Hair Medulla Care to Create an Attractive “Swinging Hair”

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Abstract

Background: The movement of beautiful and healthy hair, in addition to its lustre and colour tone, has a great impact on the impression of appearance and is becoming increasingly important. However, it is reported that the quality of hair movement deteriorates with aging and hair damage, as these factors reduce the swing amplitude and make hair movement stop more readily. We investigated whether hair movement could be improved by using Hair Medulla Care (HMC), which enhances various permeabilities, to penetrate cholesterol, which decreases from the inside of the hair due to aging and damage, into the hair's interior.

Methods: Evaluation of cholesterol penetration was performed by fluorescence microscopy of hair sections with fluorescent-labelled cholesterol. To evaluate hair movement, the root of the hair bundle was fixed, and a marker was placed at the centre of the hair tip. The hair bundle was lifted until it was horizontal and then allowed to fall freely. The movement of the bundle was photographed and observed.

Results: The cholesterol-impregnated hair increased swing amplitude and duration, was more flexible from the root to the tip, and was more manageable even after it had stopped swinging. The cholesterol-impregnated hair was able to retain more water internally, and was more flexible, bending with less force.

Conclusion: The results suggest that HMC can change the physical properties of hair by enabling penetration of various substances into the hair, thereby improving the dynamic beauty of hair.

Keywords: hair medulla care; swinging hair; cholesterol; oil penetration; beautiful and healthy hair movement

1. INTRODUCTION

The beauty of hair has a marked impact on how people are perceived by others, and it is reported that hairstyles can change those perceptions at least as much as make-up [1]. Consequently, maintaining hair beauty is considered an effective way to increase one's attractiveness.

The lustre and colour tone of hair have often been seen as factors favouring beautiful hair, and considerable research and product development has focused on these factors. However, in recent years, with the increase in opportunities for people to express themselves via video content, such as on social networking services, attention is being paid to not only the static beauty of hair, such as lustre and colour tone, but also the dynamic beauty, such as how it looks while in motion. Attractive swinging hair, i.e., hair that swings freely from root to tip with the wind or with body movements, results in a beautiful, energetic, and healthy impression not only of the hair but also of the person themselves.

Therefore, we have given consideration to the achievement of both static and dynamic hair beauty. It is reported that the quality of hair movement deteriorates with aging and hair damage, as these factors reduce the swing amplitude and make hair movement stop more readily [2] [3]. However, the factors affecting hair movement have not been elucidated fully. Changes in hair condition related to aging and bleaching share many structural issues in common including but not limited to the detachment of the cuticle, which is the outermost layer of the hair [4] [5]. For example, it is reported that aging causes emptying of the hair interior [6]. Moreover, the amount of lipids, especially cholesterol, inside the hair begins to decline as early as the teenage years [7]. Bleaching results in the removal of melanin, leading to void formation [8], and the leaching of lipids in the cell membrane complex (CMC), which is considered a pathway for the penetration of substances into the hair [9]. Although numerous care methods have been examined to remediate the structural changes in hair due to aging and damage, we have not found any reports of changes in hair movement resulting from these methods.

We have been focusing on Hair Medulla Care (HMC), which we developed previously. HMC allows certain ingredients to act on the medulla, which is the porous structure in the central part of the hair, and increases the penetration of hair by various substances, including lipid-soluble components [10] [11]. We have previously used this high-penetration technology to improve the static beauty of hair, including transparency [10] and colour [11].

In the present study, we examined whether the dynamic beauty of hair could also be improved by supplying lipid components to the hair interior using HMC. Cholesterol, which is naturally present in hair and whose content is known to decrease with aging and damage [7], was selected as the lipid component to be penetrated into the hair. The effect of cholesterol penetration facilitated by HMC on the dynamic beauty of hair was evaluated.

2. MATERIALS AND METHODS

2.1 Hair bundle processing method

Commercially available Asian hair bundles were damage-treated and then used as the test hair in this study. The damage treatment involved applying a 1:2 mixture of bleach powder and 6% aqueous hydrogen peroxide solution to the hair, leaving it for 25 min, and then washing it thrice by immersing it in 25% sodium laureth sulfate solution for 1 h.

For evaluating the hair movement, test hair bundles of approximately equal length (24.0 ± 0.5 cm) and weight (4.00 ± 0.05 g) were used.

As described in our previous study [10] [11], HMC consists of (i) solution A, which is at pH 6.5 and consists of a polypeptide, penetrant, reducing agent, and pH-adjuster; and (ii) solution B, which contains an oxidant. For the cholesterol penetration evaluation, the solution used was either 0.1 mg/mL fluorescent-labelled cholesterol (23-(dipyrroMetheneboron difluoride)-24-norcholesterol) in dimethyl sulfoxide, or 5% cholesterol in hydrogenated polyisobutene. After treatment with HMC solution A, the hair was immersed in a cholesterol solution for 20 min, rinsed with water, treated with solution B, washed with a commercially available shampoo, dried, and finally, its cholesterol penetration was evaluated.

2.2 Cholesterol penetration evaluation

To evaluate penetration by fluorescent-labelled cholesterol, 16-µm-thick hair sections were prepared using a microtome (SM2000R; Leica Microsystems GmbH), and observed using a fluorescence microscope (BZ-X810; Keyence Corporation).

2.3 Evaluation of hair movement

2.3.1 Observation and evaluation of hair bundle swing

To evaluate the swing amplitude and duration of cholesterol-penetrated hair bundles (HMC+Chol-treated hair bundles), the root of the hair bundle was fixed, and a marker was placed at the centre of the hair tip, 23 cm from the root. The hair bundle was lifted until it was horizontal and then allowed to fall freely. The movement of the bundle was photographed and observed while the amplitude gradually decreased and until the bundle came to rest (damped oscillation) [2] [3] (Fig. 1). From the video, the amplitude of the first swing after the hair bundle was dropped was taken as the maximum amplitude (A_{max}). The swing duration was evaluated by obtaining the decay rate (γ), as follows:

1. From the video, the coordinates of the marker at the centre of the hair tip were tracked every 0.042 s, and the horizontal displacement [x(t)] was obtained at each time-point.

2. Using the least-squares method, the damped oscillation equation, shown in equation (1), was applied to obtain the natural angular frequency (ω_0) and damping ratio (ζ).

$$x(t) = -A_0 \cdot \cos\left(\sqrt{1-\zeta^2}\,\omega_0 t\right) \cdot e^{-\zeta\omega_0 t} \quad (1)$$

x(t): horizontal displacement, x, per unit time

A_0 : 23 cm (distance from the root to the marker)

3. The decay rate (γ), an index of the speed of damping, was calculated from the natural angular frequency (ω_0) and damping ratio (ζ) using the following equation:

$$\gamma = \zeta\omega_0 \qquad (2)$$

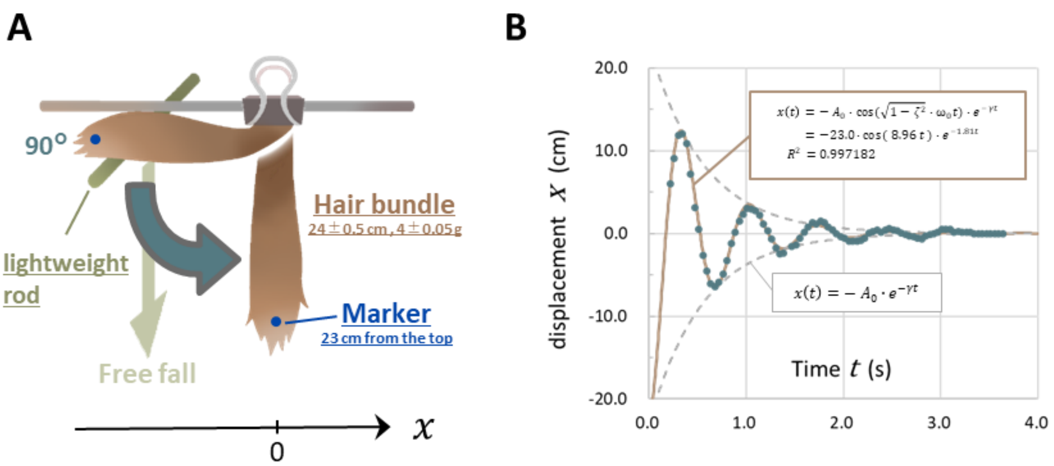

Fig. 1. Schematic representation (A) and damping-oscillation graph (B) of hair movement. The hair bundle was allowed to oscillate by lifting the bundle to the horizontal using a lightweight rod, and then allowing the rod to fall. The position of a marker at the centre of the hair tip was tracked every 0.042 s, and the displacement (x) was plotted (**B; blue markers**). From the plotted points, the optimal damped oscillation equation was obtained (**B; brown line**), and the damping ratio (ζ), natural angular frequency (ω_0), and decay rate (γ) were determined.

2.3.2 Comparison of hair bending

Using a still image in which the hair bundle was at A_{max}, a circle was drawn along the curve of the hair bundle. The curvature (K) was calculated from the radius of this circle, in order to evaluate the degree of bending of the hair bundle when swinging (Fig. 2).

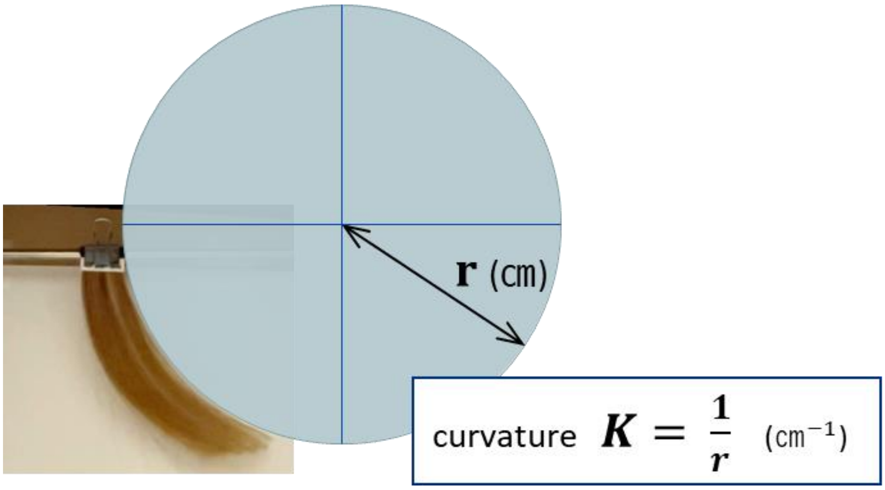

Fig. 2. How to calculate curvature.

2.3.3 Evaluation of hair manageability after oscillation

The test hair bundles were tied together at the root end, and the root was fixed to a shaking machine (Utility Shaker; As One Corporation.). The spread width of the hair bundle tips was measured after shaking 80 times/s for 30 s.

2.4 Changes in hair properties

2.4.1 Measurement of hair water content

The test hair (1 g) was placed in a box-shaped aluminium foil container, and kept in a constant-temperature and constant-humidity chamber at room temperature (25°C) and a relative humidity of 75.3%, for 24 h. The temperature of the chamber was then increased to 65°C, and after 40 min the weight was determined. The resulting weight decrease was defined W_i. The temperature was then increased to 180°C, and the weight decrease after 30 min was defined as W_{ii}. The final weight was taken as the dry weight (W_{dry}), and the transpiration moisture (%) was determined on this basis [12]:

$$the\ primary\ transpiration\ moisture\ (\%) = \frac{W_i}{W_{dry}} \times 100\ (\%)$$

$$the\ secondary\ transpiration\ moisture\ (\%) = \frac{W_{ii}}{W_{dry}} \times 100\ (\%)$$

2.4.2 Bending test for hair bundle flexibility evaluation

After 24 h of conditioning in the measurement environment (room temperature: 20 ± 5°C; relative humidity: 65 ± 10%), 200 hairs were laid flat and fixed at both ends, such that the length of the hairs was 2 cm. The flexibility of the hair was evaluated by measuring, using a bending tester (KES-FB2; Kato Tech Co., Ltd.), the B value (bending difficulty), which is the force needed to make the hair bend to a specified angle, and 2HB value (bending recovery), which is the resistance to the hair re-straightening.

3. RESULTS

3.1 Penetration of cholesterol into hair

In the case of hair immersed only in fluorescent-labelled cholesterol solution, only the cuticle was penetrated (Fig. 3C), whereas in the case of HMC+Chol-treated hair, the staining images showed penetration into the cortex and medulla (Fig. 3D). The magnified images clearly show a CMC-like reticular staining signal in the cortex (Fig. 3E). It was thus shown that HMC increased penetration of cholesterol into hair.

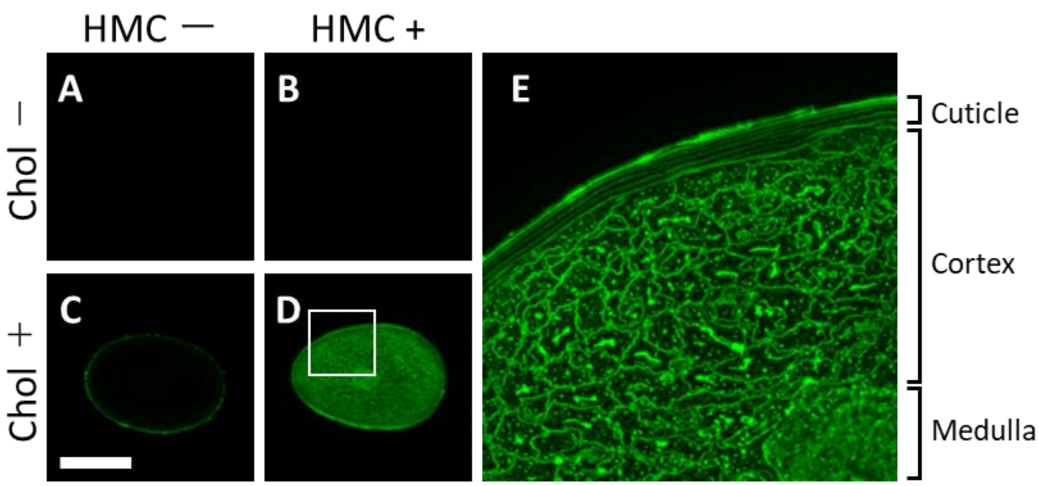

Fig. 3. Penetration of fluorescent cholesterol due to HMC The penetration of fluorescent-labelled cholesterol due to HMC was evaluated by fluorescence microscopy. **A and B**: untreated and HMC-only-treated hair sections. **C**: untreated hair sections immersed in cholesterol solution. **D**: hair sections with HMC and immersion in cholesterol solution. Penetration of the cuticle, cortex, and medulla have clearly increased. E: enlarged view of the white framed area in D. The cuticle layer and CMC-like reticular structure can be clearly seen, and penetration can be seen as far as the medulla. The bar represents 50 µm (A to D) and 8.2 µm (E).

3.2 Effects of cholesterol penetration into hair on hair swinging movement

3.2.1 Hair bundle swing amplitude and duration

When HMC+Chol-treated hair bundles were shaken, they were found to swing more widely than untreated hair (Fig. 4A). The A_{max}, measured from the video, and oscillation amplitude of the HMC+Chol-treated hair bundle increased significantly (Fig. 4B).

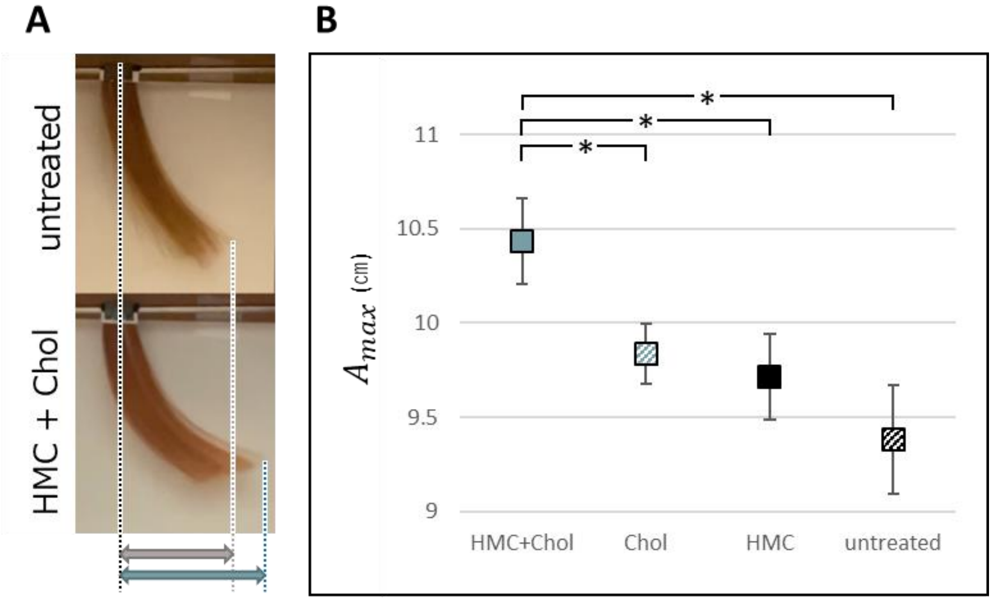

Fig. 4. Cholesterol penetration due to HMC increases amplitude. A: untreated and HMC+Chol-treated hair bundles at maximum oscillation amplitude. **B**: A_{max} of hair oscillation under each experimental condition (mean ± standard error [SE]). N = 9 (3 samples × 3 trials); *P < 0.05; Student's t-test.

Fig. 5A shows the change in the horizontal position of the hair bundles after they were allowed to fall freely. The HMC+Chol-treated hair bundles showed a longer swing duration than the untreated bundles. Comparison of the decay rate (γ), which is an index of the speed of damping, showed that the HMC+Chol-treated bundles had a significantly lower decay rate and a longer swing duration (Fig. 5B).

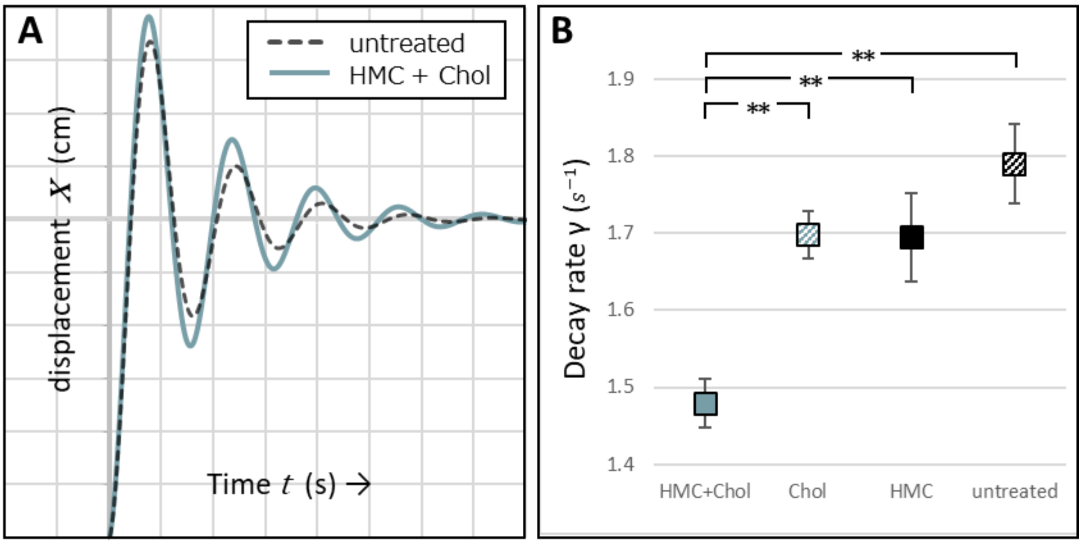

Fig. 5. Cholesterol penetration due to HMC increases swing duration. A: plots of the swing of untreated and HMC+Chol-treated hair bundles; the plotted values show the mean displacements of nine trials (three samples × three trials). **B**: the decay rate (γ) under each condition (mean ± SE). N = 9 (3 samples × 3 trials); **P < 0.01; Student's t-test.

3.2.2 Comparison of bending

Upon swinging the hair bundles, the HMC+Chol-treated bundles showed marked bending between the root and tip. Measurement of the bending at A_{max} showed that the curvature of treated hair was much greater than that of untreated hair, indicating that cholesterol penetration due to HMC made the hair more flexible (Fig. 6).

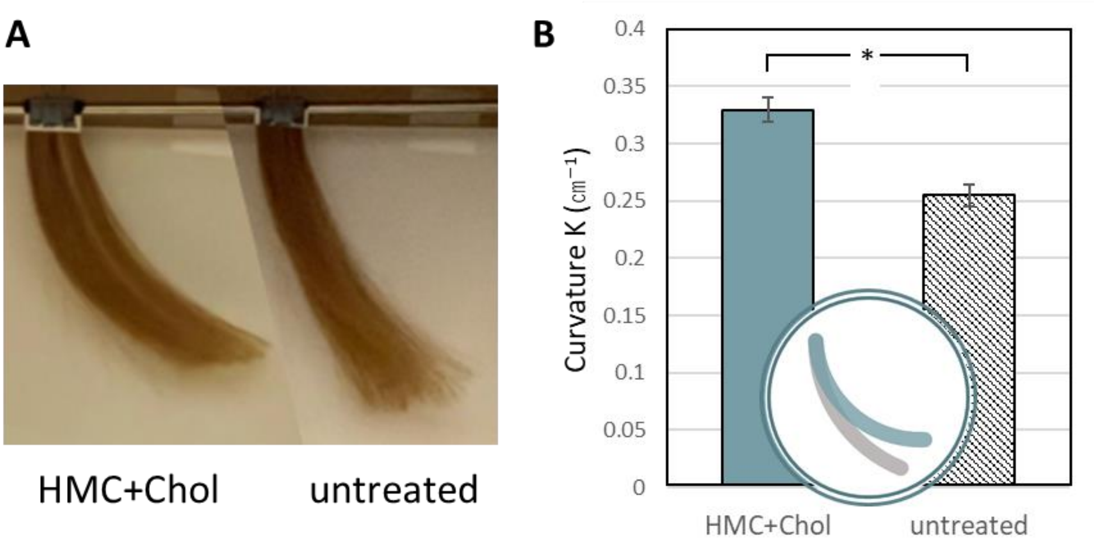

Fig. 6. Cholesterol penetration due to HMC improves hair bending. A: bending of untreated and HMC+Chol-treated hair bundles at A_{max}. **B**: curvature obtained from the bending at A_{max} (mean ± SE). The curves inside the circle, obtained from the mean curvature, show the appearance of the untreated (grey) and HMC+Chol-treated (blue) bundles. N = 9 (3 samples × 3 trials); *$P < 0.05$; Student's t-test.

3.2.3 Comparison of degree of cohesiveness

Studying the movement of the hair bundles showed that both during oscillation and after the oscillation had converged and stopped, the HMC+Chol-treated hair bundles were more cohesive than the untreated bundles (Fig. 7A). In order to investigate the cohesiveness more precisely, the hair bundles were shaken for 30 s using a shaking device, and changes in the cohesiveness of the hair tips were measured. The HMC+Chol-treated hair bundles were found to be significantly more cohesive after stopping than the untreated bundles (Fig. 7B).

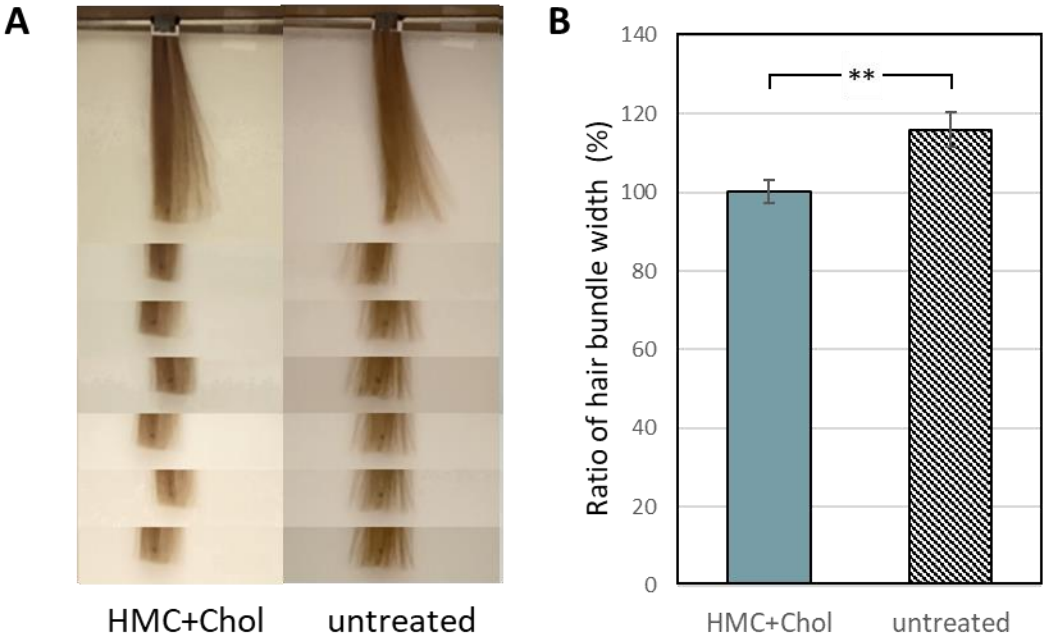

Fig. 7. Cholesterol penetration due to HMC changes the flow and cohesiveness of hair. A: damped oscillation of untreated and HMC+Chol-treated hair at 0.4 s intervals. **B**: ratio of hair bundle width after oscillation for 30 s relative to that before oscillation (mean ± SE). N = 12 (4 samples × 3 trials); **P < 0.01; Student's t-test.

3.3 Changes in hair properties

3.3.1 Water content

Measurement of the amount of water in HMC+Chol-treated hair showed that the primary transpiration moisture was almost identical to that of untreated hair, whereas the secondary transpiration moisture was significantly higher than that of untreated hair, indicating that more water was retained in the hair (Fig. 8).

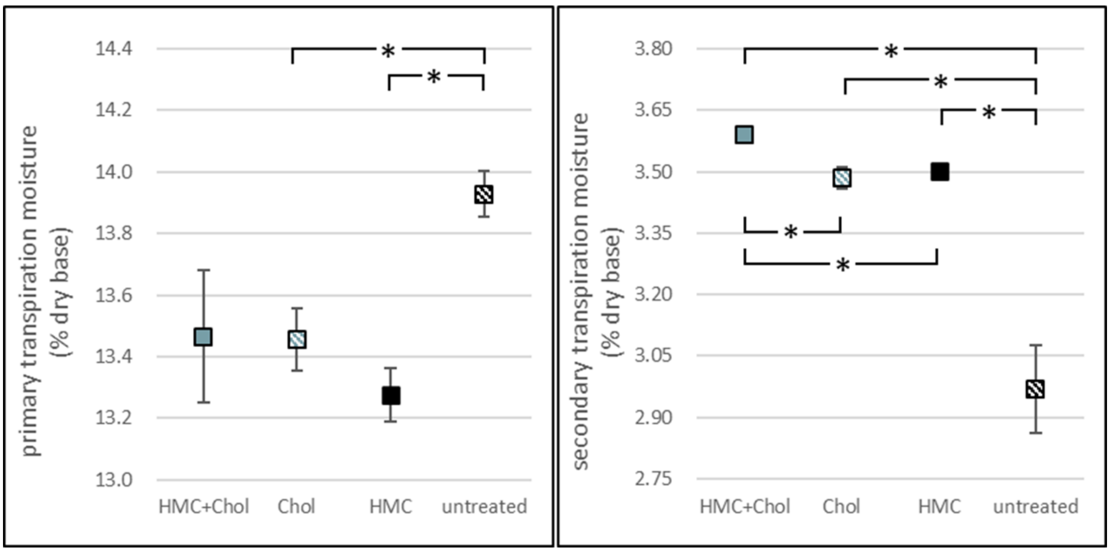

Fig. 8. Cholesterol penetration due to HMC improves hair water content. The results of hair water content measurement (mean ± SE). N = 3; *P < 0.05; Student's t-test.

3.3.2 Increased flexibility

Measurement of the flexibility of HMC+Chol-treated hair using a pure bending tester showed that the bending difficulty (B value; force required to bend the hair to a specified angle) was significantly lower for HMC+Chol-treated hair, whereas the bending recovery (2HB value; resistance to re-straighten the hair) was no different (Fig. 9).

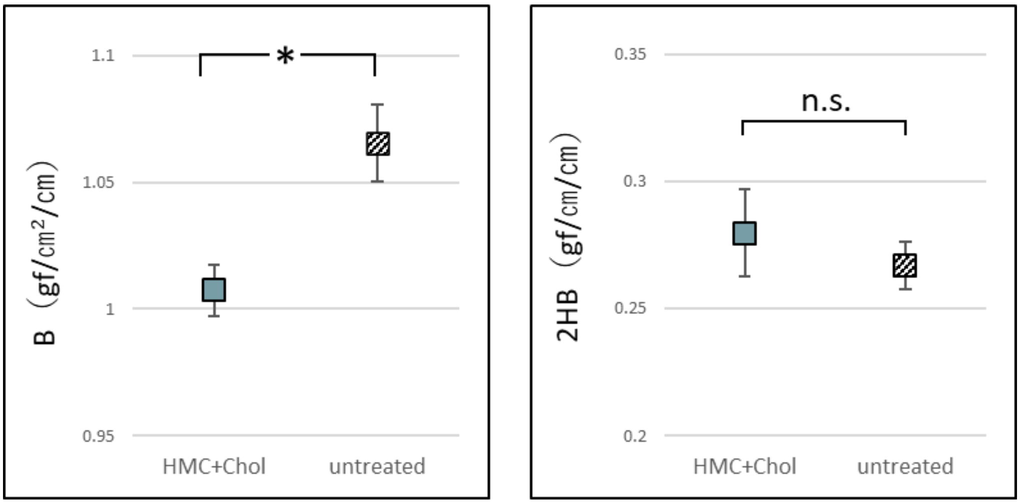

Fig. 9. Cholesterol penetration due to HMC increases hair flexibility. The results of bending difficulty, B, and bending recovery, 2HB, measurement with a pure bending tester (mean ± SE). N = 5; $^*P < 0.05$; n. s.: not significant; Student's t-test.

4. DISCUSSION

Hair has a layered structure consisting of three main layers, namely, the cuticle, cortex and medulla, from outermost to innermost. There is a barrier between the cuticle and cortex that prevents penetration of substances, and it is suggested that this barrier slows down substance penetration [13]. Therefore, it is difficult to reach the cortex and medulla simply by applying various substances. We have developed a method named HMC that enables substances to penetrate to the medulla, and have demonstrated that various fluorescent dyes can pass through the penetration barrier and reach the medulla [11].

In the present study, we investigated whether the penetration of hair by cholesterol, a lipid, could be facilitated by HMC, and whether the properties of hair changed as a result. As cholesterol is lipid soluble, penetration of cholesterol due to immersion in a cholesterol solution between treatments with solutions A and B was evaluated. The results showed that the combination of HMC and cholesterol dramatically increased the penetration of cholesterol into the hair. This indicated that cholesterol, whose content in hair decreases as a result of aging and chemical treatment, can be replenished in the entire hair, including the medulla.

Next, as it has been reported that grey and/or damaged hair has a smaller swing amplitude and shorter swing duration [2] [3], this study examined whether cholesterol penetration into hair has any effects on hair oscillation and oscillation damping. In a previous study [3], the amplitude ratio was constant from the first to sixth swings. However, with HMC+Chol-treated hair bundles, the effect of bending increased the initial amplitude, and consequently, the amplitude ratio was not constant up to the sixth swing. Therefore, in the present study, the position of the centre of the hair tip was tracked at fixed intervals, and the parameters for each oscillation, namely, the natural angular frequency ω_0 and damping ratio ζ, were determined from the waveform using the least-squares method and the optimal damped-oscillation equation (1). As a result, a waveform almost perfectly consistent with the waveform of the hair tip was obtained (Fig. 1B). It is believed that this method can simplify hair bundle movement and reduce measurement blurring through the use of actual measurements.

Evaluation of the movement of HMC+Chol-treated hair showed that its swing amplitude and duration were significantly greater than those of untreated hair. The treated hair bent better, with an appropriate curve at the termination of the swing, and the ends of the hair bundles swung cohesively, without spreading out or clumping on stopping. These changes in hair movement are attributable to changes in the physical properties of the hair due to penetration of cholesterol into the hair as a result of HMC.

Next, the water content and bending strength of hair were measured. No significant differences were found in the primary transpiration moisture between the HMC+Chol-treated and untreated hair, whereas the secondary transpiration moisture was found to be significantly higher in HMC+Chol-treated hair. Primary transpiration refers to water moving freely in and out of the hair depending on temperature and heat, and is thought to cause swelling under wet conditions and dryness under dry conditions. In contrast, secondary transpiration refers to water that is strongly adsorbed by hair, and is retained in the hair without being affected by the external environment [12] [14]. In other words, the fact that only the secondarily transpired water content increased indicates an increase in the amount of water that is strongly adsorbed by the hair, i.e., an improvement in the water retention capacity of the hair. The CMC region, which showed particularly high penetration of cholesterol in the penetration evaluation experiment, has a laminated structure comprising a layer of lipid-soluble components and a layer of water-soluble components. The lipids in the CMC are believed to act as a barrier to water diffusion, and to reduce the diffusion speed during the movement and transpiration process, thereby reducing the amount of water transpired and improving the water retention capacity [9] [15]. It is believed that the cholesterol that penetrated the lipid layer of the CMC due to HMC enhanced the water retention capacity of the hair.

The bending strength, B, was significantly lower for HMC+Chol-treated hair than for untreated hair, which means that the hair was bent with less force, and is consistent with the hair bending more at the ends upon swinging. The bending recovery, 2HB, on the other hand, shows the difficulty of collapse of the hair structure in response to bending. As hair has a certain degree of elasticity, the hair structure does not collapse when it is slightly bent, and can revert to its original state. However, if hair is bent more than a certain amount, its structure changes and it cannot revert to its original state. In other words, the lower the 2HB value, the smaller the degree of structural change due to bending. The measurements in this study showed that 2HB did not differ between HMC+Chol-treated and untreated hair, suggesting that cholesterol may soften hair without loss of bending resistance. As secondarily transpired water, which was found to increase in HMC+Chol-treated hair, is believed to be linked to various hair properties [16] [17], the water retained in the hair may act as a buffer for structural changes in the hair due to bending, making the hair softer.

This study showed that when cholesterol is supplied to the hair cortex and medulla via HMC, the water retention capacity and flexibility of the hair in relation to bending increase. It is known that the lipid and water contents in the hair can vary significantly between the roots, which have just emerged from the scalp, and the ends, which have aged or suffered cumulative damage. It is also reported that the movement of hair with reduced water content due to damage is more likely to stop and to have reduced swing amplitude [2] [3]. As no changes in swing amplitude or duration were found in hair bundles that were subjected to HMC alone or were only immersed in cholesterol solution, it is suggested that HMC + cholesterol treatment fills the voids in hair, and reliably provides intra-hair lipids, thereby improving and homogenising the physical properties of individual hairs, which in turn makes the hair swing more flexibly and cohesively.

5. CONCLUSION

This study succeeded in enabling cholesterol, which usually only penetrates to the cuticle, to penetrate the hair interior, including the medulla. As a result, the hair swing amplitude and duration increased, and the hair became more flexible from the root to the tip, making it more manageable even after it had stopped swinging. The cholesterol-impregnated hair was able to retain more water internally, and was more flexible, bending with less force. This suggests that the properties of hair can be changed readily by enabling penetration of the hair through HMC.

In the future, it may be possible to develop shampoos that provide HMC, thereby promoting the penetration of hair-repair components in treatments and out-bath products, and improving the effectiveness of home-care products by measures including HMC at hairdressing salons. Thus, this research has uncovered new opportunities for hair care.

Conflict of Interest Statement

NONE.

Reference

1) H Kamijo, A Tomita, T Toda, et al (2021) Influences of hair set and makeup on attractiveness and cleanliness. 26th JFACE Annual Conference (Forum Kaogaku 2021).
2) E Schulze zur Wiesche, N Focht, F J Wortmann (2015) The swinging behaviour of human hair: a novel method to quantify hair collective movements. Proceedings of IFSCC Conference 2015 Zurich.
3) L Bechthold, E Schulze zur Wiesche, F J Wortmann (2018) Morphological Changes of Human Hair Related to "Graying" J. Cosmet. Sci. 69(5):335–346.
4) N Fuse, M Matsui (2019) Noval Hair Conditioning System to Modulate the Cuticle Bi-Metallicity. J. Soc. Cosmet. Chem. Jpn. 53(4):278-286.
5) T Takahashi, A Mamada, S Breakspear, et al (2015) Age-dependent changes in damage processes of hair cuticle. Journal of Cosmetic Dermatology 14(1):2-8.
6) K Watanabe, K Suzuta, H Takano, et al (2015) 3D images of human hair using X-ray CT method with age. Journal of JSSRR 28(5):210-213.
7) K Nishimura, M Nishino, Y Inaoka, et al (1989) Interrelationship between the hair lipids and the hair moisture. J. Jpn. Cosmet. Sci. Soc. 13:134-139.
8) R Kuwabara, Y Saito, T Imai, et al (2012) Observation of Water Distribution in Damaged Human Hair by Cryo-SEM. J. Soc. Cosmet. Chem. Jpn. 46(4):264-270.
9) S Kobayashi, K Watanabe, K Suzuta, et al (2021) Effects of Hair Bleaching on the Structure of Cell Membrane Complex in the Cuticle and Water Sorption Behavior. Spring-8/SCALA Research Report 9(5):337-342.
10) T Mannari, K Toda, T Hirayama et al (2020) A Novel Concept "Hair Medulla Care" -Unveiling hair medulla structurecan change grey hairs appearance-. Proceedings of IFSCC Congress 2020 Yokohama.
11) T Hirayama, R Kanazawa, K Toda et al (2021) A new approach to obtain attractive hair "Hair Medulla Care". Proceedings of IFSCC Conference 2021 Mexico.
12) S Yamashita, Y Matsui, T Takano, et al (2012) A Sytudy of Heat Damage to Hair and How to Indicate Heat Damage J. Soc. Cosmet. Chem. Jpn. 46(3):219-223.
13) T Takahashi (2019) A highly resistant structure between the cuticle and the cortex of human hair. II. CARB, a penetration barrier. International Journal of Cosmetic Science, 41(1):28-35.
14) Seiwa Kasei Co,Ltd. (2009) Multifunctional hybrid polymer "PROTESIL (R) LH / GLH". Fragrance J. 37(6):60-61.

15) C. Barba, M. Martí, J Carilla, et al (2013) Moisture sorption/desorption of protein fibres. J. Thermochimica Acta. 552:70-76.
16) J B Speakman (1929) The rigidity of wool and its change with adsorption of water vapour. Trans. Faraday Soc. 25:92-103.
17) Y Ota, A Fukumashi, Y Nishimura, et al (1996) The Effect of Water Molecules on Viscoelastic Properties of Human Hair. journal of the Society of Fiber Science and Technology Japan 52(1):43-48.