Genetic Associations with Indoor Tanning Addiction among non-Hispanic White Young Adult Women

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Abstract

Background Some young people may become addicted to indoor tanning in a manner similar to other forms of addiction, but research on genetic associations with indoor tanning addiction remains limited.

Purpose To examine if liabilities in genetic addiction reward pathways and psychiatric comorbidity influence the risk of indoor tanning addiction.

Methods This was a cross-sectional study with a community sample of 292 non-Hispanic white young adult women aged 18–30 years who reported indoor tanning in the past year. Self-report measures included indoor tanning frequency, appearance orientation, depressive symptoms, and two screeners of tanning addiction. DNA samples were analyzed for 34 single nucleotide polymorphisms (SNPs) in candidate genes in addiction reward pathways.

Results No SNPs were significantly associated with tanning addiction in univariate analyses after multiplicity adjustment. In multivariable analyses adjusting for indoor tanning frequency, appearance orientation, and depressive symptoms, variant genotypes (CC or CT) in two *DRD2* dopamine receptor gene SNPs were associated with increased odds of indoor tanning addiction (rs4436578, odds ratio [OR]: 2.30, 95% confidence interval [CI]: 1.11–4.77; rs4648318, OR: 1.95, 95% CI: 1.02–3.72). Variant SNP genotypes interacted with depressive symptoms to increase the risk of indoor tanning

addiction: OR: 10.79, 95% CI: 3.25, 35.80, OR: 13.60, 95% CI: 4.13, 44.78, respectively.

Conclusions This study provides preliminary evidence that *DRD2* dopamine receptor gene SNPs are associated with indoor tanning addiction and young women with variant genotypes and elevated depressive symptoms may be at higher risk. These preliminary results support a reward-based model for indoor tanning addiction and warrant further investigation.

Keywords Indoor tanning addiction • genetics • skin cancer risk • prevention

Introduction

Ultraviolet (UV) radiation exposure is a primary cause of melanoma and nonmelanoma skin cancer. Although the majority of UV exposure occurs through natural sunlight, exposure from intentional indoor tanning is estimated to account for 10% of skin cancer cases in the USA [1]. Indoor tanning among U.S. adults has declined in recent years due in part to increasing awareness of potential risks and enactment of policies restricting youth access [2]. However, indoor tanning remains a public health concern, especially among groups such as non-Hispanic white young adult women. Nationally, approximately 15% in this group report indoor tanning in the past year [2, 3]. Indoor tanning in young adult women is associated with early-onset melanoma [4], and melanoma is the most common cancer diagnosis in this group [5, 6].

While many young adult women indoor tan in seasons of reduced sun exposure or in preparation for events [7], there is evidence that indoor tanning can become an addiction for some young people. This hypothesis is supported by preclinical research demonstrating a

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“neurocutaneous” reward model [8] where UV exposure produces effects similar to other addictive substances. The endogenous opioid β -endorphin is synthesized from UV exposure, and in animal models, prolonged UV exposure precipitates opioid-like analgesic effects, behavioral response indicative of drug seeking, and withdrawal when UV exposure is removed [8]. These effects are absent with pharmacologic opioid antagonism and in genetic knockout animals [8].

Clinical studies with human subjects provide additional support for this hypothesized model of tanning addiction. Frequent indoor tanners endorse a preference for UV light over “sham” non-UV light when blinded to the source [9] and pharmacologic opioid antagonism eliminates this preference and produces withdrawal [10]. Frequent indoor tanners report subjective effects indicative of opioid-like response after tanning, such as euphoric mood [11]. Imaging research has shown increased activation in brain regions associated with reward including dorsal striatum, anterior insula, and medial orbitofrontal cortex following tanning [12]. Among frequent indoor tanners, greater basal and striatal dopamine receptor binding has also been observed in response to tanning [13].

Like other addictive substances (e.g., tobacco, alcohol), social factors influencing tanning behavior are pervasive. Tanning retail outlets are common [14], especially in areas with substantial young adult populations such as college campuses [15]. Indoor tanning marketing often targets young people and is backed by an industry with substantial economic interests and lobbying capacity [16]. Policies restricting youth access (e.g., minimum age restrictions) are increasingly central to efforts to prevent and reduce indoor tanning [17]. Epidemiologically, substance abuse and addiction are generally more prevalent among those with psychiatric comorbidities, such as depression [18, 19], and there is evidence of a similar pattern with indoor tanning addiction [20–24].

In addition to psychiatric comorbidities, genetic factors are widely known to influence addiction, particularly variation in neurobiological reward pathways [25, 26]. Two recent studies have demonstrated associations between tanning behavior and genes in addiction reward pathways [27] and with genes that have not been functionally characterized [28]. However, these studies are subject to methodological limitations. Both were case-control studies involving patients diagnosed with skin cancer and subject to potential reporting biases. One examined any lifetime indoor tanning as a behavioral phenotype and did not assess indoor tanning addiction [27]. The second assessed tanning addiction by retrospective self-report [28]. Neither study considered psychiatric comorbidities such as depression, which appears critical given evidence that indoor tanning addiction and such comorbidities often co-occur.

Indoor tanning shares similarities to other addictive behaviors and evidence increasingly supports a “neurocutaneous” reward model for indoor tanning addiction [13]. Given the above evidence and limitations to research on genetic risks conducted to date, our objective was to investigate genetic associations with indoor tanning addiction in hypothesized neurobiological addiction reward pathways in a community sample of non-Hispanic white young adult women who indoor tan. We also investigated interactions between genetic influences and psychiatric comorbidity to identify potential co-occurring risk factors for indoor tanning addiction.

Material and Methods

Sample and Setting

Data were from a subsample of non-Hispanic white young adult women aged 18–30 years with a recent history of indoor tanning enrolled in a biobehavioral study of indoor tanning behavior and tanning addiction. Complete study procedures were reported previously [22]. Eligibility criteria included young adult women 18–30 years of age; self-identification as non-Hispanic white race/ethnicity; and indoor tanning at least once in the past 12 months. The study focused on young adult, non-Hispanic white women because it is the demographic subgroup with the highest prevalence of indoor tanning among U.S. adults and a group with increased risk of melanoma and other forms of skin cancer as a result [24]. Study participants were recruited from the community surrounding a large cancer research center in the mid-Atlantic USA through online classifieds, advertisements in local print media, and flyers. Eligibility was confirmed by telephone, participants signed informed consent, and completed an online self-report assessment of demographic, clinical, and behavioral characteristics. Participants were asked to provide a DNA sample for genotyping analysis following procedures described below.

The full study sample included 389 participants [24]. A total of 292 participants (75% of the full study sample) provided a DNA sample and were included in analyses described herein. Because the study was among the first investigations of this topic, there was not an a priori sample size target for genetic analyses. All study procedures were approved by the host institution’s Institutional Review Board. Data collection occurred from September 2013 to December 2016.

Self-Report Measures

Demographic characteristics assessed included age, household income, and educational attainment [3]. Season of study participation was also recorded (spring/

summer/fall/winter) [29]. Measures of established risk factors for melanoma and nonmelanoma skin cancer completed by participants included skin reactivity to sun exposure (always/usually burn, rarely/never burn), hair color (red/blonde, brown/black), and family history of melanoma (first-degree relative, yes/no) [30, 31]. Past year frequency of indoor tanning including sunlamps, tanning beds, and tanning booths (1 or 2, 3–9, 10–19, 20 or more times) was measured with valid items [3]. Alcohol and tobacco use were measured using items from epidemiologic surveys [32, 33]. Past 30 day alcohol use in the sample was common (94%), so we analyzed heavy drinking episodes (≥ 4 drinks on one or more occasion) in the past 30 days [33]. Current cigarette smoking was defined as smoking at least 100 lifetime cigarettes and now smoking every day or some days [32]. Additional measures were based on prior studies of indoor tanning behavior and tanning addiction [21, 23, 34, 35]. Appearance orientation was measured with a 12-item scale capturing the value participants' place on their physical appearance. Responses were averaged to create a score with higher values indicating stronger physical appearance orientation (Cronbach $\alpha = .86$) [36]. Depressive symptoms were measured using the 20-item Center for Epidemiologic Studies Depression scale (Cronbach $\alpha = .91$). A cutoff score of ≥ 16 was used to indicate a positive screen for depressive symptoms [37].

The modified CAGE (mCAGE) and the modified Diagnostic and Statistical Manual for Mental Disorders (mDSM) screeners were used to assess indoor tanning addiction [21, 38, 39]. The mCAGE comprises four items (Cut Down, Annoyed, Guilty, and Eye Opener) and endorsing two or more indicates addiction. The mDSM has eight items and endorsing three or more indicates addiction. These measures are adapted from assessments for other addictive behaviors, and research indicates they have adequate reliability when used in combination and supports use of their thresholds in combination to define indoor tanning addiction [38]. We chose these two measures because they have recommended thresholds for defining tanning addiction; others available at the time data were collected provide continuous scores with no recommended thresholds [40], and newer measures with recommended cutoffs were published after our data were collected [41]. Researchers have also recommended using multiple measures to operationalize indoor tanning addiction [28, 42] to address potential limitations of using the mCAGE as a single measure [43]. Reliability (Cronbach's α) for the four mCAGE items in our sample was 0.51, for the eight-item mDSM items was 0.52, and for the combined 12 items was 0.69. This is similar to other published data on the measures' reliability [38]. Total scores on the mCAGE and mDSM were moderately correlated ($r = .37, p < .001$), indicating

they capture different aspects of tanning addiction. The indoor tanning addiction phenotype was defined as screening positive on both the mCAGE and mDSM [28, 42].

Candidate SNPs, DNA Collection, and Genotyping

Candidate SNPs were identified and selected for analyses based on prior studies of genetic associations with addiction reward pathways [25, 26], genetic associations with tanning behavior [27, 28], and the hypothesized reward-based mechanism of tanning addiction [8]. In total, 38 SNPs from the *ANKK1* (a gene involved in D2 dopamine receptor modulation), *DRD2* (a gene encoding D2 dopamine receptors), *OPRM1* (a gene regulating mu opioid receptors), *POMC* (a gene encoding for proopiomelanocortin), and *PTCHD2* (*DISP3*; a gene previously associated with tanning addiction) genes were examined. A total of 34 SNPs met quality control criteria described below and were analyzed. [Supplementary Table S1](#) displays characteristics of the 34 SNPs analyzed.

Participants were mailed a saliva sample collection kit including instructions, a 10 mL collection tube, and mouthwash. Participants were instructed to avoid eating, drinking, or using tobacco for at least 30 min prior to sample collection. Participants swished the mouthwash, spit into the collection tube, sealed the tube, and returned the sample by mail. In a subsample of 15 participants (5% of the sample), we observed sample collection via a web-based video conference to verify participants followed collection procedures. All participants observed completed sample collection successfully with no difficulties or challenges with the procedures.

Samples were immediately transported to a genomics and epigenomics laboratory for DNA isolation, quality assessment, and SNP genotyping. DNA was isolated from saliva samples using the Epicentre MasterPure Complete DNA Purification Kit (Illumina, USA). DNA quality and quantity were estimated by Ultraviolet Visible Spectrophotometry (UV-VIS) spectrophotometry using the NanoDrop spectrophotometer (ND-1000, Thermo Fisher, USA) and isolated DNA were stored at -20°C to -10°C until genotyping.

Candidate SNP genotypes were determined by allelic discrimination using TaqMan SNP Genotyping Assays according to manufacturer instructions (Applied Biosystems). Genotyping was performed on 10 ng genomic DNA in a 5 μL volume in 384-well plates using TaqMan Genotyping Master Mix. Data were generated on the QuantStudio 12K Flex Real-Time Polymerase Chain Reaction (PCR) System using QuantStudio 12K Flex Software v1.2.2. After PCR amplification, a

post-PCR plate read was performed using fluorescence measurements, normalized reporter (Rn) values based on the fluorescence signals from each well were plotted, and alleles were determined for each sample. Genotyping was successful in 98% of samples with 99% concordance in blind quality control duplicates.

Statistical Analysis

We summarized participant demographic, clinical, and behavioral characteristics with descriptive statistics and used bivariate tests to examine whether characteristics differed among study participants providing DNA samples and those who did not. We performed quality control to filter out nonvariant SNPs among 38 candidates. SNPs were excluded if: (a) the p -value of the test of Hardy–Weinberg Equilibrium was less than 0.01, (b) the minor allele frequency was less than 0.01, or (c) there were no observations among any of the SNP genotypes. With 34 qualified SNPs, we fitted unadjusted logistic regression models to determine whether candidate SNPs were associated with indoor tanning addiction. Dominant SNP effect coding (“AB” or “BB” vs. “AA” as the reference group, where “A” represents the major allele and “B” represents minor allele) was used to improve statistical power and efficiency. p -values of the univariate analyses were adjusted for multiplicity using the false discovery rate (FDR). We fit multivariable logistic regression models adjusting for self-report covariates, including indoor tanning frequency, appearance beliefs, and depressive symptoms because these are the self-report factors most strongly related to tanning addiction in analyses with the complete study sample published previously [24]. For SNPs that showed significant associations with tanning addiction after covariate adjustment ($p < .05$), we then examined gene-gene interactions between the two SNPs and interactions between each SNP and self-report variables in separate logistic models. Missing data were present for <10% of each SNP (Supplementary Table S1). We compared the results from model-based imputations where missing genotypes were filled by the mode of that SNP with the models using observed data. Models using imputed data did not change statistical inferences, so results using observed data are reported. Analyses were conducted using SAS (version 9.3) and R (version 3.3) software.

Results

Participant characteristics are shown in Table 1. Of the complete study sample [24], participants who provided DNA samples did not differ significantly from those

who did not provide DNA samples on demographic, clinical, or behavioral characteristics assessed (Table 1). In total, 27% of participants screened positive for indoor tanning addiction on the mCAGE, 48% on the mDSM, and 22% meet screening criteria for both measures. In the univariate logistic regression analyses, no SNPs showed significant associations with tanning addiction based on p -values adjusted using the FDR (Supplementary Table S1). In multivariable logistic regression analyses adjusting for covariates, of the 34 SNPs examined, two SNPs in the *DRD2* dopamine receptor gene (rs4436578, rs4648318) showed significant associations with indoor tanning addiction ($p < .05$). Results of the adjusted logistic regression models for the two SNPs in the *DRD2* gene that were associated with indoor tanning addiction at $p < .05$ in adjusted analyses are shown in Table 2.

In models adjusting for indoor tanning frequency, appearance beliefs, and depressive symptoms with no interaction effects included, the odds of indoor tanning addiction were significantly higher among those with variant genotypes (CC or CT) compared with the homozygous major allele genotype (TT): odds ratio (OR) for rs4436578 = 2.30, 95% confidence interval (CI): 1.11, 4.77, $P = .042$; OR for rs4648318 = 1.95, 95% CI: 1.02, 3.78, $P = .026$; (Table 2). In these models, the odds of indoor tanning addiction also increased significantly with greater appearance orientation and the odds of indoor tanning addiction were significantly greater among participants reporting indoor tanning 20 or more times in the past year (Table 2). The interaction between these two SNPs tested in a separate model was not statistically significant ($p = .316$).

There was a statistically significant interaction between both SNPs and depressive symptoms in multivariable models (interaction p for rs4436578 = .01; interaction p for rs4648318 = .05). The results of multivariable models examining the interaction between the genotypes for the two *DRD2* SNPs and depressive symptoms are shown in Table 3. For rs4436578, among those with variant genotypes (CC or CT) and screening positive for depressive symptoms, the odds of indoor tanning addiction were more than 10 times greater (OR = 10.79, 95% CI: 3.25, 35.80, $p < .001$) than those with homozygous major allele genotype (TT) and not screening positive for depressive symptoms when other self-report variables are adjusted. Similarly, for rs4648318, those with variant genotypes (CC or CT) and screening positive for depression had more than 13-fold higher odds of indoor tanning addiction (OR = 13.60, 95% CI: 4.13, 44.78, $p < .001$) compared to those with homozygous major allele genotype (TT) and screening negative for depression when other self-report variables are adjusted. For both SNPs,

Table 1 Sample characteristics

	DNA sample (<i>N</i> = 292)	No DNA sample (<i>N</i> = 97)	<i>p</i>
Demographics			
Age, mean (<i>SD</i>), range 18–30 years	23.3 (3.1)	23.3 (2.9)	.979
≥College education	183 (62.7)	61 (63.5)	.878
<College education	109 (37.3)	35 (36.5)	
Income ≥\$50,000	144 (49.3)	54 (56.2)	.238
Income <\$50,000 or not reported	148 (49.3)	42 (43.8)	
Season of study participation			.595
Spring	73 (25.0)	29 (29.9)	
Summer	89 (30.5)	23 (23.7)	
Fall	85 (29.1)	29 (29.9)	
Winter	45 (15.4)	16 (16.5)	
Skin cancer risk factors			
Always/usually burn	67 (23.0)	26 (26.8)	.450
Rarely/never burn	224 (77.0)	71 (73.2)	
Red/blonde hair	109 (37.3)	36 (37.1)	.970
Brown/black hair	183 (62.7)	61 (62.9)	
FDR w/ melanoma	49 (16.8)	12 (12.4)	.301
No FDR w/ melanoma	243 (83.2)	85 (87.5)	
Past 12 month sunburns, mean (<i>SD</i>), range 0–5	2.6 (1.3)	2.5 (1.2)	.302
Past year indoor tanning frequency			.914
1 or 2 times	56 (19.2)	18 (18.6)	
3–9 times	109 (37.3)	36 (37.1)	
10–19 times	58 (19.8)	17 (17.5)	
≥20 times	69 (23.6)	26 (26.8)	
Alcohol and tobacco			
Current cigarette smoker	55 (18.8)	18 (18.6)	.951
Nonsmoker	237 (81.2)	79 (81.4)	
Past 30 day binge drinking	203 (69.5)	75 (77.3)	.141
No past 30 day binge drinking	89 (30.5)	22 (22.7)	
Appearance orientation, mean (<i>SD</i>), range 1–5	3.8 (.630)	3.8 (.629)	.844
Depressive symptoms			
Screen + depressive symptoms	133 (45.6)	52 (53.6)	.168
Screen – depressive symptoms	159 (54.4)	45 (46.4)	
Indoor tanning addiction			
Yes	64 (21.9)	24 (24.7)	.565
No	228 (78.1)	73 (75.3)	

Cells display no. (%) unless noted in the row label. Some variables do not sum to total sample size due to sporadic missing data (<1% for any given variable).

FDR first degree relative; *SD* standard deviation.

the odds of indoor tanning addiction were also greater among those with homozygous major allele genotype (TT) who screened positive for depressive symptoms and among those with variant genotypes (CC or CT) who screened negative for depressive symptoms compared to those with homozygous major allele genotype (TT) who screened negative for depressive symptoms (Table 3). Interactions between the SNP genotypes and self-report measures of indoor tanning frequency and

appearance orientation were tested in separate models and were not statistically significant.

Discussion

In multivariable analyses, we found associations between variant genotypes in two SNPs in the *DRD2* dopamine receptor gene and indoor tanning addiction. Moreover,

Table 2 Significant multivariable associations with *DRD2* dopamine receptor gene single nucleotide polymorphisms and indoor tanning addiction

	<i>DRD2</i> single nucleotide polymorphism (SNP)			
	rs4436578		rs4648318	
	OR	95% CI	OR	95% CI
SNP genotype				
Variant (CC or TT)	2.30	1.11, 4.77	1.95	1.02, 3.78
Homozygous major (TT)	Ref.		Ref.	
Depressive symptoms				
Screen +	5.36	2.68, 10.33	5.06	2.58, 9.93
Screen –	Ref.		Ref.	
Appearance orientation	2.22	1.31, 3.77	2.21	1.30, 3.75
Indoor tanning frequency				
1 or 2 times	Ref.		Ref.	
3–9 times	1.21	0.45, 3.24	1.40	0.51, 3.87
10–19 times	1.14	0.39, 3.36	1.30	0.43, 3.90
≥20 times	3.45	1.30, 9.19	3.59	1.30, 9.92

CI confidence interval; OR odds ratio.

Table 3 Interactions between *DRD2* dopamine receptor gene single nucleotide polymorphisms and depressive symptoms for indoor tanning addiction

SNP genotype	Depressive symptoms	<i>DRD2</i> single nucleotide polymorphism (SNP)			
		rs4436578		rs4648318	
		OR	95% CI	OR	95% CI
Homozygous major (TT)	Screen –	Ref.		Ref.	
Homozygous major (TT)	Screen +	10.49	4.11, 26.77	11.02	3.55, 34.22
Variant (CC or CT)	Screen –	7.62	2.40, 24.20	5.11	1.50, 17.37
Variant (CC or CT)	Screen +	10.79	3.25, 35.80	13.60	4.13, 44.78

Models also adjusted for appearance orientation and indoor tanning frequency as covariates.

CI confidence interval; OR odds ratio.

there was a significant interaction indicating that young women with variant genotypes in these SNPs and meeting a clinical screening threshold for depressive symptoms may be at especially high risk of tanning addiction.

Two prior studies have examined genetic associations with tanning behavior. Using data from a case–control study of early-onset melanoma, Cartmel et al. [28] used exome-wide screening of a panel of approximately 319,000 SNPs and examined candidate genes involved in addiction reward pathways associated with tanning addiction. After multiple testing adjustment, there was an association between tanning addiction and *PTCHD2* (*DISP3*), a gene that has not been functionally characterized. Flores et al. [27] investigated genetic associations with tanning behavior using data from a case–control study of early-onset melanoma. Results of candidate gene and haplotype analyses showed associations

between SNPs in the *ANKK1* and *DRD2* genes and tanning behavior, including *DRD2* SNPs associated with tanning addiction in this study. Notably, the *ANKK1* and *DRD2* genes are adjacent to one another, and SNPs in the *ANKK1* gene associated with tanning behavior in the Flores et al. investigation were previously thought to reside on the *DRD2* gene but the location has since been refined [27]. SNPs in both genes are involved in the modulation and encoding of D2 dopamine receptors [27].

Divergent findings between this study and the two prior investigations could be attributable to methodological differences. Prior studies differed in the study populations included methods for genetic analyses, phenotype definitions, and study design [27, 28]. However, our findings and those of Flores et al. consistently point to a genomic region involving the *DRD2* gene that is

associated with tanning behavior and tanning addiction that warrants further investigation [27]. This is consistent with the central role of dopamine in addiction reward pathways [44] and the hypothesized “neurocutaneous” reward model of tanning addiction [13]. Dopamine mediates the reward reinforcement produced by many addictive substances [45] and acts to enhance the salience of substance-related stimuli (i.e., cues) to maintain addiction and promote relapse over time [46]. For indoor tanning addiction, this hypothesis is supported by clinical studies demonstrating behavioral response to indoor tanning indicative of reward reinforcement (i.e., drug seeking) [9] and neuroimaging research indicating indoor tanning exposure produces activation in neural reward regions and increases D2/D3 dopamine receptor binding [12, 13].

Despite a supporting preclinical animal model [8], evidence on whether β -endorphin produced in response to indoor tanning reaches the bloodstream to produce a reward response in humans is mixed [47–49]. However, it is possible that the release of endogenous β -endorphin acts peripherally to deliver cutaneous pain relief from acute UV exposure and centrally tanning addiction transpires through rewarding effects such as relaxation and improved mood [13]. This is consistent with effects of other addictive substances that are not potent euphorigenics but are highly addictive due to their reward reinforcement mediated by dopamine (e.g., nicotine) [44]. In summary, the findings of clinical studies, neuroimaging research, and studies of genetic associations with indoor tanning in hypothesized addiction reward pathways including this investigation support the proposed “neurocutaneous” model of tanning addiction.

Our study adds uniquely to this research by demonstrating a significant interaction between SNPs in the *DRD2* gene and depressive symptoms. Our findings indicate young women with variant genotypes for two *DRD2* SNPs (rs4436578 and rs4648318) and meeting a clinical screening threshold for elevated depressive symptoms in particular had increased odds of reporting tanning addiction. Notably, interactions we tested between SNP genotype and other covariates (indoor tanning frequency, appearance orientation) were not statistically significant. This pattern of findings is supported by evidence linking depressive symptoms, the dopamine system, and indoor tanning behavior. Prior research has demonstrated associations between tanning addiction and depressive symptoms and other related comorbidities [20–24]. Disrupted dopamine signaling and transmission and sensitivity to reward are both features of depression [50]. Our findings suggest the possibility that a specific group of young women may be especially drawn to the rewarding properties of indoor tanning and vulnerable to addicted tanning based on their genotype and comorbid depressive symptoms. Clinically, this implies

that interventions to treat depressive symptoms (e.g., counseling, pharmacotherapy) could be effective interventions to also reduce indoor tanning in the presence of this constellation of risk factors. However, this result is preliminary and in need of additional investigation, including prospective studies testing temporality of these associations.

There are other notable findings from our study. Overall, 22% of our sample met criteria for indoor tanning addiction. The prevalence of indoor tanning addiction is higher in our sample than prior studies, but this is likely because many prior studies have involved general samples regardless of their indoor tanning history and have not used inclusion criteria related to indoor tanning behavior [20, 21, 23]. Similar to findings reported previously from this study [24], the odds of indoor tanning addiction were significantly higher among those reporting indoor tanning 20 or more times in the past year. Although this suggests the possibility that there may be a threshold of indoor tanning behavior frequency that puts young women at a greater risk for tanning addiction, more granular measures of indoor tanning frequency are needed to better understand this association.

This study included a well-characterized community sample of non-Hispanic white young adult women who indoor tan, addressing notable limitations of prior studies in this research area. Study limitations include potential reporting biases from self-report assessments and inability to draw causal inferences from the cross-sectional design. Measurement of indoor tanning addiction is an evolving research area and there is not consensus on the best measurement approach [38, 40, 41]. We chose measures that were best suited for the study at the time the data were collected. However, the mCAGE and mDSM measures were adapted from other addictive behaviors, they have not undergone extensive psychometric testing, and their reliability only reaches acceptable levels when both are used in combination. Continued research to develop and validate clinically meaningful self-report measures of tanning addiction is important to advance this research area. The study also included a convenience sample from a single geographic region and focused on young adult women of a single racial/ethnic group, limiting generalizability. The sample size and multiple testing limited statistical power for genetic analyses, particularly univariate analyses applying stringent FDR corrected *p*-values. Similar to prior research [27], we carefully selected candidate genes based on the available research to limit our analyses to biologically plausible associations within addiction reward genetic pathways, but our findings should be interpreted cautiously.

These limitations notwithstanding, our findings demonstrate associations between SNPs in the *DRD2* dopamine receptor gene and indoor tanning addiction and indicate young women with risk-conferring genotypes

and exhibiting depressive symptoms may be at higher risk of indoor tanning addiction. Future research is needed to replicate, verify, and build from these results. For example, enriched gene set analyses that include all SNPs in the *DRD2* gene would increase statistical power and reproducibility. This line of investigation has potential to inform personalized interventions tailored to neurobiological and behavioral differences to prevent skin cancer

Supplementary Material

Supplementary material for this article is available on the *Annals of Behavioral Medicine* website.

Compliance with Ethical Standards

Authors' Statement of Conflict of Interest and Adherence to Ethical Standards Michael B. Atkins is a consultant/advisory board member for Bristol-Meyers Squibb, Novartis, Merck, Roche and Pfizer. The other authors have no potential conflicts of interest to disclose.

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Authors' Contributions DM, KPT, and MBA conceived the study; DM and KPT collected the data; DG conducted the genotyping; DM, JA, and BZ analyzed the data; DM wrote the first draft of the paper; all authors contributed to and approved the final version of the paper.

Ethical Approval The Georgetown University Institutional Review Board reviewed and approved the study protocol.

Informed Consent All study participants provided written informed consent.

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