α-Keratin: Formation of the Natural Structural Hierarchy in Hair and Hair Care that Alters the Formation of α-Keratin and Healthy Hair Growth

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Introduction

Quaternary structures of proteins are those in which the arrangements of proteins subunits are three-dimensional. These structures are broken down into two groups: fibrous proteins and globular proteins. The two groups differ both structurally and functionally. Globular proteins have a spherical or globular shape with several different types of secondary structures. This type of protein gives great support for enzymes and other regulatory proteins.

Fibrous proteins on the other hand, are those that are made of polypeptide chains that are arranged in long strands or sheets. They consist mainly of a single type of secondary structure. This is one difference from the globular protein, which consists of several types of secondary protein structures. Another difference is that fibrous proteins provide shape and support to mammalian and/or vertebrate species. The fibrous proteins are divided into three classes according to their structures, α-keratin, collagen, and silk fibroin. This report will discuss the class of α-keratin and its structure and function in mammals.

Formation of α- Keratin Intermediate filaments to form hair

With approximately 40 types of keratin genes in the human body, half of those genes makeup the proteins in hair and other "hard" related keratinizing tissues [1]. The keratins are divided into two sequences: types I and II. Type I is known as the acidic type, which are arranged in pairs of heterotypic keratin chains. Type II is the neutral-basic type where the arranged keratin chains are coexpressed during differentiation of simple and stratified epithelial tissues.

α –Keratin makes up almost all of the dry weight in wool, nails, hair, claws, quills, horns, and hooves, and a great portion of the epidermis in skin [2]. Eukaryotic cells contain three filament moieties: microtubules, actin-containing microfilaments, and intermediate filaments (IFs). Keratin IFs compare to all other IFs in the fact that all consist of a central "rod" domain that contains numbers of sequences that form α- helices that are divided into segments of 1A, 1B, 2A, and 2B [1]. These segments are separated by other linkers that are not α- helices. These linkers are given the terms L1, L12, and L2, respectively [1].

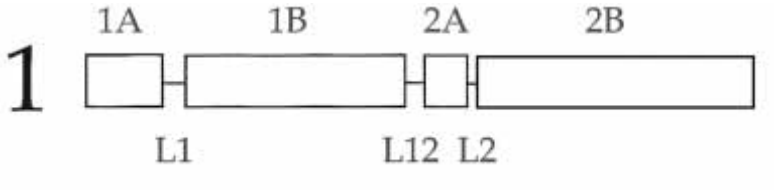

Figure 1 [1]. First step of the formation of hair: L1, L12, and L2 linking segments

This central rod contains a head and tail domain that consists of 15 amino acid residues on the 1A (head) segment and 15 amino acid residues on the 2B (tail) segment, varying in sequences among each other in the entire family of keratins. It has been found that cytokeratins that are located in the epidermis contain mostly glycines and serines; whereas those that are found in hair (trichocyte) are enriched with cysteine residues [1].

It is not quite certain how keratin is able to assemble into intermediate filaments, but there are a few steps that are understood to obtain some information on hierarchical structure [1]. What is known is that the chains are able to assemble themselves into 10nm long filaments that resemble the native keratin IFs in cells [1]. There are five steps that explain how this may happen. In the first step, a type I/type II heterodimer molecule is formed [1]. This type of structure was found in the 1950's. In the 1950's, it was

proposed by scientists Francis Crick and Linus Pauling, that these α-keratins were arranged in coiled coils. Some predictions have even suggested that approximately 2-3% of all protein residues form coiled coils [3, 4].

The coiled coil motif is often used to control oligomerisation. They consist of two to five amphipathic α- helices that wound around each other similar to that of a rope to form a strong supercoil. Sequences of parallel left-handed coiled coils contains seven amino acid residues that appear in an *abcdefg* pattern, with hydrophobic groups located in the place of *a* and *d* (first and fourth) positions (figure 2) [2, 3, 5].

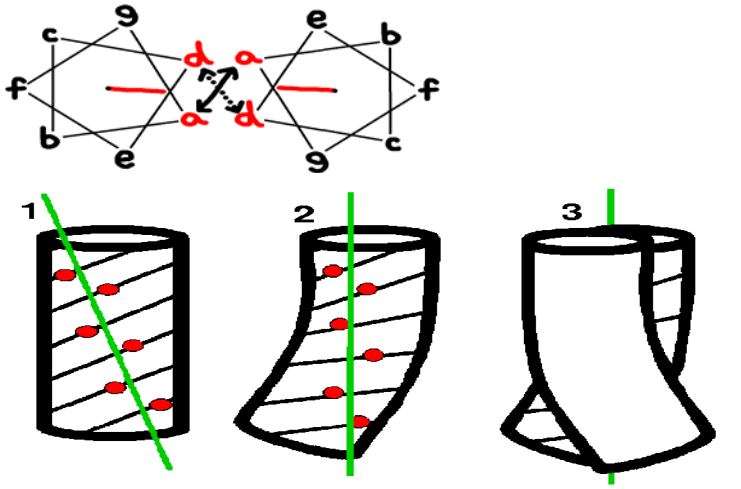

Figure 2 [5]. Amino acid sequences in *abcdefg* pattern with the formation of the coiled coil

This hydrophobic interaction in the heptad sequence is what leads to the supercoiling. In right handed coiled coils (RHCCs), a similar approach is used, except that there is an undecad repeat structure (11 amino acid residues) [3, 6, and 7]. Research suggests that the stability of these structures may be achieved by 'knobs-into-holes' packing into a hydrophobic core from apolar side chains [3].

In the second and third steps, molecules align themselves in an anti-parallel manner. The strands are partially overlapped in the mixtures of A_{11} and A_{22} alignment modes (figure 3).

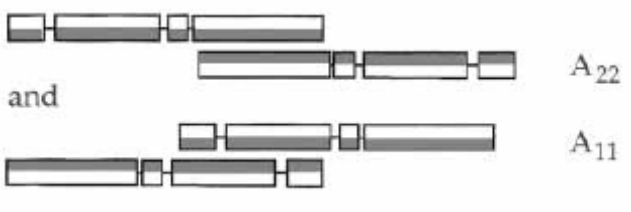

Figure 3 [1]. Linking segments lined up in anti- parallel form

This type of structure may be stabilized by either head to tail interactions between the chains, or by ionic salt bond interactions between positively or negatively charged amino acids, known as protofilaments [1] (figure 4).

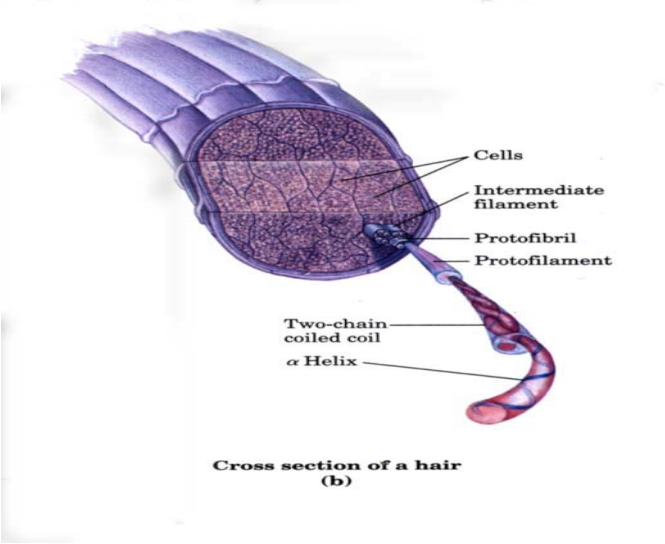

Figure 4 [2]. Cross-section of hair with protofibrils and protofilaments

The following steps are those that are assumed to take place in α- keratin.

Because the keratin IFs are approximately 12-20 molecules long, they are 70nm long before the adjacent stacking with a third A_{12} alignment mode (Figure 5) [1].

Figure 5. [1]. Adjecent A_{12} stacking of kerating intermediate filaments

These structures are now able to form more structures with the A_{12} alignment modes. The A_{12} alignment modes form longer keratin IFs, and then fold in a way so that these newly formed keratin IFs that are about 10-nm wide [1]. Due to the slightly unbalanced positions of the A_{11} and A_{22} segments, a new alignment segment, A_{CN} (Figure 6), shows up as the segments elongate to form keratin IF.

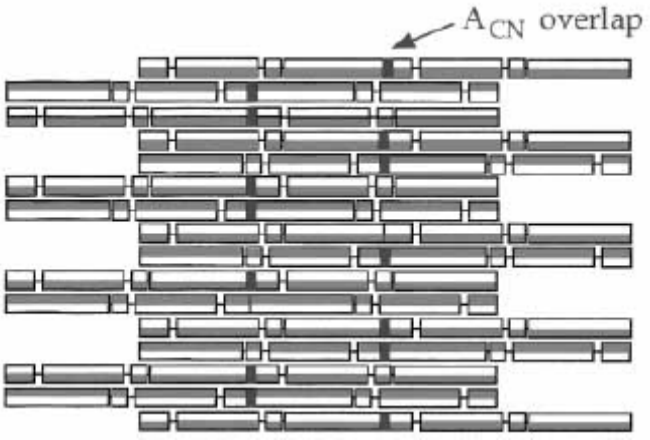

Figure 6 [1]. Introduction of new segment, A_{CN} to keratin intermediate filament

This happens when the terminal end of the 2B rod overlaps the beginning of the 1A rod of the following molecule in the same axial row by approximately 1nm or 10-15 amino acid residues [1]. This is also known as the protofibril.

The final structure of the intermediate filament that is formed is surrounded by cells. All of the steps mentioned above without any disruptions in amino acid sequences form a single, healthy strand of hair. However, there are many things that humans do to their hair that can cause structural changes in the keratin protein.

Hair care that alters the formation of α-keratin and healthy hair growth [8]

The hair fiber consists of two major components: the cortex and the cuticle. The cortex is responsible for the physical and mechanical properties of hair. The cortex contains macrofibrils that are composed of smaller microfibrils and a matrix. The microfibril, which contains the α-helices composed of a low content of cystine residues is embedded in an amorphous matrix with a high content of cystine residues consisting of cross-links of disulfide bonds. When undergoing certain cosmetic changes in hairstyle, from perms, to dyes and bleaching, the disulfide bridges are interrupted, dramatically changing the properties of hair.

Permanent waving is a technique to create curls or wavy hair through chemical treatment, which consists of two processes: the reduction stage and the oxidizing stage. The reduction stage places emphasis on the disulfide bridges. The hair is saturated with a thiol aqueous solution, usually Ammonium Thioglycolate, and then rolled on hair rollers of the desired size, in order to ensure that the hair is deformed to the size of the curlers.

In the oxidizing stage, the curls are set by restoring the hair into its original chemical structure. The thiol group of the keratin is able to react with the disulfide bond, resulting in an incomplete re- oxidation of newly produced disulfide bonds. The incomplete re-oxidizing process is the part responsible for changing the structure of α-keratin, resulting in hair of chemical structure that is not as good as that of hair that was not chemically treated. This change in the physical and mechanical properties of hair due to the reduction and re-oxidizing stages of the permanent waving technique are listed in the appendix, figures 7 and Table 1.

Table 1 The change in the fraction of α-helix, and β-sheet and random-coil in human hair by permanent waving treatment (reduction followed by oxidation) determined from the carbonyl carbon peaks in the ^{13}C CP/MAS n.m.r. spectra of human hair

Treatment	α-helix	β-sheet and random-coil
Untreated	23.7	76.3
20 min	20.7	79.3
60 min	20.4	79.6
180 min	20.7	79.3

The spectral simulation was performed, assuming a Gaussian line shape

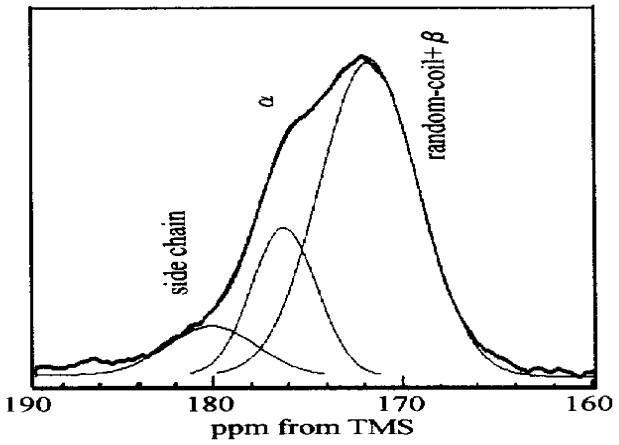

Figure 7 [8]. ^{13}C CP/MAS nmr spectrum of carbonyl carbon region human hair

X- ray diffraction and infrared spectroscopy of hair fibers that have undergone treatment of permanent waving results show that the fraction of α- helices and tensile strength both decreased as a result of the reduction and incomplete re-oxidation of the disulfide bonds that mostly existed in the matrix of the human hair. Research has suggested that this decrease in the α-helix of keratin could be the indication of damage to the hair, because this was not an issue in hair that was untreated.

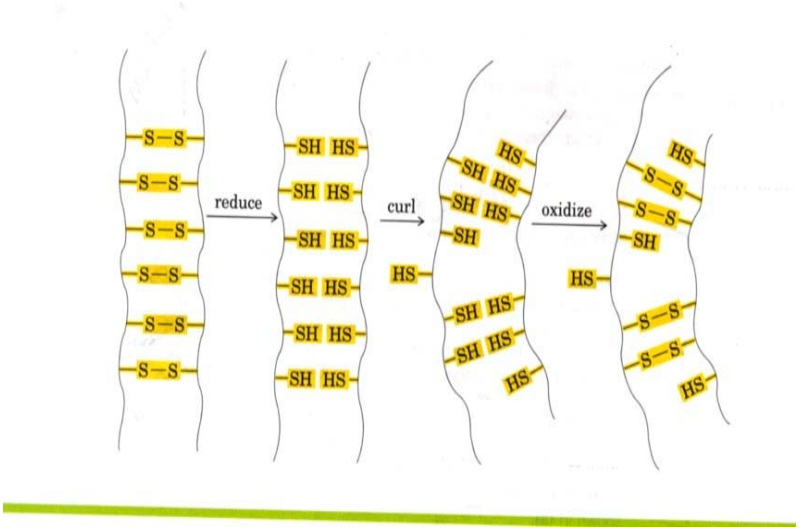

Figure 8 [2]. Hair before and after reduction and oxidation following permanent wave technique.

Keratin research has a bright future, because α-keratin is used in a wide range of biological applications. These proteins are studied in relation to the genome project and in DNA chips for gene expression. Consumers are also increasing their spending on caring for their nails, hair, and skin, all of which contain keratin. As a result, this too has a tremendous impact on the need for more innovative products to satisfy the needs of consumers in an ever changing society.

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