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Human Hair Studies: III. Refractive Index of Crown Hair

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HUMAN HAIR STUDIES

III. Refractive Index of Crown Hair*

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In common with several of the physical properties of hair which might have value in the characterization or individualization of hairs, the refractive index appears to have received little or no systematic study. It is a factor which might be expected to vary within rather narrow limits, but one which should nevertheless reflect any chemical differences existing in the hair. As pointed out in the first paper of this series (1), both chemical and morphological differences are to be expected in greater or less degree between individuals, sexes, ages, and races; and it remains for extensive investigation to decide to what extent these differences are characteristic of any of these factors, and of what utility they may be in characterizing or individualizing the hair from the forensic standpoint.

In this communication is reported a moderately extensive study of the refractive index of hair from 97 individuals, the total number of hairs measured being 2529, which was also the total number of measurements. The actual values reported refer to the refractive index of the cuticle rather than to that of the cortex of the hair, due to the limitations of the available methods. It is shown that refractive index has a definite though limited value in individualizing and characterizing human head hair, since the variation of the individual is definitely less than that of the race. In addition, refractive index appears to be one of the best criteria yet discovered for the determination of sex of hair, since a relatively large difference exists between male and female hair in most of the cases studied. Evidence is given of a definite influence of race, though the small number of cases studied do not indicate any value of the factor in indicating race.

Experimental

Hairs which were to be examined were first thoroughly cleaned by soaking them with agitation for ten minutes in a mixture of equal parts of methyl alcohol and ether. A short piece, about 0.5 mm. long, was cut at random from some part of each hair, and this was used for the determination of refractive index.

Measurements were made by use of recognized immersion methods (2) partially by use of oblique illumination and partially the Becke line with normal illumination. Essentially identical results were obtained by the two procedures, except that the oblique illumination method was somewhat

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easier to read and was consequently employed to the greater extent. The standards used were made to cover a range of refractive index from 1.541 to 1.553, in intervals of 0.002, by mixing nitrobenzene and oil of cloves in various proportions. All standards were accurately calibrated and adjusted by use of an Abbé refractometer at controlled temperature. The standards were stored in small narrow mouth bottles, and were recalibrated at frequent intervals. Necessary precautions included working rapidly to minimize evaporation; use of spherically ground slides to restrain the spreading of immersion liquid; complete removal of one liquid before applying another; and the use of a completely new standard with each sample. All data are believed to be accurate in the comparative sense to ± 0.0005, and absolutely to ± 0.001.

In both types of immersion procedure it is the edge of the material which exerts the imperfect lens effect which is observed and used to determine the relation of the solid to the immersion liquid. It is consequently this edge which is actually compared with the liquid standard and considered to be the portion measured. Since the edge involved in hair is the cuticle or scales, it seems almost certain that the data reported are refractive indices of cuticle and may well be different from those of cortex which has not yet been studied.

Results

All of the data obtained in this series of measurements are listed in the composite Table I. The order of listing is that of decreasing values of the highest refractive index measured in each case. As a rule, this is also the order of decreasing means, though some exceptions may be noted.

Examination of Table I immediately brings to light the fact that all males listed in the earlier part of the table (high refractive index) are wholly or partially non-Caucasian in ancestry or are young boys. Also, all individuals in the latter part of the table are males, usually Caucasian, except for a single Chinese girl. The central portion of the table includes both males and females. It is also to be noted that the lowest value for a female is that of the Chinese mentioned, while the highest value in the entire table is also that of an Oriental. In fact, the distribution of non-Caucasian values is not sharply demarcated on the basis of sex, but tends to group in the higher range which is shown by Caucasian females. Because of the absence of sex distinction in this group, the values of all true Caucasians were abstracted and the incidence of the sexes plotted as shown in Figure 1. The small isolated male area on the extreme right of Figure 1 is due to two boys who had not reached puberty.

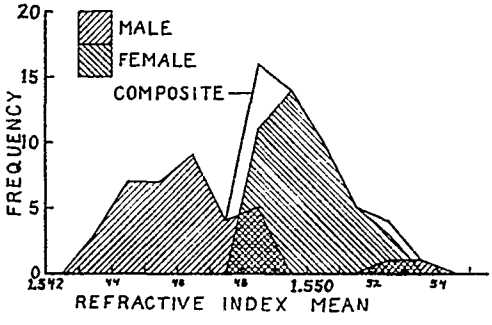

FIGURE 1

Caucasian Crown Hair: Distribution by Sexes According to the Mean of the Refractive Indices.

It is readily seen that the refractive index of hair of Caucasian males and of Caucasian females has distinctly different distribution curves, showing an overlap in only about 20% of the total cases. This distinction of refractive index appears to be definitely significant as regards Caucasians, and should have a very real value in determining the sex of a hair when no other criteria are available. In about 80% of the total cases it may be considered conclusive of the sex, provided the hair has a Caucasian origin, and assuming that the data of this investigation are sufficient in number to be statistically conclusive. Below a mean refractive index of 1.548, no Caucasian females have been found, and above one of 1.549, no Caucasian males have been found, except for young boys who strangely appear to occur in the highest range of all.

That boys under the age of puberty should have a hair refractive index similar to that of a woman may not be surprising because they also show other female secondary sex characters, such as a female hair distribution (absence of whiskers, etc.) and a voice which is more characteristic of the female than of the male. The very few cases investigated gave mean values which were actually considerably higher than the female average, regardless of race, and this is the really unexpected fact. Further work should be carried out to determine whether this is merely a coincidence due to the very small number of young male individuals investigated.

The number of non-Caucasian subjects was not large, and the complete significance of race in determining the

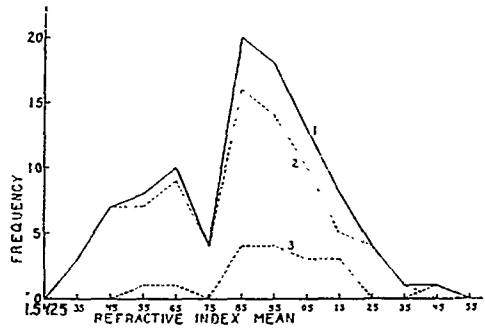

FIGURE 2

Refractive Index Distribution of Crown Hair of Various Races.
Curve 1: Composite. Curve 2: Caucasian. Curve 3: Non-Caucasian.

refractive index of hair could not be finally ascertained. Figure 2 shows the distribution of all cases studied, arranged in two groups, Caucasian and non-Caucasian, and the composite curve. The curve of Caucasians represents data from 80 subjects; that for non-Caucasians, 17 subjects. The latter included all Asiatics either pure or mixed with Caucasians, and the American Indian and mixtures with Caucasian. From the original data it was apparent that even relatively dilute admixtures of Indian with Caucasian yielded a refractive index more typical of non-Caucasian than otherwise. Inspection of those data shows little, if any, sex distinction in the non-Caucasian group, but a very low proportion of indices in the range characteristic of Caucasian males. How this should be interpreted is difficult to determine until considerably more data become available for non-Caucasians and their admixtures. The available figures give indication that non-Caucasians average a higher refractive index than do Caucasians. It is not at all clear why there should be a sharp minimum in the non-Caucasian curve at the same point that

TABLE I

Composite Refractive Index Data on Human Crown Hair

Number Determinations	Range[1]	Arithmetic Mean[1]	Standard Deviation (X 1000)[1]	Sex	Age	Ancestry[2]	Remarks
50	1.556-1.553	1.5544	0.63	M	23	J	
20	1.554-1.552	1.5532	0.60	M	2	D,E	Stored 29 years
25	1.554-1.548	1.5494	1.09	F	42	Fi	Perm. wave
20	1.553-1.552	1.5526	0.49	F	3	E,Ir,D,Fr	Stored 4 years
18	1.553-1.552	1.5523	0.47	F	30	E,Ir,Sc	
20	1.553-1.551	1.5524	0.58	F	7	E,D,Fr	
13	1.553-1.551	1.5520	0.56	F	19	E	
14	1.553-1.551	1.5519	0.46	M	12	¼ In	
50	1.553-1.551	1.5519	0.37	F	44	Ni,¼ In	
15	1.553-1.551	1.5515	0.63	M	53	In	
20	1.553-1.550	1.5521	0.83	M	4	E,FC	
100	1.553-1.548	1.5505	0.81	M	20	M	
14	1.552-1.551	1.5516	0.48	F	22	E	
20	1.552-1.551	1.5514	0.48	F	21 mo.	E,Ir,Sc,Fr,Sw,It,G	Stored 21 years
16	1.552-1.550	1.5513	0.58	F	28	E,Ir,Sp	
8	1.552-1.550	1.5513	0.66	F	12	Sw	
20	1.552-1.550	1.5509	0.70	F	30	Fr,Ir	
15	1.552-1.549	1.5510	0.90	F	20	Sp	Perm. wave
20	1.552-1.549	1.5510	0.84	F	3	Fr,E,D	Stored 7 years
20	1.552-1.549	1.5504	0.79	F	7	Fr,E,D	Stored 3 years
25	1.551-1.550	1.5509	0.26	F	13 mo.	Ir,Sc,G	Stored 17 months
50	1.551-1.550	1.5508	0.39	F	7½	Ir,Sc,G	
5	1.551-1.550	1.5502	0.40	M	22	Hi	
50	1.551-1.549	1.5507	0.54	F	2½	Ir,Sc,G	
11	1.551-1.549	1.5502	0.58	F	17	Sw	
50	1.551-1.549	1.5502	0.82	M	5	Ni,⅛ In	
50	1.551-1.549	1.5500	0.85	M	14	Ni,⅛ In	
12	1.551-1.549	1.5500	0.71	F	26	It	
20	1.551-1.549	1.5500	0.74	F	10	Fr,E,Ir,D	
20	1.551-1.549	1.5499	0.57	F	23	Fr,Ir	
50	1.551-1.549	1.5499	0.67	F	11	Ni,⅛ In	
19	1.551-1.549	1.5495	0.59	F	25	Ir	
15	1.551-1.548	1.5503	0.93	F	20	G	Perm. wave
15	1.551-1.548	1.5494	1.02	F	21	G,Sw	Perm. wave
15	1.551-1.548	1.5491	0.85	F	19	E,Ir	Perm. wave
15	1.551-1.548	1.5489	0.93	F	18	E,G	Perm. wave
15	1.551-1.548	1.5485	0.81	F	20	Ir,Sc,Sw	Perm. wave
15	1.551-1.547	1.5487	0.85	F	20	G,Ir	Perm. wave
50	1.551-1.545	1.5503	1.44	F	44	Ir	Perm. wave
2	1.550 -	1.5500	0.00	M	13	C	
5	1.550-1.549	1.5498	0.40	F	17	Sw,E,Sc,Ir	
20	1.550-1.549	1.5498	0.44	F	23	½E,½C	

[1] For an explanation of statistical terminology and of the formulae used in computing these statistics, see footnotes for Table I in the preceding article in this series—*31* (5): 631 (1941).

[2] The ancestry of the person from whom the hair is taken is indicated by the following symbols.

	Fr—French	In—American Indian	P—Polish
Ar—Armenian	FC—French-Canadian	Ir—Irish	R—Russian
C—Chinese	G—German	It—Italian	Ru—Rumanian
D—Dutch	Gr—Greek	J—Japanese	Sc—Scotch
E—English	Ha—Hawaiian	Jew—Jewish	Scan—Scandinavian
Eu—European	Hi—Hindu	M—Mexican	Sp—Spanish
Fi—Finnish	Hu—Hungarian	Ni—Nicaraguan	Sw—Swedish

Number Determinations	Range	Arithmetic Mean	Standard Deviation (X 1000)	Sex	Age	Ancestry	Remarks
20	1.550-1.549	1.5497	0.48	F	9	Eu	
20	1.550-1.548	1.5495	0.59	F	23	P	
15	1.550-1.548	1.5494	0.71	F	19	Sc	Perm. wave
20	1.550-1.548	1.5492	0.75	F	21	Ir	
12	1.550-1.548	1.5491	0.64	F	25	Sp,E,Ir	
20	1.550-1.548	1.5491	0.80	F	51	D	
6	1.550-1.548	1.5490	0.58	F	20	G,It	
20	1.550-1.548	1.5490	0.63	M	31	D,E	
8	1.550-1.548	1.5490	0.71	M	20	C	
15	1.550-1.548	1.5485	0.62	F	18	Sc,Ir	Perm. wave
100	1.550-1.546	1.5489	1.24	M	21	Fr,E	Curly blonde
100	1.550-1.546	1.5488	0.96	M	23	E,Ir	Blonde
100	1.550-1.546	1.5486	0.94	M	21	Sc,E,Ir	Blonde
100	1.550-1.546	1.5474	0.73	M	22	Ru,Ar	Curly
6	1.549-1.548	1.5487	0.47	F	24	C	
20	1.549-1.548	1.5486	0.50	F	19	G,Ir	
20	1.549-1.548	1.5485	0.50	F	24	G,Fr,E,Ir	
14	1.549-1.548	1.5484	0.48	F	23	E,Ir,Sc,Fr,Sw,It,G	
20	1.549-1.548	1.5484	0.48	F	65	G,Fr	Graying
5	1.549-1.548	1.5484	0.49	M	20	Ha,C	
9	1.549-1.548	1.5483	0.47	M	20	C	
15	1.549-1.548	1.5482	0.40	F	19	Sc,Ir	Perm. wave
20	1.549-1.547	1.5481	0.50	F	3	¾E,Ir,G,Fr	
50	1.549-1.546	1.5481	0.78	M	38	R,Ru	
50	1.549-1.545	1.5473	0.73	M	43	G,Jew	
20	1.548-1.546	1.5473	0.64	M	24	E	
14	1.548-1.546	1.5471	0.70	M	22	G,E	
9	1.548-1.545	1.5468	0.92	M	22	E,Mixed Eu	
26	1.548-1.545	1.5467	0.96	M	22	Fr,E	
100	1.548-1.545	1.5467	0.63	M	25	Fr,Ru,Jew	
50	1.548-1.545	1.5463	0.74	M	21	Ar	Curly
50	1.548-1.545	1.5457	0.71	M	20	Gr,Hu	
26	1.548-1.544	1.5463	1.00	M	22	Mixed Eu	
20	1.547-1.546	1.5466	0.49	M	29	E,Sc	
10	1.547-1.546	1.5466	0.49	M	21	Gr	
20	1.547-1.546	1.5463	0.46	M	20	C	
20	1.547-1.545	1.5463	0.66	M	22	E	
13	1.547-1.545	1.5462	0.70	M	22	Fr	
20	1.547-1.545	1.5459	0.57	M	68	E,Ir	
10	1.547-1.544	1.5452	0.75	F	19	C	
26	1.547-1.543	1.5450	1.14	M	22	Mixed Eu	
26	1.547-1.543	1.5447	1.07	M	23	E,Ir	
26	1.547-1.543	1.5444	1.53	M	21	E,Ir	
14	1.546-1.545	1.5455	0.50	M	20	Scan	
20	1.546-1.544	1.5455	0.68	M	64	E	Graying
20	1.546-1.544	1.5452	0.57	M	19	P	
20	1.546-1.544	1.5451	0.67	M	64	E	Graying
20	1.546-1.544	1.5451	0.67	M	23	Ir,Sc	
20	1.546-1.544	1.5450	0.63	M	22	P	
11	1.546-1.544	1.5449	0.67	M	22	Mixed Eu	
20	1.546-1.544	1.5446	0.58	M	18	G	
20	1.545-1.544	1.5445	0.50	M	19	G,Fr,E,Ir	
26	1.545-1.542	1.5435	1.10	M	22	E,Ir,Fr,G	
20	1.545-1.542	1.5433	0.83	M	22	E,Ir,G,Fr	
20	1.544-1.543	1.5432	0.40	M	19	E,Fr	

such a minimum occurs in the Caucasian curves, due to sex difference. This may be a coincidence, since there were only two such individuals found with indices lower than 1.5475.

In addition to the consideration of the mean values for refractive index of hair, it seemed of interest to make some analysis of the range, partially because of its significance in determining the validity of the data for individualization purposes, and also because greater variability in range was noted with certain groups than with others. The data relative to this factor are shown graphically in Figure 3. Most noticeable is the divergence of permanently waved hair from normal hair with respect to its range of values. In every other case, the distribution maximum is reached with the group centering on a range of 0.002, whereas in this case it occurs in the group centering on a range of 0.003, and reaches a maximum range of 0.006, which is 0.001 unit higher than any other group listed. With the exception of hair which has been waved, all hair, regardless of sex or race, appears to average about the same spread of refractive index from hair to hair, as is shown by the uniformity of maxima at the value 0.002. Many individuals diverge from the average value however. This being the case, it becomes apparent that if the value of two unwaved hairs differs in refractive index as much as 0.004, it is almost certain that they did not come from the same head. Since the total observed range of refractive index for all individuals studied is 0.011, it is apparent that the refractive index mean will serve as an eliminative factor in hair individualization to an extent that, on the average, will amount to elmination of at least 2 out of 3 possibilities of identity; and up to 4 out of 5 when the range is of average value. Naturally, the eliminative value will vary somewhat depending on the portion of the distribution curve in which the refractive index of the suspected hair occurs, being less as it approaches either of the maxima in the distribution curve, and greater at the ends of the curve. By considering also the range, which is less significant, the eliminative value becomes a minimum of about 3 out of 4 on the average, as indicated earlier (1). Although the range of values found for any individual is very narrow, it is not desirable to make less than 5 determinations before calculating the mean.

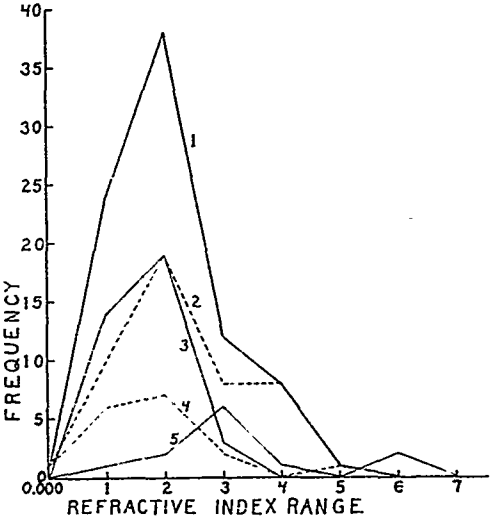

FIGURE 3

Range of Refractive Index Distribution.

Curve 1: Composite. Curve 2: Caucasian Male. Curve 3: Caucasian Female (not permanently waved). Curve 4: Non-Caucasian, both sexes. Curve 5: Caucasian Female (permanently waved).

Some special small studies were made where it was possible to obtain hair from several members of a family, or the hair of the same individual at different ages. In one case, hair of 5 individuals, representing 3 generations of the same family, was obtained, and the refractive indices measured. The data are not separated from those of Table I because of the failure to observe any significance other than the general relations of the sexes. Probably more interesting is the compilation of data from those cases in which hair of the same individual was taken at different ages. The results are given in Table II. Without exception, the refractive index of the hair showed a decrease with age, and the decrease was roughly proportional to the length of time. It was not in any case found useful for the determination of age, and, in fact, even the assumption that there is a change with age must be considered with suspicion. In every case the hair from the earlier ages had been stored since its original collection, so that all samples were run at approximately the same time. The change in refractive index may well have been due to change of the hair itself on storage, to dehydration, oxidation, or other chemical alteration, rather than to the actual change of hair on the individual's head. The only way in which this question might be answered would be by means of a lengthy investigation in which the same individual was studied over a considerable period of time, but each value run soon after collection of the hair.

TABLE II

Effect of Age on Refractive Index of Human Crown Hair

Individual	*Age*	*R.I. Mean*	*Sex*
A	12 mo.	1.5509	F
	2½ yr.	1.5507	
B	21 mo.	1.5514	F
	23 yr.	1.5584	
C	3	1.5526	F
	7	1.5524	
D	3	1.5510	F
	7	1.5504	
	10	1.5500	
E	2	1.5532	M
	31	1.5490	

Summary

A study has been made of the cuticular refractive indices of human crown hair from 97 individuals, 2529 measurements being made on the same number of hairs.

It is shown that the average refractive index mean and distribution differ considerably between males and females of the Caucasian race, but not so definitely between the sexes in individuals wholly or partially of Asiatic origin. The indices found for the hair of young boys were more characteristic of females than of males.

An evaluation is given of the utility of refractive index in individualizing hair and in determining its sex, race, age, and other factors.

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