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"Better hair, better you: A hair transformation technology that remodels keratin bonds with the precision of art."

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1. Introduction

Hair is more than just part of the body—it is a way to express identity, individuality, and diversity [1]. Many people have problems with frizzy hair or want to achieve their ideal hairstyles through straightening or curling. While salon treatments are effective, they come with drawbacks such as time commitment, high costs, and potential damage from harsh chemicals [2]. Moreover, existing home-use products are insufficient in both their effectiveness and the longevity of their effects [3]. To address these constraints, we attempted to develop a personalized hair styling technology that combines safety and convenience with salon-level effectiveness. Through extensive research, we focused on the mechanism of straightening and waving perms in hair salons, particularly the recombination of disulfide bonds in hair keratin, and discovered the effectiveness of Tetrasodium Disuccinoyl Cystine (TDC、Figure 1) [4]. In this study, we report the effects of TDC on both straightening and curling hair, as well as its benefits for hair health and the underlying mechanisms. Furthermore, we also present the development of a novel AI-based evaluation method to assess the impact of this hair care technology on people's well-being.

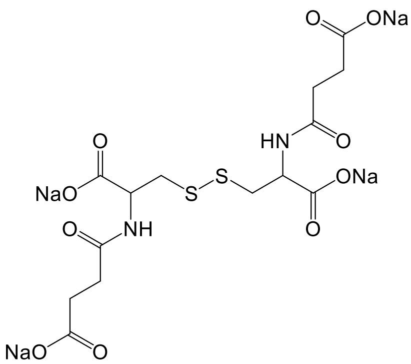

Figure 1. Molecular structure of tetrasodium disuccinoyl cystine.

2. Materials and Methods

2-1. Test to Straighten Curly Hair

As test samples, we prepared a 0.3% aqueous solution of TDC adjusted to pH4 with citric acid and a control solution of pH4-adjusted citric acid, both filled into mist containers. Brazilian human hair with natural curls (Amazon, Kinky Curl 14SIZE, UNPROCESSED HUMAN HAIR) was cut into 0.5g bundles, washed with a 10% sodium lauryl sulfate solution, and dried for 1 minute using an 80°C dryer. Approximately 1g of each solution was sprayed onto the hair bundles, followed by 30 seconds of drying with an 80°C dryer. The bundles were then treated five times with a 130°C hair iron (Osaka Brush, Professional Digital Slim Curve Hair Iron, PBHP-500). Ten randomly selected hairs from the treated samples were cut at 10cm from the root. The maximum curl width of each hair was measured, and the average value across 10 strands was calculated.

2-2. Test to Curl Straight Hair

As test samples, we prepared 0.1% aqueous solutions of TDC adjusted to pH4 or pH6 with citric acid, along with control solutions of citric acid at matching pH levels. Indian black hair (Beaulax, BS-B4-3) was prepared in 1g bundles, cleansed with a 10% sodium lauryl sulfate solution, and dried for 1 minute using an 80°C dryer. The initial length (L) of suspended hair bundles was measured. These bundles were then immersed in 50g of each test solution for 5 minutes, rinsed under running water for 5 seconds, and blotted dry with paper towels. The hair was wrapped around 20mm diameter rods secured with rubber bands and left undisturbed for 15 minutes. After drying for 5 minutes with a 120°C dryer, bundles were removed from rods and their length (L_0) measured. Subsequently, bundles were suspended for 60 minutes in a constant temperature/humidity chamber (40°C, 80% RH). The immediate post-conditioning length (L_t) was measured to calculate Set Retention (SR) using the formula below, with average values derived from three measurements:

$$SR = [(L - L_t) / (L - L_0)] \times 100$$

2-3. Hair elasticity evaluation

As test samples, we prepared a 0.3% aqueous solution of TDC adjusted to pH4 with citric acid and a control solution of pH4-adjusted citric acid, both filled into mist containers. Indian black hair (Beaulax, BS-B4-3) was prepared in 3g bundles, cleansed with a 10% sodium lauryl sulfate solution, and dried for 1 minute using an 80°C dryer. Each bundle was sprayed with approximately 2g of test solution, followed by 30 seconds of drying with an 80°C dryer. The hair was then treated 40 times with a 230°C hair iron (Osaka Brush, Professional Digital Slim Curve Hair Iron, PBHP-500). From the treated hair, ten randomly selected strands were grouped into test bundles. Weights (0.1g each) were attached to both ends of each bundle, which was then cut to maintain a 10cm span between weights. The weighted bundles were suspended over a 0.5cm diameter rod at their midpoint, and the maximum sagging distance between strands was measured. Three replicate bundles were prepared per sample, with average values calculated from these measurements. Greater sagging distances indicate superior hair elasticity.

2-4. Observation of cuticle by SEM and EDS

Hair bundles (Beaulax, BS-B-A) were immersed in a 1% aqueous TDC solution for 10 minutes. The samples were rinsed under tap water, blotted dry with paper towels, and dried for 3 minutes using a 100°C dryer. A portion of these bundles was heated at 120°C for 20 minutes. The treated hair was cut into 1cm lengths, mounted on metal stages with conductive carbon tape, and sputter-coated with gold (20 mA, 60 seconds) for observation using a scanning electron microscope (SEM, JEOL, JSM-7200F). Untreated hair served as controls. Observations were conducted in secondary electron (SE) mode with an accelerating voltage of 1.0 kV and working distance (WD) of 10.0 mm. For elemental analysis, TDC-treated hair (without 120°C heating) underwent elemental analysis using the SEM's energy-dispersive X-ray spectroscopy

(EDS) system. Measurements were performed at 20.0 kV accelerating voltage and probe current 14 (relative value), with sodium (Na) distribution mapped.

2-5. Evaluation of hair penetration by MS imaging
We prepared 1% aqueous TDC solutions adjusted to pH4 or pH6 using citric acid. Black human hair (Beaulax, BS-B-A) and bleached human hair (Beaulax, BM-W-A) from Viewlux Co., Ltd. were cleansed with a 10% sodium lauryl sulfate solution, further rinsed with ethanol, and immersed in each test solution for 10 minutes. After blotting dry with paper towels, samples were dried for 5 minutes using an 80°C dryer. Only bleached hair immersed in the pH4 solution received additional treatment with a 180°C hair iron (Osaka Brush, Professional Digital Slim Curve Hair Iron, PBHP-500) applied 10 times. Longitudinally split hair samples underwent TDC imaging of cross-sections using an optical microscope iMScope TRIO (Shimadzu Corporation). Imaging parameters included:

・Laser shots: 80

・Laser intensity: 65.0

・Detector voltage: 2.1 kV

・Spatial resolution: 11 × 11 μm

・Magnification: 10×

・Acquisition mode: Positive ion

2-6. Confirmation of D-space change by X-ray
Hair bundles (Beaulax, BS-B-A) were immersed in a 1% aqueous TDC solution for 10 minutes. After rinsing under tap water and blotting dry with paper towels, the samples were dried for 3 minutes using a 100°C dryer. Time-resolved X-ray diffraction measurements were performed on these treated hairs using the diffraction X-ray blinking (DXB) method at the KEK Photon Factory NW12A beamline. The experimental setup included:

・X-ray detector: PILATUS3 2M (S/N: 24-0140, DECTRIS Ltd.)

・X-ray wavelength: 1.0 Å

・Detector distance: 109.35 mm

・Acquisition parameters: 5,000 frames at 500 ms intervals (total ~2,500 seconds)

・Image dimensions: 1,475 × 1,679 pixels

Continuous frame images were processed using ImageJ to create a maximum intensity projection (MIP) by extracting peak intensity values from Z-stacked images. Diffraction intensities were analyzed in the one-dimensional region between the diffraction center and the 5.1 Å keratin-derived diffraction peak [5].

2-7. Happiness assessment using Beauty AI
We evaluated well-being changes in 10 Japanese residents (3 males, 7 females, aged 20-60s, including 2 foreign nationals) after curl-care treatment using a 0.3% TDC mist solution and hair iron (TESCOM NBS1200). Participants rested for 30 minutes in a controlled-environment beauty salon (22°C, 50% RH) before baseline measurements:

・Waviness improvement

・Questionnaire response trends

・Beauty AI score

Licensed stylists applied test solution based on hair length:
・Short: about 1g
・Medium: about 2g
・Long: about 3g

Hair was straightened using 130°C irons, followed by post-treatment measurements. Comparative analysis of befor/after data included:
・Waviness improvement
・Questionnaire response trends
・Beauty AI score

Well-being scores were calculated through weighted integration of these parameters, prioritizing factors showing significant inter-metric correlations.

2-7-1. Waviness improvement evaluation
Photographs of the back of the subjects' heads were taken from behind, and these images were analyzed. Vertical lines perpendicular to the ground were drawn through both shoulders of each subject, and the center line between these two lines was defined as the center of the head. The lower 70% of the area where hair overlapped this center line was set as the region for evaluating the degree of waviness (Fig. 2, left). The waviness of the hair was visually assessed by drawing polylines along the flow of the hair (Fig. 2, center). The angle between each line and the line extended from the adjacent, more superior line was measured, and the largest angle was defined as the degree of waviness (Fig. 2, right).

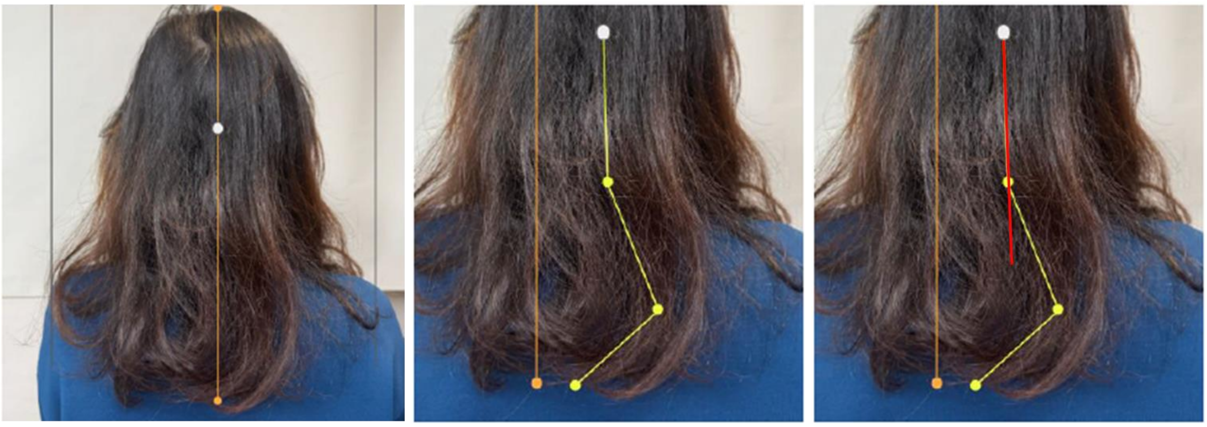
Figure 2. Method for Assessing Hair Waviness.

2-7-2. Evaluation by Beauty AI Technology
Beauty AI Technology (Komachi-no-kagami-demo, Ver68) owned by WellBy Inc. was used. The AI analyzed a 30-second video and calculated a score based on autonomic nervous activity, heart rate, respiratory rate, facial redness, mouth corner angle, and facial age.

2-7-3. Questionnaire
We conducted the following questionnaire.

[Well-being Questionnaire (5-point scale: 1–5)]
(1) Are you satisfied with your current hairstyle?
(2) Are you satisfied with the current condition of your hair?
(3) Do you feel positive when you look in the mirror?

3. Results

3-1. Test to Straighten Curly Hair

The results of the measurement of hair curl width in the treated samples are shown in Table 1.

Table1. Test to Straighten Curly Hair Results.

Sample	Maximum curl width (cm)
No TDC	1.90
TDC 0.3%	1.30

TDC-treated hair exhibited a reduced curl width, suggesting that TDC has the effect of straightening curly hair.

3-2. Test to Curl Straight Hair

The results of SR value measurements for the treated hair are shown in Tables 2 and 3.

Table2. Test to Curl Straight Hair Results (pH4).

Sample	L	L_0	L_t (60)	SR (60)
No TDC	35	11.8	33.7	5.7
TDC 0.1%	35	11.8	31.7	14.4

Table3. Test to Curl Straight Hair Results (pH6).

Sample	L	L_0	L_t (60)	SR (60)
No TDC	35	11.7	33.7	5.7
TDC 0.1%	35	12.8	32.3	12.1

TDC-treated hair showed high SR values at both pH 4 and pH 6, suggesting that TDC has the effect of maintaining curls. Furthermore, since the effect was still observed after storage for 60 minutes under high temperature and high humidity conditions, it is considered that the effect is also long-lasting.

3-3. Hair elasticity evaluation

The results of elasticity measurements for the treated hair are shown in Table 4.

Table4. Hair elasticity evaluation Results.

Sample	Maximum distance between sagging hair bundles (cm)
untreated hair	2.53
No TDC	1.67
TDC 0.3%	3.07

Hair treated with the TDC-free solution showed decreased elasticity compared to untreated hair, whereas hair treated with the TDC-containing solution exhibited even greater elasticity than untreated hair, suggesting that TDC imparts resilience and strength to hair.

3-4. Observation of cuticle by SEM and EDS

The SEM image of untreated hair is shown in Figure 3, and the SEM image of TDC-treated hair is shown in Figure 4.

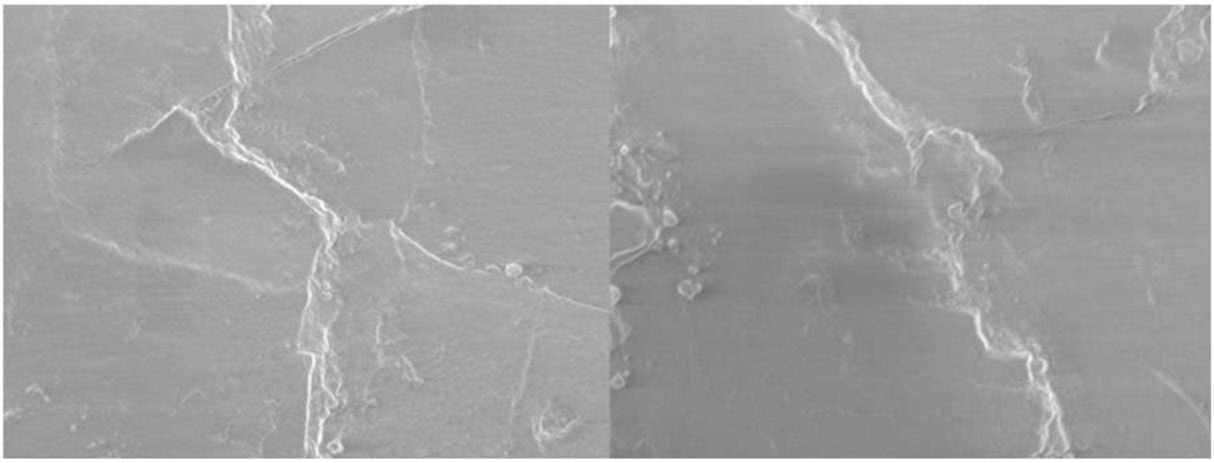

Figure 3. No TDC treatment. Left: without 120°C heating, right: with 120°C heating. 10,000× magnification.

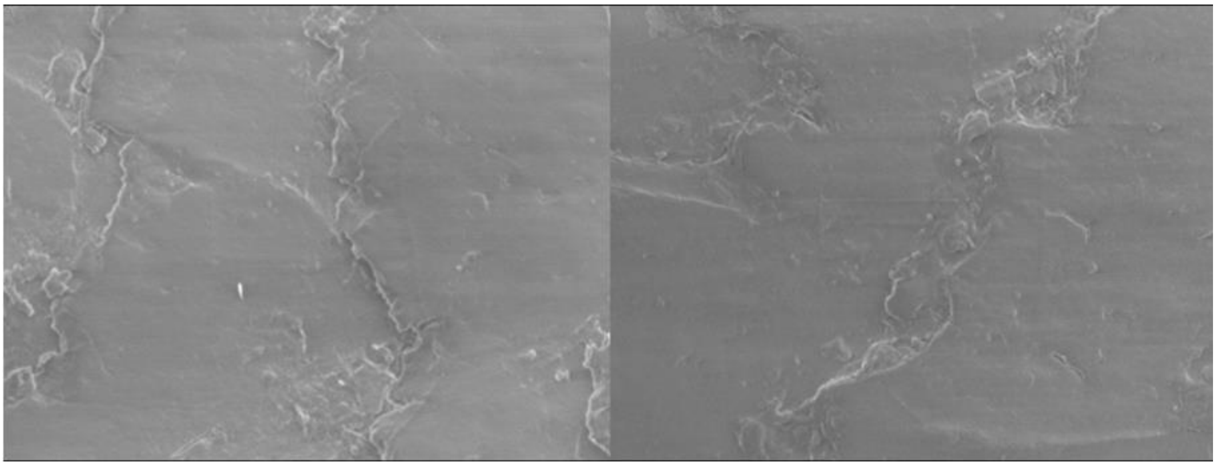

Figure 4. With TDC treatment. Left: without 120°C heating, right: with 120°C heating. 10,000× magnification.

Regardless of whether 120°C heating was applied, untreated hair exhibited lifted and peeling cuticle edges (Fig. 3). In contrast, TDC-treated hair showed tightly adhered cuticles under both heated and non-heated conditions (Fig. 4). These findings suggest that TDC has the effect of inhibiting cuticle lifting.

Next, the EDS analysis results of TDC-treated hair are presented in Figure 5. Since sodium ions were undetectable in untreated hair and TDC contains sodium, sodium mapping was employed to verify TDC presence.

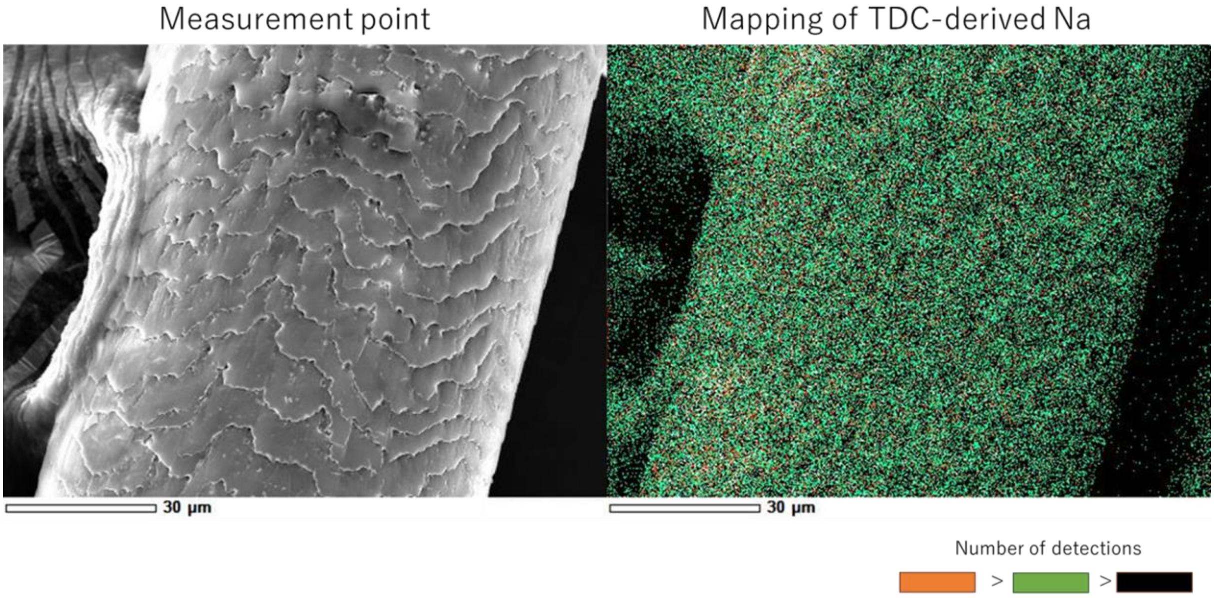

Figure 5. Mapping of TDC-derived Na.

TDC was highly detected along the hair cuticle, suggesting that as TDC penetrates into the hair from the cuticle boundaries, it may also exert effects on the cuticle itself.

3-5. Evaluation of hair penetration by MS imaging
The results of TDC imaging in hair cross-sections are shown in Figure 6.

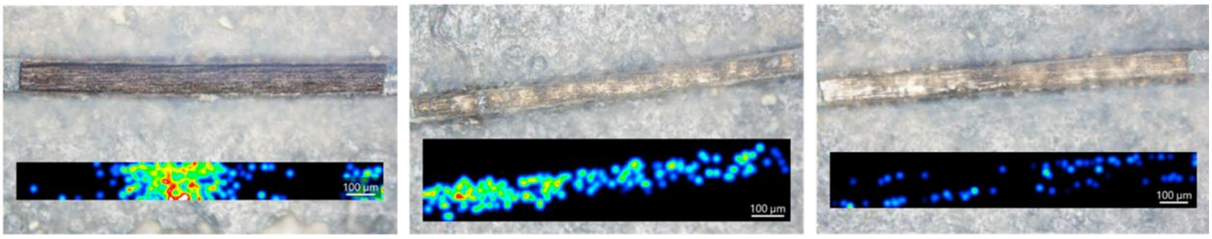

Figure 6. Imaging of TDC in hair cross-sections. Left: black hair, center: bleached hair, right: heat-treated bleached hair.

TDC was detected in both black hair and bleached hair, but was scarcely detected in heat-treated black hair. It is considered that TDC reacts with keratin and other components inside the hair upon heating, resulting in its disappearance.

3-6. Confirmation of D-space change by X-ray
The results of D-space analysis are shown in Figure 7.

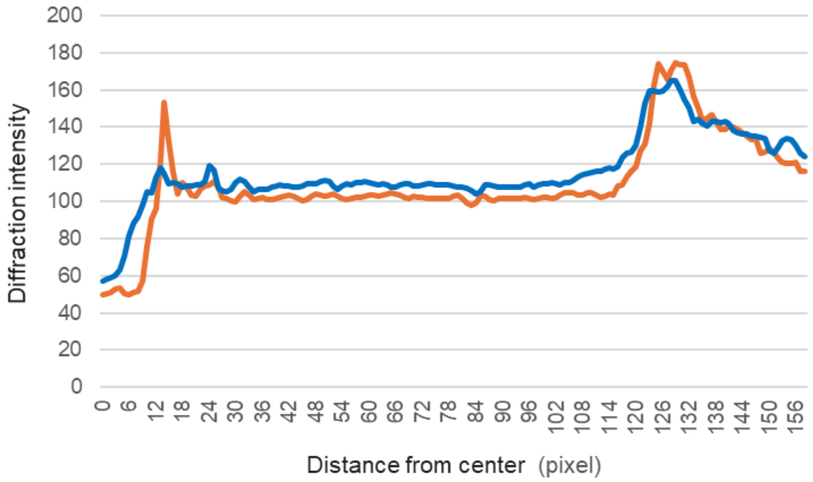

Figure 7. Changes in d-space. Blue: untreated, orange: TDC-treated.

The diffraction pattern analysis revealed that the distance from the center was 124-132 for untreated hair, while TDC-treated hair showed a smaller range of 121-130. This indicates an increase in d-space. Since the 5.1 Å peak corresponds to the keratin fiber axis direction, these results suggest TDC reacts with keratin to induce structural reorganization along the fiber axis.

3-7. Happiness assessment using health analysis AI

The results obtained from each evaluation are shown in Table 5, and an example of hair waviness improvement is shown in Figure 8.

Table5. Results of waviness, Beauty AI Technology, and questionnaire.

Subject	Waviness improvement			Beauty AI Technology score			Questionnaire					
							Before treatment			After treatment		
	Before treatment	After treatment	Amount of change	Before treatment	After treatment	Amount of change	(1)	(2)	(3)	(1)	(2)	(3)
01F	15	10	5	80	80	0	4	2	3	5	5	5
02M	20	11	9	81	78	-3	4	3	5	5	5	5
03F	61	8	53	72	74	2	1	2	2	5	5	5
04F	18	2	16	80	78	-2	2	3	3	5	5	5
05M	45	9	36	71	79	8	3	3	4	4	3	5
06F	70	5	65	78	85	7	3	3	3	4	4	4
07M	44	21	23	84	82	-2	2	2	3	4	4	3
08F	20	8	12	72	73	1	2	2	2	4	4	3
09F	51	2	49	78	78	0	3	2	2	4	4	4
10F	34	10	24	78	80	2	4	2	3	5	5	5

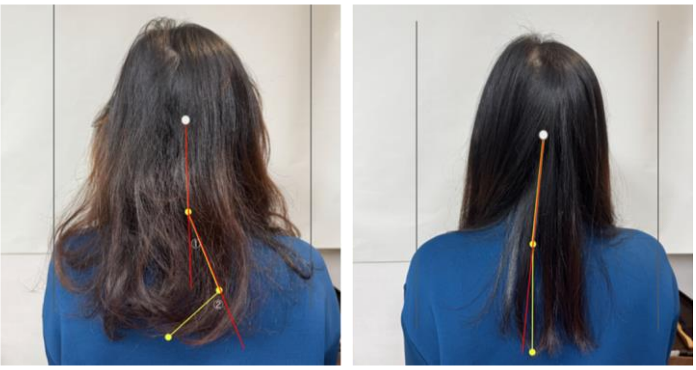

Figure 7. Changes in hair waviness before and after treatment (06F).

A paired t-test comparing the degree of waviness before and after treatment showed a statistically significant difference (p-value = 0.0196) at the 5% significance level. Hair in subjects whose waviness improved was neatly aligned. There was a moderate negative correlation between the degree of waviness and feelings when looking in the mirror: the correlation coefficient was -0.28 before treatment and -0.33 after treatment. This means that people with a higher degree of waviness tended to feel more negative when looking in the mirror. A strong correlation (correlation coefficient: 0.62) was observed between the amount of change in the health analysis AI index and the amount of change in the degree of waviness. Analyzing the amount of change for each individual revealed that the more the waviness improved, the better the Beauty AI score became. Furthermore, analysis of the amount of change for each individual also showed a clear strong correlation (correlation coefficient: 0.57) between the degree of improvement in feelings when looking in the mirror and the health analysis AI index.

Based on these results, we defined an index called “well-being” by combining the results of feelings when looking in the mirror (questionnaire) and the Beauty AI score, and assigned weighting coefficients that produced the highest correlation coefficient with well-being through simulation. Here, since the Beauty AI score ranges from 0 to 100, while the questionnaire uses a 5-point scale, the questionnaire score was multiplied by 20 to standardize the scale.Well-being was calculated using the following formula:
Well-being score = (Beauty AI score) × 0.8 + (questionnaire result × 20) × 0.2

The changes in well-being and waviness are shown in Table 6.

Table6. The changes in well-being and waviness

Subject	Well-being change amount	Waviness improvement change amount
01F	8	5
02M	-2.4	9
03F	13.6	53
04F	6.4	16
05M	10.4	36
06F	9.6	65
07M	-1.6	23
08F	4.8	12
09F	8	49
10F	9.6	24

A strong correlation was observed between the change in well-being and the change in waviness degree (correlation coefficient: 0.57). This indicates that the more the waviness improves, the greater the increase in well-being. In addition, since the average waviness degree before treatment was 38, we used 38 as the threshold to divide the subjects into groups, and conducted a correlation analysis between the change in waviness degree and the change in well-being. When comparing the group with initially low waviness and the group with initially high waviness, the correlation coefficient between the change in well-being and the change in waviness degree was 0.45 in the group with low initial waviness, and 0.72 in the group with high initial waviness. It was found that the greater the initial waviness, the greater the change in well-being when the waviness improved.

4. Discussion

TDC could both straighten curly (wavy) hair and curl straight hair, with its effects enhanced by heat from tools like flat irons. While excessive use of heat styling tools typically damages hair, our research showed that TDC-treated hair not only avoided damage but gained elasticity. Scanning electron microscopy and energy-dispersive X-ray spectroscopy analysis of the hair surface revealed that TDC aligned along cuticle edges and likely penetrated from these boundaries. TDC-treated hair also showed reduced cuticle lifting after flat iron use. Mass spectrometry imaging and X-ray D-space analysis confirmed that TDC penetrated the hair and bonded with internal keratin. We plan to elucidate the three-dimensional structure formed by keratin and TDC within hair in the future.

Furthermore, we also considered conducting human trials. It was confirmed that our developed technology could actually improve hair waviness, and additionally, that it resolved hair-related concerns, brightened participants' feelings when looking in the mirror, and increased their sense of well-being. Notably, these positive effects were consistently observed regardless of participants' gender or nationality, demonstrating the broad applicability and inclusivity of our technology. Evaluations of cosmetic use employing AI are beginning to be explored worldwide [6], and our newly developed research combining hair care efficacy, questionnaires, and AI has the potential to contribute to future studies.

5. Conclusion

Unlike salon treatments that use alkaline agents and oxidizers, our technology provides highly effective results without these harsh chemicals, ensuring both superior safety and reduced damage. This represents a true home-use adaptation of salon technology. We named this technique, which allows hair to be styled as freely and artistically through keratin remodeling, “hair transformation technology.” This innovative cosmetic solution, which promotes healthy and beautiful hair while allowing easy personalization of hairstyles, contributes to people's well-being and opens up a future where more individuals can freely pursue and achieve their ideal styles. Importantly, our technology demonstrated efficacy across participants of different genders and nationalities, highlighting its inclusivity and adaptability to diverse hair types and backgrounds. By addressing the needs of a broad range of users, this approach not only empowers individuals to express their unique identities but also contributes to advancing diversity and inclusivity in the beauty industry.

6. References

[1] Jodi Manning, Western Connecticut State University, The Sociology of Hair: Hair Symbolism Among College Students, Social Sciences Journal, 2010.
[2] Joane Nathache Hatsbach de Paula et al., Universidade Federal do Paraná, Effects of chemical straighteners on the hair shaft and scalp, Anais Brasileiros de Dermatologia, 2022.
[3] Matilde Bengtsson, Chalmers University of Technology, All-day hair manageability for textured hair types, Master's Thesis, 2016.
[4] Satoshi Ogawa et al., Milbon Co., Ltd., SEN'I GAKKAISHI, 2009.
[5] Alsop, Richard J., et al., Massey University, Structural Abnormalities in the Hair of a Patient with a Novel Ribosomopathy, PLOS ONE, 2016.
[6] Takeshi Tohgasaki et ai., FANCL Corporation, Investigation of stratum corneum cell morphology and content using novel machine‐learning image analysis, Skin Res Technol, 2024.