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Ultrasound biomicroscopy measurement of skin thickness change induced by cosmetic treatment with ultrasound stimulation

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ABSTRACT

Moisturizing creams and lotions are commonly used in daily life for beauty and treatment of different skin conditions such as dryness and wrinkling, and ultrasound stimulation has been used to enhance the delivery of ingredients into skin. However, there is a lack of convenient methods to study the effect of ultrasound stimulation on lotion absorption by skin in vivo. Ultrasound biomicroscopy was adopted as a viable tool in this study to investigate the effectiveness of ultrasound stimulation on the enhancement of lotion delivery into skin. The forearm skin of 10 male and 10 female young subjects was tested at three different sites, including two lotion treatment sites with (Ultrasound Equipment – UE ON) and without (UE OFF) ultrasound stimulation and a control site without any lotion treatment. 1 MHz ultrasound with a duty cycle of 1.7%, a spatial peak temporal peak pressure of 195 kPa and an average power of 0.43 W was used for the stimulation. The skin thickness before, immediately after (0 min), and 15 and 30 min after the treatment was measured by an ultrasound biomicroscopic system (55 MHz). It was found that the skin thickness significantly increased immediately after the lotion treatment for both UE ON (from 1.379 ± 0.187 mm to 1.466 ± 0.182 mm, $p < 0.001$) and UE OFF (from 1.396 ± 0.193 mm to 1.430 ± 0.194 mm, $p < 0.001$) groups. Further comparison between the two groups revealed that the skin thickness increase of UE ON group was significantly larger than that of UE OFF group ($6.5 \pm 2.4\%$ vs. $2.5 \pm 1.3\%$, $p < 0.001$). Furthermore, it was disclosed that the enhancement of lotion delivery by ultrasound stimulation was more effective for the female subjects than the male subjects ($7.6 \pm 2.3\%$ vs. $5.4 \pm 2.0\%$ immediately after treatment, $p = 0.017$). In conclusion, this study demonstrated that ultrasound biomicroscopy was a feasible method for studying the effectiveness of lotion treatment in vivo, and ultrasound stimulation was effective to enhance the rate of lotion absorption into skin.

1. Introduction

Nowadays, the use of ultrasound in beauty industry has been very common and demanding all over the world, especially in well developed cities such as Hong Kong. One common application is to use ultrasound to enhance the delivery of cosmetic lotion, a method called "ultrasound massage". Manufacturers of ultrasound massagers often claim that the use of these devices enhances the absorption of lotion ingredients into skin. However, the effectiveness of ultrasound stimulation on enhancing the lotion delivery has been scarcely reported in the literature.

Low weight molecules (<500 Dalton) can pass through the skin mainly depending on the mechanism of passive diffusion [1,2]. However, the rate of passive diffusion in skin is limited, particularly by the outermost stratum corneum layer. To increase the rate of transdermal absorption, ultrasound may be used as a mechanical method to disturb the skin microstructures. One challenge in studying the effect of ultrasound stimulation on transdermal lotion delivery is how to assess/quantify the absorption. Tissue biopsy and histological analysis in vitro or plasma test in vivo have been adopted to assess the efficacy of ultrasound stimulation for chemical or drug delivery [3,4]. However, these two methods are not applicable to the assessment of lotion delivery in vivo. One potential solution is to measure the change of skin thickness using a non-invasive method of high frequency ultrasound imaging [5] since the increase of skin hydration induced by the absorption of lotion will cause the increase of skin thickness. For example, it has been demonstrated that the application of glycerol solution on skin could induce swelling of the stratum corneum [6]. Fluhr et al.

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reported that 5% glycerol applied on skin increased the stratum corneum thickness by approximately 25% [7]. Because of the remarkable difference of the acoustic impedance between the coupling media and the skin and also between the dermis and the subcutaneous tissue, an echogenic skin layer is clear in high frequency (>20 MHz) ultrasound images, which can be used for the measurement of skin thickness. The measurement of skin thickness has been successfully applied in studies of skin-related pathologies such as patch test and hormonal treatment [8–11]. It is a potential method to study the effectiveness of lotion delivery with the stimulation of ultrasound.

This study aims to test the hypothesis that ultrasound stimulation can enhance lotion delivery. Therapeutic ultrasound (1 MHz) was used as a stimulation method to potentially enhance the delivery of cosmetic lotion to skin, and the skin thickness before and after the treatment was quantitatively assessed by a high frequency (55 MHz) ultrasound biomicroscopy on 20 subjects (10 male and 10 female). The change of skin thickness with and without ultrasound stimulation as well as the gender dependence of such change was reported. Details of the current study are presented as follows.

2. Materials and methods

2.1. Equipment and materials

An ultrasound biomicroscopic system (Vevo 770, Visualsonics Inc., Toronto, Canada) with a transducer of 55 MHz in central frequency was used for the skin imaging. The axial resolution of this transducer was approximately 30 μm, the lateral resolution was approximately 70 μm and 2-D imaging was achieved by a mechanical scanning of the transducer in a linear way. To the best of the authors' knowledge, this equipment is one of the best known ultrasound systems available in the commercial market for high frequency ultrasound imaging of skin in vivo. The spatial resolution provided by the 55 MHz probe is suitable for studying the skin; therefore, it was adopted in the current study. A 1-MHz ultrasound stimulation device (ST-302S Multi-Function Sonic Massager, AIKO Beauty Products Ltd., Hong Kong) (Fig. 1) was used for the ultrasound stimulation in this study. The head of the device with an embedded single-element ultrasound transducer had a diameter of 48.5 mm (Fig. 1). Through measurement in water using a needle hydrophone (HNP-0400, HN-series hydrophone, ONDA Corp., Sunnyvale, CA, USA), it was found that the ultrasound transducer of the stimulation device worked in a long tone-burst mode with a repetition period of 46 ms and a pulse duration of 768 μs, i.e., a duty cycle of 1.7%. The spatial peak temporal peak pressure was 195 kPa measured at a plane 5 mm away from the probe surface, which resembled the situation of treatment on skin. The total power measured over the acoustic beam was 0.43 W for the stimulation. The cosmetic product used in this study was a very common lotion widely available in the market (Baby Simply Soft Lotion, Johnson & Johnson Hong Kong Ltd., Hong Kong). This lotion is an oil-in-water emulsion which contains mostly water and also some other minor components such as glycerin and petrolatum.

2.2. Subjects

Ten male and ten female subjects (age: 21 ± 1 years) were recruited for test on their forearms in the study. Subjects with skin irritation, food irritation, scar, sunburn or other skin problems were excluded from the study. In addition, those who had the habit of daily use of cosmetics on forearms were also excluded. Human ethical approval was obtained from the University Ethics Committee and all the subjects were asked to sign an informed consent form before assessment.

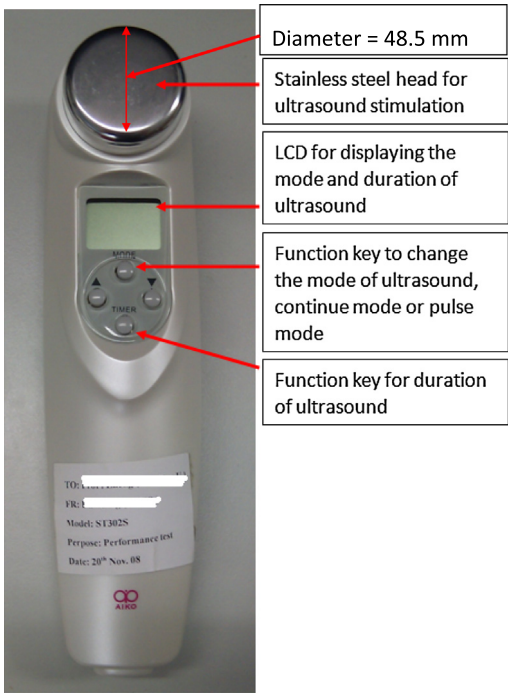

Fig. 1. A picture of the ultrasound stimulation device. The use of various parts of the device as seen in the front view was briefly introduced.

2.3. Assessment protocol and experimental test

The subjects were instructed not to use any cosmetics on forearms one day before the experiment. Before test, they were asked to wash both forearms with liquid soap, and were instructed to stay in the test room for at least 30 min. The room temperature (20 ± 2 °C) was controlled by air conditioners while the humidity (40 ± 2%) was controlled by a dehumidifier placed in the test room during the whole experiment.

The forearms of the subjects were divided into two regions including the proximal and distal parts (Fig. 2). The proximal parts of both forearms were used as control sites where no lotion or

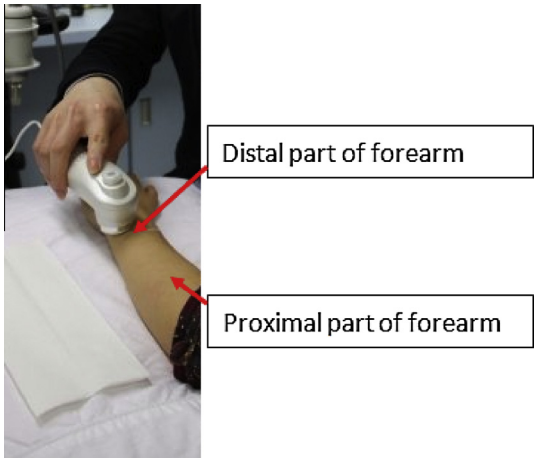

Fig. 2. The two arm locations used for lotion treatment with the ultrasound stimulation device. The stainless steel head was applied to massage the skin circularly and slowly for five minutes during lotion treatment.