The Genetics of Skin, Hair, and Eye Color Variation and Its Relevance to Forensic Pigmentation Predictive Tests

O. Maroñas[1], J. Söchtig[1], Y. Ruiz[2], C. Phillips[1]*, Á. Carracedo[1,3], M. V. Lareu[1]

[1]Unit of Forensic Genetics, Institute of Forensic Science, Genomic Medicine Group
University of Santiago de Compostela
Santiago de Compostela, Galicia
Spain

[2]Criminalistics Unit Against Violation of Fundamental Rights (UCCVDF-AMC)
Attorney General, Metropolitan Area of Caracas
Santiago de León de Caracas
Venezuela

[3]Center of Excellence in Genomic Medicine Research, King Abdulaziz University
Jeddah, Makkah Province
Saudi Arabia

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* Corresponding author: Christopher Phillips, Forensic Genetics Unit, Institute of Forensic Science "Luis Concheiro", University of Santiago de Compostela, Santiago de Compostela, Galicia, Spain; +34 981 582 327 (voice); c.phillips@mac.com.

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ABSTRACT: This review examines the potential application of single nucleotide polymorphism (SNP)-based predictive tests for skin, hair, and eye color to forensic analysis in support of police investigations lacking DNA database matches or eyewitness testimony. Brief descriptions of the biology of melanogenesis and the main genes involved are presented in order to understand the basis of common pigmentation variation in humans. We outline the most recently developed forensically sensitive multiplex tests that can be applied to investigative analyses. The review also describes the biology of the SNPs with the closest associations to, and therefore the best predictors for, common variation in eye, hair, and skin pigmentation. Because pigmentation pathways are complex in their patterns, many of the better-studied human albinism traits provide insight into how pigmentation SNPs interact, control, or modify gene expression and show varying degrees of association with the key genes identified to date. These aspects of SNP action are discussed in an overview of each of the functional groups of pigmentation genes.

KEYWORDS: DNA phenotyping, externally visible characteristics (EVC), eye color, forensic hair color, pigmentation genes, skin color, SNPs.

INTRODUCTION — The Importance of Pigmentation Analysis to the "New Forensic Genetics"

Forensic genetics focuses on the use of DNA variation to solve problems of criminal investigation by applying a broad range of polymorphic genetic markers. Whatever the markers employed, the final goal is to match the genetic profile of samples found in a crime scene with that of a suspect and calculate the probability of another individual in the same population group or DNA database showing the same profile. However, there will always be cases where the evidential DNA does not match any reference profiles and the investigation must follow other leads or apply more indirect ways to obtain a profile match such as mass screening. Mass screens, often used in Europe, where whole groups of people from a community may have their DNA tested, have been criticized for violating civil liberties, since samples are taken without "probable cause" from people who are not suspects [19].

Eyewitness testimony is a common way to direct an investigation toward a reduced suspect pool to avoid the need for screening. However, eyewitness accounts are not always available, can be hampered by inferior visual acuity in the persons involved (notably elderly victims), are not free of controversy, and have widely recorded error rates [146]. For these reasons, forensic genetics research has aimed much effort toward obtaining information about a suspect beyond their gender using DNA markers. Principal among the characteristics now amenable to genetic analysis are biogeographic ancestry (BGA) and externally visible characteristics (EVC), initiated with common variation in pigmentation. Both sets of characteristics are encompassed under the term "forensic DNA phenotyping" (FDP). The same tests are applicable to the identification of missing persons or disaster victim identification.

BGA analysis aims to infer the geographical origin of an individual based on variants diagnostic of a particular ancestry — in the first instance, differentiated as African, European, East Asian, or a mixed combination of co-ancestries in many individuals from modern urban backgrounds or regions with long histories of admixture, such as the Americas [75]. The analysis of BGA can be made by analyzing ancestry informative markers (AIMs) that can be used to estimate co-ancestry proportions in admixed individuals. Despite careful estimation of co-ancestry proportions with a battery of powerful AIMs, the physical appearance of admixed individuals is not easily predicted [167]. In fact, admixed individuals can have completely atypical pigmentation patterns (e.g., black skin and red hair); this makes a phenotypic description of a DNA donor, based on data from forensic AIM tests alone, complex and error-prone. Nonetheless, in this context the inference of pigmentation characteristics — the color of the eyes, hair, and skin of a person — can lend important detail to an ancestry test.

However, one major problem concerning reproducibility of genetic tests that predict a person's pattern of pigmentation is the phenotyping measurement system employed. Subjective assessments relying on categorical classifications, although widely used, create reproducibility problems. Pigmentation perception differs among individuals from different population groups and even among individuals from the same cultural backgrounds,

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ABOUT THE AUTHORS

O. Maroñas; J. Söchtig; Y. Ruiz
C. Phillips; Á. Carracedo; M. V. Lareu

Olalla Maroñas studied chemistry at the University of Santiago de Compostela (Santiago de Compostela, Spain), including project work at the Biology Faculty, University of Osnabrück (Osnabrück, Germany). In November 2008, she started her Ph.D. studies focused on the pigmentation field with an emphasis on the complex genetics that underlie albinism. She led a recently published study aiming to predict skin tone in admixed and unadmixed individuals and has also developed forensic RNA techniques for body fluid identification and been involved in the development of forensic tests for eye and hair color prediction.

Jens Söchtig studied biology at the University of Göttingen (Göttingen, Germany) and in 2009 completed his diploma thesis at the Department of Historical Anthropology and Human Ecology on reconstructing pigmentation characteristics of a Bronze Age family group from ancient DNA. He then began his Ph.D. studies at the Forensic Genetics Unit of the University of Santiago de Compostela, where his research has concentrated on forensic predictive tests for externally visible characteristics and ancestry, with a principal focus on hair color. His research interests also include the population genetics of South American populations and DNA extraction from bone material.

Yarimar Ruiz studied biology at the Central University of Venzuela (Caracas, Venzuela) between 2001 and 2006. She completed her Ph.D. thesis in the Forensic Genetics Unit of the University of Santiago de Compostela in 2012, with studies centered on the establishment of forensic eye color predictive tests, the development of pigmentation SNP discovery panels and analysis of SNP variation in South American populations. Since 2013, she has been working as a Forensic Professional II in the Criminalistics Unit Against Violation of Fundamental Rights, Caracas, Venezuela.

Christopher Phillips studied genetics at Birmingham University (Birmingham, UK) between 1974 and 1977 and in 1978 obtained an M.Sc. in applied genetics at the same institute. He started his forensic genetics career in 1979 at the Biochemistry Division of the Metropolitan Police Forensic Science Laboratory (London, UK). He then moved to Forensic Haematology Department, Barts and The London School of Medicine and Dentistry (London, UK) and worked there until 2001. Since 2001 he has been a full-time researcher in the Forensic Genetics Unit of the University of Santiago de Compostela. Research interests include SNP analysis applied to medical, population, and

forensic genetics, the development of novel forensic polymorphisms, and building open-access online genomics search tools for the genetics and forensic communities.

Ángel Carracedo received his degree in medicine from the University of Santiago de Compostela. Dr Carracedo is professor of legal medicine at the University of Santiago de Compostela, director of the Galician Foundation of Genomic Medicine, and director of the Spanish National Genotyping Centre. He was formerly director of the Institute of Legal Medicine at Santiago and is past president of the International Society of Forensic Genetics (ISFG). Research lines include the genetics of complex traits with different applications from forensic to clinical genetics.

Maria Victoria Lareu received her degree in medicine from the University of Santiago de Compostela. Dr. Lareu is professor of legal medicine at the University of Santiago de Compostela and the director of the Institute of Legal Medicine at Santiago. As well as directing the forensic science services provided by the Forensic Genetics Unit, she is principal investigator for many of the research projects undertaken in the department and has directed the Ph.D. studies of authors Olalla Maroñas, Jens Söchtig, Yarimar Ruiz, and Christopher Phillips.