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THE LOGIC OF FOLLICULAR UNIT TRANSPLANTATION

Robert M. Bernstein, MD, and William R. Rassman, MD

Progress in modern medicine is often the result of sophisticated technology that allows us to quietly probe into the deepest regions of the human body or to analyze its actions at the molecular level. A field of medicine is rarely dramatically changed by simple observation. After more than three decades of relative inertia, surgical hair restoration is undergoing such a change. This article discusses the logical applications of these observations to clinical practice, a logic that has literally revolutionized hair transplantation in just a few short years. It will also touch upon some of the illogic judgments that contributed to its delay.

HISTORICAL ASPECTS

> A donor (graft) is better if it is as small as possible. The reason is that if a donor is big, hairs grow in . . . a very unnatural appearance.
>
> HAJIME TAMURA—1943[1]

If we had only heeded the advice of the pioneering Japanese hair transplant surgeons in the first half of this century, we could have avoided years of unsightly surgical results that caused dismay to thousands of unwary patients, and literally tarnished an entire field of medicine. Unfortunately, the "Japanese insight" was lost to us during World War II and when we tried to "reinvent the wheel," we did it wrong.

The Punch Graft Technique

After the "rediscovery" of hair transplantation by Dr. Norman Orentreich in 1952, the excitement that hair actually grew and continued to grow after it was transplanted, clouded the very essence of hair restoration surgery (i.e., that it was a cosmetic procedure whose sole purpose was to improve the appearance of the balding patient). The 4-mm plug that had been ordained as the optimal vehicle for moving hair was actually of a size that had no counterpart in nature.

The initial problem was that the decision to use 4-mm plugs was based mainly upon technical rather than aesthetic considerations. In the original, ingenious experiments performed by Dr. Orentreich that were published in the Annals of the New York Academy of Science in 1959 establishing the concept of "donor dominance," 6- to 12-mm punches (trochars) were used to create the grafts.[18] At these sizes, there was an unacceptably high rate of hair loss in the center of the grafts due to the difficulty of oxygen to diffuse over such large distances. The initial effort to decrease graft size was thwarted by the concern

From the College of Physicians and Surgeons, Columbia University (RMB); and the New Hair Institute (RMB, WRR), New York, New York

that much smaller grafts would not move enough hair to make the procedure worthwhile. Eventually a compromise was reached, and the 4-mm graft was born.

In addition, a logic developed that postulated that by replacing bald skin with hair-bearing skin, most of the balding area could eventually be replaced with hair. No adjustments for scar contraction were accounted for, and no changes in the size of the newly transplanted grafts were expected, despite observations to the contrary. More importantly, these assumptions were based upon the mathematically impossible feat of covering a large area of balding with a much smaller donor supply, while maintaining the same density.

The punch-graft, open-donor technique was developed with tools in routine use by dermatologists of the time. In the "open-donor method" devised by Dr. Orentreich, the same trochar that was used to make the recipient sites was also used to harvest the hair. Because hair in the donor area emerges from the scalp at rather acute angles that vary in different regions, the physician was required to have the angle of the trochar exactly parallel to the angle of the hair. If there was even the slightest deviation from a perfectly parallel orientation, significant wastage of hair would occur from follicular transection. In fact, in many patients, so much transection would occur that the potentially "pluggy" appearance was reduced to a thinner look by the inadvertent reduction in the number of hairs per graft.

The hidden problem, of course, was that this harvesting technique reflected a grossly inefficient use of the donor supply, and patients often became depleted of donor hair long before the transplant process was completed. These problems were compounded by the fact that in the "open donor method" the wounds were left to heal by secondary intention and the resulting fibrosis further altered the direction of the remaining donor hair, making subsequent harvesting even more difficult.

The large donor and recipient wounds created by these punches necessitated that the procedure be performed in small sessions, usually 20 to 50 grafts at a sitting, with the sessions spaced apart in time because of prolonged healing. As a result, one of the truly unfortunate problems intrinsic to the early techniques was that neither the long-term cosmetic issues, nor the ultimate depletion of the patient's donor supply, could be appreciated for many years. Possibly because of Dr. Orentreich's deservedly high esteem in the medical community (he also did pioneering work in dermabrasion, intra-lesional corticosteroids, injectable silicon, and the hormonal treatment of hair loss to name just a few), the 4-mm size went unchanged for years.

Early attempts at reducing the size of the grafts were largely unsuccessful. A reasonable approach to making these large plugs cosmetically more acceptable was to divide them into smaller grafts (i.e., to produce split grafts or quarter grafts from the larger plugs.)[10] Unfortunately, these only resulted in further manipulation and damage to grafts that already contained populations of transected follicles. Simply reducing the size of the punches[20] was also problematic because a decreased radius greatly exaggerated the damage caused by even the slightest deviation in the harvesting angle. It seemed that a relative impasse had been reached in trying to create a smaller-size graft that would be cosmetically acceptable, contain enough hair to make the procedure worthwhile, and not be too wasteful of the donor supply. Fortunately, new techniques in harvesting the donor tissue provided solutions to these problems.

The Donor Supply

Some hair transplant surgeons, conscious of the finite donor supply, noticed that there were islands of hair-bearing skin left behind after the initial rows of plugs were harvested; however, subsequent attempts to harvest the intervening tissue and leaving the wounds open resulted in confluent areas of scarred scalp devoid of hair, and lacking adequate camouflage. Suturing the open donor wounds seemed to be a logical solution for decreasing the scarring, but this further altered the hair direction and made the remaining scalp less amenable to successful punch harvesting.

A more creative attempt to deal with this problem was to totally excise the tissue between the rows of punches and then suture the "serrated" upper edge to the serrated lower edge. The wound edges would then neatly come together if the punches were aligned properly.[14, 19] There were two important consequences of this procedure. The first was that it produced a piece of "free standing" donor tissue that could be cut into smaller pieces under direct visualization prior to transplantation. The second was that the sutured incision left a single line in the donor area (although somewhat squiggly). After looking at the result of this procedure even the casual observer would have to question the necessity of the punch graft aspect of the process. After all, why not just remove an intact strip of tissue and suture the wound edges closed, obviating the problems of the punches (i.e., the open donor wounds and the punch transection of hair follicles)? After a number of years, this is the procedure that was eventually adopted.

The double- and then multi-bladed knifes[11, 24, 28] were born out of an attempt to avoid the open donor scars produced by the punch-graft method, and to decrease the transection produced by this "blind" harvesting technique. Unfortunately, it solved only the first of these two problems. As with the punches, the multi-bladed knife was also a form of "blind-harvesting" because the surgeon would still have to match the angle of hair in order to avoid follicular transection, and the visual cues needed to accurately perform this procedure were either hidden below the surface of the skin or covered with blood. As a result, the necessary fine-tuning of the blade angle, while making the incision, always came too late (i.e., after the transection of hair follicles had occurred).

In addition to the difficulty in following the curve of the skull, as the physician moved across the donor area horizontally, the fixed relationship between the multiple blades did not allow for any adjustments in the vertical plane. To compound the problem, pressure from one blade would distort the direction of hair near the others. The surgeon could adjust one blade (usually the upper) to follow the changing hair direction as he moved around the scalp, but because the angle of hair changed in the vertical dimension as well, transection caused by the other blades would be unavoidable. In addition, as one tried to angle the knife in order to follow the vertical curve of the scalp, some blades might be too superficial, whereas others too deep. The superficial wound required a second incision which ran the risk of further transection. The deeper wound risked cutting fascia or larger nerves and blood vessels, increasing the morbidity of the procedure.

An obvious solution would be to take a single strip of tissue from the donor area. The problem with this idea was that in all but the smallest procedures, one was left with a large, 3-dimensional piece of tissue that defied further sectioning. In addition, with the trend to perform larger sessions, the fine slivers produced by the multi-blade knife grew more appealing, and the cumbersome nature of the single strip proved a hindrance to completing the surgery in a reasonable period of time.

There was still one last important issue with the multi-bladed knife, the fact that the blades moved in random planes through the donor tissue. As discussed later, hair doesn't grow randomly in the donor area, nor in the rest of the scalp for that matter, but in tightly organized bundles called follicular units. In effect then, the multi-bladed knife, even if it passed through the scalp perfectly aligned with and parallel to the growing hair, would still break up the integrity of these naturally occurring structures and reduce hair yield.

The significance of this last problem was not initially known, but it became apparent that transplanting very small grafts in large quantities produced a thin look, and that this look was thinner than one would have anticipated based solely upon the amount of transplanted hair. The role of the multi-bladed knife in contributing to this problem is still in dispute, but it is felt by these authors, as well as others, to be very substantial. Other factors are covered later in this article.

The recognition that square inch for square inch replacement of bald scalp with hair would not be possible with transplantation posed a frustrating dilemma to the surgeon, and allowed a number of other procedures to proliferate, namely scalp reductions, lifts, and flaps; however, in the illusive goal of restoring original density, the mathematics of these procedures made no more sense than the plugs they were supposed to complement or replace. Regardless of the choice, the precious donor supply was still being consumed, and the patient's long-term results compromised. In retrospect, it seems that the popularity of these procedures was not based upon their intrinsic value, but upon the fact that the alternatives were so poor. When the quality of the transplantation procedures finally improved, the frequency of these surgeries declined.

This is the position that the field of hair transplantation found itself in as it entered the 1990s and, for the most part, stayed in until 1996, when follicular unit transplantation caught on and everything changed. As discussed later in text, the logic of using follicular units is quite inseparable from the technique itself, and many of these techniques had their foundation as far back as 1982 in the "punctiform" procedure of Carlos Uebel[26] that later evolved into the "megasession" and in the work of Dr. Bobby Limmer, who began using microscopic dissection and single-strip harvesting as far back as 1988.[17] Surprisingly, the fact that hair grows in discrete bundles was largely unknown to most hair transplant surgeons for almost 40 years, and it was the general revelation that these naturally occurring groups could be used to the patient's advantage that changed the hair transplant procedure forever.

THE LOGIC OF PRESERVING THE FOLLICULAR UNIT

The underlying premise of follicular unit transplantation is that the intact, individual follicular unit is sacred. It should neither be broken up into smaller units nor combined into larger ones.[5, 7, 9] This simple idea may not seem like a radical approach to hair transplantation, but when viewed in the context of how the surgery has been performed over the past 40 years (when the very existence of the follicular unit went generally unrecognized), it is radical indeed. Even now when its existence is widely known, there is a trend in hair transplantation to not only ignore the importance of the follicular unit, but to ignore the integrity of the follicle itself.

The follicular unit (Fig. 1) was first defined by Headington in his landmark 1984 paper "Transverse Microscopic Anatomy of the Human Scalp."[13] The follicular unit includes

- 1 to 4 terminal follicles
- 1 (or rarely 2) vellus follicles
- associated sebaceous lobules
- insertions of the arrector pili muscles
- perifollicular vascular plexus
- perifollicular neural net
- perifolliculum–circumferential band of fine adventitial collagen that defines the unit

This rather dry definition belies the fact that the follicular unit is a physiologic entity rather than just an anatomic one. As discussed later, the obvious reason to preserve the integrity of the follicular unit is economy of size (i.e., it is a way to get the most hair into the smallest possible site), and create the smallest wound. The ingenious hair transplant surgeon, Dr. David Seager, gave us another definition.[23] In a bilateral controlled study, matched for the number of hairs, he showed that when single-hair micrografts were generated from breaking up larger follicular units, their growth was less than when the follicular units were kept intact. In this study, he showed that at 5 1/2 months the single-hair micrografts only had an 82% survival rate, whereas the intact follicular units had a survival rate of 113%, presumably due to the fact that hairs in telogen (that were not initially counted) also began to grow.

Clearly this example demonstrates that "the whole is greater than the sum of its parts," supporting the concept of the follicular unit as a physiologic entity. More work is certainly needed to pinpoint the mechanism for the decreased yield of this "divided unit." Determining whether it is due to factors intrinsic to the unit itself, increased susceptibility to environmental events during the transplant, or both will have an important impact upon the direction of future research when trying to find techniques that will maximize growth.

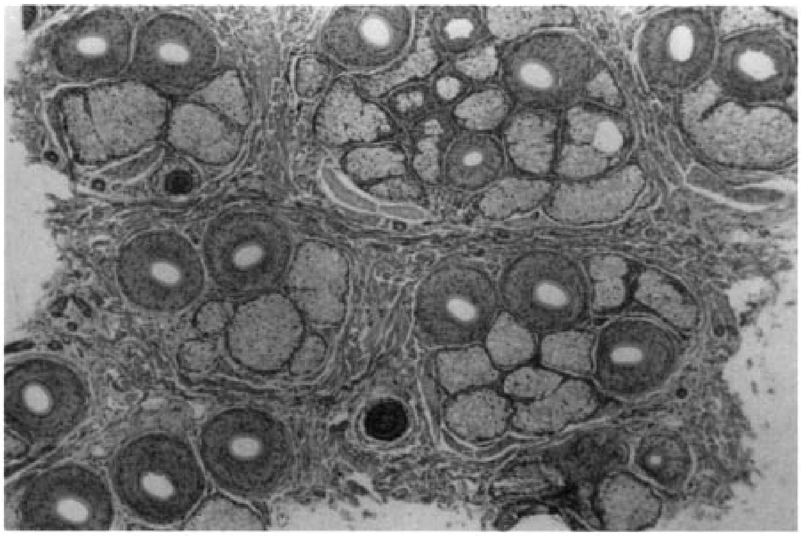

Figure 1. Transverse histologic section of adult male scalp at the level of the sebaceous glands showing 2-, 3-, and 4-hair follicular units (hematoxylin and eosin, original magnification × 40).

THE LOGIC OF TRANSPLANTING INDIVIDUAL FOLLICULAR UNITS

That scalp hair grows in follicular units, rather than individually, is most easily observed by densitometry, a simple technique whereby scalp hair is clipped to approximately 1 mm in length and then observed via magnification in a 10-mm field.[22] What is strikingly obvious when one examines the scalp by this method is that follicular units are relatively compact, but are surrounded by substantial amounts of non-hairbearing skin. The actual proportion of non-hairbearing skin is probably on the order of 50%,[16] so that its inclusion in the dissection will have a substantial effect upon the outcome of the surgery. When multiple follicular units are used and the skin is included, these effects may be profound.

To illustrate this point, use any of the "videografts" in Figure 2 and draw a circle around a single follicular unit, and then draw a circle encompassing two units, then three, etc. What one observes is that as single follicular units are combined to form larger groups, the total volume of tissue included is not additive, but geometric.

When the actual transplant is performed, two additional factors act to compound the effects of this increased volume. The first is that the donor and recipient sites are not always a perfect match for one another. In many ways, transplanting skin from the back of the scalp to the front can be as different as using a graft from the inner thigh to fill in a defect on the lower leg. The reason is that bald scalp becomes atrophic over time, as the diminution of the follicular appendages are associated with a decrease in the other cutaneous elements.[15]

The other problem is that the transplantation of multiple follicular units often requires recipient skin to be removed (via punch or laser) to allow this new volume of tissue to fit into the recipient site or to avoid unsightly compression of the newly transplanted grafts. In effect, richly vascular scalp, of maximum thickness, is transplanted into a somewhat atrophic recipient area in which tissue is further removed to accommodate the graft. Not surprisingly, the results of this technique will often look unnatural!

The great benefit of using individual follicular units is that the wound size can be kept to a minimum, while at the same time maximizing the amount of hair that can be placed into it. Having the flexibility to place up to four hairs in a tiny recipient site has important implications for the design and over-

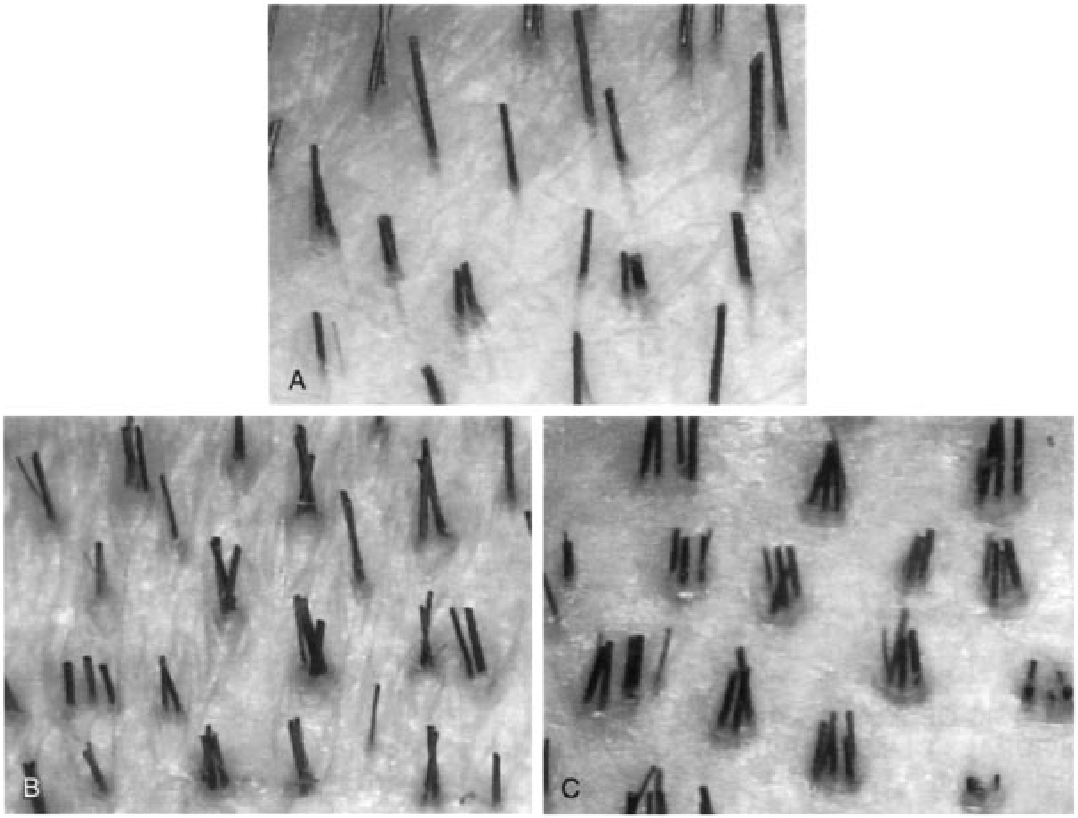

Figure 2. Densitometry[17] recorded by a videografting system[12] showing the natural follicular groupings in the donor scalp of a patient with low density *(A)*, average density *(B)*, and very high density *(C)* (original magnification $\times$ 50). These views vividly show that as the absolute hair density increases, the size of the individual follicular units increase, whereas the density of the follicular units (spacing) remains relatively constant.

all cosmetic impact of the surgery. Follicular unit transplantation has a major advantage over extensive micrografting in minimizing or eliminating the "see through" look that is so characteristic of the latter procedure.

THE LOGIC OF KEEPING RECIPIENT SITES SMALL

The importance of minimizing the wound size in any surgical procedure cannot be over emphasized and hair transplantation is no exception. The effects of recipient wounding are felt at many levels. Large wounds can lacerate blood vessels and although the blood supply of the scalp is extensively collateralized, any damage to these vessels will have an impact on local tissue perfusion. An equally important issue is to minimize the disruption of the microcirculation. This is an unavoidable aspect of all scalp surgery, regardless of the size or depth of the wounds, but keeping this disruption to a minimum is a crucial part of surgery. This is especially important when transplanting grafts in large quantities. The compact follicular unit is, of course, the ideal way to permit the use of the smallest possible recipient site, and has made the transplantation of large numbers of grafts technically feasible.[9]

Clearly, excision (removing tissue via a punch or laser) causes more damage to tissue then an incision (slit), but it is important to stress that all the parameters affecting recipient wounds have not been determined. As such, there are no absolute guidelines as to the ideal number or densities of grafts that can be used and still ensure maximum growth. The practitioner must rely on his or her clinical judgment in this regard, and it is suggested that one be conservative until one has significant clinical experience with the close placement of large numbers of grafts. In addition, there are a host of systemic and local factors that should be taken into account when planning the number and spacing of the recipient sites, regardless of their size.[7]

Another important advantage of the small wound is a factor that can be referred to as the "snug fit." Unlike the punch, which destroys recipient connective tissue, a small incision made with a needle retains the basic elasticity of the recipient site. When a properly fitted graft is inserted the recipient site will then hold it snugly in place. This "snug fit" has several advantages. During surgery, it minimizes popping and the need for the sometimes traumatic re-insertion of grafts. After the procedure, it ensures maximum contact of the implant with the surrounding tissue, so that oxygenation can be quickly reestablished. In addition, by eliminating dead space, there is less coagulum formed, and wound healing is facilitated. Because oxygen reaches the follicle by simple diffusion, its ability to do so is a function of tissue mass. Unlike larger grafts, whose centers can become hypoxic, the slender follicular unit presents little barrier to this diffusion, therefore ensuring uniform oxygenation.

It is important to note that when using larger grafts, either round or linear, compression is an undesirable consequence, and may result in a tufted appearance. In contrast, when transplanting follicular units, there are no adverse cosmetic effects of compression, because follicular units are already tightly compacted structures.

Another aspect of wound healing is the concept of "memory." Those of us whom routinely perform cutaneous surgery understand the advantage of wounds healing by primary intention. When tissue is removed by a punch or destroyed by laser, the resulting defect heals by secondary intention. One can justifiably argue that when a graft is placed in the defect, the area doesn't need to granulate in; however, because the underlying defect is still present, the wound invariably causes more scarring than when a simple incision is made (thus the term "memory"). This is readily evidenced in the scarred skin around the healed punch or laser sites. Although it is not always visible, this tissue has lost its resiliency and cannot support the same density of grafts in subsequent procedures.

Large wounds cause a host of other cosmetic problems including dimpling, pigmentary alteration, depression or elevation of the grafts, or a thinned, atrophic look. The key to a natural-appearing hair transplant is to have the hair emerge from perfectly normal skin. The only way to ensure this is to keep the recipient wounds small.

THE LOGIC OF CREATING SITES WITH COLD STEEL

In the public's mind, no single word in medicine evokes a stronger image of "state-of the art" than the word "laser," and the phrase "laser hair transplantation" is no exception.[6] Unfortunately, when the image begins to fade and we examine its actions logically, we see that not only is the laser inappropriate for follicular unit transplantation, but that it is actually detrimental.

Lasers are used in hair transplantation to create recipient sites. In contrast to other fields of medicine where its properties of selective photo-thermolysis play a role, in hair transplantation the role of lasers is purely destructive. The fact that lasers can create a hole with little surrounding thermal injury is little consolation to the surgeon who would prefer to have none. And the claim of the newest lasers, that they can make a recipient site with no thermal burn at all, is well and good, but it is missing the whole point. That point is that no matter how precise the laser is, it is still making a hole by removing tissue, and therefore is a throwback to the old punch technique.

Just to remind the reader, removing tissue destroys blood vessels and collagen, weakens the elastic support, increases the coagulum, decreases perfusion, and retards healing. Essentially, the laser "loosens" the "snug fit" that is such a benefit in follicular unit transplantation. If a physician merely wants to create a slit, which supposedly looks more natural than a hole, then lasers will do just fine. If tissue needs to be removed to make room for a large graft or prevent compression, then lasers may be the tools of choice. And, if a physician is more concerned that blood will cloud the view during surgery, rather than nourish the implants afterwards, then the laser should be given a try. But if the physician wants to maximize the growth of follicular units and keep recipient wounds to a minimum, then the beam should be pointed the other way.

THE LOGIC FOR TRANSPLANTING FOLLICULAR UNITS IN LARGE SESSIONS

Although larger sessions are made possible by the ability of follicular units to fit into very small recipient sites and to minimize wounding, the next logical question to ask is "What is the actual advantage of performing these large sessions?" After all, larger sessions are time consuming, require a larger staff, and are more expensive for the patient (at least at the outset).

There are a number of very important reasons to transplant in large sessions. Some of them are specifically related to the use of follicular units, and some to hair transplantation in general, but all significantly affect the patient's well-being. The reasons for transplanting in large sessions may be summarized as follows:

- Social reasons
- Planning for telogen effluvium
- Economizing the donor supply
- Enhancing the complexion of the follicular units

The social implications of the surgery are uncommonly discussed at medical meetings, but are in the forefront of almost every balding patient's mind. Putting aside anatomic, physiologic, and technical issues for the moment, it is important to emphasize the practical reasons to strive toward large sessions. The specific events that bring a balding patient to the doctor for hair loss will vary, but the common denominator of those seeking hair restoration is to improve their appearance, and (although generally unspoken), to improve the quality of their life, be it personal, professional, or social.

There is probably no better way for a surgeon to undermine this goal than to subject an already self-conscious patient to a protracted course of small, incomplete procedures. Until the transplant is cosmetically acceptable, the disruptions from the scheduling of multiple surgeries, the limitations in activity, and the concern about their discovery can place a patient's life "on hold." Therefore, it should be incumbent upon the physician to accomplish the patients objectives as quickly as possible. Figures 3 and 4 show what is possible using follicular units in large numbers in just one session, and Figures 5 and 6 show what is possible in two sessions. The important point is that even if one or two transplant sessions don't accomplish all of a patient's goals, he still can continue with normal activities while awaiting subsequent procedures.

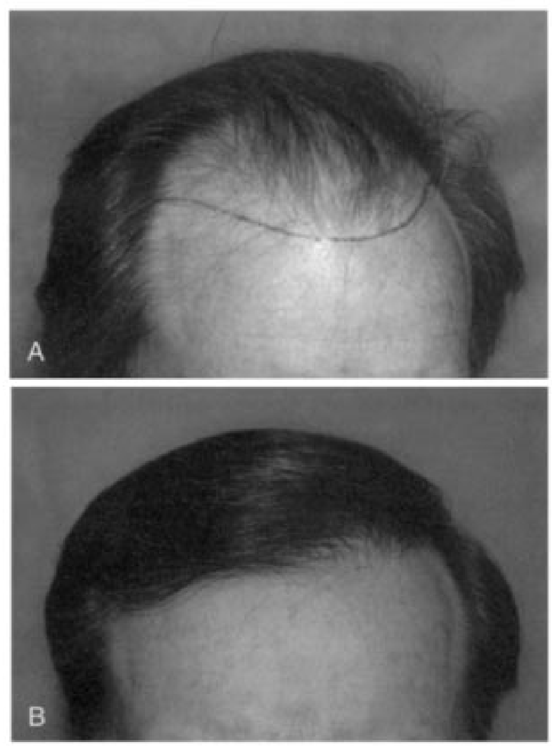

Figure 3. *A*, A 48-year-old man with a thinning Norwood Class Va balding pattern, with medium weight brown hair (donor density 2.2 hairs/mm^2). *B*, Patient 13 months after one procedure of 2,803 follicular units.

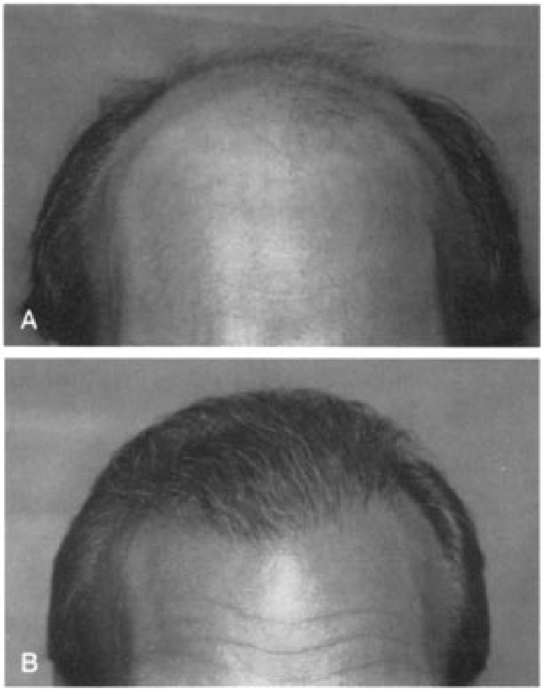

Figure 4. *A*, A middle-aged man with a Norwood Class VI balding pattern, with medium weight, slightly wavy and early graying, brown hair. *B*, Patient 8 months after one session of 2,292 follicular units.

Telogen Effluvium

Balding is a progressive process by which full-thickness terminal hairs gradually decrease in length and diameter in a process called miniaturization. This process is a consequence of both the shortening of the anagen (growing) phase of the hair cycle and the diminution of the germinative elements in the follicle. Miniaturization is a universal aspect of androgenetic alopecia and accounts for most of the early cosmetic changes in hair loss. In other words, the "thinning" that one notes early in balding is really due to thinning (i.e., miniaturization) of the hair shafts, rather than the actual loss of hair itself.[9]

Regardless of the technique, an inevitable aspect of hair transplant surgery is that the patient's existing hair, in and around the transplanted area, has a chance of being shed as a result of the procedure. The hair that is at greatest risk of being lost is the hair that has already begun the process of miniaturization, and if this hair is at or near the end of its normal life span, it may not return.

Often this shedding is mild and insignificant, but at times it can be substantial enough to leave the patient with a thinner look after the procedure than before he started. The reason is that in some patients (especially those who are young and in very active stages of hair loss) large amounts of hair can be undergoing this process of miniaturization. Identifying those patients especially those at risk, educating all patients that this process can occur, and planning for it surgically are therefore integral parts of hair transplantation.[12]

The following list explains how a physician surgically plans for these patients:

1. Defer transplanting patients who are very early in the balding process (i.e., those who are content with the way they look now but are more concerned about future hair loss). A good rule of thumb is to wait unit the patient needs a minimum of approximately 600 to 800 follic-

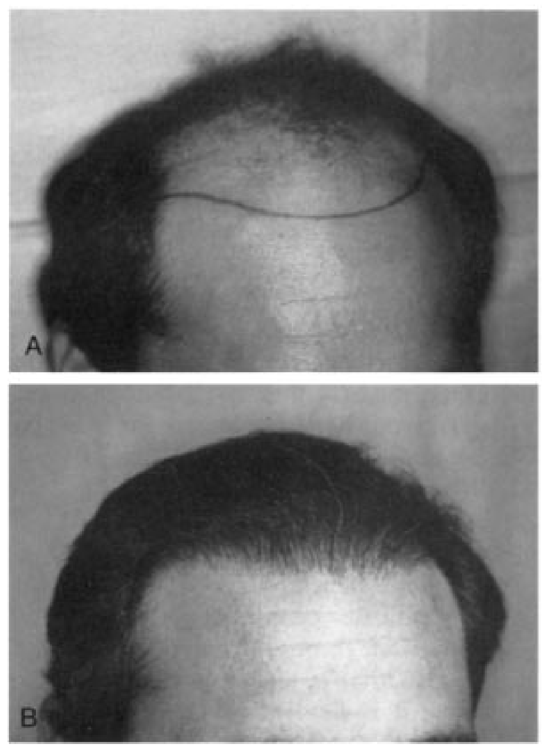

Figure 5. *A*, A 36-year-old man with early Norwood Class Va/VI balding pattern, with medium fine, dark brown hair of high density (2.8 hairs/mm^2). *B*, Patient after two procedures of follicular unit transplantation spaced 9 1/2 months apart consisting of 2,747 follicular units in the first session and 2,400 in the second session.

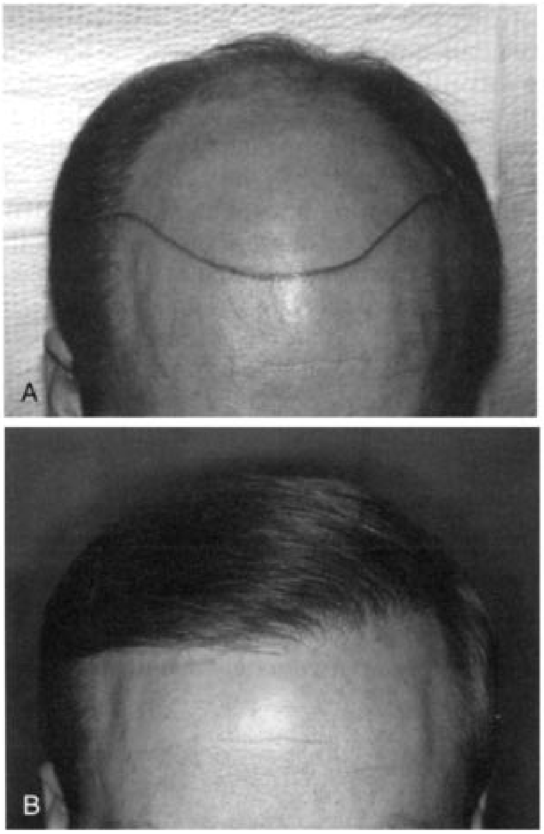

Figure 6. *A*, A 38-year-old man with a Norwood Class Va/VI, with medium fine, blonde hair (donor density of 1.9 hairs/mm^2). *B*, Patient after two procedures of follicular unit transplantation, spaced 11 months apart, with the second session fully grown in, consisting of 2,500 units in the first procedure and 1,186 in the second.

ular units before considering surgery. Often medical therapy, rather than surgery, would be appropriate for these patients.

2. When considering surgery, define the boundaries to be transplanted via densitometry as well as by gross visual inspection. Densitometry is a more sensitive indicator of miniaturization.
3. Transplant through (rather than around) an area that is highly miniaturized, because it is likely that this area will be lost by the time the transplant has grown in. Two examples of this would be a "forelock" composed of wispy miniaturized, rather than strong, terminal hair or the "bridge" of a Norwood class 5 patient that is beginning to break down.
4. Plan to use enough follicular units so that, if possible, the volume of transplanted hair is greater than the volume of hair that will likely be lost from telogen effluvium. Remember, we are never replacing "hair for hair" in the surgery, but in effect, replacing a large number of fine, miniaturized hairs with a much smaller amount of permanent, full-thickness terminal hairs.

In areas of extensive miniaturization, it may be appropriate to transplant follicular units in the same density as if the area was totally bald.

Economizing the Donor Supply

As mentioned earlier, the concern over the donor supply being finite is a rather recent development in hair restoration surgery; because it is the ultimate limiting factor in all transplantation surgery, every possible effort should be made to insure the maximum yield. We would briefly like to review the logic of using large sessions with regard to the surgical wound. The importance of proper harvesting techniques and precise follicular dissection in ensuring maximum donor yield is covered later.

The donor supply is more sensitive to donor density than one might think. In fact, for every unit change in donor density, there is a two-fold change in the amount of movable hair.[9] Although not immediately obvious, the logic of this is shown in Table 1. As discussed later in the section "A Mathematical Look at Balding," a person may loose 50% of his or her hair volume before it is clinically noticeable. Although we commonly think of this in terms of the balding scalp, it applies to the permanent zone as well.[5] In the average person with a density of 1 follicular unit/mm^2 (2 hairs/mm^2), the follicular unit density can be reduced to approximately 0.5 units/mm^2 (1 hair/mm^2) before the donor area appears too thin. In those with high hair density, a greater percentage may be removed (see Table 1). Therefore, a patient with a hair density of 2.5 hairs/mm^2 would have 50% more movable hair than the average patient with a hair den-

Table 1. THEORETICAL EFFECTS OF CHANGES IN DONOR DENSITY ON TRANSPLANTABLE HAIR*

A	**Donor Hair Density (hairs/mm²)**	**3.0**	**2.5**	**2.0**	**1.5**	**1.0**
B	Follicular Unit Density (units/mm²)	1.0	1.0	1.0	1.0	1.0
C	Total Hair in Permanent Zone	37,500	31,250	25,000	18,750	12,500
D	Follicular Units in Permanent Zone	12,500	12,500	12,500	12,500	12,500
E	Hairs that must Remain in Permanent Zone	12,500	12,500	12,500	12,500	12,500
F	Movable Hairs (C–E)	25,000	18,750	12,500	6,250	0
G	Average Hairs per Follicular Unit (G = A)	3.0	2.5	2.0	1.5	1.0
H	**Transplantable Follicular Units (F/G)**	**8,333**	**7,500**	**6,250**	**4,167****	**0**

*These numbers serve only to illustrate the effects of changes in donor density on hair supply. The actual number of grafts that can be harvested depend on a multitude of factors including donor dimensions, scalp laxity, hair characteristics (such as hair shaft diameter and wave), and skin/hair color contrast. It also assumes that the efficiency of the harvest is 100%, and that this can be maintained between procedures.

**Although the patient with a donor density of 1.5 hairs/mm^2 has half the available follicular unit grafts as a patient with a density of 3.0 hairs/mm^2 (4,167 grafts vs 8,333 grafts), each of his grafts, on average, have only half the hair content of the patient with the density of 3.0, so that his transplant will appear only one-fourth as full (4,167 grafts averaging 1.5 hairs per graft Vs 8,333 grafts averaging 3 hairs per graft).

sity of 2.0 hairs/mm^2, although the patient's hair density was only 25% more. The amount of movable hair will also depend upon other characteristics of the patient's follicular units (see section on "Characteristics of the Follicular Unit") and upon his scalp dimensions and laxity.

The density will obviously be affected by each hair transplant. If a person has a hair transplant procedure(s) that decreases his donor density by 25%, then half of his movable hair will be exhausted, because his follicular unit density will be reduced to 0.75 units/mm^2 (1.5 hairs/mm^2). If that same patient, began with 25% less hair density, i.e., 1.5 hairs/mm^2 (remember, the follicular unit density is constant and would still be 1 unit/mm^2), then the same transplant would reduce the follicular unit density to 0.75 units/mm^2 and would leave a hair density of 1 hair/mm^2 (0.75 units/mm^2 $\times$ 1.5 hairs/unit), too thin to permit further transplantation. These numbers serve to underscore the importance of trying to conserve donor hair in every aspect of the procedure.

Regardless of how impeccable the surgical technique, each time an incision is made in the donor area and each time sutures are placed, hair follicles are damaged or destroyed. This damage can be minimized (but not eliminated) by keeping the sutures very close to the wound edges so that they don't encompass much hair. In subsequent procedures the damage can be reduced by using the previous scar as the upper or lower boarder of the new excision. In this way, the amount of distortion and possible damage to existing hair is limited to only one free edge. Some physicians advocate the use of staples, feeling that this method of closure is quick, causes less trauma to the skin, and produces less damage to surrounding hair follicles (resulting in a superior scar). Others feel that staples produce unnecessary postoperative discomfort and actually produce greater scarring due to the less controlled approximation of the wound edges. Studies still need to be performed to compare these two techniques and provide a definitive answer.

There are other more subtle effects of the surgery. In all healing, even with primary intention closures, collagen is laid down and reorganized. This distorts the direction of the hair follicles and increases the risk of transection in subsequent procedures. In addition, the fibrosis makes the scalp less mobile for subsequent surgeries, therefore decreasing the amount of additional donor tissue that can be harvested. It should be clear that each time there is surgery these factors come into play, so that transplanting in large sessions, which minimizes the total number of individual procedures, will conserve on total donor hair.

Complexion of Follicular Units

A final issue regarding the use of large sessions is their ability to enhance the complexion of the follicular units generated from the donor strip. The logic behind this is very straightforward. In follicular unit transplantation the numbers of grafts present in any given size donor strip is determined by nature, because each graft represents one follicular unit. In contrast, in mini-micrografting techniques, the numbers are determined by the surgical team who cut the grafts "to size" depending upon how many of each size the surgeon feels are needed. For example if the "mini-micrografter" needed 200 single hair-grafts, he or she might divide up 100 two-hair grafts to produce 200 ones. If he or she needed 100 four-hair grafts, he or she might combine 200 two-hair grafts to satisfy his needs. As we have discussed in earlier sections, this is strictly taboo in follicular unit transplantation, because the splitting of units risks damage and poor growth, and the combining of units produces unnecessarily large wounds and results that are not totally natural.

It follows that if we are to use only the naturally occurring individual units we are then limited by their normal distribution in the scalp and with larger sessions greater numbers of each type of unit will be generated. For example, in a scalp of average hair density (2.1 hairs/mm^2), a donor strip of 1 cm $\times$ 20 cm would contain approximately 2,000 follicular units of the following distribution:

400	1 hair implants
1000	2 hair implants
500	3 hair implants
100	4 hair implants

In the same patient, a 5-cm strip of the same width would obviously contain 500 follicular units in similar proportions yielding:

100	1 hair implants
250	2 hair implants
125	3 hair implants
25	4 hair implants

In the average patient, it takes approximately 250 single hairs to create the soft transition zone of the frontal hairline, so in the smaller procedure the number of single hair grafts would be inadequate if one wanted to complete the procedure in one session. At the other end of the spectrum, one might need 500 three- and four-hair grafts placed in the "forelock" part of the scalp to give the patient a full, rather than a diffusely thin looking, frontal. The smaller strip would only generate 250 of the larger three and four hair grafts, an inadequate number for this purpose. Clearly then the logic of using larger procedures is that they will offer the surgeon the greatest flexibility in designing the transplant without having to combine or split follicular units.

As shown in Figure 7, the patient's absolute hair density will greatly affect the proportion of each of the one-, two-, three-, and four-hair follicular units found in the scalp. In patients with low hair density, a substantial proportion of follicular units will contain only a single hair and therefore the one-hair grafts needed to construct a frontal hairline will be plentiful. In patients with high density, the higher proportion of the larger three- and four-hair units will provide the "natural resources" to create significant fullness in certain areas. How the different size follicular units are used will greatly affect the cosmetic outcome of the transplant, and deciding their density and distribution is an "art" in itself.[7]

THE LOGIC OF THE FOLLICULAR UNIT CONSTANT

One of the interesting aspects of transplanting with follicular units is that nature was kind in spacing them at approximately one per square millimeter. Not only does this make the math easy but it makes estimating the donor harvest easy and gives us a logical basis for planning the density and distribution of the grafts. The relative constancy of the follicular unit density has been observed after performing densitometry on thousands of patients,[9] and has been observed histologically by Headington as early as 1982.[13]

The follicular unit density is not exactly 1/mm^2, but it is close enough to this number in most Caucasian and Asian scalps that it can be extremely useful in the surgery. The follicular unit density is significantly less in the people of African decent, averaging around 0.6/mm^2, and will decrease in everyone's scalp as one moves laterally from the densest part over the occiput, towards the temples (Table 2). It also tends to remain relatively

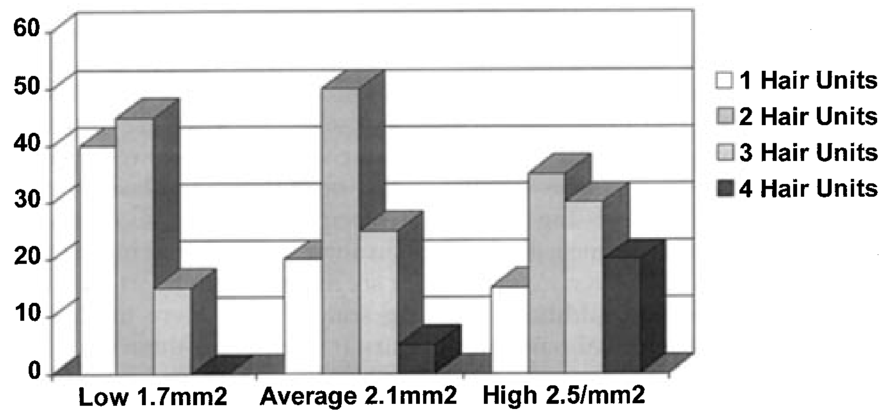

Figure 7. Size of follicular units as hair density varies. (*From* Bernstein RM: Measurements in hair restoration. Hair Transpl Forum Int 8:27 1998; with permission).

constant with age.[9] Finally, it is important to differentiate follicular unit density, which is relatively constant, from hair density, which can vary significantly from 1.5 hairs/mm^2 to 3 or more hairs/mm^2 in the general population.[3]

Once one realizes that the follicular unit density is relatively constant and that hair density varies, it follows that the number of hairs per follicular unit largely determines hair density. In other words, patients with high hair density have more hairs per follicular unit rather than follicular units spaced closer together, and those with low hair density have fewer hairs per follicular unit rather than follicular units spread further apart. This relationship is demonstrated in the three videografts shown in Figure 2. The implications of this in hair transplantation are enormous and can be summarized as follows:

- Because the follicular unit density is relatively constant, the same number of follicular units should generally be used to cover a specific size bald area regardless of the hair density of the patient.
- With low hair density, using the same number and spacing of follicular units as in a patient with high density will help to ensure that there is proper conservation of donor hair for the long-term.
- Hair density is a characteristic of the follicular unit specific to each individual, and together with hair shaft diameter, color, and wave, the density will determine the cosmetic impact of the transplant.

Table 2. RACIAL VARIATIONS IN THE FOLLICULAR UNIT

	Caucasians	Asians	Africans
Follicular units/mm^2	1.0	1.0	0.6
Average density (hairs/mm^2)	2.0	1.7	1.6
Predominant hair grouping	2	2	3

From Bernstein RM, Rassman WR: The aesthetics of follicular transplantation. Dermatol Surg 23:785–799, 1997; with permission.

Traditionally, hair restoration surgeons have "sold" the hair transplant procedure to patients by promising the high density of larger grafts. In reality, the results are determined by the hair characteristics of the patient, rather than by the promises of the physician. In a patient with low hair density (or poor hair characteristics), each follicular unit has less cosmetic value, so the results will appear less full. On the other hand, in patients with high hair density and greater hair shaft diameter, the same number of follicular units will provide fuller coverage. Because the follicular density in each patient's donor area is approximately the same, if we try to give the patient with fine hair and low density a "thick" look by combining them, we will simply run out of hair, not to mention that combining the units will also produce a pluggy, unnatural appearance.

For most patients, the limitations of the donor supply compared to the demands of the recipient area are such that trying to transplant hair in a way that approaches, or equals, the donor density will limit the ability to properly distribute the hair on the long-term. Fortunately, it takes a surprising little amount of hair to make a difference in the appearance of a bald individual. Even in individuals with thinning hair, the addition of limited amounts of healthy terminal hair can radically change a person's appearance. Logic might question this assumption, but clinical observations in thousands of patients have proven, over and over again, that when properly distributed, a limited amount of hair can radically improve the appearance of a balding man.

A Mathematical Look at Balding

To put things in perspective, let's look at some aspects of the balding process mathematically.[7] The normal hair density is approximately two hairs/mm^2 or one follicular group/mm^2. The average person can loose 50% of his hair without its being detectably thin. That means that one needs to restore only one follicular unit every 2 mm^2 in the hairline for a person's hair density to appear normal from a frontal view. In areas behind the hairline, where layering of the hair can add value, significantly less than 50% of the original density may suffice to produce fullness. For example, with modest styling considerations, significantly less than one-eigth of the original density can appear to look full if placed behind a well-constructed hairline.

In a typical patient with 50,000 follicular units on his scalp, the permanent donor area represents approximately 25% of this total number or 12,500 units, with the remaining 37,500 at risk to be lost. Of the 12,500 units in the donor area, approximately half are available for harvesting (i.e., 6,250). Therefore, we only have a total of 6,250 units to cover an area that originally had 37,500 and can replace only one-sixth (6,250/37,500) of what we had to begin with. There are many creative ways to distribute the grafts so that the transplant has the appearance of being much fuller,[7] but the point is that combining units to create more density is not one of them. That process will only make the ratios worse.

For example, if we use only individual follicular units, the average spacing between units, once they have been transplanted into the recipient area, is six times further apart than their original spacing in the donor area (or six times further apart than in the prebalding scalp). If we were to combine follicular units, (i.e., combine three units into one), then the spacing increases to eighteen times as much. Visualizing the transplant process in this way, one can easily see that there is no logic in combining grafts to give more density. It only results in larger spaces, but never more hair. Fortunately, the patient with the thin-looking donor area will look appropriately balanced and natural with a thin-looking transplant. The surgeon should promise no more.

Now that we realize that we can't combine grafts to produce more fullness, how can we use the follicular constant to design the transplant and maximize the cosmetic impact? The issue is always one of long-term planning, but unfortunately, the patient doesn't usually present with the final balding pattern. Therefore, when transplanting a patient early on, the density and distribution must be similar to how we would have transplanted him if he were further along in the process. For example, if a patient has temporal recession at age 25, we shouldn't give him any more density in this area than we would if he were 45. If we do, then when he is 45 he will look unnatural.

This is when an understanding of the follicular density comes in handy. If we have only one-sixth of the overall follicular density to work with and we want to use half of the donor density in a certain area (i.e., three times the average), then we can only use one-eighteenth of the donor density (one-third the average) in another area (given that these areas are of equal size) or we will run out of hair. For example, if we plan to eventually replace 50% of the patient's original density in the forelock area, then some other region of the scalp must "give." This might be accomplished by transplanting less on top of the scalp or transplanting the crown very lightly, or not at all. In the example of the 25-year-old above, if we decide that the final density of the lateral aspects of the frontal hairline should be only half the density of the central "forelock," then once we achieve this density, we must resist transplanting additional hair in that area, or the long-term distribution will be inappropriate.

The same would apply to the early treatment of the crown. If a patient presents with only crown balding, but because of his density, age, or family history he is expected to be very bald, one must place a limit on how much hair should be placed in this area. For example, if we assume that when he is completely bald and totally transplanted, the crown should have a density that is no greater than one-twentieth the density of the donor area, then that is all that should be placed from the outset. Too often, a young patient with a small area of balding is "packed" with hair to approximate the surrounding density and then later on he is left with a distribution so unnatural it cannot be repaired.

Procedures that Defy Logic

Scalp Reductions and Flaps

The logic in using the follicular constant applies equally to other forms of hair restoration surgery. When analyzed in this manner, it becomes clear why flaps and scalp reductions cause so many long-term cosmetic problems.[2] In a flap, follicular units are moved from the donor to the recipient area in a 1:1 ratio (i.e., in a density that is six times what we have just shown to be appropriate). As a result, the flap will consume vast amounts of the donor supply to treat a relatively small portion of the balding scalp, and produce a transplanted density that always looks unnaturally high.

In scalp reductions, the donor skin that is moved is actually being stretched, so the density transfer is somewhat less than with a flap. For example, if 2 inches of bald scalp are removed from a series of scalp reductions (after any stretch-back has occurred), and 3 inches of donor fringe from each side have participated in this movement, then, in effect, 6 inches of hair-bearing scalp have been distributed over an area of 8 inches. Assuming that the distribution is relatively uniform, the previously bald scalp now has a follicular density of approximately 75% of the donor density (6 divided by 8). On first blush one might think that this is a miracle. Especially because scalp reductions are presented as a technique that ". . . effectively conserves a significant donor area for future use,"[27] we seemingly have made something for nothing. When viewed in the context of our previous discussion, where the crown was only being transplanted to one-twentieth of the donor density to conserve hair for future transplants in the front, one wonders where all of this hair is suddenly coming from.

Remember we said that approximately half of the donor supply could be used for transplantation before it appeared too thin? Well, we have just used up half of that 50% with the scalp reduction. In other words, if we can normally remove donor hair so that a follicular density of 1 unit/mm^2 may be reduced to 0.5 follicular units/mm^2 before it appears too thin, then our scalp reductions have already taken us to 0.75 units/mm^2 or halfway there (see preceding paragraph). And what have we gained by using up half of our donor supply? We've covered only 2 inches of bald area in the back of the head, thinned the scalp, and altered the normal hair direction. Furthermore, additional donor hair will be needed to cover the resulting scalp reduction scars and additional hair will be needed to address any new cosmetic problems as the balding in the crown progresses. In summary, scalp reductions have the unfortunate effect of simultaneously decreasing donor density and scalp laxity, and therefore limiting the amount of hair available for the cosmetically important areas of the scalp.

Characteristics of the Follicular Unit

When considering the cosmetic impact of the hair restoration procedure, it is important to consider all of the patient's hair characteristics, as they can be of equal, or even greater importance, than the absolute number of hairs. For example, a close match of hair color and skin color will significantly contribute to the appearance of fullness, as will wavy hair. The follicular unit can actually be characterized by the following features:

- Hairs per follicular unit
- Hair shaft diameter
- Hair color
- Texture (wave, curl, kink)
- Other factors (emergent angle, static, oiliness, sheen, etc.)

It would seem logical to assume that the number of transplanted hairs is the major determinant in the cosmetic impact of the transplant. In reality, hair shaft diameter plays a more significant role than the absolute number of hairs. Coarse hair can be over twice the diameter of fine hair, so that when the area (πr^2) of the hair shafts are compared, coarse hair has more than five times the cross-sectional area (and therefore over five times the cosmetic value) of fine hair.[3] If we compare this variance in hair shaft size to the natural variation in hair density, we can see that the impact of the hair shaft diameter (and volume) is over 2 and a half times as significant as the absolute number of hairs. Table 3 shows the range of hair density and hair shaft diameter commonly seen in the population of patients who are candidates for hair transplantation surgery and summarizes the relationship between the two. After reviewing these data, it should be apparent that an understanding of both the aesthetic and mathematical elements of transplantation are needed to predict the outcome of the surgery.

THE LOGIC OF SINGLE-STRIP HARVESTING

The use of the multi-bladed knife is incompatible with follicular unit transplantation.

Table 3. RELATIVE SIGNIFICANCE OF HAIR DENSITY AND HAIR SHAFT DIAMETER

		Range	Variance
A	Hair density	1.5–3.0 hairs/mm^2	2
B	Hair shaft diameter	0.06–0.14 mm	2.3
C	Cross-sectional area	0.0028–0.0154 mm^2	5.4
D	Area/Density (C/A)	—	(2.7)

*Patients with a donor density less than 1.5 hairs/mm^2 or hair shaft diameter less than 0.06 mm are rarely candidates for hair transplantation.

When one remembers follicular unit anatomy and compares it to the construction of the knife, the reason should be obvious. The multi-bladed knife has blade spacing that generally range from 1.5 to 3 mm. When these blades pass through a donor area that has follicular units randomly distributed at 1/mm^2, few follicular units will be left unscathed. Clearly, one pass of the multi-bladed knife will break up many of the naturally occurring follicular units even before they leave the scalp and immediately reduce the follicular transplant procedure to one of mini-micrografts "cut to size."[8]

The "lure" of the multi-bladed knife is that it quickly generates fine strips of tissue that can easily be dissected into smaller pieces, and the finer the strips, the easier the dissection. But, besides destroying the integrity of the follicular unit, the multi-bladed knife also causes transection to the follicles themselves, and the finer the strips the worse the transection. As discussed in the first section of this article, the multi-bladed knife is a form of "blind harvesting" that makes all of its incisions in a horizontal plane where the angle of the emerging hair is the most acute and the incisions can cause the most damage. Another issue complicating the harvesting is that follicular units actually transverse though the skin in a slightly curved path because the bulbs are random in the fat and "gathered" into bundles in the dermis.[1] Regardless of the instrument, the initial incision is always going to be relatively "blind" so it makes the most sense to remove the strip with as few incisions as possible, and then perform all further cutting under direct visualization. This is the logic behind single-strip harvesting.

It is argued by some that a free hand ellipse is the preferred method for removing the strip, so that the cutting of each wound edge can be controlled separately (the upper edge should always be cut first). It is argued by others that two parallel blades offer more stability and avoid the problem of cutting through a mobile and partially distorted second edge (owing to the greater contraction of the dermis relative to the epidermis and fat). Regardless of the personal preference of the surgeon, the concept is the same. Single-strip harvesting is the best way to minimize transection, and the only way to provide adequate tissue for follicular unit transplantation.

THE LOGIC OF MICROSCOPIC DISSECTION

There is probably no other aspect of follicular unit transplantation that has generated more controversy than the use of the microscope. Fortunately, in no other area is the logic more straightforward. Stereomicroscopic dissection was introduced into the field of hair transplantation by Dr. Bobby Limmer,[17] who recognized the logic of using this tool as early as 1987. Its full value and impact are only now first being appreciated. The following three statements summarize the use of a microscope in hair transplantation:

- You can only perform follicular unit transplantation if you have follicular units to transplant.
- In order to dissect intact individual follicular units, you must be able to see them clearly.
- Only the microscope allows clear visualization in both normal and scarred skin, independent of the specific hair characteristics of color, hair shaft diameter, and curl.

Follicular dissection can logically be divided into two parts: the subdivision of the initial donor strip into smaller pieces and the further dissection of these pieces into individual follicular units. The first part of the procedure, the handling of the intact strip, has always been the most problematic. This is the main reason for the continued popularity of the multi-bladed knife, because in effect it bypasses the first part of the procedure by generating thin sections that can be laid on their sides. The thin sections, resting on their sides, then have stability for further dissection and permit transillumination from backlighting. The intact strip, however, is difficult to stabilize and is too opaque for transillumination to be useful.

The dissecting microscope allows the strip to be divided into sections (or slivers) by actually going around follicular units, leaving them intact. The dissecting stereomicroscope is able to accomplish this because of its high resolution (usually five times more powerful than magnifying loops) and its intense halogen top-lighting provides continuous illumination as one dissects through the strip. Stability can easily be achieved by applying slight traction to the free end of the strip. The thin slivers are then laid on their sides and the microscopic dissection of the individual units is completed. When using stereomicroscopic dissection, every aspect of the procedure is performed under direct visualization, except for the outer edges of the ellipse, so that follicular transection can be minimized and the follicular units maintained.

In a bilaterally controlled study,[4] the dissecting microscope was compared to magnifying loops with transillumination for the preparation of follicular unit grafts after the strip was divided into thin sections. The results showed that microscopic dissection produced a 17% greater yield of hair as compared to magnifying loops with transillumination. This study showed an increase in both the yield of follicular unit grafts as well as the total amount of hair. It is important to note is that this increase was observed only when the latter part of the dissecting procedure was studied (i.e., after the strip has already been cut into sections). When complete microscopic dissection is used, the difference in yield is even more significant, and is probably on the order of an additional 5% to 10%.

THE LOGIC OF AUTOMATION

Although in concept follicular unit transplantation may be the "ideal" transplant procedure, in its clinical application it poses special problems that have limited its widespread use.

- Follicular unit dissection is exact and requires special skill.
- Follicular units are delicate and require special handling.
- Follicular unit transplantation is labor intensive and time consuming.

One approach to these problems is to defend the status quo and rationalize the use of older techniques. The more logical solution is to solve them. The Rapid Fire Hair Implanter Carousel* is a new instrument that has been designed to address these technological problems through automation.[21] The Carousel works by creating a recipient site with a specialized knife, and then "dragging" the graft into place as the knife is withdrawn. This "dragging" action is especially useful for small, delicate grafts, such as follicular units, as they normally tend to compress or bend when pushed. By combining site creation and graft placement into a single step, the extra time it would take for the grafts to be inserted separately is virtually eliminated. The cartridge, which holds 100 units at a time, is specially designed for procedures involving large numbers of grafts and may also be used in mini-micrografting techniques.

An interesting phenomenon helps to explain why the Carousel places grafts into recipient sites so easily, while manual insertion is so problematic. The "finger" of the Carousel is able to insert the implant down to its final position in the skin in one motion. The surrounding tissues then apply a predominantly lateral force to the graft, holding it in place as the instrument is removed. In contrast, when grafts are inserted manually into a small site, the forceps allow only partial insertion on the first pass. Although the forceps are being repositioned, the vector of force on the graft is upward, and extrusion or popping occurs. Further attempts at insertion are clouded by the bloody field, and the implants, which were initially carefully grasped, are now grabbed across their growth centers and forced into the hole. This process causes crush injury and often irreversible damage. It is referred to in the literature as "H" or Human factor,[12] and is especially important when using small grafts that are more susceptible to mechanical trauma.

In all transplant procedures, economy of time is an essential element for success. Not only is a shorter procedure more practical for the staff and patient, but the grafts, subject to a relatively hypoxic environment once they have been removed from the body, are more quickly reunited with their oxygen supply. Although chilled holding solutions greatly increase the survival of tissue outside the body, the sooner the grafts are re-inserted, the greater their chance of maximum growth. In large transplant sessions, the Carousel's speed possibly represents its most important benefit.

Another source of injury that particularly affects small grafts is desiccation and warming. The grafts are at greatest risk while awaiting placement into the scalp, because at other times they can be held in chilled solutions. It has been recently shown that dried grafts are especially sensitive to mechanical trauma and will compound this form of injury.[11a] Warming will accelerate the effects of tissue hypoxia, and speed up the anaerobic metabolism. The enclosed cartridge of the Carousel helps to maintain a stable environment for the grafts from the time of dissection right until they are inserted into the scalp.

By reducing staffing requirements, operative time, and most importantly H-factor, automation appears to be a logical way of addressing many of the technical problems associated with the transplantation of large numbers of small grafts. Hopefully, this will allow a high-quality follicular unit transplantation procedure to be more easily performed by physicians, and as a result, be available to a greater number of patients.

CONCLUSION

We have come full circle in our excursion through follicular unit transplantation. We began by showing some of the illogical events that led the field astray, and then how simple observation brought us back on track. The logic of preserving the follicular unit and of using very small recipient sites was explained. The logic of using the follicular constant in the planning of the transplant and the advantage of performing it in large sessions as well as the benefits of single-strip harvesting and of microscopic dissection were demonstrated. Finally, problems intrinsic to the follicular unit transplantation procedure itself were discussed, and some logical ways

*Disclosure Statement: One of the authors of this article has a proprietary interest in Rapid Fire Hair Implanter Carousel.

to solve them were provided. It seems that hair transplantation is a logical process after all. Why didn't we notice this before?

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Address reprint requests to

Robert M. Bernstein, MD
2150 Center Avenue
Fort Lee, NJ 07024

GUEST EDITOR'S NOTE

The Logic of Follicular Unit Transplantation (Robert M. Bernstein, MD, and William R. Rassman, MD)

Everything you wanted to know about follicular unit transplantation, and then some. This monograph presented by Bernstein and Rassman can be thought of as a thesis on the subject of the follicular unit. This may be perhaps the most comprehensive accumulation of thoughts on the matter recorded thus far. Although the authors are very pro-follicular-unit, their arguments are quite sound. I would not argue with "the logic of follicular unit transplantation." Rather, I would point out that excellent results are routinely achieved by many methods. These "other methods" do not embrace the follicular unit transplant but are no less natural than a pure follicular unit transplant. Therefore, I believe the follicular unit is here to stay. After all, hair does emerge in follicular groupings and not as a single follicular unit. Perhaps it is best to keep these families together.

DOW STOUGH, MD
Guest Editor