Graft Survival and Transection Rates Across Hair Curl and Pigment Categories in FUE: A Retrospective Cohort Study at Vera Clinic

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Abstract

Background

Follicular unit extraction (FUE) outcomes are influenced by donor hair curl characteristics, with prior evidence largely restricted to small, non-stratified samples focused on tightly coiled (Afro-textured) hair. The independent contribution of hair pigment/contrast category, and its interaction with curl grade and donor skin thickness, has not been systematically examined in a single cohort.

Methods

This retrospective cohort study reviewed patients undergoing primary FUE at a single center in Istanbul, Turkey, between January 2023 and December 2023, with 12-month follow-up through December 2024. Of 420 screened patients, 320 met inclusion criteria after exclusion for scarring alopecia, keloid history, or incomplete records; a further reduction was due to loss to follow-up before the 12-month assessment. Patients were classified by curl grade (straight/slightly wavy, pronounced wavy, curly, tightly coiled) and pigment category (pigmented vs. gray/white), with donor skin thickness/firmness recorded as a covariate. The primary outcome was graft survival at 12 months; the secondary outcome was intraoperative follicular transection rate. Two-way ANCOVA and multivariable regression were used, with Bonferroni-corrected post-hoc comparisons (R, version 4.3.1).

Results

Overall 12-month graft survival was 92.1% (95% CI 91.6–92.6%), ranging from 93.5% in the straight/slightly wavy–pigmented stratum to 89.0% in the tightly coiled–gray/white stratum. Transection rate increased with curl grade, from 0.55% in the straight/slightly wavy stratum to 5.25% in the tightly coiled stratum (curl-grade means, pooled across pigment category); curl grade was independently associated with transection rate (partial $\eta^2 = 0.210$, $p < 0.001$), with smaller, independent contributions from pigment category and donor skin thickness. Overall transection rate was 1.7% (95% CI 1.3–2.1%).

Conclusions

Curl grade, more than pigment category alone, was the principal driver of technical difficulty in this cohort, with graft survival remaining within a clinically acceptable range across all strata. Findings support curl-adapted extraction protocols, particularly for tightly coiled hair, and highlight the need for larger, prospective studies in underrepresented subgroups such as gray/white tightly coiled hair.

Keywords: follicular unit extraction; hair curl classification; graft survival; follicular transection; retrospective cohort; hair pigmentation

Introduction

Follicular unit extraction (FUE) has become the predominant technique in autologous hair restoration, valued for its minimally invasive donor-site management and absence of a linear scar [1]. Successful outcomes depend on two closely linked technical parameters: the proportion of intraoperatively transected (non-viable) grafts, and the proportion of transplanted grafts that survive to produce a terminal hair shaft at follow-up. Both parameters are influenced not only by surgeon technique but by the physical characteristics of the donor hair itself, most notably its curl pattern.

Hair curl can be classified along a continuous, ethnicity-independent spectrum using objective geometric parameters such as curve diameter and curl index, rather than through categorical ethnic labels [2]. Existing surgical literature on curl-related technical difficulty has concentrated almost exclusively on the tightly coiled end of this spectrum, commonly described as Afro-textured hair. A case series of patients with tightly curled hair demonstrated that conventional rotary punches frequently produced unacceptably high transection rates, and that a curved, non-rotary punch reduced this to under 5% [3]. A subsequent multicenter retrospective cohort across seven clinics, using an extraction technique adapted to donor skin thickness and firmness, reported a mean transection rate of 3–6% among patients of African descent, rising with donor grading severity, and found that donor skin thickness and firmness had a greater independent effect on transection than curl grade alone [4]. A structured clinical classification of follicle curvature further suggested that technical adaptation requirements increase progressively across the curl spectrum, with the most pronounced step-change occurring between moderately curly and tightly coiled follicle morphology, rather than at a single fixed threshold [5].

Two gaps remain in this evidence base. First, the published cohorts examining curl-related technical difficulty are small (a case series of 18; a multicenter cohort of 64) and are constructed around a single curl category rather than stratifying outcomes across the full curl spectrum within one cohort, limiting the ability to characterize where along that spectrum technical difficulty meaningfully changes. Second, hair pigment and scalp-hair contrast, frequently discussed in clinical practice as a source of reduced extraction precision due to impaired follicle visibility, independent of curl, has not been examined as a stratified, quantified variable in any retrospective cohort identified to date. No study has jointly modeled curl grade and pigment category as independent, cross-classified exposures while adjusting for donor skin thickness, despite evidence that skin characteristics may confound or exceed the effect of curl itself [4].

The aim of this study was to determine 12-month graft survival and intraoperative follicular transection rate across four donor hair curl grades and two pigment categories (pigmented versus gray/white) in a single-center retrospective FUE cohort, adjusting for donor skin thickness and firmness as a covariate, in order to characterize the independent and joint contribution of curl grade and pigment category to technical outcomes.

Methods

Study Design

This was a retrospective cohort study conducted at a single specialized hair restoration center and reported in accordance with the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) statement for cohort studies [6].

Setting

All procedures were performed at Vera Clinic, Istanbul, Turkey, a high-volume hair restoration center. Patients underwent primary follicular unit extraction (FUE) between January 1, 2023, and December 31, 2023. Clinical, intraoperative, and follow-up records were retrieved from the Vera Clinic Academy Institutional Data Registry, with follow-up data collected through 31 December 2024, providing a minimum of 12 months of post-operative observation for every patient in the analytic cohort, including those operated on in the final week of the recruitment window.

Participants

Eligible patients were adults aged 18 years or older undergoing primary FUE at the study center during the recruitment window, with no upper age limit, who reached the mandated 12-month follow-up assessment. Exclusion criteria were: active central centrifugal cicatricial alopecia (CCCA), a scarring alopecia that predominantly affects women of African descent [7], or acne keloidalis nuchae (AKN); a known personal history of keloid scarring; prior hair transplantation performed at another facility; concurrent follicular unit transplantation (FUT/strip) procedures; or concurrent active scalp disease (e.g., psoriasis, active bacterial or fungal infection). Of 420 consecutively screened patients, 55 were excluded on eligibility grounds (active CCCA/AKN, n = 14; keloid history, n = 11; incomplete donor-characteristic or intraoperative documentation, n = 30), yielding 365 eligible patients. No patients in this cohort met the prior-transplantation or concurrent-FUT/strip exclusion criteria. A further 45 were lost to follow-up before the 12-month assessment, yielding a final analytic cohort of 320 patients (Figure 1). No formal a priori sample size calculation was performed; the cohort size reflects the number of eligible, fully documented patients available within the specified recruitment window, and the smallest stratum (tightly coiled, gray/white hair; n = 8) is likely underpowered for stable point estimation, as noted in the Limitations.

Variables

The primary exposure was donor hair curl grade, classified into four categories informed by geometric curl-classification principles: straight/slightly wavy, pronounced wavy, curly, and tightly coiled (coily). Classification was performed by the treating clinical team at the pre-operative consultation based on visual and photographic assessment; tightly coiled hair in this cohort corresponds to what is commonly referred to in the clinical and cosmetic literature as Afro-textured hair, though classification in this study was curl-based rather than ethnicity-based. The second exposure was pigment/contrast category, classified as pigmented (dark or light brown/blonde) versus gray/white, based on the predominant color of donor-area hair at consultation. Donor skin thickness and firmness (thin, medium, thick/firm), assessed by the extracting surgeon by palpation at the start of the procedure, was recorded as a covariate, consistent with prior evidence that skin characteristics independently influence extraction difficulty [4]. Extraction technique, standard (sharp-edge punch with a unidirectional rotary motor at fixed rotation angle and speed) versus blunt-adapted (dull-edge punch combined with a bidirectional rotary motor, with rotation angle and speed manually calibrated by the surgeon to individual follicle characteristics), was recorded for the curly and tightly coiled strata, where technique selection is most likely to vary. The primary outcome was graft survival at 12 months, defined as the proportion of transplanted grafts producing a terminal hair shaft ≥1 cm, assessed by standardized trichoscopy. The secondary outcome was intraoperative follicular transection rate, defined as the proportion of extracted follicular units transected during extraction, recorded by manual count.

Data Sources and Measurement

All variables were extracted retrospectively from clinical charts, intraoperative extraction logs, and 12-month follow-up trichoscopy records held in the Vera Clinic Academy Institutional Data Registry. Curl grade and pigment category were not assessed using a calibrated instrument (e.g., curl-index measurement of sampled hair fibers); classification relied on clinician judgment at consultation, without formal inter-rater reliability testing, which is addressed in the Limitations.

Bias

Selection bias from non-consecutive documentation was minimized by including all consecutively treated patients meeting eligibility criteria within the recruitment window; however, the 30 patients excluded for incomplete donor-characteristic documentation may not be randomly distributed with respect to curl grade, if certain curl types were less consistently documented. Loss to follow-up (n = 45) was handled by complete-case analysis; no formal comparison between patients lost to follow-up and those retained was performed. Information bias related to non-calibrated curl and pigment classification is addressed above.

Statistical Methods

Continuous variables are reported as mean ± SD; categorical variables as n (%). The primary and secondary outcomes were each analyzed using two-way analysis of covariance (ANCOVA), with curl grade (4 levels) and pigment category (2 levels) as fixed factors, their interaction term, and donor skin thickness/firmness as a covariate. Where a main effect was statistically significant, Bonferroni-corrected pairwise post-hoc comparisons were performed. Multivariable linear regression, with the same predictors modeled as continuous/ordinal terms, was conducted as a sensitivity analysis for the secondary outcome. An exploratory subgroup comparison of transection rate by extraction technique (standard versus blunt-adapted) was performed within the curly and tightly coiled strata only. Two-tailed $p < 0.05$ was considered statistically significant. All analyses were performed in R (version 4.3.1).

Ethics

This retrospective cohort analysis was based on de-identified clinical charts, intraoperative logs, and follow-up records collected as part of routine post-operative care at Vera Clinic. Patients were informed at the time of treatment that anonymized clinical data collected during standard follow-up visits could be used for research and quality-improvement purposes. All patient records were fully anonymized and de-identified prior to analysis. Given the retrospective, fully de-identified nature of the dataset and its collection under routine quality-improvement protocols, this analysis was conducted as an internal institutional registry review rather than a prospective research study. As such, prospective ethics committee approval under the Declaration of Helsinki was not applicable; the analysis nonetheless adhered to the Declaration's principles regarding confidentiality and data protection for retrospective, de-identified data.

Results

Participants

Of 420 screened patients, 365 (86.9%) met eligibility criteria; 320 (76.2% of those screened) were retained in the analytic cohort after loss to follow-up (Figure 1). Exclusions on eligibility grounds comprised 25 patients for clinical criteria and 30 for incomplete documentation; a further 45 were lost to

follow-up before the 12-month assessment. Baseline characteristics of the analytic cohort are summarized in Table 1.

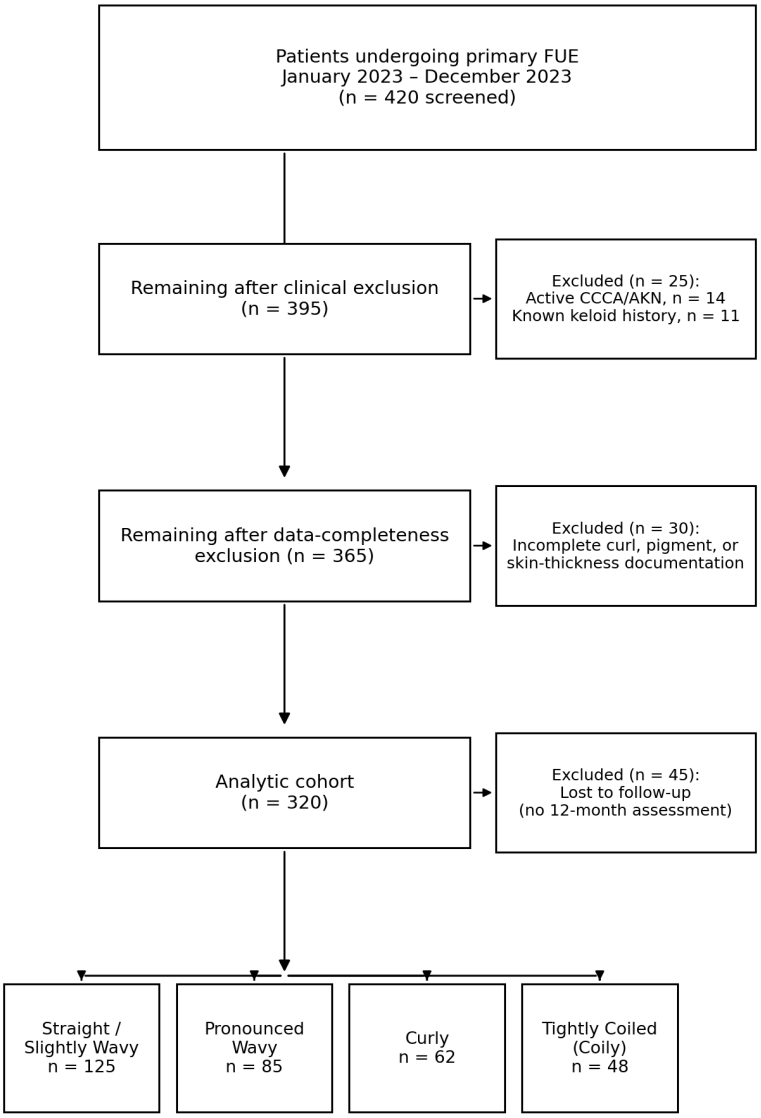

Figure 1. Patient flow through the analytic cohort.

Table 1. Baseline demographic and procedural characteristics of the analytic cohort (N = 320).

Characteristic	**Value (N = 320)**
Age, years, mean ± SD	34.2 ± 7.8
Sex, n (%)	
Male	283 (88.4)
Female	37 (11.6)
Alopecia severity, n (%)	

Characteristic	Value (N = 320)
Early	112 (35.0)
Moderate	144 (45.0)
Advanced	64 (20.0)
Total grafts transplanted, mean ± SD	3,310 ± 580
Curl grade, n (%)	
Straight / slightly wavy	125 (39.1)
Pronounced wavy	85 (26.6)
Curly	62 (19.4)
Tightly coiled (coily)	48 (15.0)
Pigment category, n (%)	
Pigmented	280 (87.5)
Gray / white	40 (12.5)
Donor skin thickness / firmness, n (%)	
Thin	86 (26.9)
Medium	141 (44.1)
Thick / firm	93 (29.1)

Primary Outcome: Graft Survival

Overall 12-month graft survival was 92.1% (95% CI 91.6–92.6%; Table 2), ranging from 93.5% in the straight/slightly wavy–pigmented stratum to 89.0% in the tightly coiled–gray/white stratum (Figure 2). Two-way ANCOVA showed a significant main effect of curl grade ($F(3,311) = 8.42$, $p < 0.001$, partial $\eta^2 = 0.075$) and pigment category ($F(1,311) = 5.16$, $p = 0.024$, partial $\eta^2 = 0.016$) on graft survival, with no significant curl × pigment interaction ($F(3,311) = 0.61$, $p = 0.607$, partial $\eta^2 = 0.006$). Donor skin thickness/firmness showed a borderline independent association with graft survival, at the threshold of statistical significance ($F(1,311) = 3.88$, $p = 0.050$, partial $\eta^2 = 0.012$). Bonferroni-corrected post-hoc comparisons indicated that graft survival in the tightly coiled group was significantly lower than in the straight/slightly wavy group (mean difference 3.1 percentage points, $p < 0.001$), with no other pairwise comparisons reaching significance after correction.

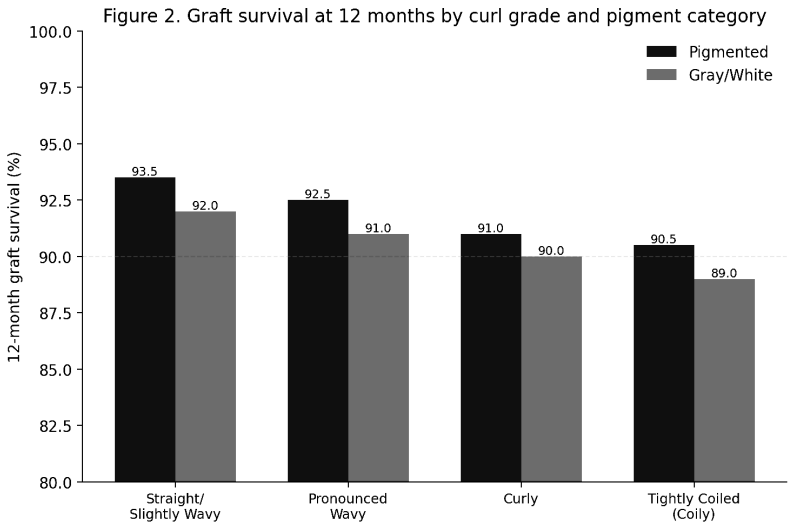

Figure 2. Graft survival at 12 months by curl grade and pigment category.

Secondary Outcome: Follicular Transection Rate

Overall transection rate was 1.7% (95% CI 1.3–2.1%; Table 2), ranging from 0.5% (straight/slightly wavy–pigmented) to 6.5% (tightly coiled–gray/white) (Figure 3). Curl grade was strongly and independently associated with transection rate ($F(3,311) = 27.56$, $p < 0.001$, partial $\eta^2 = 0.210$), with a smaller independent contribution from pigment category ($F(1,311) = 6.93$, $p = 0.009$, partial $\eta^2 = 0.022$) and no significant curl × pigment interaction ($F(3,311) = 1.24$, $p = 0.296$, partial $\eta^2 = 0.012$). Donor skin thickness/firmness was independently associated with transection rate ($F(1,311) = 15.82$, $p < 0.001$, partial $\eta^2 = 0.048$). Bonferroni-corrected post-hoc comparisons indicated that transection rate in the tightly coiled group was significantly higher than in the straight/slightly wavy group (mean difference 4.7 percentage points, $p < 0.001$) and than in the pronounced wavy group (mean difference 4.4 percentage points, $p < 0.001$); the curly group did not differ significantly from the tightly coiled group after correction ($p = 0.088$). For pigment category, gray/white hair showed significantly higher transection than pigmented hair (mean difference 0.6 percentage points, $p = 0.009$). In a sensitivity regression model ($R^2 = 0.34$, $F(3,316) = 54.2$, $p < 0.001$), each one-category increase in curl grade was associated with a 1.38 percentage-point increase in transection rate (95% CI 1.08–1.68, $p < 0.001$); gray/white pigment was associated with a 0.62 percentage-point increase relative to pigmented hair (95% CI 0.11–1.13, $p = 0.018$); and each one-category increase in skin thickness/firmness was associated with a 0.71 percentage-point increase (95% CI 0.34–1.08, $p < 0.001$).

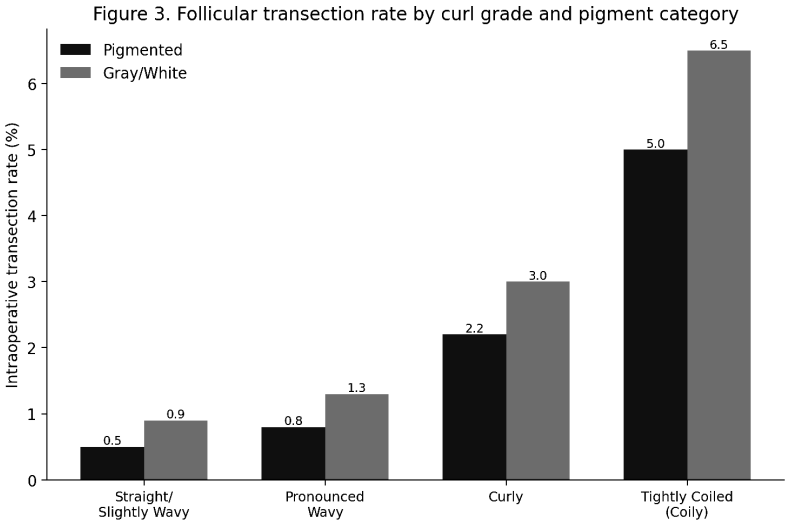

Figure 3. Follicular transection rate by curl grade and pigment category.

Table 2. Graft survival and transection rate by curl grade and pigment category.

Curl grade	Pigment	n	Graft survival, %	Transection, %
Straight / slightly wavy	Pigmented	110	93.5	0.5
Straight / slightly wavy	Gray/white	15	92.0	0.9
Pronounced wavy	Pigmented	75	92.5	0.8
Pronounced wavy	Gray/white	10	91.0	1.3
Curly	Pigmented	55	91.0	2.2
Curly	Gray/white	7	90.0	3.0
Tightly coiled	Pigmented	40	90.5	5.0
Tightly coiled	Gray/white	8	89.0	6.5
Overall	—	320	92.1 (91.6–92.6)*	1.7 (1.3–2.1)*

**95% confidence interval.*

Exploratory Subgroup Analysis: Extraction Technique

Within the curly and tightly coiled strata, where extraction technique was recorded, transection rate was consistently lower with the blunt-adapted technique (dull-edge punch combined with a bidirectional rotary motor, manually calibrated by the surgeon for rotation angle and speed) than with the standard technique (sharp-edge punch with a unidirectional rotary motor at fixed angle and speed) (curly: 1.2% vs. 3.5%; tightly coiled: 4.0% vs. 9.5%; Table 3). Within the tightly coiled

stratum, this difference did not reach conventional statistical significance ($\chi^2 = 2.87$, $p = 0.090$, n = 11 and 37 in the standard and blunt-adapted arms respectively); within the curly stratum, the difference was significant ($\chi^2 = 4.91$, $p = 0.027$, n = 29 and 33). Given the small arm size in the tightly coiled stratum, this comparison should be interpreted with caution. This subgroup analysis was not pre-specified as a primary or secondary comparison and is exploratory.

Table 3. Exploratory comparison of transection rate by extraction technique within technically challenging curl strata.

Curl grade	Extraction technique	n	Transection, %
Curly	Standard (sharp punch, unidirectional, fixed)	29	3.5
Curly	Blunt-adapted (dull punch, bidirectional, surgeon-calibrated)	33	1.2
Tightly coiled	Standard (sharp punch, unidirectional, fixed)	11	9.5
Tightly coiled	Blunt-adapted (dull punch, bidirectional, surgeon-calibrated)	37	4.0

Discussion

In this retrospective cohort, 12-month graft survival remained within a clinically acceptable range (89.0–93.5%) across all curl-by-pigment strata, while intraoperative transection rate rose substantially with curl grade, from 0.5% in straight/slightly wavy hair to 6.5% in tightly coiled, gray/white hair. Curl grade was the dominant driver of transection, with pigment category and donor skin thickness/firmness each contributing smaller, independent effects.

The magnitude of transection observed in the tightly coiled strata (5.0–6.5%) sits at the upper edge of, and in the standard-technique arm (9.5%; Table 3) above, the 3–6% range reported in a multicenter cohort of patients of African descent using an extraction technique adapted to donor skin characteristics [4]. It remains well below transection rates exceeding 80% reported with unadapted, sharp and dull rotary punches in a comparable population [3], consistent with the routine use of a blunt-punch, bidirectional-rotary protocol with rotation angle and speed manually calibrated by the surgeon for technically challenging curl grades in the present cohort; an approach mechanistically consistent with reports that a curved, non-rotary punch reduces transection in tightly coiled hair relative to sharp rotary instruments [3]. As in that multicenter cohort, donor skin thickness/firmness in the present study contributed independently to transection risk, reinforcing that skin characteristics should not be conflated with curl grade in surgical planning [4]. The progressive, rather than binary, increase in technical difficulty across curl grade observed here is consistent with a structured clinical classification of follicle curvature describing a graded continuum with the most pronounced step-change between moderately curly and tightly coiled follicle morphology, rather than a single fixed threshold [5].

Several mechanisms may explain these findings. Closed subsurface follicle curvature in tightly coiled hair likely reduces a punch's ability to track the follicle path below the skin surface; a dull-edge punch may reduce shearing at points where the follicle path deviates from the punch trajectory, while manual, per-patient calibration of a bidirectional rotary motor's angle and speed may allow the surgeon to adapt in real time to that deviation rather than applying a single fixed rotational profile, together plausibly explaining the lower transection rates observed with the blunt-adapted technique. Reduced visual contrast between gray/white hair and the scalp may independently reduce the precision of punch alignment during extraction, offering a plausible mechanism for the smaller but independent pigment effect observed on both outcomes. Thicker, firmer donor skin may reduce tactile feedback and punch control, independently elevating transection risk regardless of curl grade or pigment.

This study has several strengths, including single-center procedural consistency, a full curl-grade spectrum rather than a single curl category, and joint modeling of curl grade and pigment category with an explicit skin-thickness covariate. Limitations should be considered when interpreting these findings. The retrospective design precludes causal inference; associations reported here should not be interpreted as causal. Curl grade and pigment category were classified by clinician judgment without a calibrated measurement instrument or formal inter-rater reliability testing, which may introduce misclassification. Donor skin thickness/firmness and curl grade were modeled as continuous/ordinal terms in the ANCOVA and sensitivity regression, which assumes equal spacing between categories; this assumption is not verified for palpation-based skin grading or for the curl spectrum, which elsewhere in this study is described as having its most pronounced step-change at a single boundary rather than uniform intervals. Formal ANCOVA assumption checks (normality, homogeneity of variance, homogeneity of regression slopes) were not performed and are a limitation, particularly for transection rate, a bounded proportion with stratum means as low as 0.5%. The tightly coiled–gray/white stratum ($n = 8$) was small and likely underpowered, and these estimates should be regarded as exploratory. Extraction technique was recorded only within the curly and tightly coiled strata, and technique selection correlated with curl grade by design; because technique could not be entered into the main ANCOVA, the curl-grade effect on transection reported above may partly reflect technique choice rather than curl grade alone, and this should be regarded as a confound rather than a fully independent effect. Because CCCA is an exclusion criterion and predominantly affects women of African descent [7], the tightly coiled stratum in this cohort may be disproportionately male relative to the broader population of individuals with tightly coiled hair, which should be considered when generalizing these findings to female patients with tightly coiled hair. Loss to follow-up was handled by complete-case analysis without a formal missingness comparison, which may introduce bias if attrition was related to curl grade or pigment category. Findings arise from a single center and may not generalize to populations with different procedural protocols, surgeon experience, or patient demographics. Finally, published comparator data for gray/white hair transection risk remain sparse, limiting external validation of the pigment-related findings.

These findings support the continued use of curl-adapted extraction protocols, particularly for tightly coiled hair, and suggest that donor skin thickness/firmness assessment should be incorporated alongside curl assessment in pre-operative planning rather than considered secondary to it. The independent, if smaller, contribution of pigment category suggests that extraction precision in gray/white hair may benefit from dedicated visualization aids, a hypothesis warranting prospective evaluation. Future multicenter studies should prioritize adequately powered recruitment of underrepresented strata, particularly

gray/white tightly coiled hair, and should incorporate calibrated curl-classification instruments to reduce measurement-related bias.

Conclusions

In this retrospective single-center cohort, 12-month graft survival remained within a clinically acceptable range across all donor hair curl and pigment categories, while intraoperative transection rate increased progressively with curl grade, most sharply in tightly coiled hair, with smaller independent contributions from pigment category and donor skin thickness/firmness. These findings support the continued use of curl-adapted extraction technique, informed jointly by curl grade and donor skin characteristics rather than curl grade alone, and highlight gray/white tightly coiled hair as a specific, underrepresented subgroup warranting larger, prospective study.

Ethics Approval

This study was conducted as a retrospective, de-identified institutional registry review; see Methods, Ethics, for the applicable data-protection framework.

Conflict of Interest

All contributing personnel are affiliated with Vera Clinic Academy and Vera Clinic, where the study was conducted and which funds and commercially offers the extraction techniques evaluated. No other competing interests are declared. Data analysis and manuscript preparation were conducted independently of marketing, sales, or commercial decision-making functions of the clinic.

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Data Availability

De-identified data supporting the findings of this study are available from Vera Clinic Academy upon reasonable request.

Author Contributions

This study was conceived, conducted, analyzed, and drafted collectively by the Vera Clinic Academy research team, who jointly take responsibility for the accuracy and integrity of the work.

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