Distribution of Human Hair in Follicular Units

A Mathematical Model for Estimating the Donor Size in Follicular Unit Transplantation

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BACKGROUND. Human hair emerges from the scalp in groupings known as follicular units. In follicular unit transplantation, the follicular unit is the exclusive element to be moved in the transplant.

OBJECTIVE. To study the distribution of follicular units in the human occipital (donor) scalp.

METHODS. Using digital photography, we counted in 50 patients the hair density, follicular unit density, and the proportion of 1-, 2-, and 3-hair units per square centimeter. We measured the median distance between the follicular units. All the data obtained was statistically analyzed.

RESULTS. In the occipital (donor) scalp the number of follicular units per square centimeter ranges between 65 and 85, and the hair density ranges between 124 and 200. The proportions of the different hair groupings change according to the patient’s hair density. We have developed a mathematical model that can predict the number and the most probable distribution of 1, 2, and 3 hair groupings, based on the patient’s hair density. The distance between follicular units ranges from 1.0 mm to 1.4 mm.

CONCLUSION. Hair transplant surgeons can now predict the total number of follicular units to be obtained from any given donor strip. In addition, the proportion of 1-, 2-, and 3-hair follicular units can also be anticipated. Some variance is to be expected due to the lack of uniform density in the donor area.

Using digital photography as a tool for macroscopic analysis and quantification of hairs and follicular units, we have studied the distribution of follicular units in the donor (occipital) area of human scalp. The data obtained were used to develop a mathematical model that allows the surgeon to calculate at a glance the size of the donor strip needed to be excised, and the number of 1-, 2-, and 3-hair follicular units contained in the donor strip.

Materials and Methods

It is important to emphasize the difference between hair density and follicular unit density. Hair density refers to the number of hairs emerging from the scalp per square centimeter. Follicular unit density is the number of hair groupings per square centimeter.

The quantification of hairs and follicular units per unit area was made from digitalized photographs obtained from 50 patients. A $1 \times 0.5 \text{ cm}^2$ rectangle was drawn and shaved on the occipital scalp of each patient. This area, measuring 0.5 cm$^2$, was photographed using a digital camera (Minolta RD 175) and processed in a Macintosh computer using the Adobe Photoshop software. The pictures were magnified 12 times their original size (Figure 1). The total number of hairs present within the 0.5 cm$^2$ rectangle, as well as the number of 1-, 2-, 3-, 4-, and 5-hair follicular units were counted. Due to the scarcity of 4- and 5-hair follicular units and for the sake of simplification, all 4- and 5-hair follicular units were counted as 3-hair follicular units. In each patient, we
correlated the hair density (d) with the follicular density (n) and the proportion of 1-, 2-, and 3-hair groupings.

The mean distance (L) between the follicular units was also measured in each patient (Figure 2). The median values were expressed in millimeters according to a conversion factor based on the magnification of the photograph.

Hair density (d) can be defined as:

$$d = \frac{H}{S}$$

Within 1 square centimeter, there will be a total number of n follicular units, being:

$$n = \text{total number of follicular units/cm}^2$$

$$n_1 = \text{number of 1-hair follicular units/cm}^2$$

$$n_2 = \text{number of 2-hair follicular units/cm}^2$$

$$n_3 = \text{number of 3-, 4-, and 5-hair follicular units/cm}^2$$

Therefore, n = n_1 + n_2 + n_3.

The total number of hairs per square centimeter will be:

$$n_1 \times 1 + n_2 \times 2 + n_3 \times 3 = d = \frac{H}{S}$$

For any given surface the total number of hairs will be:

$$H = S \times d = S \times (n_1 \times 1 + n_2 \times 2 + n_3 \times 3)$$

**Example.** We have a patient with a hair density d = 124 hairs/cm^2^ distributed in n = 63 follicular units/cm^2^, of which 31 are two hair follicular units (n_2), 17 are one hair follicular units (n_1), and 15 are three hair follicular units (n_3).

$$d = n_1 \times 1 + n_2 \times 2 + n_3 \times 3$$

$$124 = 17 \times 1 + 31 \times 2 + 15 \times 3$$

$$124 = 17 + 62 + 45$$

Assuming that the surgeon excises a donor strip of 10 cm^2^, by proportion this area will contain 1240 hairs distributed in 630 follicular units, of which 170 will be of one hair, 310 of two hairs and 150 of three hairs.

$$H = S \times (n_1 \times 1 + n_2 \times 2 + n_3 \times 3) = S \times d$$

$$H = 10(17 + 62 + 45) = 1240 \text{ (hairs in 10 cm}^2\text{)}$$

This model will allow us to estimate the area of donor scalp with the greatest probability contains the number of follicular units desired to transplant, based only on the patient’s hair density. In reality, as occurs with any mathematical model applied to a biological system, small dispersions around the median values will be expected.

**Results**

**Distribution of Follicular Units and Correlation with Hair Density**

Figure 3 shows the correlation between the total number of follicular units per square centimeter with the patient’s hair density, as well as the distribution of the follicular groupings in 1 (n_1), 2 (n_2), and 3 (n_3) hair units.
In our samples, we found that the number of follicular units per square centimeter in the occipital scalp ranges between 65 and 85 with a slight tendency to increase with the patient’s hair density. The hair density ranged between 124 and 200 hair/cm². In all patients, the most common type of hair grouping was the 2-hair follicular unit, followed by the 3-hair and 1-hair unit. The amount of 2-hair and 3-hair follicular units tend to increase as the patient’s hair density increases. In contrast, the number of 1-hair follicular units increases as the patient’s hair density decreases.

These correlations can be expressed with the following mathematical equations:

\[ n = 0.29 \times d + 27 \]
\[ n_1 = -0.16 \times d + 36 \]
\[ n_2 = 0.19 \times d + 9 \]
\[ n_3 = 0.26 \times d - 18 \]

**Number of Follicular Units for Any Given Area**

From Figure 3 and supposing that the hair density is maintained constant throughout the donor scalp, we can deduce another table that correlates the number of follicular units for any given surface (Figure 4). Since the total number and the proportion of follicular units varies with the patient’s hair density, we have designed 3 independent tables corresponding to patients with low density (120 hair/cm²), average density (160 hairs/cm²), and high density (200 hairs/cm²).

**Distance Between Follicular Units**

According to our measurements, the mean distance (\( L \)) between follicular units ranges from 1.0 mm in patients with high hair density (200 hairs/cm²) to 1.4 mm in patients with low density (120 hairs/cm²).

Human hair does not have a homogeneous distribution, but the mean distance between follicular units follows approximately the distribution of a square reticular model, where

\[ L (\text{mm}) = \frac{10}{\sqrt{n}} \]

For example, if a patient has \( n = 70 \) follicular units/cm², the mean distance between follicular units (\( L \)) will be:

\[ L = \frac{10}{\sqrt{70}} = 10/8.36 = 1.2 \text{ mm} \]

**Discussion**

**Superficial Distribution of Follicular Units**

Bernstein and Rassman explored in depth the distribution of follicular units in the human scalp.4,6,7 They found that the absolute number of follicular units per unit area remains relatively constant (approximately one unit/mm²), and that it is the proportion of natural hair groupings that determines the patient’s hair density.

In our study, all patients had a follicular unit density ranging between 65 to 85 units/cm², with a slight tendency to increase in high density patients and to decrease in patients with low density. An easy rule to remember is that the follicular unit density is approximately half of the hair density (ie., a patient with 160 hairs/cm² will have approximately 75 follicular units per cm²). Although the follicular density remains between those limits (65 to 85), the hair density varies significantly, ranging between 120 and 200 hairs/cm². 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 to the methodology used to count the hairs per unit area. Limmer finds a range of 120–240 hairs/cm²,8 and Haber 144–176 hairs/cm².9 Bernstein et al7 found significant racial variations in the hair density.
density and follicular unit density among Caucasians, Asians, and Africans. The African individual has a lower hair density (average 160 hairs/cm²) than the Asian (average 170 hairs/cm²) and Caucasian (average 200 hairs/cm²).

In human scalp, the majority of the hair emerges as 2-hair follicular units. The second most common unit is the 3-hair unit. Only in individuals with very low hair density (with severe male pattern baldness) are the 1-hair units more abundant than the 3-hair units.

The progressive hair loss associated with male pattern baldness is what probably determines this dynamic change in the proportions of the follicular units. A logical reasoning is that as male pattern baldness 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 units into 1-hair follicular units, and some of the 1-hair units will disappear. New 1-hair units are formed from preexisting 2-hair units, resulting in a higher proportion of 1-hair units in low density patients. The total number of follicular units will remain fairly constant unless the individual reaches a severe degree of alopecia.

After measuring the distance between follicular units, our results indicate that they tend to maintain a certain distance between each other, which can range from 1.00 millimeter in patients with high hair density to 1.40 millimeters in low density patients. Theoretically, this is the distance in which the hair grafts should be placed in order to achieve a density equal to the donor site.

Estimation of the Number and Proportion of Follicular Units/cm² Based on the Patient’s Hair Density

Using Figure 3, we can estimate the follicular density as well as the proportion of 1-, 2-, and 3-hair follicular units per square centimeter.

For example, a patient with a measured hair density of 190 hair/cm² will probably have a total of 82 follicular units per square centimeter, of which 45 will be 2-hair units, 31 3-hair units, and 6 1-hair follicular units.

The same results can be obtained using the mathematical equations shown above:

\[ n = 0.29 \times 190 + 27 = 82 \text{ follicular units/cm}^2 \]
\[ n_1 = -0.16 \times d + 36 = 6 \text{ one hair follicular units/cm}^2 \]
\[ n_2 = 0.19 \times d + 9 = 45 \text{ two hair follicular units/cm}^2 \]
\[ n_3 = 0.26 \times d - 18 = 31 \text{ three hair follicular units/cm}^2 \]

Estimation of the Size of the Donor Strip for Follicular Transplantation

An accurate estimation of the size of the donor strip needed to excise is important for planning a hair transplant session. Most experienced surgeons can accurately predict the harvest requirements at a glance. However, for novice surgeons it is useful to follow some guidelines, because an accurate estimation of the donor area is important if surgical results are to be predictable.

The surgeon must measure first the hair density and determine the size of the donor strip to be excised according to the number of follicular units desired to transplant. A variety of devices can be used to measure hair density such as the densitometer or the trichoscope. Then, using Figure 4 that most approximates to the patient’s hair density, the surgeon estimates the size of the donor area as well as the expected number of 1-, 2-, and 3-hair follicular units that the donor strip will contain.

Example. We wish to transplant a total number of 800 follicular units in a patient with a measured hair density of 160 hairs/cm².

1. What is the size of the donor strip needed?
2. How many 1, 2, and 3 hair follicular units will be present in the donor strip?

Answer. Using Figure 4 for a patient with average density, we can estimate that at least 11 cm² of donor scalp is needed in order to obtain 800 follicular units. Moreover, the estimated proportion of follicular units contained in the donor strip will be 425 2-hair, 250 3-hair, and 110 1-hair follicular units.

It is important to note that this result assumes that no hairs are lost during the process of harvesting and graft dissection. In general, the estimated proportion of graft loss can range from 10 to 30%. This will depend mainly on the surgeon’s skill and method of harvesting (a multiple-bladed knife versus a single blade), the method of dissection (better yield using a dissecting microscope), and the skill of the technicians. This correction factor will have to be added to the final size to achieve a more realistic result.

Final Note

Our paper is not intended to discourage the physician from taking specific measurements in each patient. In fact, the only way to account for the patient-to-patient variability in the hair density and in the proportion of follicular units would be to make measurements in each individual case. However, based on the correlations that we found in our study, we can anticipate the most probable distribution of follicular units expected...
in a patient, given a predetermined hair density. The reader has to realize that the results from the tables and equations represent the most probable medium values, and as occurs with any statistical correlation, numerous small deviations around the medium can be expected.

References

Commentary
The authors are to be congratulated on an excellent study, mathematically and scientifically. Their model provides a reliable means of extrapolating the number of follicular units and their distribution in 1, 2, and 3 hair entities based upon the hair density. As mentioned by the authors, the reader is cautioned to remember that significant racial and individual variations in hair and follicular unit densities occur in nature. Based upon a Spanish population, the authors have found a range of 124–200 hair per cm² and 65–85 follicular units per cm². In primarily Caucasian populations, Headington found a range of 160–280 hair per cm² and 100 follicular units per cm². In an ongoing study of a mixed Caucasian and Hispanic population, we have found follicular unit densities to average 90 units per cm² using visual counting at 10× magnification. For these reasons, the authors’ model, while scientifically and mathematically sound, may need adjustment for specific populations and individuals.

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