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HUMAN HAIR

Volume I
Fundamentals and Methods for Measurement of Elemental Composition

Vlado Valković

CRC PRESS

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Author

Vlado Valković, Ph.D.

Professor of Physics
Department of Nuclear and Applied Physics Rugjer Bošković Institute
Zagreb, Yugoslavia

CRC Press, Inc.
Boca Raton, Florida

Library of Congress Cataloging-in-Publication Data

Valković, V.
Human hair.

Bibliography: p.
Includes index.
Contents: v. 1. Fundamentals and methods for measurement of elemental composition -- v. 2. Trace-element levels.
1. Hair--Analysis. 2. Trace elements--Analysis.
3. Trace elements in the body. I. Title.
RC73.7.V35 1988 616.07'5 87-21222

ISBN 0-8493-4861-7 (v. 1)
ISBN 0-8493-4863-5 (v. 2)

Direct all inquiries to CRC Press, Inc., 2000 Corporate Blvd., N.W., Boca Raton, Florida, 33431.

International Standard Book Number 0-8493-4861-7 (v. 1)
International Standard Book Number 0-8493-4862-5 (v. 2)

Library of Congress Number 87-21222
Printed in the United States

FOREWORD

Throughout the ages, the hair on the human head has always aroused interest, above all from an aesthetic point of view. The apparent anatomical continuity of the head hair system is in relation to the fact that, at any one point in time, the total area consists of 88% in the growing (anagen) phase and 12% in the transitional (catagen) and resting (telogen) phase. These growing phases are not synchronized. Normal head hair is made of 100,000 to 120,000 individual hairs, with a speed of growth of about 0.35 mm/day and a reproductive cycle lasting 2 to 5 years.

Hair problems are certainly not of primary importance where health is concerned. They have therefore tended to be neglected by medical science, regardless of the problems they involve for the person concerned: problems of a hygienic, aesthetic and, above all, psychological nature. Dandruff, greasy or dry hair, and loss of hair, are among the common problems of everyday life.

However, hair may help in solving a number of problems faced by a person through his lifetime. Here we shall try to contribute to such an approach by a critical analysis and presentation of collected knowledge on human hair.

Examining blood and urine provides immense insight into human diseases. It is natural to hope that the examination of hair would be added to these examinations routinely. Hair analysis appears to offer a unique approach to the investigation of human trace-element nutrition and metabolism. There is a possibility that the trace-element content of hair correlates with body stores. Analyses of feces and urine are of limited value as indicators of stores, and blood has restricted use, because the hemostatic mechanism operates to keep many of the components of blood constant. Human head hair is a recording filament which can reflect metabolic changes of many elements over a long period of time, and thus reflects past nutritional events. The idea of hair analysis is very inviting, because hair is easily sampled, shipped, and analyzed. Furthermore, concentrations of most of the trace elements in scalp-hair are an order of magnitude higher than those in body fluids or other easily accessible tissues.

Correlations between trace-element levels in blood and hair are severely confounded if the hair sample is not collected close to the scalp so as to reflect the current metabolic status. Many of the reported studies are characterized by sampling errors, improper sample preparation, and faulty statistical treatment. Without controlling for sample distance from the scalp, these studies showed great variance in hair trace-element levels and very poor correlation with circulating trace-element levels. Samples taken some length from the scalp do not reflect the current metabolic status.

Different analytical methods have been used in trace-element analysis of human hair. Some of them even allow the measurements of radial and longitudinal concentration profiles in single hairs. Results of such experiments distinguish between different processes contributing to hair trace-element levels and allow the use of human hair as a diagnostic tool in the assessment of body stores and metabolic changes.

THE AUTHOR

Vlado Valković, Ph.D., is a Professor of Physics at the Rugjer Bošković Institute, Zagreb, Croatia, Yugoslavia. He is the founder and present head of the Laboratory for Nuclear Microanalysis. He is also an adjucant professor of physics at Rice University, Houston, Texas.

Dr. Valković graduated in 1961 from the University of Zagreb, with a B.A. degree in experimental physics, obtained his M.A. degree in nuclear physics in 1963, and his Ph.D. degree in 1964. The thesis title was "Nuclear Reactions with 14.4 MeV Neutrons on Light Elements."

Dr. Valković has been associated with two institutions during his professional career — one in the U.S. and one in Yugoslavia. The institutions are the Rugjer Bošković Institute in Zagreb and the T. W. Bonner Nuclear Laboratories at Rice University, Houston, Texas.

Dr. Valković is a fellow of the American Physical Society, a member of the European Physical Society, Yugoslav Physical Society (Croatian section), Society for Environmental Geochemistry and Health, and other professional and honorary organizations.

His research has been done on both sides of the Atlantic: in the U.S. as well as in a number of laboratories in Europe.

Dr. Valković has published more than 200 research papers on nuclear physics and applications of nuclear techniques to the problems in biology, medicine, environmental research, and trace-element analysis. He is also the author of the following books: *Trace Element Analysis* (Taylor and Francis, London, 1975), *Nuclear Microanalysis* (Garland, New York, 1977), *Trace Elements in Human Hair* (Garland, New York, 1977), *Trace Elements in Petroleum* (Petroleum Publishing, Tulsa, 1978), *Analysis of Biological Material for Trace Elements Using X-Ray Spectroscopy* (CRC Press, 1980), and *Trace Elements in Coal* (CRC Press, 1983). His current major research interests include the study of the role and movements of the elements in nature.

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Chapter 1

INTRODUCTION

Hair, the unique integumentary structure of mammals, has protective, sensory, and heat-regulatory functions.[1-11] It is also likely that hair functions in the control of water transfer. Hair in animals occurs in all gradations from a covering of downlike fur to an armor of coarse, heavy spines.

Human beings are relatively hairless when compared with other living beings. Darwin suggested that the relative hairiness of man came about from the preferential selection of females with less ventral hair (and, therefore, greater sexual stimulus values).

In the amount of hair and the number of morphological types of hair, man differs from all other animals, including primates. Even in man, racial differences in the form, distribution, and development of hair are great. It is not surprising, therefore, that most racial taxonomies have used hair form and distribution, and some classifications have made hair the principal criterion of race.

Human hair has received much attention through the history of mankind. For example, in Japanese history, the hair of a woman has been regarded as of secondary importance only to her life. Her hair is regarded not only as a ''pars pro toto'' but also as the place wherein lies her spirit. Many stories linking the spirit of a woman to her hair has been transmitted from generation to generation.

Another example is the treatment of bones, hair, and teeth as objects of worship in Buddhism. After his death, the body of Buddha was cremated and the ashes were divided into eight parts, each of which was kept in a pagoda in eight different countries. Subsequently, three more pagodas were built, one of which is called the hair pagoda. The tradition of Japanese respect for hair can be traced from this Buddhist influence.

In Buddhism, one of the rituals is the shaving off of hair. According to the religious dictionary, hair signifies sexual desire and sexual potency; shaving the head, therefore, signifies the quenching of sexual desire. It represents spiritual castration and stands as a symbol of abnegation to those who live a strictly religious and ascetic life.

Since human concern about hair centers on scalp hair, we inevitably must give some consideration to baldness. Though best exemplified in man, baldness is not uniquely human. A number of nonhuman primates predictably become bald. Most adult, aging chimpanzees display degrees of baldness, and all orangutans are partially bald.

Although head hair has received the most attention, other types of hair are also of importance, e.g., the relation between pubic hair development and maturation. Some types of hair are not developed in humans such as sensory hairs of which only vestiges remain in man. Knowledge of the different types of hair in man is of use to the comparative anatomist, to the medicolegal experts, to the plastic surgeons, to the endocrinologists — to mention only some of the professions.

Most human hair, except that of the scalp, affords no protection against the elements, and the fact that the world is full of bald and semibald men who have managed to survive shows that even scalp hair cannot be regarded as indispensable. However, man is perennially preoccupied with his relatively nonessential scalp hair and totally indifferent about those hairs that do have survival value. For example, the main function of eyebrows, commonly regarded as ornaments that provide a means of expressing and communicating emotion, is to prevent briny sweat from trickling into the eyes and to keep extraneous particles from injuring the eyes. Eyelashes protect the eyes from sunlight; people who lose them have constantly swollen-bloodshot eyes. Nasal hairs retard the flow of inspired air and thus cool or warm it before it reaches the respiratory tract, keep mucous from flowing over the upper lip, and trap dust particles and insects. All hairs, whether large or infinitesimally small,

provide nearly all of the modalities of tactile sensibility since they are abundantly supplied with sensory nerve receptors.

Hair is the unique biological material which, because of its growth, reflects the biomedical and environmental history of the subject. Because of convenience in handling and sampling and relatively high concentrations of metals, trace-element analysis of human hair has been applied widely for different purposes. Being highly individualistic, hair drew particular attention in forensic applications connected with crime detection in order to match or identify the common origin of a hair specimen.

Hair may offer an answer to the nutrient regime of the body since it accumulates trace elements over a period of time and is relatively inert metabolically. The concentration in human hair may be a reliable index of the total body concentration, at least for some metals. Efforts to relate the trace-element content of human hair to some diseases that are known to influence trace elements in some other parts of the body produce different results; such investigations are still being done.

Pronounced differences in the trace-metal content of hair related to geographical locations as a result of environmental effects have been established. Some investigators even suggested that trace-element analysis of human hair could be used for geochemical reconnaissance of large areas for possible ores. Trace-element properties of human hair may be used in archeological investigations to trace human population movements from one region to the other and to understand the eating habits, diseases, etc., of different civilizations, which may influence the contents of trace elements in human hair.

Poisoning by heavy metals is accompanied by their buildup in the growing hair. For example, the detection of Pb in hair provides an additional means of confirming the diagnosis of chronic plumbism in children.

Several powerful analytical techniques have been developed for trace-element analysis of hair. Some require only small samples for the measurement of element distribution along hair. This allows many interesting studies since hair, because of its growth, reflects previous elemental concentrations in the body together with previous environmental influences.

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Chapter 2

HUMAN HAIR GROWTH

I. DISTRIBUTION AND CLASSIFICATION OF HAIR

According to Montagna,[1] hairs can be classified by size as overhairs, underhairs, or vellus hairs. Overhairs are usually long and sometimes coarse. Underhairs are soft and thin with somewhat uniform length, they are easily bent and often wavy, and they include the terminal hair of man, wool, and the fur of many other mammals. Vellus hairs are short, very fine, soft, silky, and usually unpigmented and unmedullated; they are found on many seemingly hairless areas of the human body such as the forehead, eyelids, bald scalp, and most of the areas erroneously referred to as glabrous.

However, two types of classifications are customary in the study of hair: morphological and hormonal. Morphological classification provides six types based on the hair location, pattern, and density. They are head hair, eyebrow and eyelash hair, beard and moustache hair, body hair, pubic hair, and axillary hair (see Table 1). Hormonal classification results in three types:[2]

1. Hair not dependent upon steroid hormones, but influenced by changes in growth, hormone output, and sometimes inhibited by androgenic hormone; e.g., the eyelashes, eyebrows, and some body hair
2. Hair dependent upon female amounts of steroid hormones; e.g., pubic and axillary hair
3. Hair dependent upon male amounts of steroid hormones; e.g., beard and moustache hair, nasaltip hair, ear hair, and body hair

Six morphological types of hair in man are shown in Table 1 together with their main characteristics. Sensory hair is similar to the common hair in that it is a morphologic unit, differing only in the degree of development of the individual components and in the presence of the connective tissue capsule.

Leaflike nerve endings are found in sensory hairs at the hair follicle and its base. Colloquially, this type of hair is known as a whisker; it may be larger and longer than the usual hair. Such hairs are found in all the lower animals and in the eyebrow of the gorilla, chimpanzee, and other primates. Man does not possess this structure.

Ear hair is usually present in the newborn, absent in the child and the young adult, and limited in later life to the male.

Hair follicles appear first on the eyebrows, upper lip, and chin in the second month of fetal life. General development appears about the fourth month. No new follicles appear after birth, and the follicles become more widely separated as the surface area increases. Investigations of hair direction in human embryos show that the hair inclination, in general, follows the course of the arteries.

The total number of hair follicles in an adult man is estimated to be about 5 million. Only about 1 million are found on the head, of which about 100,000 constitute scalp hair. A significant loss of hair follicles occurs with age.

Axillary hair is a secondary sex characteristic, as shown by the absence of hair until the time of sexual maturation, the failure of hair to grow in men who were castrated prior to puberty, and by the atrophy of hair following castration of adult men or at the time of oophorectomy of the menopause in women. Some factors that influence the growth of axillary hair are age, sex, inheritance, gonadal secretions, and responsiveness of the individual.

Table 1
MORPHOLOGICAL TYPES OF HAIR IN MAN

Type	Metric characteristics (normal range)	Description
Head hair	100—1000 mm in length, cross-section diameter from 25—125 mm	Relatively small root, tapered tip, and usually medullated; all variations in form known
Eyebrow and eyelash hair	Average length about 1 cm	Curved, coarse, smooth with punctate tip and large medulla
Beard and moustache hair	50—300 mm in length	Larger root than head hair, more complex medullary processes, more irregular structure, and blunter tip
Body hair	3—60 mm in length	Fine long tip, irregularly medullated, irregularities in structure, and may be banded or tipped; all forms and structural types
Pubic hair	10—60 mm in length	Coarse, irregular, and asymmetrical cross-section with many constrictions and twists and usually curved
Axillary hair	10—55 mm in length	Coarse, usually straighter than pubic hair

Table 2
BOYS HAVING HAIR IN VARIOUS AREAS OF THE BODY AT THREE AGE LEVELS(%)[a]

Area	Rank	14 Years	16 Years	18 Years	Distribution in 50 adults
Pubic	1	97	100	100	100
Axillary	2	40	97	100	100
Anterior leg	3	46	90	100	88
Posterior leg	4	38	77	95	78
Posterior thigh	5	35	70	95	86
Anterior thigh	6	30	67	95	86
Forearm	7	14	37	80	100
Abdomen	8	14	37	75	88
Buttocks	9	14	33	50	20
Chest	10	3	7	40	74
Lower back	11	3	7	20	33
Arms	12	0	0	10	24
Shoulders	13	0	0	0	9

[a] Number of cases: 14 years, 37; 16 years, 30; 18 years, 20.

From Reynolds, E. L., *Ann. N.Y. Acad. Sci.*, 53, 476, 1951.

From time to time, each factor may reflect seasonal fluctuations. Growth of this secondary sex characteristic in normal people results chiefly from gonadal secretions. Studies on eunuchs indicate that the secretions of the adrenal cortex and the steroids produced by organs other than the testes do not exert a significant effect upon growth of axillary hair.

There are wide individual variations, both in time of appearance and in patterning, of terminal body hair in man. Definitive body hair usually appears at puberty or before and may continue throughout life. The percentage of boys having hair in various areas of the body and the approximate ranking in order of appearance is shown in Table 2.[3]

Table 3
MORPHOLOGICAL CHARACTERISTICS OF HAIR[4]

Body region	Approximate number of hair follicles (per cm^2)	Approximate number of visible hairs	Length (mm)	Width (μm)
Head				
Scalp	350	200—300/cm^2; total: 90,000—140,000	Few—1.5 m	25—125
Eyebrows		600 in each	7—16	80
Eyelashes				
Upper	145	140—150	8—12	43—66
Lower	455	55—75	6—8	43—66
Face (average)	700			
Beard	520	30—40/cm^2	50—300	150
Trunk				
Chest, back, and abdomen	65—75	1/cm^2	3—60	
Axilla	65	m: 1200—1400 f: 700—900	10—50	80
Perineal	m: 60	m: 20—35 f: 30—40	10—60	90—110
Limbs				
Lower	45—60		3—60	
Upper	45—95	13/cm^2	3—60	

Hairs in a given body area differ not only in length, texture, and color, but also in diameter and shape. Hairs can be oval or round, or so flattened as to resemble ribbons. For example, ribbonlike (kinky) hairs are twisted along the longitudinal axis and give the impression of great changes in diameter, which actually remains the same. As another example, the diameter of human scalp hair increases rapidly and uniformly during the first 3 or 4 years after birth, less rapidly during the next 6 years, and scarcely at all from 12 years on. Beard and other body hairs do not attain full growth until middle age. Morphological and growth characteristics of hair in different body areas are summarized in Table 3.

Parents with a considerable amount of body hair are more likely to have children whose body hair appears early and luxuriously. Abnormal hair growth, particularly in the female, is called hirsutism. Hirsutism is seldom, if ever, a problem in the male. A possible exception to this statement is that of the so-called ''dog man'', a rare entity with some degree of familial occurrence, affecting both males and females, in which heavy vellus hair covers the entire body including the face. Permanent hirsutism may accompany a number of organic diseases, the most common being dysfunctions of the adrenal cortex, anterior pituitary gland, and ovary. For the majority of patients with hirsutism, the causes are uncertain or unknown. It seems that hereditary factors are the most important. Some authors are inclined to believe that the condition is constitutional in origin and that affected subjects represent extreme variants from normal biological ranges.

It is somewhat surprising to learn that about 30% of women had hypertrichosis to some degree. To some this is a matter of little concern, but the more severe cases represent a real problem.

Obviously the weight of hair on the head is partly a matter of the endowment of the individual and — if suitably endowed — may vary with the trends of fashion or taste. Vierordt[5] has suggested 300 g for the weight of scalp hair of an adult female, and this would probably represent a rather full head of hair. No value has been found for the male, but 20-g weight might represent a male with a full, but not extra long, head of hair. No allowance is made for sideburns or for a beard.

The weight of hair for reference in the adult male = 20 g and in the female = 300 g.

The newborn is covered with lanugo or primary hair except for palms, soles, eyelids, nipples, lips, and the distal phalanges of the fingers and toes.[6,7] The hair length is 0.1 to 10 mm and its basal width is 27 μm. The duration of its cycle is 2 months.[7]

The scalp hair begins to grow before birth. At the time of birth the average hair length in the male is about 2.4 cm and in the female about 2.6 cm.[7] The growth rate in the newborn is about 0.2 mm/24 hr but later increases to 0.3 to 5 mm/24 hr.[6]

Axillary and pubic hair begin to appear at approximately 10 years of age in the female and 12 to 15 years of age in the male. The order of appearance is mons pubis, scrotum, axillary, and beard.[6]

The total life span of a hair (including the period of growth and of quiescence before shedding) differs according to the region of the body and the type of hair. For example, eyebrows, eyelashes, and axillary hair have a life span of 3 to 4 months, but the hair of the scalp has a life span of 4 years (see Table 3 for more details).

The number of scalp hairs per square centimeter in children (3 to 9 years) is[8]

- Boys (N = 7); mean = 199; SD = ± 14.1
- Girls (N = 13); mean = 185; SD = ± 9.5
- Both sexes (N = 20); mean = 192; SD = ± 12.3

For adults, the number of hairs per square centimeter varies from 40 to 880 depending on the region of the body.[9] Detailed data are presented in Table 3.[4] For more discussion on this topic see References 10 to 14.

II. RATE OF HAIR GROWTH

Waves of hair growth occur in several mammals. In man the hair follicle passes at intervals through a life cycle divided into three phases: (1) anagen, the phase of active hair growth, (2) a short transitional phase known as categen followed by (3) a resting phase, telogen.[15-29]

In man anagen lasts 3 years or more; catagen, 1 or 2 weeks; and telogen, 3 to 4 months. Therefore, 88% of the hairs are in the anagen phase, 11% in the telogen phase, while only about 1% are in the catagen phase at a given time. This ratio is found when human scalp hair is plucked and examined.

The human scalp has approximately 100,000 hairs; slightly more for blondes and less for redheads. Since 11% or approximately 10,000 hairs are in the telogen phase for approximately 100 days, this would produce an average daily shedding of 100 hairs.

A study of hair loss in subjects living in the North Temperature Zone[30] showed a weekly average loss of 1000 hairs weighing 500 mg. The 1-year graph shows three cyclic peaks with the maximum loss in November. This study was performed in the North Temperature Zone where a seasonal difference of 30% exists between the minimum of 11 and the maximum of 15 hr of daylight. The average mean temperature in this zone ranges from 14°C in the winter to 28°C in the summer. Either or both of these seasonal variations may be the cause of maximum defluvium in the month of November.

At the equator, where the photoperiodicity is static, there is no annual effect on the hair growth cycle. The rate of hair growth in man varies from 0.1 to 0.4 mm/day depending on its location (see Table 4). Experimental data on regional differences in hair growth by Saitoh et al.[21] are shown in Figure 1. Additional data on hair growth can be found in the *Handbook of Biological Data*.[31]

The rate of growth of hairs on the scalp is faster in females than in males, even in the supraear region, which is not subject to baldness. In the axilla, the daily growth rate of hairs is more rapid in males than in females. This establishes sex as a factor in the rate of hair growth.

Table 4
RATE OF GROWTH IN HAIR

Type of hair (location)	Rate of growth (mm/day)
Chin	0.38
Crown of scalp	0.35
Axilla	0.30
Thigh	0.20
Eyebrow	0.16
Chest	0.40
Beard	0.27
Vertex	0.44

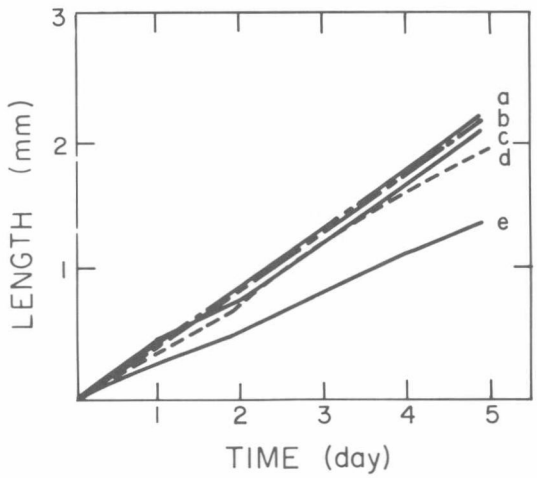

FIGURE 1. Regional differences in hair growth: (a) vertex hair, female, 0.45 mm/day; (b) vertex hair, male, 0.44 mm/day; (c) chest hair, 0.40 mm/day; (d) temporal hair, 0.39 mm/day; and (e) beard, 0.27 mm/day. (From Saitoh, M., Uzuka, M., Sakamoto, M., and Kobori, T., *Hair Growth*, (Advances in Biology of Skin Ser., Vol. 9), Montagna, W. and Dobson, R. L., Eds., Pergamon Press, Oxford, 1969, 183.)

The studies of the diameter and the average daily growth rate for different age groups (four groups: 40 to 49, 50 to 59, 60 to 69, and 70 to 79 years) as reported by Pelfini et al.[29] showed:

1. The average daily growth rate of the hairs in the four groups is different. The rate of growth in the intermediate groups (50 to 59 years = 0.36 mm/day and 60 to 69 years = 0.38 mm/day) was greater than that of the other two groups.
2. Average daily growth rates are in agreement with the results shown in Table 4.
3. There are significant differences in diameter when the hairs from various areas were compared. Pubic hair has the largest diameter (81 μm), then in decreasing order are axilla (64 μm), scalp, and thigh (62 μm) hairs.

Other studies indicate that the daily growth rate of leg hairs increases with advancing age in the 17- to 45-year period. The axillary and pubic hairs show the opposite trend — their daily growth rate decreases with advancing age.