Structural characterization of hair fiber by optical coherence tomography (OCT)

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ABSTRACT

In this work we use the optical coherence tomography (OCT) technique to produce *in vitro* transversal section images of human hair. It was possible to identify in the A-scan protocol its principal structures: cuticle, cortex and medulla. The mean diameter of medulla was 29 ± 7 μm and hair diameter was 122 ± 16 μm in our samples of standard Afro-ethnic hair. We also compared the OCT signal before and after chemical treatment with 18% w/w ammonium thioglycolate solution. After chemical treatment, it was not possible to identify the main structures of hair fiber, due the index matching promoted by deleterious action of chemical agent. A tridimensional image was built starting from 601 cross-sectional images (slices). Each slice was taken in steps of 6.0 μm at 8 frames per second, and the whole 3D image was built in 60 seconds.

1. INTRODUCTION

The hair forms a major part of the external coating of most mammals. In the human being, hair represents a structure which long time ago lost their functional significance during the species evolution process. The value of hair, however, should not be underestimated in emotional and social term. The hair thread has a cylinder structure, well organized, formed by inert cells, most of them keratinized and distributed following a very precise and pre-defined design. Hair forms a very rigid structure in the molecular level, which is able to offer the thread both flexibility and mechanical resistance.

Hair is considered as a dead mater and it is only alive when it is inserted in the scalp. When the thread emerges, it becomes dead matter although it appears to be growing since the fiber follows increasing its length by a speed of about 1.0 cm/month. Human hair has about 65-95% of its weight in proteins, more 32% of water, lipid pigments, and other components. Chemically, about 80% of human hair is formed by a protein known as keratin, with a high grade of sulfur – coming from the amino acid cystine – which is the characteristic to distinguish it from other proteins. Keratin is a laminated complex formed by different structures, which gives the hair strength, flexibility, durability, and functionality. Threads present remarkable structural differences, according to the ethnic group, and within the same group. These proprieties are related with fiber characteristics and with cosmetic attributes.

Optical coherence tomography (OCT) is a diagnostic imaging technology based on low length coherence Michelson interferometer in which the coherence features of photons are exploited, leading to an imaging technology that is capable of producing non-contact, non-destructive, high-resolution cross-sectional images of the internal microstructure of living tissue such as the retina[1], skin[2] and teeth[3]. Its applications in medicine were reported less than a decade ago, but its roots lie in early works on white-light interferometry[4,5]. The OCT image is based mainly in an optical

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property of sample, the backscattering coefficient. Each line in the image is composed by a B-scan signal from OCT, different lateral probe position in the sample correspond to a new line in the image. The OCT intensity signal are coded in false colors in the image and represents the backscattering coefficient, where white color represents high scattering and black color low scattering.

2. OBJECTIVE

In this research work, we aimed at characterizing the ultra-structures of standard hair fibers by OCT. Samples were characterized before and after chemical treatment with ammonium thioglycolate, and its main structures was reveled in both cases.

3. METHOD

An OCT system (OCP930SR, Thorlabs) working at 930 ± 5 nm with 100 ± 5 nm FWHM and optical power of 2 mW providing a resolution of 6.2 μm and 1.6 mm of maximum image depth, was used to generated cross-sectional images of standard Afro-Ethnic hair (DeMeo Brothers). The fiber was physically fixed in a sample holder Figure 1, to maintain the fiber in a straight shape, without distortions.

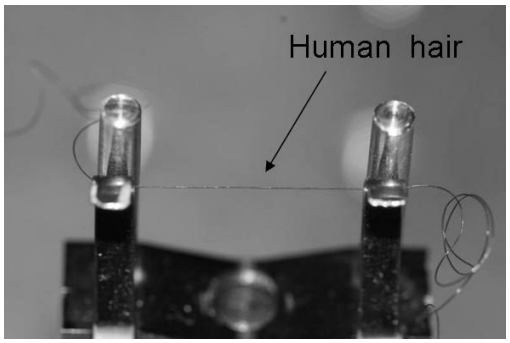


Figure 1: Sample holder used to fix the human hair

It was used 10 samples of Afro-Ethnic hair that were measured in a transversal way in three different positions: at distance of 10 mm from root, at the middle position (equidistant point between root and end) and at 10 mm from the end. Longitudinal sectional images were also produced as presented in Figure 2 (c) and (d), to produce those images a careful alignment was made to guarantee that the scanning area was perfectly aligned longitudinally to the fiber.

Chemical treatment was carried out with a hair straightening solution developed with 18% w/w ammonium thioglycolate with pH ranging from 8.8 to 9.0. Hair samples were immersed at solutions for 20 min at room temperature (22 $\pm$ 2 °C), and then, fibers were rinsed with warm distilled water for 1 min. Straightening process was finalized with immersion of the samples at solutions with pH ranging from 3.5 to 4.5 for 15 min, rinsed in water and samples were allowed to dry and to rest in temperature and humidity-controlled environment until OCT analysis.

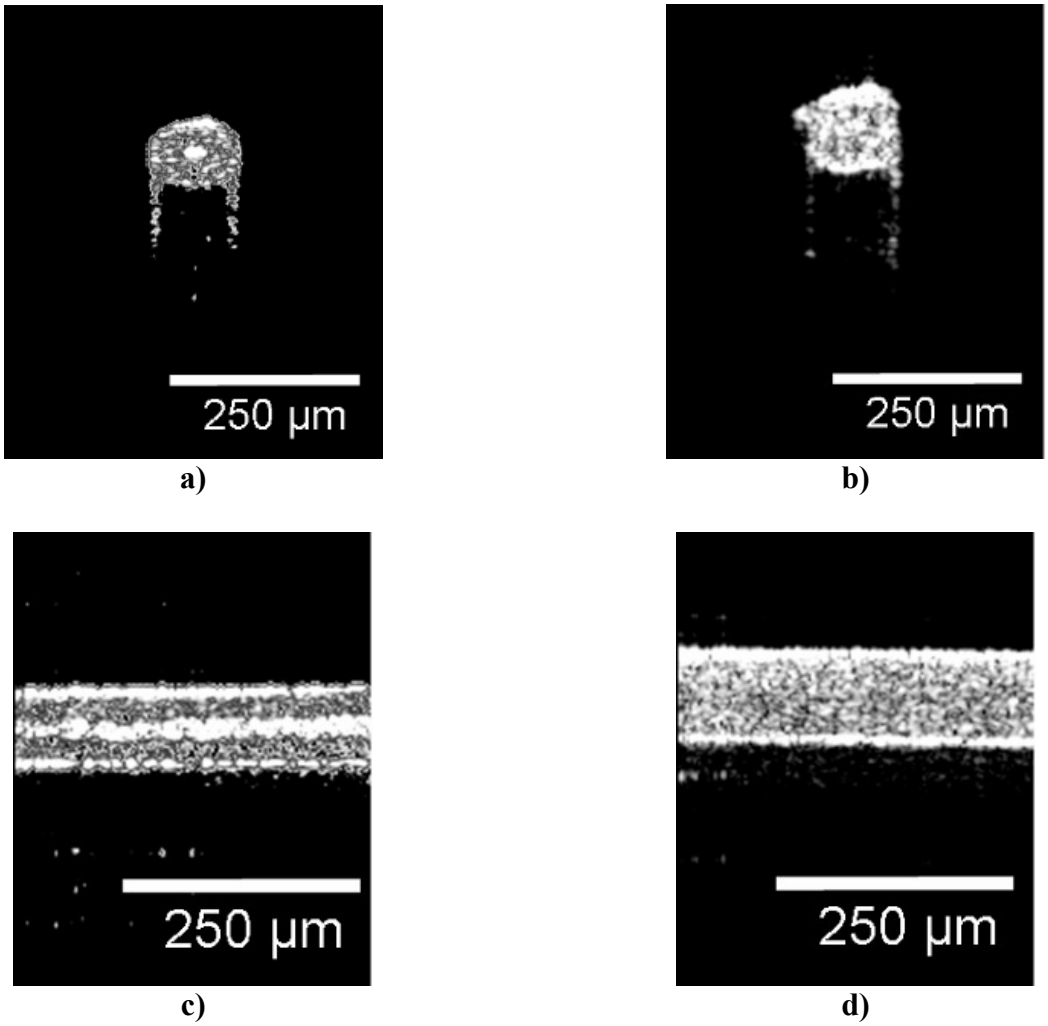


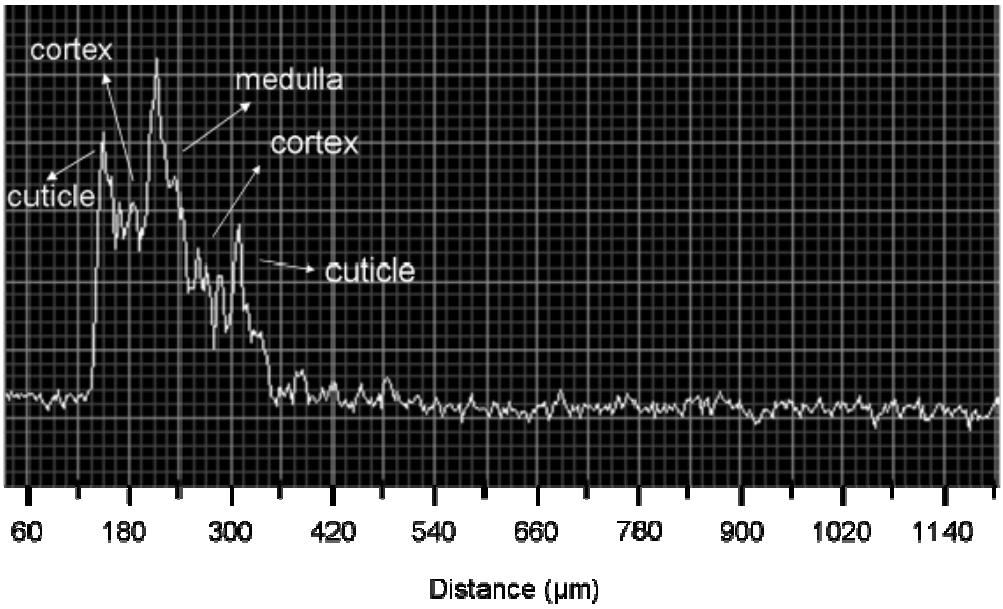
Figure 2. OCT image of an Afro-Ethnic hair sample. In (a) a sample of cross-section fiber in transversal way showing the main hair structures: medulla, cortex and cuticle and at (b) a sample of cross-section fiber after chemical treatment with 18% w/w ammonium thioglycolate solution where structures are not clear. The figure (c) and (d) shows the same condition for (a) and (b) but the images was taken in the longitudinal way.

4. RESULTS AND DISCUSSION

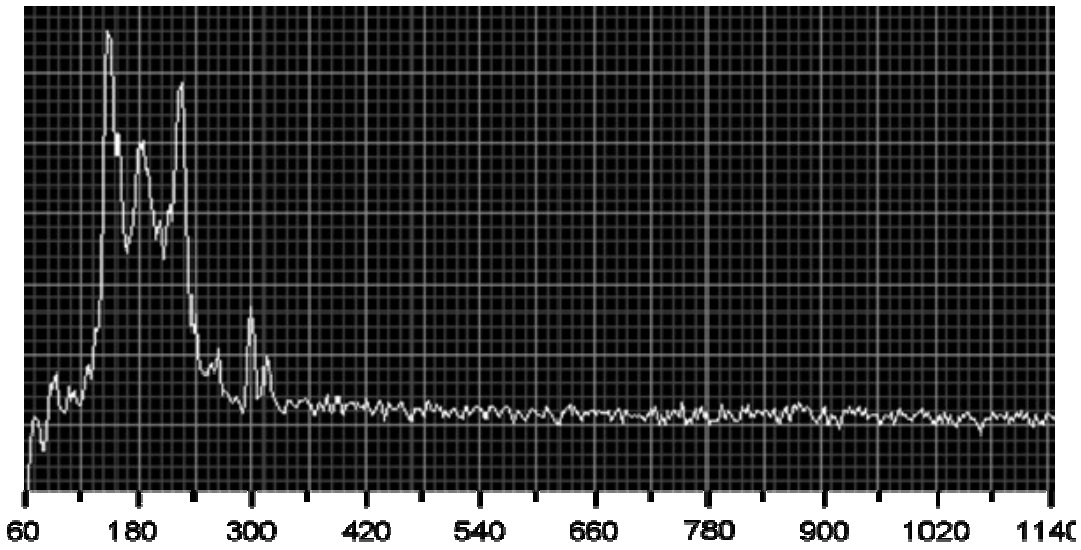
The hair fiber is composed by three main structures: cuticle, cortex and medulla. The main factor to be considered in the human hair is the high amount of the amino acid cystine, which may be degraded and afterwards may be re-oxidated under a disulphidic bounding form. The Afro-ethnic hair is very curly when compared with the Caucasian hair. The small angle of the waves makes it more susceptible to breakage, when mechanically worked. Abrasion and wear at the bending points lead to the loss of cuticle and to the appearing of stains. The hair styling is limited, since some popular styling demand a special handling when the hair is extremely curled. The transversal OCT images of hair samples, in the middle position, are show in Figure 2. Figure 2(a) illustrates the cross-sectional image of Afro-Ethnic hair, where is possible to identify the main hair structures: medulla, cortex and cuticle. The mean diameter of medulla was 29 ± 7 µm and hair diameter was 122 ± 16 µm. But these structures could not be clearly identified after straightening treatment with ammonium thioglycolate (Figure 2(b)). Hair straightening is a chemical process by which the Afro-ethnic hair is permanently straightened. The first chemical products were developed in the beginning of the '40s. Straightening products need a strong alkaline component as, for example, sodium or lithium hydroxide, or guanidine hydroxide –

formed by the *in situ* reaction of guanidine carbonate and calcium hydroxide. Active ingredients commonly found within straightening products formulations are: sodium, guanidine, potassium, lithium hydroxide and ammonium thioglycolate. In the home hair straightening products now available, one of the most used active ingredients is the ammonium thioglycolate. When incorporated into a cosmetic product, its pH value ranges from 8.5 and 9.5 and this high value promotes the hair swelling. The result of this process is the straightening. To finish the reaction a neutralizing agent is used which closes the cuticle scales and fixes the new shape of hair fibers. As they act with high pH, these straightening agents cause considerable damage to hair, making them dry and brittle, for instance. The high pH swells the hair, opening cuticle scales, which allows the alkaline agent penetrate into the hair fiber and spreads up to the endocuticle. In contact with cortex, the straightening product reacts with keratin, breaking and re-arranging disulfide bridges, which makes the thread soft and stretched. The Figure 2(c) and (d) shows the same condition for Figure 2(a) and Figure 2(b) but the images was taken in the longitudinal direction of hair fiber.

The
Figure 3 shows the OCT signal for both cases, before
Figure 3(a) and after straightening
Figure 3(b), in the later case was not possible to identify clearly the hair structures. The first peak in
Figure 3(a) corresponds to the cuticle, the valley corresponds to the cortex presenting lower scattering coefficient in relation to medulla and the two another peaks corresponds to the medulla, the last one is the cuticle in the another side of hair fiber.



a)



b)

Figure 3. (a) OCT signal for normal hair fiber where we can identify the structures in both sides and (b) OCT signal after treatment. The structures in this case are not clear.

The image analysis allows the backscattering coefficients comparison of different structures presents in hair, and still to compare these coefficients before and after chemical treatment. The main advantage of this technique is that it is non destructive, allowing to track the same fiber during whole the treatment process and can be done *in vivo*.

The tridimensional image (Figure 4) was built starting from 601 cross-sectional images (slices) like Figure 2(a). Each slice was taken in steps of 6.0 µm at 8 frames per second, and the whole 3D image was built in 60 seconds.

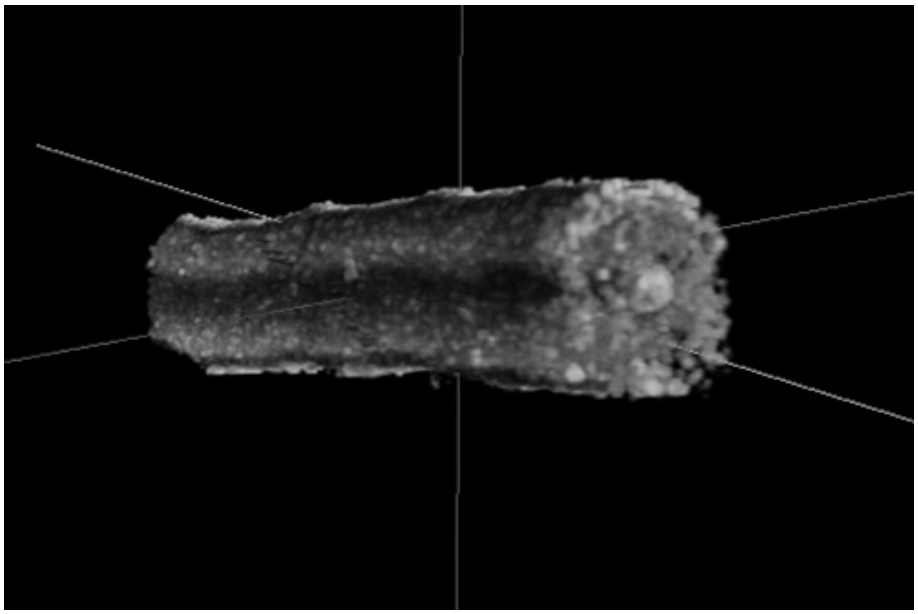


Figure 4. 3D OCT image of normal Afro-ethnic hair fiber.

5. **Conclusions:**

The OCT system provided images of the Afro-Ethnic hair sample. We showed that we can clearly identify the main structures of hair fiber, like cuticle, cortex, and medulla. In particular, we show that backscattering coefficient for hair fiber is different before and after chemical treatment. After chemical treatment was not possible to clearly identify hair structures, the difference between one structure and another is not clear. The decrease of index refraction difference between adjacent structures can explain this behavior. That decrease is related to the injuries that straightening actives, as ammonium thioglycolate (a common active presented in available commercial hair straightening) cause on hair shaft, especially on the cortex which is the target of this kind of hair-care products. The high pH value of these cosmetics provoke cuticle opening that facilitates the penetration of the ammonium thioglycolate to the target site where keratin suffer rearrangement to achieve the straightening of the hair[6]. This process associated with the ammonium thioglycolate action mechanism resulted in an index matching effect. That hypothesis should be verified with other measuring techniques, like Scanning Electron Microscopy.

The OCT provided real-time images with where structures could be identified and quantified, and the principal advantage is that it is non-destructive technique, allowing a tracking of the same sample in several experimental conditions.

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