

Photographic image tissue characterization of the ulcerated diabetic foot during treatment: technical note

Caracterização tecidual de imagem fotográfica durante tratamento do pé diabético ulcerado: nota técnica

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Abstract

Treatment of an ulcerated diabetic foot was documented photographically. We adapted the ultrasonographic tissue characterization (USTC or CATUS) technique to develop a photographic image tissue characterization (p-IMTC or CATIM) method. Five photographs, taken during medical treatment of an ulcerated diabetic foot following digital amputation, were quantified using imaging software designed to determine brightness intensity in grey scale images. The grey scale median (GSM) changed from 127 to 98; 86; 76; and 83 (out of 255) during follow-up. The area of lesion was estimated by number of pixels and reduced from 17.85 cm² to 12.44; 3.68; 2.11; and 0.15 cm². The percentage of total number of pixels showing granulation tissue increased from 11% to 34%; 56%; 62%; and 75%. p-IMTC quantified treatment progress. GSM quantified generalized changes in tissues, while the area of lesion and granulation tissue were documented quantitatively. Lesions, ulcers, wounds or other tissues can be analyzed using p-IMTC, allowing quantification, characterization and control of the progression of a condition or treatment.

Keywords: diabetic foot; ulcer; photography; quantitative analysis.

Resumo

Tratamento do pé diabético ulcerado é documentado fotograficamente. Adaptamos a técnica da caracterização tecidual ultrassonográfica (CATUS ou USTC) para análise da imagem fotográfica (CATIM ou p-IMTC). Cinco fotografias obtidas durante tratamento médico de pé diabético ulcerado, pós-amputação digital, foram quantificadas por *software* de imagem desenvolvido para caracterizar amplitudes de brilho em tons cinza. A mediana da escala cinzenta, ou *Grey Scale Median* (GSM), alterou de 127 para 98; 86; 76; e 83 durante o seguimento. Área da lesão, estimada por número de *pixels*, diminuiu de 17,85 para 12,44; 3,68; 2,11; e 0,15 cm². A porcentagem de número de *pixels* com granulação aumentou de 11% para 34%; 56%; 62%; e 75%. CATIM quantificou progresso do tratamento. GSM quantificou modificações generalizadas do tecido, a área da lesão foi estimada e a granulação foi documentada quantitativamente. Análises CATIM de lesões, úlceras, feridas, ou outros tecidos podem ser feitas, permitindo quantificação, caracterização e controle da evolução do agravo ou tratamento.

Palavras-chave: pé diabético; úlcera; fotografia; análise quantitativa.

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■ INTRODUCTION

The diabetic foot, especially the ulcerated diabetic foot, continues to be a challenge for modern medicine¹. One major consequence is amputations, ranging from removal of toes to leg amputations above or below the knee². Photography has been used to document treatment of ulcerated diabetic feet. One measure commonly used is area of the lesion³. We investigated the utility of photographic tissue analysis as a supplementary, quantitative option.

This paper describes the process of adapting ultrasonographic tissue characterization (USTC or CATUS) and ultrasound virtual histology (USVH) processes to achieve photographic image tissue characterization (p-IMTC or CATIM). The primary objective was to determine whether the p-IMTC technique based on the photographic brightness of different tissues would be capable of describing the healing process both qualitative and quantitatively. Future objectives are to a) forecast healing time and likelihood of treatment success and b) identify quantitative criteria for changing treatment. This initial step is a “discovery” process, opening up new technological options.

Transcutaneous methods have already been employed to analyze abdominal aneurysms treated with endoprostheses⁴, kidneys^{5,6}, carotid and peripheral atheromas⁷⁻¹⁰, venous thrombosis¹¹⁻¹³ and edema, in particular, lymphedema¹⁴. USTC or CATUS is a variant of IVUS. The literature contains reports of correlations between IVUS and histological findings for coronary and carotid atheromas^{7,15,16}. Grey scale median (GSM) is a practical simplification representing overall echogenicity. Low GSM correlated with an unacceptable high rate of cerebral vascular accidents during stenting of the carotid artery⁹. GSM was also related to ease of reentry during treatment of occlusive femoral atherosclerosis by subintimal angioplasty⁸. A study assessing lower extremity deep vein thrombosis showed distinctive ultrasonographic echoes and specific GSM values with either high positive predictive value, or high sensitivity to differentiate acute from subacute thrombi¹². We describe in this paper the application of p-IMTC to five photographs taken during treatment of an ulcerated diabetic foot post hallux amputation.

■ CASE DESCRIPTION

The patient was a 48-year-old male who had been diagnosed with diabetes mellitus in 1996 and had been treated with oral hypoglycemic drugs and insulin. He had attenuated distal pulses and no sensitivity to the monofilament test in either foot, but with perfusion preserved. The patient was a smoker and admitted to mild alcoholism. He was

seen at the emergency department. The patient presented with a gangrenous left hallux, developed after a trauma caused by dropping an object onto his great toe. The wound became infected and did not respond to the antibiotics prescribed by the treating physician. The toe became gangrenous and the infection was progressing to the dorsum of the foot. The hallux was amputated, the left foot debrided and the abscess was drained. The patient was given fibrous calcium alginate during the first postoperative day. ColStimulen™ collagen gel was applied. The patient responded well to treatment with satisfactory granulation and healing of the lesion; 95% of the wound underwent epithelialization within 3 months.

Photographic image tissue characterization (p-IMTC)

Five photographic images were taken during the period of non-surgical medical treatment and healing. The p-IMTC technique classified the pixels based on the brightness amplitude of grey scale versions of the photographic images. The steps involved in image analysis were as follows:

1. Selection of color photographs of the patient's foot (Figure 1 – column 1);
2. Conversion of color images into 256-tone grey scale images, where black equals 0 and white equals 255 (Figure 1 – column 2);
3. Minimization of variations by rescaling using black and the pseudo white of the 1 cm tag placed near the wound as the new 0 and 200 brightness levels, respectively;
4. Selection of area for analysis (Figure 1 – column 2);
5. Presentation of pixel brightness distribution in the image and GSM calculation (Figure 1 – column 3);
6. Calculation of percentages of number of pixels into 14 intervals of brightness amplitudes and presentation as histograms (Figure 1 – column 4);
7. Artificial colorization of pixels in the selected region of the image based on the 14 intervals of brightness amplitudes (Figure 1 – column 5);
8. Calculation of wound area based on number of pixels in the a) wound region and b) 1cm² area defined by the marker in the image.

■ RESULTS

Figure 1, column 3, lists GSM, or grey scale median, for the selected wound regions of the five photographs obtained during the treatment period. Figure 1, column 4, shows histograms for the distribution of the percentages of number of pixels in each of 14 brightness amplitude intervals. The artificial colorization of pixels based on 14 brightness intervals is shown in Figure 1, column 5. The colors and brightness amplitudes for the 14 intervals are defined in Table 1. The percentages of total number

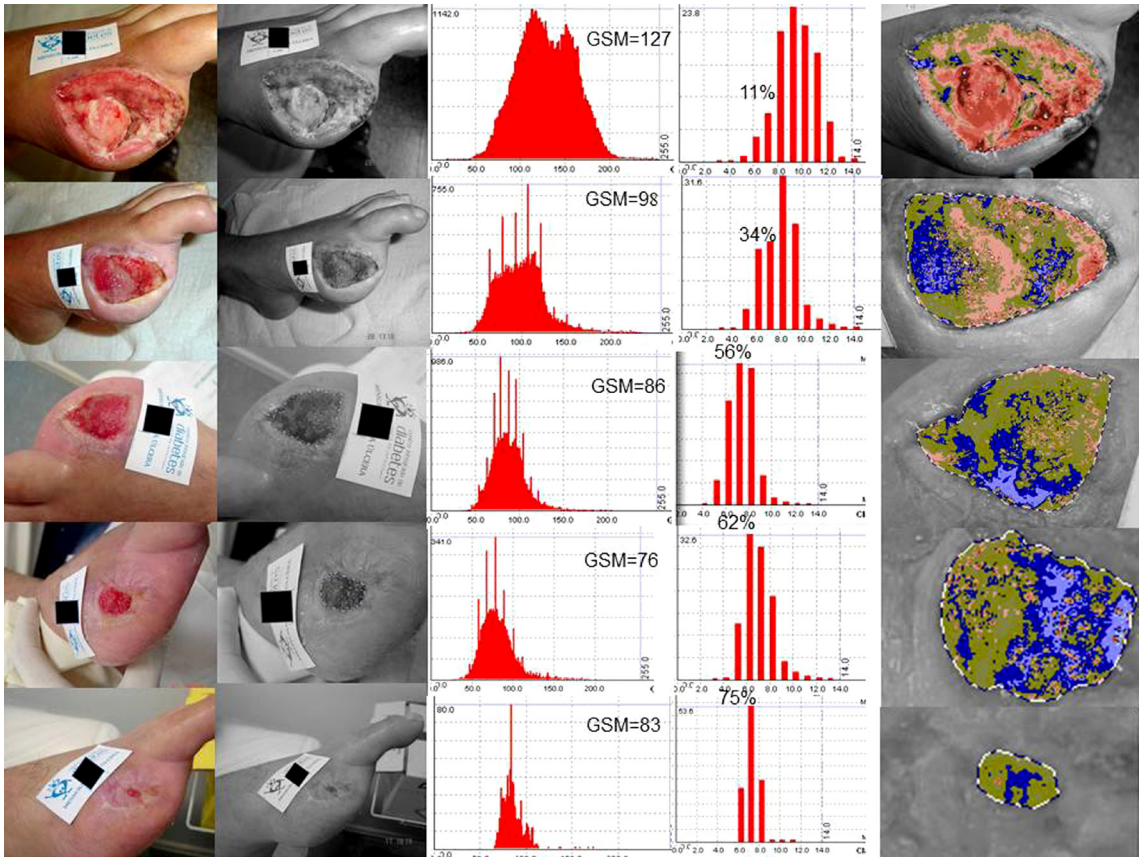


Figure 1. Photographic image tissue characterization (p-IMTC) of ulcerated region of a diabetic foot after digital amputation and during medical treatment. Five photographic images taken over 3 months of treatment. Column 1: original image. Column 2: image converted to grey scale. Column 3: number of pixels distribution and grey scale median (GSM). Column 4: histogram of percentages of number of pixels within 14 brightness intervals. Explicit proportions are for granulation tissue with brightnesses in the 61 to 90 interval. Column 5: Artificial colorization of the wound image using 14 colors to represent brightness intervals. The relationships between colors and brightness intervals are given in Table 1.

of pixels in each of the grey scale brightness intervals are listed in Table 1 for the 5 images. The proportion of pixels within intervals from 61 to 90 increased steadily from 11% to 34%, 56% and 62%, reaching 75% in the final image. The percentage of pixels with intensities within intervals from 112 to 196 reduced significantly from 67% to 29%, 8% and 6%, reaching 1% in the final image. The 61-90- and 112-196 brightness intervals were identified as granulation of the wound and exposed bone respectively by an expert based on visual observation. The area of the lesion, the percentage of pixels representing granulation and the GSM are shown in Table 2 for the 5 images analyzed.

DISCUSSION

The p-IMTC technique identified alterations in image brightness of an ulcerated diabetic foot, as the wound healed under medical treatment following digital amputation. In particular, the proportion of

granulation tissue increased as the wound healed. The granulation tissue was identified by an expert, based on visual observation, and associated to the 61 to 90 grey brightness interval of a grey scale image with 256 grey tones. The proportion of pixels with brightness within this 61-90 interval increased as the lesion healed. In contrast, the area corresponding to exposed bone tissue reduced as treatment progressed. Exposed bone tissue was associated with the 112 to 196 brightness interval; the proportion of pixels within this interval decreased during treatment. This study extended the application of the ultrasonographic USTC-CATUS technique to images in general, photographic images in this case. Analyses of aneurysms⁴, normal and transplanted kidneys^{5,6}, atheromas⁷⁻¹⁰, venous thrombosis¹¹⁻¹³ and edema¹⁴ have thereby been extended to a potential application of photographic images to ulcerated wounds or peripheral injuries.

Physiologically, the human eye is, on average, capable of distinguishing only 16 of the 256 grey

Table 1. Percentages of total number of pixels in each grey scale brightness interval for five photographic images of a diabetic foot. Intervals from 61 to 90 and from 112 to 196 were identified with granulation tissue and exposed bone respectively.












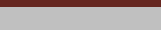

Color	Grey scale	Percentage of total number of pixels within each interval (%)				
		Image 1	Image 2	Image 3	Image 4	Image 5
	0-4	0.0	0.0	0.0	0.0	0.0
	5-7	0.0	0.0	0.0	0.0	0.0
	8-26	0.0	0.0	0.0	0.0	0.0
	27-40	0.0	0.1	0.0	0.4	0.0
	41-60	0.7	4.0	5.3	12.5	0.0
	61-76	3.7	16.4	23.5	32.6	21.1
	77-90	7.3	18.0	32.0	29.6	53.6
	91-111	20.1	31.6	31.0	18.7	24.1
	112-132	23.8	21.7	6.4	3.9	0.5
	133-153	20.9	4.9	1.3	1.6	0.5
	154-174	16.6	1.8	0.4	0.6	0.3
	175-196	6.1	0.9	0.1	0.3	0.0
	197-210	0.6	0.3	0.0	0.0	0.0
	211-255	0.4	0.3	0.0	0.0	0.0

Table 2. Photographic image tissue characterization (p-IMTC) of ulcerated lesion of a diabetic foot after digital amputation and during medical treatment. Five photographic images were obtained over approximately 3 months of treatment in chronological order from 1 to 5.

	Area of ulcer (cm ²)	Area of granulation tissue (%)	GSM
Image 1	17.85	11	127
Image 2	12.44	34	98
Image 3	3.68	56	86
Image 4	2.11	62	76
Image 5	0.15	75	83

GSM: Grey scale media.

scale tones commonly found in ultrasonographic images¹⁷. By processing and quantifying images using software designed to categorize and differentiate grey scale tones, visual perception can be enhanced and medical events and conditions can be monitored quantitatively. The artificial coloring technique produces images that direct an observer’s attention to specific brightness intervals. Such intervals and their colors can be predefined based on earlier research, or selected by a specialist as it was the case of this “discovery phase” report. Both USTC and p-IMTC (CATUS and CATIM are the original Brazilian terms) techniques are dependent on the conditions and characteristics of the original images. The method described herein involved minimization of image variations by scale standardization. The images were rescaled based on arbitrary decisions of an experienced operator. The program employed redefined brightness values 0 and 200 of a 0 to 255 grey scale. We recommend that the operator does not attempt to optimize original images visually, particularly when using ultrasonography. This avoids introducing the effect of imperfect human vision into the process.

Tissue characterization is a precursor of virtual histology. In the case described herein, a specialist associated specific brightness intervals to granulation tissue or exposed bone tissue. The a priori intervals listed in Table 1 have been successfully used in past applications already described in the literature. In this specific case, the intervals used for granulation or exposed bone tissue did not require reformulation. Future analyses may confirm these intervals or may specify tissue intervals more precisely. Virtual histology is reached when the brightness intervals become adapted or redefined in response to histological data. As an example, Menezes et al. compared USTC or CATUS, of carotid artery plaques with histopathology findings⁷. Variability in histological sections and planes of ultrasound images were evaluated in such study. Virtual histology offers the advantage that it can be done in vivo without harming the patient. Certain images, however, cannot be considered histological, but supplementary, providing independent information. Therefore, p-IMTC/CATIM and its subgroup, USTC/CATUS may become an analytical tool in itself and not as a predictor of present day technologies.

CONCLUSIONS

The technique of tissue characterization in images quantified information related to treatment of a diabetic foot. In particular, in addition to the size of the wound, grey scale median brightness and proportions of pixels within brightness intervals identified notable changes of granulation tissue or exposed bone as a result of treatment. Medical information has been extended by p-IMTC both qualitative and quantitatively. In the future, the p-IMTC technique could be used to analyze ulcers, wounds, lesions or other tissues, allowing quantification, characterization, and control of progression of a disease or treatment benefits. Serial assessments may indicate whether treatment needs to be adapted or modified. Following this report of a discovery, future research could improve imaging tissue characterization in daily medical practice.

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