Computers in Biology and Medicine 63 (2015) 11–18

Contents lists available at ScienceDirect

Computers in Biology and Medicine

journal homepage: www.elsevier.com/locate/cbm

Evaluation of vermillion border descriptors and relevance vector machines discrimination model for making probabilistic predictions of solar cheilosis on digital lip photographs

Panagiota Spyridonos [a,*], Georgios Gaitanis [b,1], Ioannis D. Bassukas [b,1], Margaret Tzaphlidou [a]

[a] Department of Medical Physics, Faculty of Medicine, School of Health Sciences, University of Ioannina, University Campus, Ioannina 45110, Greece
[b] Department of Skin and Venereal Diseases, Faculty of Medicine, School of Health Sciences, University of Ioannina, University Campus, Ioannina 45110, Greece

ARTICLE INFO

Article history:
Received 17 February 2015
Accepted 15 April 2015

Keywords:
Lip features
Solar cheilosis
Actinic cheilitis
Image analysis
Relevance vector machines

ABSTRACT

Introduction: Solar cheilosis (SC), a common precancer of the lower lip with a high potential to progress to invasive squamous cell carcinoma, presents with characteristic morphological vermillion-skin border alterations, like the border retraction.
Aim: To determine robust macro-morphological descriptors of the vermillion border from non-standardized digital photographs and to exploit a probabilistic model for SC recognition in real clinical environments.
Methods: Lip borders of 150 individuals (75 SC patients, 75 non-SC controls) were quantified on the basis of the extent of vermillion retraction and the degree of border irregularity employing fractal features and type-P Fourier descriptors. Eight lip border quantifiers were evaluated in terms of their reliability and reproducibility. The probabilistic 'diagnostic' model was implemented using the relevance vector machine (RVM) algorithm.
Results: Picture acquisition contributes substantially to overall variability of lip border images; however, for the different lip descriptors 33% to 65% of border morphological variability is due to differences among individuals. Different camera operators or the use of cameras with different specifications did not affect significantly the extracted lip features. The proposed RVM probabilistic model yielded a high sensitivity and specificity of 94.6% and 96%, respectively.
Conclusion: We explored the use of digital photography within the clinical routine setting to validate a probabilistic model for the assessment of lip conditions like SC. The proposed method opens new perspectives toward a cost effective, non-invasive monitoring of SC to support large scale epidemiological and interventional studies in different clinical environments.

1. Introduction

Solar cheilosis (SC) is a common condition that mainly affects the lower lip of elderly, chronically sun exposed individuals. It is considered an *in situ* carcinoma equivalent to actinic keratoses of the skin [1,2]. However, the likelihood that precancer will progress into invasive squamous cell carcinoma (SCC) in a SC affected lip is about 2.5 fold higher than that for a comparable skin area with actinic keratoses [2,3]. Consequently the development of SC more than doubles the SCC risk of an individual [2,4]. Moreover, lower lip localization is considered as a distinct risk factor for recurrence or metastasis of SCC [5,6]. The predominant etiologic factor of SC is long term exposure to ambient sunlight ultraviolet radiation and for this reason it affects almost exclusively the stronger exposed lower lip (95% of the cases) [2,7,8]. Since as a rule SCC develops many years after the diagnosis of SC the current consensus for the prevention of lip SCC is timely treatment of all patients with SC and structured follow-up to monitor for disease recurrences [4,9]. However, all currently recommended therapeutic modalities for SC are associated with substantial discomfort and morbidity as they inflict significant symptoms (primarily pain in the highly innervated lower lip), while abrasive surfaces that result from treatment

* Corresponding author. Tel.: +302651007782; fax: +302651007854.
E-mail addresses: pspyrid@cc.uoi.gr (P. Spyridonos), Ggaitan@cc.uoi.gr (G. Gaitanis), ibassuka@cc.uoi.gr (I.D. Bassukas), mtzaphli@uoi.gr (M. Tzaphlidou).
[1] Tel.: +302651007425; fax.: +302651007031.

http://dx.doi.org/10.1016/j.compbiomed.2015.04.024
0010-4825/

interfere with the daily intake of food and water for weeks. Thus development of objective measures that would assist appropriate patient selection who need treatment is pivotal for improving healthcare in this subset of patients. Currently the evaluation of SC severity is primarily subjective based on clinical criteria as are alterations of the configuration of lower lip vermillion-skin border [4,10] and variations of color, consistency or keratinization of the lower lip surface as well as relapsing fissuring. Histopathological evaluation offers insight of the presence and severity of the condition at tissue, yet, as SC involves the entire lower lip at various degrees of severity, it is only representative of the biopsy site [5,11]. Persistent erosions or ulcers usually denote the development of SCC [2]. A reliable, objective evaluation of lip alterations would significantly contribute in the identification and monitoring of disease progression and treatment outcome.

In a recent publication, utilizing digital photography and image analysis techniques we introduced a workable methodology for accurate vermillion border detection and we applied it to monitor SC improvement after treatment with immunocryosurgery [12]. We presently expand this approach by exploiting the application of additional, robust lip border descriptors that provide both, adequate agreement with our visual perception of the irregularity of the lip boundary and sufficient ability to discriminate between lip boundaries with different degrees of abnormality.

In addition, the dichotomous classification approach to discriminate healthy from SC diseased lips, presented in our previous study [12], is now expanded to assess the degree of lip abnormality by incorporating a probabilistic model approach based on relevance vector machine (RVM). The Bayesian framework of RVM formulation constitutes an attractive discriminative model alternative, since it permits the prediction of the posterior probability of abnormal lip configurations which is essential in treatment evaluation and patient monitoring. RVM have been used with success in different bio-medical application fields, such as, neonate pain intensity assessment [13], epilepsy diagnosis [14], gene selection in cancer classification [15], identification of functionally significant promoter sequences by microarray data analysis [16], detection of micro-calcifications in mammograms [17], and the diagnosis of glaucoma [18].

From a clinical point of view, the proposed methodology is adequately efficient with respect to time and resource sparing as it did not require any specific equipment (e.g. chin holders or customized cameras). However, to establish the applicability of the proposed approach we need to safeguard for sufficient reliability and reproducibility of the evaluated macro-morphological lip border markers. Reliability is inherently flowed by different face postures taken by the subject, while practical problems that may interfere with the reproducibility of lip feature evaluation, include the use of dissimilar cameras with variable specifications or even different operators (different dermatologists). These confounding parameters have been herein addressed in order to make the suggested automated approach to the identification and quantification of SC suitable for large scale epidemiological studies in different clinical settings.

2. Material and methods

2.1. Acquisition of lip images

The probabilistic model for SC assessment was trained and validated, incorporating lower lip vermillion border features extracted from non-standardized pictures taken from 75 SC patients and 75 healthy control volunteers.

Institutional Review Committee approval was granted and patients with SC and appropriate controls (patients with non-SC related skin conditions and healthy patients' companions) attending the Dermatology ambulatory of the University Hospital of Ioannina were recruited after informed consent for clinical evaluation of the lower lip and subsequent photography.

The diagnosis and severity assessment of SC relies on the recognition of certain macro-morphological disease characteristics [4]. In this study diagnosis and severity assessment resulted from a consensus of clinical examination and independent review of the clinical pictures by two certified Dermatologists (GG, IDB).

The clinical examination included inspection for the presence of whitish-gray or brown, scaling or not plaques, areas of dryness or fissuring and of course alterations of the lip vermillion border that was the target of our study. Clinical examination was completed with palpation for recording roughness of the texture of the lip. SCC suspicion was raised and a 3 mm punch biopsy was performed when persistent erosion with distinct borders was present or when a palpably indurated hyperkeratotic papule was present. In the case of SCC histopathological confirmation the patient was excluded from subsequent analysis.

All pictures were taken with the volunteers seated and instructed to look straightforward at the camera, to keep their head perpendicular to the floor and to slightly open their mouth so that both mouth corners become visible. Images were taken to demonstrate the lower third of the face. To save computation time all images were manually cropped to include only the mouth area for further processing. All digital pictures employed in the core analysis were taken by one and the same 'operator' (physician) with a Nikon SLR 5100 camera and original resolution 4928×3264 pixel.

2.2. Image pre-processing and lip vermillion border extraction

The method of image pre-processing and the segmentation of lower lip border has been presented in our previous study [12]. The procedure can be summarized in the following steps:

i. Image rescale, to have approximately the same spatial resolution in all cropped images
ii. Image correction for non-uniform illumination
iii. Image enhancement based on local gamma correction.
iv. Image transformation from RGB to YIQ color space. Q color channel was retained to discriminate between lip and non-lip pixels.
v. Lip border segmentation using a spatial fuzzy *c*-means clustering algorithm with adaptive selection of fuzzy exponent m.
vi. Estimation of the "ideal" lip border by the four degree polynomial curve that best fits the convex hull points of the segmented lip border.

2.3. Extraction of vermillion border descriptors for lower lip disease assessment

With respect to the characteristic alterations of the lower lip vermillion-skin border in SC patients [2], two types of morphological features were quantified: (i) The extent of vermillion replacement by expanding skin or erosions and (ii) the degree of the irregularity of this border.

2.3.1. Extent of vermillion retraction

The degree of pathological deviation of the vermillion border was quantified using the distance between the extracted and modeled vermillion lip border C and C^* respectively [12]. Three different metrics were employed:

The average version of Hausdorff distance (H_{AVG}) [19], the 0.95 quantile partial Hausdorff distance (95%-HD) [20], and the Mean