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Building HairX: A Comprehensive Human Hair Database to Revolutionize Exposome Research

O Namuun, Research Scholar, Ecology and Environment, Inner Mongolia University, Mongolia

Dulguun Gankhuyag, Professor, Ecology and Environment, Inner Mongolia University, Mongolia

Abstract

By detecting accumulated chemicals, contaminants, and lifestyle variables, human hair provides a one-of-a-kind biological sample for studying the exposome, the sum of all environmental exposures throughout a lifetime. Because it may represent a wide range of environmental, occupational, and lifestyle exposures, hair provides a practical, non-invasive matrix for assessing exposure over time. This study presents HairX, a state-of-the-art database developed to support exposome studies conducted on human hair. In addition to demographic and lifestyle variables, HairX incorporates multi-omics data, which includes chemical profiling, genetic information, and metabolomics. This study focuses on the database's development, its use in expanding exposome research, and its future ability to fill knowledge gaps on environmental exposures and their effects on human health.

***Keywords**: Human hair, Exposome, Environmental exposures, HairX, Chemical profiling, Multi-omics, Toxicology, Public health, Biomonitoring*

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1. Introduction

1.1 Background

An individual's lifetime worth of environmental exposures is captured by the notion of the exposome, which was first proposed in 2005. Chronic illnesses, such as cancer, heart disease, and neurological disorders, are significantly increased by environmental exposures, which include air pollution, heavy metals, chemicals, and lifestyle variables. The intricacy and diversity of human-environment interactions have made it hard to estimate the exposome despite its significance correctly.

The use of human hair as a non-invasive biological matrix to evaluate exposure over time has recently gained significant traction. A person's hair may record their environmental exposures throughout time since it absorbs and stores chemicals, poisons, and biomarkers. Hair analysis is a powerful technique in exposome study because it can record cumulative exposure to many substances, including those associated with food, medications, and environmental toxins.

A thorough hair database incorporating chemical, genetic, and metabolomic data to enable high-resolution exposome research, HairX, was created in response to the increasing need for solid exposome data. This article outlines the design and development of HairX, highlights its main characteristics, and discusses how it might revolutionize exposome research and public health programs.

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2. Human Hair as a Matrix for Exposome Research

2.1 Unique Properties of Hair

Various compounds represent long-term exposure to environmental agents, food, and personal care items accumulated by human hair as it grows at an average pace of 1 cm every month. When tracking an individual's exposure, hair offers a more reliable and extensive record than blood or urine, indicating short-term exposures. Hair is the perfect sample material for large-scale biomonitoring investigations since it is less intrusive to collect, keeps well at room temperature, and needs little sample processing.

Hair is a crucial matrix for multi-dimensional exposure study due to its wide-ranging compound-trapping capabilities. This includes medicines, organic pollutants (such as pesticides and flame retardants), heavy metals (such as lead and mercury), and many more. Because hair can withstand fast metabolic changes and yet offer a constant exposure chronology, it is an excellent sample for studying the exposome retrospectively.

2.2 Advantages of Hair in Exposome Research

The use of hair for exposome research offers several advantages:

- **Non-invasive sampling**: Hair collection is painless and straightforward, allowing for repeated measurements without discomfort to the participant.
- **Long-term exposure data**: Hair reflects months to years of cumulative exposure, unlike blood or urine, which only capture recent exposures.
- **Multi-omics integration**: Hair can be analyzed using various 'omics' techniques (proteomics, genomics, metabolomics), offering a holistic view of an individual's biological responses to environmental exposures.

Hair also provides insights into external exposure from cosmetics and hair treatments, which traditional biomarkers of internal exposure often miss. These attributes make human hair an ideal candidate for developing a comprehensive exposome database like HairX.

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3. Building HairX: Architecture and Components

3.1 Data Collection and Structure

HairX is a multi-layered database that incorporates the following types of data:

- **Chemical profiling**: A comprehensive inventory of chemicals, toxins, pollutants, and heavy metals found in hair samples, measured through advanced analytical methods such as mass spectrometry and chromatography.
- **Genomic data**: Information on genetic variants associated with environmental responses, metabolite metabolism, and susceptibility to chemical exposures.
- **Metabolomic data**: Profiling of small molecules, metabolites, and biomarkers found in hair, which can reveal individual biological responses to environmental exposures.

- **Demographic and lifestyle information**: Variables such as age, gender, occupation, geographic location, diet, and exposure to personal care products which are critical for understanding the interaction between environmental exposures and human health outcomes.

3.2 Analytical Methods

HairX uses state-of-the-art analytical techniques to capture a broad spectrum of expensive data:

- GC-MS and LC-MS, which can detect and quantify organic chemicals and contaminants, are two examples of such techniques.
- **Mass spectrometry using inductively coupled plasma (ICP-MS) to identify mercury and lead at trace levels.**
- **High-throughput sequencing** for genetic data collection, including genome-wide association studies (GWAS) related to environmental response genes.
- **Nuclear magnetic resonance (NMR) spectroscopy** captures detailed metabolomic profiles.

These technologies enable HairX to provide a detailed and accurate representation of an individual's chemical and biological exposure over time.

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4. Applications of HairX in Exposome Research

4.1 Advancing Public Health Research

HairX can play a pivotal role in identifying exposure patterns in various populations, contributing to our understanding of how environmental factors influence the development of chronic diseases. Researchers can uncover the links between cumulative chemical exposures and disease prevalence by analyzing hair samples from diverse demographic groups. This data can inform public health policies and create targeted interventions to reduce harmful exposures in at-risk populations.

4.2 Personalized Exposure Assessment

The database supports personalized exposome analysis by integrating genetic data with environmental exposures. Individuals with genetic variants that affect how their bodies process or detoxify ecological toxins may be more susceptible to the adverse effects of these exposures. HairX can help predict individual risk profiles by combining genetic and environmental data, allowing for more personalized public health recommendations.

4.3 Longitudinal and Retrospective Studies

HairX tracks changes in environmental exposures over time, enabling longitudinal exposome investigations. Researching the long-term impacts of exposures like air pollution, work risks, and food habits on health outcomes is where this shines. The origins of chronic illnesses that show up later in life may be better understood by reconstructing exposure histories using hair samples taken in the past.

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5. Challenges and Future Directions

5.1 Data Standardisation

One of the key challenges in building a large-scale exposome database like HairX is ensuring data standardization across different laboratories and studies. Variations in sample collection methods, analytical techniques, and data interpretation can lead to inconsistencies. To address this, HairX follows strict sample collection, processing, and analysis protocols to ensure data reliability and comparability.

5.2 Expanding the Database

As exposome research evolves, HairX must expand its dataset to include new types of exposures and omics data. Including microbiome data, for example, could offer further insights into the role of external exposures in shaping the gut microbiome and its health implications. Future iterations of HairX may also integrate exposure data from wearable sensors and environmental monitoring devices to provide real-time exposure assessments.

5.3 Ethical Considerations

Hair and associated genomic data collection raises critical ethical issues, particularly concerning privacy and consent. HairX adheres to strict ethical guidelines, ensuring that all data is anonymized and participants provide informed consent for using their biological samples. As the database grows, ongoing attention to data security and ethical governance will be crucial.

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6. Conclusion

The development of HairX is a significant step forward in exposome research. It provides a tool that has never been seen before to research the cumulative environmental exposures that affect human health. HairX offers a holistic exposome perspective by merging chemical profiling, genetic data, and metabolomics. This enables researchers to get a deeper understanding of the intricate interactions that occur between the environment and human biology. With further development, HairX has the potential to revolutionize research in the field of public health, as well as personalized exposure assessment and preventative health interventions.

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