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FORUM

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IN THIS ISSUE

The Development and Application of the Hair Diameter Index (HDI)

James A. Harris, MD, FISHRS | *Greenwood Village, Colorado, USA* | jharris@hsccolorado.com

ABSTRACT

Introduction: A study was presented in New York in 2003 investigating a proposed measurement system, the Hair Volume Index (HVI), for evaluating visual hair density. This was based on the idea that scalp coverage was related to the measured volume of hair in a given area. The study results did not support this contention but rather that visual density was correlated with the number of hairs and the hair shaft diameter, which led to the development of the Hair Diameter Index (HDI). This article describes the study results and the application of the HDI in hair restoration surgery for follicular unit excision (FUE) donor area planning and graft implantation density.

Keywords: Hair Diameter Index, Hair Volume Index, FUE limits, scalp coverage, implantation density

INTRODUCTION

The concept of the Hair Diameter Index (HDI) was first presented at the ISHRS Annual Scientific Meeting in New York in 2003.[1] The concept did not create any interest to speak of except for some interest by Dr. Bernie Cohen as he was involved in the measurement of hair volume and its impact on visual density. His interest and work in this area resulted in the development of cross-sectional trichometry (CST) and the HairCheckTM device.[2] There has been a surge of interest in this concept since Dr. Koray Erdogan began discussing his concept of hair coverage, which will be discussed later.

The HDI was an "accidental" development and was formulated after conducting a study to present a rationale and proof for the concept that coverage of the scalp by hair was a result of the total hair cross-sectional area of a group of hair shafts in a given area of scalp as suggested by Arnold[3] and other colleagues, such as Cole, in non-referenced presentations

Arnold offered the concept of the "Hair Mass Index" and had a simple methodology to measure this value. He tied a string around a bundle of hair in a given area of scalp, which in effect measured the circumference of the bundle. This value provided an "index" of the volume of the hair contained in the bundle. I felt that the idea could be refined and validated for general use.

Based on Arnold's work, my working theory was that if I could determine total cross-sectional area of a group of hairs by using the average hair shaft diameter of the hairs in a region, I could develop an "index" with values that would correlate with ranges of visual hair density in either the donor or recipient area.

By using the average hair shaft diameter and the average number of hairs per follicular unit to calculate an index, we could use this information to guide us in two important ways: 1) it could help us in determining how many follicular units could be removed from an area before it would look thin, or 2) in determining how many follicular units would be required to transplant into a given area to provide "thin," "moderate," or "thick" coverage in the recipient area, which would be applicable for general hair restoration.

The first step in the process was to determine how many hairs in the safe donor area had to be sampled to give an accurate estimate of the average Hair Shaft Diameter (HSD) in a given area of the donor region. This study was presented in a poster at the 2003 ISHRS Annual Scientific Meeting in New York meeting.[4] The hair shaft diameters of 100 hairs in each of 64 patients were measured by using a Starrett

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President's Message

Paul J. McAndrews, MD, FISHRS | *Pasadena, California, USA* | president@ishrs.org

Happy New Year to all my ISHRS colleagues!

I hope all of you had a very blessed and healthy holiday season with your family and office staff. If there is one thing the COVID pandemic has taught me, it is how important my family and friends are to me. I am so grateful for my family, my friends, and my ISHRS family. Thank you for all the joy you bring to my life.

Even though the COVID cases increased this holiday season, the future looks much brighter for the world and the ISHRS with the arrival of 3 different COVID-19 vaccines. I just received my COVID-19 vaccine and am left with only a sore arm. The ISHRS staff did such an amazing job in 2020 keeping us virtually connected to our 3 pillars: our members' education, comradery, and research. It looks like the sun is coming back out in 2021 knowing the vaccines will bring us back to "live" education, comradery, and research. I am looking forward to going back to life as we knew it.

I also am looking forward to our Hybrid World Conference in Lisbon that Marie Schambach, the World Congress Committee, and the ISHRS staff are already hard at work preparing. We will have the best of both worlds—live and virtual.

Happy New Year and I am absolutely looking forward to seeing you all in 2021. ■

Co-Editors' Messages

Jeffrey S. Epstein, MD, FISHRS ❙ *Miami, Florida, USA* ❙ forumeditors@ishrs.org

As I write this message, a Bitcoin is over $33,000, up more than 50% from a month ago. I wish I had in early December at the advice of a numbers-wonk friend of mine bought more than a half a Bitcoin, but fortunately my day job—hair restoration surgery—allows me to not have to rely on speculative investments to improve my financial situation. This surgery that I perform happens not only to be a vocation but also an avocation, with rewards that far exceed the financial. I am unable to think of any better investment than putting my money on "me"—my knowledge and skills, let alone my overwhelming willingness to work hard, a far better bet than any speculative currency (although I am optimistic about the future of a trustless, decentralized, non-repudiable currency). And like most savings that compound over time, the sooner one builds up his/her practice, the more dividends to be earned over the course of one's professional years in the form not only of money but also satisfaction and respect. Think of how much investing in yourself you undertook just to get you to the point of opening your practice doors in the form of formal education and residency training, and perhaps a fellowship. There is no time like the present to parlay that initial investment into a much bigger payout, not only monetarily but also reputation-wise.

Which brings me to what I share with any doctor who seeks my advice. First, invest in yourself and your practice. Second, seek to become an expert in your chosen field and you will always be recession proof, as well as the recipient of the respect of peers. If there was one conclusion of the ISHRS's Covid Task Force study, it was that those who specialized in hair restoration surgery had the least decline in practice volume and income in 2020. Third, when you love what you do, it is not work you do every day. Finally, particularly for the more "senior" of those who are reading this, avoid complacency. This phenomenon is not limited to doctors, but is a risk in just about every form of work. It can result in a lower level of care to patients, and (for fans of the movie *Seven* or of the bible) it also is related to two of the seven "deadly sins": pride and sloth (laziness). Approach each day, each surgery, each professional challenge with curiosity and passion.

As with many of the articles that appear in the *Forum*, the author of this issue's cover article, Jim Harris, perfectly exemplifies passion and focus. At the forefront of FUE, Dr. Harris continues to explore the nuances of hair science and its impact on hair procedure outcomes, expanding on the prior work of some exceptional minds in our field including the late Jim Arnold, Bernie Cohen, John Cole, and Koray Erdogan. What started as a passing thought in Dr. Arnold's mind led Dr. Cohen to create a device to help objectively quantify this concept that led Dr. Cole to provide a doctoral-thesis-level of exploration, that in this issue is presented as a refinement of Dr. Erdogan's formula.

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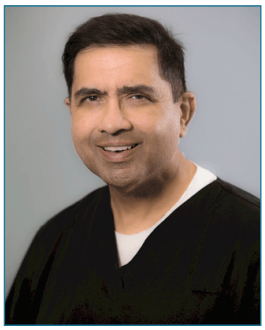

Aditya K. Gupta, MD, PhD, FISHRS ❙ *London, Ontario, Canada* ❙ forumeditors@ishrs.org

Happy New Year to our readers! I would like to take this opportunity to thank everyone who continues to work through these unprecedented times to bring together this amazing *Forum*. It is because of all your hard work that we continue to have such a diversity of high-quality articles. I would also like to encourage new contributors to come forward, and for all contributors to use our checklist (https://ishrs.org/wp-content/uploads/2020/06/ISHRS_Forum_ArticleSubmission_checklist_Fillable.pdf) to assist in preparing their article.

This issue highlights the variety of expertise in our field. Editor Emeritus Russell Knudsen discusses the difficult conversations that we sometimes have with patients who regret their treatment. These conversations are rarely discussed afterwards, but are important to share as many other transplant surgeons likely have similar encounters. Such stories are reminders to ensure that our patients, especially younger patients, understand the long-term upkeep and lifestyle changes required after surgery.

Our lead article by Jim Harris, one of the pioneers of FUE, accurately explains how the visual appearance of hair density is correlated with not only hair count but with hair diameter as well. The Hair Diameter Index could become an important tool for surgical planning, especially for new doctors and repeat patients. Other hair transplant innovations discussed in this issue include the dual-needle T-Fast multi-implanter by Roberto Trivellini, and the automation of FUE graft handling described by Pascal Boudjema and William Rassman. Such innovations could revolutionize hair transplant procedures, and we are honored to present them in their development stage here in the *Forum*.

Our newest column, Gregory Williams's "Conversations with the ABHRS Diplomates," presents the wide array of expertise and experience of the ABHRS Diplomates and offers useful advice regarding common practices. Vlad Ratushny's Hair Sciences column discusses the interesting world of organoid development, where culture-grown skin and hair follicles appear to have come a long way. In "Regenerative Medicine," Gorana Kuka-Epstein explains what is currently known in the literature regarding microneedling, its potential benefits, and the differences between dermarollers and dermapens. Sara Wasserbauer's Q&A column is, as always, a thought-provoking exercise. In "Hear from the Assistants," Marwan Noureldin profiles Song Yang from the Shapiro Medical Group in Minneapolis, USA, where she has great advice for assistants and physicians alike. In "ABHRS President's Corner," Sam Lam and Sara Wasserbauer discuss the merits of the ABHRS exam going online in 2021, thereby enabling participants to take the exam without having to travel, which is especially beneficial during this time of travel restrictions and quarantine. Finally, both our president, Paul McAndrews, and program chair, Marie Schambach, invite us to attend the upcoming World Congress. ■

Notes from the Editor Emeritus, 1999–2001

Russell Knudsen, MBBS, FISHRS | *Sydney, Australia* | drknudsen@knudsen.com.au

The Buyer's Remorse Dilemma

Yesterday, I had one of those consultations with an existing patient that you never want to have. He first came to see me aged 26 years with Norwood 3 pattern of balding. He was commenced on finasteride and eventually decided to proceed to temporal thickening via strip FUT surgery.

He arrived yesterday, aged 33 years, with his pregnant wife to tell me:

1. He wasn't using medication (hadn't for a long time).
2. He had lost the central forelock and was beginning to thin in the vertex.
3. He didn't care about balding anymore and wished he hadn't had the surgery!
4. What were his options?

Luckily, these conversations don't happen very often, but they are distressing when they do occur. The first time it happened to me was many years ago when I had (perhaps foolishly) agreed to operate on a very distressed 19-year-old at his mother's urging. He arrived 10 years later with spaced plug grafts and sadly informed me he wished he had never had the surgery. I felt very guilty about this, and ever since I repeatedly stress to patients during consultation that proceeding with surgery requires commitment to the process as you have to manage the balding for the rest of your life.

Thankfully, my recent patient "owned" the decision to have surgery, and we then proceeded to discuss the possible responses to his dilemma. As I explained it to him, he could either go forward (more grafts) or backward (laser the hairs out). He expressed an opinion that without having had surgery he would have just shaved everything off. This is problematic in that he has a very nice, thin, strip scar in the donor area, but it would be slightly visible and he wasn't interested in scalp micropigmentation (SMP) because it isn't permanent. This led me to wonder whether FUE would have been a better choice in this young man.

The important lesson to learn here is that patients may change their mind about the significance of their hair loss. When single men are seeking to attract a partner, their appearance has great importance to them. When they are happily partnered up, it is perhaps less so. I always tell my patients they can walk away from medication and the worst thing that can happen is that they bald according to their genes. I tell them they can't walk away from surgery as they now have to care about, and maintain, a normal appearance for the rest of their lives.

Young patients often tell me they prefer FUE because they can decide to shave their head later and not worry about visible scarring. While this is potentially valid, I don't like them to make a decision to proceed to surgery on the basis of a temporary result. After all, they have invested time and money in the decision, and it shouldn't be made flippantly.

When Richard Shiell was teaching me hair grafting, he told me he NEVER operated on men under 23 years of age as they didn't have sufficient emotional maturity to make the decision. We are now told many young men don't intellectually and emotionally mature till age 27. It just reinforces to us all how we should take our time with our younger patients and get them to make their decisions over a period of time with repeated emphasis on the consequences of their decision making.

So, what was the outcome for my patient? He appears to be moving in the direction of having further grafting to even the coverage in the frontal forelock area. We will not attempt to graft the mid-scalp or vertex. This is an expense he will have to wear because of his previous decision to have temporal grafting.

We will never get it perfect, but we owe it to our patients to help them make good decisions that they can live with over time. ■

EPSTEIN MESSAGE FROM PAGE 4

Also in this issue are two articles describing devices designed to optimize the hair transplant process. Roberto Trivellini and Aditya Gupta present the T-Fast multi-implanter and describe how they overcame the problem of popping when using a two-graft-at-a-time sharp implanter. In a more conceptual presentation, Pascal Boudjema and William Rassman describe the steps to automation to facilitate graft handling when using implanters. Personally speaking, the use of dull implanters in my practice has improved my regrowth rate and smoothed out the planting process, allowing me to continue to make my recipient sites by a tiny sharp blade, my preferred approach. The need for an assistant to load the implanters puts to good work those members of my team who once were kept busy doing FUT graft dissection. Gorana Kuka-Epstein once again achieves her column's goal of cutting through the hype of cell therapies, this time looking at microneedling and exploring whether the pain is really worth it. Editor Emeritus Russell Knudsen looks at the challenges of treating young men, and Vlad Ratushny has an excellent "Hair Sciences" column.

Enjoy your read, and please, all our U.S. members, turn to page 11 where you are requested to join the AMA and help to maintain the ISHRS's seat in the AMA's House of Delegates. And for those who are not ABHRS Diplomates, consider Sam Lam's invitation to sit for the exam virtually. ■

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digital micrometer. There was a recognition that this type of device may not be the best for measuring an elliptical hair shaft, but since the idea was to develop an "index," the measurement just had to be representative of the width of the hair shaft.

The statistical analysis revealed that to obtain an individual's mean HSD, approximately 25 hairs would have to be measured. This value would have a 95% probability that the true mean would be within 3 microns of that value. In order to increase the probability to 98%, with the same 3-micron confidence interval, 33 hairs needed to be sampled.

HAIR VOLUME INDEX STUDY

The concepts presented by Arnold provided the basis for the study to develop the Hair Volume Index (HVI).[5] The process would theoretically provide correlates between the calculated HVI and the subjective appearance (thin, medium, dense) of hair density. If in fact the appearance of hair density is related to the aggregate hair shaft volume in a given area, patients with similar HVIs should have a similar visual density regardless of the individual's average HSD. This study attempted to determine if this relationship exists and to quantify the ranges of HVIs that correlate with different apparent densities.

The HVI representing volume would vary to the square of the HSD and proportionally to the number of hairs in a given area. This relationship is described in the following equation:

$$\mathbf{HVI = (HSD^2) \times (\#hairs/cm^2) \div 100^*}$$

HSD is measured in microns.

*The division by 100 is to bring the values to between 1 and 200.

Eight subjects with no evidence of hair loss were evaluated under the following protocol. A 1cm^2 area was identified in the occiput and a nonvellus hair count obtained from that area. At least 25 hairs from the area were sampled, the average HSD in microns was determined using a Starrett digital micrometer, and the starting HVI was calculated.

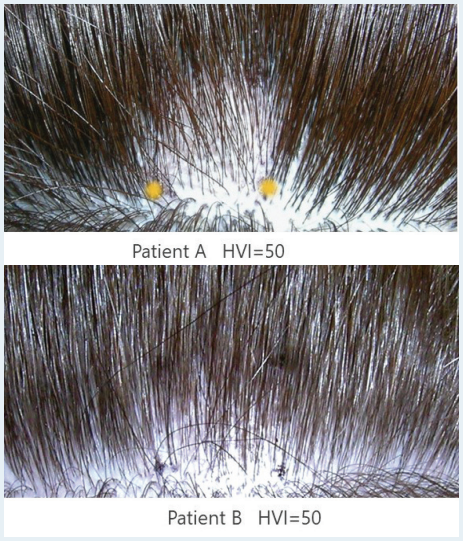
Given a subject's average HSD, calculations were performed to determine the number of hairs that had to be removed from the marked area to result in the target HVI values of 10, 20, 30, 40, 50, 60, and 70. The hair in the marked area was bundled and twisted, and a random hair selected and plucked from the lower hair shaft adjacent to the skin surface. This process was repeated until the appropriate number of hairs were removed to result in the target HVI. The area was photographed to provide a visual representation of an area of scalp with a given HVI.

The photographs of the individual subjects' test areas, with the study area having the same HVI, were presented to 6 blinded observers for side-by-side comparison. Their task was to subjectively determine if equal HVI values for different patients with differing hair counts and HSDs had similar visual densities. They were instructed to mentally ignore the effects of hair color and skin contrast and focus on the "amount of hair" and "scalp coverage" that was represented in the study area.

HVI Study Results and Development of the Hair Diameter Index (HDI)

Following the completion of the study protocol, it was apparent that in a given test subject, the appearance of an HVI of 60 appeared denser than an HVI of 30. However, when the test area of one individual was compared to another individual with a significant difference in the mean HSD, similar HVI values did not show similar visual densities. The photographs in Figure 1 illustrate this point. Although both patients had approximately the same HVI, the visual densities were different due to differences in the HSDs. When the observers were shown paired photographs of HVI values of 40 to 100, there was a similar finding: there was no correlation of similar HVI values between patients.

FIGURE 1. Both patients with HVI values of 50 appeared to have different hair densities.



Patient A HVI=50

Patient B HVI=50

To review, the observations by the blinded observers refuted the theory that the total "volume" of hair was responsible for visual density and that similar indices of volume (HVI) would appear to have similar densities. The results suggested that squaring the HSD raised the index to a value that was disproportionately high.

In order to further investigate the concept of visual density, the blinded observers were asked to group subject photographs into density equivalents, that is, a similar appearance of density. The instructions were again given to ignore the effects of hair color and skin contrast and focus on the "amount of hair" that was represented in the study area.

It was found that the observers grouped subjects into categories that correlated with the product of the HSD times the hair count. This result contradicted the assertion that the measured volume of hair contributes to visual density to a degree greater than the diameter alone.

The product of the HSD and hair count is a proportional relationship rather than an exponential one as described by the equation for the HVI. An alternative measure of the appearance of hair density based on these observations was proposed and was called the Hair Diameter Index (HDI). It is calculated as follows:

$$\mathbf{HDI = HSD \times (hairs/cm^2) \div 100^*}$$

HSD is measured in microns.

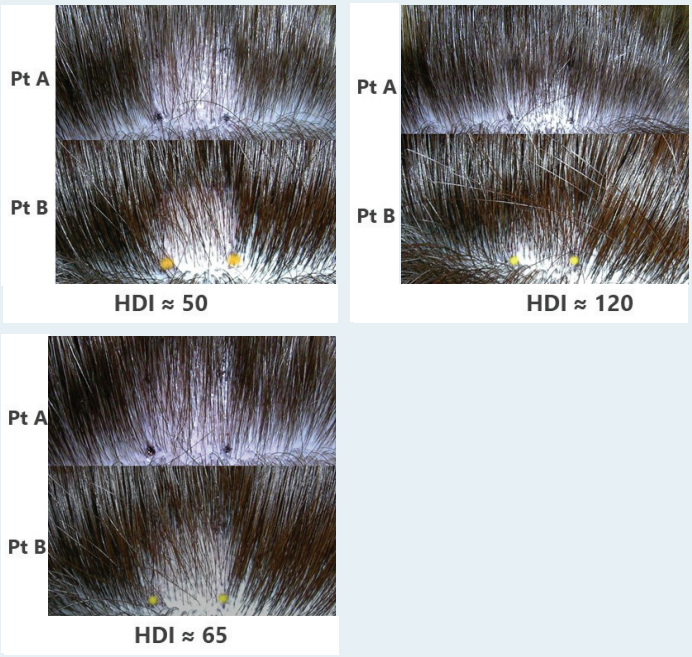
*This term is to bring the range of HDI values between 1 and 200 when the the HSD is measured in microns.

Based on the categorizations by blinded observers, with less than 10% disagreement of the total observations, HDI values above 80 appear "dense," values between 60 and 70

are of "moderate" density, and values below 50 appear "thin" (Figure 2). The importance of this is that these values were applicable to subjects with different hair colors, hair shaft diameters, and hair densities.

Dr. Koray Erdogan, in an independent presentation in 2015, presented a concept called the Hair Coverage Value (HCV)[6] that was the product of the average hair shaft diameter times the number of hairs in a given area; the same equation for the HDI. The difference between the HCV and HDI is that the value differs from the HDI by a factor of 10.

FIGURE 2. Examples of two different patients with HDI values of approximately 50, 65, and 120. This demonstrates the correlation of various HDI values with different apparent densities matched between patients.



Application of the HDI

The clinical correlates for the HDI values can be used for two main purposes. The first is to estimate the number of grafts required to achieve various thresholds of density in the recipient area. The second use is to determine either the number of grafts that need to remain in the donor area after FUE or the maximum number of grafts that can be removed from the donor area to prevent the appearance of overharvesting. These are calculated by simple manipulations of the equation used to calculate the HDI.

Using the HDI calculations, we can make some generalizations about the differences in donor capacity of Caucasian and Asian populations to illustrate the utility of the HDI concept. Given the differences in average HSDs and follicular unit densities in these populations, we can characterize the limits of FUE harvests.

The starting point is the average HDI of the donor area in these two populations. It's interesting to note that the HDI is essentially the same, 125, in these two groups in spite of the difference in the average HSD and follicular unit density (Figure 3). These differences will play a significant role in the extraction limits. Figure 4 illustrates how many grafts are available in each ethnic group to maintain a residual HDI of 60 required for moderate donor area density. The Caucasian group has the potential to provide 45 grafts/cm^2 while the Asian population may be able to provide 34 grafts/cm^2, almost a 25% reduction in number of available grafts.

FIGURE 3. The HDI for the average Asian and Caucasian donor area is approximately equal due to the larger HSD in the Asian group.

Hair Type	Hair/cm^2	FU/cm^2	Caliber µm	HDI
Asian	125	65	100	**125**
Caucasian	180	85	70	**126**

FIGURE 4. To allow for acceptable donor area coverage, fewer grafts can be extracted in the Asian population than in the Caucasian population.

Residual HDI = 60

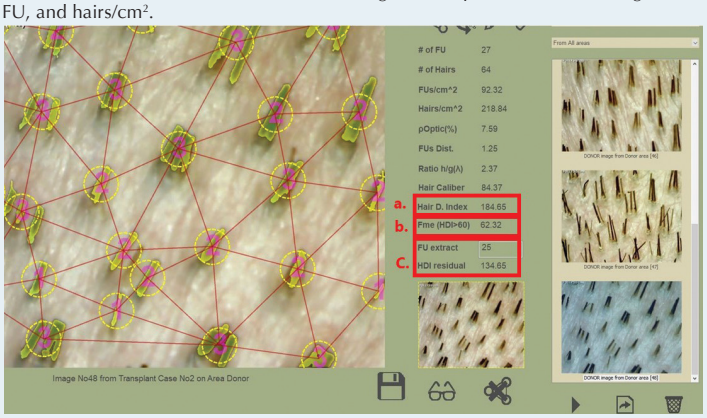
Hair Type	Starting Hair (# FU cm^2)	Hair/cm^2 removed	FU/cm^2 Removed	Remaining hairs	Remaining FU
Asian	125 (**65**)	65	**34**	60	**31**
Caucasian	180 (**85**)	95	**45**	85	**40**

The importance of these results is the illustration of how changes in hair shaft diameter and follicular unit density will a have definite impact on graft availability. Using the HDI will provide details as to the magnitude these factors play.

The actual process of determining these values by measuring the HSDs, calculating the average HSD, and counting the number hairs and follicular units/cm^2 can be time consuming and unwieldy. The process also has to be repeated for different areas of the scalp that are being considered for harvest. This application yields itself nicely to automation by trichoscopy devices.

The HDI calculations have been automated by Zontos and his Follysis device for the evaluation of scalp hair.[7] The system will measure the number of hairs/cm^2, follicular units/cm^2, average hairs/follicular unit, average HSD, and the HDI (Figure 5a) in the evaluation area. In addition to these measurements, the system will calculate the maximum number of follicular units that can be extracted to maintain an HDI > 60 (Figure 5b), and the calculated residual HDI for a planned number of excisions (Figure 5c).

FIGURE 5. Screen from Follysis analysis: a) the calculated HDI of the area examined; b) the Fme is the maximum number of follicular units that can be removed per cm^2 to maintain a residual HDI of 60; c) illustrates that the planned extraction density of 25 units/cm^2 results in a residual HDI of 134 given this patient's HSD, average hairs/FU, and hairs/cm^2.



DISCUSSION

FUE as performed today is, for the most part, dependent upon the skills of estimation by the surgeon to determine how many follicular units are available in a given area. In

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a submaximal, first passage (generally extracting less than 2,800 grafts in the "average" safe donor area) extraction case, there is little risk of overharvesting and creating a thin donor region. Having said that, the differences in Caucasian and Asian hair as presented in Figure 4 illustrates the fact that a surgeon must be very careful and not assume all patients have similar donor capacities.

The article by Keene et al described a strategy for "safe" excision densities in a first pass.[8] While the logic is sound, the difficulty arises when dealing with subsequent sessions and not really knowing what extraction density will push the HDI to a value less than 50 and thereby create an overharvested appearance. The use of an automated device to calculate the HDI would provide the surgeon with some information about the safe excision limits in a given area.

There has been some discussion that the HDI does not account for differences in hair color, hair length, curl, and hair/skin color contrast. The study in which the HDI concept was developed utilized patients that had the most unforgiving characteristics, basically patients with high hair/skin color contrast. The values obtained were the most conservative, and adding favorable characteristics such as light hair color, curl, and low contrast will only provide a margin of safety.

The concept of the HDI is not new, but it has been relegated to the obscure for many years. It was not until FUE had become the most commonly performed graft harvest method and some attention was paid to the issue of overharvesting that this method of measurement has received some attention. The independent corroboration by the work of Erdogan also gave credence to the concept. Its utility in general hair transplantation, regardless of the harvest method, is also clear. The concept applies to pre-surgical planning to determine how many grafts of a given average HSD will be required to create a desired visual density. If this number exceeds the surgeon's capacity to transplant at this density in a single surgery, then the patient can be counseled to the probability of the need for subsequent sessions.

In retrospect, perhaps the index should have been named the "Hair Density Index" as it really represents visual hair density. That may have resulted in greater exposure and development in its application in hair restoration. The importance of the HDI is that it can be useful in the planning for FUE harvesting densities and for recipient area transplant density estimates given the measured hair shaft diameters and hairs/follicular unit. The automation of these measurements will increase the ease and utility of the application of this concept.

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