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Experimental study of remittance spectra of various anomalies of a healthy human skin

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The optical remittance spectra of the various human skin anomalies have been measured by use of the optical fibre probes of the different types. The mechanism of the creation of the remitted light beam is elucidated.

1. Introduction

Various anomalies may occur on a human skin. Some of them are not important from the point of view of the dermatology or have only a cosmetic effect, while the others may be problematic and may lead to severe diseases or even malignant transformations.

As the light impinges upon a human skin, it is absorbed, transmitted and reflected in various proportions depending on the physical parameters of the light and the optical properties of the skin. Among the optical characteristics describing the biological state of the skin, the remittance spectra play a special role. The knowledge of these spectra is important in understanding the interaction mechanism between the light and the skin as well as in diagnostics of various human diseases.

Over the past several years a variety of methods and techniques for the measurement of optical properties of the human skin and various tissues have been reported, as well as their advantages and disadvantages [1]–[4]. However, the optical properties gained from some tissues have been found to be different. The discrepancies may be attributed to the different experimental conditions concerning the measurement, especially the physical and chemical properties of the tissues, and also to the different methods used in making the experiments. In fact, the measurement accuracy of the optical properties of the tissue strongly depends on the way the tissue has been prepared, experimental set-up, and data-correction evaluation technique.

The optical methods of investigation of the skin and tissue properties have advantages over the chemical ones which are mostly used in medicine practice, for example, the chemical reaction analysis, because they are essentially high-speed and noninvasive. The remarkable advance has been made by using the lasers and the fibre-optic technology. A wide wavelength range of the light and silica or plastic optical fibres for making both in vivo and in vitro experiments have now become available.

This paper is the experimental contribution to the study of the optical properties of the skin. It presents the remittance spectra of various anomalies of the healthy skin. The design and development of the optical fibre probes is given. To our knowledge, the optical properties of the skin anomalies described in this paper have not been published yet. Generally, they exhibit very complex and complicated problem.

2. Remittance spectra

A simplified model of a normal human skin is given in Figure 1. The skin is composed of the following layers: the stratum corneum, the epidermis, the dermis and the subcutaneous fat. The layers are supposed to comprise the uniformly and randomly distributed light absorbing and scattering particles, the dimensions of which are much less than the thickness of the layers. The epidermis is further assumed to be composed of the two layers – the protein and the melanin. The dermis comprises the blood haemoglobin. It is supposed that the protein, melanin and haemoglobin layers obey the Beer–Lambert law of light absorption while the fat layer is considered to be reflecting.

The light absorbed in the tissues can cause the photochemical and thermal effects in biomolecules. The energy of photons in the ultraviolet and partly in the visible spectral range is sufficient to cause the electronic transitions of chromophore molecules, thus leading to the photochemical reactions. The thermal effect caused by the impinging light is usually not specific. It does not differ from the effects

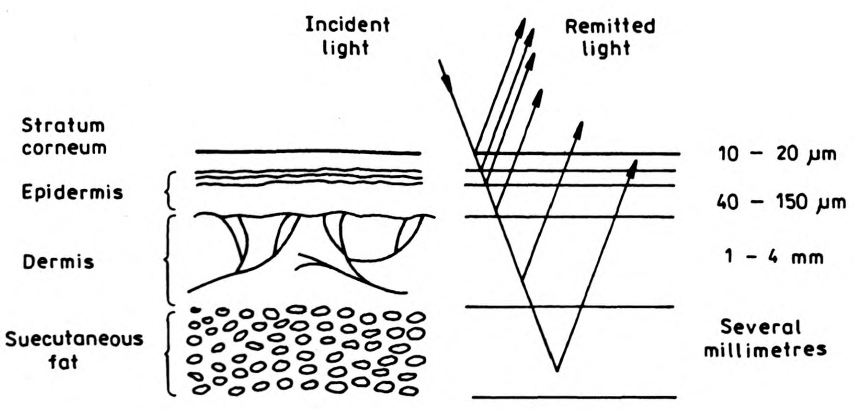

Fig. 1. Schematic layered model of the human skin and the mechanism of creation of the remitted optical beam

caused by the other forms of the thermal energy, unless the laser light is used. The lasers allow the coherent light to be spatially confined to the targets of dimensions as small as the cell organelles. The result can be the specific biological reaction which may be highly photochemically selective.

In the ultraviolet and infrared spectral ranges, the optical radiation impinging on the skin surface enters the skin but it does not penetrate too much into it. The maximum penetration depth of the whole skin lies in the vicinity of the wavelength of 760 nm, while the dermis has its maximum transmittance around the wavelength of 550 nm. The stratum corneum reflects about 5 percent of the incident radiation. Its surface is rough and it acts as an optical diffuser. In the vicinity of the wavelength of the maximum skin transmittance, a great part of the remitted light is composed of the radiation which transverses the epidermis, and after having been backscattered in the dermis returns through the epidermis out from the skin surface. About 40–60 percent of the impinging radiation is supposed to be reflected back from the epidermis and dermis.

3. Instrumentation technique and tissue objects

The usual experimental set-up was used to measure in vivo the remittance spectra of the various human skin anomalies [3]. The optical spectrum of the xenon light source used for the measurements in the wavelength range of 360–800 nm is shown in Fig. 2. The optical fibre probe allowing the delivery of the optical light to the skin

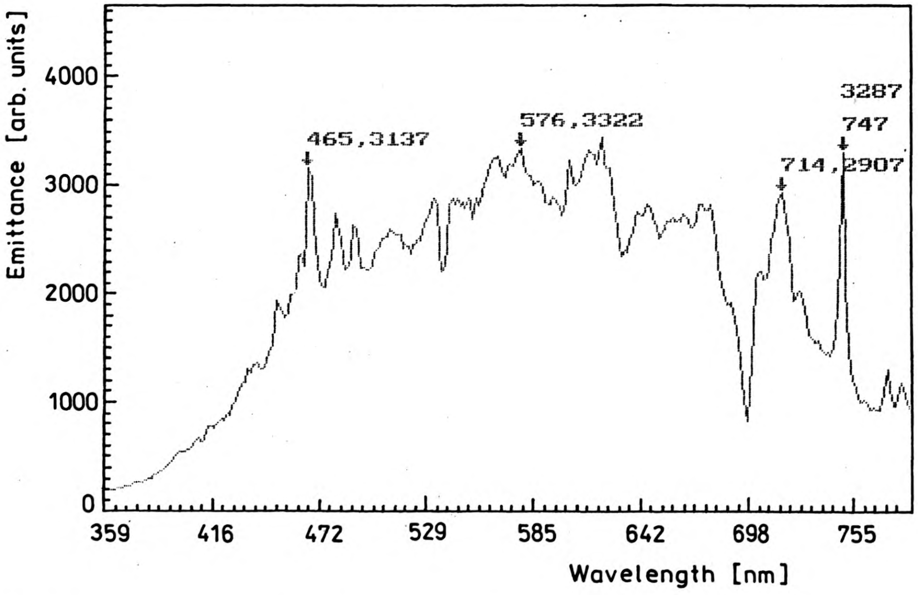

Fig. 2. Spectral remittance curve of the xenon-arc light source used for the measurement of the remittance spectra

surface and detecting its remittance from the skin is the crucial element of the measurements. Our aim was to design and construct the instrument that is relatively simple and versatile in dermatological experiments.

Several different types of the optical fibre probes were designed and fabricated. For the measurement of the remittance spectra, we have used the optical probe made of the two PCS fibres (the step refractive-index profile). The characteristic optical parameters of these fibres were the following: the outer diameter of the fibre – 1 mm, the diameter of the core – 0.6 mm, and the attenuation – 5 db/km. The material was the fuse silica. The other fabricated probes differ from the preceding one in the type of the optical fibre used. We have also used the communication optical fibres of the standard optical and geometrical parameters and the special polarisation-maintaining optical fibres of the W-refractive-index profile allowing the selective detection and transmission of the polarised optical signals. The use of optical fibres of different types makes it possible to achieve different sensitivities of the fibre probes, which is necessary for investigation of the various skin anomalies. We have also checked the probes composed of several optical fibres of the same or different inner diameters and refractive-index configurations.

The following skin anomalies were examined: normal skin, warts, freckles, birth-marks, pigmented spots, nails, and skin tissues of the various levels of the blood background. We should like to emphasize that our investigation has focused only on the healthy tissues of the human individuals of the white race. The results of the investigation may be different when performed on other objects and also under different experimental conditions. We suppose the effect of the probe light beam on the skin objects was negligible during the exposure time.

4. Measuring procedure

In order to assure the experiments to be repeatable, the skin was carefully washed with warm water and dried with cotton before each measurement. The place to be irradiated was then selected so that it did not have abnormal pigmentation, any perceptible erythema or large blood vessels close to it. The fibre optic probe was put in proper place and allowed to stay there for 2–3 min, so that the equilibrium temperature could be reached. The data were then collected and the measurement procedure was repeated several times.

Several light sources were checked: halogen lamp, tungsten bulb, slide projector and xenon-arc lamp. The intensity of the output light could be changed electrically with the potentiometer or optically with the iris diaphragm. The output of the light source entered one fibre leg of the bifurcated optical probe, while the other leg connected the joined measurement end with the spectral analyser. The holder of the fibre probe was made from the teflon disc because of its low thermal conductivity. The thermocouple temperature probe was used to monitor the temperature changes of the skin surface.

5. Results and discussion

The remittance spectra of the normal healthy skin, freckles, warts, burns, birth-marks, sallows, lip hematoma, nails, and different parts of the legs are shown in Figs. 3–8. The representative curves have been chosen from a series of measurements. The remittance spectra of these skin anomalies express the reflectance and scattering of the incident light by the anomalies of the upper surface cells, further the absorption and scattering that take place inside the inner anomaly, and respectively

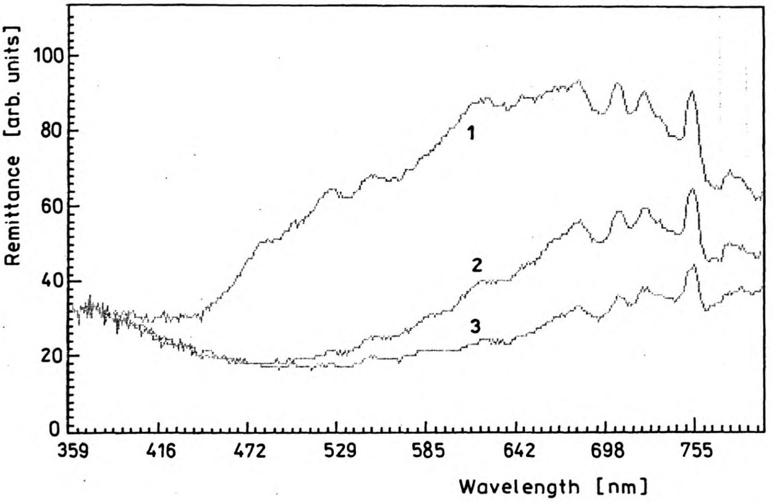

Fig. 3. Remittance spectra of: 1 – black birth-mark, 2 – brown freckle, and 3 – normal healthy skin

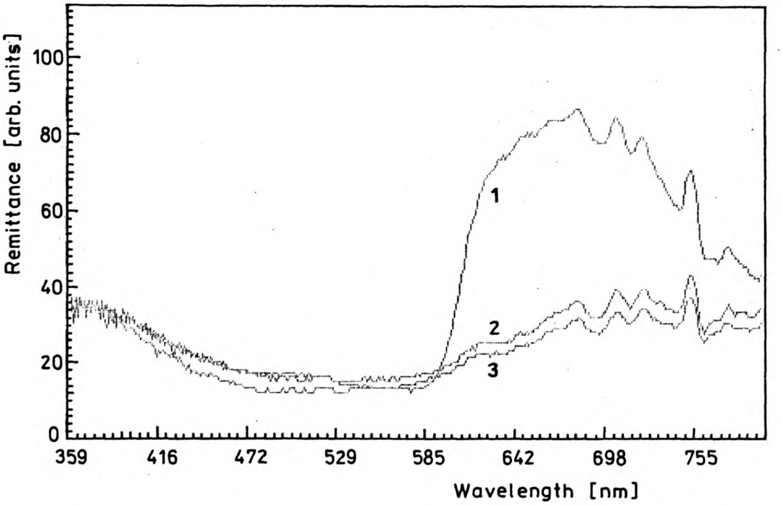

Fig. 4. Remittance spectra of: 1 – red skin outgrowth, 2 – dark-brown freckle, and 3 dark-brown wart

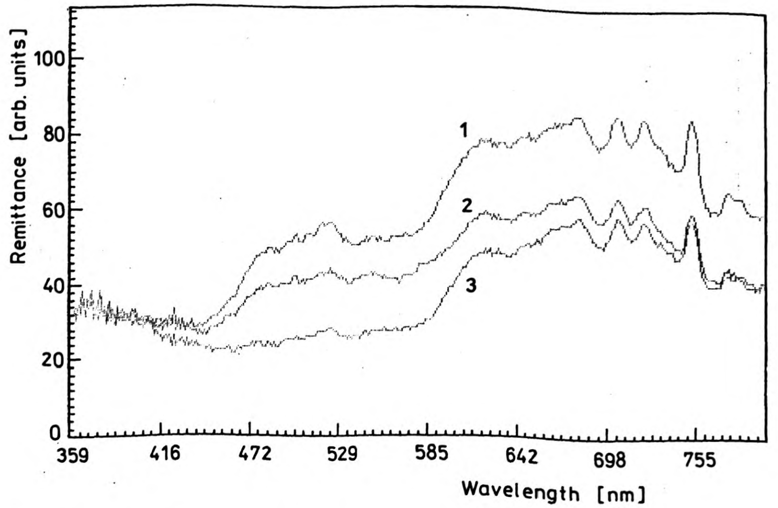

Fig. 5. Remittance spectra of: 1 – light-blue blood vessel under the skin, 2 – gel sallow, and 3 – reddish skin burn

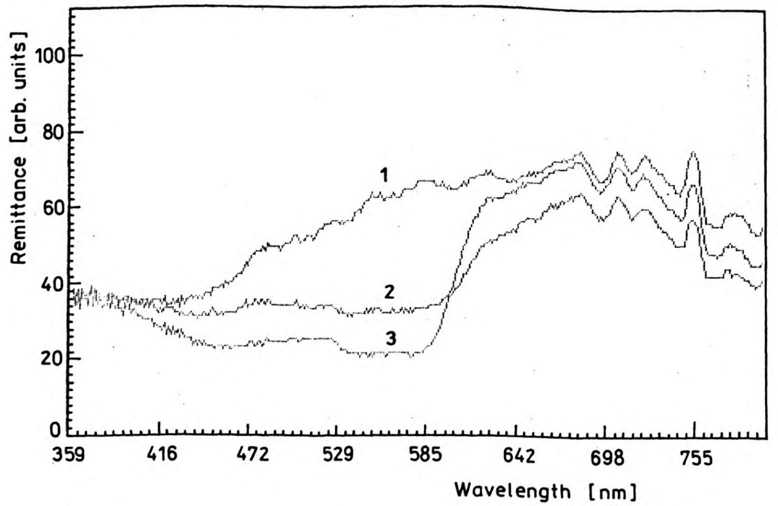

Fig. 6. Remittance spectra of: 1 – tooth, 2 – lip haematoma, 3 – healthy lip

those of epidermis and dermis. Every skin object has its characteristic spectral course.

The characteristic feature of all skin anomalies under study is a relatively low remittance at the short optical wavelengths, *i.e.*, in the far UV spectral range. Besides the teeth, nails and horny skin, this is caused most probably by the absorption of the melanin and haemoglobin which largely modulate the reflectance in this spectral range and determine the colour of the skin and its anomalies. The melanin has a slightly decreasing absorption coefficient, while the haemoglobin has a very high

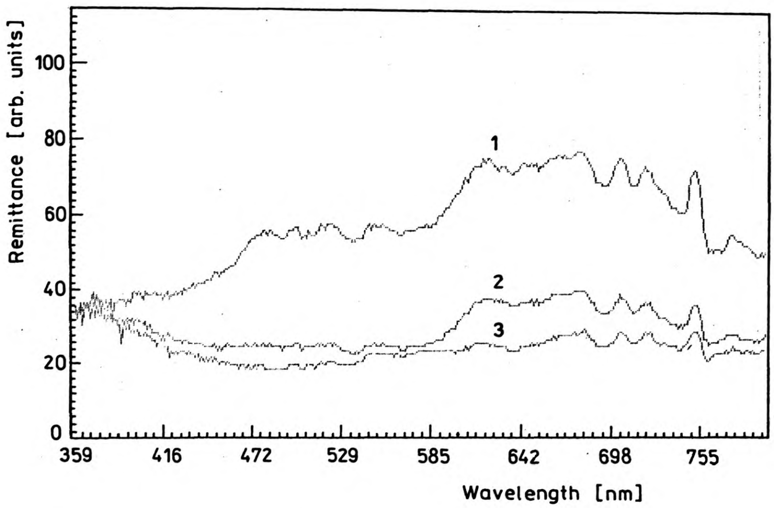

Fig. 7. Remittance spectra of: 1 — nail-bedding, 2 — healthy nail (middle part), and 3 — healthy nail-edge

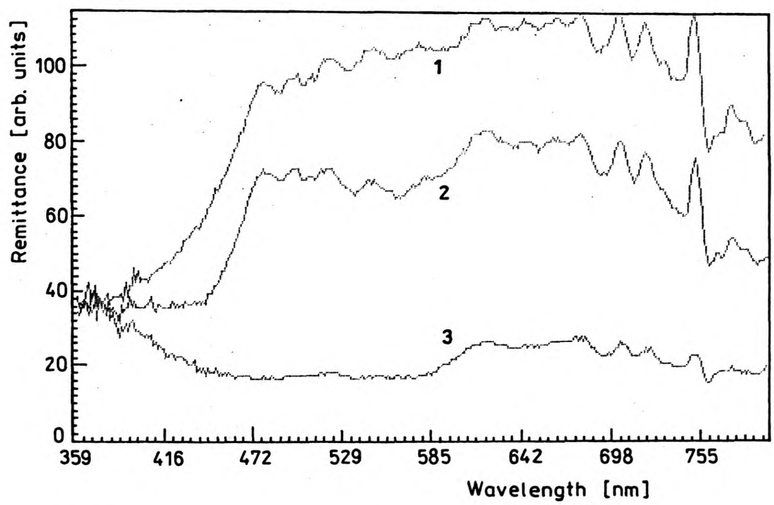

Fig. 8. Remittance spectra of: 1 — horny skin (the heel of the leg), 2 — leg instep, and 3 — sole

absorption maximum around the wavelength of 405 nm and small absorption maxima in the 520—580 nm wavelength range.

Generally, the remittances of the anomalies measured increase with wavelength. The remittance growth in the middle wavelength range can be monotonous, undulate or sharp as seen in Fig. 4 (1 — the red birth-mark) and Fig. 6 (3 — the lip). The remittance spectra in the upper part of the wavelength range of the anomalies under study are undulate and slightly decreasing. The curves given in Figs. 3—8 have not been normalised. This means that the vertical distances between the two curves at the specified wavelength express the relative remittances even when they are given in the arbitrary units.

6. Conclusion

The remittance spectra of the human skin anomalies are important not only in dermatology and other medicine branches but also in physics. In many cases, they can show both the current health state of the human individual, indicate severe diseases or show their development. For physicists, especially opticians, the skin objects exhibit the surroundings, which has not been well defined yet, and further theoretical and experimental investigations are needed.

The remittance spectra give basic optical information. As shown above, the spectral course of every skin anomaly is specific and differs from the others. We are convinced that this individual spectral course is the characteristic feature of every skin object and that it also expresses the information about the health state of some inner organs, and, consequently, of the whole human body. However, detailed investigations in this field have to be done.

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