Optical coherence tomography monitors therapy of skin disease

Rudolf Steiner and Karin Kunzi-Rapp

High-resolution optical coherence tomography serves both as a noninvasive observation method and a therapeutic tool in chronic skin diseases such as scleroderma.

High-resolution optical coherence tomography (OCT) is a promising new and noninvasive technology for diagnosis of dermatological diseases. Commercially available OCT instrumentation\(^1\) provides 2D images of morphological microstructures of the skin with high resolution of 3.4\(\mu\)m laterally and 5.1\(\mu\)m axially. However, the penetration depth of the light is limited to about 1mm due to the strong scattering of skin tissue. Because OCT imaging does not cause trauma and has no side effects, this technique allows evaluation of treatment effects by monitoring therapy over time.

In this study we used OCT to monitor the course of plaque-type morphea. Also known as localized scleroderma, this disorder is characterized by excessive collagen deposition leading to thickening and hardening of the dermis, the subcutaneous tissues, or both. Plaque-type morphea is the most common and benign morphea subtype. The lesions are relatively superficial, primarily involving the dermis. Clinically, plaque-type morphea lesions are described as circumscribed hardened plaques that range from 1cm to more than 20cm in diameter. They often begin as red to violet patches or slightly edematous plaques. With disease progression, sclerosis develops centrally as the lesions expand peripherally. The surface becomes smooth and shiny over time, with loss of hair follicles and sweat glands (see Figure 1). Over a period of months to years, the skin softens and the dermis atrophies.

Ultrasound examination has been used to monitor the dynamics of this skin disease noninvasively.\(^2\)-\(^4\) The increase in corium thickness is the most frequently found ultrasound criterion of localized scleroderma. But there is large variability in corium thickness in differing parts of the body, as well as differences between individuals. For a single individual, comparison of sclerotic and healthy skin showed an increase in the corium thickness between 2 and 251%.\(^4\) Ultrasonographic regression was marked by a decrease in thickness. For this reason, only several ultrasound examinations at several time points can determine the course of the disease.

Current OCT systems have a high spatial resolution of about 5\(\mu\)m compared with 110\(\mu\)m for high-resolution ultrasonography. Based on Michelson interferometry, OCT uses low coherence light to produce a 2D image of optical scattering from microstructures inside tissue.\(^5\) The coherence length of the source and the spot size of the focused beam on the sample determine the depth resolution and lateral image resolution, respectively (see Figure 2). Skin is a highly scattering medium with a complex structure consisting of many inhomogeneities. Skin components have a range of refractive indices, most of which are different from that of the interstitial space. These variations in refractive index cause a great deal of random scattering, which decreases light penetration into tissue to about 1mm. This depth reproduces the horny layer, the epidermis with the basal membrane zone, and the structures of the upper dermis, which consists of fibroblasts embedded in a network of collagen fibers and small blood vessels.

Continued on next page
The aim of our work was to assess the value of OCT for quantifying and monitoring changes during therapy, and compare it with clinical examination and histology. In a histological study, early lesions of localized scleroderma are characterized by cellular infiltration into the upper dermis: see Figure 3(a). In the OCT image the junction is not clearly demarcated between the dermis and epidermis due to inflammatory cells that form highly scattering tissue. Regions of inflammation appear as dense areas, without providing information about the embedded structures. In some areas, light scattering is lower than in healthy skin due to edema, leading to a less-dense arrangement of the collagen fibers, as shown in Figure 3(b).

In the sclerotic state, histological sections show thickening and homogenization of the collagen bundles. They often appear oriented parallel to the surface epithelium. Typically in advanced cases, the hair follicles and sweat glands are absent or markedly compressed by the dermal sclerosis, as shown in Figure 4(a). In OCT pictures of the sclerotic-state morphea, the epidermis is clearly distinguished from the dermis by the basal membrane zone, which appears as a dark border to the papillary layer. In the papillary layer, a band of dense light-scattering collagen structures parallel to the surface epithelium is clearly demarcated from the underlying healthy dermal structures: see Figure 4(b). This stage seems to be the endpoint of therapeutic intervention and is correlated with clinical improvement.

Because OCT is a noninvasive technique, it allows frequent and multifocal examination. OCT can image subsurface skin structures because it offers high spatial resolution and maximum imaging depth of about 1mm. The clinical study revealed that OCT is a suitable tool for imaging skin alterations in the superficial layers, the stratum corneum, the epidermis with the dermo-epidermal junction, and the upper dermis.

Due to its high resolution and simple application, OCT is an interesting addition to other morphological techniques and a versatile tool in the therapeutic control of chronic skin diseases like plaque-type morphea.

**Author Information**

**Rudolf Steiner**

Institute of Laser Technologies in Medicine and Metrology
University of Ulm
Ulm, Germany

Rudolf Steiner received his PhD in 1972 from the Technical University in Munich. He was a NATO fellow at CNRS in Montpellier, France, and took a position at the University of Düsseldorf in 1973. There he established a laser laboratory for medical diagnostics and became an assistant professor at the Institute of Clinical Physiology. Since 1986 he has been director of the Institute of Laser Technologies in Medicine and Metrology at the University of Ulm.

*Continued on next page*
Karin Kunzi-Rapp
Institute of Laser Technologies in Medicine and Metrology
University of Ulm
Ulm, Germany

Department of Dermatology and Allergology
University of Ulm
Ulm, Germany

Karin Kunzi-Rapp is a medical resident in the Department of Dermatology, University of Ulm, where she is also a senior scientist at the Institute of Laser Technologies in Medicine and Metrology. She received her university degree in biology in 1978 and her MD in 1994 from the University of Ulm.

References
1. Specifically, OCT equipment from ISIS Optronics GmbH, Mannheim, Germany.