Comparative Evaluation of Hair Density and Grouped Hair Unit Pattern between Androgenetic Alopecia and Normal Scalp

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Background: Human hair usually emerges from the scalp in groups of 2 or 3-hair units. Hair densities and grouping patterns in androgenetic alopecia (AGA) patients are known to be different from those in normal adults, but no comparative study has ever before been made in Korea. Therefore we have developed some technical improvements on phototrichogram methodology to evaluate the differences between these two groups.

Objectives: This study was performed to quantify Koreans' hair characteristics at each site (vertex, occipital, temporal) of the scalp according to the age and to compare the differences of hair characteristics of AGA and normal adults using phototrichogram.

Methods: Hairs in the precisely defined circle at each (vertex, temporal, occipital) site of the scalp in 37 AGA male patients and 15 healthy male volunteers were evaluated according to age. Each circumscribed area of the scalp, centered with a dot tattoo to ensure reproducibility, was photographed just after shaving, and named 'primary image'. Two days later, the same area was again photographed, and named 'secondary image', from which the hair density and the grouping pattern of hair follicular units were determined by the image analyzer program.

Results: The results can be summarized as follows:

1. In normal adult males, the range of hair density was $117 \pm 13/cm^2$~$140 \pm 16/cm^2$, with the hair density of the occiput being significantly higher than that of the temple. No significant differences in hair density were shown between vertex and occiput.
2. In AGA male patients, the range of hair density was $102 \pm 23/cm^2$-$137 \pm 17/cm^2$, and the differences of the hair density between vertex and occiput were statistically significant.
3. The numbers of grouped hair units per square centimeter in the non-bald adult male group ranged from $59 \pm 11/cm^2$ to $73 \pm 14/cm^2$. The most common grouped hair unit was a 2-hair unit, followed by a 1-hair unit and a 3-hair unit group.
4. In the AGA group, the numbers of grouped hair units per square centimeter ranged from $57 \pm 6/cm^2$ to $72 \pm 12/cm^2$, showing no significance with the control group. The most common grouped hair unit was a 1-hair unit, followed by a 2-hair unit and a 3-hair unit group.

Conclusions: The AGA group compared remarkably with the normal adult male group, showing a lower hair density with a larger proportion of 1-grouped hair units. Based on

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the data about hair density and hair grouping patterns in AGA patients, surgeons can estimate the area of donor scalp with the most probable number of follicular units in hair transplantation procedures. (Ann Dermatol 16(1) 1~8, 2004)

Key Words: Phototrichogram, Hair density, Grouped hair unit

INTRODUCTION

Over the last several decades, many attempts have been made to evaluate the characteristics of human hair. Various techniques have been used for this purpose, including capillary method[1], radioisotope labelling[2], fluorescent dyes[3], scalp biopsies[4], tissue trichogram[5], and unit area trichogram[6]. Each of these techniques showed particular advantages and disadvantages; the choice of which examination to perform has been linked to the individual preferences of the dermatologist.

Phototrichogram, first introduced by Saitoh[7] in 1970, is a non-invasive technique that allows the in vivo evaluation of various parameters of hair quality, including density, linear growth rate, thickness, and the grouping pattern of hair. With the progressive innovation in biotechnology, we have developed some technical improvements in phototrichogram methodology to assess the characteristics of hair. Using a color CCD camera equipped with a rigid frame and connected to a 3CCD digital camcorder, we could get appropriately magnified digital images taken at fixed focus and distance[8]. Due to its digital image, the operator can alter the color contrast, magnify some details or use filters that could enhance a clear perception of thin hairs that are difficult to be observed in ordinary photos. Not only does it guarantee sensitivity, simplicity, and reproducibility, but also enables the monitoring of the response to therapy and to follow up chronologically the exact same area in long-term studies or large-scale clinical trials.

These days, follicular transplantation, using follicular units, has become the most popular technique in hair restoration surgery. To achieve the best clinical result, it is essential for the surgeon to understand the distribution of scalp hair. It has been reported that the densities and grouping patterns of scalp hair in androgenetic alopecia (AGA) patients are different from those in normal adults, and racial variation. This study was aimed to quantify the characteristics of Korean hair in AGA patients and normal adults at each site of the scalp (vertex, occipital, temporal), and to compare our data with previously reported studies from Asian, Caucasian, and African candidates.

MATERIALS AND METHODS

1. Selection of subjects

Between April 2001 and March 2002, 37 bald adult male volunteers were enrolled as subjective groups. These presented a clinical diagnosis of AGA with various degree of involvement (modified Norwood's classification IIv-VII), while not exhibiting any other clinical evidence of endocrine abnormalities. In addition, 15 normal males were selected as a control group. They had experienced no episodes of hair thinning, excessive hair shedding, recent illness or general health disturbances. Clinical examination revealed no evidence of hair disorder in either group. The 52 candidates were classified into two groups according to their age (before and after 45 years of age). They were all aware of the nature of this study and partook with their informed consent.

2. Methods

A. Shaving of hair

Two or three areas of each adult scalp were shaved with a diameter of 2cm^2, including the vertex(the leading edge of the balding area in the AGA group), the occiput, and the temple. They were centered with a dot tattoo to ensure long-term reproducibility.

B. Recordings of digitalized images

The outline of the system for phototrichogram and image analysis used in our study is shown in Fig. 1. Each of the scalp areas were photographed using colored CCD camera (Sony, Japan) connected to a 3CCD digital camcorder (DSR-PD150

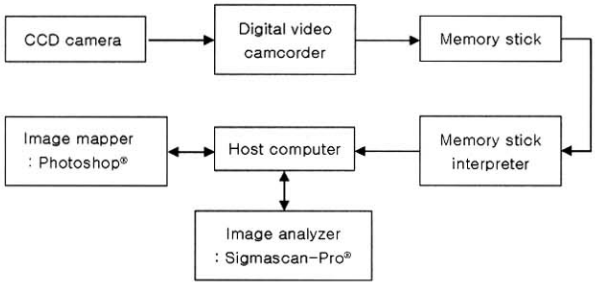

Fig. 1. The outline of phototrichogram and image analyzer system.

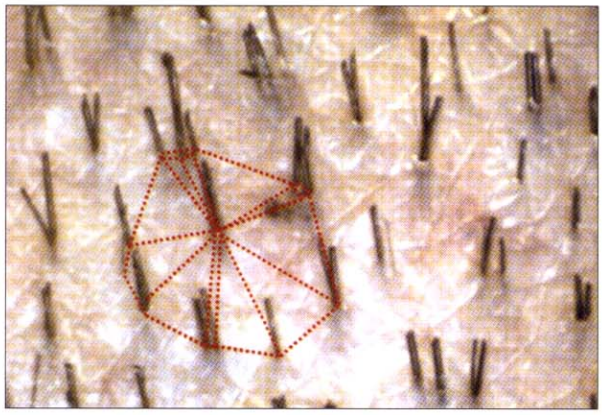

Fig. 2. Distances between adjacent hairs were measured using Sigmascan-Pro®, from which 2-dimensional frequency histogram were generated. The least frequent value was defined as 'minimal distance(MD)' between hair units.

Digital Video Camcorder. Sony, Japan), which was named 'primary image'. The hairs were placed parallel to the scalp using a transparent membrane. 48 hours later, the same areas were photographed again and named 'secondary image'. Both primary and secondary images were saved in the memory stick (Sony, Japan), and transmitted to a computer through the memory stick interpreter (MSAC-US5, Sony, Japan).

C. Mapping of the hair

To identify each hair in the serial images of the same site, hair mapping was performed using Photoshop® (V 6.0, Adobe Inc, USA). A code name was allocated to the same hair in both primary and secondary images. Using this method, hairs at the same site could be measured and saved repeatedly at intervals.

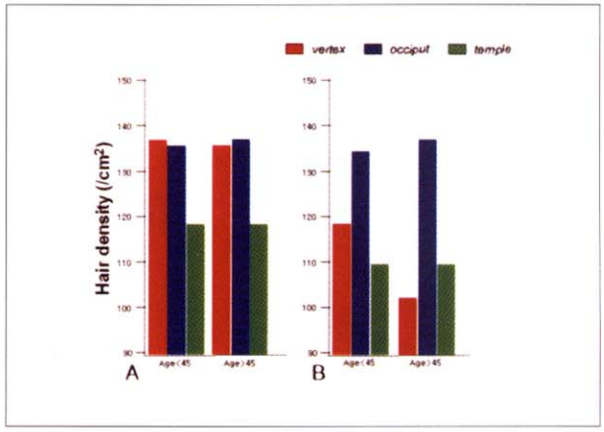

Fig. 3. Hair densities of vertex, occiput and temple in normal adults (A) and bald patients (B) according to sex and age. Statistical significance in densities between occiput and temple was seen in normal group, whereas alopecia group showed significant difference of densities between vertex and occiput.

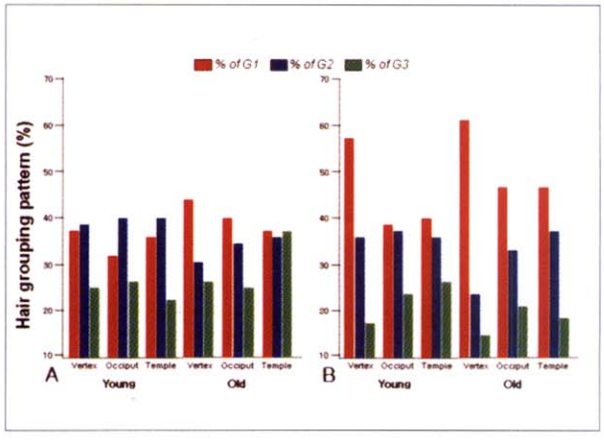

Fig. 4. Hair grouping pattern in vertex, occiput and temple in normal adult (A) and bald group (B) according to age. Percentage of 1-hair unit increases as the patient's age increases, whereas those of other hair units decrease. 1-hair unit is the most common type of hair grouping in bald patients (G1: 1-hair unit group, G2: 2-hair unit group, G3: 3-hair unit group).

D. Determination of minimal distance between hair units

After magnification of the images by Photoshop®, the distances between adjacent hairs were mea-

sured using an image analyzer program (Sigmascan-Pro®, V 5.01, SPSS Inc. USA), by which 2-dimensional frequency histograms were generated, showing bimodal distribution. The least frequent value was defined as 'minimal distance (MD)' between hair units, and the value below MD was excluded from the calculation, and regarded as a single hair unit.

E. Analyzing of the hair

Two parameters of hair were measured by comparing consecutive pictures using Photoshop® (V 6.0, Adobe Inc. USA) and Sigmascan-Pro®. First, the number of hairs in a square centimeter was calculated from the images by hair count divided by dimension of measured area. Secondly, adjacent hairs were collected into a grouped hair unit (GHU) according to the proximity ($\leq 40\mu m$) of the follicular openings. The ratios of one-hair, two-hair, three-hair and four-hair groups to the total number of hairs were calculated. Due to the scarcity of 4- and 5-hair units and for the sake of simplicity, they were counted as 3-hair follicular units.

F. Statistics

For the statistical comparison of hair density and hair grouping patterns between the groups, a sample *t*-test was used (paired & independent) and *p*-values <0.05 were considered to be statistically significant. The means and standard deviation were calculated and the influence of age of the patients was evaluated by the ANOVA test.

RESULTS

A total of 37 bald adult males with an average age of 37.4 years (range 29-73 years) and 15 normal adult males with an average of 35.6 years (range 17-58 years) were studied. The distribution of the subjects is summarized in Table 1.

1. Estimates for total hair density (Table 2)

In the balding group, the hair density ranged from 102 ± 23 to $137\pm17/cm^2$, and the differences of the hair density between vertex and occiput were statistically significant.

In the control group, the hair density ranged from 117 ± 13 to $140\pm16/cm^2$ and, in contrast, the hair density of the vertex in the balding group was diminished. However, those of the vertex and occiput were not significantly different in the normal male group. The hair density of the occiput was significantly higher than that of temple in the control group ($p<0.05$).

2. Distribution of grouped hair units and correlation with hair density

From the measurement of the distances between adjacent hairs and frequency histogram, minimal distance between hair units was calculated as $30\mu m$ (Fig. 5), and the ratios of 1-hair, 2-hair, 3-hair groups to the total number of hairs are presented in Table 3.

The numbers of grouped hair units per square centimeter in the non-bald adult group ranged from $59\pm11/cm^2$ to $73\pm14/cm^2$. In the group of non-bald adults under 45 years old, the most

Table 1. The Distribution of Subjects

	NORMAL		AGA	
	Young	Old	Young*	Old**
Number	7	8	16*	21**
Age, year	17 - 31	46 - 57	29 - 44	48 - 73
(Mean±SD)	24.7±3.2	50.1±3.6	36.6±5.30	56.9±6.60
Vertex	6	7	15	19
Occiput	7	7	10	14
Temple	5	6	4	8

* Distribution of young AGA patients by Norwood's AGA classification: IIv(2), III(1), IIIV(5), IV(3), V(2), VI(2), VII(1)

** Distribution of old AGA patients by Norwood's AGA classification: IIv(3), III(1), IIIv(1), IV(5), V(3), VI(5), VII(3) 1

Table 2. Total Hair Density in Normal Adults and Bald Patients Obtained with Phototrichogram (hairs/cm^2, mean±SD)

	NORMAL		AGA	
	Male		Male	
	Young	Old	Young	Old
Vertex	137±11	134±24	119±12	102±23
Occiput	135±11	140±16	133±18	137±17
Temple	119±14	117±13	109±0	109±20

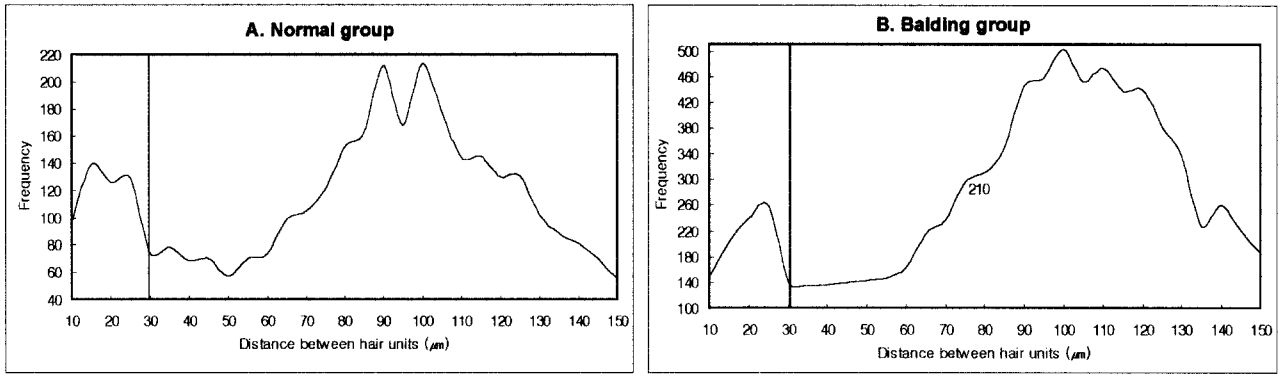

Fig. 5. The frequency histogram was drawn by measuring the distance between adjacent hairs. In both normal (A) and bald group (B), the minimal distance between hair units (MD) were measured around 30㎛.

common type of hair grouping was the 2-grouped hair unit, followed by the 1-hair and 3-hair unit. The amount of 1-hair units tended to increase as the patient's age increased, whereas those of other hair units decreased. When compared with Table 2, the number of grouped hair units per square centimeter increased as the patient's hair density decreased.

In the alopecia group, grouped hair units per square centimeter in the bald adult group ranged from 57±6/cm^2 to 72±12/cm^2, showing no significant difference with the control group. The most common type of hair grouping was the 1-grouped hair unit followed by 2-hair and 3-hair unit, regardless of age. Compared to the control group, significant mean differences for hair grouping pattern were found in the vertex, while in the occipital area the reduction in total hair density (135 hairs/cm^2) was the only significant ($p<0.05$) finding.

DISCUSSION

Human hair does not always grow singly, it usually emerges from the scalp in groups of 2 or 3. Histologically, these structures are called a "follicular unit[10]", composed of 1, 2, 3, and rarely 4 or 5 hairs that form a distinct group bounded by a circumferential band of outer root sheath, having a remarkably distinct and uniform distribution at the middermal level. On the other hand, "Compound hair", first described by Lowenthal[9] in 1946, is defined as the phenomenon of more than two living hairs emerging from a single follicular opening. However, by carefully examining the emergent hair shafts in a magnified image of scalp, hairs emerging from single follicular unit are very rare, so we define a new term "grouped hair" based on the proximity of distance between emergent hair shafts.

In our study, the frequency histogram was drawn by measuring the distance between adjacent hairs. The point of indicating the value of the least frequency was defined as 'minimal distance (MD)' between hair units. From this definition, if the measured value was below the MD, it is concerned as single hair unit. On the other hand, if the value was above the MD, it is concerned as two separated hair units. In both groups, the minimal distance between hair units was measured around 30㎛; in the normal group, however, another peak was found at 15㎛, and is thought to be the result from having a higher proportion of 2- and 3-hair groups in normal

adults. According to our study, the majority of the hair in a normal Korean adult male emerged as 2-grouped hair unit, followed by the 1-hair and 3-hair unit. The 2-hair unit constituted 40.4% of the total hair unit.

In contrast to the control group, the most common hair unit was a 1-hair unit in AGA patients, and this is thought to be associated with the dynamic change in the proportions of the follicular units. That is, as AGA progresses, the hair is lost as single hairs from all types of follicular groupings in the same proportion. Therefore, the 3-hair follicular units will be converted into 2-hair follicular units, the 2-hair follicular units into 1-hair follicular units, and some of the 1-hair follicular units will disappear. New 1-hair units are formed from pre-existing 2-hair units, resulting in a higher proportion of 1-hair units in low hair density patients[15]. The total number of follicular units is known to remain constant, unless the AGA patient reaches a severe degree of alopecia; despite the difference in hair density between the bald and normal adult male, there was no statistical significance in the number of grouped hair units between the two groups, which is consistent with the report of Bernstein and Rassman[16].

In our study, the hair density of the normal adult male was measured as $132 \pm 23/cm^2$ in the vertex, $111 \pm 26/cm^2$ in the temple, and $131 \pm 19/cm^2$ in the occiput. A review of the literature reveals a significant variation among different authors regarding the counts of hair density, which is probably due to either racial variations or the methodology used to count the hairs per unit area (Table 4). Bernstein and Rassman[16] mentioned significant racial variations in follicular unit densities and hair grouping patterns among Caucasians, Asians, and Africans. Also, Tsai et al[14] recently reported the average hair density and number of follicular units per square centimeter in the Chinese scalp (Table 5). From our data and that of previous studies, the genetic

Table 3. Percentage of Hair Grouping Patterns in Normal Adults and Bald Patients (%)

	NORMAL		AGA	
	Young	Old	Young	Old
Vertex				
% of G1	37.6	42.0	58.0	62.6
% of G2	38.3	31.0	25.0	22.6
% of G3	24.8	26.0	16.7	14.8
Occiput				
% of G1	32.7	40.3	38.9	46.3
% of G2	40.1	35.5	37.4	31.7
% of G3	26.5	23.6	23.0	21.6
Temple				
% of G1	36.8	37.0	39.1	45.8
% of G2	40.6	36.0	34.5	35.2
% of G3	22.5	37.0	25.9	18.7

Table 4. Comparison of hair Counts between Asians, Caucaians, and Africans (mean±SD)

Author	Technique	Subject	Avg. age	Hair density ($/cm^2$)
Our study	PTG	41 Asians	35.6±12.1	131.2±19.4
Lee[16]	PB	35 Asians	33.1±10.0	128.2±28.6
Hayashi[17]	PTG	10 Asians	27 – 48	181±21
Whiting[18]	PB	22 Caucasians	43±3.5	318.5±17.5
Sperling[19]	PB	12 Caucasians	34.7±12.2	282.6±43.8
Rushton[20]	UAT	13 Caucasians	24.2±3.3	301±30
D'amico[21]	VMS	28 Caucasians	23.3±3.5	300±20
Sperling[19]	PB	22 Africans	31.7±8.5	171.2±39.8

PTG, phototrichogram; PB, punch biopsy; UAT, unit area trichogram; VMS, videomicroscopy

Table 5. Racial Variations in Follicular Unit (preliminary observations)

	Caucasians	Asians	Africans	Chinese
Follicular units/mm^2	1	1	0.6	0.7
Predominant hair grouping	Two	Two	Three	Two

differences in the follicular unit may have an adaptive value, and the total hair count, along with the number of hair follicular units, in the Korean and Oriental subjects are found to be less than in Caucasian and African subjects.

In the occiput of the normal male, the measured density of the grouped hair unit was 69.9/cm^2, and one grouped hair unit was composed of 1.95 hairs. When compared with hair density per square centimeter (60.4/cm^2) and hairs per one follicular unit (2.24 hairs/follicular unit) reported by Lee et al[23], our data showed a difference of 15.7% and 12.9% each, which may be due to some variations in methodology, including the difference in total number of hairs counted, and selection of the subjects.

These days, follicular transplantation[11,12] using follicular units has become the most popular technique in hair restoration surgery. Because the hair is transplanted in the same way as it grows, most surgeons agree that they can reconstruct hair patterns that closely mimic nature. The report by Seager[13] suggests that the preservation of the whole morphology of the follicular unit could play a role in graft survival, by showing that single hair grafts which split away from naturally occurring follicular clumps have a decreased survival rate when compared with intact follicular units.

However the distribution and average number of follicular units per unit area are quiet different between Caucasians and Asians, and the result of transplantation is not always the same in different races. We hope that the result of this study could provide the hair surgeon with general information on hair density and grouping pattern in Korean hair, and be helpful in their daily practice concerning preoperative consultation, surgical design, and operational results. Based on the patient's hair density and hair grouping pattern, surgeon can estimate the area of donor scalp with the most probable number of follicular units desired to transplant. Follicular transplantations have been performed in our clinic since 2001, where consideration of the number of follicular units to be implanted is calculated according to the bald area, the expected density, and the budget of the patient.

For the quantative evaluation of human scalp hair, three principal approaches have been introduced so far. These have involved the use of invasive (biopsies), semi-invasive (trichogram; unit area trichogram), and non-invasive techniques (visual count; phototrichogram)[5]. Scalp biopsy is useful in the morphologic observation of follicular units and the diagnosis of hair disorders, but it has limitations in that the sample size of hairs evaluated is too small for statistical purposes. Classic trichogram and unit area trichogram, because they require the tearing of hair tufts, are another painful method, and if not properly done, can modify the characteristics of the bulbs and thus, often produce errors. In contrast, phototrichogram is a non-invasive, easy tool for the operator and is well tolerated by the patients. In the early days this technique was developed and used to study the duration of hair cycles, but with the help of computer-assisted image analysis, phototrichogram has become a very feasible examination tool in various aspects of trichology. We suggest that the wider application of this 'phototrichogram' will provide a reliable assessment of basal hair status and clinically acceptable results to evaluate the baldness or other disorders of hair, and monitor the response of hair to therapeutic agents.

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