

A novel cosmetic approach to treat thinning hair

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Summary

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Background Many of today's treatments associated with 'thinning hair', such as female pattern hair loss and telogen effluvium, are focused on two of the key aspects of the condition. Over-the-counter or prescription medications are often focused on improving scalp hair density while high-quality cosmetic products work to prevent further hair damage and minimize mid-fibre breakage. Fibre diameter is another key contributor to thinning hair, but it is less often the focus of medical or cosmetic treatments.

Objectives To examine the ability of a novel leave-on technology combination [caffeine, niacinamide, panthenol, dimethicone and an acrylate polymer (CNPDA)] to affect the diameter and behaviour of individual terminal scalp hair fibres as a new approach to counteract decreasing fibre diameters.

Methods Testing methodology included fibre diameter measures via laser scan micrometer, assessment of fibre mechanical and behavioural properties via tensile break stress and torsion pendulum testing, and mechanistic studies including cryoscanning electron microscopy and autoradiographic analysis.

Results CNPDA significantly increased the diameter of individual, existing terminal scalp hair fibres by 2–5 µm, which yields an increase in the cross-sectional area of approximately 10%. Beyond the diameter increase, the CNPDA-thickened fibres demonstrated the altered mechanical properties characteristic of thicker fibres: increased suppleness/pliability (decreased shear modulus) and better ability to withstand force without breaking (increased break stress).

Conclusions Although cosmetic treatments will not reverse the condition, this new approach may help to mitigate the effects of thinning hair.

The age-related visual and tactile change to terminal scalp hair is frequently interpreted as 'thinning hair' by patients and physicians. Two common diagnostic labels attached to this situation of reducing hair quantity (amount) are female pattern hair loss (FPHL) and telogen effluvium.^{1,2} The patient with thinning hair often compounds the problem by grooming practices that can further weaken existing fibres and, over time, lead to breakage.

Generally, current medical and cosmetic treatments for thinning hair focus on two key aspects of the condition: fibre density and damage prevention. Over-the-counter or prescription medications are often focused on improving scalp hair density^{3,4} while high-quality cosmetic products work to prevent further hair damage and minimize mid-fibre breakage, in addition to masking the appearance of thinning hair. Key among the protective benefits which conditioning ingredients in cosmetic shampoos and conditioners offer are: (i) lubricating the fibre surface to minimize the effects of damaging fric-

tion and/or (ii) temporarily 'gluing' uplifted cuticles to prevent further degradation.⁵ Regular usage reduces the fibre breakage rate, enables grooming routines and imbues the remaining quantity of hair with potentially greater volume to help ameliorate the visual, tactile and even psychological effect of the condition.

Fibre diameter is one of the three key contributors to thinning hair, but it is less often the focus of medical or cosmetic treatments. The age-related changes in fibre diameter often encountered in patients experiencing FPHL^{6,7} not only contribute to the look of thinning hair but also change the fibre's physical and mechanical behaviour. It has been well documented that the mechanical tensile break strength and torsional or twisting properties of a fibre are dependent on its diameter. This, in part, helps explain why thinner hair looks and behaves differently than thicker hair.

The research presented here describes a technology combination that has recently been shown to increase fibre diameter

and to mimic the behaviour of thicker fibres. The combination, which includes caffeine, niacinamide, panthenol, dimethicone and an acrylate polymer (CNPDA), stemmed from efforts to understand potential hair benefits of known skin care ingredients. This report demonstrates CNPDA's ability to thicken individual, existing hair fibres and to alter the fibre's mechanical properties as a novel approach to counteract decreasing fibre diameters and to help treat patients with 'thinning hair'.

This controlled study examined the ability of a novel leave-on technology combination, CNPDA, to affect the diameter and behaviour of individual terminal scalp hair fibres of multiple types – virgin, bleached, fine and thick.

Materials and methods

All hair switches used for technical testing were purchased from International Hair Importers & Products (Glendale, NY, U.S.A.). The CNPDA leave-on treatment is a formula composed of the following ingredients: water, denatured alcohol, panthenol, caffeine, niacinamide, acrylates/C10–30 alkyl acrylate crosspolymer, triethanolamine, PEG/PPG-20/23 dimethicone and fragrance.

Fibre diameter measurements via laser scan micrometer

Fibre diameter measurements via laser scan micrometer were conducted on virgin and bleached hair fibres before and after treatment on a Mitutoyo Laser Micrometer model LSM-500S (Mitutoyo, Aurora, IL, U.S.A.) mounted on a Dia-Stron MTT680 platform tensile tester (Dia-Stron, Andover, U.K.). Prior to diameter measurements, all fibres were wetted and let dry under controlled environmental conditions before baseline measurements to control for hysteresis effects.

The baseline fibre diameter was measured prior to treatment with CNPDA. In total, 50 virgin fibres and 50 bleached fibres were treated with CNPDA by direct immersion into the product and allowed to dry under controlled conditions. Within each fibre type, CNPDA was applied to 25 rewetted fibres and 25 equilibrated dry fibres. Fibres treated with water alone were used as the control. The instrument collected five scans down the length of each 3 cm fibre, and the five replicate measures were then averaged to get the mean parameters for each fibre. Results were averaged within treatment groups and post-treatment diameters were compared with pretreatment readings by paired *t*-test. Significant differences were determined at $P < 0.05$.

Mechanical property testing: tensile and torsion

Tensile and torsion tests were conducted at TRI Princeton (Princeton, NJ, U.S.A.). CNPDA was applied to hair fibres via a plastic dropping pipette. A uniform distribution of product was dispensed down the length of each individual fibre at a dose of 0.25 g CNPDA g^{-1} of hair. The CNPDA remained on the fibres for 1 min before fibres were removed and placed

on a clean Pyrex dish to dry under controlled conditions. All fibres were tested under controlled humidity conditions.

Tensile break stress testing was performed with a Dia-Stron Mini Tensile Tester. Experiments were performed on bleached hair in the dry state at 60% relative humidity (RH). Fifty individual fibres were prepared and tested per sample.

Torsion testing was performed in a bench-top humidity chamber controlled at 80% RH. For each sample (CNPDA-treated or control, which, in this case, was the full formula minus CNPDA), 30 individual fibres were measured. The automated torsion pendulum method was performed by first measuring the fibre dimensions using a scanning laser micrometer. Using a proprietary instrument at TRI Princeton, the fibres were then twisted 360°, released, and the oscillation measured as described by Persaud and Kamath.⁸ The period and decay in amplitude were measured and used to calculate the torsional properties of the fibre. The period, or time between the two peaks representing a full cycle, was determined by the software and used to calculate the shear modulus, (G'), using the equation

$$\text{Shear modulus} = G' = \frac{16\pi LM}{T^2 (a^2b + ab^2)}$$

Where L = fibre length, M = moment of inertia for the pendulum mass, T = period, a = semimajor axis and b = semiminor axis.

Hair surface analysis

Fifteen fibres from CNPDA-treated and control-treated switches of bleached hair were cut 1 cm long, mounted, frozen in liquid nitrogen, sublimed at -95°C for 30 min in the scanning electron microscope chamber, coated with Au/Pd for 45 s, and analysed at -120°C by Hitachi S-4700 FE high resolution scanning electron microscope with PCI imaging software (Hitachi, Tokyo, Japan). To view fibre cross-sections, 10 strands of hair from control and CNPDA-treated hair switches were prepared by peeling hair apart, mounted with the open side of hair facing up, then prepared and analysed as described for the surface analysis.

Autoradiography

Radiolabelled ^{14}C caffeine (MM = 195.9; spec. activity = 53 mCi mmol^{-1} ; concentration = 0.1 mCi mL^{-1}), ^3H niacinamide (MM = 123.9; spec. activity = 26.1 Ci mmol^{-1} ; concentration = 1 mCi mL^{-1}) and ^{14}C panthenol (MM = 202.3; spec. activity = 50 mCi mL^{-1} ; concentration = 0.1 mCi mL^{-1}) were purchased from Moravek (Brea, CA, U.S.A.) and American Radiolabeled Chemicals, Inc. (St Louis, MO, U.S.A.). They were added to the treatment matrix at the appropriate concentration and mixed thoroughly.

Hair treatment protocols were as follows: (i) 2 g hair switches were washed with 0.2 mL of nonconditioning shampoo before being rinsed for 30 s; (ii) 1.3 mL of radiolabelled CNPDA was applied to each of six hair switches and

distributed from root to tip; and (iii) hair was allowed to dry naturally for 8 h before being measured. The blank switch was washed and treated using the same procedure; however, it was treated with the matrix only, void of caffeine, niacinamide and panthenol.

Treated switches were sent to the University of Ghent, where the fibres were sectioned (cross-sections and longitudinal sections) and placed in a photographic emulsion in a dark room for a 4-week exposure time. The radiation forms metallic silver at the place where the radiation touches the emulsion, and the resulting image was viewed with an Olympus Type BX51 microscope (Olympus, Tokyo, Japan).

Results

Impact of CNPDA on fibre diameter

As shown in Table 1, CNPDA resulted in a significant increase in fibre diameter after one application of CNPDA compared with the water control, in both virgin and bleached hair. Variations in the treatment's presence and effect were accounted for by averaging five diameter readings taken along the length of the fibre. There was no difference observed when product was applied to wet vs. dry hair. The thickening effect was observed to be of similar magnitude for thick and fine textured hair, as shown in Table 2, with a diameter increase of approximately 5.8% and 4.3%, respectively (baseline mean \pm SEM fibre diameter $66.9 \pm 1.4 \mu\text{m}$ for fine hair and $90.4 \pm 1.9 \mu\text{m}$ for coarse hair). This diameter increase translates roughly to a 10% increase in the cross-sectional area of an individual fibre.

Fibre mechanical properties

As previously described, thicker fibres are known to have different mechanical properties compared with thinner fibres.⁹

Therefore, the mechanical tensile and torsional properties of treated vs. untreated fibres were monitored to understand whether increased thickness via CNPDA application was accompanied with a change in the fibre's mechanical properties. To accomplish this we employed two methods with a reported history of use in fibre research, tensile extension and torsion pendulum.

Tensile studies

Tensile studies are commonly used in fibre research to understand the stress and strain relationship as a fibre is pulled at a given extension rate. Tensile behaviour is believed to be a function of the fibre cortex as reported studies have shown no change in the tensile properties between a fibre void of cuticle and a completely intact fibre.¹⁰ Break stress is an important tensile property relating to the internal strength of a fibre as it describes how much force is required to break the fibre. Generally, the larger the fibre the more force is required before breakage occurs.

Results of the treated vs. untreated break stress studies shown in Figure 1 indicate that CNPDA can change the tensile properties of hair by increasing the break stress of bleached hair fibres. Bleached hair is commonly used as the substrate in break stress studies to improve the understanding on how well a treatment can alter the behaviour of a damaged fibre. This suggests that CNPDA can improve the internal strength of a hair fibre after one application.

Torsion studies

Torsion studies, like the tensile method, came to human hair research from the wool industry, where they were used to understand a fibre's rigidity and ultimate tactile comfort.^{8,11,12} These studies are performed by suspending a single fibre from a weighted pendulum, twisting the suspended fibre 360°,

Table 1 Mean \pm SEM hair fibre diameter increase measured via laser scan micrometer for individual hair fibres

Hair type	Baseline diameter, μm	Post-treatment diameter, μm	n	P-value ^a	Mean diameter increase, μm	% increase
Water-treated virgin hair	72.4 ± 2.4	72.4 ± 2.6	22	0.99	0.0 ± 0.46	0
CNPDA-treated virgin hair	74.0 ± 1.7	77.0 ± 1.6	36	< 0.0001	3.1 ± 0.7	4.2
Water-treated bleached hair	70.2 ± 1.9	69.4 ± 1.9	25	0.12	-0.8 ± 0.5	-1.1
CNPDA-treated bleached hair	68.8 ± 2.0	72.6 ± 2.2	36	< 0.0001	3.9 ± 0.5	5.6

^aPaired t-test treated vs. baseline.

Table 2 Mean \pm SEM fibre diameter changes with CNPDA on fine and coarse textured hair

Hair type	Baseline diameter, μm	Post-treatment diameter, μm	n	P-value ^a	Mean diameter increase, μm	% increase
Coarse textured	90.4 ± 1.9	95.6 ± 1.6	44	< 0.0001	5.2 ± 1.1	5.8
Fine textured	66.9 ± 1.4	69.8 ± 1.4	41	< 0.0001	2.9 ± 0.4	4.3

^aPaired t-test treated vs. baseline.

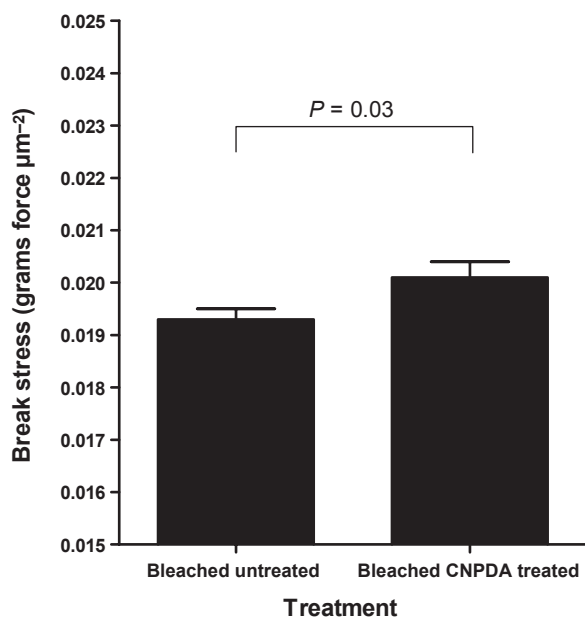


Fig 1. Fibre break stress for CNPDA-treated hair fibres at 60% relative humidity. Data reported as mean \pm SEM.

then releasing the fibre and monitoring how it oscillates back and forth until the energy is released. Given the geometric dispersion of the twisting force, one can attribute the torsional behaviour of a hair fibre to the fibre's cuticle layer.

To understand a fibre's pliability or suppleness, one needs to examine the shear modulus, which is a measure of a fibre's ability to resist a twisting action. The shear modulus of hair decreases as fibre diameter increases,⁸ as was observed in the shear modulus test comparing CNPDA-treated with untreated fibres. The decrease in shear modulus was observed from the first application on both bleached and virgin hair and continued lowering with repeated application of CNPDA to bleached hair (Fig. 2a, b). The effect was independent of RH, as indicated by the results of the studies conducted at both 20% and 80% RH, demonstrating that the resultant fibre plasticization is due to the CNPDA treatment, not just the hydration state of the fibre (Fig. 2a). The plasticization effect was more pronounced when the trio of caffeine, niacinamide and panthenol was included in the formula (Fig. 2b). These data suggest that CNPDA, and specifically the caffeine, niacinamide and panthenol trio, adds flexibility or suppleness as characterized by reduced shear modulus, in addition to the diameter increase.

Mechanistic research

To understand CNPDA's mechanism of action throughout the fibre, methods including cryoscanning electron microscopy and autoradiography were used. Deposits on and between hair's cuticle layer were observed via cryoscanning electron microscopy to augment the fibre's baseline diameter, as shown in Figure 3. Under cryogenic conditions, the morphology and location of deposited materials are preserved during the scanning electron microscopy analysis.

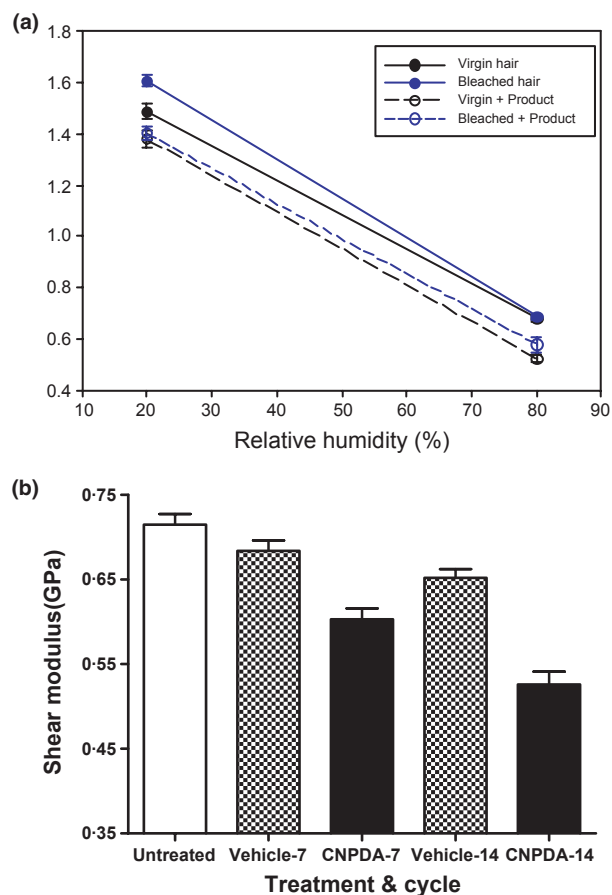


Fig 2. Torsional shear modulus of treated hair fibres. (a) Shear modulus of virgin and bleached hair fibres at 20% and 80% relative humidity before and after one treatment with CNPDA. (b) Shear modulus of bleached hair fibres equilibrated at 80% relative humidity before and after multicycle treatment with CNPDA or vehicle control. Data reported as mean \pm SEM.

The change in the fibre's mechanical properties suggested that at least some ingredients within CNPDA were acting beyond the fibre's surface as a fibre's mechanical properties generally stem from within the cuticle and cortex. Specifically, a fibre's break stress is linked to the cortex⁸ and the torsional properties depend on the cuticle layer.⁸ Caffeine, niacinamide and panthenol are significantly lower molecular weight molecules than the dimethicone or acrylate polymer; therefore, they have greater potential for penetrating into the fibre. To understand the connection between the behavioural changes and the three small molecules, autoradiographic studies were conducted with radiolabelled versions of caffeine, niacinamide and panthenol.

Autoradiographic images of cross-sections and longitudinal sections of CNPDA-treated fibres show both deposition on to and significant penetration into bleached fibres by caffeine, niacinamide and panthenol (Fig. 4). Differential extraction and high-performance liquid chromatography studies (data not shown) indicated that caffeine, niacinamide and panthenol also penetrate into virgin hair fibres, although autoradiography

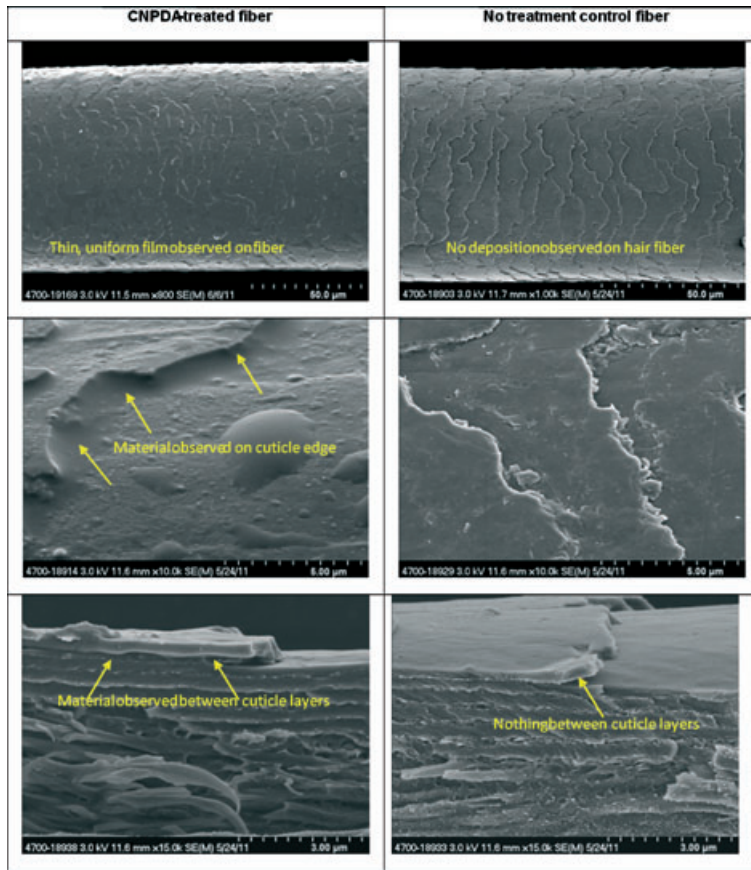


Fig 3. Cryoscanning electron microscopy images showing CNPDA deposits on fibre surface and between cuticle layers in cross-sectional view.

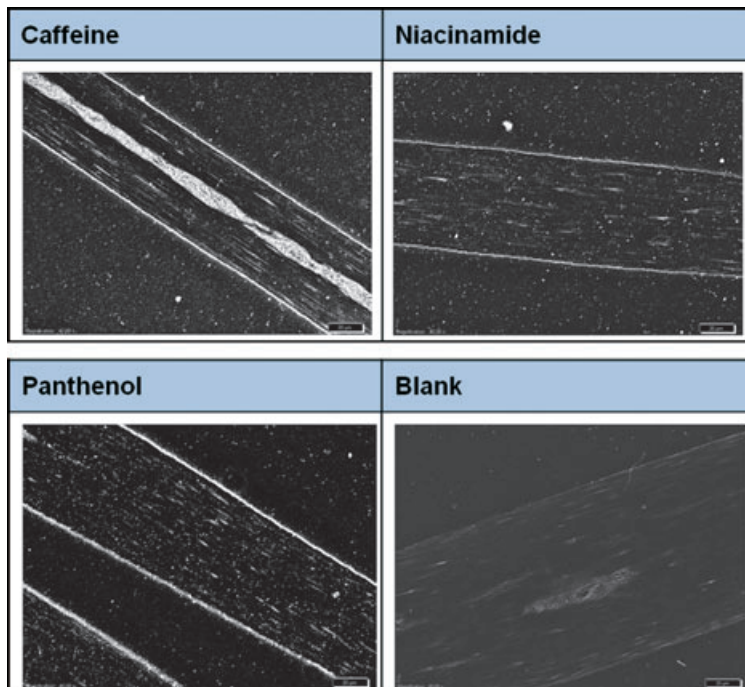


Fig 4. Autoradiographic images with caucasian, bleached hair: white represents the radioactive compound penetrated into and deposited on the surface of the hair fibre. The higher the intensity, the more radiolabelled material was detected.

was conducted only on bleached hair. All monitored analytes appeared with a highly concentrated ring of deposition and penetration throughout the cuticle region of the fibres, most likely in the intercellular regions as indicated by the regular

distribution pattern. It should be noted that variation in signal intensity across analytes was expected as the concentrations of the analytes in the treatment are not equal [(niacinamide) > (caffeine) > (panthenol)] and niacinamide's tritium

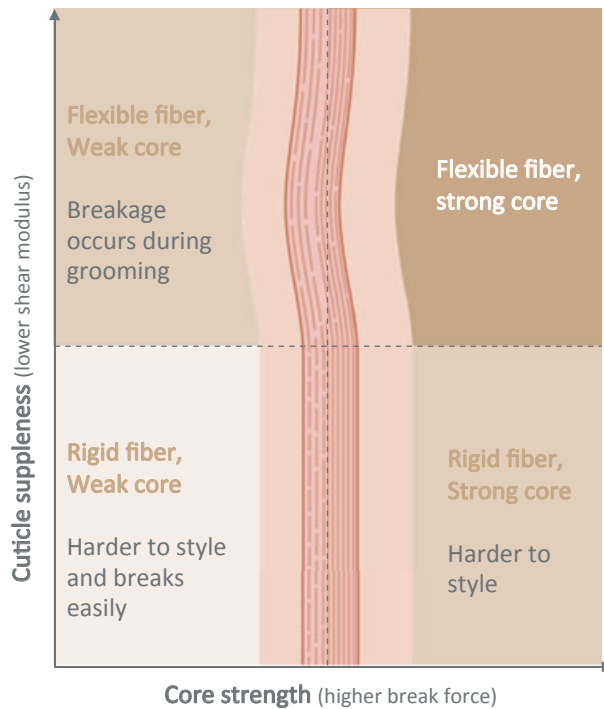


Fig 5. Aesthetic effects of changes in fibre suppleness and core strength.

label gives a less intense signal than the ^{14}C label used with caffeine and panthenol.

Discussion

A novel technology combination, CNPDA, in leave-on form was determined to produce a significant increase in the diameter of individual, existing terminal scalp hair fibres of multiple types – virgin, bleached, fine and thick. The 2–5 μm increase in diameter yields an increase in the cross-sectional area of approximately 10%, which has potential for a considerable cumulative thickening effect when applied to the thousands of fibres on a head of hair.

Beyond the diameter increase, the CNPDA-thickened fibres demonstrated the altered mechanical properties characteristic of thicker fibres: increased suppleness/pliability (decreased shear modulus) and better ability to withstand force without breaking (increased break stress). Taken together with the findings from the autoradiographic penetration studies, it is possible that the small CNPDA ingredients, specifically caffeine, niacinamide and panthenol, have a strengthening and softening effect as they penetrate throughout the cuticle layer and into the cortex layer. Caffeine, niacinamide and panthenol also appear to have a combined, chronic effect on the fibre's pliability/suppleness as the torsional improvements were observed to increase with repeated use.

For patients experiencing thinning hair, specifically thinning fibre diameters, it is important for grooming purposes that a thickening treatment improves both the tensile and torsional

properties, as explained in Figure 5. If only the torsional properties were improved, the fibre would be flexible yet weak, and therefore prone to breakage which only compounds the appearance of thinning hair. With improvements in tensile properties only, the fibre is strong yet rigid, which can be challenging to style and aesthetically undesirable. With improvements in both torsional and tensile properties, hair becomes stronger and more flexible, leaving it easier to manipulate into desired styles while having an increased ability to remain intact during the grooming process.

The psychological impact of FPHL can be reduced by cosmetic products that improve the properties of the hair, whether as stand-alone treatment or as adjunct therapy to other therapies. This novel leave-on technology combination (CNPDA) has been shown to increase the diameter and alter the mechanical properties of existing, individual scalp fibres. Although cosmetic treatments will not reverse the condition, this new approach may help to mitigate the effects of thinning hair.

What's already known about this topic?

- Many of today's treatments associated with thinning hair, such as female pattern hair loss and telogen effluvium, are focused on two of the key aspects of the condition: scalp hair density and fibre damage levels.
- Fibre diameter is another key contributor to thinning hair, but it is less often the focus of medical or cosmetic treatments.

What does this study add?

- Evidence for the ability of a novel leave-on technology combination to increase the diameter and alter the mechanical properties of existing, individual scalp fibres as a new approach to counteract decreasing fibre diameters, commonly associated with thinning hair.

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