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Towards Robotized Multi-Axis Lens-Less Holographic Trichoscopy and Trichometry: From Five-Axis Arm-Manipulator Systems Based on Robotic Feodorov Stages to QUATERNION Metrological Setups

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Abstract
A new principle of differential trichomorphological analysis and diagnostics on a chip is proposed. This principle can be considered as a transition from a trichoscope to a metrologically efficient trichometer based on holographic system, in particular robotic multi-axis lens-less holographic technology. In addition to obtaining images in certain projections at different angles, this approach makes it possible to measure using orthogonal transformations, in particular using software products such as QAVIS (based on the FFTW library) and "KSA Image". It is possible to register (and identify with machine learning) such micromorphological abnormal trichological states and pathologies as trichonodosis , trichoptilosis, trichonoresis, allotrichia, trichoclasia (including idiopathic trichoclasia), as well as some mesomorphological deviations (such as club-shaped, bayonet-shaped, loop-shaped, knotty hair). We simultaneously carry out scanning of the profile of the features and relief of the underlying skin (for example, detection of nevi). The developed technology for non-damaging holographic micromorphological analysis can also have applications in research practice, and not only for clinical diagnostics or preventive medicine. It is possible to combine schemes of lens-less holographic trichometry on a chip with other methods of lens-less microscopy on a chip - such as lens-less interference microscopy, lens-less incoherent holography on a chip and off-axis microholography on a chip, lens-less polarization microscopy and lens-less DIC. This paper is a shorted version of the seminar report of the Trichologist Union "Bezlinzovaya Golograficheskaya Trikhoskopiya I Trikhometriya" (2017), which was published only in Russian and was not readable for any foreign readers. The authors list of the seminar paper also truncated due to the elimination of some experimental data and theoretical considerations from the original seminar paper by the corresponding author (OFK).

Keywords: Lens-Less Holographic Trichoscopy, Lens-Less Microscopy and MicroHolography, Lens-Less Trichometry, 2D FFT, Corellogrphic Images, Five-Axis Arm-Manipulator Systems, Robotic Feodorov Stages, Quaternion Representation, On-Chip Holographic Trichoscopy.

1. Introduction

Until now, not only in clinical trichology, but also in experimental and laboratory trichology that determines the etiology of hair diseases, there is a lack of high-quality methods for identifying and validating a number of diagnoses [1]. Diagnosis at the quantitative and analytical level is significantly complicated due to the difficulty of entering reference values of norms and deviations into computer expert systems, which requires, in the ideal case associated with automatic pattern recognition, also a comparison of the most common morphologically detectable characteristics of diseases (the so-called descriptors) with corresponding diagnosable classes using machine learning (supervised learning) [2]. At the same time, there are still no technologies for analytical microscopy of hair under unified calibration conditions, which would be sufficient to create a system of computer diagnostics of hair condition that would be valuable for trichologists.

The bulk of diagnoses are made using trichoscopic rather than trichometric data, which improves the speed of diagnosis, but does not improve the metrological reliability of the data obtained and the diagnosis that follows from them; or, in other words, a set of metrological data produced by modern means of trichogram analysis (hair density per square centimeter in androgen-dependent and androgen-independent zones; percentage of thick pigmented and vellus hair; a number of morphometric measurements, often limited by hair diameter; number and percentage of thin, thick and medium by hair diameter) is not universal or sufficient for all types of potentially diagnosable conditions, especially for individual detection of pathologies of individual hairs in the early stages of a particular pathological process [3, 4].

Thus, the last word remains with the doctor, and not with the automatic expert system, which does not play a decisive role in this type of diagnosis (and is often, in principle, absent in the software package of a number of modern trichoscopes that display register records on a computer), which leads to the preservation of a large the role of subjective judgments and assessments in making a diagnosis. At the same time, existing methods that allow for an objective quantitative or semi-quantitative assessment of hair parameters are quite labor-intensive, which is why they are practically not used by many specialists who could extract diagnostic information from the relevant data. As an example of this, it is possible to cite multispectral polarization microscopy and also based on the use of a system with prisms - polarizers, differential interference contrast microscopy (DIC) with Nomarski / Pluto optics, and from indirect systems of morphometric diagnostics - imprint methods [5, 6].

It should be emphasized that in most accurate microscopic methods, the eye of an experienced diagnostician is, by definition, insufficient to detect differences between normal and pathological conditions or differences between borderline hair conditions. Moreover, even comparative trichology with human-mediated comparison of clinical micrographs annot be used when it comes to subtle changes in color gradients in polarization microscopy. Here it is necessary to resort to methods of microcolorimetry on digital images and microphogrammetry with restoration of the 3D structure of the hair, as is done in submillimeter laser measurements of deformations, electron scanning / raster microscopy [7-10]. However, such high-tech systems in trichology are exotic and are not actually used due to their extreme cost. Due to the lack of demand for these systems, it is quite obvious that there are no trichological databases for them for machine pattern recognition during computer-mediated diagnostics, as well as even the simplest expert systems that allow working in a semi-automatic interactive mode. Overcoming this state of affairs, which impedes the introduction of modern methods of high-tech diagnostics in trichology, is seen in the creation of systems that are both very informative for diagnostic purposes (and, therefore, physically and algorithmically complex) and quite cheap and accessible to average personnel without technical or physical education (then yes – robust).

Attempts to simplify and reduce the cost of medical diagnostic technologies by introducing into mass production installations that are entirely similar to complex systems, but with more primitive components of low cost, are not a working palliative solution, since they do not lead to sufficient simplicity for personnel and reduce the metrological accuracy of measurements, preventing correct diagnosis, at the same time. In other words, diagnostic trichometry needs a serendipitous innovation (which has worked more than once in trichology as a fairly intuitive taxonomy before), which allows us to move en masse from anamnesis and examination to a completely objective multiparametric machine-mediated diagnosis [11]. A microscope/trichoscope, which three-dimensionally reconstructs and automatically identifies hair structures in its software, must be so complex as to be able to carry out the appropriate types of analysis, up to microcolorimetry and pseudospectral analysis (for biochemical purposes) of hair, and so simple as not to be intimidating potential consumer - a trichologist, being automated to the extent that it will simplify and speed up the latter's work... but no more. Otherwise: the device becomes such a massive democratized tool (like a glucometer) that it goes beyond the control of qualified specialists, giving in mass versions scope for speculative diagnostics that have no value either for prevention or for possibly required treatment.

In other words, 3D - trichoscopy or high-resolution holographic / tomographic trichoscopy with machine identification functions (deep learning), but without complex optical / optomechanical circuits, is ideal for implementation as a diagnostic tool for trichology for mass use. These functions are simultaneously provided by only one type of system - systems of lensless (that is, by definition, not containing an optical path or complex optomechanics) optical holography on a chip and tomography on a chip with automatic identification of objects based on high-resolution microscopy data obtained at these installations [12-14]. The design of these devices is so simple that their use and even production can be carried out by a person without a physical or engineering background.

So that the reader can imagine the design of such a device, in Fig. Figure 1-a shows a contact optical diagram of such a device, and Figure 1-b shows an example of its operation with samples in a droplet state. The CMOS sensor that underlies this device is equivalent to CMOS arrays used in web cameras or digital devices. Therefore, reproducing both lensless microscopy and holographic lensless micro-trichoscopy on the same basis is not difficult even for a non-specialist in the field of laser microscopic or holographic optics. However, as can be seen from Fig. 1, the main type of analysis in systems of this kind relates to liquid analytes (blood, urine, etc.) and partially ordered media. At the same time, nothing prevents their implementation for analysis in real time (in situ) and without any preliminary sample preparation of non-liquid analytes, which can include, in particular, hair and epidermis.

2. Methods and Materials

For hair analysis purposes, we have adapted a lensless microscope of our own assembly with the ability to operate in immersion and “dry” modes in the R, G and B ranges, including excitation by laser diodes of the corresponding wavelengths (R – 650–660 nm; G – 510–530 nm or 532 nm for diode-pumped solid-state laser source, DPSS; B – 445 nm or 405 nm). The measurements were carried out in the schlieren mode, i.e. in the “shadow” geometry of measurements. In this case, it was not possible to make accurate photometric measurements, however, the contrast achieved was optimal for subsequent binarization of the image and carrying out correlation-spectral or scanning correlographic analysis, which revealed classes of individual conditions and changes in hair. Several software products for measurements were tested: GUI of our own development for MATLAB and LabVIEW, domestic software products KSA and QAVIS distributed under a freeware license (developed by POI FEB RAS), used for processing space images and remote sensing of the earth from space, but based on the application of orthogonal transformations, also used in the analysis of microscopic images AM Lab Hesperus (Rus) [15, 16]. The best metrological and ergonomic qualities were shown by QAVIS software (FEB RAS), therefore the following reference indicators were obtained with its help. Contours of reference values were obtained for normal hair and for microphotographs of hair with damage and pathologies. Methods have been tried for obtaining holograms of the full (wide-aperture) range and with the so-called apodization - a procedure leading to a change in the intensity distribution in the diffraction image of light points in the sample space. A virtual diffraction mask technique was also tested, which uses convolution of an image with a pattern generator or a grid of scanning pixels (see Fig. 1).

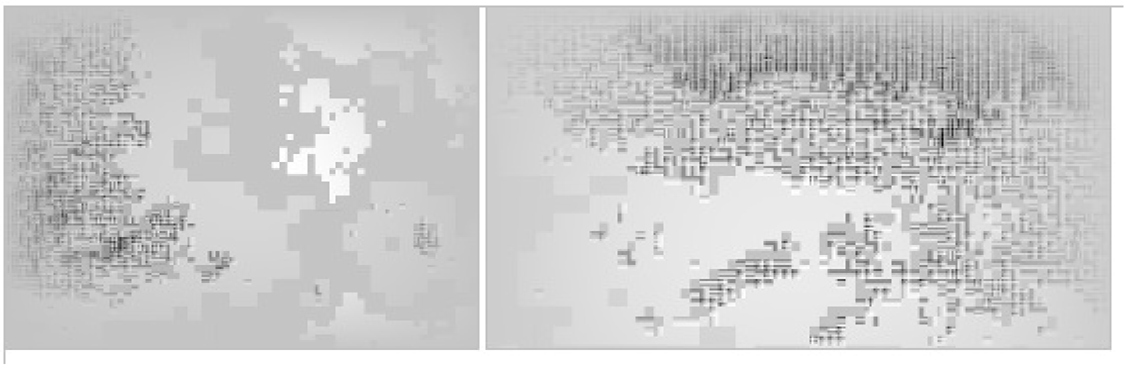


Figure 1: Examples of using adaptive (by illumination isolines / isophotes) pixel binning (combining groups of pixels) diffraction masks.

3. Results

Initially, tables of reference values of variables and graphs with annotated numerical values for each measurement point were obtained. As follows from Table 1, the sets of descriptors characteristic of various hair pathologies (for example, trichoclasia, trichonodosis and trichoptilesis) are not equivalent and, as a consequence of this, these pathologies can be morphologically distinguished and differentially diagnosed using these descriptors. Next, lensless microscopy was carried out on a contact chip with the identification of probable pathologies using a database of descriptors obtained in the first stage. An example of the results of multiparameter identification of holographic hair records is given in Fig. 3.

Below are holographic projections made using apodization methods. Unfortunately, visualization of the three-dimensional structure of holographic micrographs with a digital lensless registration method cannot be implemented on a two-dimensional paper medium, so we are talking about individual apodized diagnostic patterns, and not about holograms as a whole, although visualization of the 3D structure based on registrationogram files is also possible , as can be seen from Fig. 4, 5. Moreover, it should be noted that the advantage of this method lies not in the possibility of improved morphological display with increased resolution parameters, but in the ability of the above algorithms to extract a diagnostic result with morphologically insufficient quantity and quality of data, since in this case the advantage of the method is achieved due to the metrology of spectral-correlation analysis and the “holographic” nature of the original set of images.

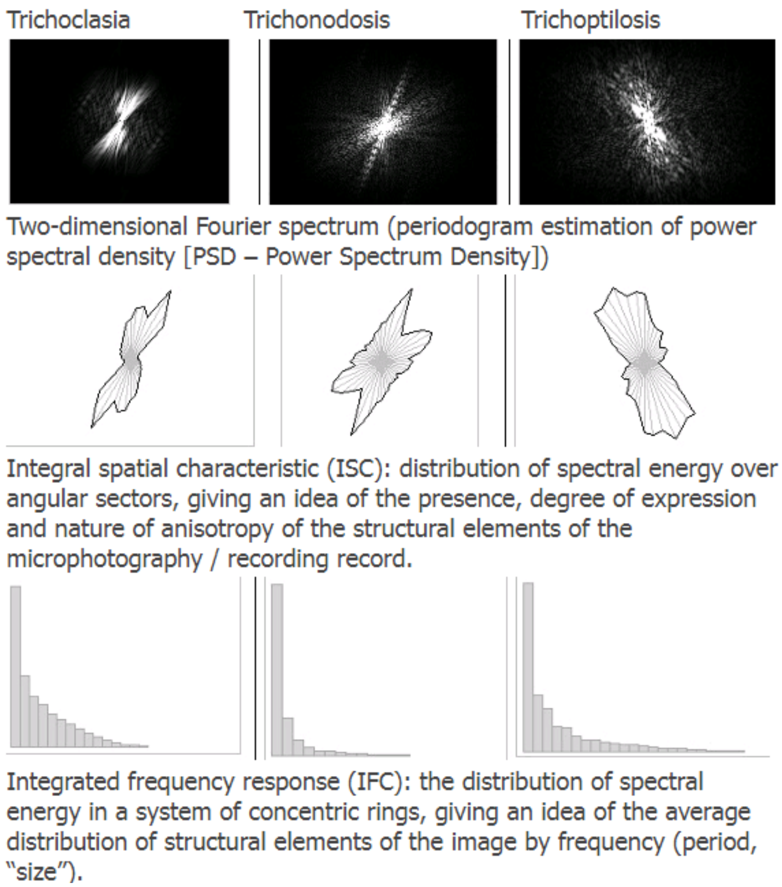
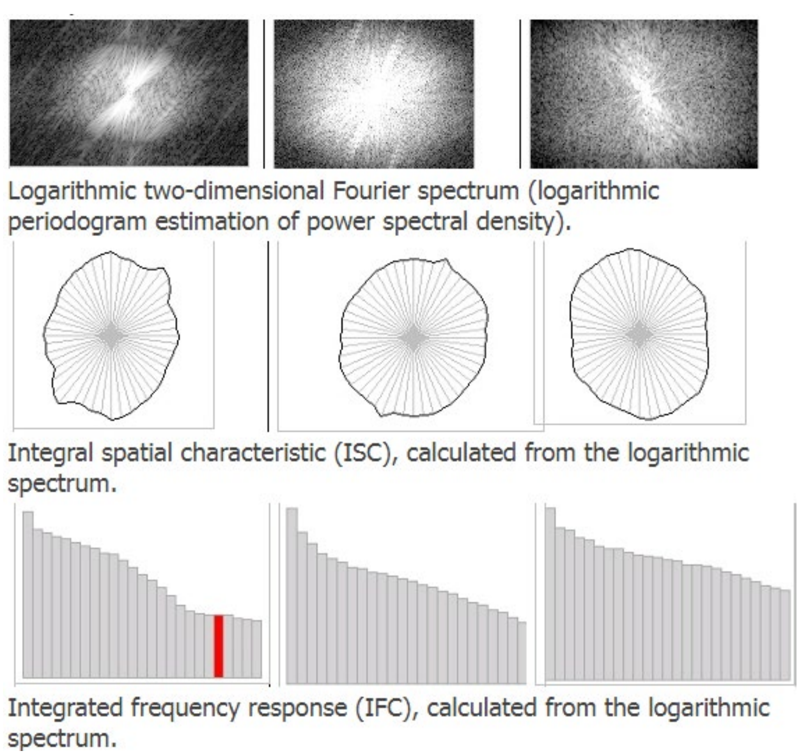


Figure 2-a: The sets of descriptors characteristic of various hair pathologies (for example, trichoclasia, trichonodosis and trichoptilesis)



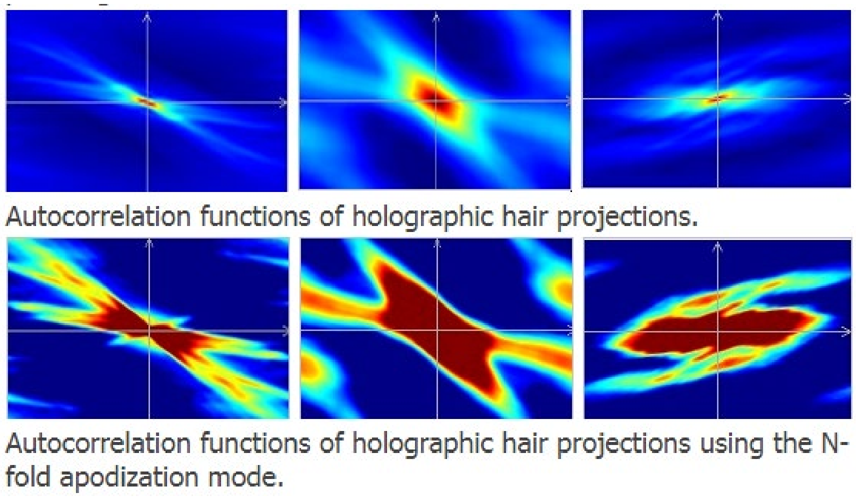


Figure 2-b: The sets of descriptors characteristic of various hair pathologies (for example, trichoclasia, trichonodosis and trichoptilesis)

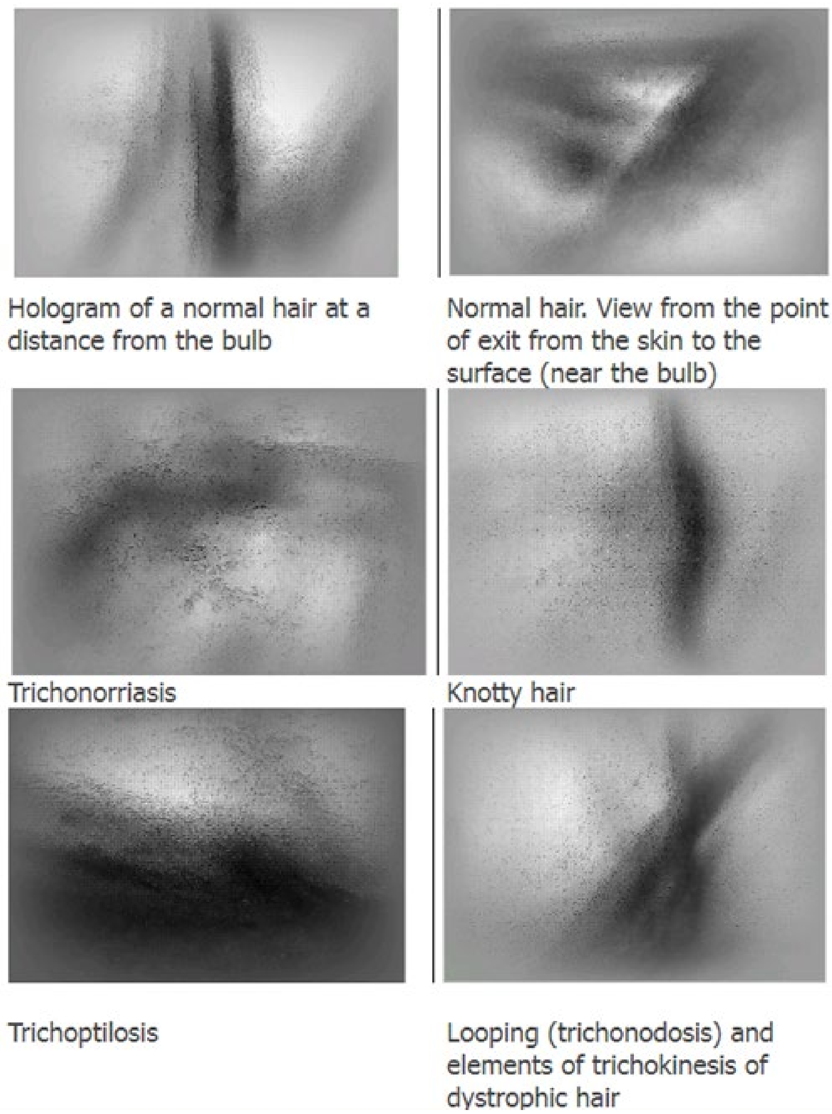


Figure 3: Holographic hair records (holograms of some hair types in normal and pathological conditions).

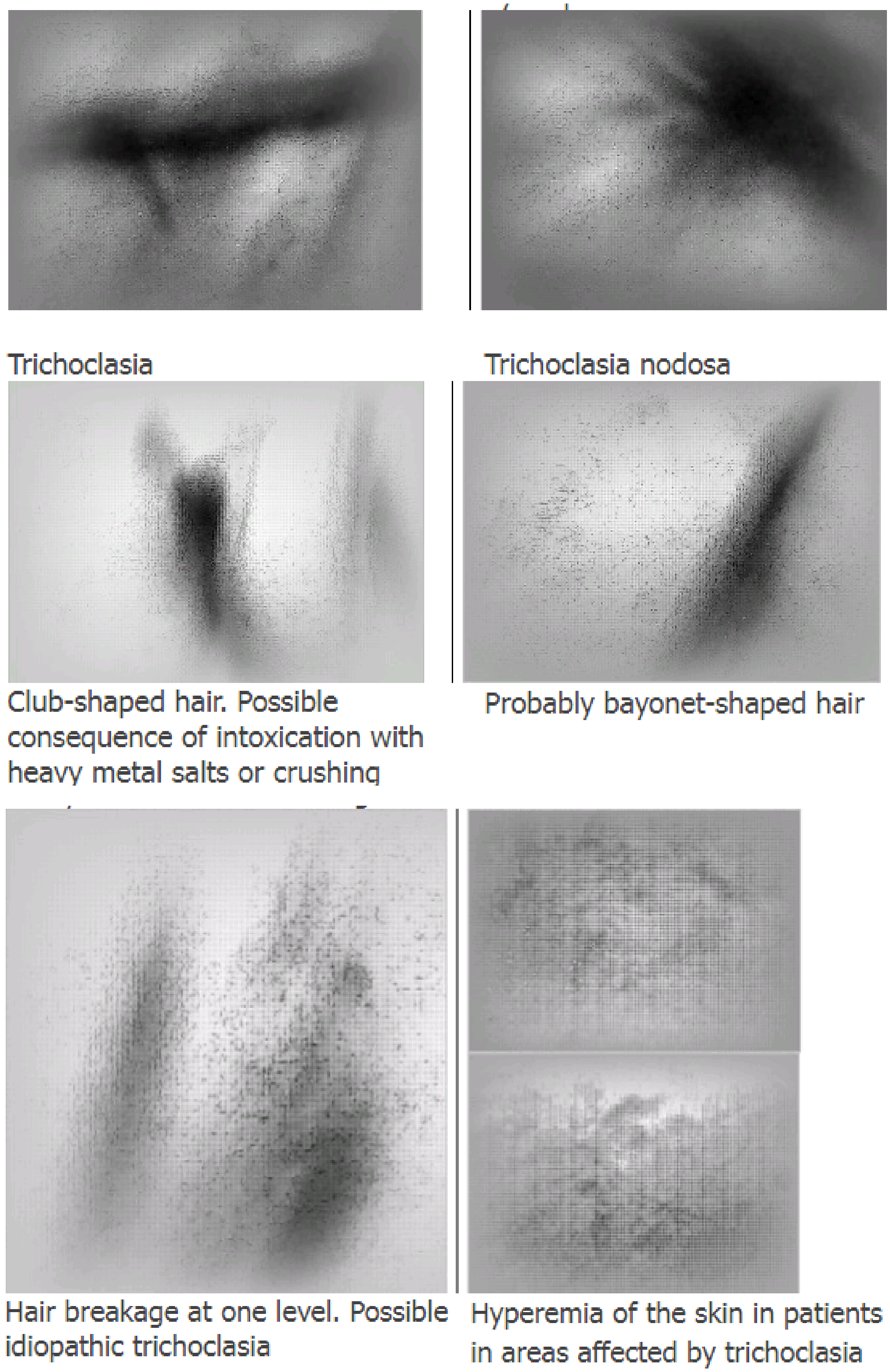
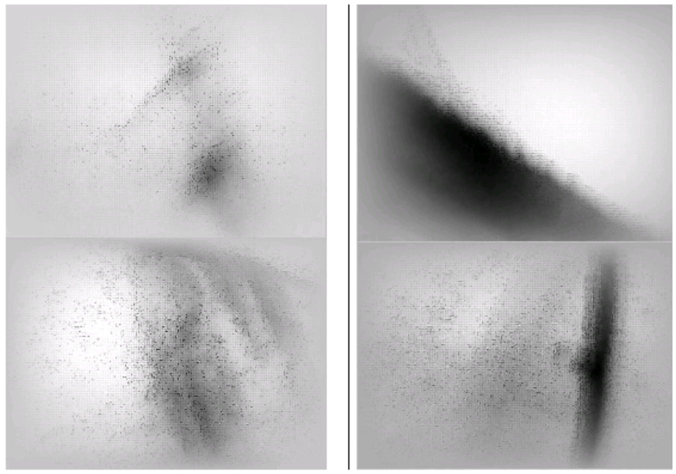


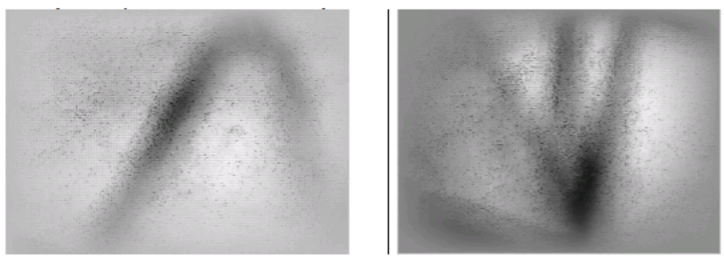
Figure 3-b: Holographic hair records (continuation).



Allotrichia, characterized by spirally twisted hair, is poorly detected by the holographic method due to differences in the distances between the sensor and various points of the hair (weak phase visualization)

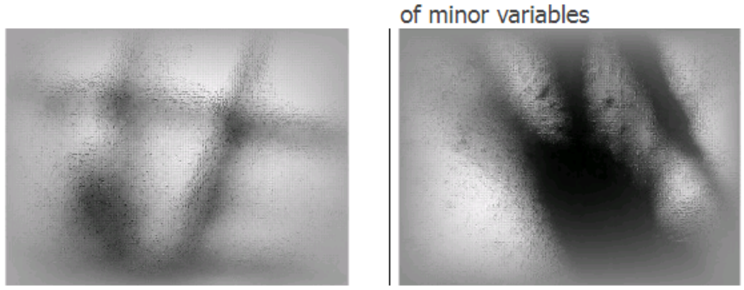
The edge of the hair is encrusted - a descriptor of a possible fungal infection

Figure 3-c: Holographic hair records (continuation).



Ingrown hair

Several hairs from one point. The same nature of spectral-correlation data is typical for tufted hair, except for a number of minor variables



A classic source of optical artifacts is an increase in optical density at the points of contact of the hair. In differential diagnostics in a number of methods, lensless micro-/trichoscopy can be a source of errors if its diffraction descriptors are not taken into account (see below). Otherwise, a false-positive diagnosis of nodularity is possible.

The problem of differential diagnosis in holographic lensless trichoscopy is associated with the measurement of correlation values. Otherwise, for example, this frame can be considered both as a normal manifestation of knotty hair, and as a phenomenon of "bamboo hair" with invaginative fragility

Figure 3-d: Holographic hair records (continuation).

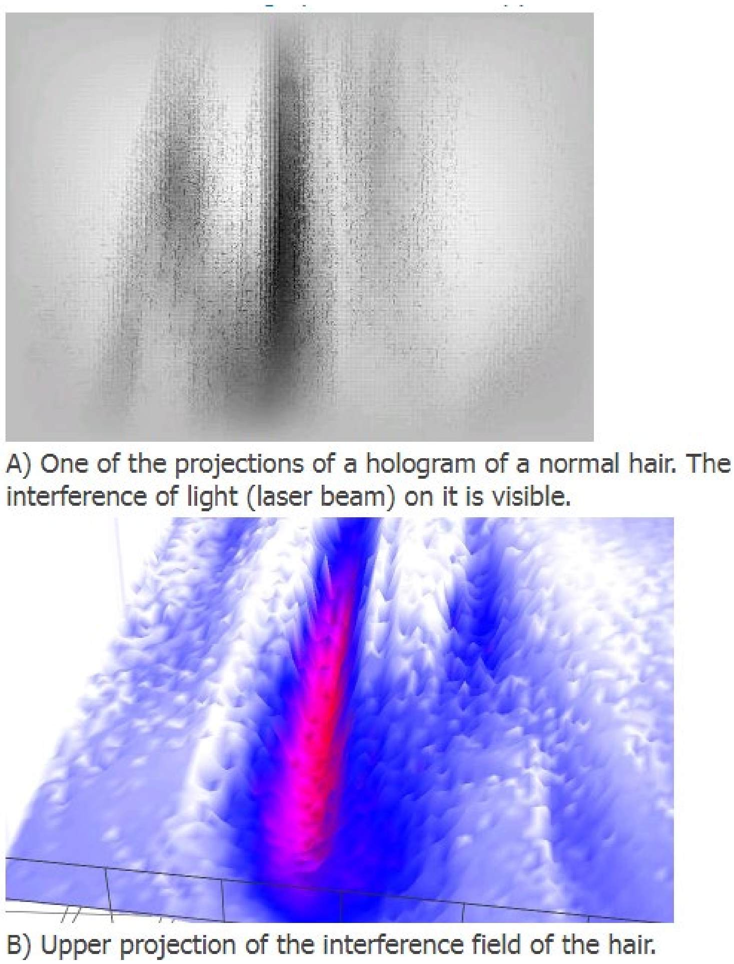


Figure 4: Interference structure of a hologram of a hair section (with apodization). Using interference microscopy data, it is possible to reconstruct the volume of an object (hair).

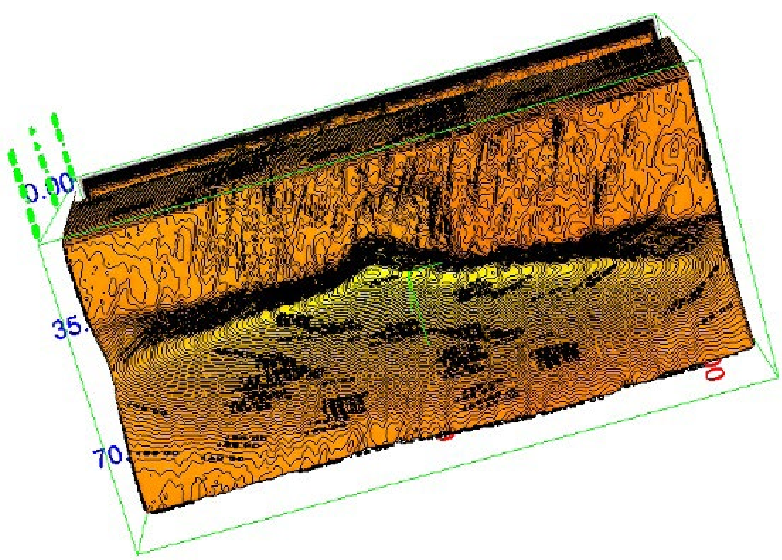


Figure 5: Three-dimensional representation of the hair structure, presumably with a tendency to break (trichonoresis). Registration method: lensless holographic 3D microscopy.

As practice shows, with sufficient characteristics of the laser beam, data on a more in-depth study of not only hair, but also the underlying skin can be quite interesting, therefore, for the purpose of a comprehensive diagnosis, it is logical to analyze the colocalization of hair pathologies and skin conditions. The source of artifacts in the case of results of focal colocalization of deramtological and trichological data (when scanning with a lensless holographic trichoscope mounted on a razor) can be the overlap of many hairs and dots on the surface of the skin, as well as rasters since this shifts the spectra and microdiffraction characteristics that underlie automated diagnostics. Currently, as part of the development of the QUATERNION PAK, a solution to this problem is being sought, which consists of using many lens-less sensors that record the signal from different angles. Comparative measurements of diffraction characteristics at different angles and analysis of angular descriptors are one of the few possible solutions to the problem within the framework of research and testing system for hardware and software systems of the QUATERNION circuits [17-21].

4. Conclusions

From the presented graphic material, it can be seen that microholographic lensless trichoscopes with tunable image scale are capable of providing information sufficient to identify certain pathologies both from primary registerograms (images / projections of digital holograms) and from secondary distributions of descriptors (IFC - Integrated Frequency Characteristics; ISC – Integral Spatial Characteristics; Waveletograms; Correlograms), with the use of which databases can be built for machine identification of certain pathologies using computer pattern recognition and fingerprinting methods, i.e. one-to-one recognition of the numerical characteristics of image descriptors in a sample upon completion of "computer training" / machine learning on diagnostic samples.

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