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MECHANICAL PROPERTIES OF HAIRS FROM PATIENTS WITH DIFFERENT TYPES OF HAIR DISEASES*

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ABSTRACT

The following mechanical properties of hair have been studied: tensile strength, strain at break, and elastic modulus. The determinations were made at constant temperature and humidity on fifty separate hairs from each patient. The mechanical properties of the fibrous material were similar for thick and thin hair. The elastic modulus and tensile strength showed a good correlation. Five patients with ectodermal dysplasia and one with congenital ichthyosiform erythrodermia had a lower elastic modulus than the other groups. Hair from those with ectodermal dysplasia also showed a low tensile strength. No significant difference in mechanical properties were found between normal-appearing hair and hair from patients with male pattern baldness, alopecia areata and various types of female defluvium capillorum.

The etiology and pathogenesis of most hair diseases is unknown. For several of them we do not even know if the disorder has its origin in the germinative cells of the hair cortex, the blood supply to the hair follicle, or in the surrounding connective tissue.

In ichthyosis and psoriasis, for instance, there are abnormalities in epidermal keratinization (1). No such abnormalities at the molecular level are known in hair keratinization. With electron microscopy and x-ray diffraction analysis, no differences between hairs from ectodermal dysplasia patients and normal hair has been found (2). Such negative results do not exclude a difference at the molecular level. Data on mechanical properties of hair may not be interpretable in molecular terms, but may reveal differences between hair from patients with various hair diseases. In this screening study we have looked for abnormalities in elastic modulus, tensile strength and extensibility of hairs from patients with male pattern baldness, defluvium capillorum in women, alopecia areata and ectodermal congenital defects.

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PATIENTS

Controls. These were four men, ages 21 to 26 years. They were healthy medical students with no known family history of idiopathic baldness.

Male pattern baldness. These were four men, ages 20 to 26 years. They complained of loss of hair which began shortly after adolescence. Examination revealed a circular thinning over the crown and a M-shaped frontal hairline.

Defluvium capillorum. These were five women, ages 20 to 56 years. One of the patients complained of hair loss and oily hair during the past two years. Two patients had a diffuse hair loss for about one year with increased shedding of club hairs as seen in telogen effluvium. Two had a family history of female pattern baldness with diffuse alopecia for 5 to 10 years.

Alopecia areata. These were three men and one woman, ages 17 to 50 years. The patients had several round bald patches. The hairs surrounding the patches could all easily be lifted out. In one patient the alopecia became total. In the others regrowth was seen within a few months.

Congenital ectodermal dysplasia. These were two boys and three girls, ages 2 to 15 years. The patients had hypotrichosis of the scalp since birth. All had blond, lifeless, harsh, rather short hair without luster. They also had dystrophy of the nails. Two patients also had depressed nasal bridges, one had renal dys-

TABLE I

Mechanical properties of hairs. The figures show the mean and the limits of the 95% confidence interval using T-test. Figures within parentheses give the confidence interval using variance analysis

Diagnosis	No. patients	Tensile strength $N/m^2 \cdot 10^{-8}$	Strain at break %	Elastic modulus $N/m^2 \cdot 10^{-9}$
Normal hair	4	1.64 ± 0.10	62.4 ± 1.6	2.62 ± 0.18 (0.47)
Congenital ectodermal dysplasia	5	1.28 ± 0.14	60.0 ± 3.2	1.64 ± 0.19 (0.42)
Congenital ichthyosiform erythrodermia	1	1.66 ± 0.20	65.9 ± 4.3	1.81 ± 0.20
Male pattern baldness	4	1.81 ± 0.14	70.3 ± 2.5	2.80 ± 0.23 (0.70)
Alopecia areata	4	1.75 ± 0.16	65.8 ± 2.5	2.66 ± 0.23 (0.43)
Defluvium capillorum	5	1.40 ± 0.10	69.3 ± 1.3	2.44 ± 0.16 (0.19)

plasia and one deformed teeth. We found no signs of anhidrosis.

Congenital ichthyosiform erythrodermia. There was one boy, 2 years old, with thickening and fissuring of erythematous skin since birth. The hairs were thin and white.

MATERIAL AND METHODS

Hairs were removed by scissors close to the scalp. They were defatted in ether for twenty-four hours and, before testing, the hairs were placed in water overnight. Stress-strain testing of the hair was performed at a constant temperature of 20° C in a universal tensile tester, type "Alwetron".[1] The hair was exposed to a water fog during testing in order to minimize the influence of hydrogen bonds. It was mounted in the mechanical clamps with the faces covered by silicon carbide finishing paper which eliminated slippage of the hair.

The upper clamp was mounted in a strain-gauge load cell, which measures the load developed during the straining, and the lower clamp in the moving bar of the tensile tester. The output from the load cell was fed to a potentiometric recorder. The feed rate of the recorder chart is synchronized with the motor which drives the moving bar. In this way the ratio of the paper feed rate to the elongation rate is fixed very exactly. The span length used was 15 mm and the elongation rate 5 mm/min giving a strain rate of 33.3 per cent/min. The ratio of the paper feed rate to the elongation rate was chosen to be 1:60 giving a precision of about ±0.02 mm in the elongation determination. The precision of the load determination was about ±0.5 gt. About fifty different hairs from each patient were measured one at a time. The diameters of the hairs were measured in a microscope equipped with a "Dyson"[2] image splitting eye piece giving a setting accuracy of about 0.5 μm. At the same time the hairs were scrutinized for local abnormalities, cracks or evident non-circularity of the cross sections. The cross-sectional area was then calculated assuming a circular cross section.

Definitions: Stress = load per unit area of the cross section (Newton/m²), Strain = elongation/span length, Elastic modulus = slope of the initial linear portion of the stress-strain curve.

In the preliminary statistical analysis the values of all hairs from the patients in a group have been pooled and the 95 per cent confidence interval has been calculated and given in Table I. These confidence intervals are somewhat optimistic. In the case where there is a significant difference between some groups, the variation between the patients in a group has been taken into account using variance analysis. The method used is given in reference 3. This method has only been used for the elastic modulus and the more pessimistic confidence intervals obtained are given within parentheses in Table I.

RESULTS

A typical stress-stain curve is shown in Figure 1. The mean values and the limit of the

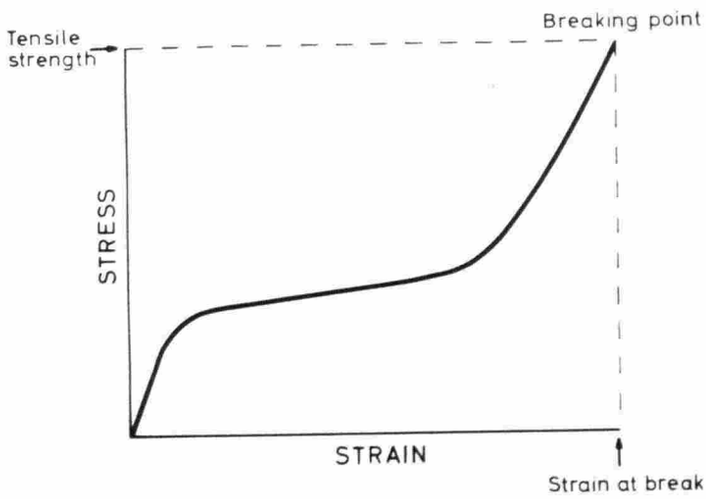

FIG. 1. A typical stress-strain curve illustrating strain at break and tensile strength.

[1] Made by Lorentzen & Wettre Ab., Stockholm, Sweden.

[2] Made by Vickers, Ltd., York, England.

95 per cent confidence interval for different categories of hair anomalies and different properties investigated appear in Table I. The tensile strength and elastic modulus are expressed per unit cross-sectional area of the hair. The ectodermal dysplasia and ichthyosis congenita patients have a lower elastic modulus than the other groups. This difference is statistically significant at the 95 per cent level as tested by variance analysis. The tensile strength is also lower for ectodermal dysplasia. Hairs from patients with alopecia areata, male baldness and defluvium capillorum show the same values as normal hairs. When the elastic modulus for each of these patients is plotted as a function of mean hair diameter, no correlation can be seen between the two parameters (Fig. 2). Neither did we find any correlation between the diameter of the hair and its tensile strength. The elastic modulus and tensile strength, however, were well correlated (Fig. 3). The strain at break was similar for all groups of patients studied.

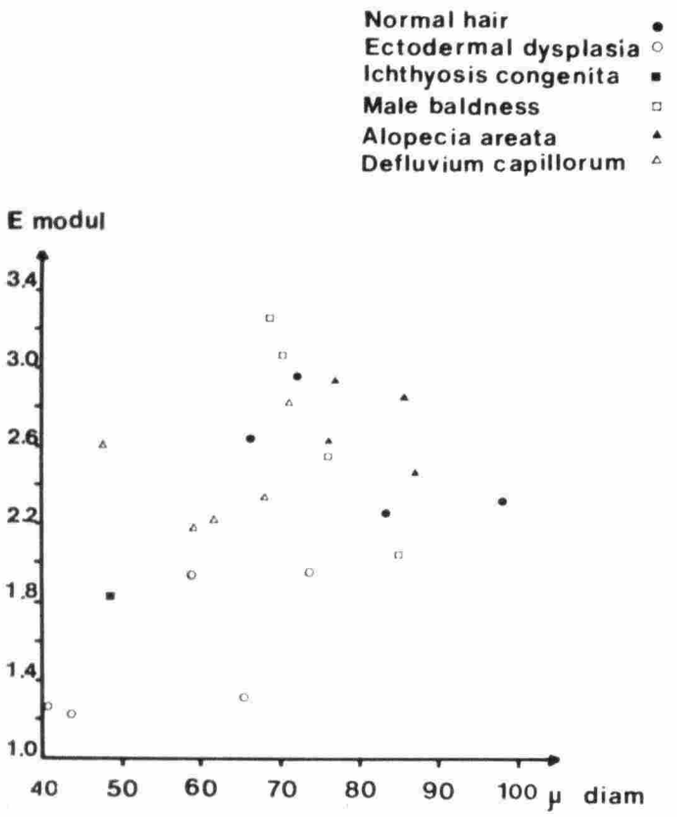

FIG. 2. Diameter and elastic modulus of hairs from normal subjects and patients with various hair disorders.

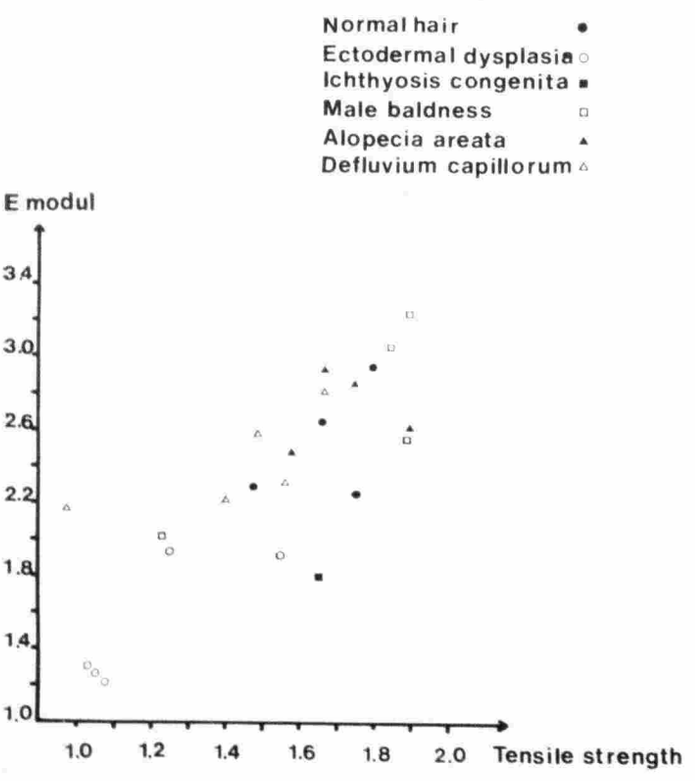

FIG. 3. Tensile strength and elastic modulus of hairs from normal subjects and patients with various hair disorders.

DISCUSSION

The structure of keratin is very complex and not completely known. The primary structure, the amino acid sequence, is unknown. The secondary structure is mainly α-helical and there is, without doubt, a transition from α-helical to extended β-structure during stretching of the hair (4). The mode of aggregation is complex and different models have been proposed (5, 6). One type or another of helical aggregation is probably involved. Even the filaments aggregate in a helical way (7).

We are not able to interpret changes in mechanical properties of hair in molecular terms. There are, however, data that support the idea that disulfide bonds are of great importance for the mechanical properties (8). Abnormalities in sequence or content of nonsulfur-containing amino acids may possibly also affect the mechanical properties.

In the present study we have found normal tensile strength, strain at break and elastic modulus of the hairs from patients with male baldness, alopecia areata and female defluvium capillorum. This indicates that the keratin is normal in these conditions.

As there is no correlation between the diameter of the hair and its elastic modulus, strain at break or tensile strength, one may conclude that the mechanical properties of the fibrous material are similar for thick and thin hair.

In the diagnosis, ectodermal dysplasia, one implies a genetic defect of the ectoderm. The same may also be said about ichthyosis con-

genita. It is interesting to find abnormal mechanical properties of the hair cortex in these diseases. The findings of Scriber (9) of a lower disulfide content of the hair in a Canadian family with ectodermal dysplasia are of special interest in this connection. The lower disulfide content was found only in children affected by the disease while their healthy relatives had a normal disulfide content.

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