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Abstract. Skin erythema has been widely used as a diagnostic parameter in dermatology. This study describes a methodology for real-time measurement of skin erythema variation induced by negative compression. This study developed an optical measurement probe, which includes a RGB color sensor that translates in the vertical direction, with the magnitude of vertical translation dependening on the amount of skin deformation. Real-time measurement of erythema variation as a function of both negative compression and time was performed *in vivo* on 10 measurement sites located on the back of each of 12 volunteers who participated in this study. Negative compression was sequentially applied from −30 to −80 kPa and continuously at a constant magnitude (−80 kPa) condition. The results showed that skin erythema was uniformly induced at the measurement sites and linearly increased as a function of both negative compression and time. A wide range of individual variation was noted for skin erythema, which may be due to variations in anisotropic skin properties between volunteers. This study demonstrated the clinical feasibility of a novel optical device for skin erythema measurement. Future studies are needed to investigate the clinical applications of this device. [DOI: 10.1117/1.JBO.17.8.081422]

Keywords: negative compression; erythema; optical device; skin deformation.

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1 Introduction

Skin color information has been widely used as an useful parameter to evaluate skin lesions in dermatology, cosmetology, orthopedic and plastic surgery, and alternative medicine.[1–9] Skin color is primarily determined by melanin and hemoglobin contents, which can indicate the presence or absence of cutaneous pathology or patient response to therapy.[8,10,11] Melanin and hemoglobin contents have been indirectly measured using the melanin and erythema index (EI) in the absence of skin deformation.[12]

Negative compression applied to the skin surface causes mechanical skin deformation,[9] reshapes the collagen and elastic fibers, changes the viscoelastic and anisotropic properties of the skin, and finally, affects skin color.[13] Skin deformation results in variations of skin properties, including epidermal thickness, melanin concentration per unit area, displacement of blood vessels toward the skin surface, blood vessel dilation, destruction of capillary vessels, and an increase in skin erythema.[4,7,13]

Variations in skin properties due to negative compression have been used clinically for therapy.[4–7,14] In laser therapy for port wine stain (PWS) lesions, negative compression is applied to treat PWS lesions by dilating local blood vessels.[4–6] Pain clinics have used negative compression applied using a small round cup on the back, chest, abdomen, and buttock for pain relief.[7] In reconstructive surgery, negative compression has also been used clinically to treat multiple burns, substantial scar tissue, and contracture.[14] Future diagnostic use of the variations in skin properties induced by negative compression may be useful to enhance treatment results.

Although various color measurement devices[1,2,8,11] have been used clinically to objectively measure skin color, to the best of our knowledge, current devices cannot perform real-time measurement of skin erythema variation based on skin deformation induced by negative compression. This study aimed to investigate the clinical feasibility of a novel optical skin erythema measurement system (OSEMS) for real-time measurement of skin erythema variation induced by negative compression. The OSEMS stimulates human skin with an adjustable level of negative compression and simultaneously measures the skin EI in real-time as a function of both negative compression and time. The hardware and software of the OSEMS were developed for automatic data acquisition and processing, and clinical feasibility was investigated by evaluating skin erythema variation in human volunteers.

2 Material and Methods

2.1 *Optical Skin Erythema Measurement System*

Figure 1(a) illustrates a schematic diagram of OSEMS which consists of an optical measurement probe (OMP) and RGB color sensor module (modEVA-TOP plug module; JENCOLOR MAZeT GmbH, Jena, Germany), electronic control system (ECS), and a vaccum pump (N815KNDC12; KNF Neuburger Inc., Freiburg, Germany) with a negative compression sensor (PSB-V01C; Autonics Corporation, Gyeongsangnam-do, ROK). The OMP [Fig. 1(b)] includes a RGB color sensor that translates in the vertical direction, with the magnitude of vertical translation depending on the amount of skin

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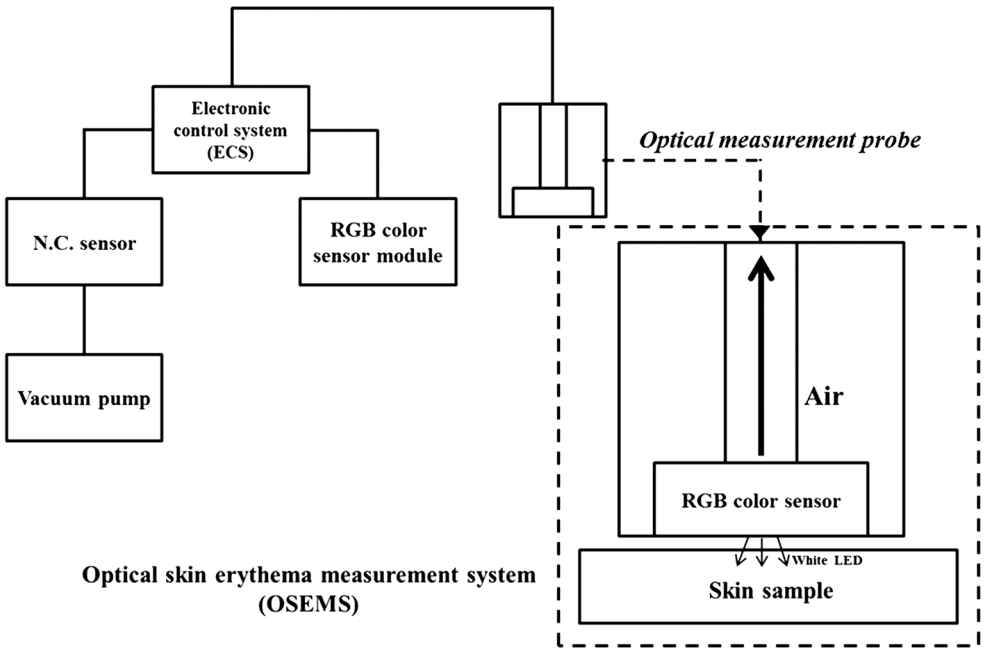
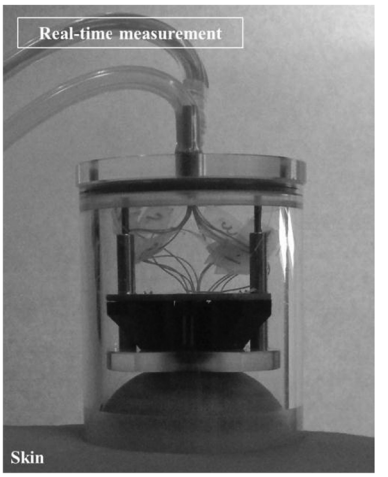


(a)



(b)

Fig. 1 (a) Schematic diagram of optical skin erythema measurement system (OSEMS) which consists of an optical measurement probe (OMP), RGB color sensor module, electronic control system, and a vacuum pump with a negative compression sensor. (b) The movement of the OMP due to the skin deformation.

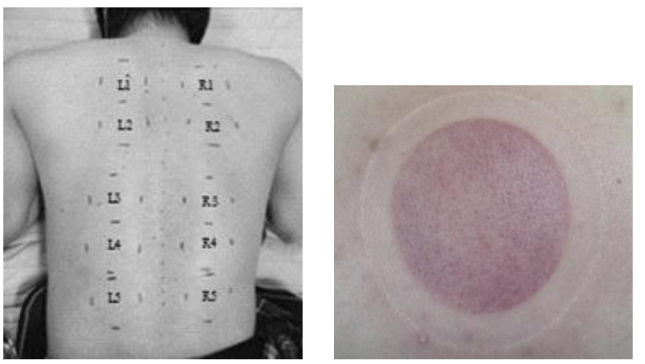
deformation. The OSEMS was designed for automatic measurement of skin erythema variation as a function of both negative compression and time. System control and EI[8,10,12] measurement were automatically performed using a laboratory-built GUI.

$$EI = 100 \times \log_{10}[(R_{measure}/R_{WR})/(G_{measure}/G_{WR})], \quad (1)$$

where $R_{measure}$ and $G_{measure}$ indicate the red and green color values measured with the OSEMS. R_{WR} and G_{WR} indicate reference red and green color values measured from a diffuse reflectance target.

2.2 *Clinical Feasibility of OSEMS*

Twelve male volunteers (mean age = 24 year) participated in the *in vivo* clinical feasibility study of the OSEMS. The



(a) (b)

Fig. 2 (a) Representative locations of the 10 measurement sites for skin erythema and (b) representative image demonstrating the uniformity in distribution of skin erythema induced by negative compression.

study was approved by the Institutional Review Board at Yonsei University, Wonju-si, Korea. The OMP was characterized by observing the uniformity of the distribution of skin erythema after the application of negative compression and the vertical translation motion throughout skin deformation. Skin EI variations in volunteers were measured at 10 different measurement sites [Fig. 2(a)] on their backs. EI variations were assessed as a function of both negative compression, which ranged from −30 to −80 kPa, and time at a constant negative compression of −80 kPa.

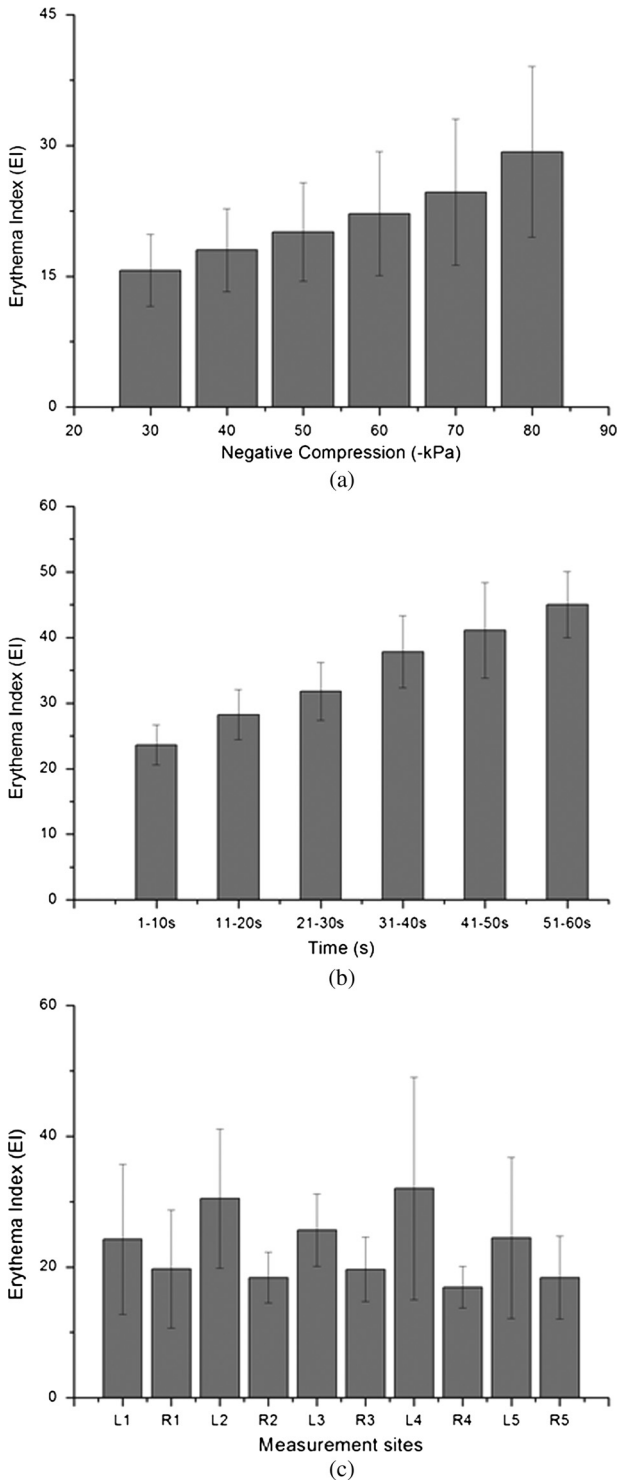


Fig. 3 Erythema index (EI) variation as a function of (a) negative compression, (b) time at a constant negative compression of −80 kPa, and (c) for 10 different measurement sites at a constant negative compression of −80 kPa.

3 Results

3.1 *Clinical Feasibility of OSEMS*

As shown in Fig. 2(b), the OMP induced a uniform erythema distribution after the application of negative compression in the region of interest (ROI). During the application of negative compression, the OMP demonstrated reliable vertical translation depending on the amount of skin deformation without excessive horizontal translation. Skin EI on 4 volunteers was measured at the L4 measurement site [Fig. 2(a)] and linearly increased as a function of negative compression [Fig. 3(a)]. Skin EI variation at a constant −80 kPa was measured on 8 volunteers every 10 s for 1 min at the R5 measurement site [Fig. 2(a)] and also linearly increased as a function of time [Fig. 3(b)]. In both cases, skin EI demonstrated volunteer-dependent variation. Figure 3(c) illustrates the skin EI variations on 8 volunteers measured for 10 s at −80 kPa on 10 measurement sites. The results demonstrate the volunteer-dependent and measurement site-dependent variations of skin EI, which may be due to anisotropic skin properties among volunteers.

4 Discussion

Various optical devices have been developed to objectively measure skin erythema, which has been used as a useful indicator of blood hemoglobin content. To the best of our knowledge, current devices measure skin erythema under nondeformed skin conditions by simply placing the measurement device on the ROI. In this study, the OSEMS was evaluated for real-time measurement of skin erythema variation induced by the application of negative compression in the presence of skin deformation.

In PWS laser therapy, the blood vessel diameters decrease due to sequential laser therapy, and therefore, treatment efficacy decreases due to insufficient thermal confinement caused by the lower blood volume-to-vessel wall surface area.[15] Negative compression has been applied to PWS lesions to address these decreases in treatment efficacy by inducing blood vessel dilation.[4,6] The OSEMS may be used to indirectly measure the variation in blood volume fraction induced by negative compression. Therefore, by enhancing blood volume-to-vessel wall surface area, the OSEMS could be used to determine the threshold of laser energy necessary to induce sufficient thermal confinement.

The clinical feasibility of the OSEMS was verified in Fig. 3. The skin EI linearly increased as a function of negative compression [Fig. 3(a)]. Skin surface expansion, induced by negative compression, results in blood vessel dilation and an increase in the degree of erythema due to an increase in the blood volume fraction at the skin surface.[4] Skin EI also linearly increased as a function of time at a constant negative compression of −80 kPa [Fig. 3(b)]. This result may be due to a gradual increase in the blood volume fraction achieved through the dilation of blood vessels or may be due to increased blood flow velocity as time progresses. Further studies are needed to determine the optimal time and magnitude of negative compression in order to maximize the diagnostic and therapeutic efficacy for specific clinical applications.

Skin EI was measured at 10 different measurement sites and demonstrated volunteer-dependent variations even at identical

measurement sites [Fig. 3(c)]. This variation may be caused by volunteer-dependent skin properties such as color and thickness, elasticity, and moisture. Future studies are needed to determine the impact that these parameters have on skin erythema. Figure 3(c) also shows the measurement site-dependent variation of skin EI. In fact, measurement site-dependent erythema variation was frequently observed across volunteers, and may affect results. These results suggest that skin properties may differ depending on the skin condition and presence or absence of skin disorders even in a healthy volunteer. Future studies are needed to investigate erythema variation induced by negative compression and its association with skin properties.

The OSEMS successfully induced skin erythema through the application of negative compression and simultaneously performed real-time measurement of skin erythema as a function of both negative compression and time without being physically affected by skin deformation. The clinical feasibility of the OSEMS was demonstrated through an *in vivo* human study. Clinical use of the OSEMS may provide objective diagnostic parameters in clinics, such as dermatology, cosmetology, orthopedic and plastic surgery, and alternative medicine.

Acknowledgments

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