dermatologists. This group has a more homogeneous and accurate criterion in the delimitation of wound edges, and therefore obtained higher reliability scores than non-experts.

The comparison of the wound measurements made by dermatologists and non-experts (Table 3) showed significant differences in most variables. A reasonable interpretation of this fact could be that non-experts overestimated the size of wounds (higher projected area values) and outlined their edges less accurately (lower perimeter values) than dermatologists. Consequently, non-experts obtained higher circularity coefficient values, since it is calculated from these two variables. Despite the surface area and reference surface area values were higher in the measurements of non-experts, their ratio (evenness coefficient) was not different from the one obtained by dermatologists. Volume was also similar, since the extra areas measured by non-experts were healthy skin without depth. Severely damaged areas, including the maximum depth and maximum length, were identified as part of the wound in a similar way by dermatologists and non-experts.

No significant differences between the three procedures were found when comparing their projected area values. The wound measurement procedure SfM-3DULC is accurate and valid for the measurement of this variable as its results were similar to those obtained using ImageJ. Ortho-ImageJ did not demonstrate an advantage over ImageJ, possibly because of the shallow wounds (maximum depth < 7.9 mm) included in this project.

5.1 | Limitations and future research

A reference surface is necessary for calculating the following variables: evenness coefficient, maximum depth, reference surface area, and volume. 3DULC software interpolates this reference surface from 2 cm of healthy skin around the wound. Therefore, this procedure is not useful for very wide wounds that extend on both sides of the leg.

The scanning time of SfM-3DULC is approximately 45 seconds. During this time, the patient must keep the leg in a static position, otherwise the photo acquisition must be restarted as the leg would change its relative position to the calibrated paper. Two possible solutions to reduce this time are as follows: using several cameras with known relative orientation that take the photographs simultaneously, or using a video camera. The first solution has the disadvantage of needing a specific scanning device, while the second solution requires a system that automatically selects the frames with optimal sharpness and geometry.

In order to increase inter-rater reliability scores and for telediagnosis, it would be interesting to develop and improve algorithms for automatic delimitation of wound edges, since this is a source of variability in wound measurement.

6 | CONCLUSIONS

The wound measurement procedure SfM-3DULC has an excellent reliability and is accurate for the measurement of projected area. It uses photographs taken with a digital camera and dermatologists can use it for wound monitoring in everyday clinical practice.

Similar projected area values were obtained using orthophotos and frontal photographs in ImageJ.

Significant differences between the measurements of dermatologists and non-experts were found in most of the variables: circularity coefficient, perimeter, projected area, surface area, and reference surface area.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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REFERENCES

1. Gorecki C, Brown JM, Nelson EA, et al. Impact of pressure ulcers on quality of life in older patients: a systematic review. *J Am Geriatr Soc*. 2009;57(7):1175-1183.
2. Sen CK, Gordillo GM, Roy S, et al. Human skin wounds: a major and snowballing threat to public health and the economy. *Wound Repair Regen*. 2009;17(6):763-771.
3. Järbrink K, Ni G, Sönnergren H, et al. Prevalence and incidence of chronic wounds and related complications: a protocol for a systematic review. *Syst Rev*. 2016;5(152):1-6.
4. Nussbaum SR, Carter MJ, Fife CE, et al. An economic evaluation of the impact, cost and Medicare policy implications of chronic nonhealing wounds. *Value Health*. 2018;21(1):27-32.
5. Phillips CJ, Humphreys I, Thayer D, et al. Cost of managing patients with venous leg ulcers. *Int Wound J*. 2020;17(3):1-9.
6. Cardinal M, Eisenbud DE, Armstrong DG. Wound shape geometry measurements correlate to eventual wound healing. *Wound Repair Regen*. 2009;17(2):173-178.
7. Lavery LA, Barnes SA, Keith MS, Seaman JW, Armstrong DG. Prediction of healing for postoperative diabetic foot wounds based on early wound area progression. *Diabetes Care*. 2008;31(1):26-29.
8. McGinnis E, Greenwood DC, Nelson EA, Nixon J. A prospective cohort study of prognostic factors for the healing of heel pressure ulcers. *Age Ageing*. 2014;43(2):267-271.
9. Langemo D, Anderson J, Hanson D, Hunter S, Thompson P. Measuring wound length, width, and area: which technique? *Adv Skin Wound Care*. 2008;21(1):42-45.
10. Jorgensen LB, Sorensen JA, Jemec GBE, Yderstraede KB. Methods to assess area and volume of wounds—a systematic review. *Int Wound J*. 2016;13(4):540-553.
11. Aragón-Sánchez J, Quintana-Marrero Y, Aragón-Hernández C, Hernández-Herero MJ. ImageJ: a free, easy, and reliable method to measure leg ulcers using digital pictures. *Int J Low Extrem Wounds*. 2017;16(4):269-273.
12. Laios A, Volpi D, Kumar R, Traill Z, Vojnovic B, Ahmed AA. A novel optical bioimaging method for direct assessment of ovarian cancer chemotherapy response at laparoscopy. *Cancer Inform*. 2017;15:243-245.
13. Collins TJ. ImageJ for microscopy. *Biotechniques*. 2018;43(1S):25-30.
14. Jeffcoate WJ, Musgrove AJ, Lincoln NB. Using Image J to document healing in ulcers of the foot in diabetes. *Int Wound J*. 2017;14(6):1137-1139.
15. Foltynski P. Ways to increase precision and accuracy of wound area measurement using smart devices: advanced app Planimator. *PLoS One*. 2018;13(3):1-16.
16. Pavlovcic U, Diaci J, Mozina J, Jezersek M. Wound perimeter, area, and volume measurement based on laser 3D and color acquisition. *Biomed Eng Online*. 2015;14(39):1-15.
17. Sheng J, Li H, Jin J, et al. Application of three-dimensional wound analyzer in the small wound area measurement during the process of wound healing. *J Burn Care Res*. 2018;39(2):268-273.
18. Mamone V, Di Fonzo M, Esposito N, Ferrari M, Ferrari V. Monitoring wound healing with contactless measurements and augmented reality. *IEEE J Transl Eng Health Med*. 2020;8:2700412. https://doi.org/10.1109/JTEHM.2020.2983156 eCollection 2020.
19. Bills JD, Berriman SJ, Noble DL, Lavery LA, Davis KE. Pilot study to evaluate a novel three-dimensional wound measurement device. *Int Wound J*. 2016;13:1372-1377.
20. Anghel EL, Kumar A, Bigham TE, et al. The reliability of a novel Mobile 3-dimensional wound measurement device. *Wounds*. 2016;28(11):379-386.
21. Frampton CM, Nixon MA, Watson RW. Electronic wound measurement systems. *A Review of, and Template for, the Development and Validation*; Christchurch, New Zealand: ARANZ Medical Ltd; 2017. https://www.aranzmedical.com/wp-content/uploads/Electronic-Wound-Measurement-Poster_2017_no-bleed.pdf. Accessed January 29, 2021.
22. Khoo R, Jansen S. The evolving field of wound measurement techniques: a literature review. *Wounds*. 2016;28(6):175-181.
23. Davis KE, Constantine FC, MacAslan EC, Bills JD, Noble DL, Lavery LA. Validation of a laser-assisted wound measurement device for measuring wound volume. *J Diabetes Sci Technol*. 2013;7(5):1161-1166.
24. Dastjerdi HM, Töpfer D, Rupitsch SJ, Maier A. Measuring surface area of skin lesions with 2D and 3D algorithms. *Int J Biomed Imaging*. 2019;15:1-9.
25. Buchón-Moragues F. *Sub-Millimetric Photogrammetric Systems for Acquiring Three-Dimensional Data Applied to Dermatology* [Dissertation]. Valencia: Universitat Politècnica de València; 2015.
26. Sánchez-Jiménez D, Buchón-Moragues F, Escutia-Muñoz B, Botella-Estrada R. Development of computer vision applications to automate the measurement of the dimensions of skin wounds. *Proceedings*. 2019;19(1):1-4.
27. Miller VC. *A Quantitative Geomorphic Study of Drainage Basin Characteristics in the Clinch Mountain Area, Virginia and Tennessee*. New York,NY: Department of Geology Columbia University; 1953:389-402.
28. Stacey MC, Phillips SA, Farrokhyar F, Swaine JM. Reliability and measurement error of digital planimetry for the measurement of chronic venous leg ulcers. *Wound Repair Regen*. 2017;25(5):901-905.
29. Bilgin M, Gunes UY. A comparison of 3 wound measurement techniques: effects of pressure ulcer size and shape. *J Wound Ostomy Continence Nurs*. 2013;40(6):590-593.
30. Koo TK, Li MY. A guideline of selecting and reporting Intraclass correlation coefficients for reliability research. *J Chiropr Med*. 2016;15(2):155-163.

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