Biological and Medical Physics, Biomedical Engineering

Biophysics of Human Hair

Structural, Nanomechanical, and Nanotribological Studies

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Chapter 1
Introduction—Human Hair, Skin, and Hair Care Products

This book presents the biophysics of human hair and hair treatment. It deals with the structure of hair, the nanomechanical characterization, nanotribological characterization, the conditioner thickness distribution and binding interactions on hair surface, and surface potential studies. It is the first book on the biophysical properties of hair.

1.1 Human Hair

Figure 1.1a shows a schematic of a human hair fiber with its various layers of cellular structure (Feughelman, 1997; Negri et al., 1993; Robbins, 1994; Zviak, 1986; Jollès et al., 1997; Smith and Swift, 2002). Hair fibers (about 50–100 μm in diameter) consist of the cuticle and cortex, and in some cases medulla in the central region. All are composed of dead cells which are mainly filled with keratin protein. Table 1.1 displays a summary of the chemical species of hair (Chen and Bhushan, 2005). Depending on its moisture content, human hair consists of approximately 65–95% keratin proteins, and the remaining constituents are water, lipids (structural and free), pigment, and trace elements. Proteins are made up of long chains of various mixtures of some 20 or 50 amino acids. Each chain takes up a helical or coiled form. Among numerous amino acids in human hair, cystine is one of the most important amino acids. Every cystine unit contains two cysteine amino acids in different chains which lie near to each other and are linked together by two sulfur atoms, forming a very strong bond known as a disulfide linkage; see Fig. 1.1b (Gray, 2003). In addition to disulfide bonds, hair is also rich in peptide bonds, and the abundant CO- and NH-groups present give rise to hydrogen bonds between groups of neighboring chain molecules. The distinct cystine content of various cellular structures of human hair results in a significant effect on their physical properties. A high cystine content corresponds to rich disulfide cross-links, leading to high mechanical properties. The species responsible for color in hair is the pigment melanin, which is located in the cortex of the hair in granular form.

An average head contains over 100,000 hair follicles, which are the cavities in the skin surface from which hair fibers grow. Each follicle grows about 20 new hair

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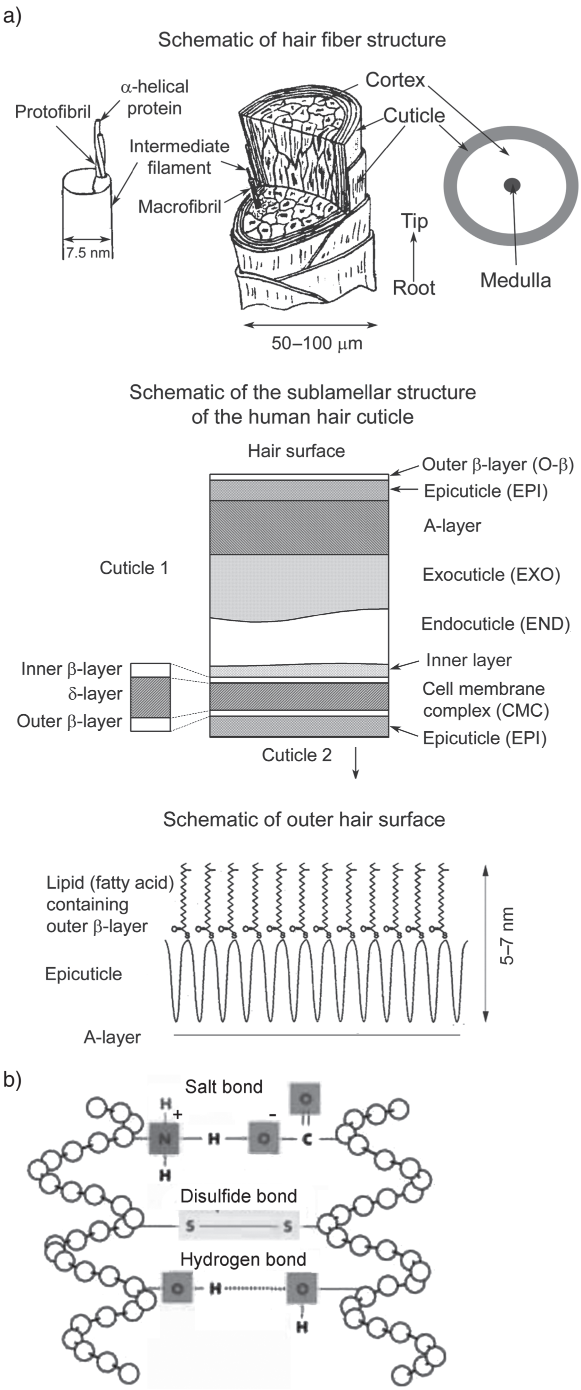
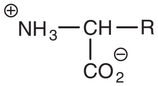
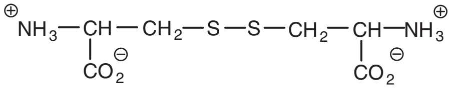
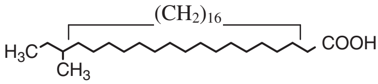


Fig. 1.1 (**a**) Schematic of hair fiber structure and cuticle sublamellar structure (Robbins, 1994; Smith and Swift, 2002) and (**b**) various bonds within hair cellular structure (Bhushan and Chen, 2006; Gray, 2003)

Table 1.1 Summary of chemical species present in human hair

Keratin protein	65–95%
(Amino acids)	 (R: functional group)
Cystine	
Lipids	Structural and free
18-Methyl eicosanoic acid (18-MEA)	
Water	Up to 30%
Pigment and trace elements	Melanin

fibers in a lifetime. Each fiber grows for several years until it falls out and is replaced by a new fiber. Hair typically grows at a rate on the order of 10 mm/month.

1.1.1 The Cuticle

The cuticle consists of flat overlapping cells (scales). The cuticle cells are attached at the root end, and they point toward the tip end of the hair fiber, like tiles on a roof. Each cuticle cell is approximately 0.3–0.5 μm thick, and the visible length of each cuticle cell is approximately 5–10 μm. The cuticle in human hair is generally 5–10 scales thick. Each cuticle cell consists of various sublamellar layers (the epicuticle, the A-layer, the exocuticle, the endocuticle, and the inner layer) and the cell membrane complex (see Fig. 1.1a). Table 1.2 displays the various layers of the cuticle, their respective cystine levels (Robbins, 1994), and other details. The outer epicuticle layer is covered with a thin layer of covalently attached lipid (fatty acid), predominantly 18-methyl eicosanoic acid (18-MEA) (see Table 1.1). This layer constitutes the outer β-layer of the cuticular cell membrane complex, which acts as a boundary lubricant, responsible for low friction and provides a hydrophobic surface. The A-layer is a component of high cystine content (∼30%) and located on the outer-facing aspect of each cell. The A-layer is highly cross-linked which gives this layer considerable mechanical toughness and chemical resilience, and the swelling in water is presumed to be minimal. The exocuticle, which is immediately adjacent to the A-layer, is also of high cystine content (∼15%). On the inner-facing aspect of each cuticle cell is a thin layer of material which is known as the inner layer. Between the exocuticle and the inner layer is the endocuticle which is low in cystine (∼3%). The cell membrane complex (CMC) itself is a lamellar structure,

Table 1.2 Various layers of the cuticle and their details

Cuticle layer	Cystine component	Details
Epicuticle	~12%	18-MEA lipid layer attached to outer epicuticle contributes to lubricity of the hair
A-layer	~30%	Highly cross-linked
Exocuticle	~15%	Mechanically tough Chemically resilient
Endocuticle	~3%	
Inner layer	–	
Cell membrane complex (CMC)	~2%	Lamellar structure Consists of inner β-layer, δ-layer, and outer β-layer

which consists of the inner β-layer, the δ-layer, and the outer β-layer. The outer β-layer of the CMC separates the cuticle cells from each other. Low cohesive forces are expected between the lipid-containing outer β-layer and the δ-layer of CMC, which provides a weak bond. It may result in cuticular delamination during mechanical wear, with the potential advantage of revealing a fresh layer of 18-MEA to the newly exposed surface (Smith and Swift, 2002).

Figure 1.2 shows the SEM images of virgin Caucasian, Asian, and African hair (Wei et al., 2005). It can be seen that Asian hair is the thickest (about 100 μm), followed by African hair (about 80 μm) and Caucasian hair (about 50 μm). The visible cuticle cell is about 5–10 μm long for the three hairs. A listing of various cross-sectional dimensional properties is presented in Table 1.3 (Wei et al., 2005). While Caucasian and Asian hair typically have a similar cross-sectional shape (Asian hair being the most cylindrical), African hair has a highly elliptical shape. African hair is much more curly and wavy along the hair fiber axis than Caucasian or Asian hair.

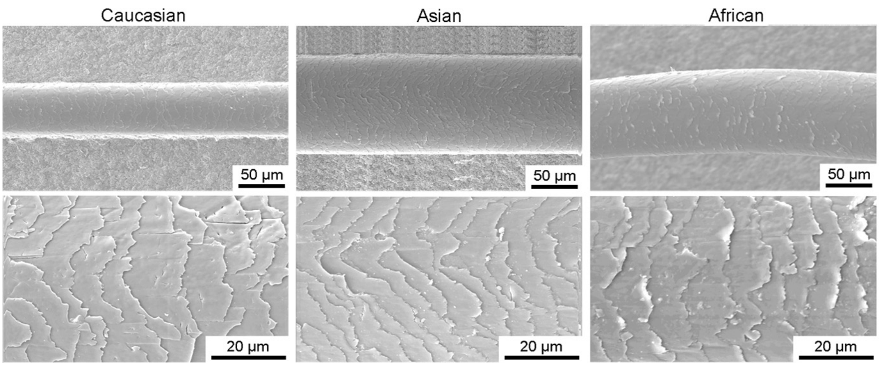


Fig. 1.2 SEM images of various hair (Wei et al., 2005)

Table 1.3 Variation in cross-sectional dimensions of human hair

	Shape	Maximum diameter (D_1) (μm)	Minimum diameter (D_2) (μm)	Ratio D_1/D_2	Number of cuticle scales	Cuticle scale thickness (μm)
Caucasian	Nearly oval	74	47	1.6	6–7	0.3–0.5
Asian	Nearly round	92	71	1.3	5–6	0.3–0.5
African	Oval-flat	89	44	2.0	6–7	0.3–0.5

Average length of visible cuticle scale: about 5–10 μm

Chemically, all ethnic hair is found to have similar protein structure and composition (Dekoi and Jedoi, 1988, 1990; Menkart et al., 1984; Nappe and Kermici, 1989). African hair has less moisture content than Caucasian hair. The shape (diameter, ellipticity, and curliness) of various ethnic hair depends on several factors, including the shape of the hair follicle and its opening; these vary from one person to another and also between races (Gray, 2003; Thibaut et al., 2005). The pronounced ellipsoidal cross section of the hair shaft in African hair could be caused by a heterogeneous and asymmetric fiber framework, in addition to internal mechanical stresses (Thibaut et al., 2005). Previously, it was thought that the elliptical cross section of hair is responsible for curl. While straight hair has circular cross sections (Asian and Caucasian), curly hair has a predominantly elliptical cross section (African). However, recent studies suggest that hair follicle shape and not the cross section is responsible for hair curl (Thibaut et al., 2005). This means that if the follicle is straight, even an elliptical cross section could give rise to straight hair. Both in vitro growth studies and computer-aided 3D reconstruction (Lindelof et al., 1988) support this claim. Curvature of the curly hair is programmed from the basal area of the follicle. This bending process is apparently linked to a lack of symmetry in the lower part of the bulb, affecting the hair shaft cuticle.

Figure 1.3 shows the SEM images of virgin Caucasian hair at three locations: near scalp, middle, and near tip. Three magnifications were used to show the significant differences. The hair near the scalp had complete cuticles, while no cuticles were found on the hair near the tip. This may be because the hair near the tip experienced more mechanical damage during its life than the hair near the scalp. The hair in the middle experienced intermediate damage, i.e., one or more scales of the cuticles were worn away, but many cuticles stayed complete. If some substructures of one cuticle scale, like A-layer or A-layer and exocuticle (see Fig. 1.1a), are gone, or even worse, one or several cuticle scales are worn away, it is impossible to heal the hair biologically, because hair fibers are composed of dead cells. However, it is possible to physically "repair" the damaged hair by using conditioner, one of whose functions is to cover or fill the damaged area of the cuticles. Figure 1.4 shows the high-magnification SEM images of virgin and treated Caucasian hair. The endocuticles (indicated by arrows) were found in both hair. In order for the conditioner to physically repair the hair, it is expected for it to cover the endocuticles. In the case of severely damaged hair, for example, an edge of one whole cuticle scale worn

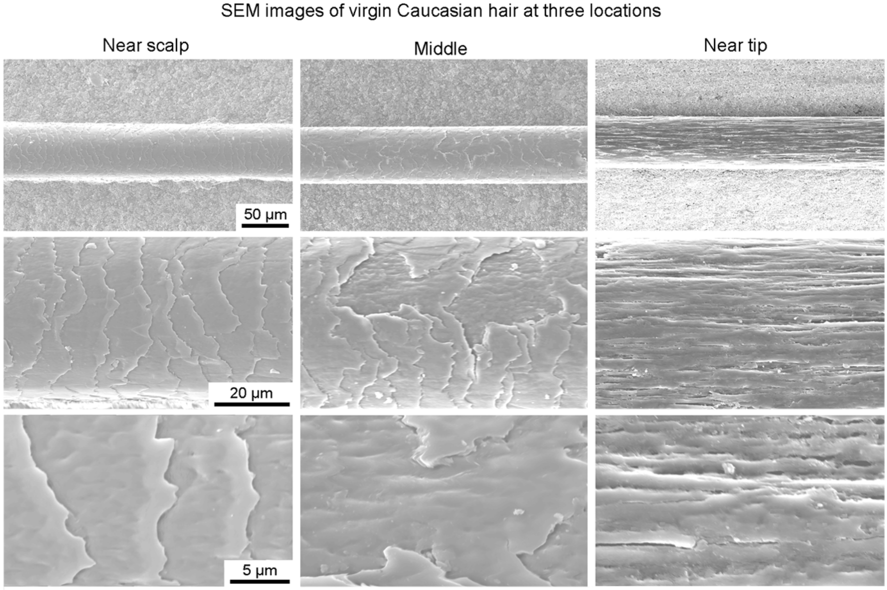


Fig. 1.3 SEM images of virgin Caucasian hair at three locations (Wei et al., 2005)

away, the conditioner may fill that damaged edge. In the SEM image of the treated hair in Fig. 1.4, the substance which stayed near the cuticle edge is probably the conditioner (indicated by an arrow).

Figure 1.5 shows the AFM images of various virgin hair, along with the section plots (LaTorre and Bhushan, 2005a). The arrows point to the position where the section plots were taken from. Each cuticle cell is nearly parallel to the underlying cuticle cell, and they all have similar angles to the hair axis, forming a tile-like hair surface structure. The visible cuticle cell is approximately 0.3–0.5 μm thick and about 5–10 μm long for all three hairs.

1.1.2 The Cortex and Medulla

The cortex contains cortical cells and the intercellular binding material, or the cell membrane complex. The cortical cells are generally 1–6 μm thick and 100 μm long, which run longitudinally along the hair fiber axis and take up the majority of the inner hair fiber composition (Randebrook, 1964). The macrofibrils (about 0.1–0.4 μm in diameter) comprise a major portion of the cortical cells. Each macrofibril consists of intermediate filaments (about 7.5 nm in diameter), previously called microfibrils, and the matrix. The intermediate filaments are low in cystine (∼6%), and the matrix is rich in cystine (∼21%). The cell membrane complex consists of cell membranes and adhesive material that binds the cuticle and cortical cells together. The intercellular cement of the cell membrane complex is primarily

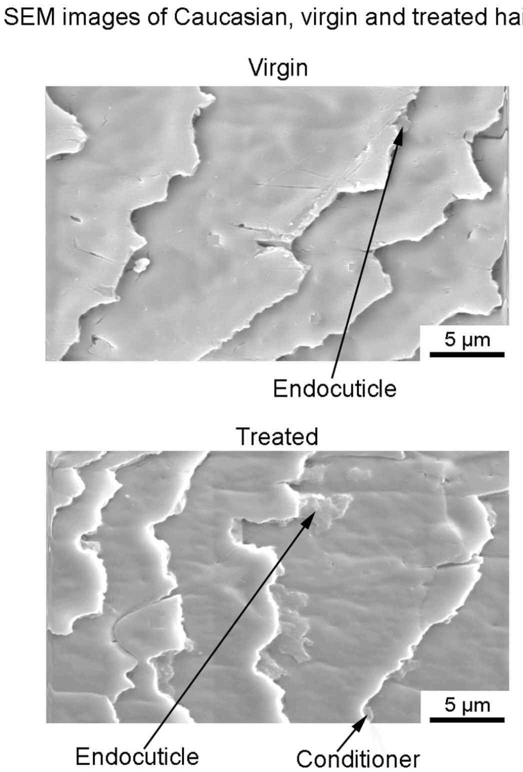


Fig. 1.4 SEM images of Caucasian, virgin and treated hair (Wei et al., 2005)

non-keratinous protein and is low in cystine content (∼2%). The medulla of human hair, if present, generally makes up only a small percentage of the mass of the whole hair and is believed to contribute negligibly to the mechanical properties of human hair fibers.

Figure 1.6a shows the SEM images of virgin hair cross section (Wei et al., 2005) and Fig. 1.6b shows the TEM images of a cross section of human hair (Swift, 1997).

1.2 Skin

Skin covers and protects our bodies. The skin at the forehead and scalp areas are of most interest when dealing with human hair, since most hair care products are developed specifically for head hair. The skin of the hand and fingers is also of importance because the "feel" of hair is often sensed by physically touching the fibers with these regions. In general, skin is composed of three main parts: epidermis, dermis, and subcutaneous tissue; see Fig. 1.7. The subcutis lies under the dermis and consists

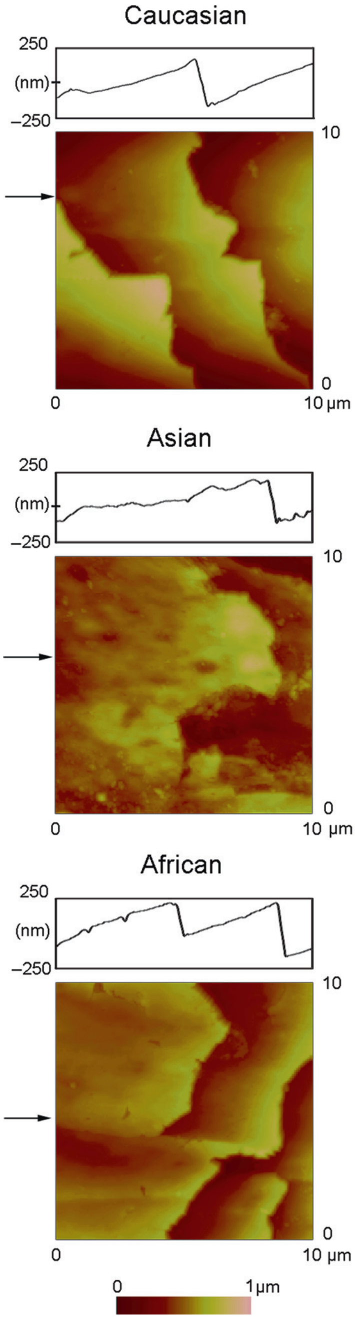


Fig. 1.5 AFM images of various virgin hair (LaTorre and Bhushan, 2005a)

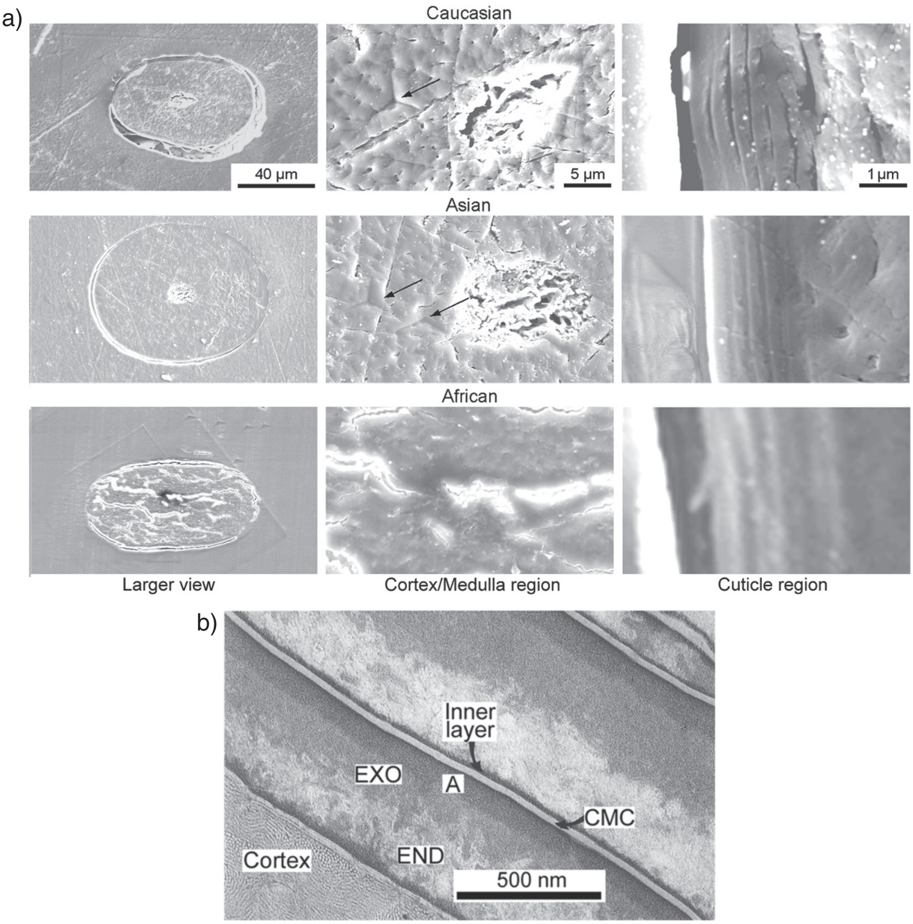


Fig. 1.6 (**a**) SEM images of virgin hair cross section (Wei et al., 2005); (**b**) TEM of hair cross section (in the figure EXO, END, and CMC stand for exocuticle, endocuticle, and cell membrane complex, respectively) (Swift, 1997)

of adipose tissue or fat cells with collagen partition. The dermis lies below the epidermis and supports it structurally and nutritionally. It contains blood vessels, nerves, hair follicles, arrector pili muscle, sweat glands, and sebaceous glands. The epidermis is the outer layer of the skin. It contains four distinct cellular layers: basal layer, spinous layer, granular layer, and keratin layer. Cells proliferate in the basal layer of the epidermis. Upon leaving the basal layer, cells start to differentiate and migrate upward through the spinous layer and granular layer, finally reaching the keratin layer, from which they are shed. The keratin layer is about 10–20 μm thick and is composed of 10–15 layers of anuclear, keratin-rich corneocytes imbedded in an extracellular lipid matrix (Lodén and Maibach, 2000; Shai et al., 2001). It is the keratin layer which comes in contact with cosmetic products, fabric, and other surfaces. It serves as a penetration, dehydration, and protection barrier against various environmental hazards. Water is a crucial factor to keratin layer barrier function and structure (Leyden and Rawlings, 2002). In soft and flexible skin, the water content of the keratin layer is between 10 and 30% (Elsner et al., 1994). If insufficient water remains in the keratin layer, it leads to epidermal hyperplasia, mast cell degranulation, and cytokine secretion. These issues are considered to be harmful to the requirement for healthy and desirable skin.

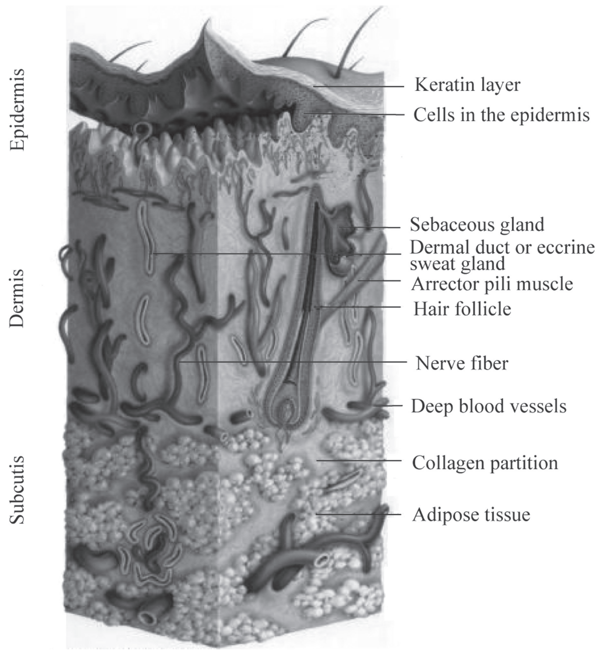


Fig. 1.7 Schematic image of human skin structure with different layers: subcutis, dermis, and epidermis (Shai et al., 2001)

1.3 Hair Care: Cleaning and Conditioning Treatments, and Damaging Processes

Everybody wants beautiful, healthy hair and skin. For most people, grooming and maintenance of hair and skin is a daily process. The demand for products that improve the look and feel of these surfaces has created a huge industry. Beauty care technology has advanced the cleaning, protection, and restoration of desirable hair properties by altering the hair surface. For many years, especially in the second half of the twentieth century, scientists have focused on the physical and chemical properties of hair to consistently develop products which alter the health, feel, shine, color, softness, and overall aesthetics of hair. Hair care products such as shampoos and conditioners aid the maintenance and grooming process. Shampoos clean the hair and skin oils, and conditioners repair hair damage and make the hair easier to comb; prevent flyaway; and add feel, shine, and softness. Mechanical processes such as combing, cutting, and blowdrying serve to style the hair. Chemical products and processes such as chemical dyes, colorants, bleaches, and permanent wave treatments enhance the appearance and hue of the hair. Of particular interest is how all these common hair care items deposit onto hair and change its properties, since these properties are closely tied to product performance. The fact that companies like Procter & Gamble, L'Oreal, and Unilever have hair care product sales consistently measured in billions of US dollars (http://www.pg.com; http://www.loreal.com; http://unilever.com) suggests that understanding the science behind human hair has more than just purely academic benefits, as well.

While products and processes such as combing, chemical dyeing, and permanent wave treatment are used to enhance appearance and style of the hair, they also contribute a large amount of chemical and mechanical damage to the fibers, which leads to the degradation of structure and mechanical properties. As a result, the fibers become weak and more susceptible to breakage after time, which is undesirable for healthy hair. Shampoos and conditioners which typically serve cleaning and repairing functions to the hair surface, respectively, have a distinct effect on mechanical properties as well.

The tribology of the hair also changes as a function of the various hair care products and processes. Figure 1.8 illustrates schematically various functions, along with the macro- and micro/nanoscale mechanisms behind these interactions that make surface roughness, friction, and adhesion very important to hair and skin (LaTorre and Bhushan, 2005a). Desired features and corresponding tribological attributes of conditioners are listed in Table 1.4 (LaTorre et al., 2006). For a smooth, wet and dry feel, friction between hair and skin should be minimized in wet and dry environments, respectively. For a good feel with respect to bouncing and shaking of the hair during walking or running, friction between hair fibers and groups of hair fibers should be low. The friction one feels during combing is a result of interactions between hair and the comb material (generally a plastic), and this too needs to be low to easily maintain, sculpt, and comb the hair. To minimize entanglement, adhesive force (the force required to separate the hair fibers) needs to be low. In other cases, a certain level of adhesion may be acceptable and is often a function of the hair style. For individuals seeking "hair alignment," where hair fibers lay flat and parallel to each other, a small amount of adhesive force between fibers may be desired. For more complex and curly styles, even higher adhesion between fibers may be optimal.

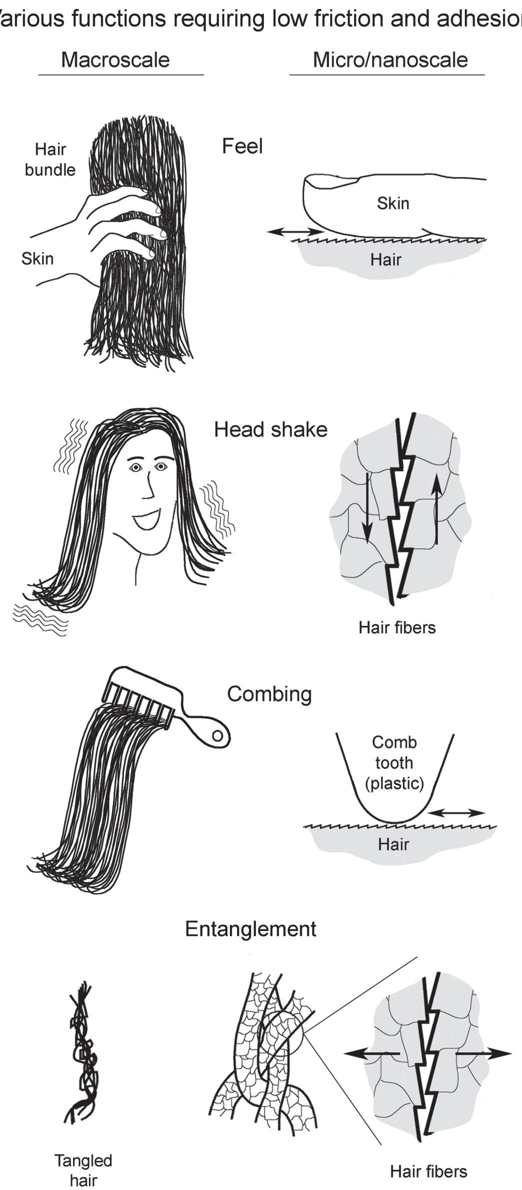


Fig. 1.8 Schematics illustrating various functions with associated macroscale and micro/nanoscale mechanisms of hair and skin friction during feel or touch, shaking and bouncing of the hair, combing, and entanglement (LaTorre and Bhushan, 2005a)

Table 1.4 Desired features and corresponding tribological attributes of conditioners

Desired hair feature	Tribological attributes
Smooth feel in wet and dry environments	Low friction between hair and skin in respective environment
Shaking and bouncing during daily activities	Low friction between hair fibers and groups of hair
Easy combing and styling	Low friction between hair and comb (plastic) and low adhesion. Note: More complex styles may require higher adhesion between fibers

1.3.1 Cleaning and Conditioning Treatments: Shampoo and Conditioner

Shampoos are used primarily to clean the hair and scalp of dirt and other greasy residue that can build up after time. Shampoos also have many secondary functions including controlling dandruff, reducing irritation, and even conditioning. Conditioners, on the other hand, are used primarily to give the hair a soft, smooth feel which results in easier hair combing. Secondary functions include preventing "fly-away" hair due to static electricity, giving the hair a shiny appearance, and protecting the hair from further damage by forming a thin coating over the fibers.

Further developments in marketing and aesthetic factors (brand name, fragrance, feel, and color of the shampoos and conditioners) have created new market segments. In many instances, these factors have become primary reasons for use.

1.3.1.1 Shampoo: Constitution and Main Functions

The following discussion is based on Gray (2001, 2003). As stated above, shampoos serve various cleaning functions for the hair and scalp. In the past, typical shampoos were mainly soap-based products. However, soaps did not have very good lathering capability and often left a residual "scum" layer on the hair that was undesirable and could not be rinsed off.

In modern shampoos, advances in chemistry and technology have made it possible to replace the soap bases with complex formulas of cleansing agents, conditioning agents, functional additives, preservatives, aesthetic additives, and even medically active ingredients. Clarifying shampoo (with no conditioner), typically used for full volume with lot of air between hair, is transparent. The pH value is typically 5–6. Table 1.5 shows the most common ingredients of shampoos and their functions.

Cleansing agents: In most modern shampoos, the primary cleansing agents are anionic surfactants which are known to be good in cleaning. Dirt and greasy residue are removed from the hair and scalp by these surfactants, making them the most important part of the shampoo. Surfactants have great lathering capabilities and rinse off very easily; see Table 1.5 for a full list of features.

Table 1.5 Components of common shampoos and their functions

Shampoo component	Functions
Cleansing agents	– Produce lather to trap greasy matter and prevent re-deposition – Remove dirt and grease from hair and scalp – Stabilize the mixture and help keep the ingredient network together – Thicken the shampoo to the desired viscosity
Conditioning agents	Condition the hair
Functional additives	Control the viscosity and pH levels of the shampoo
Preservatives	Prevent decomposition and contamination of shampoo
Aesthetic additives	Enhance color, scent, and luminescence of shampoo
Medically active ingredients	Aid treatment of dandruff or hair loss

Surfactant molecules have two different ends, one which is negatively charged and soluble in water (unable to mix with greasy matter) and another which is soluble in greasy matter (unable to mix with water). In general, surfactants clean the hair by the following process: Surfactant molecules encircle the greasy matter on the hair surface. The molecule end which is soluble in greasy matter buries itself in the grease, which leaves the water-soluble molecule end to face outward with a negative charge. Since the hair fibers are negatively charged as well, the two negative charges repel each other. Thus, the greasy matter is easily removed from the hair surface and rinsed off.

Shampoos contain several surfactants, generally up to four, which clean the hair differently depending on the hair type of the individual. Mild cleansing systems, which do not damage or irritate the scalp, hair, and eyes, are now quite common.

Conditioning agents: Many shampoos contain conditioning agents which serve many of the same roles as full conditioners. Conditioning agents are further described in the following subsection.

Functional additives: Functional additives can aid in controlling the thickness and feel of the shampoo itself. Simply stated, the right blend is required so that the shampoo is not too thin and not too thick. Functional additives can also control the acidity of the shampoo by obtaining a goal pH level, typically around a value of 4.

Preservatives: Preservatives resist germs and prevent decomposition of the shampoos. They also prevent various other health risks that accompany contamination by germs and bacteria. Typical preservatives in shampoos are sodium benzoate, parabens, 1,3-dimethylol-5,5-dimethyl (DMDM) hydantoin, and tetrasodium ethylenediamine tetraacetic acid (EDTA).

Aesthetic additives: Shampoos contain many aesthetic additives which enhance the appearance, color, and smell of the mixture. These additives typically give the shampoo the luminous shine and pleasant fragrance to which many consumers are accustomed.

Medically active ingredients: For people with dandruff and other more serious hair and scalp disorders, shampoos are available with active ingredients which aim to treat or control these conditions. In the treatment of dandruff, zinc pyrithione is a common shampoo additive. For hair loss issues, panthenol is commonly added to shampoos to aid in hair growth and moisture content.

1.3.1.2 Conditioner: Constitution and Main Functions

As stated earlier, many shampoos have certain levels of conditioning agents which mimic the functions of a full conditioner product. Conditioner molecules contain cationic surfactants which give a positive electrical charge to the conditioner. The negative charge of the hair is attracted to the positively charged conditioner molecules, which results in conditioner deposition on the hair, see Fig. 1.9. This is especially true for damaged hair, since damaging processes result in hair fibers being even more negatively charged. The attraction of the conditioner to hair results in a reduction of static electricity on the fiber surfaces, and consequently a reduction in the "flyaway" behavior. The conditioner layer also flattens the cuticle scales against each other, which improves shine and color. The smooth feel resulting from conditioner use gives easier combing and detangling in both wet and dry conditions (see Table 1.4).

Conditioner consists of a gel network chassis (cationic surfactants, fatty alcohols, and water) for superior wet feel and a combination of conditioning actives (cationic surfactants, fatty alcohols, and silicones) for superior dry feel. Figure 1.10 shows the transformation of the cationic surfactants and fatty alcohol mixture into the resulting gel network, which is a frozen lamellar liquid crystal gel phase (Bhushan and Chen, 2006). The process starts as an emulsion of the surfactants and alcohols in water. The materials then go through a strictly controlled heating and cooling process: the application of heat causes the solid compounds to melt, and the solidification process enables a setting of the lamellar assembly molecules in a fully extended conformation, creating a lamellar gel network. When this network interacts with the

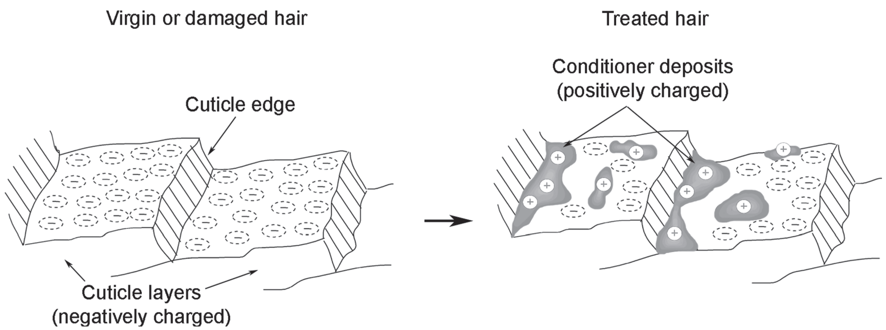


Fig. 1.9 Negatively charged hair and the deposition of positively charged conditioner on the cuticle surface (LaTorre et al., 2006)

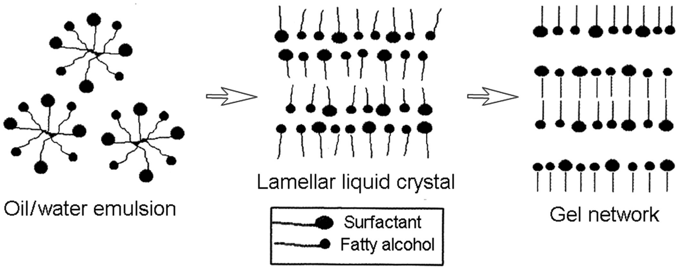


Fig. 1.10 Conditioner formation from emulsion to gel network (Bhushan and Chen, 2006)

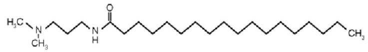
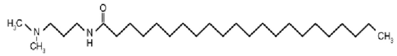
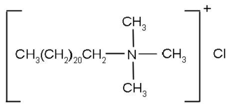
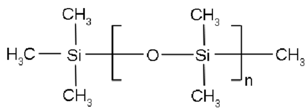
hair surface, the high concentration of fatty alcohols make it the most deposited ingredient group, followed by the silicones and cationic surfactants. Typical deposition levels for cationic surfactant, fatty alcohol, and silicone are around 500–800, 1000–2000, and 200 ppm, respectively. Typical concentrations are approximately 2–5, 5–10, and 1–10 wt%, respectively (LaTorre et al., 2006).

The benefits of the conditioner are shown in Table 1.6 (LaTorre et al., 2006). The wet feel benefits are creamy texture, ease of spreading, slippery feel while applying, and soft rinsing feel. The dry feel benefits are moistness, softness, and easier dry combing. Each of the primary conditioner ingredients also has specific functions and roles that affect performance of the entire product. Table 1.7 displays the functions of the major conditioner ingredients and their chemical structure (LaTorre et al., 2006). Cationic surfactants are critical to the forming of the lamellar gel network in conditioner and also act as a lubricant and static control agent, since their positive charge aids in counteracting the negative charge of the hair fibers. Fatty alcohols are used to lubricate and moisturize the hair surface, along with forming the gel network. Finally, silicones are the main source of lubrication in the conditioner

Table 1.6 Combinations of conditioner ingredients and their benefits toward wet and dry feel

Gel network chassis for superior wet feel	
Key Ingredients	Benefits
– Cationic surfactant	– Creamy texture
– Fatty alcohols	– Ease of spreading
– Water	– Slippery applying feel
	– Soft rinsing feel
Combination of “conditioning actives” for superior dry feel	
Key Ingredients	Benefits
– Silicones	– Moist
– Fatty alcohols	– Soft
– Cationic surfactant	– Dry combing ease

Table 1.7 Chemical structure and purpose/function of conditioner ingredients

Ingredient		Chemical structure	Purpose/function
Water			
Cationic surfactants	Stearamidopropyl dimethylamine		– Aids formation of lamellar gel network – Lubricates and is a static control agent
	Behenyl amidopropyl dimethylamine glutamate (BAPDMA)		
	Behentrimonium chloride (BTMAC) $CH_3(CH_2)_{21}N(Cl)(CH_3)_3$		
Fatty alcohols	Stearyl alcohol ($C_{18}H_{37}OH$)		– Lubricates and moisturizes – Aids formation of lamellar gel network along with cationic surfactant
	Cetyl alcohol ($C_{16}H_{33}OH$)		
Silicones	Polydimethylsiloxane (PDMS) blend (Dimethicone)		– Primary source of lubrication – Gives hair a soft and smooth feel

formulation. Conditioners are opaque because of silicone particles. The pH value is low, about 3. Compositions are ethnic based. For example, Asian hair have large diameter; therefore, a higher concentration of silicon is used as compared to that for Caucasian hair (3–5% vs. 0.5%).

1.3.2 Damaging Processes

In Sect. 1.3.1 we discussed some of the products which aid in "treating" the hair. There are other hair care products and processes which, while creating a desired look or style to the hair, also bring about significant damage to the fibers. Most of these processes occur on some type of periodic schedule, whether it be daily (while combing the hair) or monthly (haircut and coloring at a salon). In general, hair fiber damage occurs most readily by mechanical or chemical means or by a combination of both (chemo-mechanical).

1.3.2.1 Mechanical Damage

Mechanical damage occurs on a daily basis for many individuals. The damage results from large physical forces or temperatures which degrade and wear the outer cuticle layers. Common causes are

- combing (generally with plastic objects, and often multiple times over the same area lead to scratching and wearing of the cuticle layers)
- scratching (usually with fingernails around the scalp)
- cutting (affects the areas surrounding the fiber tips)
- blowdrying (high temperatures thermally degrade the surface of the hair fibers)

1.3.2.2 Permanent Wave Treatment

Permanent wave treatments saw many advances in the beginning of the twentieth century, but have not changed much with the invention of the Cold Wave around the turn of that century. Generally speaking, the Cold Wave uses mercaptans (typically thioglycolic acid) to break down disulfide bridges and style the hair without much user interaction (at least in the period soon after the perm application) (Gray, 2001). The Cold Wave process does not need increased temperatures (so no thermal damage to the hair), but generally consists of a reduction period (whereby molecular reorientation to the cuticle and cortex occurs via a disulfide–mercaptan interchange pathway; Robbins, 1994) followed by rinsing, setting of the hair to the desired style, and finally neutralization to decrease the mercaptan levels and stabilize the style. The chemical damage brought on by the permanent wave can increase dramatically when not performed with care.

1.3.2.3 Chemical Relaxation

Commonly used as a means of straightening hair (especially in highly curved, tightly curled African hair), this procedure uses an alkaline agent, an oil phase, and a water phase of a high-viscosity emulsion to relax and reform bonds in extremely curly hair. A large part of the ability to sculpt the hair to a desired straightness comes from the breakage of disulfide bonds of the fibers.

1.3.2.4 Coloring and Dyeing

Hair coloring and dyeing have become extremely successful hair care procedures, due in part to "over-the-counter" style kits which allow home hair care without professional assistance. The most common dyes are para dyes, which contain para-phenylenediamine (PPD) solutions accompanied by conditioners and antioxidants. Hydrogen peroxide (H_2O_2) is combined with the para dyes to effectively create tinted, insoluble molecules which are contained within the cortex and are not small enough to pass through the cuticle layers, leaving a desired color to the hair. Due to the levels of hydrogen peroxide, severe chemical damage can ensue in the cuticle and cortex.

Bleaching: Like dyeing, bleaching consists of using hydrogen peroxide to tint the hair. However, bleaching can only lighten the shade of hair color, as the H_2O_2 releases oxygen to bind hair pigments (Gray, 2001). Bleaching may also be applied to limited areas of the hair (such as in highlights) to create a desired look. The chemical damage brought on by bleaching leads to high porosity and severe wear of the cuticle layer.

1.4 Organization of the Book

In this book, we present a comprehensive study of various hair and skin structural, nanomechanical, and nanotribological properties as a function of ethnicity, damage, conditioning treatment, and various environments. Various cellular structures (such as the cortex and the cuticle) of human hair and fine sublamellar structures of the cuticle, such as the A-layer, the exocuticle, the endocuticle, and the cell membrane complex, are easily identified and studied. Nanomechanical properties including hardness, elastic modulus, tensile deformation, fatigue, creep, and scratch resistance are discussed. Nanotribological properties including surface roughness, friction, adhesion, and wear are presented, as well as investigations of conditioner localization and thickness. To understand the electrostatic charge buildup on hair, surface potential studies are presented.