

# Association between parkinson's disease and melanoma: putting the pieces together...

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## Introduction

Epidemiological studies have provided substantial insight into our understanding of Parkinson's disease (PD). Many risks and inverse risk factors have been identified to play important roles in the development and progression of the disease ( [Ascherio and Schwarzschild, 2016](#) ). The association between PD and melanoma discovered by epidemiological studies appears to be particularly intriguing. Melanoma is a form of cancer that develops from melanocytes, which produce melanin, the pigment that colors skin, eyes, and hair. Melanoma is among the most aggressive and treatment-resistant human cancers and it accounts for 75% of all skin cancer deaths. PD and cancer are distinct diseases, with cancer resulting from uncontrolled cell growth and proliferation whereas PD is characterized by the premature death of dopaminergic neurons. Epidemiological evidence indeed supports an overall reduced risk of total cancer in patients with PD ( [Zhang and Liu, 2019](#) ), and reduced risk of developing PD in cancer patients ( [Bajaj et al., 2010](#) ; [Fois et al., 2010](#) ; [Tacik et al., 2016](#) ; [Cui et al., 2019](#) ; [Zhang and Liu, 2019](#) ). This is, however, not the case with melanoma. A large number of epidemiological studies have reported that the occurrence of melanoma was higher than expected among subjects with PD, and melanoma patients were reciprocally more likely to develop PD ( [Huang et al., 2015](#) ; [Bose et al., 2018](#) ). A meta-analysis showed that the risk of developing melanoma in individuals with PD was 3.6-fold higher than expected, with a pooled odds ratio of 2.1 from 12 studies ( [Liu et al., 2011](#) ). A more recent meta-analysis reported a 2.4-fold increased risk of melanoma

in PD and an overall pooled odds ratio of 1.83 from 22 studies ( [Huang et al., 2015](#) ).

## **Shared Risk Factors and Inverse Risk Factors Between PD and Melanoma**

Both PD and melanoma are considered multifaceted disorders that result from complex interactions of genetic and environmental factors. Growing evidence suggests that there are shared risk factors between PD and melanoma, which include:

**Age.** The risk of developing PD or melanoma increases with age. People typically develop PD around age 60 or older, while about half of melanomas occur in people over the age of 50.

**Family History and Genetics.** Having a close relative with PD increases the risk of developing PD, and having a close relative with melanoma also increases the risk of developing melanoma ( [Ward et al., 2017](#) ). The finding that a family history of melanoma in first-degree relatives was associated with a higher risk of PD suggests shared genetic predispositions ( [Gao et al., 2009a](#) ).

**Gender.** Men are 1.5 times more likely to develop PD ( [Wooten et al., 2004](#) ) or melanoma ( [National Cancer Institute, 2019](#) ; [Rastrelli et al., 2014](#) ) than women.

**Ethnicity.** PD is more common in the white population than in black or Asian population ( [Van Den Eeden et al., 2003](#) ; [Dahodwala et al., 2009](#) ; [Wright](#)

[Willis et al., 2010](#) ). Melanoma is also more common in the white population ( [Wooten et al., 2004](#) ).

Red Hair and Fair Skin. Melanoma is strongly linked to fair skin and red hair, the phenotype of the gene MC1R (melanocortin 1 receptor) polymorphisms. Red hair color has also been associated with an increased risk of developing PD ( [Chen et al., 2017b](#) ).

Toxins. Continuous exposure to environmental toxins such as pesticides has been reported to increase the risk of developing both PD ( [Goldman, 2014](#) ; [Nandipati and Litvan, 2016](#) ) and melanoma ( [Dennis et al., 2010](#) ).

PD and melanoma also share inverse risk factors, such as:

Smoking. Many epidemiologic studies have consistently reported that PD was less common in people who smoke cigarette ( [Hernán et al., 2001](#) , [2002](#) ; [Ritz et al., 2007](#) ; [Li et al., 2015](#) ), use smokeless tobacco ( [Benedetti et al., 2000](#) ; [O'Reilly et al., 2005](#) ), and even only with environmental tobacco exposure ( [O'Reilly et al., 2009](#) ; [Searles Nielsen et al., 2012](#) ). Smoking is usually associated with an increased risk of developing many types of cancer. Though surprisingly, studies have suggested that smokers had lower risks of melanoma than nonsmokers ( [Kessides et al., 2011](#) ; [Dusingize et al., 2018](#) ). However, smoking was linked to an increased risk of melanoma metastases ( [Jones et al., 2017](#) ).

Coffee Consumption. Coffee consumption is associated with a decreased risk of developing PD, suggested by a large number of studies ( [Benedetti et al., 2000](#) ; [Hernán et al., 2002](#) ; [Hu et al., 2007](#) ; [Costa et al., 2010](#) ). The risk of

developing melanoma was also reported among different populations to be decreased in individuals who drink coffee ( [Loftfield et al., 2015](#) ; [Wu et al., 2015](#) ; [Lukic et al., 2016](#) ; [Caini et al., 2017](#) ).

## **Common Clinical Features of PD and Melanoma**

Although their major symptoms are distinct, PD and melanoma share some common clinical features:

### **Vitamin D Deficiency**

Both PD and melanoma have lower serum vitamin D levels, which are associated with more severe symptoms. Lower serum vitamin D levels were found in patients with PD ( [Sleeman et al., 2017](#) ), and vitamin D deficiency was associated with increased risk of the disease ( [Sato et al., 1997](#) ; [Evatt et al., 2008](#) ). Studies also found that in PD patients, vitamin D levels significantly correlated with falls and some non-motor symptoms such as insomnia, depression, and anxiety ( [Zhang et al., 2019](#) ), and lower serum 25-hydroxy vitamin D in early PD may predict greater disease severity ( [Sleeman et al., 2017](#) ). Conversely, higher plasma vitamin D levels were associated with lower symptom severity, better cognition, and less depression in PD patients without dementia ( [Peterson et al., 2013](#) ). Decreased serum vitamin level was also detected in patients with melanoma ( [Field and Newton-Bishop, 2011](#) ; [Field et al., 2013](#) ), and lower levels of vitamin D were associated with thicker tumors and reduced patient survival ( [Slominski et al., 2017](#) ), tumor ulceration, and high tumor mitotic rate ( [Timerman et al., 2016](#) ; [Moreno-Arrones et al., 2019](#) ).

### **Sleep Disorders**

Patients with PD often have sleep disorders ( [Menza et al., 2010](#) ). Sleep disturbance such as sleep apnea correlates with a higher risk of PD ( [Chen J.-C. et al., 2015](#) ; [Yeh et al., 2016](#) ; [Chou et al., 2017](#) ). The risk of melanoma was significantly higher in patients with sleep apnea as well ( [Gozal et al., 2016](#) ). Additionally, sleep apnea was reported to be associated with aggressive melanoma ( [Martínez-García et al., 2014](#) ; [Martinez-Garcia et al., 2018](#) ).

### **Extended Echogenic SN Area**

Abnormally extended echogenic SN area was observed in both PD and melanoma patients by transcranial sonography ( [Rumpf et al., 2013](#) ). Later, a prospective observational study revealed that patients with melanoma had increased frequency of SN hyperechogenicity and prodromal motor and non-motor features of PD. This study also showed that larger echogenicity of SN correlated with lower serum iron in patients with melanoma, consistent with prior findings in PD ( [Walter et al., 2016](#) ).

### **Possible Underlying Mechanisms for the PD and Melanoma Association**

The epidemiological and clinical associations between PD and melanoma suggest common underlying mechanisms. Known PD- and melanoma-related genes/gene products and pathways have been implicated in the PD and melanoma associations.

## PD-Related Genes in Melanoma

PRKN gene encodes protein parkin, which belongs to a group of proteins called E3 ubiquitin ligases, and is involved in the maintenance of mitochondria, and also act as a tumor suppressor protein ( [Wahabi et al., 2018](#) ). More than 200 PRKN gene mutations were identified to cause PD, especially early-onset PD. PRKN mutations were also identified in melanoma cases, and its expression level was found to decrease in melanoma cell lines. PRKN somatic mutations were found in ~13% melanomas ( [Inzelberg et al., 2016b](#) ). Expression of PRKN in melanoma cells attenuated cell proliferation and conversely, inhibition of PRKN in melanocytes induced cell proliferation ( [Hu et al., 2016](#) ).

SNCA encodes protein alpha-synuclein ( $\alpha$ -Syn), which is abundant in the brain. It plays a role in controlling the mobility of synaptic vesicles, regulating the release of neurotransmitters such as dopamine.  $\alpha$ -Syn may interact with tyrosinase (TYR) and tyrosine hydroxylase (TH; [Pan et al., 2012](#) ), which are enzymes involved in the biosynthesis of melanin and dopamine, respectively. Mutations in SNCA cause dementia with Lewy bodies, as well as PD. Elevated expression levels of  $\alpha$ -Syn were indicated in skin cells from PD patients ( [Rodríguez-Leyva et al., 2014](#) ; [Rodriguez-Leyva et al., 2017](#) ) and metastatic tissues from melanoma patients ( [Matsuo and Kamitani, 2010](#) ; [Welinder et al., 2014](#) ). A study using melanoma cells showed that  $\alpha$ -Syn might have inhibitory effects on melanin synthesis in melanoma cells ( [Pan et al., 2012](#) ). Some researchers proposed that neuromelanin might have direct interaction with  $\alpha$ -Syn ( [Xu and Chan, 2015](#) ). However, whether  $\alpha$ -Syn

has a direct role in dermal melanin synthesis or melanoma is uncertain ( [Inzelberg et al., 2016a](#) ).

LRRK2 encodes protein dardarin, which is involved in protein-protein interactions, kinase activity, and GTPase activity. LRRK2 mutations are the most common genetic cause of familial as well as sporadic PD. PD patients carrying LRRK2 G2019S mutation had a higher overall cancer risk ( [Agalliu et al., 2015](#) ) Although LRRK2 somatic mutations were demonstrated in human melanomas ( [Inzelberg et al., 2016b](#) ), melanoma is not among specific cancers that have been associated with LRRK2 mutations, which include leukemia, colon and skin cancer ( [Agalliu et al., 2019](#) ), breast cancer in women ( [Agalliu et al., 2015](#) ), and non-skin cancers ( [Inzelberg et al., 2012](#) ).

PARK7 encodes protein DJ-1, with functions in regulating protein folding and oxidative stress. PARK7 mutations are associated with early-onset PD. DJ-1 is also considered as an oncogene ( [Vasseur et al., 2009](#) ). In melanoma cell lines, PARK7 expression is positively correlated with migratory ability ( [Cecconi et al., 2017](#) ), and patients with metastatic uveal melanoma had significantly higher levels of serum DJ-1 ( [Chen L.-L. et al., 2015](#) ).

PINK1 encodes the protein PTEN induced kinase 1, a mitochondrial serine/threonine-protein kinase and a tumor suppressor. Mutations in this gene cause early-onset PD. PINK1 appears to protect mitochondria from stress-induced malfunctioning. PINK1 targets parkin to depolarized mitochondria to induce autophagy ( [Arena and Valente, 2017](#) ). Altered expression levels of PINK1 were detected in melanoma cells ( [Brown et al., 2017](#) ).

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PLA2G6 encodes the enzyme A2 phospholipase, which is involved in metabolizing phospholipids. Mutations in PLA2G6 cause early-onset parkinsonism ( [Tomiya et al., 2011](#); [Lin et al., 2018](#) ). PLA2G6 variants were associated with increased nevus counts, a major indicator for melanoma risk ( [Law et al., 2012](#) ).

HTRA2 encodes a serine protease localized in the endoplasmic reticulum (ER) and mitochondria. It is regulated by PINK1 and is involved in apoptosis in PD ( [Strauss et al., 2005](#); [Plun-Favreau et al., 2007](#); [Desideri and Martins, 2012](#) ). It is reported that HTRA2 expression levels were changed in melanoma cells ( [Su et al., 2009](#) ).

UCHL1 encodes a deubiquitinating enzyme called ubiquitin carboxy-terminal hydrolase L1, abundantly presents in all neurons. It is a PD susceptibility gene ( [Maraganore et al., 2004](#) ) and may link to alpha-synucleinopathy ( [Cartier et al., 2012](#) ). The aberrant expression level of UCHL1 was detected in melanoma cells ( [Wulfänger et al., 2013](#) ). It appeared to regulate melanin production and distribution in melanocytes ( [Seo et al., 2017](#) ).

## **Cancer-or Melanoma-Related Genes in PD**

TRPM7 encodes protein Trpm7, which is an essential ion channel and serine/threonine-protein kinase. It regulates cellular calcium and magnesium levels. In melanocytes and melanoma cells, TRPM7 functions as a protector and detoxifier ( [Guo et al., 2012](#) ). TRPM7 channel was shown to regulate dopamine-dependent developmental transition and dopaminergic cell survival ( [Sun et al., 2015](#) ). Decreased TRPM7 expression was found in the SN area of PD patients ( [Sun et al., 2015](#) ).

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TP53 encodes p53 protein, a well-known tumor suppressor. It binds to DNA and triggers DNA damage repair or apoptosis. It is the most frequently mutated gene in human cancers and it plays broad roles in many types of cancers including melanoma. In PD, it may be responsible for inducing the death of dopaminergic neurons ( [Alves da Costa and Checler, 2011](#) ).

PTEN encodes protein Pten, which is also a major tumor suppressor. It involves in signaling pathways that regulate cell death. Similar to p53, PTEN is related to many cancers including melanoma ( [Aguissa-Touré and Li, 2012](#) ). *De novo* variants of PTEN were implicated in PD ( [Kun-Rodrigues et al., 2015](#) ), and PTEN was proposed to be a potential therapeutic target for the disease.

GPNMB encodes the protein transmembrane glycoprotein NMB, which is a transmembrane protein enriched on the cell surface of various cancer cells, including melanoma cells. It appears to have both inhibitory and tumor-promoter roles in different cancers ( [Taya and Hammes, 2018](#) ). Increased brain GPNMB expression may explain the association between the GPNMB gene locus and PD risk ( [Murthy et al., 2017](#) ).

MC1R encodes the melanocortin 1 receptor. In melanocytes, MC1R determines the relative amount of brown-black eumelanin and yellow-red pheomelanin by facilitating eumelanin production. Loss-of-function MC1R variants are associated with red hair, fair skin, poor tanning and increased risk of melanoma . Red hair color and loss-of-function MC1R R151C variant have also been associated with PD ( [Gao et al., 2009a](#) ; [Chen et al., 2017b](#) ).

Further, MC1R was reported to be expressed in dopaminergic neurons and it influenced dopaminergic neuron survival ( [Chen et al., 2017a](#) ).

## **Other Genes That May Be Involved in Both PD and Melanoma**

CYP2D6 encodes the enzyme cytochrome P450 2D6, which catalyzes many reactions involved in drug metabolism. CYP2D6 polymorphisms have been associated with increased susceptibility to melanoma ( [Strange et al., 1999](#) ), as well as increased susceptibility to PD ( [Lu et al., 2014](#) ; [Aslam et al., 2017](#) ).

GSTM1 encodes a human glutathione S-transferase. It functions in the detoxification of electrophilic compounds including drugs and environmental toxins. Its association with PD is still up for debate ( [Wang et al., 2016](#) ), some suggested that it linked to PD *via* pesticide exposures ( [Pinhel et al., 2013](#) ). GSTM1 was linked to melanoma ( [Kanetsky et al., 2001](#) ), and the protective effect of coffee consumption was reported to be particularly high for subjects with GSTM1 null polymorphisms ( [Fortes et al., 2013](#) ).

VDR encodes the vitamin D receptor, a member of the nuclear receptor family of transcription factors, which binds to the active form of vitamin D. VDR expression was decreased in melanoma ( [Brożyna et al., 2014](#) ), and VDR variants were associated with a higher risk of PD ( [Butler et al., 2011](#) ; [Meamar et al., 2017](#) ). Its role in PD and melanoma is likely linked to vitamin D deficiency.

GRIN2A encodes the regulatory GluN2A subunit of the glutamate-gated N-methyl-D-aspartate receptor (NMDAR). NMDA receptors are a class of

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ionotropic glutamate receptors found in neurons. Variants of GRIN2A were associated with the protective effect of coffee against PD ( [Hamza et al., 2011](#) ; [Yamada-Fowler et al., 2014](#) ), and mutations of GRIN2A in melanoma correlate with decreased survival ( [D'Mello et al., 2014](#) ).

The genes discussed above have varied strengths of evidence for their involvement in PD and melanoma, from multidisciplinary studies. To understand their pleiotropic roles in both conditions, it is important to further investigate their biological functions, interactions, and involvements in molecular pathways.

## **The Pigmentation Pathway**

Dopaminergic neurons and melanocytes share common pathways or cascades that control the final fate of the cells, including cell cycle, DNA repair, oxidative stress, and immune responses. They are both pigmented, and L-dopa is an intermediate product for the synthesis of both dopamine in dopaminergic neurons and melanin in melanocytes.

The associations between red hair color, redhead-related MC1R variants, and risk for both melanoma and PD support a possible role of systemic pigmentation in the PD-melanoma link ( [Gao et al., 2009b](#) ; [Edwards et al., 2011](#) ; [Rumpf et al., 2015](#) ; [Chen et al., 2017b](#) ). In addition, light skin/hair pigmentation was related to abnormal SN echogenicity ( [Rumpf et al., 2015](#) ), and the TYR melanogenesis pathway was identified in the GWAS database as the top significant pathway for PD ( [Edwards et al., 2011](#) ). Furthermore, vitamin D regulates cutaneous pigmentation by enhancing melanogenesis ( [Pavlovitch et al., 1982](#) ; [Watabe et al., 2002](#) ). PD and melanoma both have

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vitamin D insufficiency ( [Sato et al., 1997](#) ; [Evatt et al., 2008](#) ; [Field and Newton-Bishop, 2011](#) ; [Field et al., 2013](#) ), and a lower expression level of VDR was found in melanoma ( [Slominski et al., 2017](#) ). These findings suggest that systemic melanogenesis may be compromised in both conditions.

In addition to eumelanin and pheomelanin in the periphery, there is the third melanin—neuromelanin in the human brain. Neuromelanin may be synthesized from dopamine precursor L-dopa, or it could derive from non-enzymatic oxidation in mitochondria from excess cytosolic dopamine accumulated by synaptic vesicles ( [Zecca et al., 2001](#) ). Evidence supports both the protective and cytotoxic effects of neuromelanin ( [Enochs et al., 1994](#) ). PD patients have significantly less neuromelanin in the brain ( [Zecca et al., 2002](#) ). It is unclear whether the decreased level of neuromelanin is a result of the loss of neurons, or the death of neurons is triggered by loss of neuromelanin as its protective function may be compromised. A new study showed the age-dependent production of neuromelanin in rat SN overexpressing TYR. Neuromelanin accumulation was associated with Lewy body-like inclusions and nigrostriatal neurodegeneration ( [Carballo-Carbajal et al., 2019](#) ). The findings that neuromelanin structurally consisted of a pheomelanin core and a eumelanin surface led to a hypothesis that thinning eumelanin surface and exposing pheomelanin core may be responsible for the selective vulnerability of pigmented dopaminergic neurons in PD ( [Bush et al., 2006](#) ; [Ito, 2006](#) ). Excessive pheomelanin in the periphery (e. g., in red-haired individuals) plays a causal role in melanomagenesis ( [Roider and Fisher, 2016](#) ). It is unknown how neuromelanin might be related to skin

melanin or whether MC1R has any role in neuromelanin synthesis. Albino humans with TYR were reported to have pigmented SN ( [Foley and Baxter, 1958](#) ). Further studies should aim to elucidate the exact role of the periphery pigmentation and the central nervous system (CNS) pigmentation in the PD-melanoma association.

A related question is whether L-dopa is involved in high melanoma occurrence in PD. Although bidirectional, the risk ratio for PD preceding melanoma has overall consistently been higher than that for melanoma preceding PD ( [Liu et al., 2011](#) ; [Huang et al., 2015](#) ), indicating that there might be additional factors contributing to the former. L-dopa as the mainstay therapy for PD and common rate-limiting intermediate products for the biosynthesis of both dopamine in dopaminergic neurons and melanin in melanocytes has long been proposed to be such a contributing factor. In fact, the very first reported melanoma cases in PD were from patients taking levodopa ( [Skibba et al., 1972](#) ). However, subsequent findings that rates of melanoma increased among early PD patients not yet taking L-dopa argue against levodopa's involvement in this link ( [Zanetti et al., 2006](#) ; [Vermeij et al., 2009](#) ). This issue has not been fully settled as there have been so far only a few observational studies ( [Fiala et al., 2003](#) ; [Constantinescu et al., 2007](#) ; [Olsen et al., 2007](#) ). Melanoma history is still listed as a contraindication to L-dopa use. With the identification of the possible genetic risk factors for both PD and melanoma, it may be necessary to reevaluate L-dopa's role in melanoma development in PD, especially in populations at risk.

## The Immune System

The immune systems are often weakened in cancers including melanoma ( [Rangwala and Tsai, 2011](#) ). In fact, melanoma is considered the immunogenic tumor, and cell proliferation, as well as apoptosis, are associated with immune system dysfunctions during melanomagenesis ( [Passarelli et al., 2017](#) ). Further, immunotherapy is in use to treat advanced melanoma ( [Passarelli et al., 2017](#) ). Once considered immune-privileged, the CNS, in fact, possesses abilities to elicit immune responses.

Neuroinflammation plays a role in the pathogenesis as well as disease progression of PD ( [Tansey and Goldberg, 2010](#) ; [Vivekanantham et al., 2015](#) ; [Gelders et al., 2018](#) ). Post-mortem studies found elevated levels of pro-inflammatory factors in the brains of PD patients. Glial cell activation was detected in the brains of PD patients or the animal models of PD. As the disease progresses,  $\alpha$ -Syn and other molecules released from the degenerating dopamine neurons may further activate microglia, which may result in more neuron death and thus forming a vicious cycle of neurodegeneration ( [Wang et al., 2015](#) ). Emerging evidence supports the involvement of peripheral inflammation and the peripheral immune system in PD pathogenesis and progression ( [Garretti et al., 2019](#) ; [Kustrimovic et al., 2019](#) ). Constipation is often a symptom of PD, and PD patients have altered gut microbiome, which may increase inflammation ( [Garretti et al., 2019](#) ). T cells from PD patients respond to  $\alpha$ -Syn to a greater degree when compared to the control subjects ( [Sulzer et al., 2017](#) ). A study using human induced pluripotent stem cell (iPSC)-based PD model showed increased neuronal death induced by upregulation of IL-17 receptor (IL-17R) and NF- $\kappa$ B

activation, and the neuronal death could be rescued by blockage of IL-17 or IL-17R or the use of an IL-17 antibody ( [Sommer et al., 2018](#) ). More studies are needed to explore immune dysregulation, particularly the systemic immune system and its interactions with the central immune system in the PD-melanoma link.

## **Conclusion and Future Perspectives**

PD patients have a significantly higher risk of developing melanoma, and vice versa. The association is well-documented by epidemiological studies and supported by clinical and biological studies. PD and melanoma share several risk factors, inverse risk factors, as well as some common clinical features. Genetic studies have identified genes that may be associated with both conditions. Studies using cellular and animal models further provided evidence for a possibly critical role of the pigmentation pathway in this association. As complex as the two pathologies separately, their association is likely a result of complex interactions between environmental and genetic factors. The immune dysregulation may represent one of the convergent mechanisms leading to neurodegeneration in dopaminergic neurons and tumorigenesis in melanocytes. Future studies using detailed systems analysis focusing on the multi-level interactions between PD and melanoma may lead to a more comprehensive understanding of the mechanisms underly the PD-melanoma link, thus shed fresh insight on both pathologies and help develop treatment strategies.

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QY, YW, NA-K, and XC wrote the article.



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## Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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