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To cite this article: Narumichi Kajihara and Katsuya Nagayama 2018 *IOP Conf. Ser.: Mater. Sci. Eng.* **297** 012022

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Numerical simulation of the hair formation –modeling of hair cycle

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Abstract. In the recent years, the fields of study of anti-aging, health and beauty, cosmetics, and hair diseases have attracted significant attention. In particular, human hair is considered to be an important aspect with regard to an attractive appearance. To this end, many workers have sought to understand the formation mechanism of the hair root. However, observing growth in the hair root is difficult, and a detailed mechanism of the process has not yet been elucidated. Hair repeats growth, retraction, and pause cycles (hair cycle) in a repetitive process. In the growth phase, hair is formed through processes of cell proliferation and differentiation (keratinization). During the retraction phase, hair growth stops, and during the resting period, hair fall occurs and new hair grows. This hair cycle is believed to affect the elongation rate, thickness, strength, and shape of hair. Therefore, in this study, we introduce a particle model as a new method to elucidate the unknown process of hair formation, and to model the hair formation process accompanying the proliferation and differentiation of the hair root cells in all three dimensions. In addition, to the growth period, the retraction and the resting periods are introduced to realize the hair cycle using this model.

1. Introduction

In recent years, interest in the field of beauty care has increased. In particular, hair has been very important in determining the human appearance. The growth process of human hair has remained a mystery for quite some time, and with the upsurge of the beauty care fields, understanding this phenomenon has become important. Therefore, this study developed method for analyzing the formative process of the hair root using a particle model.

Hair repeats the processes of growth and retraction, with a pause interval in a repetitive cycle, which is also called the hair cycle. In the growth phase, hair is formed through processes of cell proliferation and differentiation (keratinization). Hair growth stops in the regressive period, and during the resting period, old hair falls out and new hair replaces it. The elongation rate, thickness, strength, and shape of hair are believed to be affected by the hair cycle. Therefore, many studies have dealt with observation and experimentation of hair growth. However, observation of the hair formation process that occurs internally is difficult, so the relation between the hair growth cycle and the process of hair formation is still unknown.

Therefore, in this study, we introduce a particle model as a new method to elucidate the process of hair formation, and to model the hair formation process that accompanies the proliferation and differentiation of cells in the three-dimensional hair root. The model attempts to describe the growth, regression, and resting phases of the hair cycle. This model may be useful for elucidating the phenomenon of hair formation, which prior analysis methods have failed to explain. The goal of this



work is to contribute to the field of medical care and beauty by establishing the basis for this hair formation. [1, 2]

2. Object of analysis and analytical model

At first, in this research we use a method called particle method. In this method, one cell is regarded as one particle, and the equilibrium between the particles is solved to express the particle movement. As a feature, it is possible to represent a method involving deformation of cells, it is also possible to express movement and deformation at the time of cell extinction.

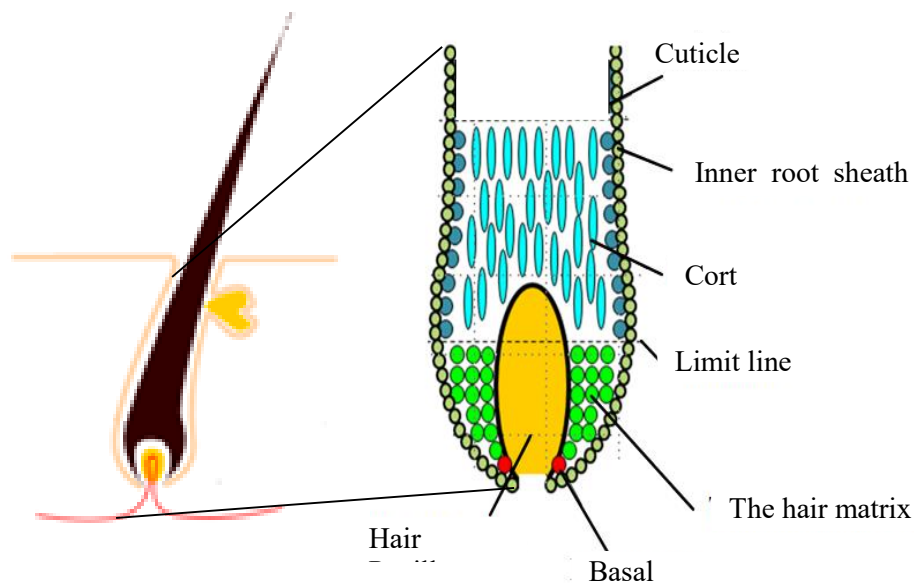


Figure 1. Cross section of hair and analytical model

Figure. 1 depicts the cross section of a hair strand and the proposed analytical model. The subject of analysis in this study is the root of the part below the cornered cells shown in the figure. The hair dermal papilla and basal cells divide from this region, resulting in hair matrix cells, cuticles, and the cortex. Further, analysis was performed on the part of the root sheath located outside, the dermal papilla by arranging the cells in an initial state and then extending them over a constant period [5].

In this study, we analyzed the process of hair formation using a particle model. This model treats a calculation point as a moving particle, which is then analyzed by tracking the movement of the particle. We introduced this method to model each particle as one cell.

In this analysis, we considered the volume and spring forces to be acting between the particles. The volumetric force is generated between all particles within a region where the force is applied. When particles enter the inside of their own region, the repulsive force causes the particles to separate, and an attractive force is exerted by the attractive force. In addition, the spring force works only between two connected particles, and maintains particles at a stable distance. The relational expressions for the volumetric force and spring forces assumed in this analysis are denoted by equations (1) and (2), respectively, where dr_0 denotes the stable distance, ddr denotes the interparticle distance, k is an interparticle coefficient, k' is an elastic coefficient, r is the basic particle diameter, and a is a cell variation coefficient.^{1,2)}

$$\vec{F} = \left\{ k \cdot \left(1 - \frac{ddr}{dr_0} \right) \cdot (a/r) \right\} \frac{ddr}{dd_0} \quad (1)$$

$$\vec{f} = \left\{ -k \left(1 - \frac{ddr}{1.0 \times dr0} \right) \cdot \left[1 - \left(1 - \frac{ddr}{1.0 \times dr0} \right)^4 \right] \right\} \frac{\vec{ddr}}{dr0} \quad (2)$$

$$\vec{x}' = \vec{x} + (\alpha \cdot \sum \vec{F} + \beta \cdot \sum \vec{f}) \quad (3)$$

The analysis protocol for this work is shown in figure 2. The initial setting and placement of each particle at the beginning of the analysis were determined. Subsequently, the cell particle was divided based on the function of the basal and hair matrix cells. At this time, the particles that exceeded the limit became cuticle or cortex, and when going up further it will kerage. For each particle, the volume and spring forces were calculated using equations (1) and (2), respectively. Finally the particles moved according to equation (3). The data is the output and the process returned to cell division. This cycle was repeated to analyze the model.

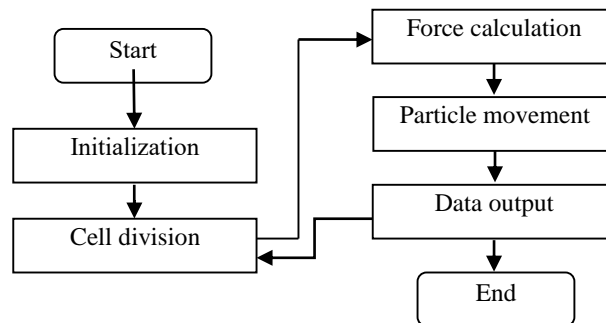


Figure 2. Analysis flowchart

Figure 3 is a schematic diagram of the hair cycle. [3] The hair cycle is a representation of the periodic growth process of hair, and it is divided into three periods of the growth period, retraction period, and rest period. The growth period is the period from the synthesis of hair to the growth of hair. Approximately one month is required to synthesize hair, and, it takes 1-6 years for hair to grow to the maximum length and width. In the retraction phase, the color pigment falls, and the root sheath begins to degenerate, this takes two to three weeks. In the telogen phase, hair growth stops and hair fall occurs, which requires a period of approximately 3-9 months. After the quiescent period, new hair is generated and the cycle returns to the growth period.

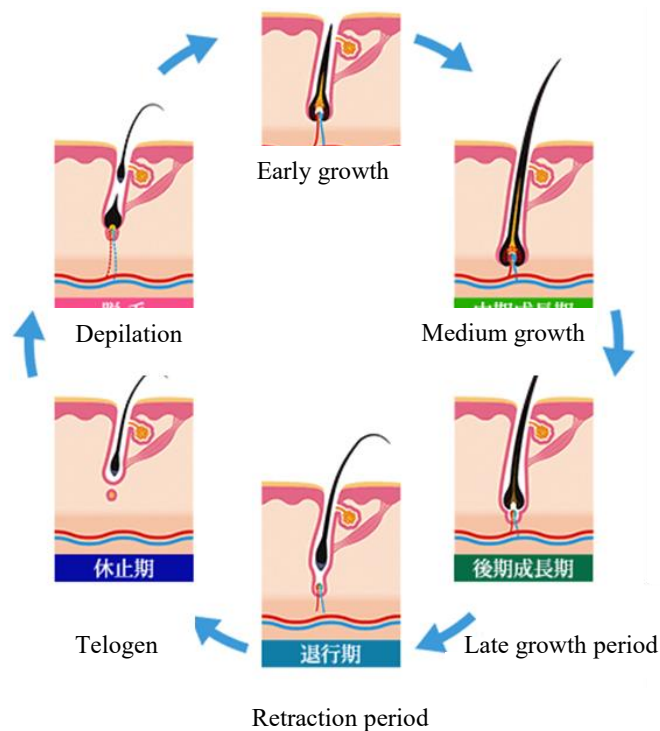


Figure 3. Hair Cycle

3. Analysis conditions

In the three-dimensional formation process model of hair, the initial arrangement comprises the inner root sheath, the hair papilla and hair matrix cells as shown in Figure 4. Further, no cells existed in the interior. Cell particles in the early stage of development have a spherical shape with a diameter of 10 μm . From this point, the cells divide and keratinize beyond the limiting line. With regard to the inner root sheath, it has an initial spherical shape of 3 μm . The quantity of inner root sheaths increases by division, which causes it to grow upward.

The frequency of basal cells formation is about one per day, and the frequency of division of the birth cells is believed to cause cell division at a rate of about three per day. Immediately after dicing, cell migration is unfettered because of the force of volume preservation. However, as the changes in cell shape become slow, the spring force develops between neighboring particles and the shape of the hair is determined by solidification of the cell group.

Each figure below has a brief caption describing it and, if necessary, a key to interpret the various lines and symbols on the figure.

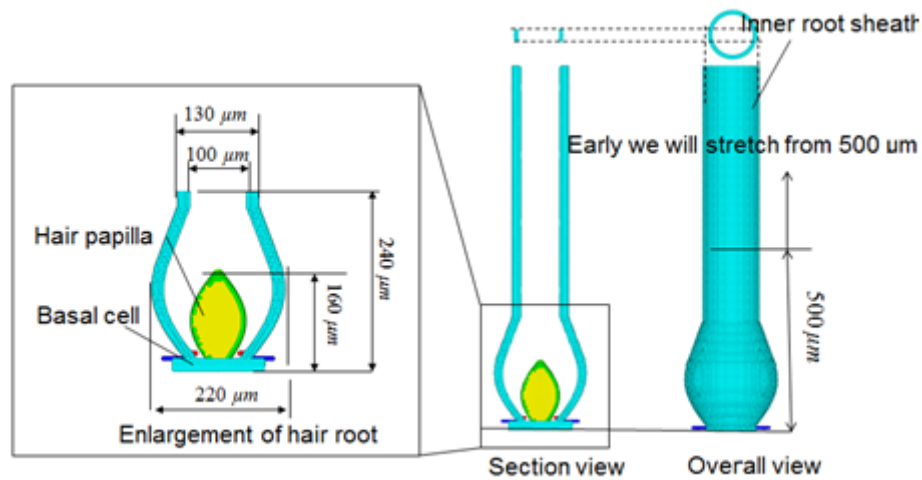


Figure 4. Initial Shape

In the modeling of the hair cycle, the growth period expresses how the hair is actually stretched by the elongation of the inner root sheath and, cell division of the hair matrix cells and the basal cells. In the retraction phase, hair retraction is expressed by the phenomenon of particles and expresses how the dermal papilla is retracting. The resting period shall be expressed by stopping the division of how the growth of hair stops.

4. Analysis Result

The results of the modeling of the hair growth process are shown in figure 5. In the growth period, internal growth was observed while the inner root sheath extended, and we confirmed that growth stopped after a certain period in the retraction phase. In the telogen phase, the hair cycle was reproduced by stopping the growth of hair, which was considered to be a state of hair sloughing.

The actual modelled phenomenon was compared to images and research results. We found that the increase of the period was consistent with results of previous studies. As shown in figure 3, we found that the growth, retraction, and rest periods coincided with the results shown in figure 5. The process model results agreed with, each period of the cycle shown in figure 5. The growth period was 1-6 years, the retraction period was 2-3 weeks, and the telogen period was 3 months, but the expression of that period was also possible. Actually, in the animation of the process, the growth period was longer than the retraction and quiescence periods, so the growth period was shortened and displayed. However, calculating the results based on the actual phenomenon was possible. In addition, although a sectional view is displayed in figure 5, since the analysis was performed in three-dimensions, a stereoscopic analysis was also possible.

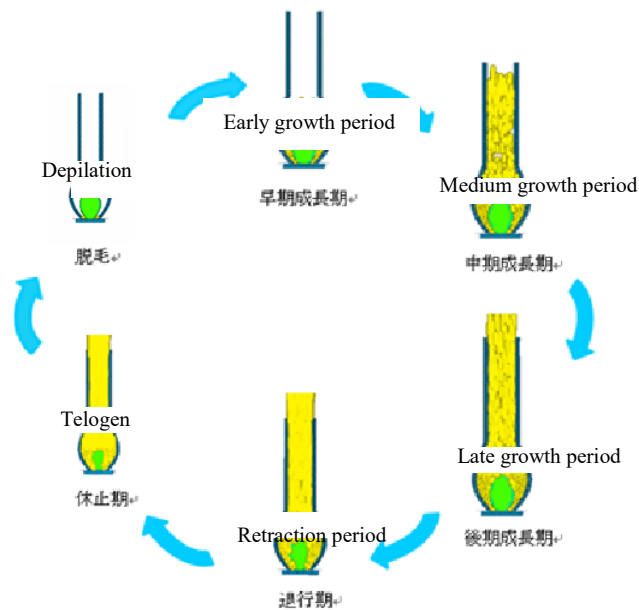


Figure 5. Analysis results of hair cycle

5. Conclusion

In this study, numerical simulation of hair formation at the hair root using a particle model was performed. By following the state of the hair growth from the proliferation of the basal cells and the hair matrix cells to extraction and contraction of the inner root sheath, fabricating the hair growth process similar to the real phenomenon was possible. In addition, we also constructed a model using the spring and volume forces, and used the model to simulate the actual hair growth cycle. From these results, we think that we can construct a hair process analysis tool with shrinking of the root sheath part. As a result of this research, it can be said that human hair grows at a rate of 5 μm per day, and its value can be quantitatively evaluated by a numerical analysis of this study. From the viewpoint of comparison with actual phenomena, hair growth is considered to be qualitatively due to large individual difference.

Future work will focus on the hair papilla portion to better approximate the actual hair growth process, and this will be utilized for analysis of hair formation mechanism, beauty diagnosis systems, etc. As part of our ongoing research, the process of hair thinning is also being considered. This interrupted phenomenon occurs when growth in early stages of growth is interrupted and enters the retraction period or the telogen period, resulting in hair thinning. [4] Therefore, it is a simulation that can change hair thickness simultaneously with growth retraction. In the future, we will analyze such types of hair growth phenomena.

Reference

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