

# The Vibrational OptoScope: A New Device to Evaluate Efficacy of Esthetic Treatments and Development of an Accelerated Skin Care Protocol

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## ABSTRACT

Vibrational optical coherence tomography (VOCT) is a new non-invasive and non-destructive technique that can be used to image and measure the mechanical properties of tissues *in vivo*. The technique uses infrared light and audible sound to image and measure the resonant frequency of tissue components. The stiffness (modulus) of each major tissue component is obtained from a calibration equation using values of the measured resonant frequency and tissue thickness determined *in vitro*. In this study, the Vibrational OptoScope is used to quantitatively compare the outcomes of cell proliferation and collagenous tissue changes as a result of: (1) A topical treatment (CE Ferulic); (2) microneedle roller application; (3) use of an OTC skin cream (Vaseline intensive care); and (4) removal of the stratum corneum in an accelerated skin care protocol. Both microneedle rolling and CE Ferulic topical treatment after about 1–7 months, respectively, appear to quantitatively increase the ratio of cells to dermal collagen and the ratio of reorganized collagen to dermal collagen. In addition, CE Ferulic treatment resulted in thinning of the stratum corneum and thickening of the epidermis. In comparison, removal of the stratum corneum using salicylic acid and sodium chloride shortened the time period required to see these changes to about 12–18 min. Application of a collagen/hyaluronic sealing gel after the stratum corneum was removed resulted in an increased smoothness and swelling of the epidermis. Topical treatment with Vaseline intensive care did not appear to affect the structure or properties of the epidermis. However, it did make the stratum corneum feel smoother and look less rough.

**Key words:** Audible sound, CE Ferulic, dermal collagen, epidermis, hyaluronic acid, microneedling, reorganized collagen, resonant frequency, skin, topical treatment, vibrational optical coherence tomography, virtual biopsy

## INTRODUCTION

Numerous techniques have been proposed to rejuvenate a youthful skin look that includes use of skin fillers such as hyaluronic acid (HA),<sup>[1,2]</sup> introduction of topical drugs,<sup>[3]</sup> delivery of substances into cutaneous and subcutaneous tissues through micro-needling, use of radiofrequency and laser treatments, and the use of topical patches.<sup>[4]</sup> The wide spread use of cosmeceuticals such as ascorbic and glycolic acids has created a large demand for new products.<sup>[5]</sup> However, the utility of many of these products is

dependent on their ability to penetrate the stratum corneum and facilitate diffusion through the papillary and reticular dermis.

The stratum corneum is the major barrier controlling hydration of skin and diffusion of hydrophilic compounds into the dermis. There are 18–20 layers of keratinized cells in the epidermis that are cemented together by lipids including ceramides that form intracellular lamellae. These intracellular lamellae are the permeability barrier for diffusion through the epidermis.<sup>[6]</sup> Lipid-enriched lamellar bodies, which compose 20% of the cell volume, are found at the interface between

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the stratum corneum and the stratum granulosum, the top two layers of the epidermis.

The hydration of the skin below the epidermis is largely controlled by the polar nature of the macromolecules that are found in the dermis. Proteoglycans in skin as well as HA are charged macromolecules that interact with water molecules by forming weak electrostatic interactions.<sup>[7-11]</sup> During aging, the HA and proteoglycan contents of skin decrease as well as the polarity of collagen fibers.<sup>[7-11]</sup> All of these factors limit the ability of dermis to retain moisture, especially the skin of older individuals.

Different chemical-mechanical methods have been used to promote diffusion of molecules through the epidermis. They include transdermal patches, chemical enhancers, iontophoresis, sonophoresis, jet systems, radiofrequency ablation, laser ablation, ultrasound stimulation, biochemical enhancers, electroporation, microneedling, thermal ablation, and microdermabrasion.<sup>[12-16]</sup> However, none of these techniques alter the charge profile of the epidermis and dermis to better retain water.

Injectable fillers composed of polymers such as HA are used to create esthetic bulking and moisturization of the skin.<sup>[17,18]</sup> However, these injections need to be repeated often and are costly. The alternative approach is to introduce HA in skin creams; the limitation of this approach is that high-molecular-weight HA cannot diffuse through the epidermis.

The purpose of this paper is to introduce a new device, the Vibrational OptoScope, which uses vibrational optical coherence tomography (VOCT) to evaluate the efficacy of different esthetic treatments. We compare the outcomes using VOCT of a topical treatment, CE Ferulic, microneedling, and an OTC topical skin care product, Vaseline intensive care. In addition, an ASCP involving removal of the stratum corneum is introduced to facilitate the introduction of topical agents and swelling of the skin.

## METHODS

### Patient consent

Skin from 20 subjects was studied *in vivo* as controls after informed consent was obtained. The subjects ranged in age from 25 to 75 years of age with a mean age of 57 years old. Tissues examined include skin from the cheek, back of the hand, forehead, palm, and skin over the radial artery in the wrist.

A topical preparation CE Ferulic (SkinCeuticals, Dallas Tx) was applied daily to the forehead on one of the subjects for a period of about 7.0 months. A second subject applied a needle roller to their forehead with a needle length of 1.5 mm (Micro540 Needles Derma Roller, HIEGOO, UK) 10 times

at the beginning of the study. The needled skin was evaluated for a period of 1 month post-treatment. Another subject treated their skin daily for 4 weeks with Vaseline intensive care lotion. OCT images and vibrational data were collected twice a week for the next 2 weeks.

The skin on the wrist of a third set of subjects was treated with 0.1 ml of 17% salicylic acid (SA) followed by removal of the stratum corneum with a forceps after treatment using 1.0 ml of 2.0 M NaCl. The skin on these subjects was subsequently treated with 1.0 ml of 0.2 M sodium pyrophosphate and covered with 0.5 ml of a 1% HA solution (Timeless Skin Care, Rancho Cucamonga, CA) mixed with 0.5 ml of a collagen gelling solution supplied by Dr. Dale DeVore.

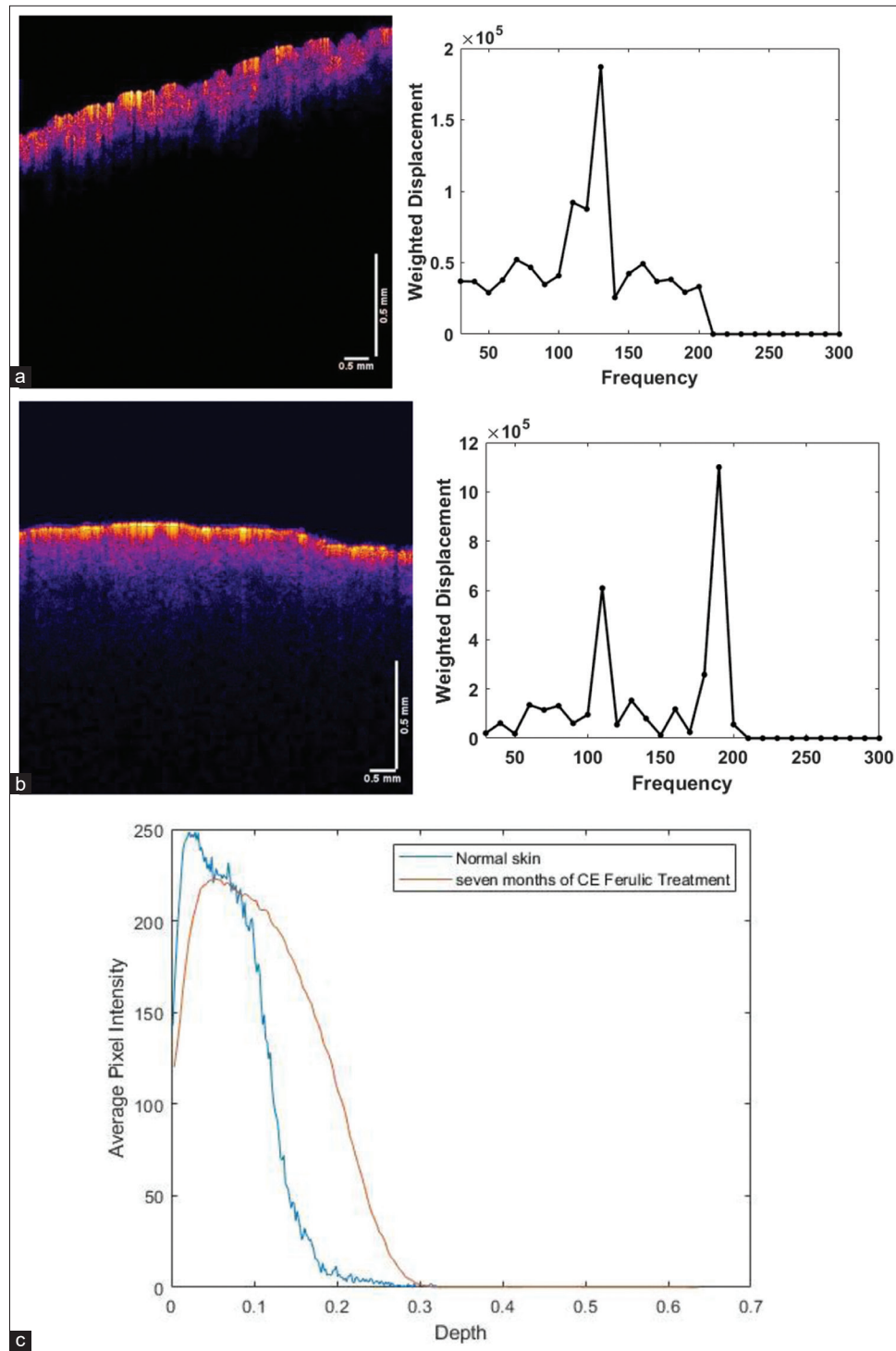
Images and resonant frequency changes of the skin were evaluated after each treatment using the Vibrational OptoScope (OptoVibronex, LLC). The OptoScope consists of an OCT and an audible sound component that is capable of imaging and measuring the resonant frequency of each major skin component as discussed previously.<sup>[19-23]</sup> The technique of using OCT in combination with vibrational analysis is termed vibrational OCT (VOCT) and the details of the methods used have been published previously.

## RESULTS

In this study, we introduce the use of the OptoScope to quantitatively compare the responses of different skin treatments including, a topical agent (CE Ferulic), microneedling, an over-the-counter skin cream (Vaseline intensive care), and removal of the stratum corneum followed by application of sodium pyrophosphate with a HA/collagen sealing gel. Needling creates small holes in the epidermis and dermis leading to a wound healing response; SA is a defoliating agent, while CE Ferulic and Vaseline are topical products.

### Skin treatment using CE Ferulic

The weighted displacement versus frequency data and OCT images obtained initially and at 1 and 7 months post-treatment are shown in Figure 1. The OCT images on the left side of Figure 1 illustrate that the skin is composed of an epidermis (yellow and pink regions) and papillary dermis (blue) and that the epidermal surface appears to have fewer surface undulations as the treatment time increases. Table 1 shows the ratio of the cellular (50–70 Hz) to dermal collagen (100–120 Hz) peaks as well as the ratio of the reorganized collagen (190–220 Hz) to dermal collagen peaks. CE Ferulic treatment increases the ratio of the cell/dermal collagen and reorganized collagen/dermal collagen peaks in a period of about 7 months as shown by the data in Table 1 and increased the skin thickness after 7 months, as indicated in Table 2.



**Figure 1:** (a) OptoScope image and weighted displacement versus frequency (Hz) for normal skin. Note the undulations in the epidermis of skin (yellow surface layer) and the presence of a normal dermal collagen peak at 120 Hz. The small peak at about 70 Hz is the epidermal cellular contribution. (b) OptoScope image and weighted displacement versus frequency (Hz) for skin treated with CE Ferulic for 7 months. Note the decreased undulations in the surface of the epidermis (surface layer in yellow) and the increased reorganized collagen peak height at about 190 Hz compared to (a). (c) Average pixel intensity versus depth (mm) for normal skin and skin treated with CE Ferulic for 7 months. Note the reduction in pixel intensity of the surface layers of the epidermis after 7 months of treatment with CE Ferulic at depths of less than 0.1 mm. This is consistent with the thinning of the stratum corneum with increasing treatment time

**Skin treatment using microneedling**

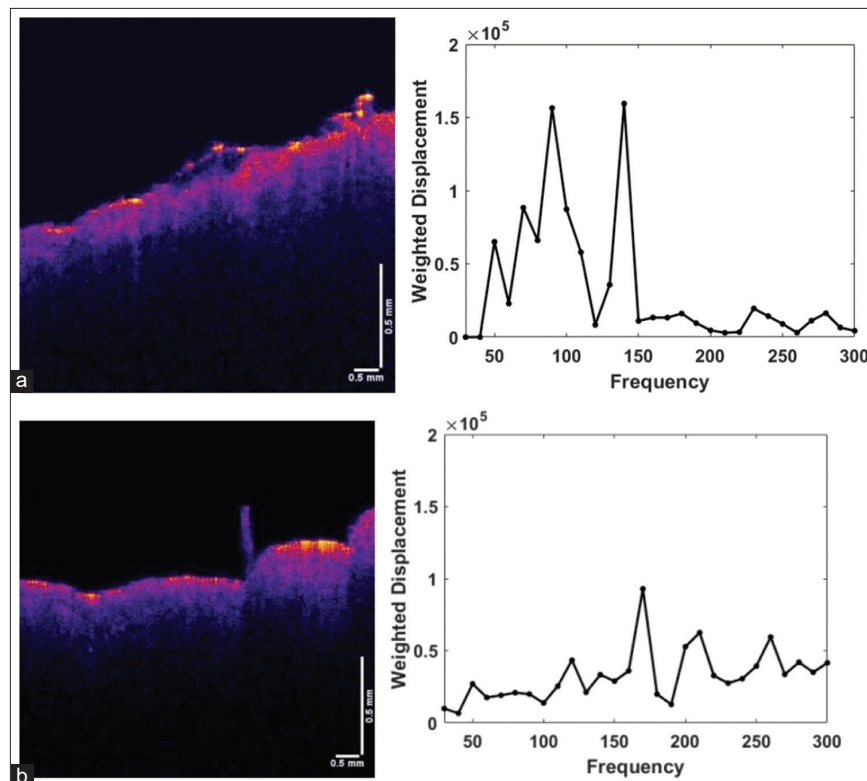
Microneedle rolling of skin with 1.5 mm needle length creates small holes in the epidermis and dermis leading to

a wound healing response [Figure 2]. The OCT images just before and after treatment illustrate that the needle holes close very rapidly and are difficult to observe after the needle

**Table 1:** Resonant frequency peak height ratios of cell (50–70 Hz) to dermal collagen (90–120 Hz) and for reorganized collagen (200–230 Hz) to dermal collagen (90–120 peak heights) for CE Ferulic topical treatment versus microneedle rolling of forehead skin versus time after treatment

| Treatment  | Time (months)  | Cell/dermal coll | REORG coll/dermal coll |
|--|----------------|------------------|------------------------|
| Topical CE Ferulic   | 0              | 0.0667           | 0.0625                 |
|  | 1.5            | 0.118            | 0.034                  |
|  | 6.5            | 0.417            | 0.66                   |
|  | 7.0            | 0.182            | 1.82                   |
| Treatment  | Time (weeks)   | Cell/dermal coll | Reorg coll/dermal coll |
| Microneedling  | 0 pre          | 0.231            | 0.0769                 |
|  | 0 post         | 0.330            | 0.0667                 |
|  | 1              | 0.330            | 0.0833                 |
|  | 2              | 0.667            | 1.10                   |
|  | 4              | 0.454            | 1.36                   |
| Treatment  | Time (minutes) | Cell/dermal coll | Reorg coll/dermal coll |
| Normal skin before treatment                                 | 0 pre          | 0.275            | 0.637                  |
| 17% salicylic acid   | 0 post         | 0.405            | 0.788                  |
| Top layer of skin peeled off using 2.0 M sodium chloride     | 12             | 0.446            | 0.774                  |
| 0.2 M pyrophosphate buffer, collagen and hyaluronic acid gel | 18 (approx)    | 0.387            | 1.111                  |

Cell/dermal coll: Ratio of cellular resonant frequency peak to dermal collagen resonant frequency peak. Reorg coll/dermal coll: Ratio of reorganized collagen resonant frequency peak to dermal collagen resonant frequency peak heights



**Figure 2:** (a) Skin OptoScope image and weighted displacement versus frequency (Hz) immediately after micro needling. Note the bleeding (bubble in center of figure at surface) increases the peak at 150 Hz. (b) OptoScope image and weighted displacement versus frequency (Hz) of skin 2 weeks post-needling. Note the relative increase in the reorganized collagen peak about 200 Hz; however, this peak is smaller than the peak seen with CE Ferulic [Figure 1b]

is removed. Needling did appear to generate a peak at 150 Hz indicative of blood and blood vessels that appeared to remain for periods up to 2 weeks. Skin thickness was increased 4 weeks after microneedling was conducted; however, there was no increase in epidermal cell content based on the pixel intensity.

### Skin treatment with an OTC product (Vaseline intensive care cream)

Vaseline intensive skin care was applied daily to the forearm skin of a subject. Scans of the OCT skin image were taken twice a week for 2 weeks and then weekly after that. Skin scans results are shown in Figure 3 after 1 month of treatment. No change in the OCT image or in the ratio of the cell/dermal or the reorganized collagen/dermal collagen peak ratios are observed after using the Vaseline product.

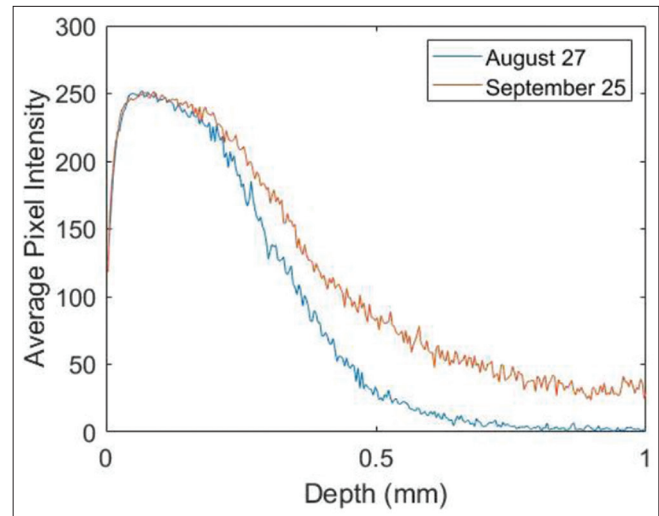
### Skin treatment after removal of the stratum corneum

Skin from a third set of volunteers was treated with 0.1 ml of 17% aqueous SA solution applied with a nail polish brush. At approximately 2.5 min after treatment, an OCT scan was performed and a measurement of weighted displacement versus frequency data was made using the OptoScope. After 10 min, 1.0 ml of a saline solution (2.0 M NaCl) was applied to the top of the skin that had been pretreated with SA and another scan was then taken [Figure 4a]. One milliliter of 0.2 M sodium pyrophosphate was then applied to the top of remaining skin and a data were taken after this treatment step. Sodium pyrophosphate treatment increased the skin thickness but not as much as CE Ferulic treatment or microneedling [Table 2]. Removal of the stratum corneum was verified by decreases in the pixel intensity [Figure 4b]. The thinning of the epidermis is consistent with the loss of pixel intensity of the epidermis below 0.1 mm as compared to a non-treated control.

### Skin treatment after removal of the stratum corneum and stratum corneum-stratum granulosum junction and application of a collagen/HA gel

Skin from the forearm of a volunteer was treated with 17% aqueous SA, saline solution, and sodium pyrophosphate as described above and 0.5 ml of a collagen/HA sealing solution was applied to the top of treated skin. The collagen/HA sealing gel swells the treated skin and leads to fewer wrinkles based on the data contained in Table 2 and the OptoScope image [Figure 5].

The data contained in Table 2 illustrate that application of sodium pyrophosphate after removing the stratum corneum increases the skin thickness due to water retention, more rapidly as compared to CE Ferulic and microneedling. The application of SA, sodium chloride, and sodium



**Figure 3:** Pixel intensity versus depth (mm) for human skin treated with Vaseline intensive care for day 0 and at 1 month of daily treatment. Note the pixel intensity of the epidermis (left hand side of plot) does not change with treatment time

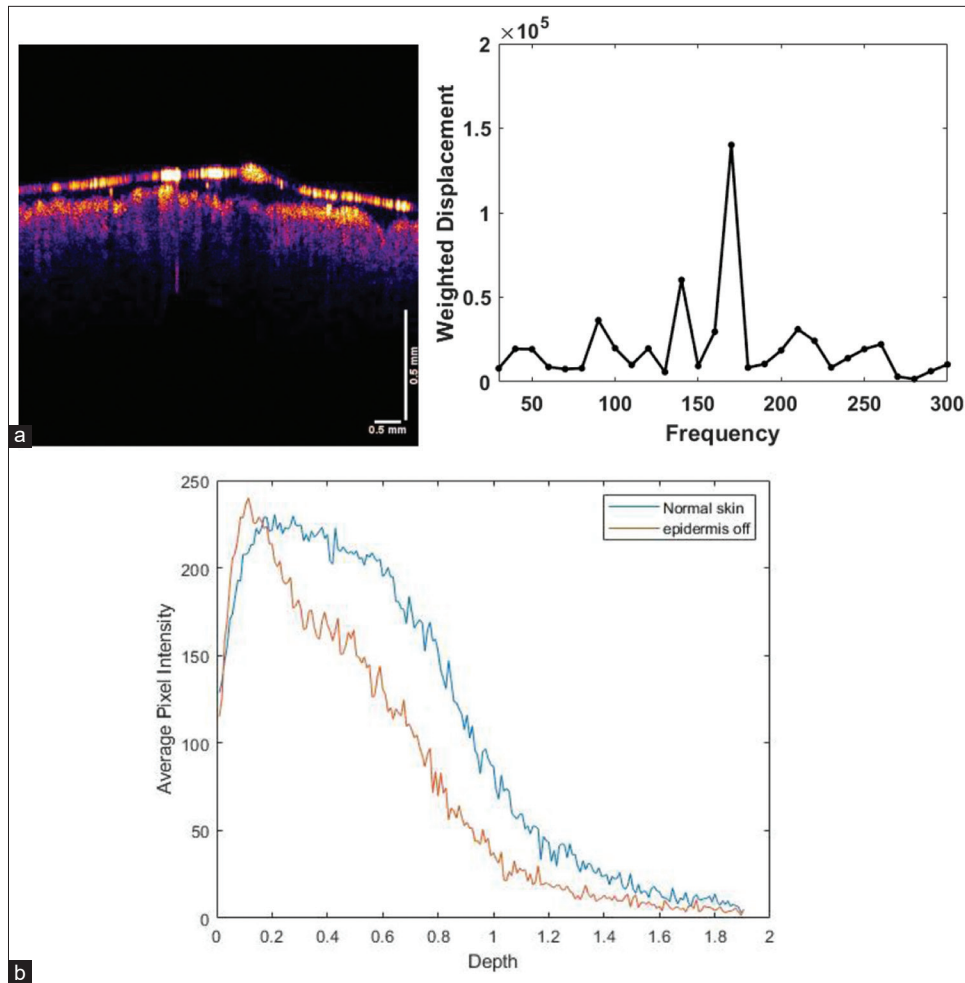
**Table 2:** Skin thickness after treatment with CE Ferulic, microneedling, and pyrophosphate. Note skin thickness increases in minutes after removal of the top layers of skin compared to weeks and months using microneedling and CE Ferulic treatments, respectively. The skin thickness was measured from the OptoScope image

| Sample    | Time     | Thickness (mm) | Change in thickness (mm) |
|-----------|----------|----------------|--------------------------|
| Figure 1a | 0        | 0.320          |                          |
| Figure 1b | 7 months | 0.365          | 0.045                    |
| Figure 2a | 0        | 0.396          | 0.120                    |
| Figure 2b | 2 weeks  | 0.336          | 0.060                    |
| Figure 4a | 0        | 0.312          | 0.032                    |
|           | 12 min   | 0.290          |                          |
|           | 12 min   | 0.305          | 0.015                    |
| Figure 5  | 18 min   | 0.365          | 0.043                    |

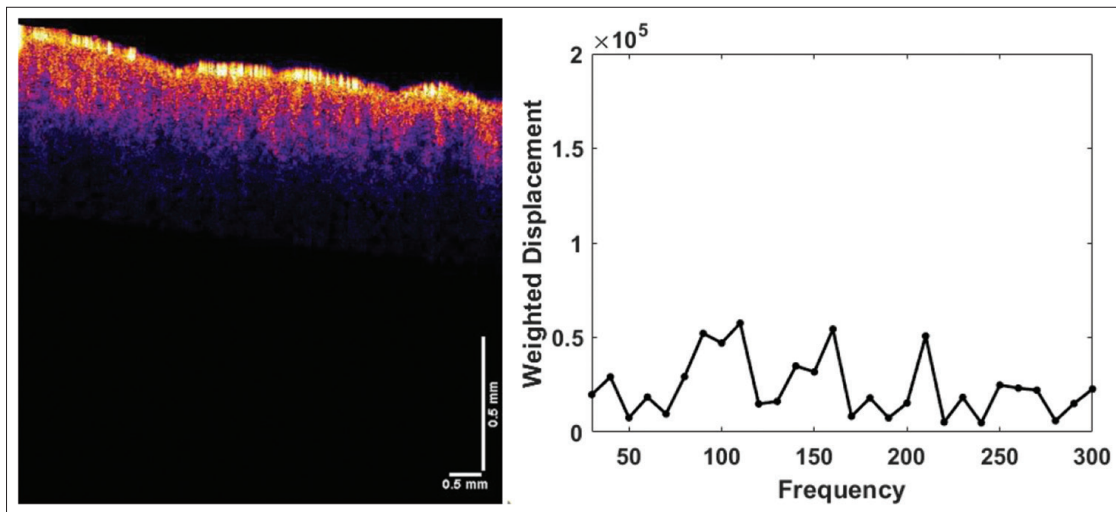
pyrophosphate is painless and when sealed with a gel appears to accelerate the swelling of skin and retention of hydration.

## DISCUSSION

VOCT and the OptoScope are used to in this study measure changes in epidermal and collagen components and skin wrinkling rapidly. This device provides images and mechanical measurements of internal tissue as deep as 1.0–2.0 mm in real time.<sup>[19-23]</sup> For deeper tissues, the OptoScope in combination with high-frequency ultrasound can be used to collect images and mechanical data on tissues as deep as 8.0 cm.<sup>[19]</sup>



**Figure 4:** (a) OptoScope image and weighted displacement versus frequency (Hz) after 17% salicylic acid treatment. Note separation space at top between the surface layers and remaining epidermis. Figure 4(b) Pixel intensity versus depth (mm) of normal skin and skin after the surface layers and are removed using 17% salicylic acid and then 2.0 M sodium chloride. Note the rapid drop in pixel intensity of the surface of the treated skin at about 0.1 mm indicating the thinning of the epidermis after removal of the top layers of skin



**Figure 5:** OptoScope image and weighted displacement versus frequency after applying 0.2 M pyrophosphate buffer, collagen, and hyaluronic acid gel for 18 min. Note the swelling and increased smoothness of the epidermis after removal of the top layers of the epidermis

Our results suggest that both topical skin treatment (CE Ferulic) and needle rolling appear to produce changes in both the epidermis and dermis that revitalize skin. Both treatments increase the ratio of the cellular peak to the dermal collagen peak and the ratio of the reorganized collagen peak to the normal dermal collagen peak observed [Table 1]; however, these techniques can be painful and require at least 4 weeks achieving rejuvenation. Based on pixel intensity data, after removal of the stratum corneum, the remaining epidermis appears to swell instantaneously which leads to decreased skin wrinkling. CE Ferulic and microneedling increase the number of cells in the epidermis and the ratio of the reorganized collagen peak/dermal collagen peak increases with time [Table 1]. This result suggests that the new collagen formed is composed of reorganized collagen and is not the same as the collagen in the normal papillary dermis.

Normal dermal collagen consists of thin collagen fibrils that form fibers in a biaxial network within the plane of the skin. In contrast fibrous scar tissue, collagen forms an aligned network similar to that seen in tendon.<sup>[24]</sup> The consequence of depositing reorganized collagen versus dermal collagen is that too much fibrous tissue deposition will cause stiffening of the skin and limit the ability of skin to deform when subject to mechanical loading.<sup>[24-26]</sup>

Using the OptoScope, it is now possible to generate images and physical data to quantitatively assess the outcomes of different skin treatments for varying time periods. This will lead to better evaluation of the outcomes and facilitate development and optimization of skin treatments. The efficacy of outcomes and treatment methods using lasers, radiofrequency, and ultrasound can be tailored to each patient based on OptoScope data. It is well known that there is a patient-to-patient variation in the response to injury and wound healing that depends on the underlying biological responses. Using the OptoScope, the physician or esthetician can evaluate each client's response to a treatment and tailor the outcome based on the subject's internal skin response to each treatment.

In addition to optimizing skin care protocols, removal of the stratum corneum may facilitate new product evaluation. This will speed up topical treatment efficacy evaluation to a period of days as opposed to periods of up to several months using the ASCP.

## CONCLUSIONS

The OptoScope provides a non-invasive and non-destructive technique that can be used to quantitatively evaluate the outcomes of cell proliferation and fibrous tissue deposition as a result of a skin topical treatment and needle rolling. These results presented in this paper indicate that chemical or mechanical treatment can lead to cell proliferation and new

collagen deposition; however, it appears these results can be obtained more rapidly if the stratum corneum is removed before a topical is applied.

Removal of the stratum corneum and use of the ASCP reduce topical treatment evaluation times to minutes as opposed to days and weeks. Removal of the stratum corneum before skin testing cuts topical treatment evaluation time by an order magnitude or more.

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