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Original Research Article

First results of a new hyperspectral camera system for chemical based wound analysis

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ABSTRACT

Hyperspectral imaging and near infrared spectroscopy (NIRS) for wound analysis have been used in many scientific studies with good results for the chemical analysis of wounds and have the potential to raise objective measurement and assessment of wounds to a new level with considerable higher clinical informative value. Up to now the clinical and scientific use of this technology has been hindered by the lack of a hyperspectral measurement system usable in clinical practice. We present the first hyperspectral camera for quick and robust acquisition of hyperspectral data in the combined VIS and NIR spectral range with high spectral and spatial resolution from wounds. First case studies and evaluations of chemometric parameters like the oxygenation of hemoglobin and perfusion quality are presented and exhibit the high quality and potential of this new wound measurement system.

1. Introduction

1.1. Description and documentation of wounds

Assessment and documentation of wound states and wound processes is at present mainly performed by recording visually accessible wound features in documentation sheets, complemented by conventional color photos [1–3]. Such wound features are the size of the wound area, different wound components like granulate, fibrin or necrosis which are recognizable by color and texture. Additional relevant wound information as smell, moisture and algesia are recorded in the documentation sheets, but are only qualitatively and subjectively influenced descriptions. Because there are no exact measuring methods for all those features, they depend on the experience and accurateness of the examiner, are not objective and only roughly quantifiable and comparable, so that considerable differences result in the assessment of the same wound by different examiners [4–6]. The evaluation and comparison of different wound treatment methods is very difficult with this description standard.

In the cost extensive treatment especially of chronic wounds, therapy outcomes and life quality of the patients strongly depend on a consistently objective and quantitative high-quality wound documentation as basis for the selection of an adequate therapy in the different wound healing phases. Increasingly complex and differentiated wound treatment methods, for instance the application of wound bandages using different physical principles of operation, require the accurate description of the actual wound state and wound processes to be effective [7–11]. Just the difficult and protracted treatment of chronic wounds is still performed very unsystematic [12–14].

1.2. Objectifying wound description

By digital color (RGB-)photo documentation and software with interactive image processing, at least the size of the wound area and different main components (segments) of the wound ground can be determined more precisely [15–27]. By stereoscopic photometry or laser scanning methods [28] also three-dimensional wound structures can be principally detected [29,30]. The oxygenation of hemoglobin can be determined by tissue oximetry technologies [31], laser-Doppler imaging (LDI) measurements provide [32] a measuring value (depending on the specific method and device) correlated with an averaged local blood flow.

But except of photo documentation the other mentioned methods are not widely or routinely used for wound description and assessment due to a lot of restrictions and problems in practical use. Even a system for automated determination of wound size is not available at present.

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1.2.1. Optical remission spectroscopy

Optical remission spectroscopy in the visible and near infrared range (400–1000 nm), as a contact-free method without any influence on skin and wounds, offers in principle the potential to extract clinically relevant information from the wound. In expansion of multispectral imaging measuring techniques [33,34], hyperspectral imaging methods record a complete remission spectrum at any image point with a spectral resolution of up to some hundred values. Hyperspectral imaging (HSI) is an emerging medical technology that offers the possibility of extracting both spectral and spatial information about each pixel from a tissue image. From this data chemometric parameters, wound area segmentations and exact determinations of the wound dimensions are determinable enabling a complete and differentiating wound analysis and description with only one measurement method [35–46].

2. Material and methods

2.1. Measuring principle

The physical measurement principle of remission spectroscopy consists in irradiating the wound with white light and the detection of the light remitted from the upper layers of the wound. In the upper wound layers the incoming light is scattered by different inhomogenities of the wound structure and absorbed by different wound components, for instance hemoglobin, water and other tissue substances. Scattering and absorption effects depend on the wavelength, so that characteristic different remission spectra result for different states of the wound.

With the optical effects the penetration depth of the light is also dependent from wavelength and is between approx. 0.5 mm (400 nm) and 3.5 mm (900 nm). The penetrating light passes through the different layers and components, defining the measuring volume. The resulting remission spectrum is a complex superposition of diverse component spectra.

2.2. Hyperspectral camera

A new hyperspectral (HSI-) camera system in prototype status with an internal pushbroom imaging spectrograph (HSI-CAM, SpekLED GmbH, Germany) was used for image acquisition. The spectrograph aquires a full spectrum for every point of a row (*x*-axis) in parallel. This row is then moved along the *y*-axis by an internal stepper motor realizing a hyperspectral imaging measurement. So a three dimensional hyperspectral data cube can be acquired in typical 3–15 s without moving of any external part or object.

The parameterization of the hyperspectral data cubes was performed with the camera specific acquire module of the Perception Studio Software (Perception Park, Austria), which allows for the simultaneous acquisition of >100 spectral bands in the range from 500 to 980 nm with a spectral resolution of 1.95 nm and a CMOS camera with high recording speed at a spatial resolution of 640×480 pixels. The recording time in this parameterization of the HSI camera is currently approx. 10 s.

The whole system was mounted on a medical cart with flexible camera extension arm (Fig. 1).

Fig. 1. Hyperspectral camera mounted at a flexible medical cart system.

Uniform illumination of the entire investigation area was provided by an illumination unit containing two 120 W halogen lamps equipped with diffusive reflectors.

A commercial image acquisition laptop with image acquisition software (Perception Studio) and an original image processing and analysis software was connected to the hyperspectral system.

In comparison with hyperspectral imaging systems used before and described in literature this camera is the first compact and flexible system with high spectral and spatial resolution and a acquisition time short enough for the use in clinical practice.

2.3. Primary model-based evaluation of remission spectra

Hyperspectral imaging records a full optic remission spectrum for every pixel. This creates a so-called data cube with two spatial (*x*,*y*) and one spectral dimension (λ) (Fig. 2a). This data cube contains chemical information (e.g. oxygenation, hemoglobin index, humidity, signs of inflammation) in the λ-coordinate (Fig. 2b) and the spatial segmentation and characterization of the wound area in the *x*,*y*-coordinates. The comprehensive interpretation of the spectral data is a complicated and ambitious task. This will be performed in several steps of development, beginning with relevant primary parameters, which can be determined with relative high reliability.

The rough form of the remission spectra is strongly dominated by the absorption of hemoglobin. Because the oxygen supply is a fundamental factor for wound healing, problems of the perfusion and oxygenation should be detected precisely in the wound area and the wound surrounding.

For the determination of oxygenation in a first attempt a model-based approach is used, which is already comprehensively described in the literature [47]. This method uses the spectral region from 510 to 590 nm with 5 isosbestic points of hemoglobin and the characteristic double peak of the hemoglobin absorption spectrum to adapt a model-based spectrum to the actual measured spectrum. The model includes hemoglobin (Hb and HbO_2) as the main absorber and a second component representing background absorption (for instance melanin) and scattering effects.

Fig. 3 shows the adaptation of the model spectrum (blue) to the measured values (black).

Additionally to the determination of oxygen saturation of hemoglobin, from the modeling a parameter is determined, which is mainly depending on the volume fraction of hemoglobin in the measuring volume. This parameter is called tissue hemoglobin index (THI).

From the NIR-region of the spectrum a parameter is determined, which depends on the "perfusion" in the deeper layers of